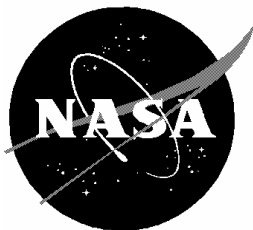


# EGIL Console Handbook

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Systems Division  
Electrical Systems Branch

Revision F PCN-2  
June 8, 2007



National Aeronautics and  
Space Administration

Lyndon B. Johnson Space Center  
Houston, Texas

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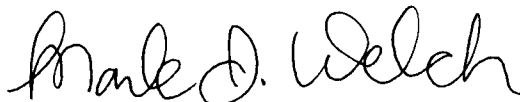
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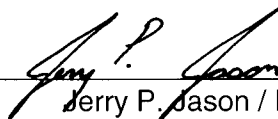
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**REVISION LOG**

<b>REV. LETTER</b>	<b>CHANGE NO.</b>	<b>DESCRIPTION</b>	<b>DATE</b>
E			08/01/92
F			01/31/02
F	1	PCN - 1	12/18/03
F	2	PCN - 2	06/08/07

## EGIL Console Handbook

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## **PREFACE**

The EGIL Console Handbook was prepared by the Electrical Systems Group, DF73.

The primary responsibility is with Mission Operations Directorate (MOD), Systems Division.

Questions concerning the technical content of this document should be directed to H. Preston Easton at 281-244-2596, mail code DF7.

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## **TITLE**

### **INTRODUCTION**

## **PURPOSE**

The purpose of the Electrical Generation and Illumination (EGIL) Console Handbook is to assist the EGIL and Electrical Power System (EPS) Mission Control Center (MCC) console operators in their real-time mission responsibilities and to describe the systems for which this position is responsible. The book is divided into seven sections as follows:

Section 2: Fuel Cells - Describes Fuel Cell (FC) hardware, operation, procedures, and failure history.

Section 3: Cryogenics and Consumables - Describes the Power Reactant Storage and Distribution (PRSD) system hardware, operation, procedures, and failure history.

Section 4: Electrical Power Distribution System (EPDS) - Describes hardware, operations, procedures, and failure history for the DC power distribution and control, AC power system, general wiring and bus info, vehicle lighting, Orbiter Docking System (ODS), and Assembly Power Converter Unit (APCU), as well as some general information on the Spacehab and how it relates to EGIL systems.

Section 5: Caution and Warning (C&W) and Pyrotechnic (pyro) systems - Describes hardware, operation, procedures, and failure history for the C&W and pyro systems.

Section 6: Console Operations - Describes console aids such as quick reference material and console procedures.

Section 7: Workstations and Software - Describes many of the tools used while on console for monitoring the vehicle and fulfilling console responsibilities.

## **RESPONSIBILITIES**

The EGIL console positions have the overall responsibility for the real-time configuration, operation, and use of the following space shuttle systems:

- Fuel cells
- PRSD
  - Cryogenic oxygen and hydrogen
  - Tank heaters and logic controllers
  - O<sub>2</sub> heater sensors
  - Tank and manifold valves

- EPDC
  - DC power distribution and control
  - AC power distribution and control
  - Utility power
  - Circuit protection
- APCU
- Lighting
  - Interior lights
  - Exterior lights
  - Annunciator lights
  - Instrument and panel lighting
- Caution and Warning (C&W)
- Generalized operation of pyrotechnic NASA Standard Initiators (NSIs) and Pyrotechnic Initiator Controllers (PICs)
- Range safety system (status monitoring only, except Radio Frequency (RF) components)
- Systems operation
  - Systems monitoring
  - Cryogenic usage, management, and predictions
  - PRSD failure analysis and isolation
  - Fuel cell load management, purging, standby, shutdown, and in-flight startup
  - Fuel cell failure analysis and isolation
  - DC and AC load management
  - Electrical energy use vs. preflight predictions
  - Powerdowns and configuration management
  - EPDC failure analysis and isolation
  - C&W failure analysis and isolation
  - APCU analysis and isolation
  - Lighting activation/deactivation monitoring

**TITLE**

STANDARD CONSOLE PROCEDURES CHANGE PROCESS

**PURPOSE**

This Standard Console Procedure (SCP) provides instructions for making changes to the EGIL Console Handbook.

**PROCEDURE**

To make changes to any of the SCPs in this handbook, the change initiator must complete an SCP Change Request (CR) form and submit it to the JSC/DF73 Group Lead for change implementation. An SCP CR form is shown in Figure 1.1-1. A copy of the SCP CR form is also available in the front of the EGIL Console Handbook immediately following the preface. A copy of this page should be used when submitting an SCP CR.

If the CR includes changes related to command procedures, a Command Procedures Handbook (CPH) CR will be written and the SCP CR attached to it. Contact the Communications Systems Group Lead at JSC/DF24 for a CPH CR.

Instructions on how to fill out the SCP CR are provided below.

**Initiated by:** Indicate the name of the change initiator in this field.

**Submit Date:** Indicate the date the CR is being submitted.

**CR #:** The CR tracking number is determined by the EGIL CHB Book Manager. Leave this field blank.

**Title:** Provide a brief descriptive title that indicates why the change is being proposed.

**Description of Change or Addition:** This field includes a detailed description of the change, rationale for the change, and the initiator's organization/name.

Technical Author, Technical Reviewer, Assigned Completion Date, Assigned PCN, Group Lead Authorization Signatures:

These fields are for administrative use only and will be completed by the EGIL CHB Book Manager and Group Lead.



Standard Console Procedures Change Request (CR) Form

Initiated by:	Submit Date:	CR #
---------------	--------------	------

For Administrative Use Only

Title:
Description of Change or Addition:

For Administrative Use Only

Technical Author:	Assigned Completion Date:
Technical Reviewer:	Assigned PCN:
<b>Group Lead Authorization Signatures</b>	
<b>IMPLEMENT</b>	<b>CLOSE</b> Completion Date: PCN =

Revised September 1999

Send to: JSC/DF73  
Attention Group Lead

**Figure 1.1-1. SCP CR form**

**Verify that this is the correct version before use**

**SECTION 2  
CONTENTS**

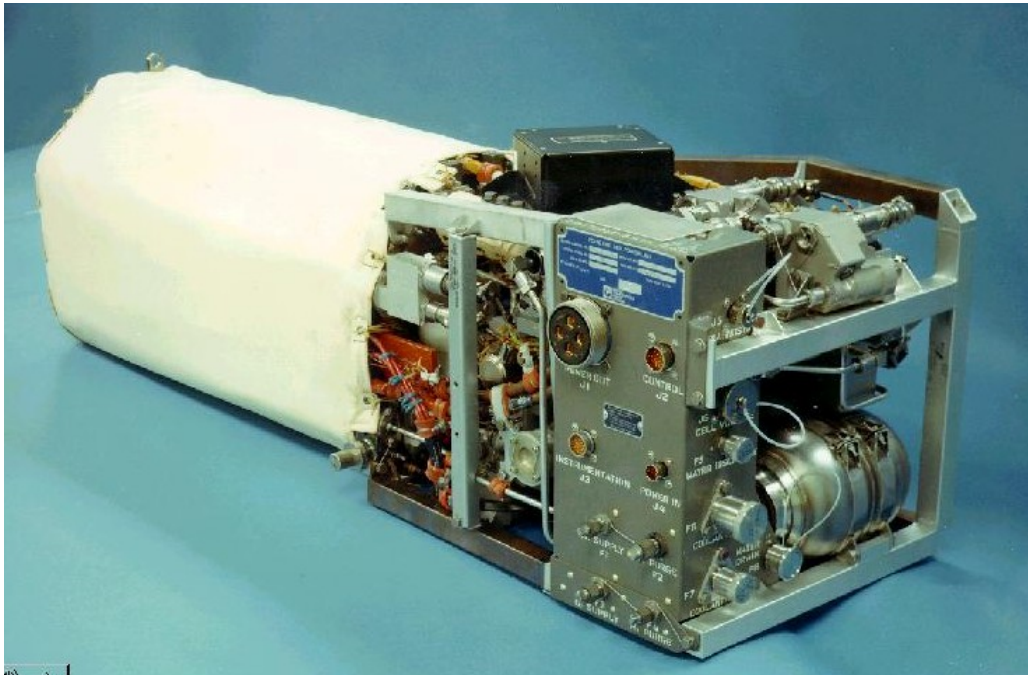
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## TITLE

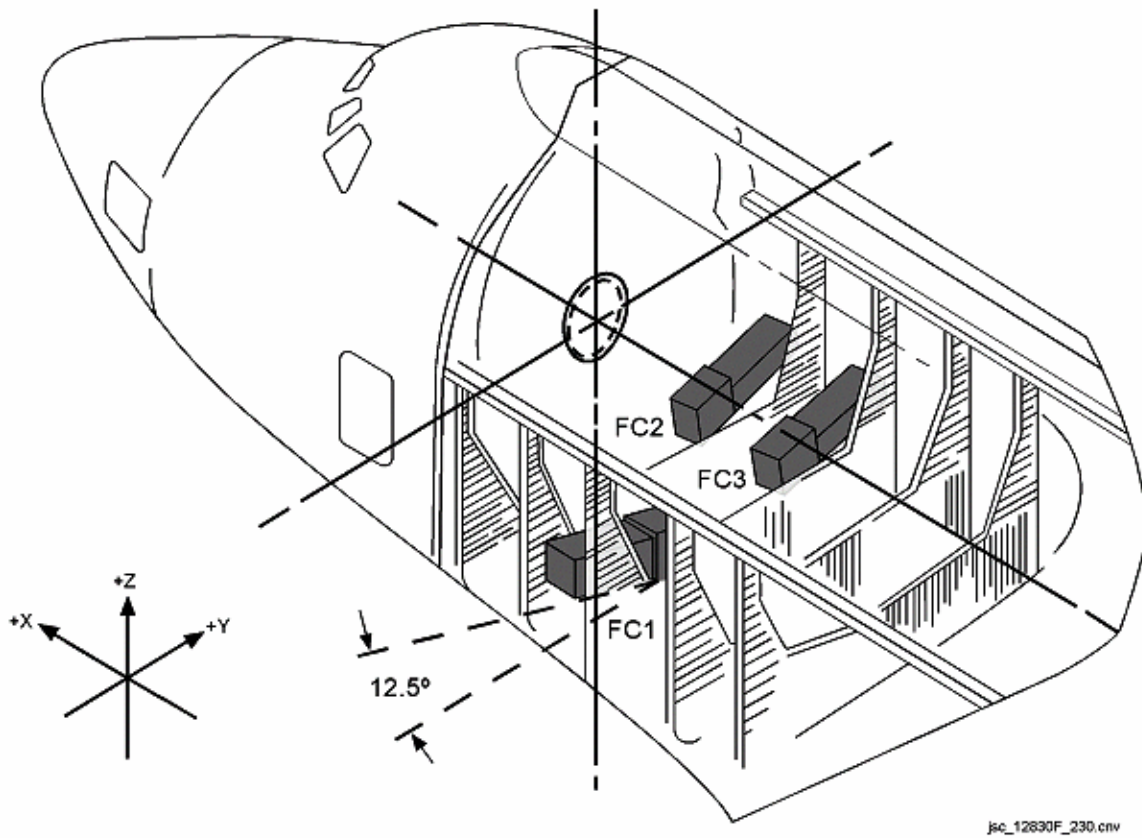
FUEL CELL - GENERAL OVERVIEW

## DISCUSSION

The fuel cell system produces all the electrical power required by the orbiter during all mission phases. The three fuel cells, through a chemical reaction, operate as independent electrical power sources. Each supplies its own isolated, simultaneously operating 28-V DC bus. The fuel cell, as a unit, consists of two sections: a power section, where the chemical reaction occurs, and an accessory section that controls and monitors the power section performance (Figure 2.1-1). The power section, where the electrical power is actually generated, consists of 96 individual cells contained in 3 substacks of 32 cells each. These three substacks, in turn, are connected end to end to make up the fuel cell stack. The accessory section monitors the reactant flow, removes the waste heat and water from the chemical reaction in the stack, and controls the temperature of the stack. The accessory section consists of the H<sub>2</sub> and O<sub>2</sub> regulation system, the fuel cell coolant loop, the Electrical Control Unit (ECU), the Cell Performance Monitor (CPM), and the H<sub>2</sub> pump/H<sub>2</sub>O separator. The three fuel cells are located in the midbody area of the orbiter under the payload bay envelope (Figure 2.1-2).



*Figure 2.1-1. Fuel cell powerplant*



**Figure 2.1-2. Fuel cell locations**

## DESCRIPTION

The following paragraphs describe the individual components of the fuel cell system. Refer to Figure 2.1-3 for a functional drawing of a typical fuel cell. Drawing 3.4 in the SSSH provides a more detailed view of the fuel cell.

### A. H<sub>2</sub> and O<sub>2</sub> flow

The cryogenic reactants, H<sub>2</sub> and O<sub>2</sub>, are supplied from the Power Reactant Storage and Distribution (PRSD) system in a single-phase fluid state at a mass rate as demanded by the fuel cells. Reactant consumption is directly related to the current produced; if there are no internal or external loads on the fuel cell, no reactants will be used. Because of this direct proportion, leaks may be detected by comparing reactant consumption and current produced; an appreciable amount of excess reactants used indicates a probable leak.

After entering the fuel cells, the reactants flow through a preheater, a 15-micron filter, and a two-stage integrated dual gas regulator module. The first stage of the regulator drops both the H<sub>2</sub> and O<sub>2</sub> pressure down to 100 to 120 psia; the second stage regulates the O<sub>2</sub> pressure to a range of 60 to 65 psia and maintains the H<sub>2</sub> pressure at 4.5 to 6 psia below the O<sub>2</sub> pressure. The regulated O<sub>2</sub> line is connected to the accumulator, which maintains an equalized pressure between the O<sub>2</sub> and the fuel cell coolant. In cases where the O<sub>2</sub> and H<sub>2</sub> pressures decrease for some reason, the coolant accumulator automatically decreases the coolant pressure to prevent a large differential pressure inside the fuel cell stack. A large differential pressure would crack the thin walls of the fuel cell that separate the coolants, H<sub>2</sub> and O<sub>2</sub>, effectively destroying the fuel cell. The O<sub>2</sub> from the dual gas regulator module flows directly through two ports into a closed-end manifold in the fuel cell stack, permitting optimum oxygen distribution in the cells. All oxygen that flows into the stack is consumed, except during purge operations.

After leaving the dual gas regulator module, the incoming hydrogen mixes with the hydrogen-water vapor exhaust from the fuel cell stack. This gas is routed through a condenser, where the temperature of the mixture is reduced below the boiling point of water, condensing the water. Liquid water is then separated from the hydrogen-water mixture by the H<sub>2</sub> pump/H<sub>2</sub>O separator. The H<sub>2</sub> pump circulates the H<sub>2</sub> gas back to the fuel cell stack, where some of the H<sub>2</sub> is consumed in the reaction. The remainder flows through the fuel cell stack, removing the product water by evaporation from the fuel cell. The hydrogen-water vapor mixture then combines with the regulated H<sub>2</sub> from the dual gas regulator module, and the loop described earlier starts over again.

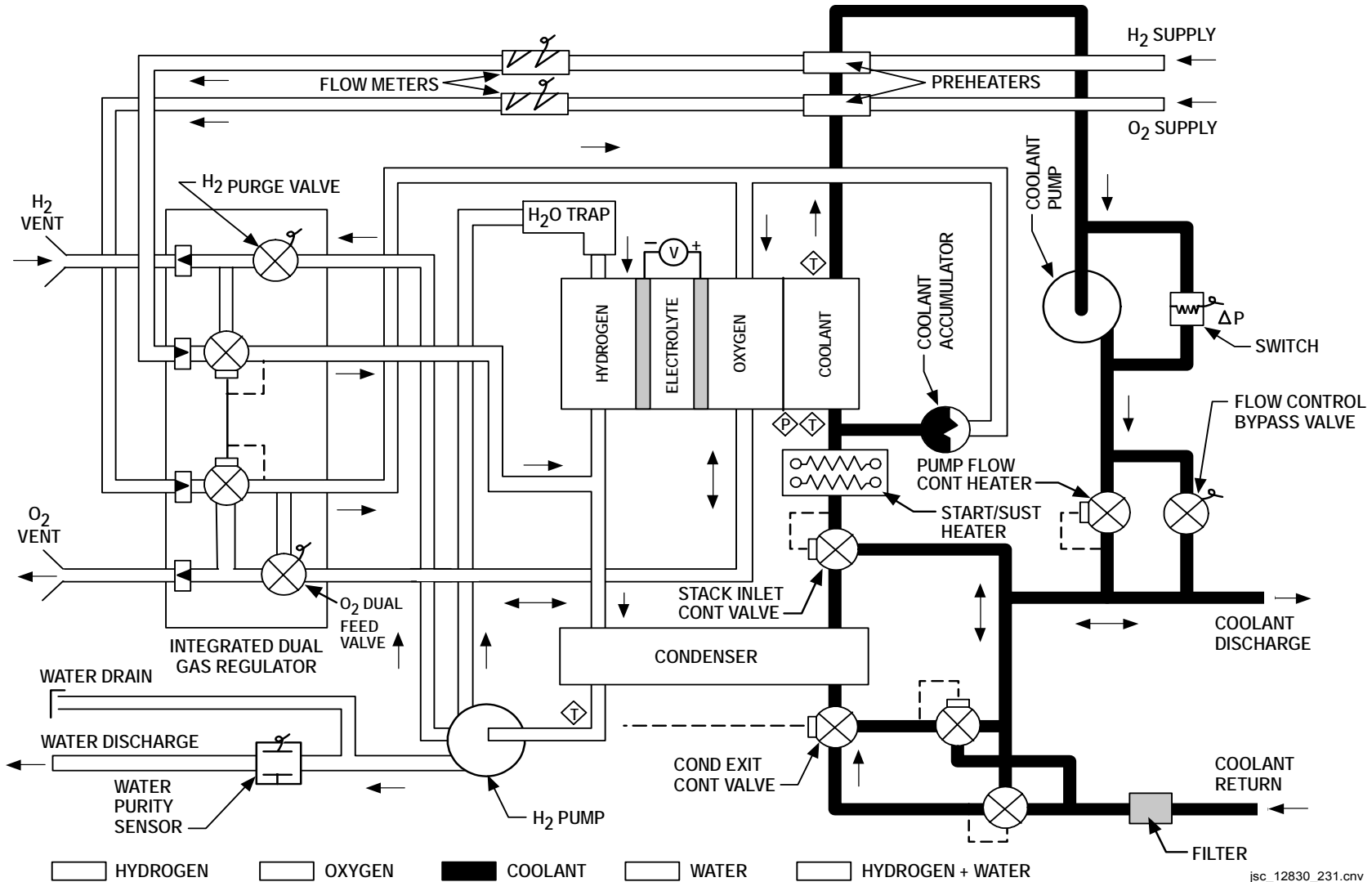


Figure 2.1-3. Typical fuel cell schematic

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2.1-4

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B. Water removal

Water and electrical power are the products of the chemical reaction of oxygen and hydrogen that takes place in the fuel cells. This water must be removed, or the stack will become saturated with water, causing decreased reaction efficiency. The fuel cell can continue to operate for about 110 amp-hours before the fuel cell floods with product water, thus effectively halting power generation. Therefore, with an operating load of about 7 kW, it takes about 25 to 30 minutes to flood the fuel cell. The H<sub>2</sub> is pumped through the stack, reacting with the oxygen and picking up and removing water vapor on the way. After being condensed, the liquid water is separated from the H<sub>2</sub> pump/H<sub>2</sub>O separator and discharged from the fuel cell to be stored in the potable water tanks.

A check valve in the water discharge line prevents a back pressure from the water tanks from flooding the fuel cells. If the water tanks are full or if there is line blockage, the water from the fuel cells will then flow through the alternate water system. The alternate water system tees off each individual fuel cell prior to the water relief panel and provides a redundant path for the water to flow to the ECLSS tanks (Figure 2.1-4). The alternate water path connects directly into supply H<sub>2</sub>O tank B. Each path in the alternate system has a relief valve that operates at 6 to 8 psid above tank B pressure. This design allows an individual fuel cell to flow through the backup system if it is the only one affected by a blockage.

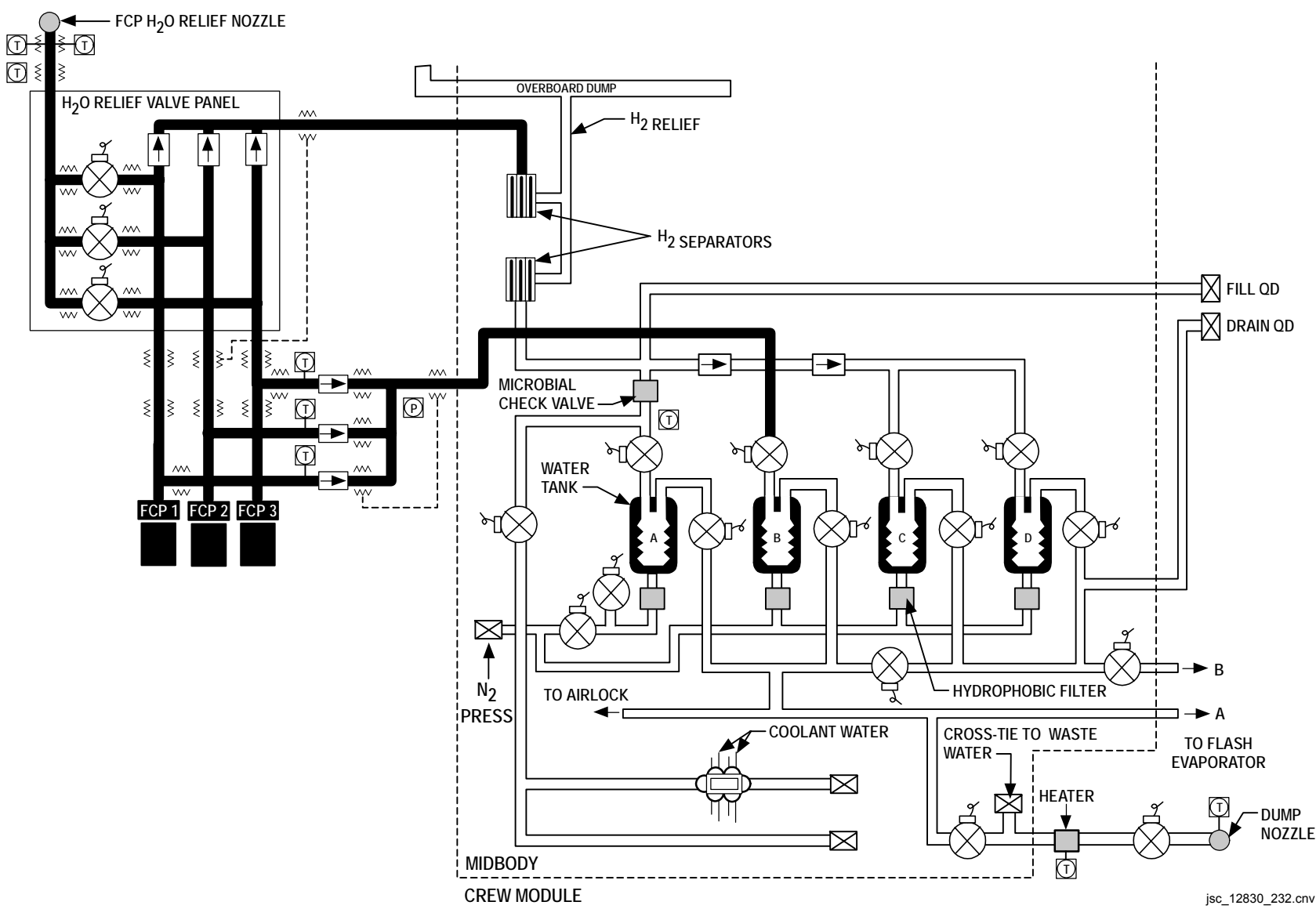
Each individual fuel cell also has a water relief valve, located on the water relief panel, that allows the product water to relieve overboard if both the primary and alternate paths fail to operate properly. The water relief valves crack at 45 psia to allow the water to vent overboard through the H<sub>2</sub>O relief line and nozzle. For redundancy, two thermostatically actuated heaters are wrapped around the discharge and relief lines to prevent line blockage caused by the formation of ice in the lines.

C. Purging

During normal fuel cell operation, the reactants, O<sub>2</sub> and H<sub>2</sub>, are present in a closed-loop system. Any inert gases or other contaminants present will slowly accumulate in and around the porous electrodes in the cells. This accumulation will reduce the reaction efficiency and load support capability of the fuel cell. Purging is not to exceed 96 hours between each purge to cleanse the cells. When a purge is initiated by opening the purge valves, the O<sub>2</sub> and H<sub>2</sub> become open-loop systems with increased flows, allowing the reactants to circulate through the stack, pick up the contaminants, and blow them out overboard

through the purge lines and vents. Electrical power is continually being produced throughout the entire purge sequence. The capability exists for either manual or automatic control of the purge sequence but, independent of the mode selected, the basic purge sequence is the same. Reference Section 2.6 for a detailed review of the fuel cell purge sequence and commanding via manual or automatic operation.





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Figure 2.1-4. Water relief system

2.1-7  
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D. Coolant loop

In order to cool the fuel cell stack during its operation, distribute heat during fuel cell startup, and warm up the cryogenic reactants entering the stack, the fuel cell circulates a coolant, fluorinated carbon (FC-40), throughout the fuel cell. Figure 2.1-3 is a schematic of a fuel cell that shows the coolant loop in the fuel cell and its interface with the orbiter Freon coolant loops. At the coolant entrance to the fuel cell, the temperature of the coolant returning from the orbiter Freon loops is sensed just before it passes through a 75-micron filter. After the filter are two temperature-controlled premixing valves that allow some of the hot coolant to mix with the cool coolant. This premixing conditions the temperature of the coolant flowing into the condenser exit control valve and prevents it from undergoing repeated oscillations. The condenser exit control valve adjusts the flow of the coolant through the condenser to maintain the H<sub>2</sub>/O<sub>2</sub> vapor exiting the condenser at a temperature between 145° and 160° F. The stack inlet control valve maintains the temperature of the coolant entering the stack between 178° and 190° F. The accumulator is the interface with the O<sub>2</sub> cryogenic reactant to maintain an equalized pressure between the O<sub>2</sub> and the coolant (the O<sub>2</sub> and H<sub>2</sub> pressures are equalized at the dual gas regulator) to preclude a high-pressure differential in the stack, which could burst the thin walls of the cells. The pressure in the coolant loop is sensed right before the coolant enters the stack.

The coolant is circulated through the fuel cell stack to absorb the waste heat from the H<sub>2</sub>/O<sub>2</sub> reaction occurring in the individual cells. The hot coolant just out of the stack flows through the O<sub>2</sub> and H<sub>2</sub> preheaters, where it warms the cryogenic reactants before they enter the stack.

The coolant pump uses three-phase AC power to drive the coolant through its loop. The ΔP sensor senses a pressure differential across the pump to determine the status of the pump. Downstream of the pump is the flow control valve, which is a temperature-actuated valve. It adjusts the coolant flow to maintain the fuel cell coolant stack exit temperature between 196° and 235° F. The stack inlet control valve and flow control valve have bypass orifices to allow coolant flow through the coolant pump and to maintain some coolant flow through the condenser for water condensation, even when the valves are fully closed because of the requirements of thermal conditioning.

The coolant that is not made to bypass exits the fuel cell to interface with the Freon loop fuel cell heat exchanger, where it transfers its excess heat to the orbiter Freon system. In addition to the thermal conditioning by means of the coolant loop, the fuel cell has internal startup and sustaining heaters. The startup heater is used only during startup to warm the fuel cell to its operational level. The sustaining heaters are normally used during low power periods to maintain the fuel cells at their operational temperatures. To maintain constant temperature throughout the stack prior to STS-26, the fuel cells had control elements attached to the end cells at each end of the stack. After STS-26, end plates were added to

the fuel cells that circulate warm coolant around the end cells of the stack to maintain a constant temperature from end to end.

E. Electrical control unit

The ECU is the brain of the fuel cell. It is an electrical module located within the fuel cell that contains the startup logic, heater thermostats, and 30-second timer and is the interface with crew controls and displays for fuel cell startup, operation, and shutdown. The ECU controls the supply of both AC power to the coolant pumps, H<sub>2</sub> pump/H<sub>2</sub>O separator, and the pH sensor; the DC power supplied to the flow control bypass valve (open only during startup), and the internal startup and sustaining heaters. The ECU also controls the status of the “ready for load” and “coolant pump DP” talkbacks. A detailed review of the ECU can be found in Section 2.3.

## TITLE

FUEL CELL DUAL GAS REGULATOR OPERATION

## PURPOSE

To describe the function and operation of the fuel cell dual gas regulator and to assist the Electrical Power System (EPS) and EGIL console operators in recognizing nominal and abnormal regulator operations.

## REFERENCES

Orbiter Fuel Cell Powerplant Review and Training Course (booklet and videotapes), International Fuel Cells, March 1999.

Orbiter Fuel Cell Powerplant Review and Training Course (part 10, videotape), International Fuel Cells, March 1988.

Orbiter Fuel Cell Powerplant Review and Training Course 2103, Reactant Components (videotape no. 2), 1978.

International Fuel Cells Letter FCR011203, TT&E Report, Reactant Regulator PN 800658A, August 3, 1990.

SSSH, drawing 3.4-1, Fuel Cell.

## BACKGROUND

The dual gas regulator, officially called the coupled reactant regulator, is part of the accessory section of the fuel cell. The regulator consists of two regulators, one for the H<sub>2</sub> side and one for the O<sub>2</sub> side, coupled together through a small bellows (aneroid) section. The regulator is built by Scott Aircraft and was originally designed for an undersea program to withstand rugged conditions. In fact, each regulator is tested with 3500-psia inlet pressure.

Originally, during the Apollo program, the H<sub>2</sub> and O<sub>2</sub> regulators were not coupled. Fourteen regulators failed because of an incorrect pressurization sequence, along with other various causes, resulting in improper pressure balances between the O<sub>2</sub> and H<sub>2</sub> sides of the fuel cell. In the early 1970's, a coupling device was developed that prevents H<sub>2</sub> from flowing into the regulator without the O<sub>2</sub> side already pressurized. No power section has been lost due to pressure imbalance since the coupled design has been in place.

The dual gas regulator steps down the pressure of the feed gas in two stages. The first stage steps down the pressure to 100 to 120 psia, and the second stage regulates the O<sub>2</sub> side to 65 psia. H<sub>2</sub> is regulated to 5 psi below the O<sub>2</sub> pressure. The H<sub>2</sub> molecules are smaller than the O<sub>2</sub> molecules. The 5-psia delta keeps the H<sub>2</sub> molecules from crossing over to the O<sub>2</sub> side, which would cause uncontrolled mixing of the two gases. The coupling device maintains the pressure balance between the two regulators.

Eight ports and 15 valves are within the regulator; two inlet ports, two exit ports (used for venting or purging away from the power section), and four discharge ports from the regulator to the power section. The rubber parts of the regulator are made from neoprene. The body of the regulator is made of aluminum. The two sides of the regulator are almost identical, with two exceptions: the O<sub>2</sub> dual feed valve and the sizing of the valves in stage 2 are slightly different because of the difference in molecule size between H<sub>2</sub> and O<sub>2</sub>. The regulator is a mechanical device and does not depend on any electrical input, with the exception of the solenoid reactant valves.

The regulator is intolerant of contamination, and even a molecule can cause a leak to develop. Filters are used to protect the regulator from contaminants in the feed gas and within the stack. The regulator can supply enough reactant flow to support a 32-kW load for a few seconds. This allows the regulator to support either fault clearing or to burn out a large short. The regulator is guaranteed to supply full reactant flow with the feed gas at 100 psi and might be able to support its full capacity with a small drop below. With the feed gas at 70 psi, the regulator can continue to supply a certain amount of reactant flow but will no longer have the ability to support its full capability. All leak checks for the plumbing are performed at 100 psi, which is also referred to as the lockup pressure of the regulator.

The regulator performs two major functions, as follows:

- A. Supplies controlled pressured reactant to the cell stack - There are two primary objectives for regulation of the cryogenic gases. The first is to maintain a balanced pressure delta of 5 psia between the O<sub>2</sub> and H<sub>2</sub> sides, and the second is to maintain pressure. This pressure differential takes precedence over all other regulator priorities. The regulator will always try to balance pressure between the O<sub>2</sub> and H<sub>2</sub> sides before it tries to maintain pressure within the standard operational range. Ideally, reactants from the regulator to the power section will be maintained at approximately 60 psia.
- B. Provides reactant purge capability - During powerplant operations, inert gases build up on each cell plate, reducing available reaction surface and, subsequently, fuel cell performance. Periodic purging, by increasing O<sub>2</sub> and H<sub>2</sub> flow through the fuel cell power section, helps to cleanse the reaction sites and gain back some of the lost performance. Although this SCP will discuss some aspects of the fuel cell purge process from a regulator standpoint, reference Fuel Cell Purge, SCP 2.6, for a full discussion on purging operations.

## **OPERATIONAL OVERVIEW**

O<sub>2</sub> and H<sub>2</sub> reactants flow from the PRSD system cryogenic tanks into the O<sub>2</sub> and H<sub>2</sub> manifolds. Both the O<sub>2</sub> and H<sub>2</sub> reactants pass through a preheater that warms the cryogenic fluid to prevent water and elastomer freezing in the regulator. The preheater utilizes hot coolant coming out of the stack to warm the O<sub>2</sub> and then the H<sub>2</sub> fluid. The cryogenics then enter the regulator to step down the reactant pressure prior to entering

the stack. Reference the Fuel Cell General Overview, SCP 2.1, for further discussion on overall fuel cell operation.

Two stages of pressure regulation are used to make it easier to regulate the pressure within the stack. Each half of the regulator contains a two-stage pressure regulator. Each first-stage regulator receives gas at the vehicle supply pressure (100 to 1050 psia O<sub>2</sub>, 100 to 335 psia H<sub>2</sub>) and reduces this pressure for presentation to the second stage at a relatively constant pressure (100 to 120 psia), regardless of the supply pressure. The cryogenic gas comes into the first stage through a filter screen before passing through an inlet check valve. Check valves are incorporated into the first-stage regulator sections to prevent powerplant depressurization, should one or both supply gas pressures be removed. The second set of check valves prevents gas from backfilling the regulator.

The second stage of the pressure regulators is mechanically coupled together and referenced to an evacuated, sealed bellows so that output pressures at a level of 60 psia, nominally, are produced. The coupling device is an aneroid device with a chained spring within it. The H<sub>2</sub> and O<sub>2</sub> bellows are sealed and evacuated. The pressure on one side of the rubber diaphragm is at 60 psi, and the evacuated side is at the ambient room pressure at the time when the regulator was sealed. The spring inside each is then chained together.

In the early stages of fuel cell development, the regulator would vent uncontrollably during dynamic simulator testing at 8.2g and Y-axis vibration tests. A damping fluid, which is thicker than molasses and unaffected by temperature, fills half of the cavity to resolve the venting problem. As a result, there is no venting at 3g and very slight venting at 8g. Approximately 8 to 10/cm<sup>3</sup> of the fluid are utilized for this purpose. After the fluid is inserted through a cap and sealed, Scott Aircraft performs a pressure test to ensure that damping fluid is not leaking through the O-ring seals or the rubber diaphragm.

The 5-psia bias between the O<sub>2</sub> and H<sub>2</sub> sides comes from the set of springs within the coupler. The demand diaphragm (aneroid) evacuated reference spring pushes against the path section of each side's reference plunger. This set of springs pushes the assembly toward the O<sub>2</sub> side and makes the O<sub>2</sub> side "think" that the H<sub>2</sub> side is at a slightly higher pressure than it actually is. The two hooks inside the aneroid prevent expansion beyond the operational range and allow tracking of depressurization within the regulator. The total stroke of the regulator from zero to maximum flow (50 to 60 kW) is less than 0.020 of an inch.

The whole coupler will slide over to let in either O<sub>2</sub> or H<sub>2</sub>, depending on the pressure. With no demand, the inlet check valves are seated with the 135-psi gas. As the fuel cell consumes cryogenics to support the electrical demand, the pressure decreases within the regulator, and the second stage of regulation is pushed against the demand diaphragm, allowing the spring in the aneroid to expand. The spring is regulated to press against the plunger, forcing the valve off its seat and allowing in the 135-psi gas. When 60 psi on the H<sub>2</sub> side or 63 psi on the O<sub>2</sub> side is reached, both sides will collapse

and will be shut until the pressure drops. Because it is coupled, both sides must have gas to maintain pressure. It is impossible to get adverse pressure, because the H<sub>2</sub> and O<sub>2</sub> regulators adjust to one another mechanically. If pressure is lost on either the O<sub>2</sub> or H<sub>2</sub> side, the regulator will drop pressure equally between the two sides, and damage will not occur. This causes the regulator to fail in a safe mode.

The cryogenic fluid can flow in the regulator through several paths.

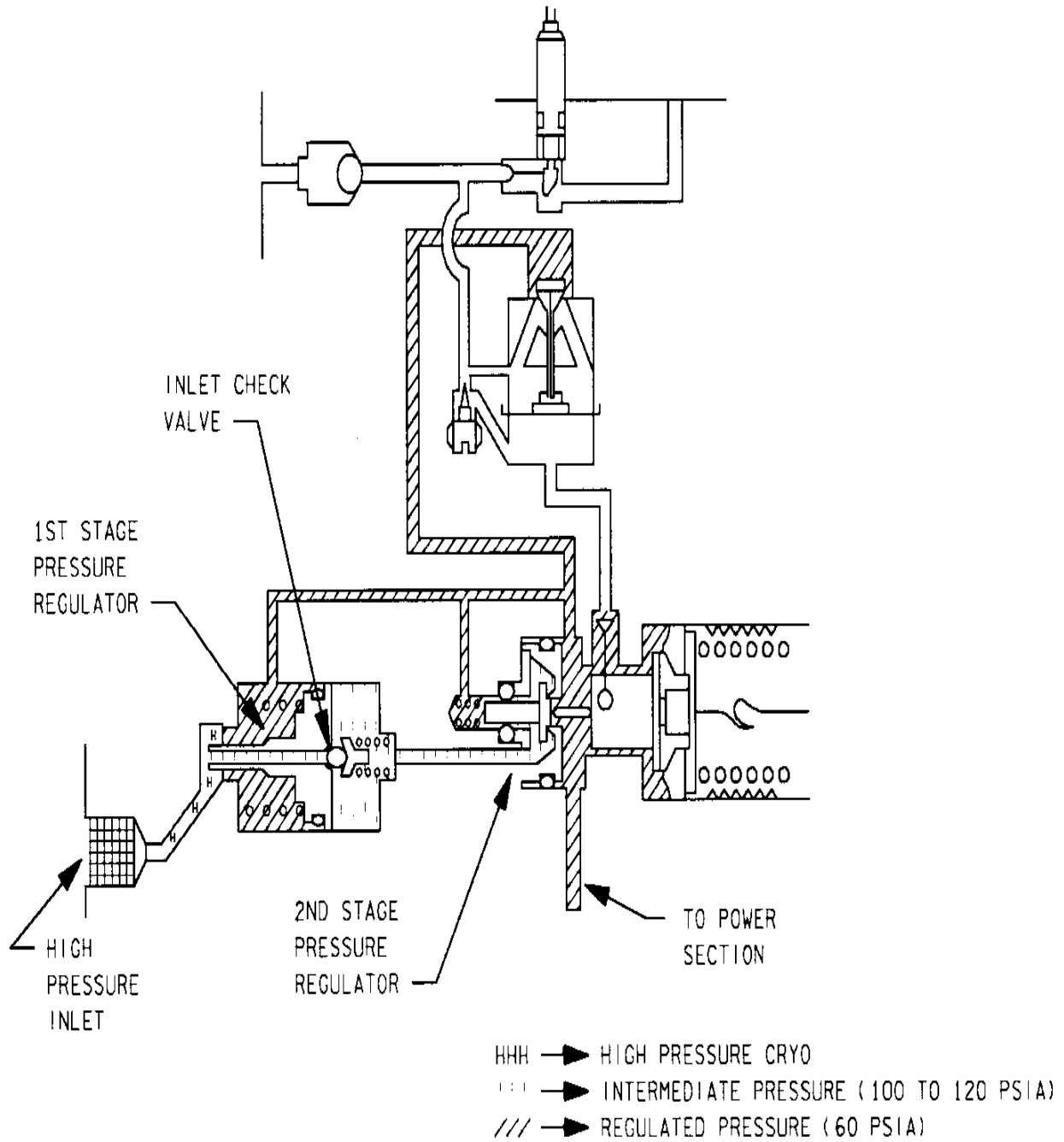
1. It can go straight overboard from the regulator to the inlet of the power section.
2. It can backflow in the second stage to maintain pressure balance and keep the regulator operations smooth.
3. It can backflow to the first stage, so that if either O-ring develops a leak, pressure can be built to force the vent valve to operate.
4. It can flow into the vent valve/orifice area.
5. On the O<sub>2</sub> side, it can flow from the dual feed valve into the discharge manifold.

Figure 2.2-1 shows a functional representation of the two-stage pressure regulator system.

A. O<sub>2</sub> regulator

The major difference between the H<sub>2</sub> and O<sub>2</sub> sides of the regulator is that the H<sub>2</sub> feeds through one manifold, while the O<sub>2</sub> feeds through two sides. During initial development of the fuel cells, it was found that one feed on the O<sub>2</sub> side was insufficient to adequately feed the end cells. The pressure differential became low enough toward the end of the fuel cells that inadequate amounts of O<sub>2</sub> were being received, which would starve the cells. As a result, the O<sub>2</sub> purge inlet port acts as a feed port except during purges. This causes the O<sub>2</sub> to not be circulated, or deadheaded, through the stack. A dual feed valve controls the O<sub>2</sub> path for both nominal and purge operations. The dual feed valve acts as a purge vent valve, check valve, and out vent port.

A solenoid operates the dual feed valve. When the solenoid is activated, it retracts the pole, which allows the spring valve to close. When the spring valve closes, the purge valve is opened, and then the gas can come from the exit port into the vent port. The regulator utilizes the dual feed valve to deliver O<sub>2</sub> to the power section "exit" manifold, in addition to the normal delivery from the regulator to the "inlet" manifold. This dual feed valve diverts 30 percent of the feed flow to the power section through the exit manifold during nonpurging periods. This provides a more uniform distribution of O<sub>2</sub> within the power section for maximum cell performance by preventing inerts from collecting at the cell exits.



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**Figure 2.2-1. Regulator stage operation**

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## B. Venting

The supply valves are smaller than the vent valves. If a supply valve sticks open, the vent valve will open to get rid of it. This prevents overpressurization of the powerplant, while still maintaining some pressure control on the powerplant. The vent valve has a very rough operation. It has no monitoring capability, but opens and shuts (burping).

If pressure builds up too much or if a pressure imbalance occurs, the vent valve is tilted and allows some gas flow into a diaphragm and into the vent orifice. This will build a back pressure to overcome the force and open the valve, allowing high-pressure gas to flow through the vent valve/orifice and overboard. Normally, the vent valves never operate except during depressurization-type modes. The vent valve system has a tilt pilot valve, which can handle the majority of venting requirements. When the power plant is depressurized, the valves can be heard releasing the pressure. The vent valve is designed to open at 70 psia. For normal operations, there is no venting required within the regulator. A leak inside the regulator, such as one between the first and second stages, could cause venting.

Coolant pressure is usually lower than the O<sub>2</sub> side. If pressure between accumulator and O<sub>2</sub> reaches 70 psi, the regulator will vent. A regulator depressurization will activate both the purge valves and the shutoff supply valves and will try to depressurize one side or the other first. Typically, H<sub>2</sub> is depressed first, with O<sub>2</sub> tracking. If the delta pressure cannot be maintained because of the rapidity of the depressurization, the vent valve will open to assist.

Overpressurization has other characteristics. Although the vent valve is designed to relieve at 70 psia, there is a scenario that can cause the regulator to overpressurize. If H<sub>2</sub> develops a problem and cannot relieve overboard, the O<sub>2</sub> side will try to compensate to maintain pressure by allowing in more gas. The O<sub>2</sub> will not vent at 70 psia because it is attempting to track the 5-psi delta against the H<sub>2</sub> side. The power section can withstand up to 200 psia of pressure before springing a leak overboard.

## C. Purging

Contaminants, also known as inerts, begin to build on the cell plates over a period of time, reducing the surface area for the reaction and, therefore, the ability to generate voltage. When either a 0.2-volt degradation is seen in fuel cell performance during a mission or when 96 hours have passed since the last purge, a fuel cell purge is performed (Reference NSTS 12820, Space Shuttle Operational Flight Rules, Volume A, FC purge, A9-52). Heaters are turned on along the fuel cell purge lines to warm them and to prevent freezing of the lines and nozzle.

When the required temperatures are reached, the solenoid purge valves are opened. The purge valves are 28 V DC nonlatching solenoid valves that can be controlled by either a software command or by a manual switch. There are no

operational constraints on the valves. Although the valves will get hot, there is no concern that they will overheat.

The purge orifices are designed for the molecular weight of the gas. The size of the O<sub>2</sub> purge orifice is that of a toothpick. A drilled hole is immediately downstream of the purge orifice. A gas of a heavier weight can clog the purge orifice. For example, N<sub>2</sub> is heavier than H<sub>2</sub> and could clog that side of the regulator. Subsequently, venting would occur to compensate.

During nominal operations, the H<sub>2</sub> is constantly circulated through the stack, and the O<sub>2</sub> is deadheaded (i.e., not circulated). Purging is more critical on the O<sub>2</sub> side because there is no constant flow completely through the stack, except during purge operations. After the purge valves are opened, the O<sub>2</sub> path is changed so that O<sub>2</sub> can freely pass through the stack and carry inerts away. Both O<sub>2</sub> and H<sub>2</sub> reactants are flowed through the stack at a higher rate and are then expelled overboard through the purge lines.

H<sub>2</sub> is delivered to the power section exit manifold (condenser inlet). The purge gas does flow through the H<sub>2</sub> pump. The purge solenoid lifts, and the H<sub>2</sub> gas flows through the purge inlet port and out the vent port.

When fuel cell purging is performed, electrical solenoids operate the valves so that H<sub>2</sub> gas is returned from the exit manifold through a line to the regulator and then overboard. The O<sub>2</sub> gas stops flowing to the power section through the dual feed line to the O<sub>2</sub> exit manifold and, instead, returns to the regulator through this line, carrying impurities overboard.

Figure 2.2-2 is a plot of fuel cell coolant pressure and reactant flows during pulse purges prior to a fuel cell startup. When the reactant valves are closed, the coolant pressure drops as the reactants are consumed. When the coolant pressure reaches approximately 27 psi, it levels out for a time, and an increase in the O<sub>2</sub> flow rate is seen. This occurs because H<sub>2</sub> is being consumed at a slower rate than the O<sub>2</sub>, and the leveling of pressure allows the H<sub>2</sub> to catch up.

## **FAILURE MODES, POTENTIAL UPGRADES, AND HISTORY**

Several potential failure modes are discussed, along with what the operator might see within their data. Although leaks internal to the regulator are unlikely to cause the pressure regulation to fail, there are several other scenarios that have been seen and are realistic.

### **A. Failure modes**

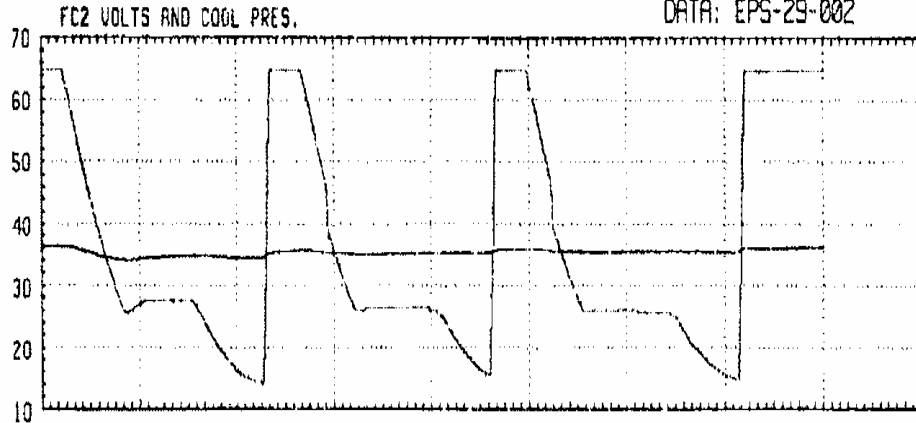
1. Pressure imbalance – If an imbalance occurs in regulated pressure between the H<sub>2</sub> and O<sub>2</sub> output pressures, the control moves immediately to restore balance by admitting gas to the low-pressure side. If insufficient makeup gas is available to achieve a pressure balance in this manner, or if additional gas would exceed regulation pressure, the control vents excess gas from the

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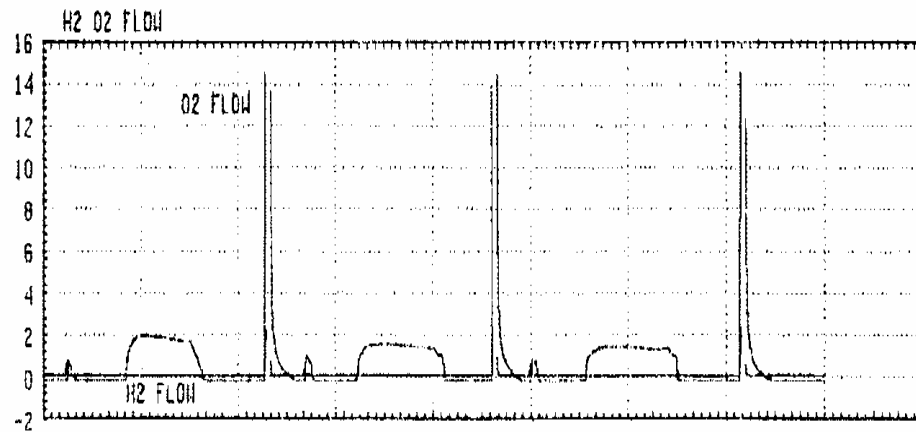
FC2 PULSE PURGES

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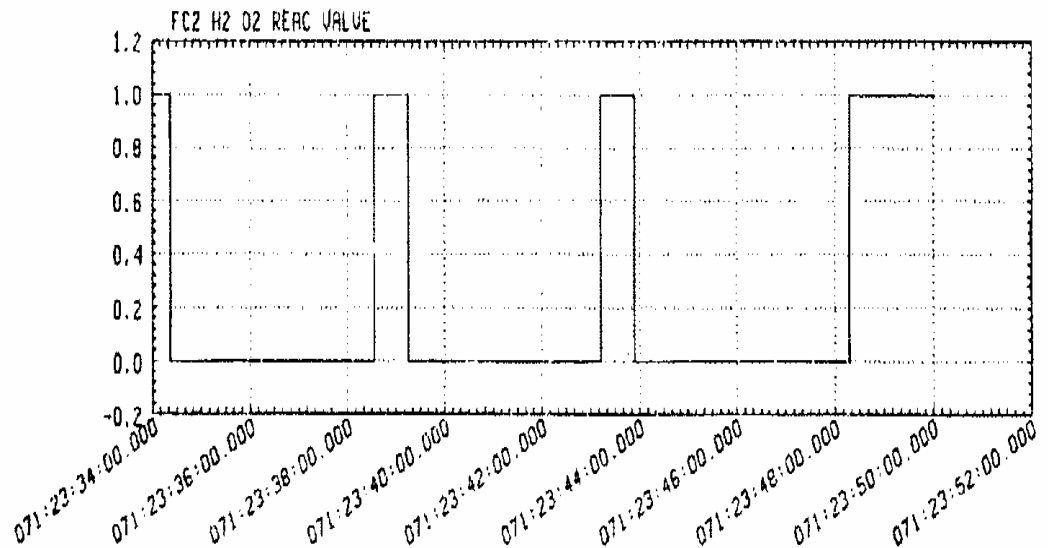
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V45R0260R  
(UNITS N/A)



V45X1155E  
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Figure 2.2-2. Pulse purges

high side to maintain a balanced pressure level. The regulator closes the supply valve when the vent valve opens.

If a malfunction occurs that causes the powerplant to become overpressurized for any reason, even though the reactant pressure remains balanced, simultaneous reactant venting immediately reduces the excess pressure to the 60-psia regulated level. If venting is not possible, the regulator action maintains the pressure balance but provides higher-pressure reactants until the malfunction is cleared.

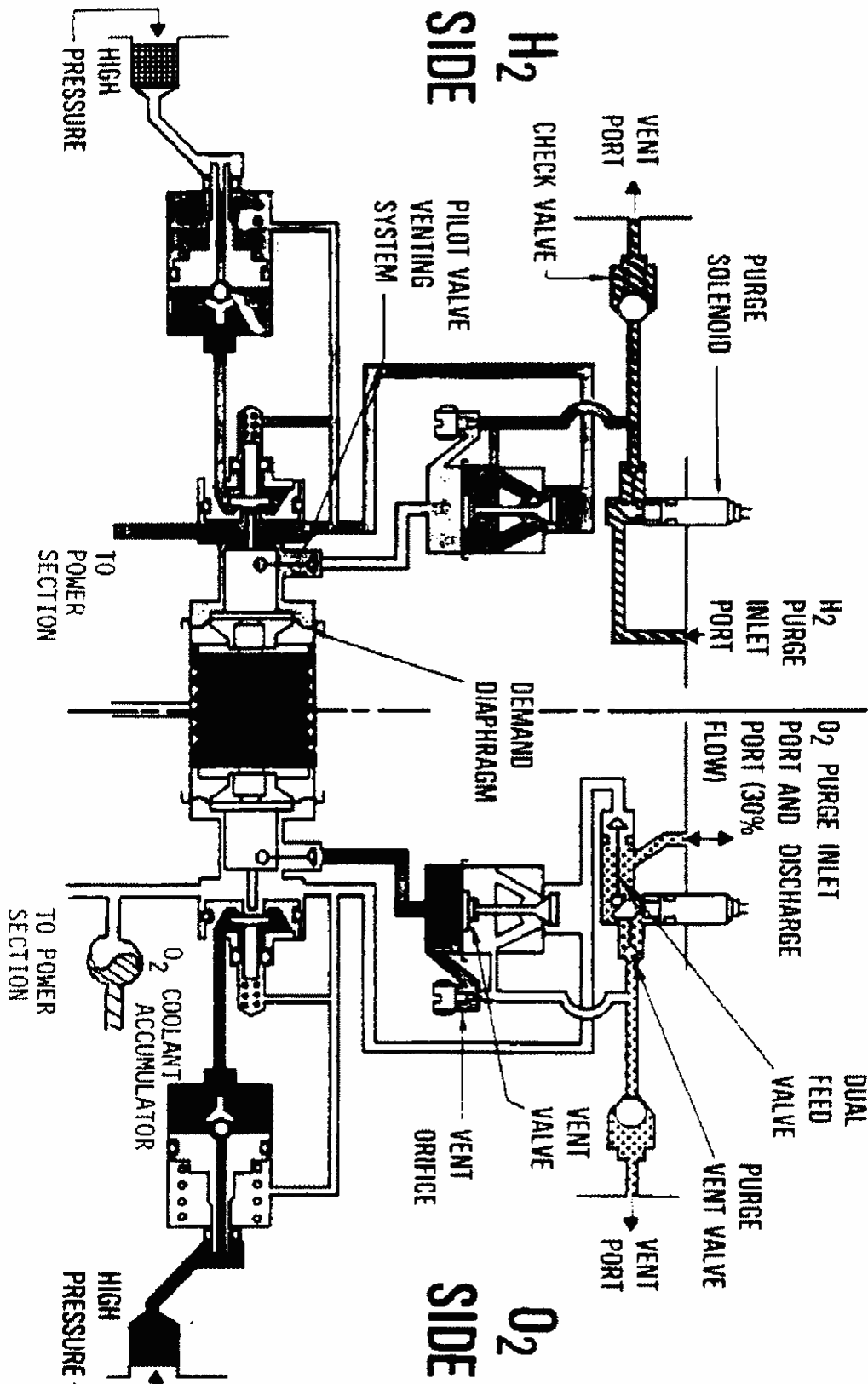
Figure 2.2-3 shows the operation of the regulator in balancing the regulated pressure between O<sub>2</sub> and H<sub>2</sub>.

2. H<sub>2</sub> overpressurization – A H<sub>2</sub> overpressurization is detrimental to the cells and can be sustained only for a few minutes. The spec range is 4.5 to 6 psi for the pressure difference between O<sub>2</sub> and H<sub>2</sub>, including purge operations. This 5-psi delta is set by slightly adjusting a set of springs toward the O<sub>2</sub> side in the reference bellows that joins the H<sub>2</sub> and O<sub>2</sub> regulators. The H<sub>2</sub> side then compensates for this adjustment by lowering the H<sub>2</sub> pressure until it evenly matches where it mechanically senses the O<sub>2</sub> pressure to be. The second stage provides for minimal dropoff in regulated pressure as the demand flow changes from zero to maximum and maintains all pressures within 4 psia of the normal steady-state operating setting during fuel cell pressurization and depressurization operations. Failure of the first stage of the regulator will not prevent the second stage from regulating the output pressures. However, the second stage would probably not operate within specifications.
3. Coupler - If the spring breaks within the coupler, the coupler loses the ability to adjust pressure, both valves shut, and pressure drops. If the diaphragm breaks, O<sub>2</sub> leaks in and fills the chamber. However, the area of the chambers was designed to equal the diaphragm. The diaphragm will continue to regulate O<sub>2</sub> within the coupler instead of without. As a result, no pressure change will be seen. Both diaphragms would have to break for this to become a problem.

IFC did receive a delivery of torn diaphragms, which had unnecessarily sharper edges. IFC was able to recall all the regulators with this problem.

Another problem that has occurred with the coupler is that the silicon grease used to damp the aneroid has absorbed N<sub>2</sub>. As a result, some outgassing occurs, and the regulator pressure point has been offset.

An aneroid leak causes pressure to rise very slowly. This could start as a pinhole leak. Checks for aneroid leaks are performed. The pressure could reach 75 psi, because the vent system references the regulated gas pressures so that the reference points will adjust together.



L 12830\_250

Figure 2.2-3. Pressure regulation, gas supply, and purge  
2.2-10

Verify that this is the current version before use

4. STS-31 regulator anomaly - During purges on STS-31, FC2 O<sub>2</sub> flow showed a large increase near the end of the purge cycle. It was confirmed that the flow increase was real, because the associated H<sub>2</sub> flows showed a decrease, which is indicative of the regulator responding to a pressure drop on the O<sub>2</sub> side (Figure 2.2-4). This failure signature occurred several times but was not detected until a high O<sub>2</sub> flow alarm was enunciated. There were no subsequent purges performed on the fuel cell.

The postflight investigation indicated that the purge anomaly was the result of leakage of the O<sub>2</sub> dual feed tube O-ring, caused by KOH electrolyte corrosion of the O-ring. The resulting high flow rate carried additional corrosion products from the O<sub>2</sub> exit manifold to the O-ring groove, which subsequently plugged the leak site. The most likely source of KOH in the area was an inadvertent H<sub>2</sub> overpressure at some time prior to the mission, which expelled some KOH into the O<sub>2</sub> compartments of the cell and then to the O<sub>2</sub> exit manifold. From this point, the KOH could easily migrate to the O-ring if the powerplant was tilted in that direction.

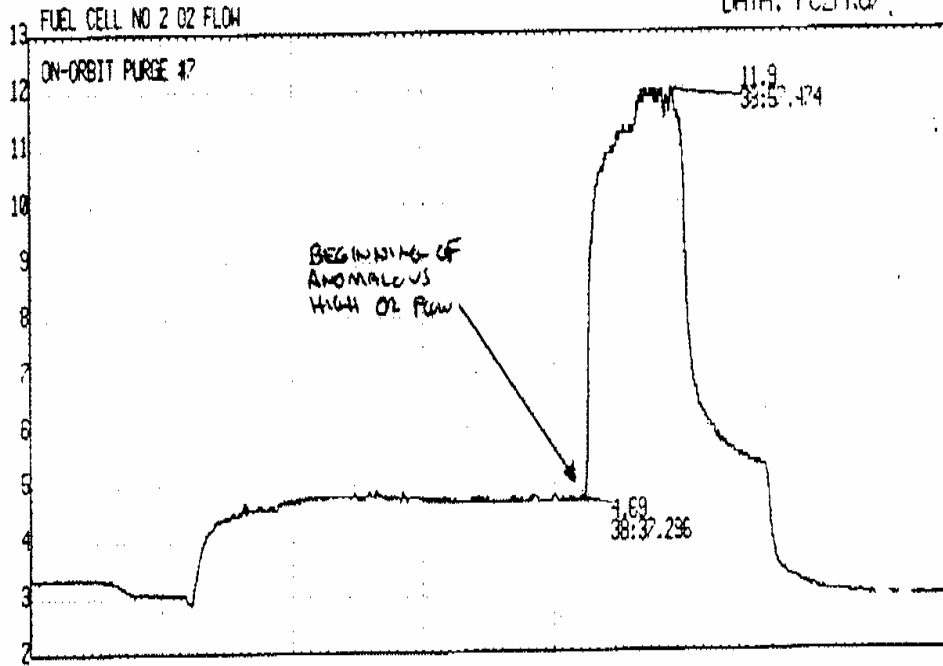
Figure 2.2-4 is a plot of O<sub>2</sub> and H<sub>2</sub> flows on STS-31 during the fuel cell purge anomaly. The plot demonstrates the reaction of the regulator to changes in pressures and flows of one of the reactants. As the pressure was reduced on the O<sub>2</sub> side of the regulator through the venting of reactants (seen by the increased flows), the regulator responded by lowering the pressure on the H<sub>2</sub> side (seen as a small drop in flow).

SUBSYSTEM: TMS  
STS-031

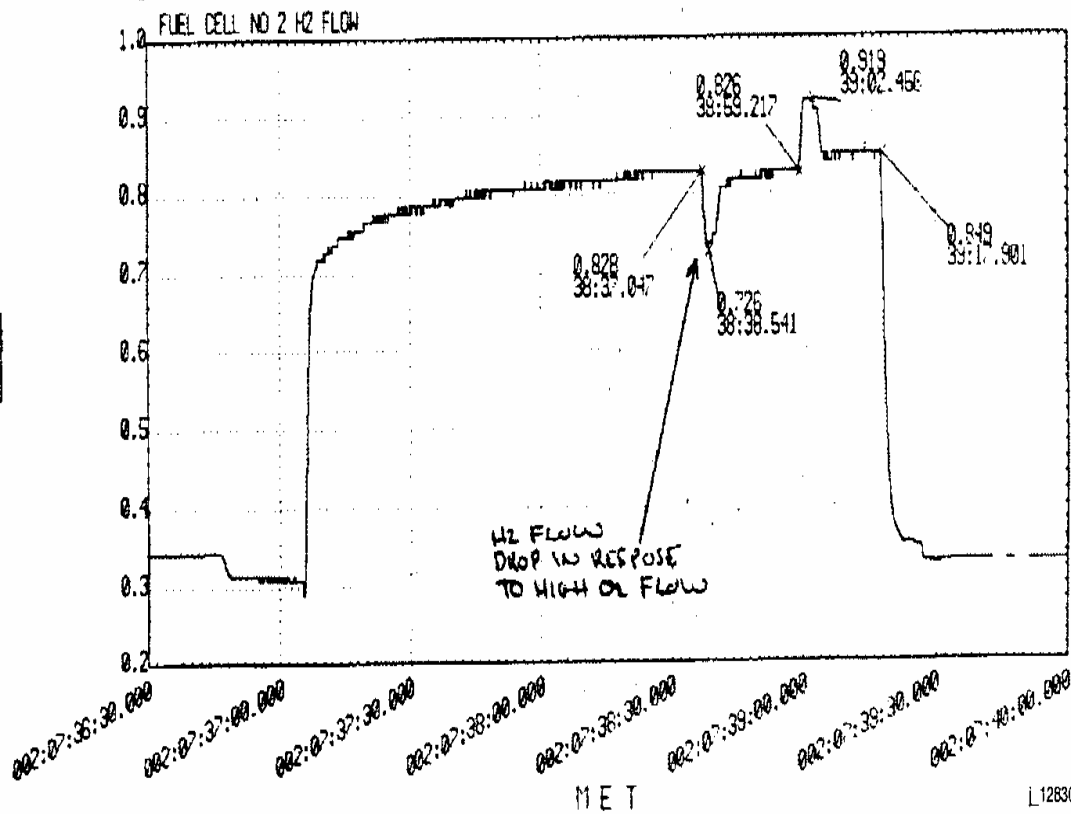
FUEL CELL 2 FLOW

FORMAT: FFZ  
DATA: FC2FRG7

V45R0260A  
(LBM/HR)



V45R0270A  
(LBM/HR)



L12830\_251

Figure 2.2-4. STS-31 purge anomaly

5. Potential upgrades

- a. Corrosion - The regulator body is made from aluminum that is susceptible to corrosion from moisture, expelled KOH, and particulates from stack corrosion. Water vapor from the stack will find a cool spot and form water, and the aluminum eventually corrodes. IFC has seen corrosion reduced over the past few years because of improved treatment processes and better supply gas. Additionally, there is less exposure to water corrosion because the amount of time between fuel cell purges on orbit has increased since the beginning of the shuttle program. IFC is looking at possible options for replacing aluminum, but alternate materials will add weight to the fuel cell. The regulator can fail from heavy corrosion, such as dumping electrolyte into the regulator during flooding.
- b. Elastomer degradation – Currently, the regulator does not meet expected lifetime standards. The old elastomer is neoprene, which has problems under normal regulator conditions. The seals have not lived up to expectations and have been cracking and leaking after 1500 hours. The suspected reason is that the preheater is more efficient than expected, and the cryogenic fluid entering the regulator is hotter, which exceeds the spec of the regulator seals. A new elastomer is being used, and new regulators will be delivered in a few months. Degradation of elastomers (o-ring, diaphragms, etc.) is caused by higher-than-expected reactant temperature and could result in reactant leakage. To correct this, a new elastomer material will be used and is included in the Fuel Cell Powerplant (FCP) upgrade program.

The O-ring seal will harden and crack at high temperatures. As a result, the high-pressure gas will flow under a separate path, causing the O<sub>2</sub> pressure to build up and be vented overboard.

- c. Coolant pressure transducer - The strain-gauge pressure transducer has a precision based on a 10-volt supply and an extremely low output. The coolant pressure reading tends to slowly drop between prelaunch and on orbit. The pressure will then usually reflect prelaunch values after touchdown. After studying this phenomenon for some time, IFC believes that the bonding on the transducer elastically slips and creeps in zero g, and the slow drop in coolant pressure during the course of the mission is due to this slippage. At publication, the manufacturer does not yet have a solution to this problem.



**TITLE**

FUEL CELL ECU OPERATION

**PURPOSE**

This brief describes the operation of the fuel cell Electrical Control Unit (ECU) and includes a detailed description of the startup and stop sequences.

**DESCRIPTION**

The ECU controls the startup, stop, and run sequences of the H<sub>2</sub> motor and the coolant pump (Table 2.3-1). The ECU also controls the fuel cell thermal conditioning during the startup sequence via the operation of various heaters, relays, valves, and solenoids. In addition, the ECU serves as a junction box for the coolant pump differential pressure ( $\Delta P$ ) status and ready for load discrettes, which route to the Fuel Cell Power Plant (FCP) external interface panel in the accessory section.

It should be noted that the ECU does not control FC operation. The FC stack will produce electricity as long as the regulator and thermal control valves (TVC) are working; not does the ECU monitor FC Health.

The power required to operate the ECU is 25W during startup and 15W once the FC is running (this assumes 28Vdc ESS Bus power). The ECU can tolerate a total power loss for up to 5 seconds.

**Table 2.3-1. ECU controls**

Nomenclature	Panel	Function
FUEL CELL 1 (2,3) PUMP cb (3)	L4	Supplies 3-phase ac power to the coolant pump and H <sub>2</sub> motor relay contacts
STARTUP HEATER 1 (2,3) INHIBIT	R11U	Powers K5, which disables the power path to the startup heater driver stages
ENABLE		No contact, enables the power path to the startup heater driver stages
FC1 (2,3) CNTLR ON	O14 (O15,O16)	Supplies ESS1BC (2CA,3AB) power to the ECU (ECU Bus through multiple paths and the timer module)
OFF		No contact, the ECU is unpowered
FUEL CELL 1 (2,3) START	R1	Applies ESS1BC (2CA,3AB) power to K8, which starts the timer module, energizes the pump package relays,

		and starts the sustaining heater by allowing ECU Bus (control) power through
STOP		Applies ESS1BC (2CA,3AB) power to K4, which removes the control power which unpowers the ECU Bus that is holding all the relays in the correct config

## START SEQUENCE

Referring to the fuel cell ECU start sequence schematic in Figure 2.3-1, note that all relay wipers have been oriented to show the direction of power/signal flow and then labeled alphanumerically to represent the approximate closure sequence. Initial conditions presume that the FC1 (2,3) CNTLR switch has been placed in the ON position, and the STARTUP HEATER 1 (2,3) switch has been placed in the ENABLE position. Additionally, the coolant pump Differential Pressure ( $\Delta P$ ) talkback (tb) and the Ready For Load tb reads barber pole (bp). To begin the start sequence, a crew-member holds the FC1(2,3) switch in the START position for approximately 5 seconds or until the  $\Delta P$  tb is gray. The ECU start sequence follows:

- A: Coil K8 energizes, which pulls in two contacts (B1 and B2).
  - B1: The B1 contact closure applies power to the ECU bus (power comes from the Cntrl Pwr switch).
  - B2: The B2 contact closure routes ECU power to the K9:H2 contact.
- Now that the ECU Bus is powered:
- C1: The ECU 30-second timer module starts.
  - C2: Coils K6A and K6B energize, pulling in three contacts (D1, D2, and D3).
  - C3: With the ECU bus powered and a STK OUT T less than 185°, coil K2 energizes, pulling in one contact (D4).
  - D1: Contact D1 closure (K6B) routes 3 $\phi$  AC power to the FC Pump package (coolant pump and H2 motor) and single  $\phi$  ( $\phi A$ ) power to the pH sensor.
  - D2: Contact D2 closure (K6A) provides a redundant 3 $\phi$  AC power feed to the pump package.
  - D3: The D3 contact closure (K6A) completes one part of the circuit to power relay K9.
  - D4: The D4 contact closure (K2) allows power to the 870-W sustaining heater.
  - E: The fuel cell coolant pump and H<sub>2</sub> pump start (K6A/K6B).
  - F: Once the coolant pump builds up a  $\Delta P$  of 5  $\pm$  1 psid, the  $\Delta P$  switch closes two contacts (G1 and G2).
  - G1: The fuel cell coolant pump  $\Delta P$  tb changes to gray.

2.3-2

- G2: Contact G2 closure energizes coil K9, pulling in two contacts (H1 and H2).
- H1: The H1 contact closure (K9) provides a redundant power feed to the ECU bus.
- H2: The H2 contact closure (K9) completes the power path from the ECU Bus to the coolant Inlet and Coolant Out temp since electronics units (I).
- I: If the STK OUT T is less than 185° or the STK IN T is less than 212°, the coolant temp electronics units enable coil K3A to energize (J).
- J: Coil K3A energizes, pulling in four contacts (K1, K2, K3, and K4).
- K1: The K1 contact (K3A) closes to provide power to coil K3 (L).
- K2: The K2 contact (K3A) closes to provide a redundant power feed from the ECU Bus to the coolant temp electronics units K3: The K3 contact (K3A) opens to preclude ESS1BC power to the K10:Q2 (ready for load tb) contact.
- K4: The K4 contact (K3A) closure powers the 1771-W startup heater.
- L: Coil K3 energizes and pulls in one contact (M).
- M: The M contact (K3) closes to provide power to coil K1 (N).
- N: Coil K1 energizes (O).
- O: The coolant bypass valve opens, allowing maximum flow through the loop.
- P: Thirty seconds after receiving a “timer start” (C1), coil K10 energizes and pulls in two contacts (Q1 and Q2).
- Q1: Contact Q1 on K10 closes to provide a redundant power feed to the ECU bus (power comes from the Cntrl Pwr switch).
- Q2: Contact Q2 on K10 closes, once K3 closes the signal path to the ready for load tb.
- R: Once the STK OUT T reaches 185° or the STK IN T reaches 212°, the coolant temp electronics units disable the startup heater driver stage by unpowering coil K3A.
- S: Coil K3A deenergizes and releases four contacts (T1, T2, T3, and T4 same contacts as K1-K4).
- T1: Contact T1 on K3A opens, which removes power from coil K3 (U1).
- T2: Contact T2 on K3A opens, which removes power from the coolant temperature electronics units for the startup heater. (At this point, startup heater “lockout” occurs.)
- T3: Contact T3 on K3A closes, which completes the signal path to the ready for load tb (U2).
- T4: Contact T4 on K3A opens, which deenergizes the startup heater.
- U1: Coil K3 deenergizes and releases one contact (V).
- U2: The ready for load tb changes from bp to gray.

- V: The V contact (K3) opens, which interrupts power to coil K1.
- W: Coil K1 deenergizes.
- X: The bypass valve closes.

The fuel cell start sequence is complete.

The prime function of the timer module is to provide a backup to the FC  $\Delta P$  switch so that if it fails the FC can still be started and ran. It should be noted that if the  $\Delta P$  switch and the timer both fail, the FC may still be run by holding the FC switch in the START position continuously.

Tables 2.3-2 and 2.3-3 show an ECU failure summary for the fuel cell startup sequence and while the FC is in run.

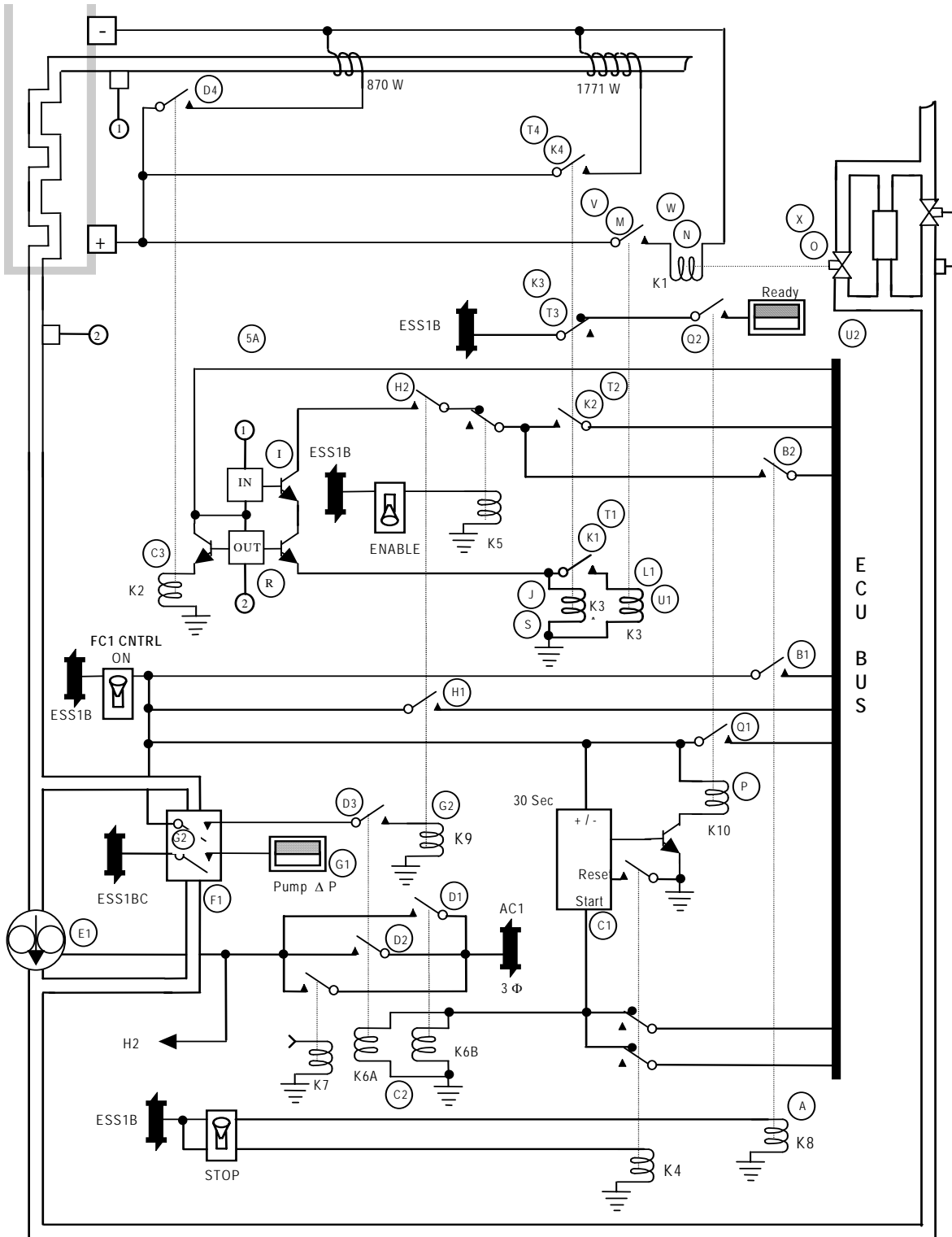


Figure 2.3-1. Fuel cell ECU start sequence

Table 2.3-2. ECU failure summary – fuel cell start  
2.3-5

Verify that this is the correct version before use

Component	Failure mode	Operational impact	Symptoms	Workaround
K10/timer	ON	FC CNTLR power ON starts the ECU without FC START	Ready for Load tb = gray throughout start	None
	OFF	Loss of redundant power to the ECU bus	Ready for Load tb fails to transition to gray following startup	Redundant power via K9 and K8
K4	OFF	None	None	
	ON	Pump package/timer cannot receive power	Coolant pump, H2 motor, and timer fail to start	None
K6A	OFF	Loss of redundant AC path; startup heater/bypass valve lockout and loss of redundant ECU Bus power (K9 unable to energize)	FC stack warmup slowed resulting in a prolonged start	Redundant AC power via K6B K10/timer provides redundant ECU Bus power could also use K8
	ON	Pump package runs continuously	$\Delta$ P tb remains gray regardless of FC STOP	Pull AC cb's to remove power
K6B	OFF	Loss of redundant AC path	None	Redundant power via K6A
	ON	Pump package runs continuously	$\Delta$ P tb remains gray regardless of FC STOP	Pull AC cb's to remove power
K8	OFF	ECU fails to start	$\Delta$ P tb and Ready for Load tb remain bp	Possible LF MDM commanding or FC contingency powerup
	ON	FC CNTLR power ON starts the ECU without FC to Start		None
K2	ON	Sustaining heater ON continuously	Elevated STK OUT T and Cryo usage	None
	OFF	Sustaining heater lost, Startup heater only warms stack	Prolonged Ready for Load tb to gray transition	None
K3A	OFF	Startup heater/bypass valve will NOT activate	Prolonged FC start; ready for load tb gray after 30 sec	Connect FC to MN (Bootstrap the FC)
	ON	Startup heater ON continuously	Ready for Load tb will remain bp; elevated STK OUT T	Possible FC Shutdown required
K3	OFF	Bypass valve NEVER opens	Prolonged FC start	None
	ON	Bypass valve remains OPEN		None
K9	OFF	Startup heater/bypass valve lockout; loss of redundant ECU bus power	FC stack warmup slowed resulting in a prolonged start	K10/timer provides redundant ECU power; can also use K8

	ON	Startup heater will activate as soon as FC START is commanded		Coolant boil if coolant pump fails to start
Temp sense electronics units	OFF	Startup/sustaining heaters lost	Ready tb will not transition to bp during FC start	Connect FC to MN (Bootstrap the FC)
	ON	Sustaining heater will not deactivate	Elevated Stk Out T	INHIBIT startup heater
ΔP Switch	OFF	Loss of K9 relay – Startup heater/bypass valve lockout, loss of redundant ECU Bus power	ΔP tb remains bp. FC stack warmup slowed resulting in a prolonged star	K10/timer provides redundant ECU power; can also use K8
	ON	None	ΔP tb always gray	None

**Table 2.3-3. ECU failure summary – fuel cell run (assumes normal startup)**

Component	Failure mode	Operational impact	Symptoms	Workaround
K10/timer	ON	None, FC in Run	None	None
	OFF	Loss of redundant power to the ECU bus	Ready for Load tb bp	Redundant power via K9 and K8
K4	OFF	Crew will be unable to execute FC STOP	ΔP tb and Ready for Load tb = gray after FC taken to STOP	FC CNTRL Pwr to OFF
	ON	Loss of FC ECU	Loss of FC Pump package and ΔP tb and Ready for Load tb bp	Possible LF MDM commanding or FC Contingency Powerup
K6A	OFF	Loss of redundant AC path; loss of redundant ECU Bus power (K9 lost)	None	Redundant AC power via K6B Redundant DC power via K10/timer or K8
	ON	Pump package runs continuously	ΔP tb remains gray regardless of FC STOP	Pull AC cb's to remove power or FC CNTRL pwr to OFF
K6B	OFF	Loss of redundant AC path	None	Redundant power via K6A
K2	OFF	Sustaining heater lost; Operation below 2 kW may cause FC flooding	None unless FC Stk T <185.	Increase FC load > 2 kW (at >2kW temps will not get below 185) If temps do

				decrease <183 Hold FC to START to enable the startup heater
	ON	Sustaining Heater ON continuously	Increased FC Stk Temps	None
K9	OFF	Loss of redundant ECU Bus power	None	Redundant power via K10/timer or K8
ΔP Switch	OFF	Loss of redundant ECU Bus power (K9 lost)	ΔP tb transitions to bp	Redundant power via K10/timer or K8
K8	ON	FC STOP will be effective ONLY as long as the crew holds the switch in the STOP position		Take FC to STOP and hold switch in that position

## STOP SEQUENCE

Referring to the fuel cell ECU stop sequence schematic in Figure 2.3-2, again note that all relay wipers have been labeled alphanumerically to represent the approximate release sequence. To begin the stop sequence, a crewmember holds the FC1(2,3) switch in the STOP position for approximately 1 seconds. The ECU stop sequence follows:

- A: Coil K4 energizes and pulls away three contacts.
- B1: The B1 contact set (two contact) (K4) opens. Resulting in C2 and C3.
- B2: The B2 contact (K4) closes, which immediately resets the timer. (C1)
- C1: Coil K10 deenergizes opening two contacts (D4 and D5).
- C2: Power is removed from the timer.
- C3: Coils K6A and K6B deenergize opening three contacts (D1, D2, and D3).
- D1: Contact D1 (K6B) opens the redundant AC power to the FC pump package.
- D2: Contact D2 (K6A) opens, removing AC power to the FC pump package (E1).
- D3: Contact D3 (K6A) opens, interrupting the power path to relay K9 opening F2.
- D4: Contact D4 (K10) opens, removing redundant power to the ECU bus.
- D5: Contact D5 (K10) opens causing the Ready for Load tb to go bp.
- E1: The fuel cell coolant pump and H<sub>2</sub> pump stop (E2 and F1).
- E2: Coil K9 deenergizes (F2).
- F1: The ΔP switch contacts open (G1).
- F2: Contact F2 (K9) opens, removing all power to the ECU bus (G2).



- G1: The fuel cell coolant pump  $\Delta P$  tb changes to bp.
- G2: Coil K2 deenergizes opening one contact (H1).
- H1: Contact H1 (K2) opens, disabling the sustaining heater.

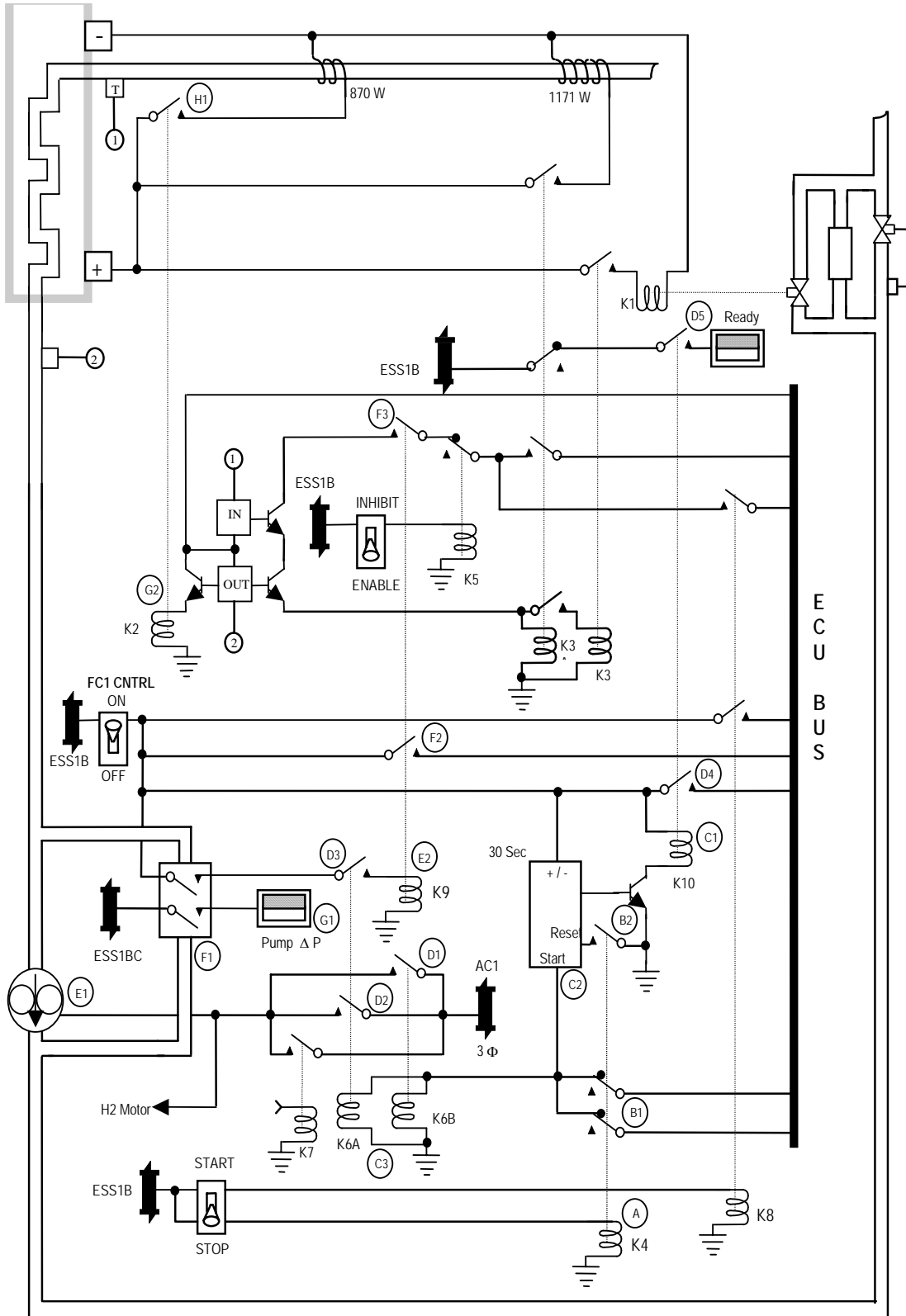


Figure 2.3-2. Fuel cell ECU stop sequence

Verify that this is the correct version before use

## TITLE

FUEL CELL REACTANT VALVE

## BACKGROUND

The FC reactant valves are used to control the flow of cryogenic reactants to the FCs. The O<sub>2</sub> and H<sub>2</sub> reactant valves on each FC are independent of each other, yet both valves are commanded simultaneously via a switch on panel R1. The location of the reactant valves is external to the FC, between the cryo tanks and the FC accessory section. The reactant valves belong to a family of shutoff valves that are used to control the cryogenics throughout the vehicle. A unidirectional valve has a positive shutoff capability in the normal flow direction and relief capability in the opposite direction (outlet to inlet). The relief function occurs when outlet pressure exceeds inlet pressure by 15 to 30 psi.

The O<sub>2</sub> valves are required to be operated with an inlet pressure of 0 to 1035 psig, while H<sub>2</sub> valves are operated at an inlet pressure of 0 to 320 psig. The valve has a filter with an absolute rating of between 15 and 25 microns internal to the valve body at both the inlet and outlet.

Figure 2.4-1 shows a cross-sectional drawing of the unidirectional valve. The basic part number of the valve is MC284-0429-XXXX, where XXXX is a four-digit number for the specific valve type (see chart on the drawing).

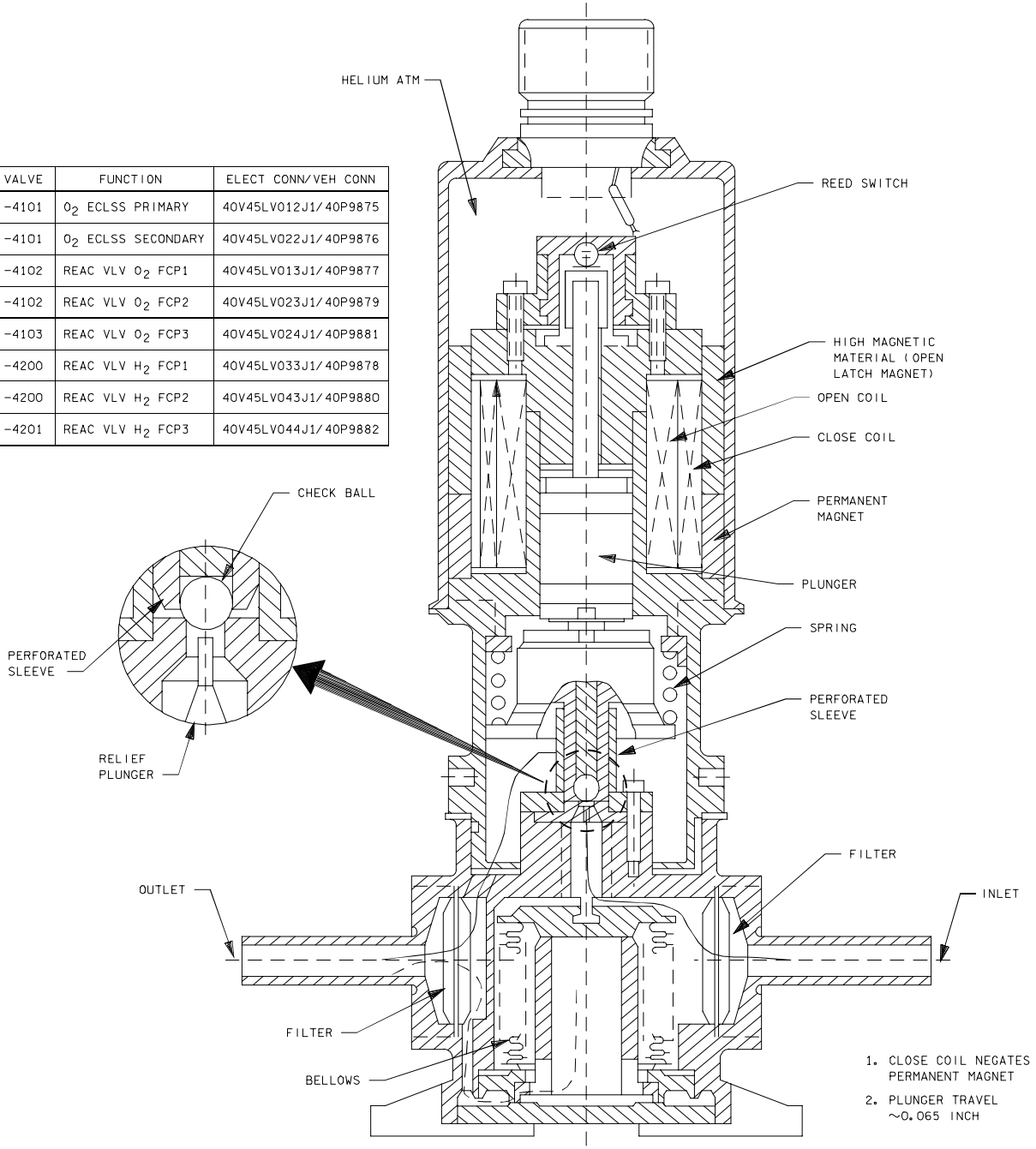
## OPERATION

- A. The reactant valves are solenoid-driven latching valves. The valve holds position when unpowered. The valves are controlled by two electrical solenoid coils, an Open Coil and a Close Coil. An electrical current is required to create the magnetic field which drives the valve open/close. If for some reason (e.g., pressure relief) the plunger is moved to the open position without energizing the Open coil, the plunger will not stay open. The valves are latched open when the Open coil is energized, the plunger moves to the open position and is held there by a permanent magnet. The valves are closed when the Close Coil is energized and breaks the permanent magnet's field, allowing the spring to force the plunger down and hold it closed.
- B. When the Open Coil is energized, the plunger moves up approximately 0.065 inch. This movement unseats the check ball, allowing gas to flow through the filter and up to the check ball. With nothing holding the ball in place, the pressure raises the ball, allowing gas to flow past the ball, through the perforated sleeve, and out through the outlet filter. The solid line on figure 2.4-1 indicates this flow path. The perforated sleeve (see insert in fig. 2.4-1) has three holes which allow gas flow.
- C. The electrical specifications of the solenoid require it to open or close with a minimum operating voltage of 18V dc. Maximum current is specified at 5.0 amps

at 32V dc. Test data has shown that the valve draws less than 1.5 amps at 28V dc, and operates down to 16.5V dc drawing 0.55 amps.

- D. A reed-type microswitch is mounted in the top of the valve to indicate when the valve is open. The switch is actuated when the plunger is raised, closing the contacts of the switch. Test data has shown that the switch is actuated when the plunger rises approximately 0.037 inch, indicating the valve is open. From the fully open position, the plunger drops approximately 0.020 inch before the switch indicates closed. In other words, the switch is actuated at  $0.042 \pm 0.005$  of plunger travel.
- E. The unidirectional valves have a backup relief feature, which prevents pressure in the output line from increasing to more than 35 psid above the input pressure. As pressure in the outlet increases, the bellows mechanism overcomes the bellows mechanism spring and rises. The bellows mechanism is connected to a pin which pushes the check ball up, allowing gas to flow from the outlet line through the perforated sleeve and into the input line. The dotted line in figure 2.4-1 indicates the relief flow. As pressure is relieved, the bellows mechanism falls, allowing the check ball to reseat. The bellows mechanism travels about 0.015 inch before pressure relieves. This is not enough to cause the microswitch to indicate that the valve is open. Also, since the Open Coil is not energized, there is no possibility that the valve will latch open due to travel by the bellows mechanism.
- F. Figure 2.4-2 (sheets 1 through 4 and figure 2.4-3 (sheets 1 through 4) were published in Rockwell internal letter P&PP/EPS/81/010, dated 24 March 1981. These charts indicate the time in seconds to FC failure after a reactant valve fails closed at different tank quantities.

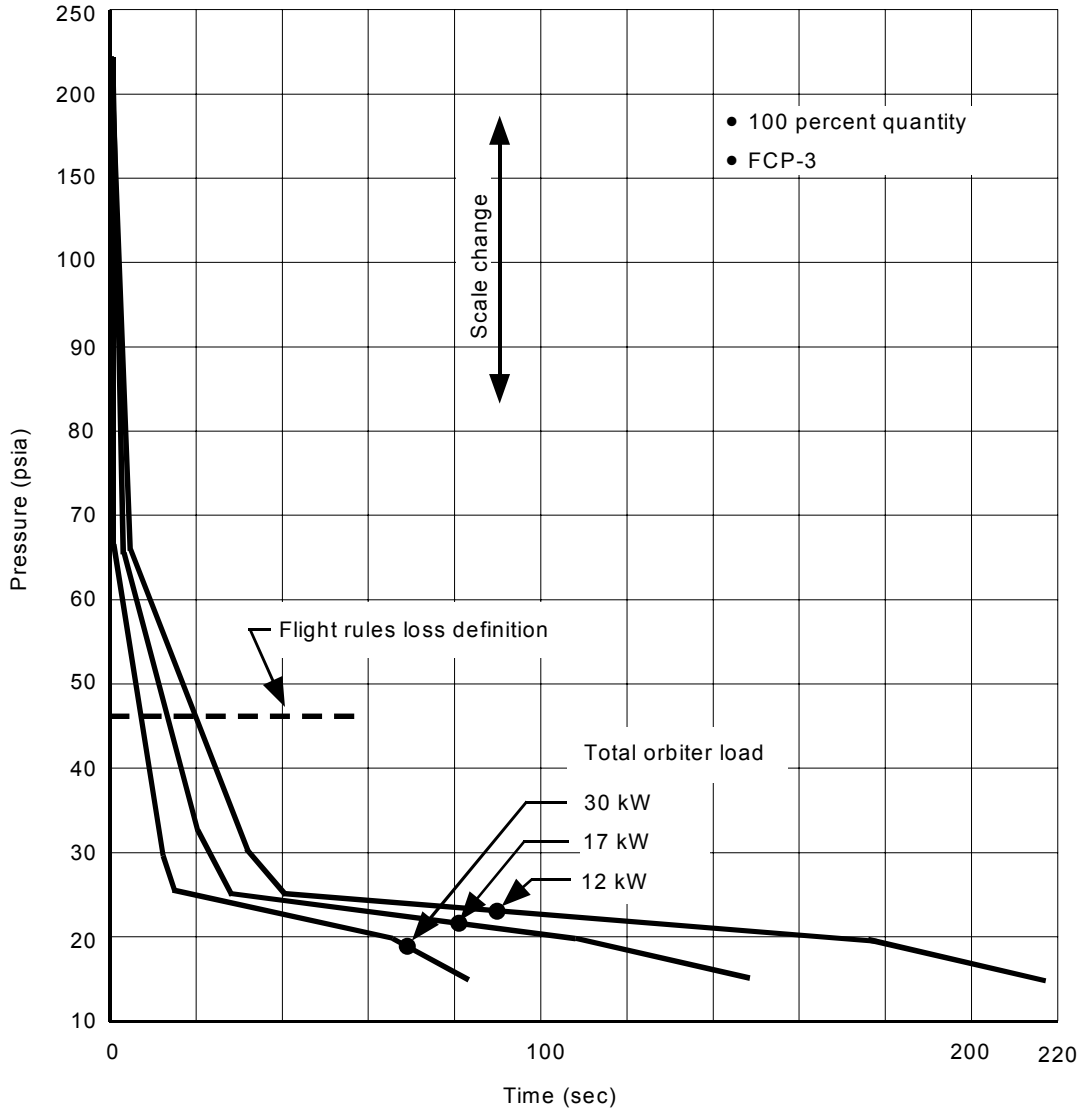
VALVE	FUNCTION	ELECT CONN/VEH CONN
-4101	O <sub>2</sub> ECLSS PRIMARY	40V45LV012J1/40P9875
-4101	O <sub>2</sub> ECLSS SECONDARY	40V45LV022J1/40P9876
-4102	REAC VLV O <sub>2</sub> FCP1	40V45LV013J1/40P9877
-4102	REAC VLV O <sub>2</sub> FCP2	40V45LV023J1/40P9879
-4103	REAC VLV O <sub>2</sub> FCP3	40V45LV024J1/40P9881
-4200	REAC VLV H <sub>2</sub> FCP1	40V45LV033J1/40P9878
-4200	REAC VLV H <sub>2</sub> FCP2	40V45LV043J1/40P9880
-4201	REAC VLV H <sub>2</sub> FCP3	40V45LV044J1/40P9882



1. CLOSE COIL NEGATES PERMANENT MAGNET
2. PLUNGER TRAVEL ~0.065 INCH

128304141. ART. 2

**Figure 2.4-1. Fuel cell reactant valve – unidirectional shutoff, H<sub>2</sub> and O<sub>2</sub> (MC284-0429-XXXX)**



j\_12830\_520.cv5

Figure 2.4-2. FCP I/F pressure response following H<sub>2</sub> valve shutoff (sheet 1 of 4)

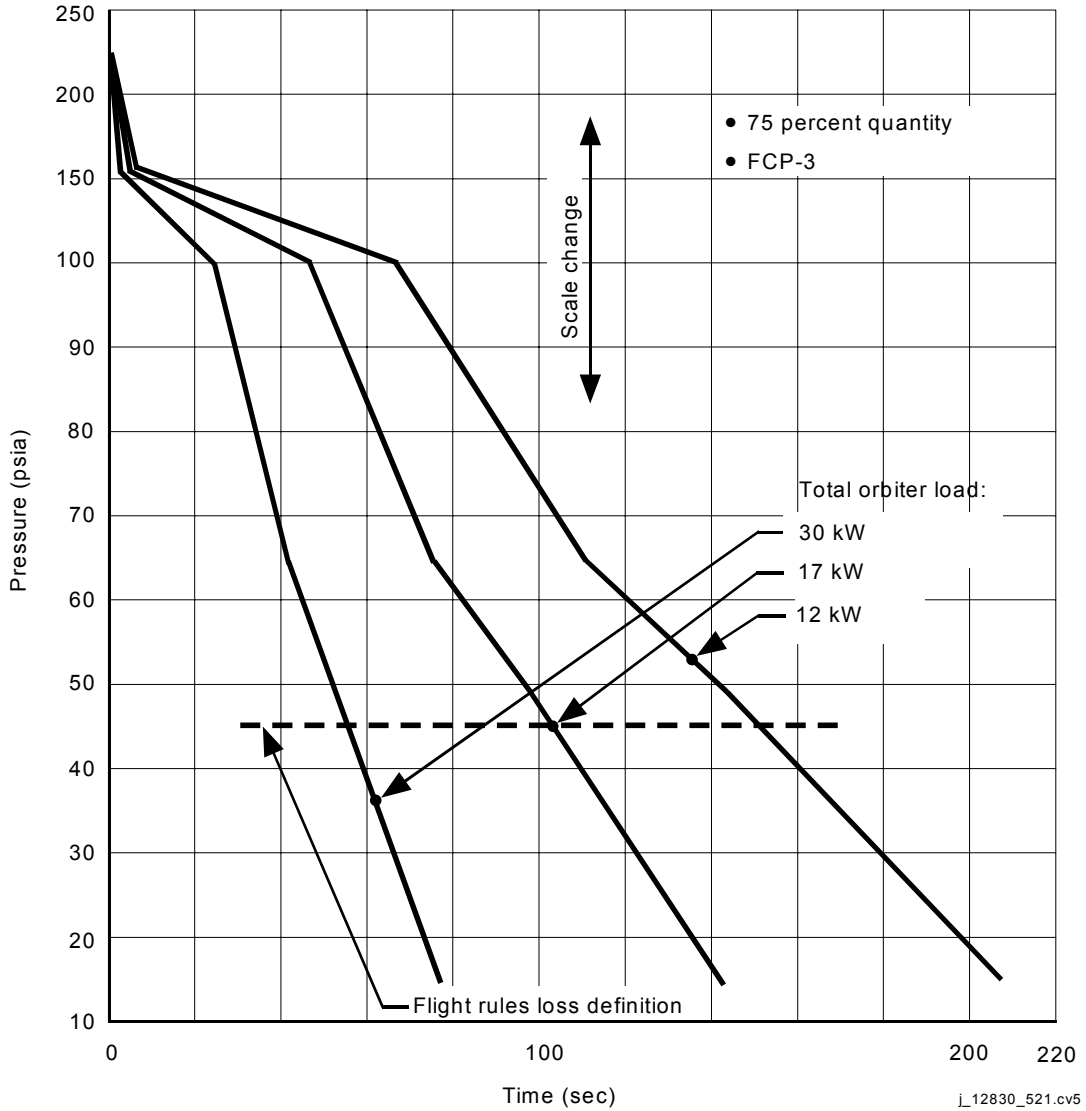


Figure 2.4-2. FCP I/F pressure response following H<sub>2</sub> valve shutoff (sheet 2 of 4)

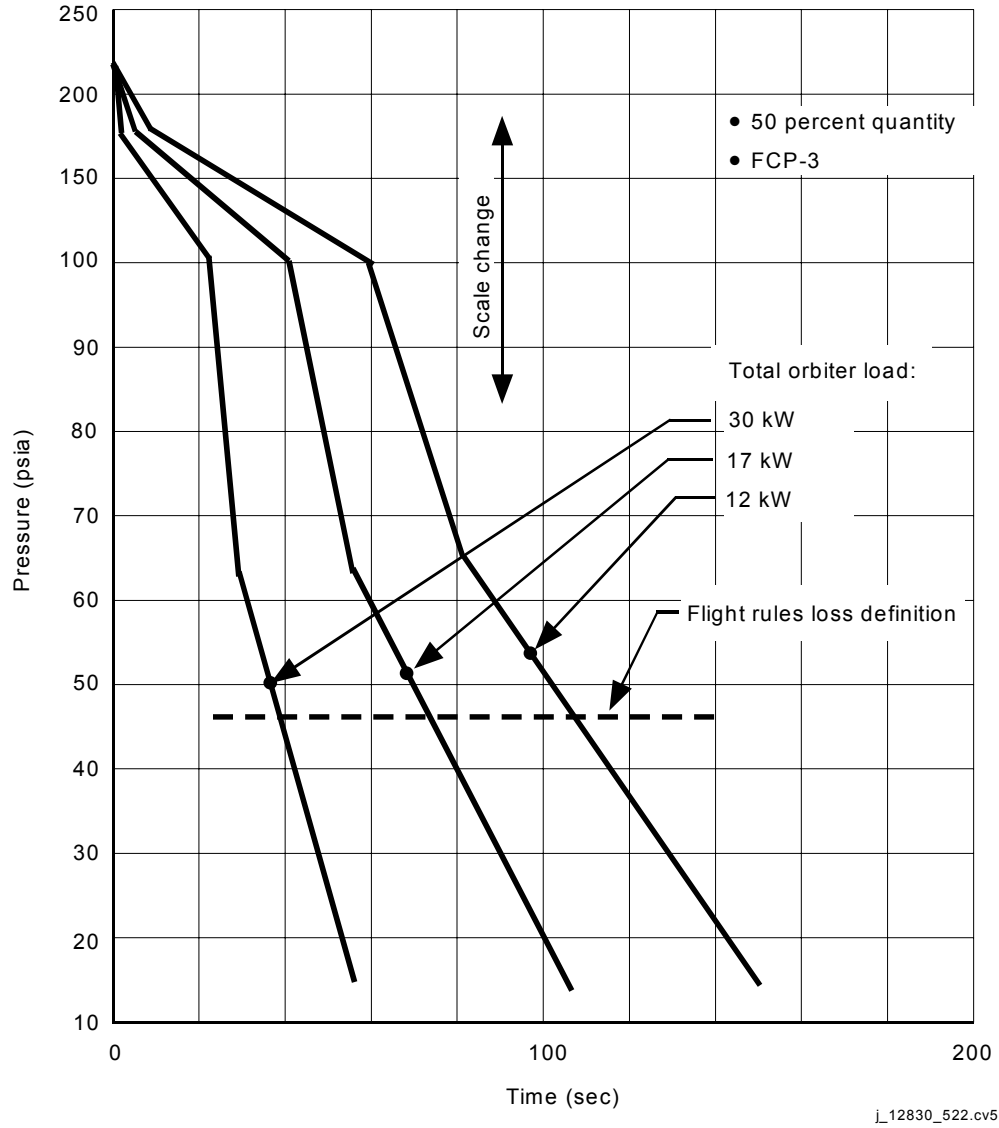
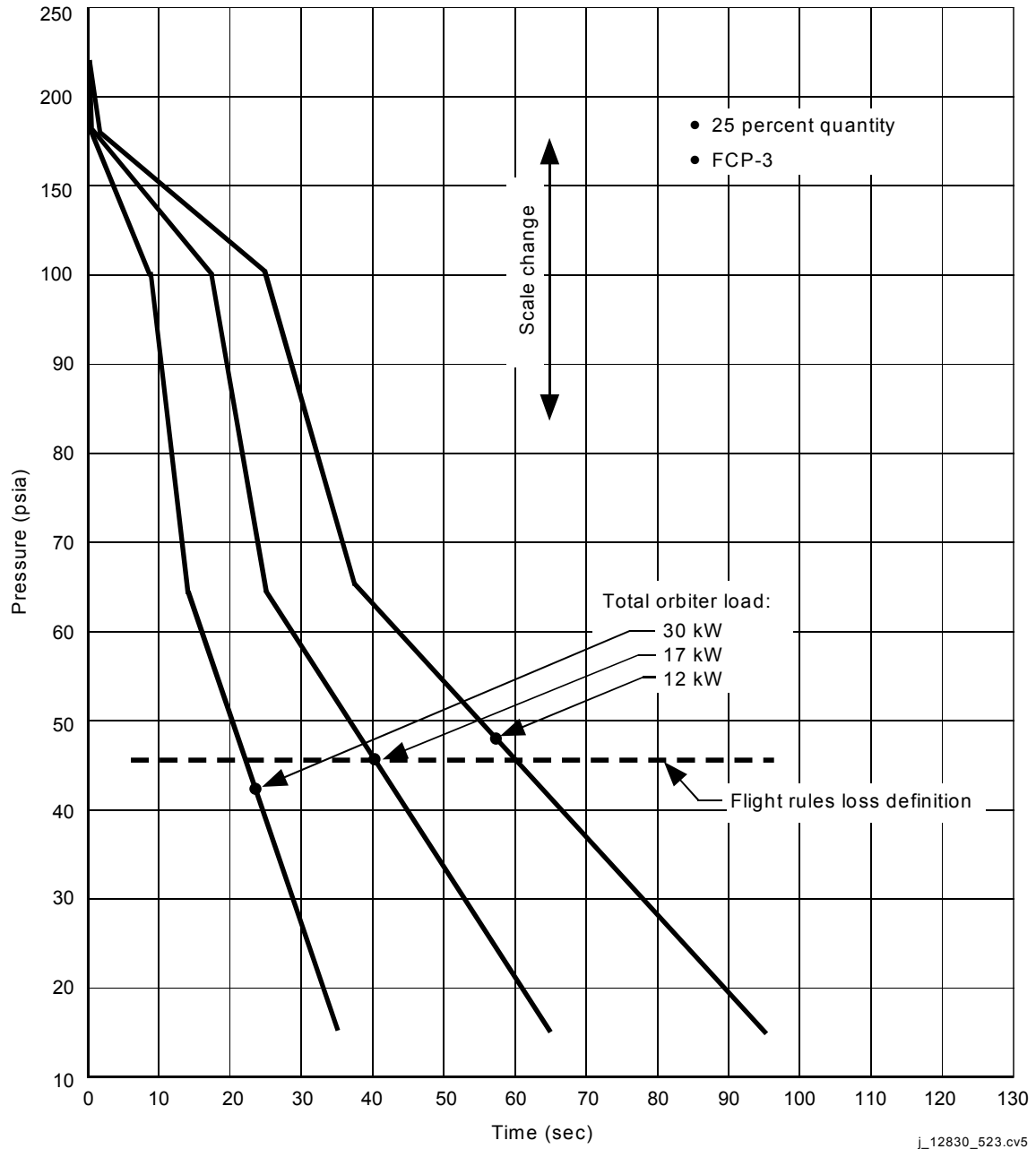
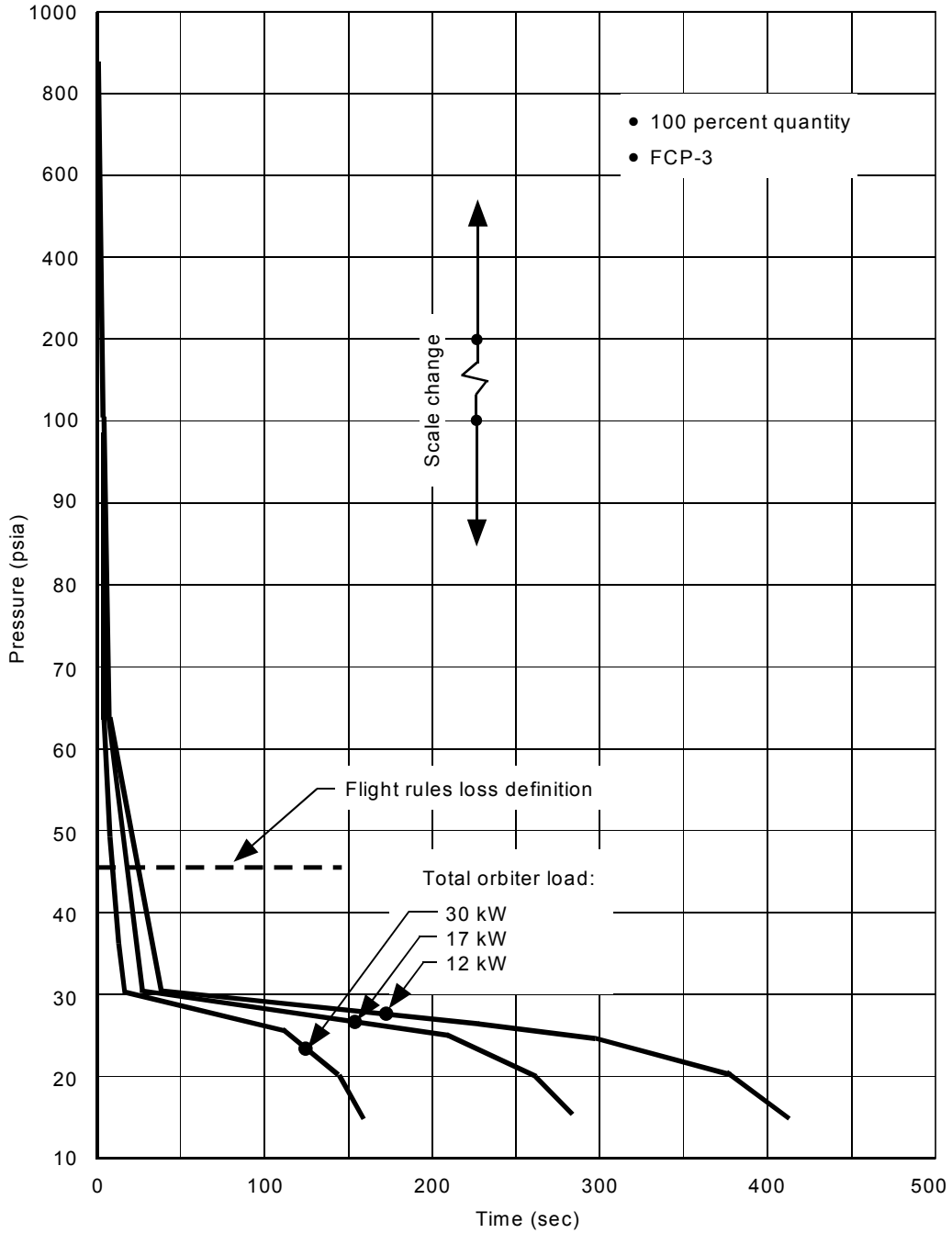


Figure 2.4-2. FCP I/F pressure response following H<sub>2</sub> valve shutoff (sheet 3 of 4)





**Figure 2.4-2. FCP I/F pressure response following H<sub>2</sub> valve shutoff  
(sheet 4 of 4)**



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**Figure 2.4-3. FCP I/F pressure response following O<sub>2</sub> valve shutoff (sheet 1 of 4)**

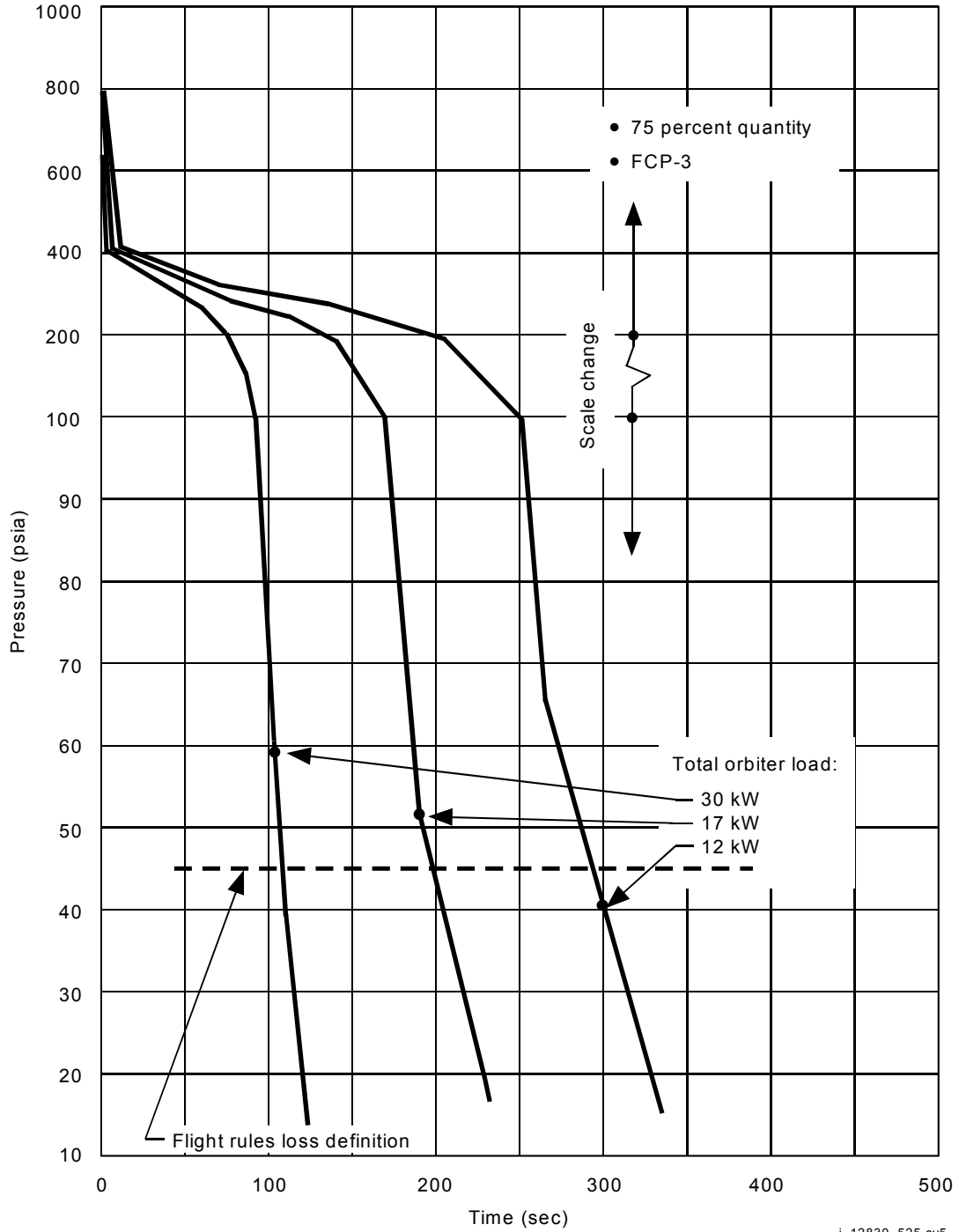


Figure 2.4-3. FCP I/F pressure response following O<sub>2</sub> valve shutoff (sheet 2 of 4)

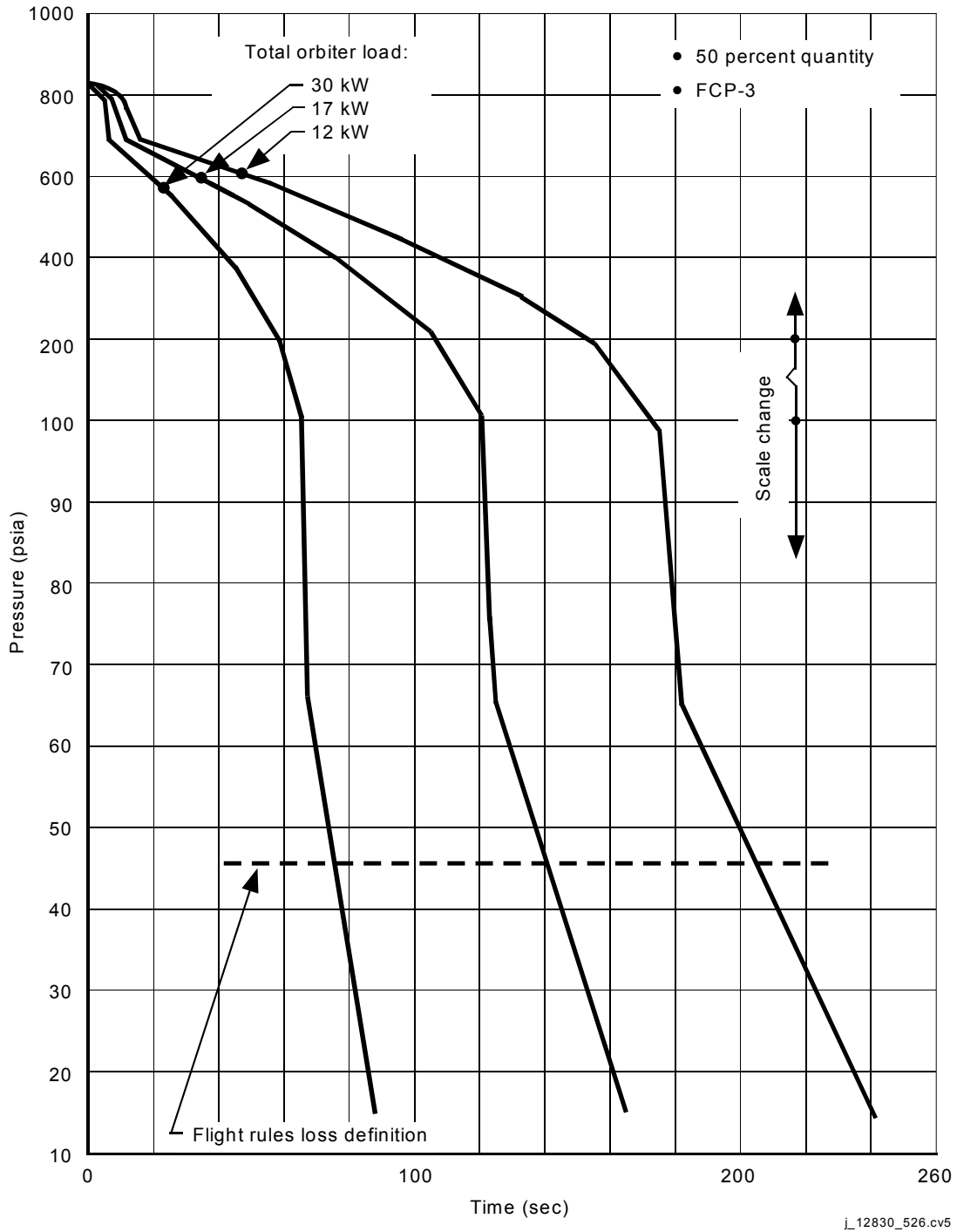


Figure 2.4-3. FCP I/F pressure response following O<sub>2</sub> valve shutoff (sheet 3 of 4)

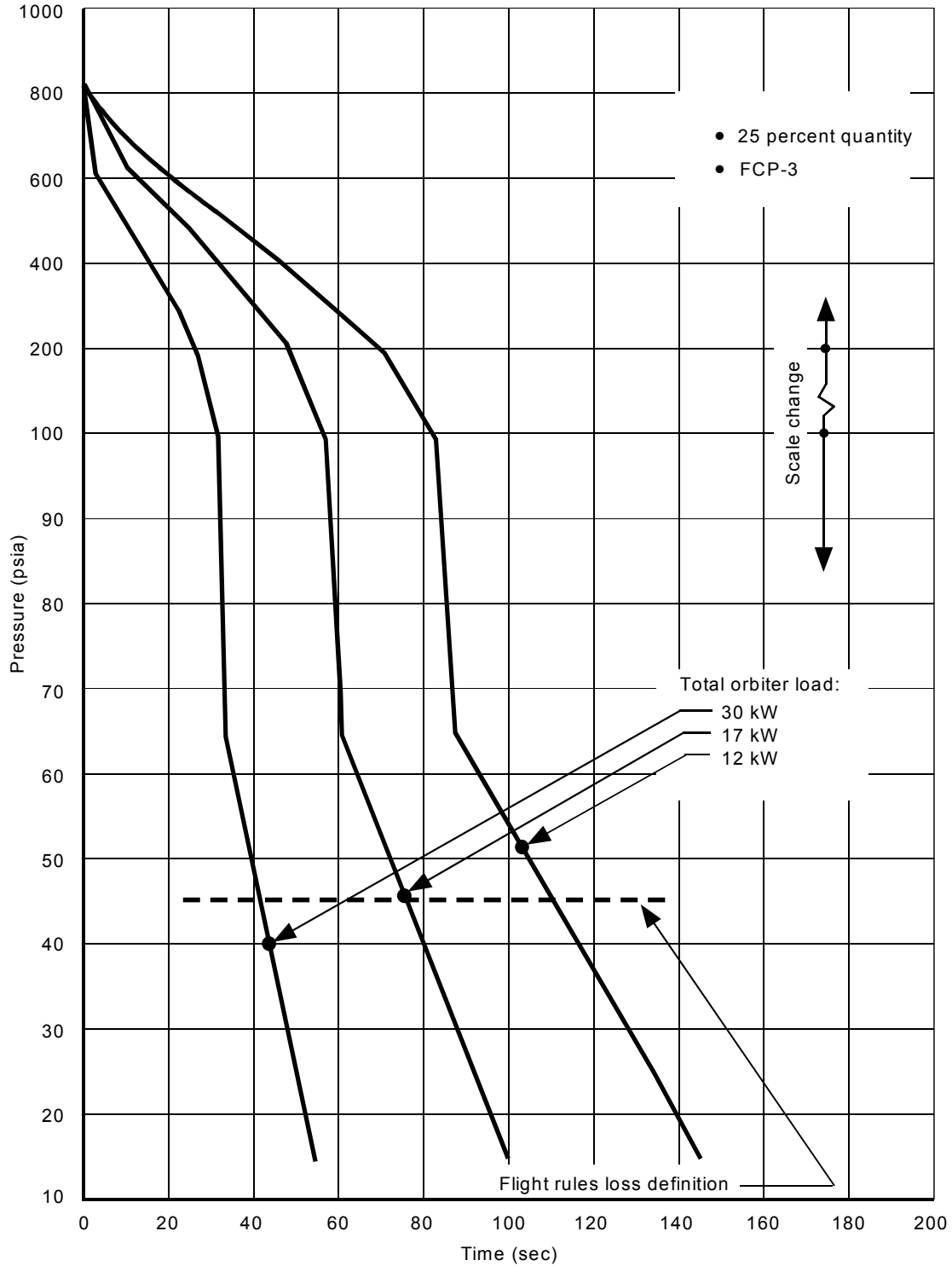


Figure 2.4-3. FCP I/F pressure response following O<sub>2</sub> valve shutoff (sheet 4 of 4)

## TITLE

FUEL CELL H<sub>2</sub>O RELIEF NOZZLE HEATER LOGIC

## PURPOSE

The purpose of this brief is to clarify the operation of the fuel cell water overboard relief system heaters.

## BACKGROUND

The fuel cell water overboard relief system is a backup means of removing water from the fuel cells when the product water cannot be routed to the ECLSS tanks by the primary or the alternate water paths. The relief system is thermally conditioned by heaters to prevent the water from freezing. The location of the relief heater system is shown in Figure 2.5-1.

The single-exit nozzle (Figure 2.5-2) on the starboard side of the spacecraft has been sized at 0.035 inch in diameter to ensure that the product water will be expelled at a sufficient back pressure over the expected water quantity production range to prevent icing in the relief system. To prevent water from freezing and plugging the nozzle in a vacuum environment, a 48-watt heater surrounding the nozzle activates when water flows through and shuts off after the water has ceased to flow. Nozzle temperature feedback to the heater control logic is provided by two thermocouples embedded in the nozzle faceplate.

Originally, there was total redundancy in the entire fuel cell water overboard relief heater system, including two nozzle heaters (system A and system B). A single-point failure was identified, whereby the A heater could fail on with no water relieving through the nozzle. Analysis indicated that within approximately 3 minutes, the Room Temperature Vulcanizing (RTV) around the nozzle barrel/spacecraft penetration would vaporize because of the high temperature, possibly causing structural damage. The concern was that during entry, plasma ingestion might occur through the weakened structure around the nozzle.

As a result of this concern, the relief nozzle heater circuitry and the driver logic were modified so that only one nozzle heater is operable (system B). Redundancy is retained in the other relief system heaters.

Recent analyses indicate that a failed-on nozzle heater may not cause as much damage as originally thought, but the A heater will probably not be rewired due to the addition of the alternate water system.

The fuel cell relief nozzle heater system, as it now exists, is shown schematically in Figure 2.5-3. The nozzle heater control signal generation schedule as a function of measurement of DC voltage and temperature in °F is shown in Figure 2.5-4. The other heaters in the system are diagrammed in Figure 2.5-5. The temperatures around the relief nozzle when the nozzle heater comes on (with no water relieving) are shown in

Figure 2.5-6. Nozzle heater duty cycle at 1 atmosphere as a function of ambient temperature is estimated in Figure 2.5-7. On orbit, the barrel heater should keep the nozzle temperature high enough so that the nozzle heater should cycle only if water relieves through the nozzle.\* On the pad, because of greater convective cooling, the nozzle heater will cycle. A first-order approximation of the duty cycle for the system is shown in Figure 2.5-7.

It should be emphasized that the relief system is a backup system to get rid of the product water produced by the fuel cells; the primary and alternate H<sub>2</sub>O paths would have to be inoperative. However, if the fuel cells are required to vent water through this system and the nozzle blocks, all three fuel cells will flood in approximately 15 to 30 minutes, assuming orbital loads. When a fuel cell is flooded (average KOH concentration of 24 percent), the damage is irreparable.

## DISCUSSION

Each fuel cell has a relief valve that cracks at 45 psi, allowing fuel cell product water to vent through the relief system. (The relief valve has full flow at 51 psi and closes at 43 psi). The relief valve heaters (3.5 watts each) are thermostatically controlled to cycle ON at 70° F and OFF at 90° F. If water relieves through this system, these temperatures indicate such an event via Telemetry (TM) by elevating to temperatures around 120° F because of the hot fuel cell water flowing through the valve (Figures 2.5-1 and 2.5-5).

The barrel heater remains on continuously as long as the relief heater system is on. While on orbit, it keeps the nozzle and barrel at a temperature above the point where the nozzle heater activates, as long as water is not venting through the nozzle.\* If water vents through the nozzle, the orifice temperature rapidly decreases and the nozzle heater comes on, preventing blockage by ice. If the nozzle heater fails and water is required to vent, a problem results because even with the barrel heater on, the nozzle will freeze in a few seconds and the fuel cells will flood. Discussions were held with Rockwell thermal personnel about the possibility of pointing the nozzle at the Sun in case of loss of the nozzle heater. Unfortunately, the Sun provides an equivalent of only 5 watts of heating power on the nozzle, and an additional 35 to 40 watts are required to preclude freezing. Continuous purging of the fuel cell would remove only about 5 percent of the water required at nominal orbital loads.

There are six differential amplifier drivers, two each labeled "E" for emergency low, "N" for normal, and "H" for high (Figure 2.5-3). Each driver uses a reference voltage from the power supply, plus an input from one of the two thermocouples located at the nozzle (T SNSR A/T SNSR B) and signal conditioned in the OM2 and OM1 signal conditioners.

Logic state diagrams for the E, H, and N drivers are shown in Figure 2.5-4. The ordinate shows two scales: one is in volts (0 to 5 volts DC), and the other is a parenthesized temperature scale. The thermistor range is 0° to 450° F, and this is

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\*For a worst-case cold STS-2 mission, the barrel heater will maintain the nozzle at 184° F.

converted by the signal conditioners to a 0- to 5-volt DC analog voltage input to each driver. When the nozzle initial temperature has been elevated to 360° F and the fuel cell H<sub>2</sub>O relief heater switch is placed in A or B AUTO mode, the states of the E, H, and N drivers are shown at 360° F (i.e., H is high; N and E are both low). The B NOZ HTR can come on only when the two PNP power transistors are biased ON (Figure 2.5-3). This occurs when the base of each transistor is low in this schematic. Now the base of each power transistor is controlled by voting logic shown as NAND gates; the output of the voting logic is low for only one set of input conditions: the N driver must be high (A2), the H drivers must be low, and the A1 input must be high.

In the hypothetical situation in which the nozzle has been heated to 360° F, it can be seen that the E driver is low, the N driver is low, and the H driver is high; therefore, the heater is not on (Figure 2.5-4). As the nozzle cools to 279° F, the heavy vertical line indicates that the H controller is expected to go low at that temperature; however, it must go low at 270° F. The E and N drivers remain in a low state. At 216° F (the heavy vertical line), the N controller can first be expected to change state. It normally will go high at 198° F (indicated by the heavy arrow), but it must go high at approximately 180° F. A similar line of discussion follows for the E controller. As the nozzle continues to cool to 189° F (the dark vertical bar), the E controller can flip states: at 171° F, it is expected to go high, but it must go high at 153° F. The voltage voting logic should go low at 171° F, but it must go low at 153° F, turning on the nozzle heater. As the nozzle heater drives the temperature to 189° F, the E driver will first be expected to go low at 189° F, will normally flip at approximately 210° F (but must flip at approximately 220° F), and the heater will turn off. It is worth noting that the control range of the N and E drivers overlap and that the N driver could flip and turn off the heater before the E driver gets it. Assume that the drivers flip when they are supposed to. When that happens, the E driver controls the temperature range and the nozzle heater cycles to keep the nozzle between 171° and 207° F. Additionally, the barrel heater should keep the nozzle at a sufficiently high temperature so that the nozzle heater will not come on unless water passing through the orifice cools it to 171° F.

Refer to Figure 2.5-3 and notice that the two B-heater pass transistor base logic gates are labeled \_ and \_. When the RELIEF HTR switch is in the A-AUTO position, the A1 input on \_ is driven high by the switch wiper, while the A1 input on \_ is driven by the output of the E driver. Also the A barrel, relief valve, and line heaters are selected. In the B-AUTO position, the A1 input on \_ is driven high by the switch wiper, while the A1 input on \_ is driven by the output of the E driver. The B barrel, relief valve, and line heaters are activated.

The system has been modified so that certain component failures will manifest themselves by controlling the nozzle temperatures to different ranges. As an example, suppose that the pass transistor driven by NAND gate \_ short-circuits, and the relief system switch is in A-AUTO. As long as the switch remains in A-AUTO, the nozzle heater will continue to cycle between 171° and 207° F. Switching to the B-AUTO position, however, will now cause the temperature control range to shift to the 198° to 234° F range. If the switch is in A-AUTO and the control range shifts to the 198° to



234° F range, the pass transistor driven by NAND gate \_ may have shorted or the E comparator (system B) may have failed high (as confirmed by the SEC HTR ON TM discrete). The H drivers are cross-strapped so that an H output from either the A or the B system will shut down the nozzle heater. As can be seen, only the E and N (system B) drivers can turn on the nozzle heater, while H drivers for both systems A and B can turn off the heater.

There are two TM points indicated in Figure 2.5-3. The point labeled SEC HTR ON is a leftover from the days when two nozzle heaters were used. It now indicates that either E driver has activated. The NOZ OVER T discrete indicates that one of the H drivers has fired.

It should be noted that if the relief heater system is enabled and the system B nozzle temperature sensor fails to zero, the logic will command the heater on. If the system A temperature sensor is operative, the H driver (system A) will turn the heater off at approximately 270° F.

If both temperature sensors fail to zero, the nozzle heater will fail ON unless the H<sub>2</sub>O relief heater switch is placed to off. If only the system A temperature sensor fails to zero, the system A "H" driver will not be operative to provide a redundant heater off signal at 270° F, but the B system will control the heater normally. The system A temperature sensor uses MDM OF2 and DSC OM2; the system B temperature sensor uses MDM OF3 and DSC OM1. If the output of the MDM or DSC fails to zero, the same effects described above will occur.

The nozzle heater system is fraught with single-point failures that will preclude the operation of the nozzle heater. Some of these failures include the following: opening of one of the driver transistors, physical breakage of the heater, failure of the N driver low on the B system, H driver high, failure of the B signal conditioner, or temperature sensor high.

It appears that the nozzle heater can fail on at least two failures. However, in many cases the first failure will not be detected until the second failure occurs. The system A heater was disabled because two single-point failures allowed the heater to come on (i.e., the driver transistor shorts, or the NAND gate output fails low).

## **ASCENT AND ENTRY SIGNATURES**

During both ascent and entry dynamic flight, the H<sub>2</sub>O relief line and nozzle temperature show peculiar temperature transients.

Figure 2.5-8 shows the relief line temperature for STS-29. Lift-off was at a GMT of 072/14:57. Within 3 minutes, the temperature is already decreasing and finally levels out approximately 45 minutes after lift-off. The cause of the drop in temperatures is believed to be the result of residual water vapor in the line evaporating once the vehicle is near vacuum. This phase change thus carries the heat with it as it is vented overboard.

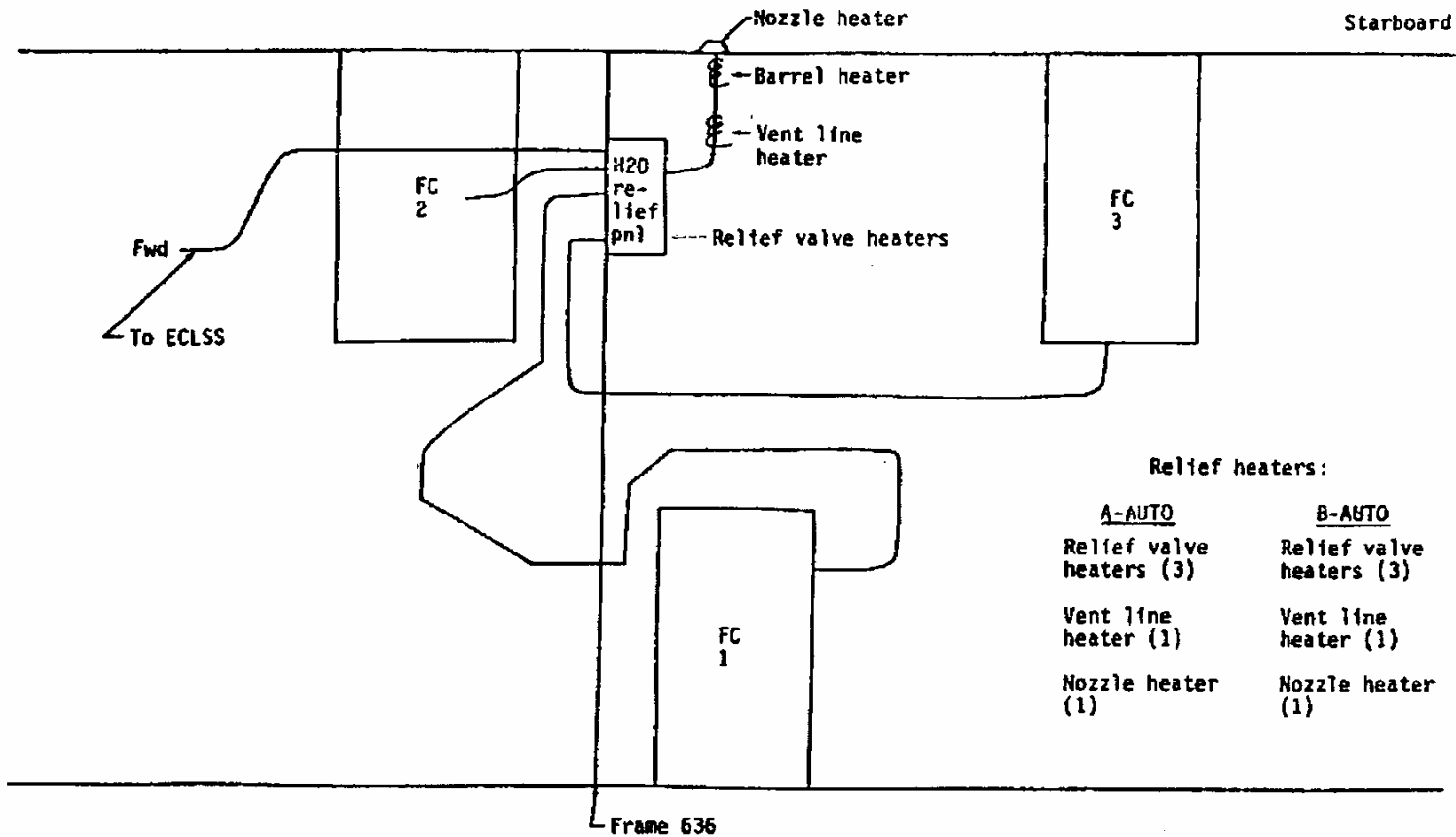
The effects of entry on the relief nozzle temps are more pronounced and fully understood. Figure 2.5-9 shows the nozzle temperatures on STS-26. TIG was at an MET of 3:23:58, or just prior to 96 hours. It can be seen that at approximately 96:30 the temperatures rise dramatically Offscale Hinges (OSH). This is the result of atmospheric heating caused by reentry and begins just after entry interface.

## SUMMARY

- A. The relief system is a backup means of allowing product water to be removed from the fuel cells. The heater system consists of three relief valve heaters, one relief line heater, one barrel heater, and one nozzle heater for each of the two systems (A and B).
- B. The system A nozzle heater has been disconnected because of a single-point failure allowing the A nozzle heater to come on and cause possible damage to the spacecraft.
- C. As the system now exists, at least two failures are required for a nozzle heater to fail on. Only the B controllers can activate the nozzle heater; however, the A and/or B controller can turn it off.
- D. On orbit, the barrel heater should keep the temperatures around the nozzle high enough to prevent the nozzle heater from coming on unless water vents through the nozzle.\* On the pad, the nozzle heater can be expected to cycle ON for approximately 1 minute out of 12 (Figure 2.5-7).
- E. The relief heater switch in the spacecraft now performs the following functions:
  - 1. In A-AUTO - Enables the A system relief valve heaters, barrel heaters, and line heaters and controls the nozzle temperature between 171° and 207° F, nominally.
  - 2. In B-AUTO - Enables the B system relief valve heaters, barrel heaters, and line heaters and controls the nozzle temperature between 171° and 207° F, nominally.
- F. If the temperature range changes to approximately 198° to 234° F, a malfunction has occurred in the controller.

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\* For a worst-case cold STS-2 mission, the barrel heater will maintain the nozzle at 184° F.



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Figure 2.5-1. The FCP H<sub>2</sub>O relief nozzle

2.5-6

Verify that this is the correct version before use

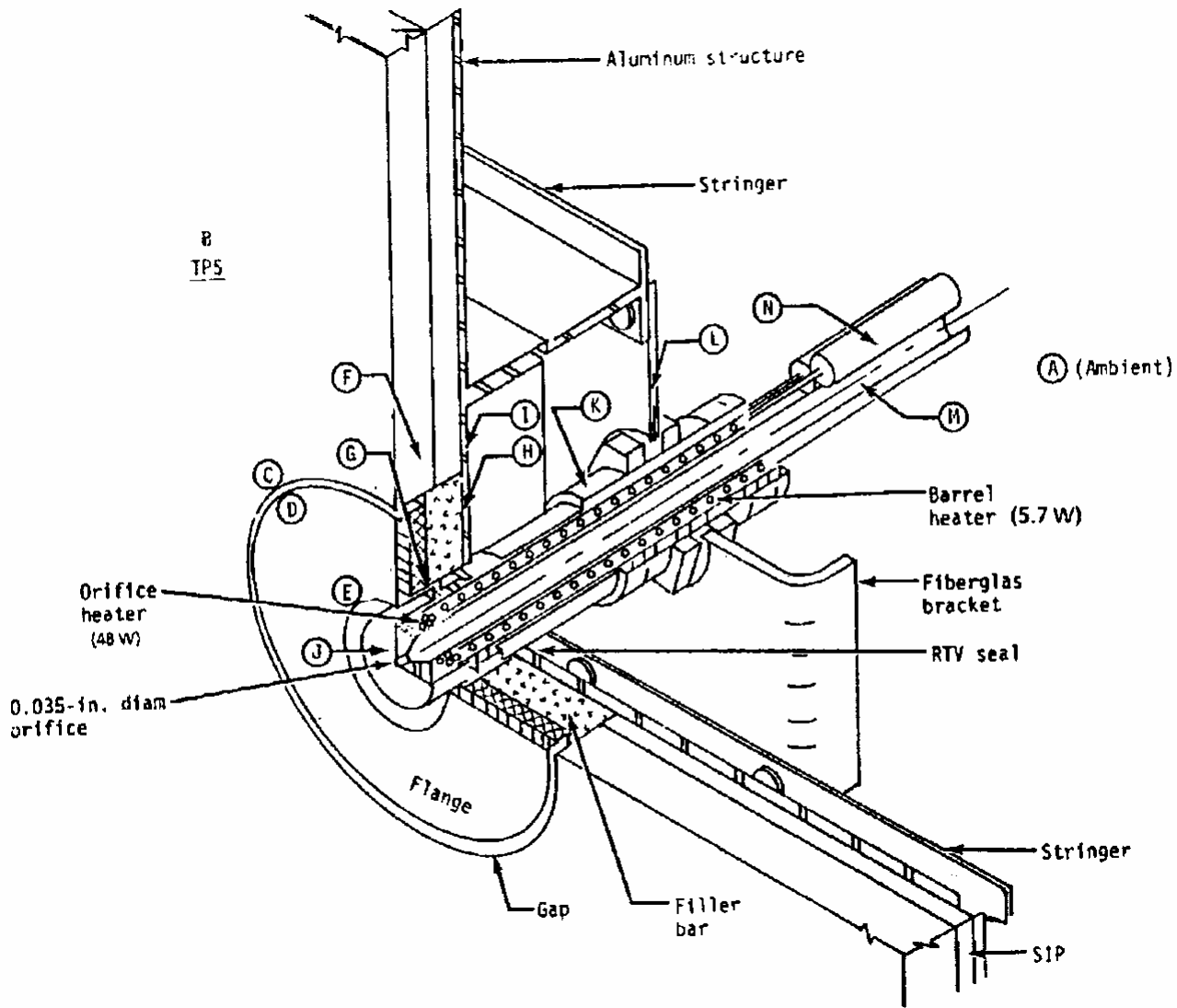
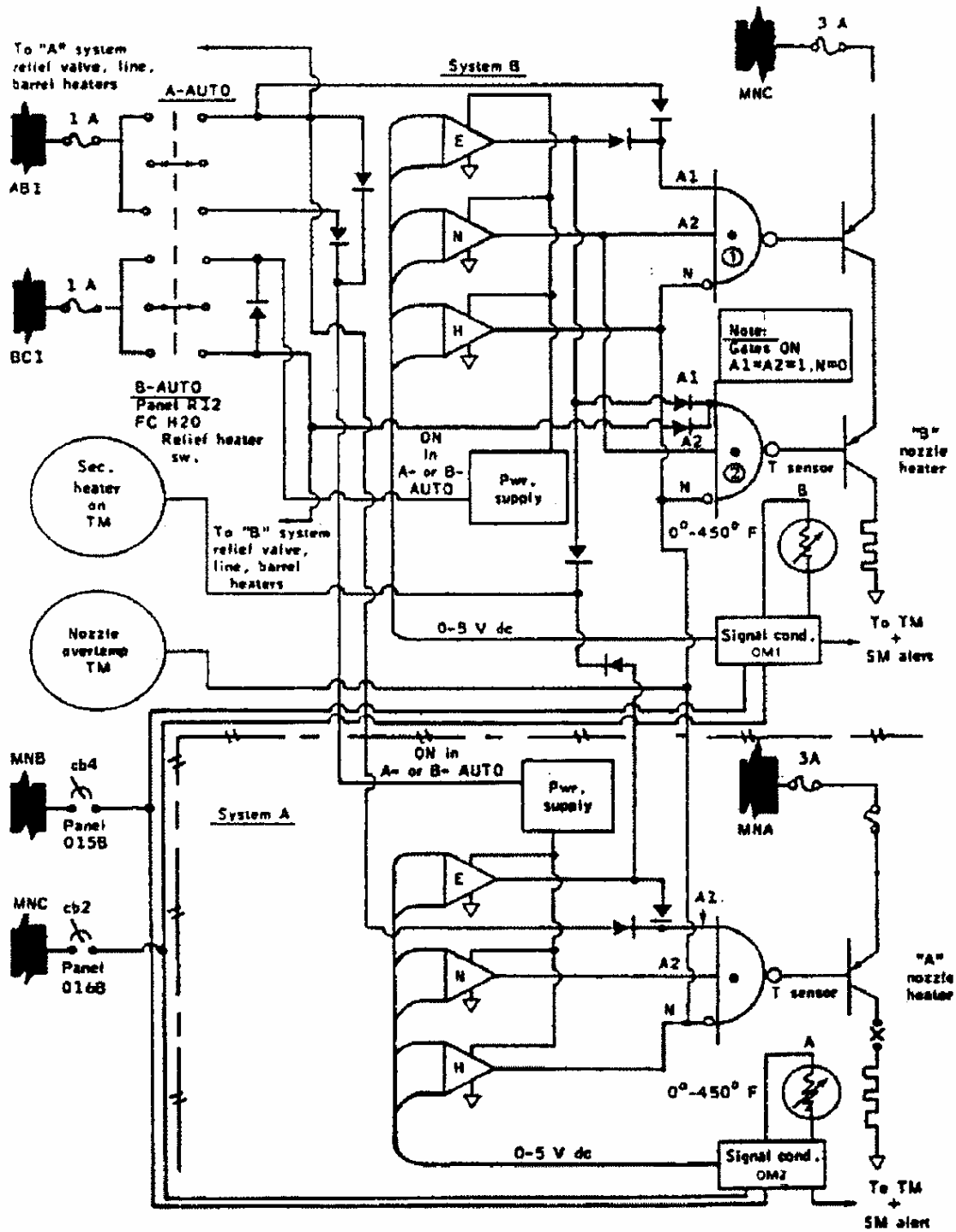


Figure 2.5-2. The FCP H<sub>2</sub>O relief nozzle

2.5-7

Verify that this is the correct version before use



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Figure 2.5-3. STS FC relief nozzle heater logic

Verify that this is the correct version before use

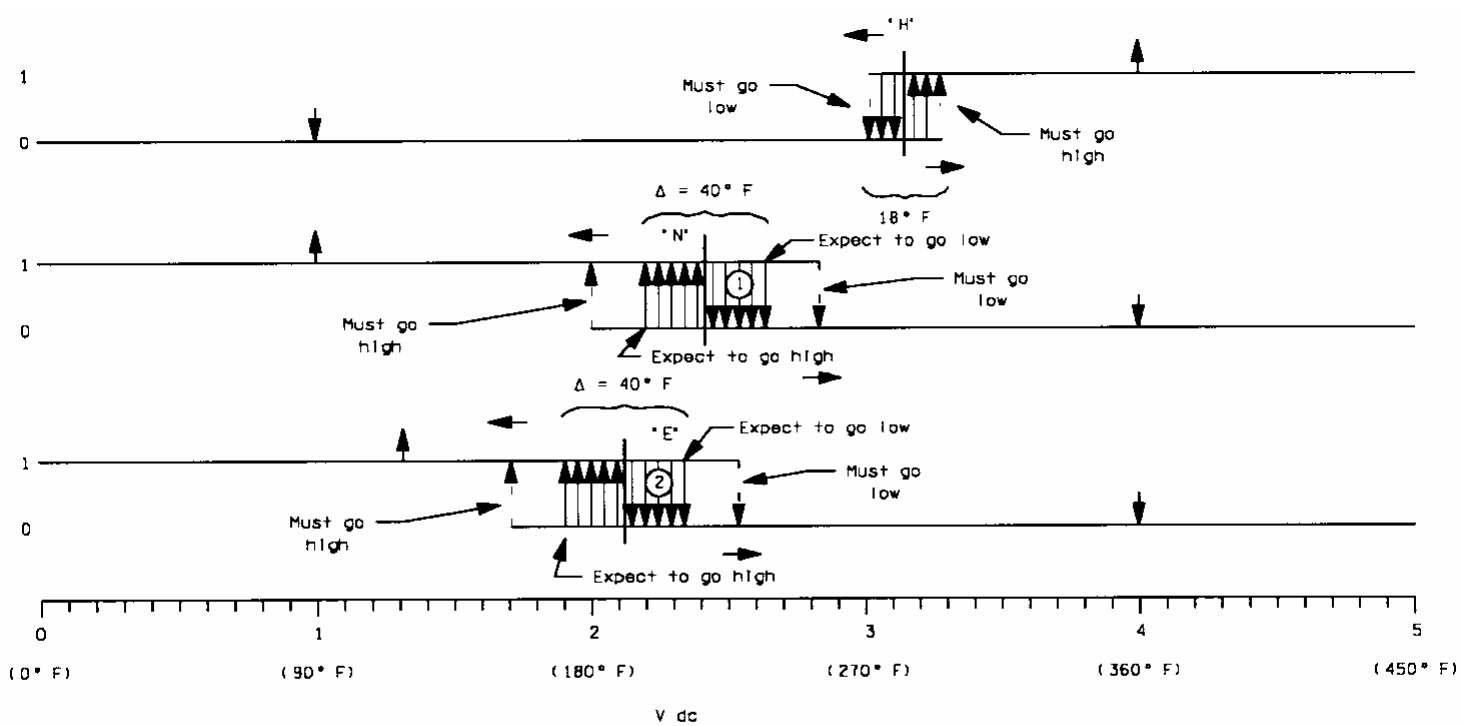
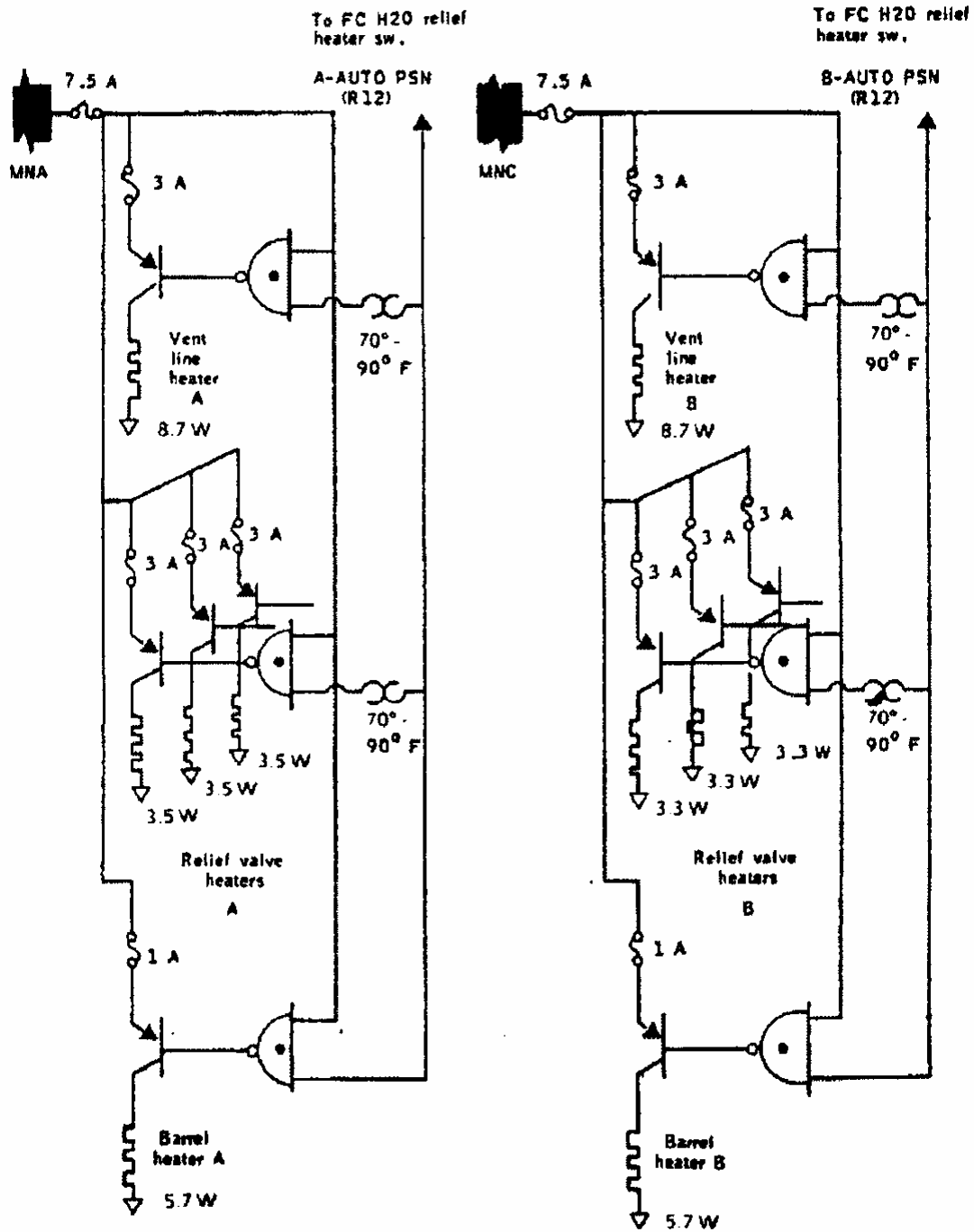


Figure 2.5-4. Relief nozzle heater driver schedule

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j 128305\_243

2.5-9

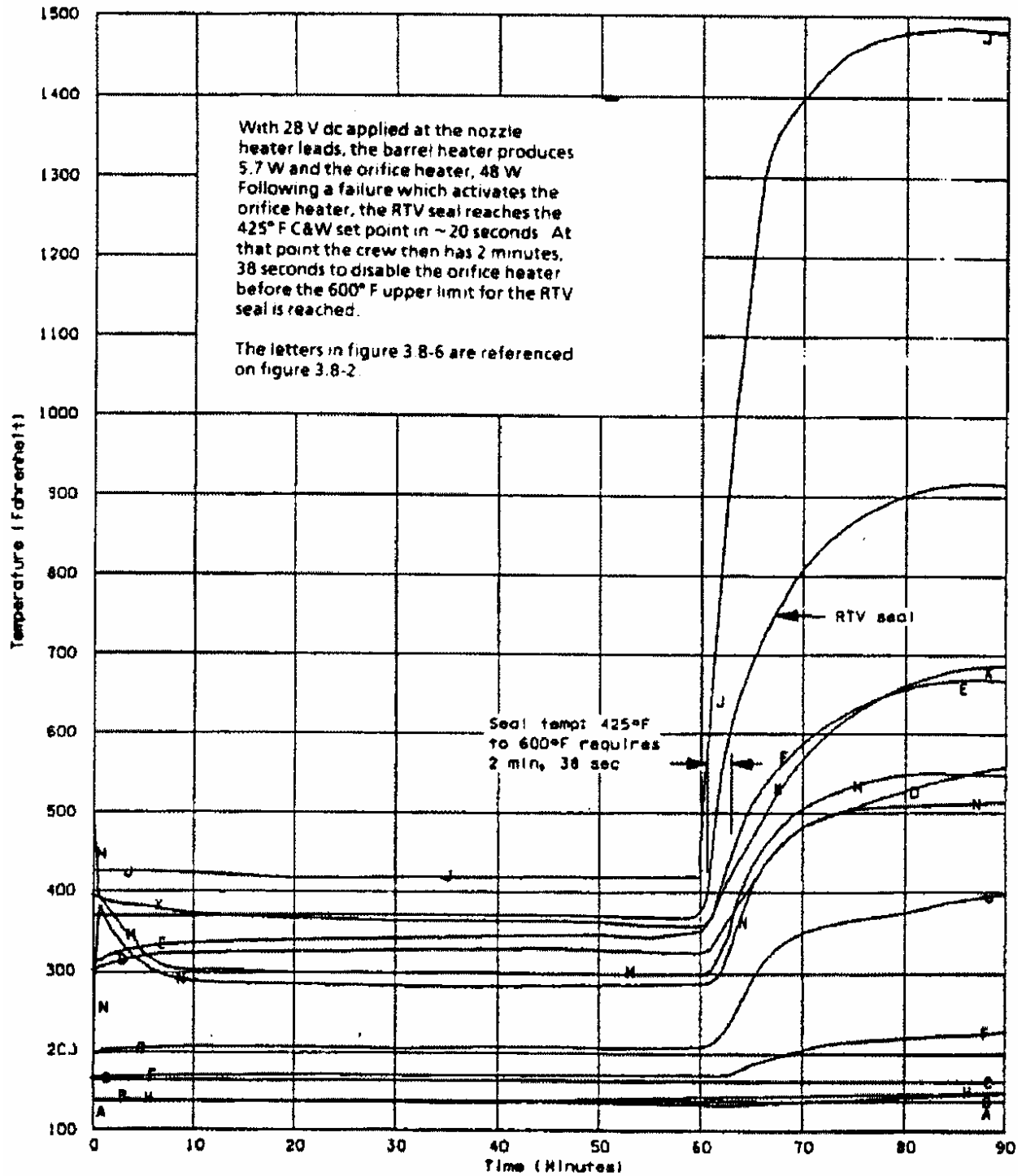
Verify that this is the correct version before use



Relief valve control logic shown for one valve heater. Other two gates for the remaining system relief valves omitted for drawing clarity.

[\_12830\_244

Figure 2.5-5. Relief system thermostatic heaters

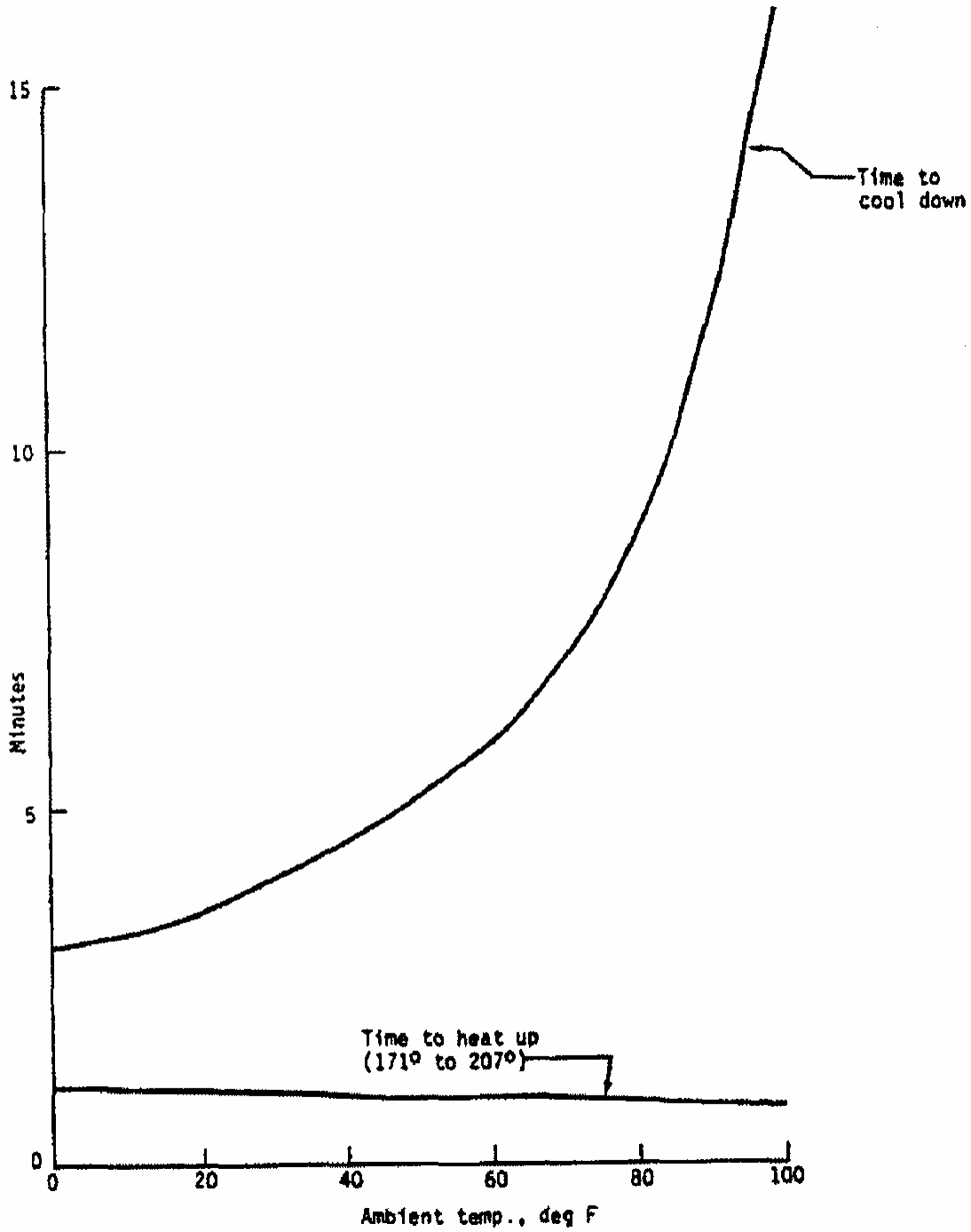


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Figure 2.5-6. Hot case failed-on orifice heater at time = 60 minutes



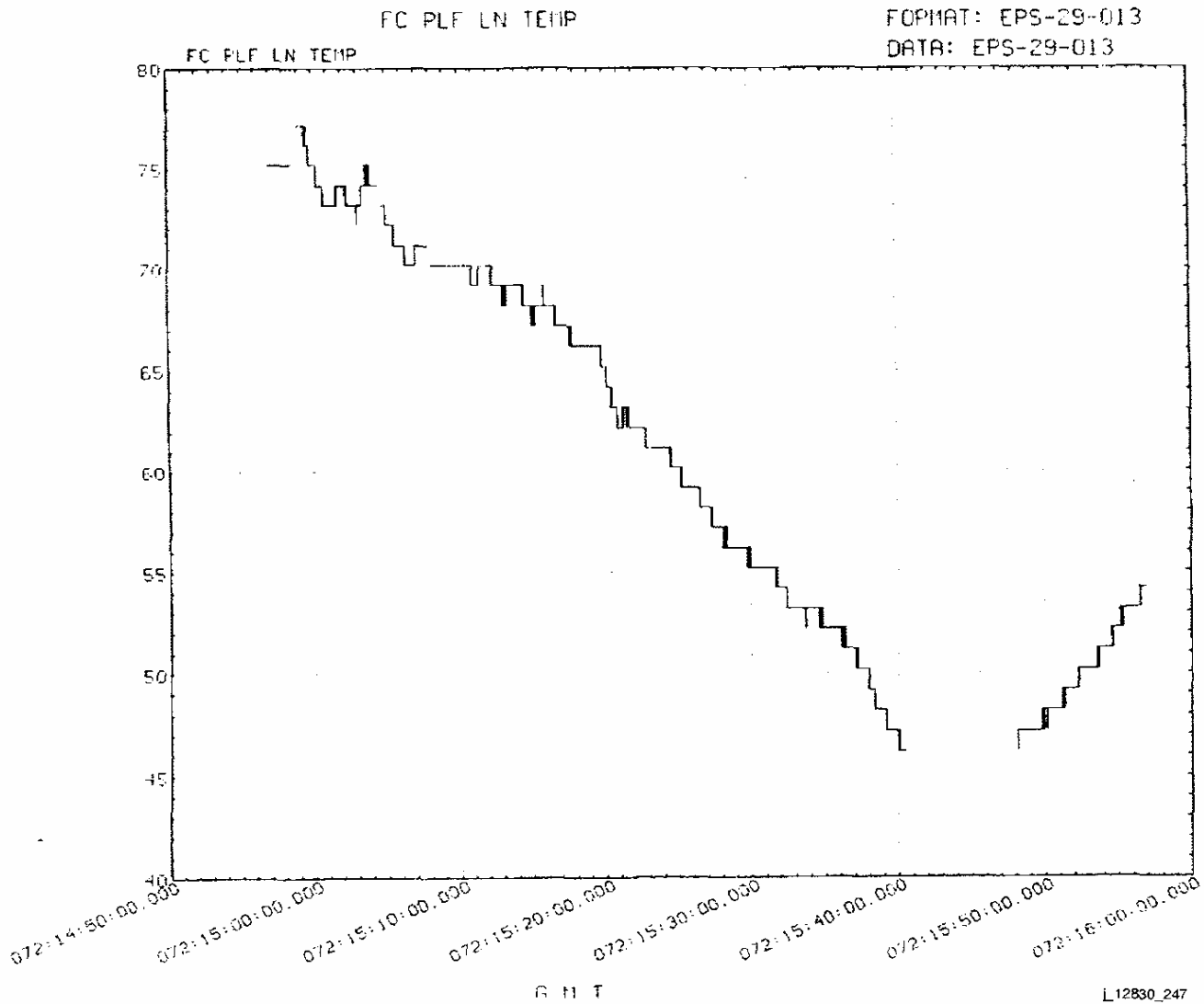


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Figure 2.5-7. Fuel cell nozzle heater duty cycles on pad

THIS  
STS-029

FORMAT: EPS-29-013  
DATA: EPS-29-013



V4510-50A  
(UNITS N/A)

L12830\_247

Figure 2.5-8. Relief line temperature for STS-29

2.5-13

Verify that this is the correct version before use

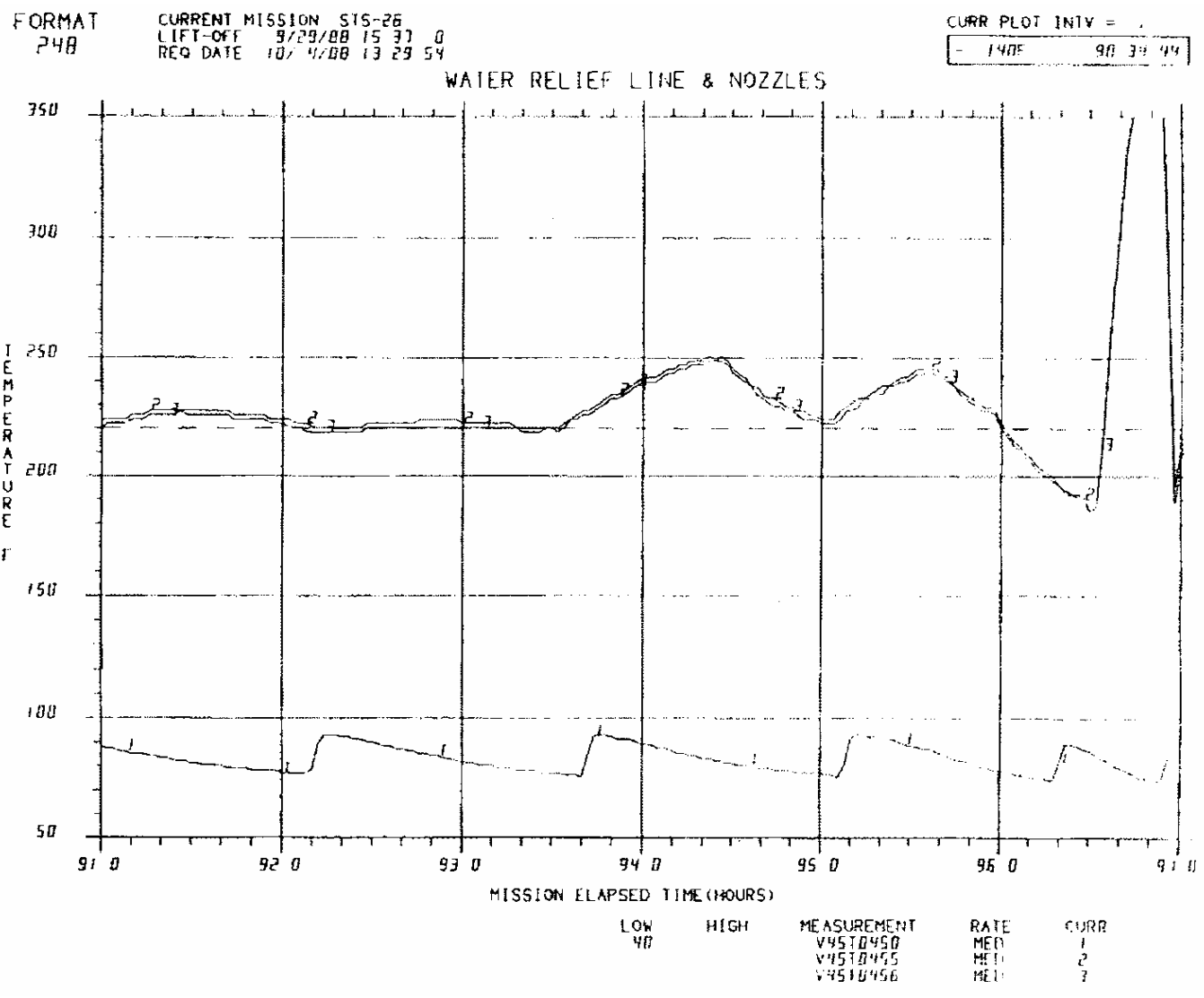


Figure 2.5-9. Nozzle temperatures on STS-26

2.5-14

Verify that this is the correct version before use

## TITLE

FUEL CELL PURGE

## PURPOSE

This brief describes reasons for performing a fuel cell purge, explains the mechanics behind a purge, outlines console operations and operator responsibilities, and also describes the various methods for performing a purge.

## BACKGROUND

Fuel cell purges must be performed periodically throughout the mission to rid the fuel cells of contaminant buildup, thus ensuring proper voltage at the fuel cell electrical terminals and preventing “hot spots” caused by less reactant sites from occurring. Typically, the contaminants are inert materials (He or N<sub>2</sub>) that enter the fuel cell from the PRSD subsystem during normal mission phases. As the “dirty gas” enters the fuel cell, the inerts randomly plug active O<sub>2</sub>/H<sub>2</sub> reaction sites. Over an extended period of time, the fuel cell “loses” enough reaction sites to cause a drop in the overall terminal voltage, which significantly decreases the efficiency of the fuel cell. To clear the reaction matrix of the unwanted inerts, the fuel cell subsystem is equipped with purge valves that allow flowthrough O<sub>2</sub> and H<sub>2</sub> gases to capture and carry inert materials overboard.

Purges are most critical on the O<sub>2</sub> side. O<sub>2</sub> flowing into the stack “deadheads” within each cell, resulting in a layout containing an entrance but no exit. Therefore, the only elements that can be removed from a cell are those that react. Because the contaminants cannot react, they are left behind to occupy reaction sites normally reserved for O<sub>2</sub> molecules. Activating the dual flow control purge valve closes one of the O<sub>2</sub> inlet paths and simultaneously opens an O<sub>2</sub> outlet path, which creates an O<sub>2</sub> flow path through each cell in the stack. Once trapped in the cell, impurities can be removed by the mechanical scrubbing action of O<sub>2</sub> gas flowing through the cell.

The H<sub>2</sub> system, on the other hand, is not deadheaded. Because International Fuel Cells (IFC) designed the H<sub>2</sub> system with a flowthrough path to accommodate water removal, impurities inherently circulate through the stack, which minimizes the opportunity for contaminants to occupy reaction sites on the H<sub>2</sub> side of the cell.

From the beginning of the space shuttle program with STS-1 to the completion of STS-31, the crew routinely purged the fuel cells every 8 to 12 hours. However, following a purge valve failed in the open position on STS-50, the fuel cell community determined that frequent purging resulted in the expulsion of KOH from the cell matrix and subsequently caused the breakdown of O<sub>2</sub> and H<sub>2</sub> sealing gaskets. Based on observed fuel cell performance data, a method was drafted and adopted to begin fuel cell performance purges, limiting in-flight purges to 96-hour intervals or when the actual interface voltage drops 200 millivolts below the expected maximum interface voltage.

Purges can be performed either manually or automatically. As implied, manual purges will be completed by the crew, requiring switch throws to activate the line heaters and

the FC1 (2,3) purge valves. Automatic purge sequences run under the control of the Systems Management (SM) machine (OPS 2,4) and can be initiated after a single onboard switch throw or a Table Maintenance Block Update (TMBU). Additionally, the Backup Flight System (BFS) can be used to command the heaters or purge valves individually. Although the automatic purge sequence is normally performed, at least one manual purge will be performed on orbit to verify the manual purge capability. Automatic purges commanded through the BFS machine (OPS 1,3) take advantage of Real-Time Commands (RTCs) that activate the purge line heaters and the purge valves individually or simultaneously, using the Multiple Real-Time Command (MRTC).

## PROCEDURE

### A. Auto purge sequence

Once initiated, the auto sequence turns on the purge line heaters to preheat the purge vent lines, opens the fuel cell purge valves sequentially for a specific amount of time (normally 2 minutes), and then performs a purge line bakeout. The auto purge software (see Flight Systems Software Requirements (FSSR)) also monitors selected parameters during the purge. Refer to Space Shuttle Systems Handbook (SSSH), drawing 3.4, sheet 2, for a description of the auto purge logic sequence.

Before initiating an auto purge, the following switch configuration must be verified:

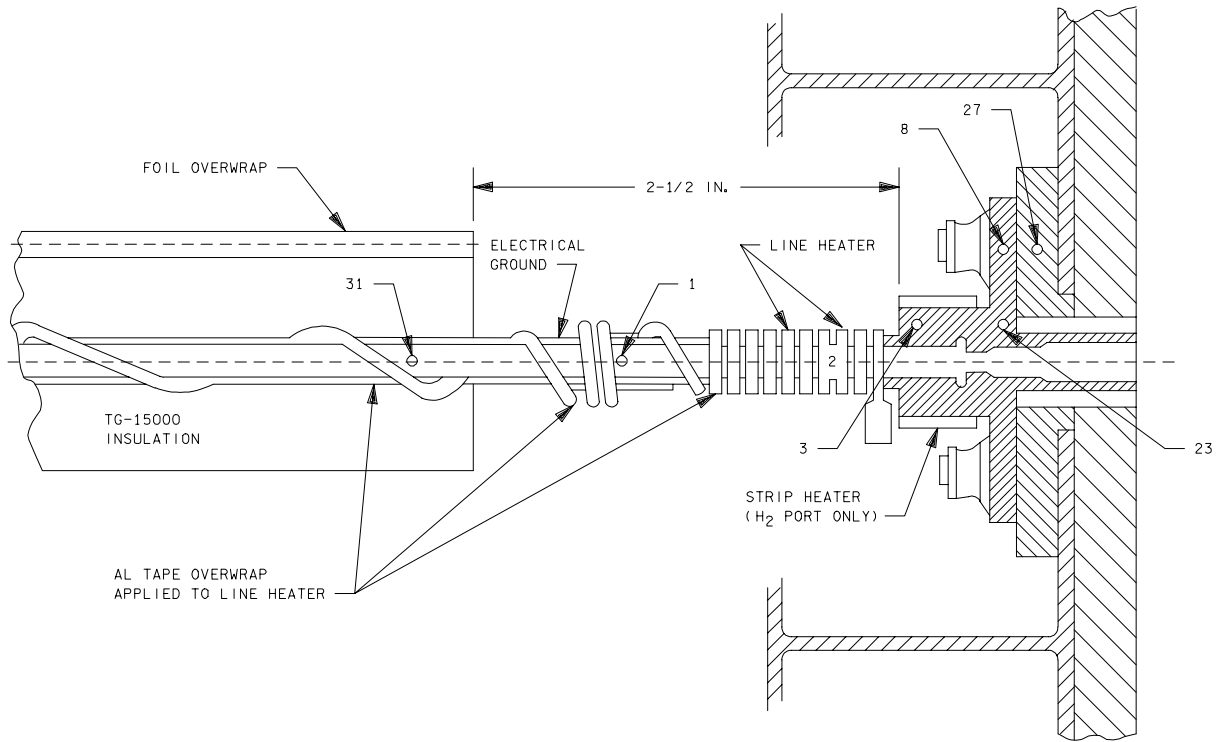
Panel R11U:  
FC PURGE HEATER - GPC  
FC PURGE VALVES 1(2,3) - GPC

The crewmember holds the FUEL CELL GPC PURGE SEQ switch to START until the GPC PURGE SEQ talkback stays gray for 3 seconds. If the switch is not held long enough for the purge software to sense an engaged talkback, the General Purpose Computer (GPC) aborts the purge with an accompanying S69 FC PURGE SEQ message. The crewmember must then attempt to restart the purge. Following the auto sequence, a good talkback is now started and no further action is required by the crewmember. Step E, SM Auto Purge Ground Command, details the sequence start procedure using a TMBU.

At sequence initiation, one set of purge line heaters is commanded on, and the GPC starts a 27-minute preheat timer. The heaters are redundantly powered by two redundant Remote Power Controllers (RPCs), B and C-2, and are completely independent of those used during a manual purge. The purge line temperatures must meet minimum limits prior to expiration of the preheat timer. Specifically, the limits are

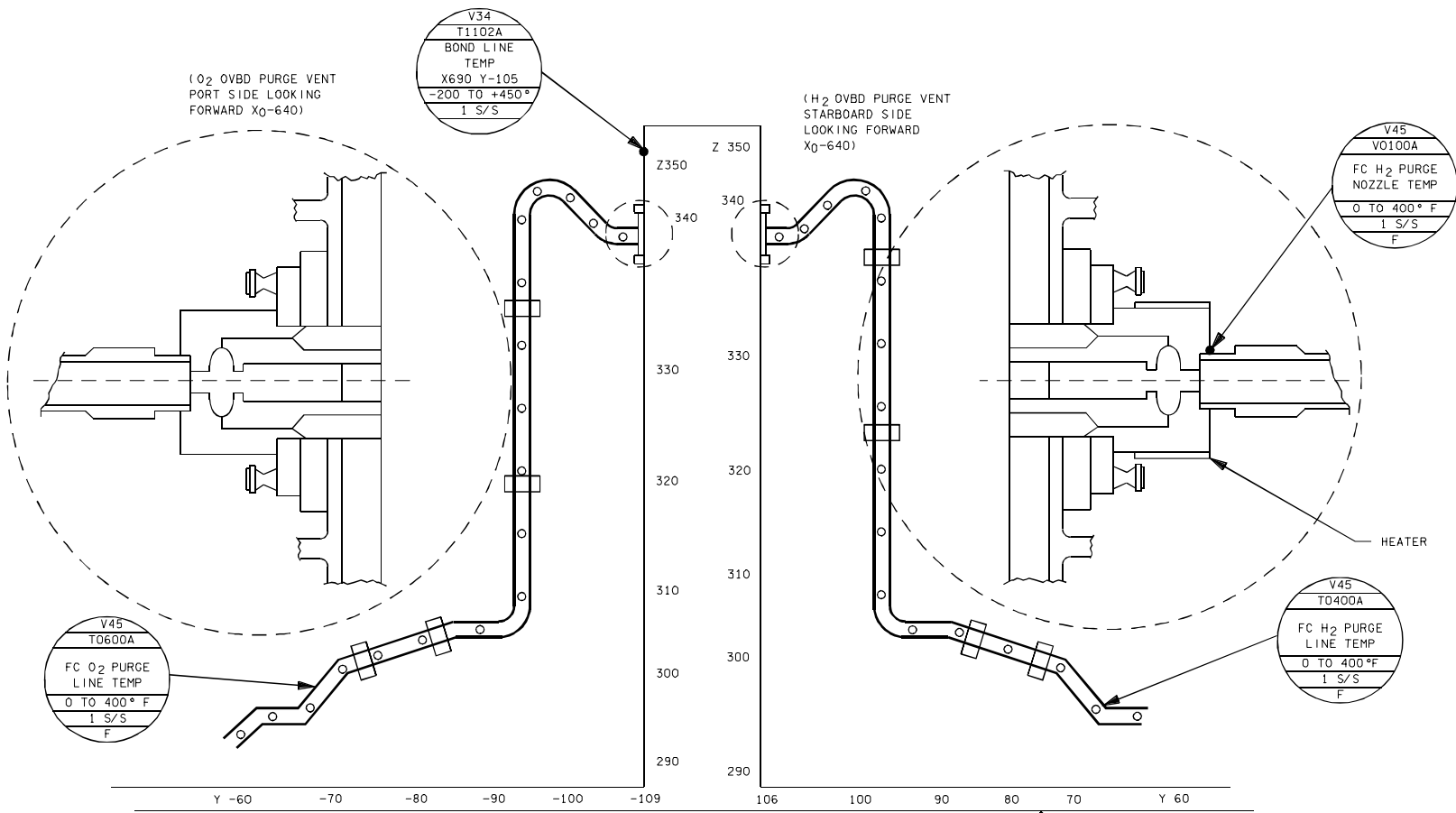
O<sub>2</sub> VENT LINE TEMP (V45T0600A) - 69° F  
H<sub>2</sub> VENT LINE TEMP 1 (V45T0699A) - 79° F  
H<sub>2</sub> VENT LINE TEMP 2 (V45T0700A) - 40° F

The expiration time for the timer satisfies the worst-case vehicle thermal conditions. If the timer expires, the sequence stops and an SM alert is annunciated for S69 FC PURGE TEMP. The vent line temperature transducer locations can be seen in Figure 2.6-1 and Figure 2.6-2. Actual flight temperature profiles and the associated purge reactant flows are shown in Figure 2.6-3.



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**Figure 2.6-1. Typical fuel cell purge vent line nozzle**

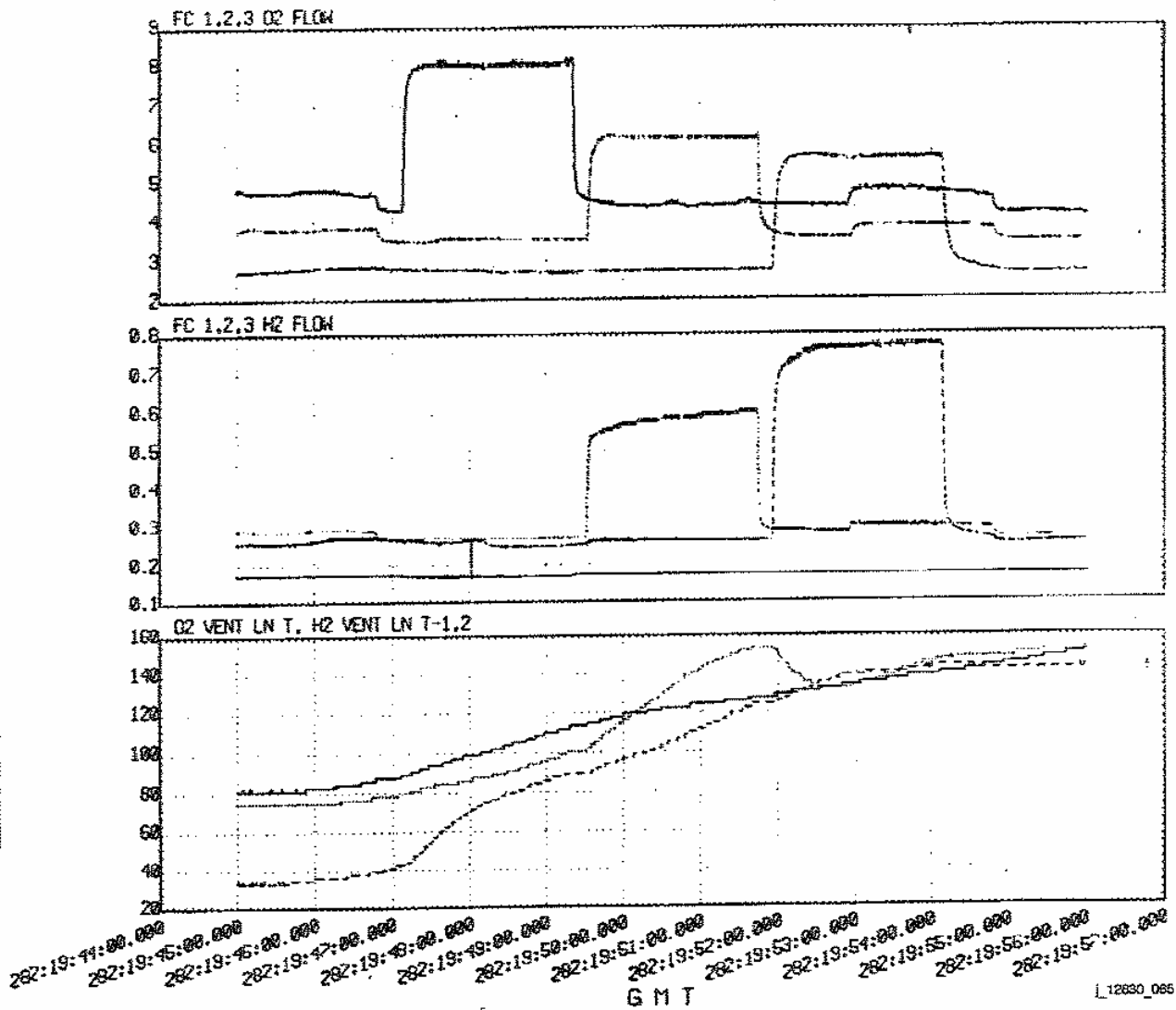


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Figure 2.6-2. H<sub>2</sub> and O<sub>2</sub> vent line temperature transducer locations

2.6-4

Verify that this is the correct version before



V45P0160A  
(LEH1R )  
V45P0260A  
(LEH1R )  
V45P0360A  
(LEH1R )

V45R0170A  
(LEH1R )  
V45P0270A  
(LEH1R )  
V45P0370A  
(LEH1R )

V45T0500A  
(DEGF )  
V45T0600A  
(DEGF )  
V45T0700A  
(DEGF )

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Figure 2.6-3. Typical purge vent line temperatures and reactants flows during purge  
(Note: FC1 H<sub>2</sub> flowmeter is failed in this example.)

2.6-5

Verify that this is the correct version before



When all three temperature limits are satisfied, the GPC immediately begins fuel cell purging. The GPC checks the FC1 purge valve switch and, if in the GPC position, both purge valves are commanded open. After 10 seconds, the GPC compares actual reactant flow against the calculated flow (actual flow - fuel cell current x constant > delta). Historically, the check has been done to ensure that the valves opened properly; however, because of instability in the flow transducers, these measurements have effectively been inhibited by setting the delta offscale low.

After a default purge time (I-loaded 2 minutes), the GPC commands the valves closed. It should be noted that the same purge duration time is used for all three fuel cells; however, a TMBU will allow changing a particular fuel cell purge duration time independently of the other two fuel cells. (The single purge duration time is a TMBU constant and can be changed by sending a TMBU for parameter V92W0635C.) The numeric value supplied should be in decimal minutes. To change individual fuel cell purge times, see step E, SM Auto Purge Ground Command. GPC once again performs a flow check to ensure that the valves closed properly. Again, instability in the flow transducers drove the need to disable the computation, which is accomplished by setting the delta value to an offscale high number. Because the flow checks are still performed in the software by the GPC, there will be a 10-second wait between successive fuel cell purges.

When the GPC completes the FC1 purge, the software repeats the entire process for FC2 and then FC3. After FC3 has been purged, the GPC continues to power the purge line heaters for 30 minutes to bake residuals out of the lines. The GPC PURGE SEQ talkback transmitting to bp after bakeout is complete.

The line heaters are not thermostatically controlled; however, some temperature fluctuations may be observed as the reactants flow through the lines. After the fuel cells are purged, the line temperatures will increase steadily, perhaps in excess of 300° F. The H<sub>2</sub> VENT LINE TEMP 2 may not increase much, because the heat goes into ice vaporization and is dissipated. The O<sub>2</sub> Vent Line Temperature (VLT) may show little increase, perhaps even some decrease. Typical flight temperature responses during bakeout can be seen in Figure 2.6-3. If, during the sequence, a temperature indicates an uncharacteristic decreasing trend, a heater failure may have occurred. In this situation, the auto purge sequence is lost and subsequent purges must be performed manually. The manual purge heaters must be used to bake out the lines, and this is accomplished by switching the FC PURGE HEATER from GPC to ON. Consideration may be given to extending the bakeout time for an extra accumulation of ice or water. If the failure occurred in the H<sub>2</sub> vent system, the bakeout time should be extended to 2 hours, which ensures complete ice removal in the line or at the port (ref. Shuttle Orbiter EPS Thermal Control Design and Analysis, Rockwell SD77-SH-0284, pp. 108). The 2-hour bakeout is also recommended for failures in the O<sub>2</sub> system.

It should be noted that when the line temperature limits are satisfied and the first actual purge begins, the purge sequence will not abort for a failed heater element or line temperature transducer failure (both of which produce a substandard line temperature reading). Also, placing an individual purge valve switch in the CLOSE position while purging that particular fuel cell will not cause the software sequence to abort, because the GPC checks the switch position prior to commanding the purge valves open. On the other hand, removing power from the heater elements, whether it is done by intentionally moving the heater switch to the OFF position or from a bus loss, RPC, or switch failure, will cause the software sequence to abort. This occurs because the loss of heater power causes the loss of the FC AUTO PURGE ON discrete, which the GPC uses to sequence through the purge logic flows.

The only constraints on fuel cell purges, besides verification of the normal switch positions, are to restrain from purging while fuel cell currents exceed 350 amps and within 3 hours prior to deorbit Time to Ignition (TIG). The 350-amp constraint is observed to ensure that total reactant flows (normal + purge flows) do not exceed the capacity of the reactant preheaters, thus causing dual gas regulator freeze-up. For off-nominal or contingency situations, the fuel cell may be purged for 2 minutes at load levels up to 430 amps. The 3 hours before deorbit TIG constraint is intended to prevent an ops transition from disturbing the purge, to allow bakeout, to prevent lines from being hot, and to prevent possible nozzle damage caused by entry heating.

To summarize the auto purge sequence

1. If the fuel cell purge valve switch is in the CLOSE position, the GPC bypasses that particular fuel cell and purging continues with the next fuel cell.
2. Purge sequence start can be commanded via single switch initiation (must hold >3 seconds) or by TMBU (MCC).
3. One set of line heaters will be activated for warmup.
4. If the purge lines reach minimum temperature in < 27 minutes
  - a. Fuel cells are purged sequentially for default 2 minutes (may be changed by TMBU).
  - b. Lines are baked out for 30 minutes after last purge.
5. The following conditions are monitored for purge sequence abort:
  - a. S69 FC PURGE TEMP - Lines not warmed in <27 minutes.
  - b. S69 FC PURGE - Heater power lost during sequence. (The GPCs produce the same message if the start switch is not held long enough.)

6. Normal purges will not be performed for fuel cell current in excess of 350 amps or 3 hours prior to deorbit TIG.

B. Manual purge

The manual purge process accomplishes the same function as the auto purge process, but the crewmember must manipulate the heaters and purge valves manually. The manual purge procedure is normally performed once per flight to validate the operation of the manual heater string, and it is also performed as a backup procedure to complete the fuel cell purge. It is almost completely redundant in the fact that it has separate heater elements, powered through separate RPCs (A and C-1), and separate control bus power to the switch contacts. The only common components are the purge valves themselves.

The manual purge procedure for the crew can be found in the Orbit Operations Checklist, which requires crew verification that the fuel cell to be purged is active and is supporting less than 350 amps of load. The purge line heaters are then activated on panel R11 to bring the lines up to minimum temperatures. The crew then sequentially opens the appropriate purge valve by using the associated switch on panel R11. The crew verifies that the flow increases are within specified limits, maintains the valves open for 2 minutes, and finally closes the purge valves to complete the purge. When the last purge valve has been closed, the heaters are left on for an additional 30 minutes to bake out of the lines any ice that may have formed.

C. Console monitoring

In the past, fuel cell purges were scrutinized very heavily by the Electrical Power System (EPS) operator. All purge characteristics were recorded on strip-chart recorders and verified against normal signatures. Purges performed during Loss of Signal (LOS) periods were reviewed by requesting playbacks of data when the onboard ops recorders were dumped. This intense level of scrutiny changed to merely watching digital data of the purges and also requesting Orbiter Data Reduction Center (ODRC) plots of purges performed during LOS.

Although we have relaxed our intensity in reviewing fuel cell purges, it is important not to downplay the importance of these data. As we know from experience, certain fuel cell failures can be detected by monitoring fuel cell purges. Hindsight shows that certain AC bus current changes during purges can be indicative of H<sub>2</sub> pump blockage, which eventually caused the loss of FC1 on STS-2. Data collected during purges on STS 61-B indicated that no performance gain could be noted on FC2 during or after purges. This eventually led to the discovery of a faulty purge valve in the dual gas regulator. High purge flows seen on STS-31 as a result of a fuel cell regulator failure led to the discovery that high flows on a previous purge had been overlooked.

Using ODRC, it has become much less labor intensive to review purges performed during LOS. It is, therefore, suggested that all EPS operators use this capability to

review purges, providing that it is done on a noninterference basis with higher-priority issues. Such items that can be reviewed are as follows:

1. Reactant flows
  - a. DELTA VOLTS response
  - b. STACK OUT TEMP/TCE response
  - c. AC bus current response
  - d. Vent line temperatures
2. If watching purge line temperature warmup in real time, verify the following parameters on MSK FC\_EPDC:
  - a. FC1,2,3 PURGE VALVES - GPC (if auto purge).
  - b. PURGE HEATERS - GPC (if auto purge).
  - c. AUTO PURGE DISCRETE (if applicable).
  - d. Appropriate heater RPCs (B and C-2) or (A and C-1).
  - e. O<sub>2</sub> and H<sub>2</sub> line temperature responses.
  - f. Record all reactant flows (6) before valves open.
  - g. Record all DELTA VOLTS comps (3) before valves open.
3. During a purge
  - a. GPC discrete indicating which fuel cell is purging (if applicable).
  - b. Purge valves manually opened (if applicable).
  - c. Reactant flow increase of 0.6 (H<sub>2</sub>) and 3.3 (O<sub>2</sub>) lb/hr and steady.
  - d. AC bus current changes as noted on Plotting In Real-Time (PIRT) charts.
  - e. Verify that COOL PRESS is maintained.
  - f. Note STACK OUT TEMP/TCE response.
4. After a purge
  - a. Verify that GPC fuel cell-specific purge discrete is gone (if applicable).
  - b. Verify purge valve - GPC (after manual purge).
  - c. Verify that reactant flows are returned to prepurge values.

- d. Record new DELTA VOLTS reading after fuel cell stabilizes (typically average value).
  - e. Check for any AC bus current changes.
  - f. Scan all other fuel cell parameters for abnormalities.
5. After all fuel cells have been purged
- a. Verify that heaters remain on for 30 minutes after purge.
  - b. Verify line temperature response.
  - c. Change limit lines on the performance format in Mission Evaluation Workstation System (MEWS).
- D. BFS command procedures

WARNING

**This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations).**

Hazard safety implication: The commands 5400-5407 are safed in group 1. Sending any purge valve open command without sending RTC 5406, Purge Heaters ON, could result in freezing of the purge vent lines.

Valid software major modes: All BFS

Valid OI loads: All

Vehicle, LRU/hardware version constraints: None

Time constraints, crew coordination requirements: None

The BFS purge commands provide a means by which to initiate a fuel cell purge while the crew is strapped into their seats and cannot access the purge switches on panel R11U.

The ground must command the purges for certain failure cases during ascent and entry. Fuel cell purging will be initiated using the RTC function available through the INCO console.

These RTCs set specific PL MDM output bits that subsequently command the purge valves and line heaters. In order for the RTCs to function properly, the associated purge heater switch and the three purge valve switches must be configured to the GPC position before crew seat ingress.

The RTC command set provides options for turning on the purge heaters and then purging a selected fuel cell or issuing an MRTC, which energizes the heaters and opens the purge valves on all three fuel cells simultaneously.

The only failure mode currently identified that requires a simultaneous purge on all three fuel cells is for loss of both Freon loops in the orbiter. With loss of both Freon loops, cooling and water removal capability in the fuel cells are lost. Purge flow through the fuel cells offers a minor degree of compensation for cooling losses.

RTC command numbers and their associated functions are listed below. To execute the purge(s), you must use CMD procedure in the Flight Control Operations Handbook (FCOH), Sections 3.1 and 3.2.3. For successful commanding, it is mandatory that the following switch configuration be verified via telemetry:

Panel R11U:

FC PURGE HEATER - GPC  
FC PURGE VALVES 1 (2,3) - GPC

**CAUTION**  
**Sending any purge valve open command without sending RTC 5406, Purge Heaters ON, could result in freezing of the purge vent lines.**

<u>Function</u>	<u>RTC</u>
MRTC - All purge valves open and heaters on	5410
Purge line heaters - ON	5406
Purge line heaters – OFF	5407
FC1 valves - OPEN	5404
FC1 valves – CLOSED	5405
FC2 valves - OPEN	5402
FC2 valves – CLOSED	5403
FC3 valves - OPEN	5400
FC3 valves – CLOSED	5401

Command group 1 (5400 to 5407 and MRTC 5410) must be unsafed before MRTC 5410 can be sent. After sending 5410, RTC group 1 should be resafed. Reference FCOH, Section 3.1.5, for safing and unsafing.

E. SM auto purge ground command

WARNING

This procedure is governed by FCOH, SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations).

Hazard/safety implication: None

Valid software major modes: SM Ops 2 and Ops 4

Valid OI loads: All

Vehicle, LRU/hardware version constraints: None

Time constraints, crew coordination requirements: None

This section documents the auto initiation capability for SM OPS 2 or 4 fuel cell auto purges from the ground. Also included are the crew procedures to initiate an auto purge and change purge timers using the SPEC 60 SM Table Maintenance page.

With the exception of one manual purge per flight, the MCC performs nominal fuel cell purges via TMBU (see the TMBU process, reference the FCOH, 3.3.2. and the EGIL Console Procedures Handbook). The TMBU command that begins the auto purge sequence performs in the same manner as a crew switch throw on panel R11U. Commanding the auto purge discrete to a "1" using the TMBU process starts the sequence. The Measurement Stimulation Identification (MSID) is

AUTO PURGE SEQ START - V92X0634X                      1 = Start

When the purge sequence is complete or if the purge sequence fails, the discrete will return to "0." Refer to the Space Shuttle Systems Handbook (SSSH), drawing 3.4, sheet 2.

The steps required by the flight crew to initiate an auto purge using the SPEC 60 page are as follows:

- R11U
1. FC PURGE VLV (three) - GPC
  2. HTR - GPC

**SM 60 SM TABLE MAINT**

- CRT
3. CONSTANT ID - ITEM 16 + 0920634 EXEC
  4. √Update of ID
  5. VALUE - ITEM 17 + 1 EXEC
  6. √Update of VALUE

Additionally, the fuel cell purge time during the auto purge sequence can be adjusted independently. The purge times (the Y-minute time value in the purge sequence) can be changed from the default value of 2 minutes using the following MSIDs in the TMBU program:

FC 1 AUTO PURGE TIME - V92W0636C (set in minutes)  
FC 2 AUTO PURGE TIME - V92W0637C  
FC 3 AUTO PURGE TIME - V92W0638C

Note: Setting the time to "0" will still result in the fuel cell purging for 10 seconds because of the design of the purge software. To bypass a fuel cell purge during the auto purge sequence, the fuel cell purge valve switch on R11U must be in the CLOSED position.



The steps required by the flight crews to change the fuel cell purge times are as follows:

**SM 60 SM TABLE MAINT**

- CRT 1. CONSTANT ID - ITEM 16 + \_\_\_\_\_ EXEC  
(ID = 0920636 for FC1  
0920637 for FC2  
0920638 for FC3)
2. ✓Update of ID  
3. VALUE - ITEM 17 + \_\_\_\_\_ EXEC (minutes)  
4. ✓Update of VALUE  
5. Notify MCC of changed VALUE(s)

If the auto purge sequence is interrupted for any reason, the purge switch must be placed in the ON position for 30 minutes to bake out the purge lines to prevent freezing.

**Fuel cell purge commands procedure**

**BFS**

1. Coordinate with INCO to unsafe command group 1 and RTC 5410 if needed.
2. Send commands.

**Safed command groups**

Group	Commands	Enable/disable	DSM no.	Command
1	8	Disable	5400	FC3 Purge Vlv A/B Open
			5401	FC3 Purge Vlv A/B Closed
			5402	FC2 Purge Vlv A/B Open
			5403	FC2 Purge Vlv A/B Closed
			5404	FC1 Purge Vlv A/B Open
			5405	FC1 Purge Vlv A/B Closed
			5406	FC Purge Heaters On
			5407	FC Purge Heater Off

**RTC inventory**

DSM	MSID	Command	MDM1/2	RST	MDM1/2	Set
5400	V45K0837U	FC3 Purge Vlv A/B Open	708A	0000	788A	C000
5401	V45K0838U	FC3 Purge Vlv A/B Closed	708A	C000	788A	0000
5402	V45K0839U	FC2 Purge Vlv A/B Open	E089	0000	E889	C000
5403	V45K0840U	FC2 Purge Vlv A/B Closed	E089	C000	E889	0000
5403	V45K0841U	FC1 Purge Vlv A/B Open	7089	0000	7889	C000
5405	V45K0842U	FC1 Purge Vlv A/B Closed	7089	C000	7889	0000
5406	V45K0843U	FC Purge Heaters On	E08A	0000	E88A	C000
5407	V45K0844U	FC Purge Heaters Off	E08A	C000	E88A	0000

**MRTC inventory**

5410	FC 1/2/3	Purge start (heaters on, valves open)	5406, 5400, 5402, 5404
------	-------------	---------------------------------------	------------------------

**PASS/SM (TMBU)**

Sequence start	V92X0634X	(set to 1)
FC1 time	V92W0636C	(set value in minutes)
FC2 time	V92W0637C	(set value in minutes)
FC3 time	V92W0638C	(set value in minutes)

Fuel cell auto purge line temps:

O<sub>2</sub> = 69°, H<sub>2</sub> - Temp1 = 79°,  
H<sub>2</sub> - Temp2 = 40°

## TITLE

FUEL CELL/CHEMSTRIP PH TEST

## PURPOSE

This brief will describe one use of the pH Wide Stick strips carried onboard the orbiter. Although it is not the main purpose of the strips to detect abnormal levels of pH in the crew's drinking water, the EPS pH-high malfunction procedure uses the strips for that purpose.

## DISCUSSION

During the course of failure definition and procedure development for a flooding fuel cell, it was determined that if the fuel cell releases KOH from within its cell matrix, the KOH will cause a high pH condition in the fuel cell product water. This pH condition should be picked up by the pH transducers located in the primary water flow path from the orbiter fuel cells (see Figure 2.7-1). Each fuel cell has an individual pH transducer located outside the fuel cell, but before the water relief panel. Once the water paths from the three fuel cells meet and leave the water relief panel, the water then flows past a common pH transducer before entering the supply water tanks.

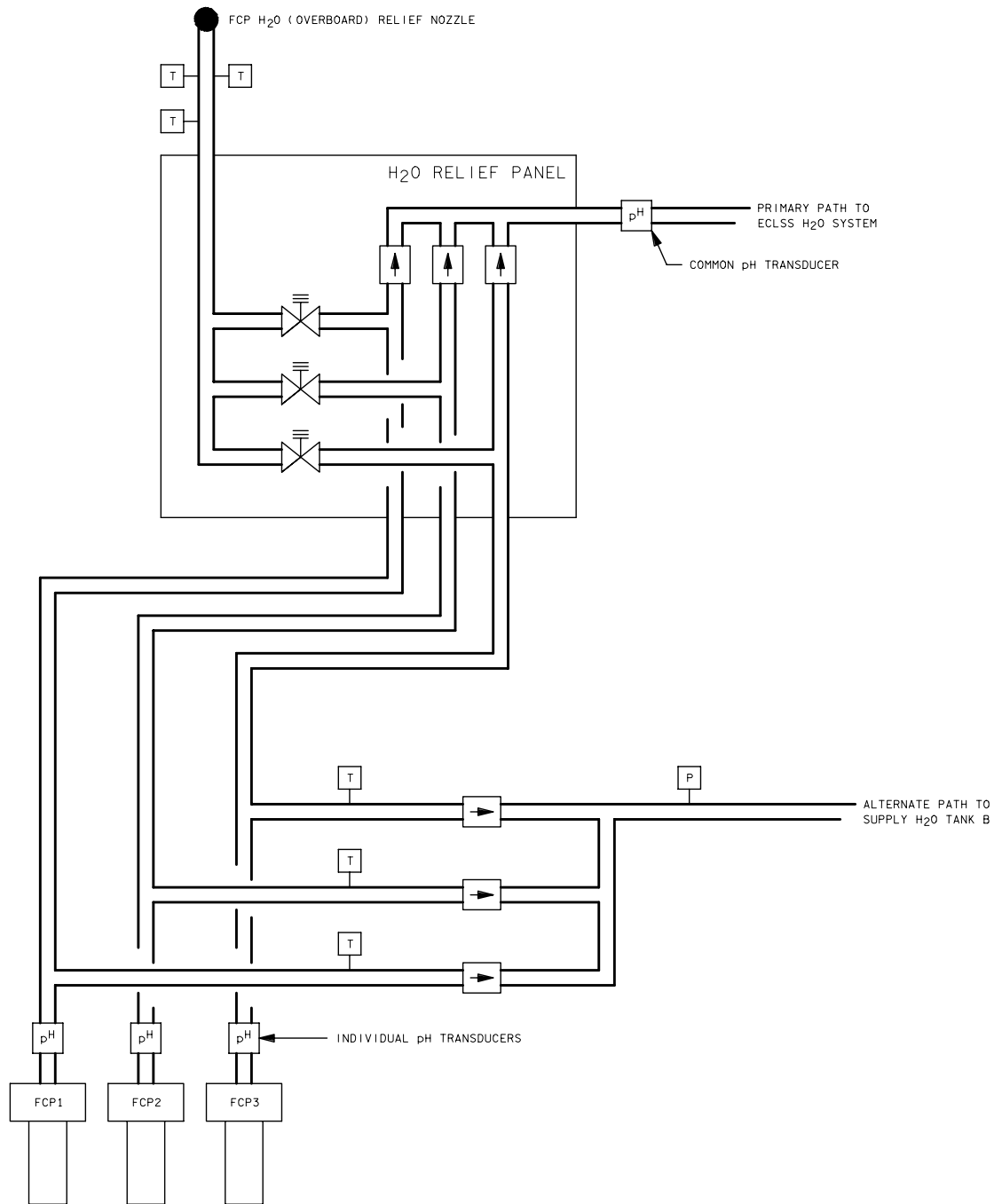
The pH sensor is a conductivity sensor, so the presence of any conductive ions (not just KOH) will appear as a high pH condition in the telemetry. The pH strip is used to verify that an actual alkaline situation is present and that there is not some other conductive contaminant or a sensor failure causing a false indication.

Two possible EGIL-related uses for the pH Wide Stick are documented: (1) check water alkalinity to verify early signs of fuel cell flooding and (2) verify water purity following the flushing of contaminated water lines.

The alkalinity check is required because pH sensors may give a false reading in cases where other contaminants are present. An IFM procedure (IFM, W-13) is performed that checks the water at the galley interface. A sufficient amount of time must pass after the pH sensor indication is received before the reading can be taken. This allows for the contamination to travel through the lines and into the crew module. It takes approximately 10 minutes after a fuel cell pH alarm is received for contaminated water to get to the common pH sensor and another 10 minutes before the water reaches the tank A inlet. Depending on which sensor occurs first, the crew must wait either 10 or 20 minutes before checking the water. If the results of the water test indicate that KOH is present (>9 pH) and the sensor telemetry does not clear, the fuel cell will be shut down and safed. Following shutdown, another IFM procedure (IFM, W-15) will flush out the supply water lines into the wastewater system. The water will again be checked with the pH strip to verify that the flush worked.

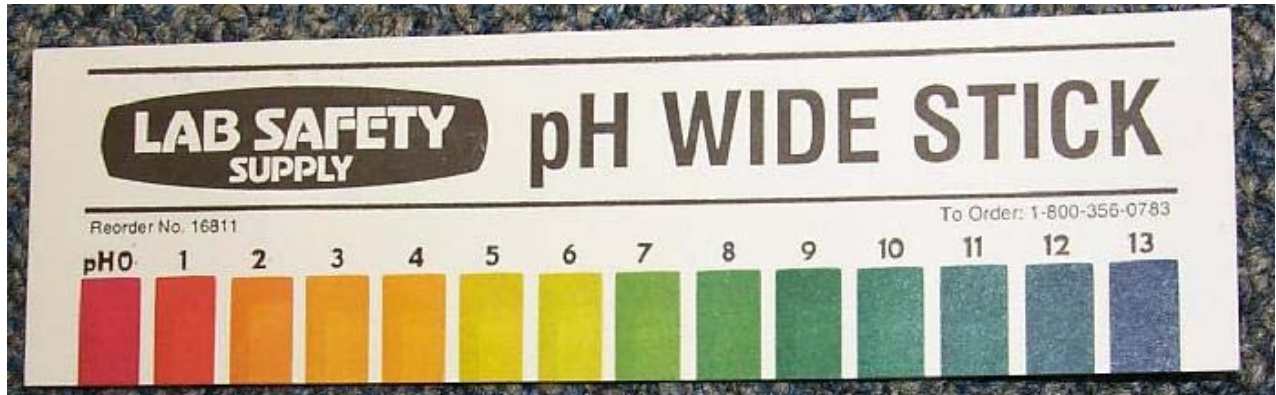
The primary use of the pH Wide Stick strips onboard the orbiter is to monitor the crew's health. The crew will use the pH chart on a chart flown with the strips to determine the pH level of the drinking water (see Figure 2.7-2). The crew will look for a dark green

test result as an indication of unacceptably high pH levels in the drinking water. Water with a pH of approximately 8.5 may be reported as having an unpleasant alkaline taste that could be described as “bitter”, “soapy”, or “soda-like”. Water with a pH indication of 9 or greater is considered too high for crew consumption. At a pH level of 10 or greater, the water is likely to cause skin or eye irritation.



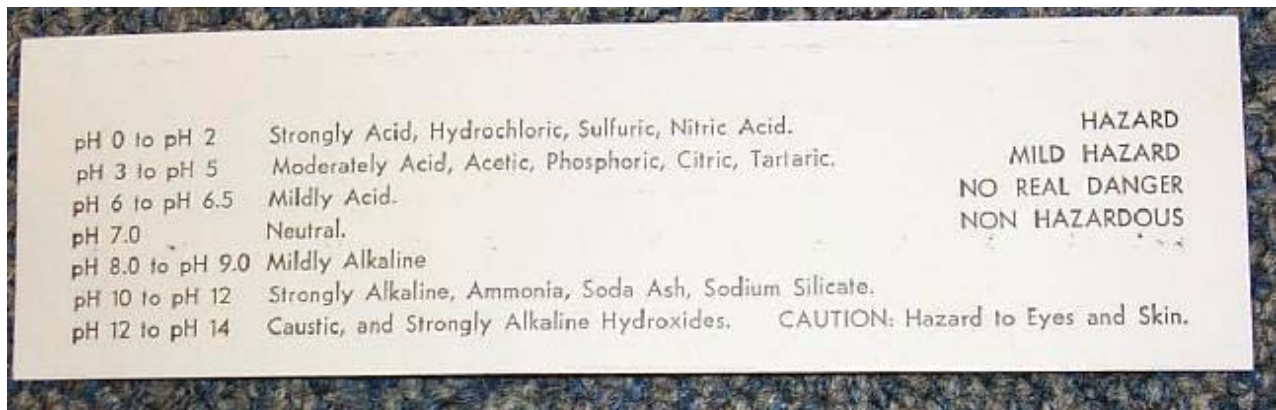
12830361. ART. 4

**Figure 2.7-1. Primary water flow path from the orbiter fuel cells**



(a) Front

Figure 2.7-2. pH Wide Stick label



(b) Back

Figure 2.7-2. Concluded

## TITLE

N<sub>2</sub> DIAGNOSTICS AND CATHODE ACTIVATION

## PURPOSE

To describe the processes and procedures performed on the fuel cell during turnaround at Kennedy Space Center (KSC) and the cathode activation test performed at IFC.

## INTRODUCTION

The N<sub>2</sub> diagnostics test and cathode activation are performed every flight or every time oxygen has been introduced to the fuel cell. Approximately 2 to 3 weeks after landing, the N<sub>2</sub> diagnostics test and cold cathode activation are performed as part of the KSC ground procedures (OMI V1093 and V1040.003). The cathode activation test is performed at IFC on fuel cells with more than 1000 hours to detect the presence of O<sub>2</sub> port plugging.

### Inerting

Inerting is the process of backfilling the fuel cell with either He or N<sub>2</sub> on both the O<sub>2</sub> and H<sub>2</sub> sides of the fuel cell. (KSC uses He; IFC uses N<sub>2</sub>.) This process occurs after landing during the turnaround process to keep the fuel cell pressurized and to minimize stored energy in the fuel cell in case of handling damage, a fuel cell failure, or a bus fault. The inert gas used must have a purity of 99.99 percent. The purity requirement is similar to that of the reactant gases. Two different gases can be used at the same time to inert the fuel cell. However, the inert gas used on the O<sub>2</sub> side must have a higher molecular weight to allow the regulator to maintain the proper differential pressure control. The fuel cells are inerted whenever they are nonoperational.

### N<sub>2</sub> Diagnostics

The N<sub>2</sub> diagnostics test determines the health of the individual cells. When the test is performed, the fuel cell has approximately 200 hours of predictive operation. The test looks for any signs of shorting or crossover by measuring the voltage drop on each cell when only the O<sub>2</sub> side of the fuel cell is inerted. Shorting is a continuous low-level load on the cell. Crossover is a function of corrosion within a cell that develops very slowly and will eventually lead to uncontrolled mixing of reactants within the cell across the cell matrix.

IFC believes that when crossover begins to occur, it can be run for several hundred hours as a benign situation before the problem will escalate. The N<sub>2</sub> diagnostics test is mandatory because the test is sensitive to low levels of crossover or shorting that may not be detected through any other method. IFC testing has proven that crossover will not be seen in the CPM until well into the failure. An example of this situation occurred during the evaluation of extending fuel cell lifetime.

A fuel cell developed crossover at 2800 hours and was kept running until 3000 hours. The crossover in this case was caused by frame corrosion within three to five cells. The voltage indications were insignificant and, without the diagnostics test, the crossover would not have been detected.

The requirements to start the N<sub>2</sub> diagnostics test are for the fuel cell to be cold/nonoperating and for the fuel cell to be pressurized with reactants (O<sub>2</sub>, H<sub>2</sub>). The N<sub>2</sub> diagnostics test begins by removing and replacing the inerts in the fuel cell with pressurized O<sub>2</sub> and H<sub>2</sub> (in their respective sides) by performing a flowthrough purge and three pulse purges. The O<sub>2</sub> and H<sub>2</sub> are then allowed to sit in the stack for 10 minutes to stabilize. During this 10-minute period, the single-cell voltages are recorded once per minute. After the stabilization time is complete, a flowthrough purge of N<sub>2</sub> is performed on the O<sub>2</sub> side of the fuel cell for 10 minutes while recording the single-cell voltages once per minute. The 10-minute purge is terminated by closing the purge valves, and the fuel cell remains filled with N<sub>2</sub> while the single-cell voltages are recorded once per minute for 10 minutes.

Any cell voltages that decay below 0.5 mV are suspected of having shorting or crossover. The N<sub>2</sub> diagnostics test cannot distinguish between cell shorting or crossover. When the O<sub>2</sub> supply is removed from the cell, the short will consume any remaining O<sub>2</sub> that is absorbed on the catalyst, thus lowering the voltage potential of the cell. The magnitude of the short is proportional to the voltage loss. If crossover is occurring, the H<sub>2</sub> will diffuse to the cathode, where it reacts with the O<sub>2</sub> to form H<sub>2</sub>O. When the O<sub>2</sub> supply is removed, the H<sub>2</sub> continues to diffuse while consuming any O<sub>2</sub> remaining on the catalyst, thus lowering the cell's potential. The magnitude of the crossover is also proportional to the voltage loss.

### **Cathode Activation**

Two types of cathode activation tests are performed on the fuel cell. KSC performs a cold cathode activation test to regain fuel cell performance. IFC performs a test to detect O<sub>2</sub> port plugging. Both tests are described in detail in the following paragraphs.

#### **A. KSC cathode activation**

The KSC cathode activation test is performed to remove any form of O<sub>2</sub> on the cathode catalyst. This procedure is not mandatory, but does ensure the highest voltage from the fuel cell. A load is placed on the fuel cell when gaseous He (or N<sub>2</sub>) is applied to the O<sub>2</sub> side of the stack and H<sub>2</sub> is supplied to the H<sub>2</sub> side. The cathode activation will dissipate any O<sub>2</sub> contaminants that have accumulated on the cathode catalyst, restoring approximately 0.3 volts of performance that were "lost" because of previous fuel cell operations.

Cathode activation is performed at KSC during turnaround. For a scrub turnaround, there is an option in the Operations and Maintenance Requirements and Specifications Document (OMRSD) to not perform the cathode activation based on engineering judgment. This decision is based on the fuel cell performance and consumables analysis.



The procedure starts by inhibiting the startup heater and sending the fuel cell start command, allowing the fuel cell to run for 90 to 120 seconds. The start command activates only the fuel cell sustaining heater to create a load on the fuel cell stack. The fuel cell uses any remaining oxygen molecules in the stack to supply the energy needed for the sustaining heaters to operate. The voltage will be reduced to approximately 1 volt. The fuel cell is then stopped and the startup heater is enabled. When the cathode activation procedure is complete, both sides of the fuel cell reactants are backfilled with He.

B. IFC cathode activation test

The cathode activation test is performed at IFC on fuel cells that have more than 1000 hours of operation. The test detects the presence of O<sub>2</sub> port plugging by measuring the voltage dropoff over time when the O<sub>2</sub> side is inerted. Port plugging detection is desirable because the CPM cannot distinguish between port plugging and other cell failures. Port plugging can also bias the results of the N<sub>2</sub> diagnostics test because port plugging prevents O<sub>2</sub> from being removed from the cell. Therefore, when the N<sub>2</sub> diagnostic is performed, the cell that has port plugging still contains O<sub>2</sub>, which will present itself as a crossover or a shorting situation.

The fuel cell must be nonoperating at the time of the test. The first step of the cathode activation test is to stabilize the fuel cell by purging the H<sub>2</sub> and O<sub>2</sub> systems with reactants for 10 minutes and recording the single-cell voltages every 30 seconds. At the end of the 10 minutes, the O<sub>2</sub> side is inerted. The O<sub>2</sub> is inerted by inhibiting the startup heater, closing the fuel cell purge valves, and switching the O<sub>2</sub> reactant supply system to He or N<sub>2</sub>. The next step is to simultaneously send the fuel cell start command and open the fuel cell purge valves. When the fuel cell is started, only the sustaining heater turns on, creating an internal load on the fuel cell. The single-cell voltages are recorded every 30 seconds for the next 15 minutes. The fuel cell uses any remaining oxygen molecules in the stack to supply the energy needed for the sustaining heaters to operate. The voltage is reduced to approximately 0.1 volts. After the 15 minutes have passed, the fuel cell is stopped and the startup heater is enabled.

If the cell voltage decays within 10 minutes, it does not have any port plugging. Any cells that require 10 minutes or more to decay to 0.1 volt are suspected of port plugging. If port plugging is found, the data are compared with the CPM data for a history of shifting.

**REFERENCES**

Orbiter Fuel Cell Powerplant Review and Training Course, March 1999.

KSC Procedures, OMI V1093 and OMI V1040.003, sequences 9 and 10.

## TITLE

FUEL CELL ACTIVATION

## PURPOSE

To describe the fuel cell startup sequence of events and workarounds of potential problems.

## INTRODUCTION

The fuel cells are activated approximately 12 hours prior to lift-off and provide continuous orbiter power until deactivated postlanding. Nominally, each fuel cell will be connected to its associated main bus.

On-orbit restarts of the fuel cell are possible, but depend on the severity of the fuel cell problems, its thermal condition, and/or the criticality of regaining the fuel cell. The restart capability was demonstrated on orbit during the STS-54 Detailed Test Objective (DTO).

### Prelaunch Fuel Cell Activation

Fuel cell startup procedures are found in OMRSD, file III, Volume 45, and OMI S0007, Prelaunch Countdown. Startup procedures typically involve three phases:

1. Preparing the fuel cell for activation with purges
2. Starting the fuel cell
3. Monitoring the startup sequence

The first step in prelaunch fuel cell activation is to remove the inert gases from the fuel cell. It is desired to have less than 1 percent inert gases in the stack prior to use. The flowthrough purge and pulse purges, respectively, are performed prior to startup to remove the inert gases that are present in the fuel cell during turnaround operations. A flowthrough purge is performed for 10 minutes, allowing O<sub>2</sub> and H<sub>2</sub> to flow through the stack and out of the vehicle's overboard purge vent lines. The majority of the inerts are pushed out of the stack and replaced with O<sub>2</sub> and H<sub>2</sub> supplied by the Ground Support Equipment (GSE). (The orbiter does not use the cryogenics in the tanks until about T-2 minutes, 30 seconds prior to lift-off when the GSE supply valves are closed.) The flowthrough purge cannot remove all the inerts because of the parallel passages within the stack.

Next, the pulse purges are performed three times on each fuel cell. First, the purge valves (O<sub>2</sub>, H<sub>2</sub>) are opened and the reactant valves are closed, allowing the O<sub>2</sub> and H<sub>2</sub> to evacuate the stack, causing the stack pressure to decay. When the pressure of the stack drops below 20 psia, the reactant valves are opened to allow O<sub>2</sub> and H<sub>2</sub> flow into the stack. The pulse purge should remove any remaining inert from the fuel cell stack.

A precaution during the pulse purge is to NOT overpressure the H<sub>2</sub> side of the stack, because cell electrolyte (KOH) could be expelled. Some possible causes of H<sub>2</sub> overpressurization are restricted/blocked purge overboard vent lines, improper pressurization (i.e., the H<sub>2</sub> side is pressurized prior to the O<sub>2</sub>), or improper depressurization (i.e., the O<sub>2</sub> side is depressurized prior to the H<sub>2</sub>).

After the inerts have been removed, the Astronaut Support Personnel (ASP) (KSC personnel preparing the vehicle for flight) verify that the following equipment is in the proper configuration before proceeding with fuel cell activation:

- A. Pnl R1 - Fuel cell disconnected from main and essential buses.
- B. Pnl R1 - Fuel cell O<sub>2</sub>, H<sub>2</sub> reactant valves are open (tb-OP).
- C. Pnl L4 - AC fuel cell pumps cb's closed.
- D. Pnl O14, O15, O16 - FC CNTLR in ON position.
- E. Pnl R11 - FC STARTUP HEATER in ENABLE position.

Fuel cell activation usually requires approximately 23 minutes, depending on the initial thermal conditions of the stack. A flowthrough purge is initiated 2 minutes prior to starting the fuel cell to clear any condensate from the H<sub>2</sub> pump impeller and to preclude a hard start because of water buildup on the pump. Next, the fuel cell is started by sending the fuel cell start command through the GSE Multiplexers/Demultiplexers (MDMs). This activates the Electrical Control Unit (ECU) that controls power to the coolant pump, H<sub>2</sub> pump, pH sensor, and sustaining heaters. As soon as power is received, the pH sensor performs a self-test that annunciates a pH alert for approximately 30 seconds. When the coolant delta P switch closes, the startup heater is activated, and the coolant bypass valve opens. The purge continues to clear residual inerts. The heaters warm up the coolant flowing through the stack, which heats the stack until one of the following two conditions is met:

- A. The stack exit temperature reaches 186° F.
- B. The stack inlet temperature reaches 212° F.

When this criterion is met, the startup heater is deactivated, and the ready-for-load talkback goes barber pole. The sustaining heater will maintain stack temperature until the fuel cell is connected to its main bus. When the ready-for-load indication is received, the fuel cell is connected to its main bus, and the flowthrough purge continues for 10 more minutes.

Fuel Cell Monitoring System (FCMS) data are available during prelaunch for more insight into single-cell performance. Also, the operator should use the fuel cell Start RT-Plots with the background lines.

Figure 2.8.2-1 shows a nominal prelaunch fuel cell activation.

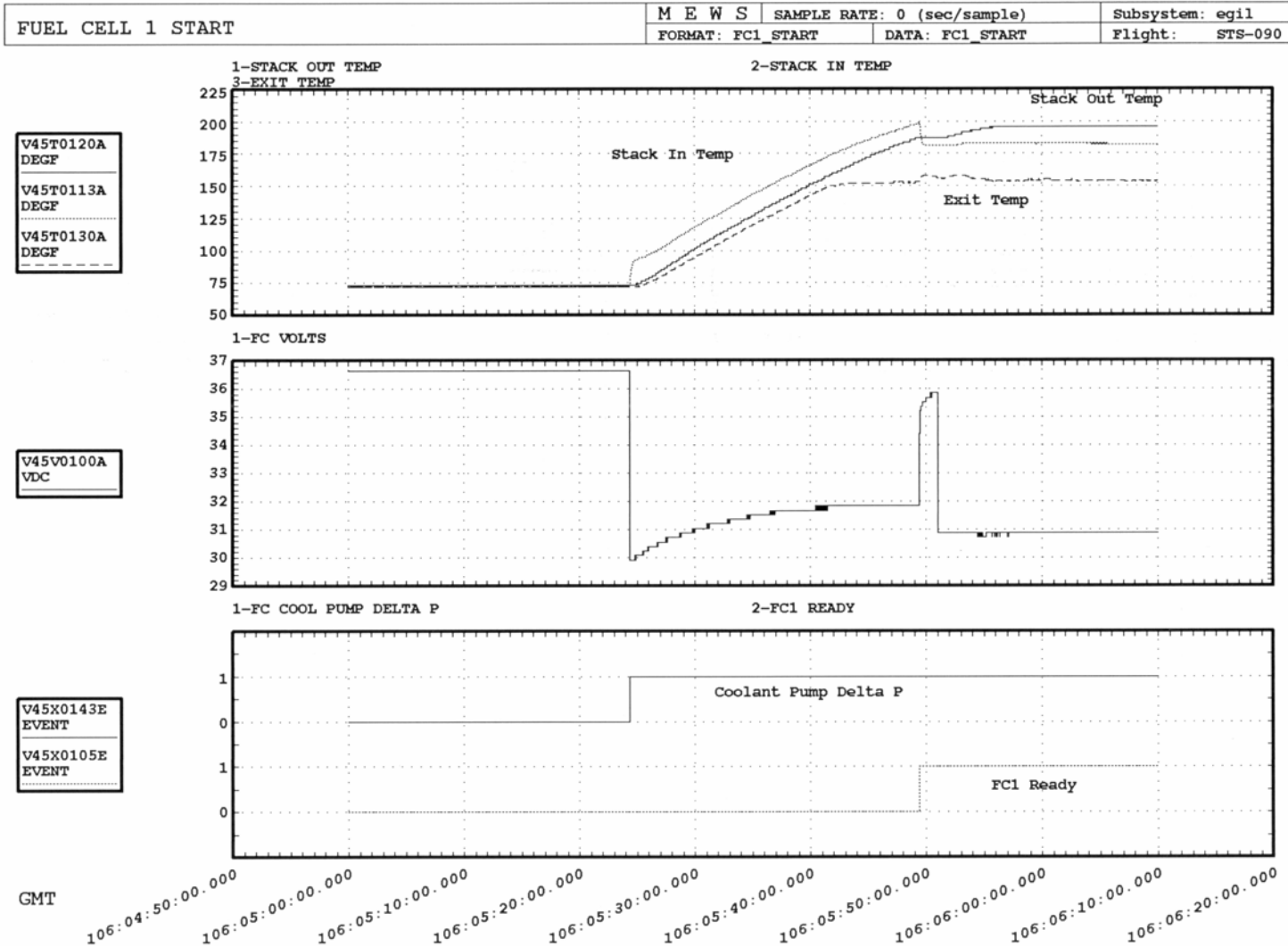


Figure 2.8.2-1. Fuel cell start

2.8.2-3

Verify that this is the correct version before use

## Fuel Cell On Orbit

The on-orbit fuel cell startup procedure is MAL EPS SSR-6. It is important to verify that the stack temperature of the shut down fuel cell has always been maintained above 40° F to avoid the possibility of freezing. Block 1 in EPS SSR-6 FC RESTART verifies the following:

- A. Pnl L4 - cb's AC FC PUMPS closed
- B. Pnl O14, O15, O16 - FC CNTLR ON
- C. Pnl R11U - FC STARTUP HEATER enabled
- D. Pnl R11U - FC PURGE VLV GPC
- E. Pnl R11U - FC PURGE HEATER ON
- F. Pnl R1 - FC/MN Bus OFF
- G. Pnl R1 - ESS BUS to FC OFF
- H. Pnl R1 - Open REACs (tb-OP)

Block 1 instructs the crew to turn on the purge heaters and ensures that the reactant valves are open, allowing the heaters adequate time to bring purge line temperatures within operating range for a purge to be initiated. If the reactant valves are not open prior to fuel cell ECU activation, the fuel cell will begin safing itself as soon as its internal loads (sustaining and/or startup heaters) come on.

If the fuel cell software Caution and Warning (C&W) parameters are changed while the fuel cell is shut down, the next step is to reset the parameters back to nominal values. Typically, this is performed through the use of a TMBU. Otherwise, the crew can accomplish this by using SPEC 60. Blocks 3 through 18 of SSR-6 can be utilized as a guide for building the TMBU. A verification that all parameters changed for shutdown are changed for the restart should be performed. When the software C&W changes are implemented, the fuel cell is restarted.

In Block 20, the crew starts the fuel cell with an MCC "go" by taking the switch on pnl R1 FC to START and holding it until the coolant pump delta P talkback goes gray, but not for more than 10 seconds. At this, time the coolant pump and H<sub>2</sub> pump start running (~0.8 amps/phase increase on the associated AC bus), and the sustaining heaters turn on (flow increase ~0.6 lb/hr, and fuel cell volts go from open circuit voltage ~38V to ~31V). The fuel cell pH sensor will perform a self-test, which should clear after approximately 30 seconds.

Failure of the coolant pump delta P talkback will inhibit the fuel cell startup from continuing. If the coolant pump delta P talkback does not go gray, the EPS operator should verify whether the pump is operating nominally by checking the AC currents associated with that fuel cell. If the pump is operating nominally, the crew can hold the fuel cell switch to START for longer than 30 seconds to bypass the logic timer in the ECU and allow the startup to continue.

The EPS must also verify that the H<sub>2</sub> motor is running with nominal currents. If the currents are slightly degraded, Block 23 will initiate a purge to try to remove any slugs of water that may have built up on the H<sub>2</sub> motor. If the H<sub>2</sub> motor currents return to normal range within 2 minutes, startup can proceed and the purge is continued. If the H<sub>2</sub> motor currents are not nominal within 2 minutes, the purge is terminated and the fuel cell is shut down.

After the fuel cell pumps and heaters are activated, the operator should verify that the temperatures are increasing within 2 minutes of startup, per Block 26. If the temperatures are increasing when the ready-for-load indication is received, the fuel cell can be connected to its associated main bus. If temperatures do not increase, it could indicate that the startup heater has failed. This condition can be confirmed by evaluating the amount of cryogenics being utilized by the fuel cell along with fuel cell voltage. If the startup heater has failed, the fuel cell should be connected to its associated main and essential buses (Block 28). The fuel cell will generate sufficient heat by supporting the main bus to raise its temperatures within operational limits. If the ready-for-load talkback is not received and the fuel cell stack temperature is less than 187°, the fuel cell should be shut down. For a ready-for-load talkback failure, proceed with fuel cell startup.

Block 36 monitors the fuel cell for any performance problems for a 20-minute time period. The following conditions are evaluated during that time: fuel cell stack temperature <185° or >243° F, fuel cell exit temperature <130° or >160° F, fuel cell stack temperature minus fuel cell exit temperature <30° or >70° F, fuel cell SS ΔV 1, 2, or 3 >150 mV, or fuel cell pH indication continuously for >10 minutes. If any of the conditions are met, the fuel cell should be shut down. If fuel cell performance is nominal and none of the conditions are met, the bus tie is broken (Block 38); the fuel cell hardware C&W parameters (Block 39), backup C&W, and the remainder of the SM parameters (Block 48) are reset to their nominal values. The pnl R11U fuel cell purge heater switch is placed in GPC position, and a FC AUTO Purge is initiated. The purge is required to recover performance lost with the fuel cell shutdown and restart. Fuel cell restart is now complete.

For certain situations, the fuel cell may need to be restarted soon after it was shut down. In this case, the fuel cell has not had time to thermally cool down and can be restarted by working the fuel cell shutdown procedure steps in reverse order. This should be performed only when the fuel cell is at its nominal operating temperatures.

## Adding Fuel Cell Start Background Lines in RT-Plot

There are three plots in RT-PLOT called FC1 (2,3) start to monitor fuel cell startup. Background lines can be added to these plots to show a nominal fuel cell startup temperature profile. The console operator should bring up the FC1, FC2, and FC3 start plots in RT-PLOT during the prelaunch shift to monitor fuel cell start. When the fuel cell start plots have been opened, the operator should go to COMMAND>PLOT INFO and click on the FC1 start plot. This will bring up the window shown in Figure 2.8.2-2.

```

RTPLLOT Information
PLOT NAME : FC1 START
TITLE : FC1 START
STATUS : Static
DATA FILE : /mcc/rw_local/egil/RTPLLOT/EGIL/DATA/rtp.fc1start

BACK FILE : /mcc/rw_remote/common/egil/RTPLLOT/EPS/DATA/fc1start.bkline1
BACK COLOR : YELLOW

BACK FILE : /mcc/rw_remote/common/egil/RTPLLOT/EPS/DATA/fc1start.bkline2
BACK COLOR : GREEN

BACK FILE : /mcc/rw_remote/common/egil/RTPLLOT/EPS/DATA/fc1start.bkline3
BACK COLOR : CORAL

COLOR : MIDNIGHTBLUE
FONT : 9x15
RATE : 10
TYPE : Scroll
X SPAN : 000/00:30:00
X SAVE : 25%
X TIME : Time
X AUTO : Auto-scale
Y AUTO : Auto-scale

X MIN : None
X MAX : None
Y MIN : 0
Y MAX : 250
LO LIMIT : None
HI LIMIT : None

LO VALUE : None
HI VALUE : None

X NAME : MET
X MSID : M50Q0027HP
X VALUE : None S
X UNITS : DDD/HH:MM:SS

Y NAME : FC1 STK OUT T
Y MSID : V45T0120A
Y VALUE : 200.647738S
Y UNITS : deg. F
Y COLOR : GREEN
Y CONNECT : Step

Y NAME : FC1 STK IN T
Y MSID : V45T0113A
Y VALUE : 179.147546S
    
```

**Figure 2.8.2-2. FC1 Start plot info window**

To set the fuel cell start background lines GMT, go to COMMANDS>CHANGE BIAS in the RT-PLOT INFORMATION window, then click on the BACK FILE line. An additional window will appear. Set the GMT to the expected fuel cell start GMT. This must be repeated for all three BACK FILE lines in the RT-PLOT INFORMATION window. (To get an accurate time, set the GMT for the fuel cell start background lines to 2 minutes after the fuel cell purge is initiated in the fuel cell start sequence.) When all three BACK FILE lines have been set to the correct GMT in the RT-PLOT INFORMATION window, go to COMMAND>INFO OFF. The background lines for FC1 start should now be updated and aligned for the actual FC1 start.

Repeat the above for FC2 start and for FC3 start.

## **TITLE**

FUEL CELL SHUTDOWN

## **PURPOSE**

To describe the procedure and sequence of events during fuel cell shutdown and the definition of a reusable fuel cell. The fuel cell shutdown procedures for the first fuel cell will be discussed, followed by the second fuel cell shutdown.

## **INTRODUCTION**

On orbit, fuel cell shutdowns are not performed unless a fuel cell has failed or if required to troubleshoot off-nominal situations in the fuel cell, power distribution, or cryogenic systems. A fuel cell is considered shut down when it has been disconnected from its associated main and essential buses, the ECU has been taken to stop (stopping the pumps and disabling the sustaining heater), and the reactant valves are closed. (For more information, refer to the ECU operation procedure.) For a fuel cell that is considered reusable in flight, the reactant valves do not need to be closed.

Disconnecting a fuel cell from its main and essential bus removes all the external loads. Taking a fuel cell to stop removes power from its ECU, which turns off the internal loads (sustaining heater), the coolant pump, and the H<sub>2</sub> pump.

For more information on the on-orbit shutdown and restart Detailed Test Objectives (DTOs) on STS-54, STS-57, and STS-51, reference the Fuel Cell On-Orbit Shutdown/Restart Developmental Test Objective report (JSC-26545, February 1994). This report is an excellent resource for more information on the signatures observed during the DTOs.

## **FC SHUTDOWN PROCEDURE**

The fuel cell shutdown procedures are found in the Ascent/Entry Systems Procedure (AESP), the Ascent Pocket Checklist (APCL), the Orbit Pocket Checklist (OPCL), the Entry Pocket Checklist (EPCL), and on the PLT cue card (attached with Velcro to panel R1).

The first step in the fuel cell shutdown procedure is to turn the Master Modular Auxiliary Data System (MADS) to off. The Master MADS is an archival data recorder that records orbiter flight data (temperatures, pressures, etc.), primarily during the ascent and entry timeframe, for postmission analysis. Unpowering the Master MADS is a general power savings of about 350 watts, which is especially significant during the ascent/entry timeframe when the Master MADS is at its highest power level.

The second step is to bus tie the main bus on the affected fuel cell to a main bus on a healthy fuel cell. The bus tie will prevent interruption of power or dropping the associated main bus during the shutdown. The IF ORB (NOT D/O PREP), kW>18: MN BUS TIE (three) -ON step was added to the procedure to prevent the load from becoming too high on one of the two remaining good fuel cells. The fuel cell maximum



load should not exceed 12 kW continuous, or 12 to 13 kW for a maximum of 4 hours. The intent of tying three across is to divide the load between the remaining two good fuel cells and for the load balancing to be accomplished later in the powerdown procedures.

Next, the fuel cell is disconnected from its essential bus. It is necessary to disconnect the essential bus prior to disconnecting the fuel cell's associated main bus because the essential bus would be exposed to open circuit voltage. This may cause the essential bus voltage to be greater than essential bus LRUs spec limit of 38.5 volts. It would be acceptable to disconnect the essential bus after the main bus, but that is not the recommended sequence because the essential bus LRUs are rated up to 38 volts. When the fuel cell is disconnected from its essential bus, it is disconnected from its associated main bus. This will disconnect the majority of the external load on the fuel cell. The loads that were previously on that fuel cell/main bus will now be powered by the other fuel cell via the main bus tie.

The next step is to take the fuel cell to STOP. Taking the fuel cell to stop unpowers the ECU, which unpowers the pumps (coolant and H<sub>2</sub>) and fuel cell internal heaters. There is a note for the FC-STOP switch to be held until the "Cool Pump ΔP tb-bp or 1 sec," to ensure that the ECU is deenergized. The fuel cell is now technically shut down. The rest of the shutdown procedure isolates the system and proceeds to the necessary powerdown.

The next step in the shutdown procedure is to close the reactant valves. This will isolate the fuel cell from the cryogenic O<sub>2</sub> and H<sub>2</sub>. Closing the reactant valves in a shut down fuel cell precludes any additional reactants from entering the fuel cell in a crossover, shorting, internal load, or leak situation (reference Flight Rule A9.1.2-5A, FC Shutdown Definition). However, for the situation in which the fuel cell is considered reusable in flight, the reactant valves can be left open. Leaving the reactant valves open eliminates the failure scenario of the reactant valve failing to reopen when restart is attempted.

The last step of the fuel cell shutdown procedure is to work the appropriate loss of one fuel cell powerdown procedure. When one fuel cell is shut down, the electrical loads should be reduced to protect for the next-worst failure, a second fuel cell shutdown. The intent of the powerdown procedure is to unpower only noncritical equipment and to put the orbiter in a configuration that could withstand a second fuel cell failure. On orbit, the loss of one fuel cell powerdown procedure manages the electrical loads to be <18 kW. (The 18-kW number was derived on engineering judgment.) The loss of one fuel cell powerdown also sends the crew to MAL EPS SSR-3, FC SHUTDOWN C&W LIMIT CHANGE and will have the crew perform the necessary Flight Data File pen and ink changes.

The first block of EPS SSR-3 is to verify that fuel cell H<sub>2</sub>O line heaters are in A-Auto or B-Auto and to take the shut down fuel cell's purge valve to the closed position. The fuel cell H<sub>2</sub>O line heaters are verified to be on to ensure that freezing the H<sub>2</sub>O line does not occur. Taking the purge valve to close will prevent the fuel cell from purging while it is

shut down. If the fuel cell is purged while shut down (with its associated reactant valves closed), all the cryogenic O<sub>2</sub> and H<sub>2</sub> downstream of the reactant valves would escape and the fuel cell would be exposed to vacuum, essentially safing the fuel cell. The crew will need to perform the hardware C&W changes. The Mission Control Center (MCC) will uplink the backup C&W and the SM alert parameter changes via TMBU if the TMBU capability is available.

## Second Fuel Cell Shutdown

### A. Second fuel cell shutdown in the APCL/OPCL/EPCL

The second fuel cell shutdown procedure is essentially the same in the APCL, OPCL, and EPCL Flight Data File books. The procedure reconfigures the tie so that the one remaining good fuel cell can support two main buses and dioded loads while the second fuel cell is being shut down. If the fuel cell being shut down powers only one main bus, the procedure continues with shutting down the fuel cell (no tie reconfiguration). This will drop the associated main bus for that fuel cell, which is an instantaneous powerdown. The dropped main bus will be recovered later in the loss of second fuel cell powerdown procedure. If time allows, MCC/EGIL can make a real-time call for the preferred bus tie so that the main bus dropped temporarily is of the least impact to the vehicle.

If the fuel cell being shut down is powering two main buses, the bus tie is reconfigured. To reconfigure the tie, all three tie switches are taken to off. This will cause the main bus with the previous fuel cell shutdown to be dropped (instant powerdown). Next, the fuel cell being shut down is tied to the remaining good fuel cell.

With the exception of the bus tie steps, the second fuel cell shutdown procedure is identical to the first fuel cell shutdown procedure. The general intent of the loss of second fuel cell powerdown is to achieve a power level of about 12 kW by unpowering all unnecessary equipment. If any of the equipment that is unpowered is needed for a flight-critical function, it can be repowered for use. When a safe power level is reached in the powerdown, the buses will be tied three across via a long-form bus tie to regain flight-critical redundancy.

### B. Second fuel cell shutdown procedure in the AESP

The loss of second fuel cell shutdown in the AESP unpowers equipment and reconfigures the ties so that one fuel cell can support two main buses and dioded loads. For the entry portion of the AESP, the procedures for a nominal entry are different from the procedures for the Glide Return to Landing/Launch Site (GRTLS)/Transoceanic Abort Landing (TAL) because, during ascent, the electrical loads are higher. The first step in the powered flight and GRTLS/TAL procedures is for the commander to start the powerdown, while the pilot continues in the second fuel cell shutdown.

When the initial powerdown actions are complete, a main bus tie is configured to support two main buses. When the system is in a good configuration, the second fuel cell is shut down (disconnected from its main and essential buses, fuel cell to stop, and reactant valves closed). When the second fuel cell is shut down, the pilot (and commander for nominal entry) proceeds with the loss of second fuel cell powerdown procedure.

***Note: For more rationale about the above procedure steps, refer to the Flight Procedures Handbook.***

### **Reusable Fuel Cell**

A fuel cell that is shut down and considered reusable must be thermally maintained to >48° F (operationally). It is also mandatory that the restart capability be demonstrated when the fuel cell has reached thermal equilibrium with its environment. For a -ZLV attitude, restart demonstration will need to be performed about 48 hours after shutdown. The thermal data were based on fuel cell shutdown data from STS-2, STS-54, and STS-51 (all three flights were a -ZLV attitude). For STS-54, the thermal data were based on the accessory section of the fuel cell during the 9-hour shutdown time period. On STS-51, the fuel cell was shut down for 25 hours.

***Note: On STS-2, the fuel cell had only two substacks and had less thermal blanketing.***

When it is demonstrated on orbit that a fuel cell can be restarted when it reaches thermal equilibrium, the requirement to demonstrate restart capability will go away. (Reference Flight Rule A9.1.2-5B, FC Shutdown Definition.)

## TITLE

FUEL CELL STANDBY

## PURPOSE

To describe the procedures associated with putting a fuel cell in standby.

## INTRODUCTION

To define the term, a fuel cell is in "standby" when its associated main and essential buses are disconnected, but the ECU remains powered (sustaining heaters, coolant pump, and H<sub>2</sub> motor still running), and the reactant valves are left open. The standby operating condition will allow the fuel cell to maintain its thermal operating temperatures and thus be available for immediate use.

## PROCEDURE

The fuel cell standby procedure can be found in the Malfunction Procedures Handbook, EPS SSR-4. In short, the steps for placing a fuel cell in standby are

1. Perform a bus tie (prevent dropping main bus).
2. Take the fuel cell to essential bus source off.
3. Take the fuel cell to main bus off. The ECU will continue to operate, and the reactant valves are left open.

The external load on the fuel cell is removed by disconnecting the main and essential buses. Because the ECU remains powered, the fuel cell sustaining heater will continue to cycle as required to maintain proper operating temperatures on the fuel cell. When the fuel cell starts to cool down and the coolant leaving the stack (STACK OUT TEMP) reaches 183° F, the sustaining heater will cycle on. When the coolant leaving the stack reaches 185° F, the sustaining heater will cycle off. The sustaining heater will continue to cycle on and off to keep the fuel cell at operating temperatures. The sustaining heater acts as a load on the fuel cell, causing the fuel cell to produce water. The ECU also keeps the coolant pump running to circulate the fuel cell coolant and the H<sub>2</sub> motor running to remove any water produced by the fuel cell.

The reactant valves are left open to supply reactants to the fuel cell to operate the sustaining heater. The reactant valves must remain open at all times. If the reactant valves are closed while the ECU is still powered, the cycling sustaining heater will safe the fuel cell as the remaining reactants in the fuel cell are consumed.

To monitor a fuel cell in standby conditions, the EPS operator will need to verify good sustaining heater operations. The EPS operator should verify that when the stack out temperature reaches 183° F, the sustaining heater comes on, and then the sustaining heater turns off again at 185° F. To verify the operation of the sustaining heater, the operator should observe the following indications:

1. The stack in and out temperatures should increase.
2. The fuel cell O<sub>2</sub> and H<sub>2</sub> flows will increase (~0.6 lb/hr O<sub>2</sub>, ~0.08 lb/hr H<sub>2</sub>). The sustaining heater draws approximately 870 watts.
3. The fuel cell voltage should drop from open circuit voltage to ~32 V (see Flight and Testing Data in this section for more information on the expected voltage).

**Onboard Limit Changes**

To avoid receiving nuisance alarms while the fuel cell is in standby, the onboard SM Fault Detection and Annunciation (FDA) limits for the following parameters must be modified. The EGIL team will take care of modifying these limits by using prebuilt TMBUs for this purpose. These onboard limit changes are also documented in EPS SSR-4 in case MCC uplink commanding is unavailable and the crew has to update the limits.

SM FDA to be changed:

	<b>Parameter</b>	<b>Lower/upper</b>	<b>New value</b>	<b>Previous value</b>
1.	Fuel cell current	Upper	20.0	360
		Lower	-10.0	54
2.	Fuel cell voltage	Upper	37.5	32.5
		Lower	31.0	27.5
3.	Fuel cell product H <sub>2</sub> O Ln T	Lower	50.8	60
4.	Fuel cell delta V SS 1,2,3		Inhibit	Enable

There are no hardware C&W parameters requiring changes. When the fuel cell is backed out of standby, the SM alert parameters that were previously changed should be reset to their nominal values.

**Flight and Testing Data**

A. IFC development test

In March 1988, IFC performed a fuel cell powerplant incremental development test to demonstrate fuel cell-to-standby capability. The fuel cell was started and when

the ready talkback was received, no load was ever placed on the fuel cell. The fuel cell was run for 24 hours under no load. The sustaining heater cycled, keeping the fuel cell at its thermal operating temperatures. A purge was performed every 8 hours. After 24 hours, the fuel cell was placed under a 4.5-kW load for 3 hours and then manually shut down.

All fuel cell systems functioned nominally, resulting in good temperature and electrolyte control. A normal 70 percent sustaining heater duty cycle was observed. The sustaining heater switched on at an average stack exit temperature of 183° F and turned off at an average of 186° F. Stack inlet temperature cycled with the sustaining heater between 179° F and 195° F. The condenser exit temperature cycled between 151° F and 152° F. The test concluded that the fuel cell is capable of sustained operation under no load. (Reference: Orbiter Fuel Cell Program, Fuel Cell Powerplant Incremental Development Test Report, Twenty-Four Hour Zero Net Power Test, Fuel Cell R-9389, March 14, 1988.)

B. STS-83 flight data

On STS-83, FC2 was safed on orbit by closing the reactant valves and letting the sustaining heater cycle on. The fuel cell safing flight data can be referenced as to what the signature of a fuel cell in standby should look like. Prior to safing, the fuel cell was operating at ~180 amps and 30.8 V. When the essential and main buses were disconnected, the open-circuit voltage was approximately 37 V. When the sustaining heater turned on, the fuel cell voltage dropped to approximately 33 V. Because of problems related to this fuel cell, the open-circuit voltage may have been slightly exaggerated. Typically, open-circuit voltage is about 36 V.

**REFERENCES**

Orbiter Fuel Cell Program, Fuel Cell Powerplant Incremental Development Test Report, Twenty-Four Hour Zero Net Power Test, Fuel Cell R-9389, March 14, 1988.

Orbiter Fuel Cell Powerplant Review and Training Course, IFC, March 1999.

STS-83 Flight Data; Flight Rule A9.1.2-4, FC Standby Definition.

## TITLE

FUEL CELL SAFING

## PURPOSE

This SCP describes the procedures and the sequence of events during fuel cell safing.

## INTRODUCTION

A fuel cell is safed to preclude a dangerous fuel cell condition. Flight Rule A9.1.2-6, FC Safing, dictates that a fuel cell will be safed under the following circumstances:

- A. Confirmed pH high in the fuel cell product water
- B. Crossover of reactants within the fuel cell
- C. A short circuit within the fuel cell
- D. Confirmed coolant pressure >74.1 psia operational limit (actual limit 75 psia)

To safe a fuel cell, the reactant valves are closed while the fuel cell is still trying to supply power to an electrical load. The fuel cell will consume reactants remaining downstream of the reactant valves as it attempts to supply power to the electrical load. As the reactants are consumed, the pressure within the fuel cell stack drops. The decreasing pressure is reflected in the fuel cell coolant pressure, because the coolant pressure provides direct insight into the pressure of the stack. When the fuel cell coolant pressure has decreased to below 15 psi, the fuel cell is considered safed. A fuel cell that has been safed cannot be restarted for on-orbit use.

Two fuel cells have been safed while on orbit, on STS-2 and STS-83. The STS-2 fuel cell was safed because the fuel cell H<sub>2</sub> pump degraded and water removal decreased, causing the fuel cell to flood. The STS-83 fuel cell was safed because of unexplainable CPM readings, which could have been indicative of a crossover condition.

## FUEL CELL SAFING BACKGROUND

Originally, a fuel cell was safed by disconnecting the fuel cell from its main bus, closing the reactant valves, and letting the internal heaters produce an internal load sufficient to consume the remaining reactants until the fuel cell stack pressure was below 15 psia. When the pressure was below 15 psia, the fuel cell was taken to "stop." This process of safing the fuel cell took approximately 20 minutes to complete. Both the STS-2 and STS-83 fuel cells were safed using this method.

Since STS-83, a new philosophy was adopted to safe a fuel cell. The reactant valves are closed while the fuel cell is still connected to its main and essential buses, and the pumps continue to run. The new method safes the fuel cell in a timelier manner, which minimizes the exposure to the hazardous situation, because the fuel cell spends less than 1 minute at 7 kW. The original method of safing, allowing the sustaining heater

load to consume the reactants, takes about 30 minutes. In addition, exposing a fuel cell experiencing crossover to open-circuit voltage will aggravate the situation and can accelerate crossover. In either method, it is critical to keep the pumps running to provide cooling to the fuel cell until safing is complete. This will help to remove any localized heating at the site of crossover.

During the flight rule CR process to update Flight Rule A9.1.2-6, FC Safing, to reflect the new philosophy, the following data were brought to light. If the fuel cell current is equal to zero amps before the coolant pressure is less than 15 psi, the fuel cell should be disconnected from its essential and main buses to allow the sustaining heaters to complete fuel cell safing. The fuel cell being safed must be disconnected from its main and essential buses when the amps reach zero, because when two fuel cells are in parallel (bus tied to one another), the healthy fuel cell could drive the cells of the unhealthy fuel cell in the negative direction. Driving the cells in the negative direction would result in the evolution of free O<sub>2</sub> and H<sub>2</sub> molecules on either side of the cell, creating extra heat and water production. Therefore, if at any time the fuel cell amps are zero during fuel cell safing, the fuel cell will be disconnected from its main and essential bus. Fuel cell safing is complete when the coolant pressure decreases to less than 15 psi. When the safing is complete, the fuel cell will be taken to stop, which unpowers the ECU, thus turning off the sustaining heater and pumps.

#### **FUEL CELL SAFING PROCEDURE**

The fuel cell safing procedures in the OPCL, APCL, and EPCL are essentially the same. The first step of the procedure determines if the fuel cell requiring safing has already been shut down.

A. If fuel cell is already shut down

The procedure assumes that the bus tie is already complete because the fuel cell has been previously shut down. If the reactant valves were not closed during the shutdown, they should be closed. After the reactant valves are closed or verified closed, the fuel cell is taken to start via the panel R1 FC START switch. This powers the ECU, providing cooling and water removal to the fuel cell by starting the fuel cell coolant and H<sub>2</sub> pumps. When the fuel cell is started, it is connected to its main bus. The load of the main bus will consume the reactants downstream of the reactant valves. If the fuel cell amps are zero prior to the coolant pressure becoming less than 15 psi, the fuel cell is disconnected from its main bus. The sustaining heater will provide the load to finish safing the fuel cell. When the coolant pressure reaches less than 15 psi, the fuel cell is safed, disconnected from its main bus, and taken to stop via the panel R1 FC STOP switch.



B. If fuel cell is not already shut down

The Master MADS is powered off. The Master MADS is an archival data recorder that records orbiter flight data (temperatures, pressures, etc.), primarily during the ascent and entry timeframe, for postmission analysis. Unpowering the Master MADS is a general power savings of about 350 watts. This is especially significant during the ascent/entry timeframe when the Master MADS is at its highest power level.

If a bus tie has not already been performed, the main bus of the fuel cell to be safed should be bus tied to the main bus of a healthy fuel cell. Some calling procedures perform a bus tie to provide insight into fuel cell health. As soon as a good bus tie is established, the reactant valves are closed. If the reactant valves do not close, the circuit breaker on panel C3 will be closed, and the reactant valves will be closed via the C3 panel. If the reactant valves are not successfully closed with the C3 panel switch, a switch retention device will be installed on the panel R1 switch to try to close the reactant valves. Refer to the PRSD System Failures brief for more information on the reactant valve failing to close.

The main and essential bus loads will consume the reactants downstream of the reactant valves. When the fuel cell coolant pressure is less than 15 psi, the essential bus followed by the main bus is disconnected from the fuel cell. After the fuel cell has been disconnected from its essential and main buses, the fuel cell is taken to stop and the ECU is unpowered, stopping the coolant and H<sub>2</sub> pumps. Safing is now complete. During fuel cell safing, if the fuel cell amps are zero prior to the coolant pressure becoming less than 15 psi, the fuel cell will be disconnected from its essential and main bus. The sustaining heater will provide the load to finish safing the fuel cell. When the coolant pressure is less than 15 psi, the fuel cell is taken to stop, and safing is complete. The appropriate powerdown should be worked to achieve a safe operating power level.

The only difference in the fuel cell safing procedure between the ascent, entry, and orbit pockets is in the orbit pocket. In the orbit pocket, after the bus tie is performed, it asks if the mission phase is orbit or deorbit prep and if the power level is greater than 18 kW. If the power level is greater than 18 kW, the main buses will be tied three across. The old Shuttle Operations Data Book (SODB) maximum power level on one fuel cell (with one fuel cell lost) was 10 kW. This step was added to ensure that neither of the two remaining fuel cells will supply greater than 10 kW.

C. Fuel cell safing in the Ascent/Entry System Procedures (AESP)

There is no fuel cell safing procedure in the AESP. The steps to safe a fuel cell are embedded in the procedures of the MN BUS UNDER V/FC V, FC pH↓, or FC DELTA V, FC STACK T, and the FC COOL P procedures. Closing the reactant valves is the only step taken in these procedures to safe the fuel cell in a hazardous situation. Closing the reactant valves will cut off the supply of reactants to the fuel cell, and the loads of the main and essential buses will consume all reactants downstream of the reactant valves. All other steps to finish the fuel cell safing, disconnecting the fuel cell from its main and essential bus, and stopping the fuel cell will be performed post-Main Engine Cutoff (MECO) or postlanding.

**REFERENCES**

Orbit Pocket Checklist.

Ascent Pocket Checklist.

Entry Pocket Checklist.

Ascent/Entry System Procedures.

Flight Procedures Handbook.

SODB.

SSSH.

Flight Rules, Section 9.

## TITLE

FUEL CELL CONTINGENCY POWERUP

## PURPOSE

To describe the fuel cell contingency powerup procedures in the STS Flight Data File (FDF) and the failures that would result in the use of the procedures. This procedure will be executed per Flight Rule 9-41, Preflight Test Bus Management.

## DISCUSSION

Some failures exist that can cause loss of AC power to the fuel cell H<sub>2</sub>/water separator and coolant pumps. This, of course, will result in loss of the fuel cell. For some of these failures, it is possible to implement an In-Flight Maintenance (IFM) procedure to regain AC power to the fuel cell pump package. This procedure takes advantage of a circuit in the ECU used preflight to check the pump package (Figure 2.12-1). To accomplish this procedure, thermal debris traps and lockers must first be removed to access the applicable Power Controller Assembly (PCA) and MDM LF1. DC utility power (MNC/MNA, depending on which fuel cell is lost) should be verified OFF. An IFM power cable is connected between a DC utility outlet (MO30F/FC1) and an IFM breakout box. One lead from the breakout box is connected to the F10 fuse receptacle on a Forward Power Controller (FPC) with a fuse cap test lead. This will supply power (28 V DC) to the fuel cell pump check load driver in a Mid Power Controller (MPC) through the preflight test bus. The other lead will be connected to launch MDM LF1 (Figure 2.12-1). This connection will supply 28 V DC power to the enable input of the same pump check load driver. This final connection will cause relay K7 in the ECU to operate applying AC power to the pump package.

The types of failures that can occur requiring this IFM action are as follows: short-to-ground in the ECU on the circuit noted in heavy lines in Figure 2.12-2, or in the fuel cell control power load driver circuit causing the 3-amp fuse to blow; fuel cell control power switch failure; and loss of the ESS bus in the MPC or in the FD. However, if a short occurred on ESS1BC DA1 (FC1), ESS2CA DA2 (FC2), or ESS3AB DA3 (FC3), this procedure would not work because the preflight test bus attempts to power the ESS APC bus through a 15-amp RPC (Figure 2.12-3). For any of these failures where the fuel pumps can be restarted with the IFM procedure, it is mandatory that the fuel cell be shut down immediately when the failure is confirmed. The signature (for fuel cell parameters) of the failures mentioned above would be coolant pump  $\Delta P$  tb and ready for load tb both bp; H<sub>2</sub> pump status will read 0.0, accompanied by a fuel cell pump C&W and SM alert message. MCC would also receive these indications. Also, the appropriate AC three-phase loading would decrease by 0.8 amps/phase (10 Pulse Code Modulation (PCM) counts). If the ESS MPC or FD sub-bus failed, other indications would be observed as listed in the malfunction bus loss SSRs.

## PROCEDURE

The Malfunction Procedure EPS SSR-202, Preflight Test Bus Use, identifies appropriate steps to perform for the recovery of a fuel cell. There is a definite risk associated with powering up a preflight test bus. Other preflight test circuits are powered by these buses. A failure in a driver in one of these circuits could result in an “uncommanded on” condition in the driver and cause that test circuit to function. These test circuits include fuel cell valves and MN bus control functions. Because of these circuits, powering up the preflight test bus puts the vehicle in a single-point failure condition. Therefore, the use of the IFM procedure should be considered carefully. For any problems experienced that could be attributed to preflight bus, remove power to the preflight bus, recover lost systems, and shut down affected fuel cell within 9 minutes, if required.

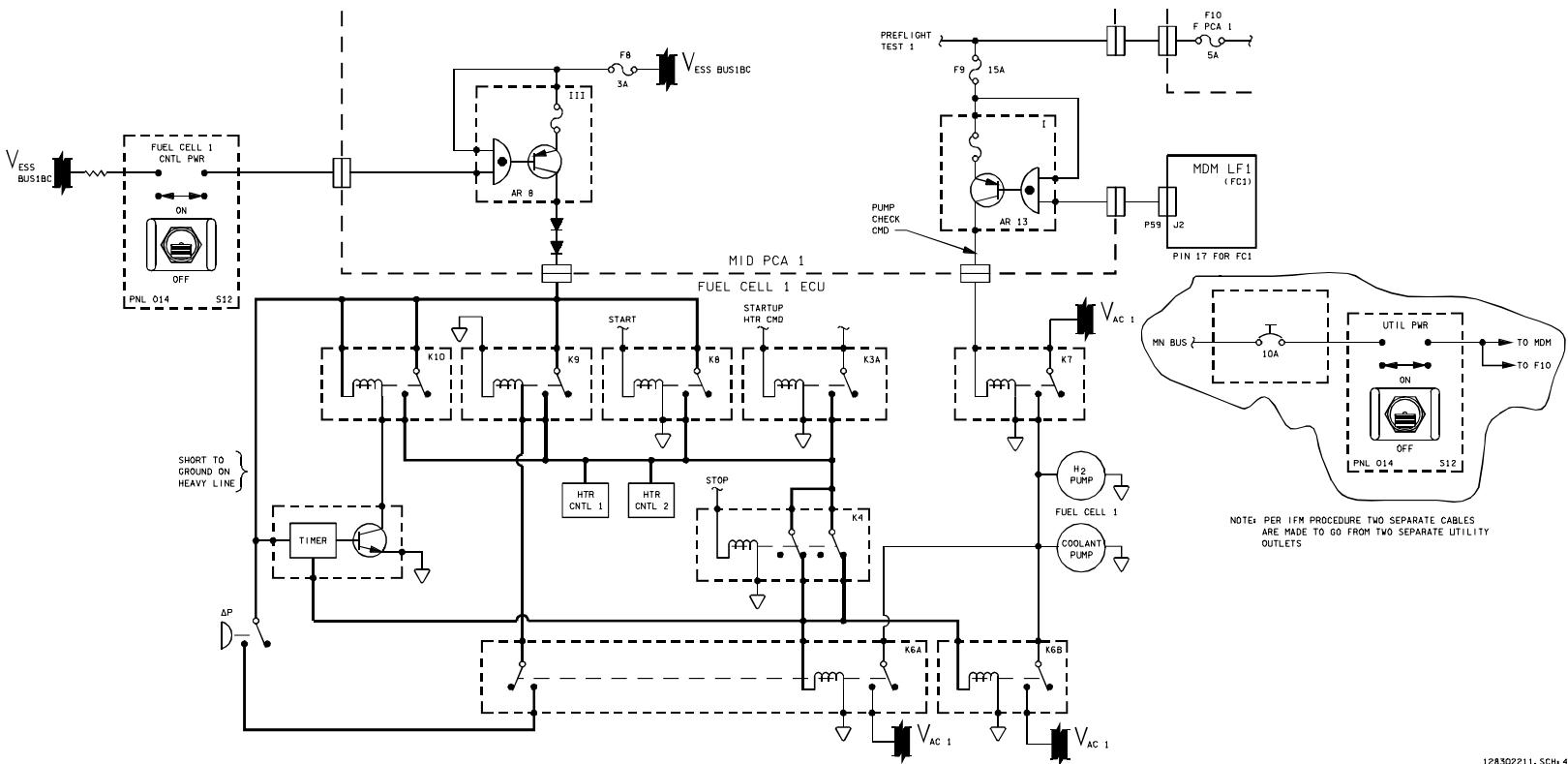
The fuel cell contingency powerup procedure can be modified to operate some of the other test circuitry previously mentioned. The commands are sent to the appropriate drivers by changing the plug and pin assignments from the LF1 MDM as required. The LF1 pin/plug assignments are documented in SCP 2.13. Once again, using this procedure is risky, and the amount of time that a preflight test bus is energized should be minimized.

## REFERENCES

Preflight Test Bus Setup, Flight Data File, In-Flight Maintenance Checklist.

Preflight Test Bus Use, EPS SSR-202, Flight Data File, Malfunction Procedures.

Space Shuttle Operational Flight Rules A9.1.2-7, Reusable Fuel Cell, and A9.1.3-10, Preflight Test Bus Management.

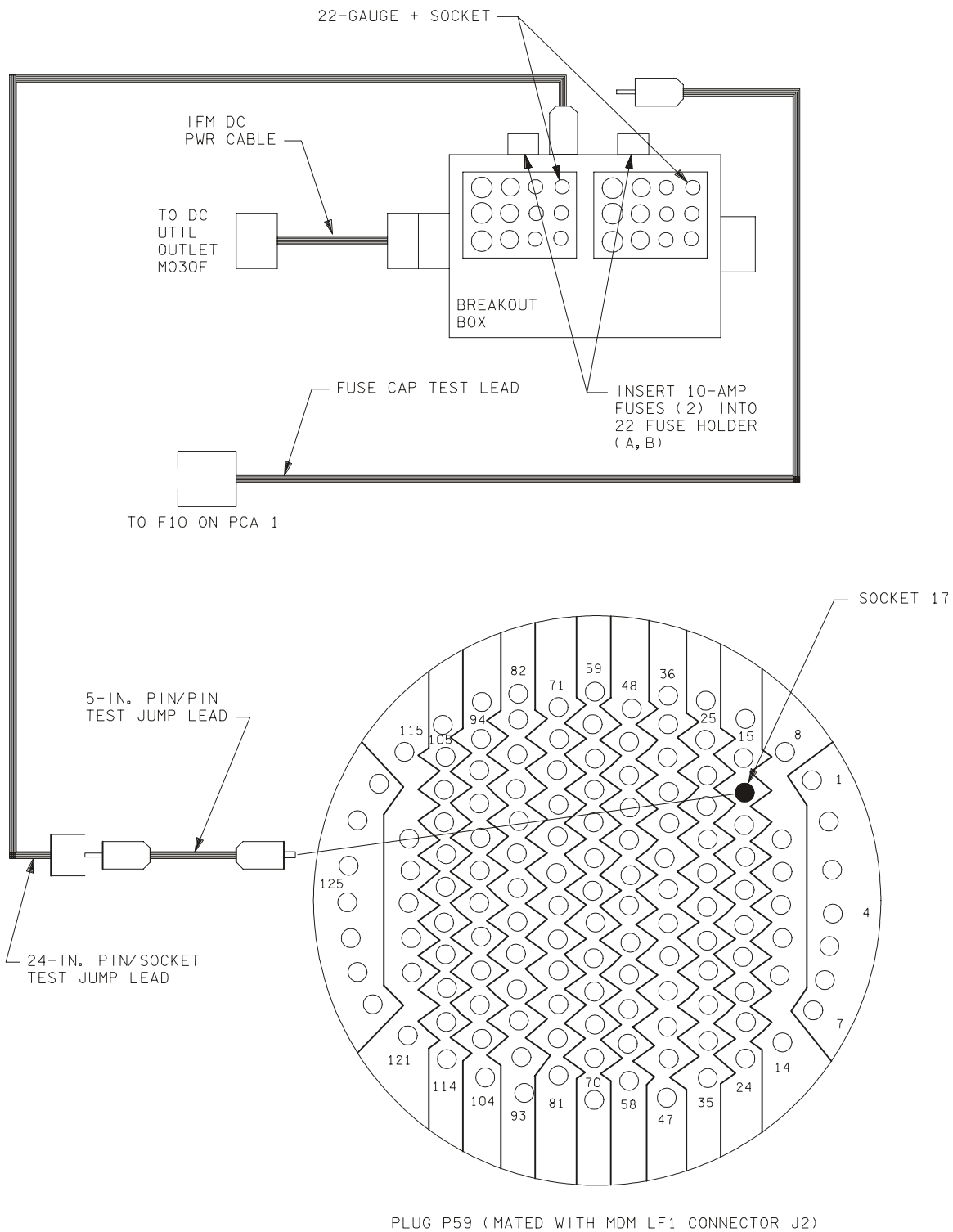


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Figure 2.12-1. Fuel cell contingency powerup circuit (fuel cell 1 shown)

2.12-3

Verify that this is the correct version before use

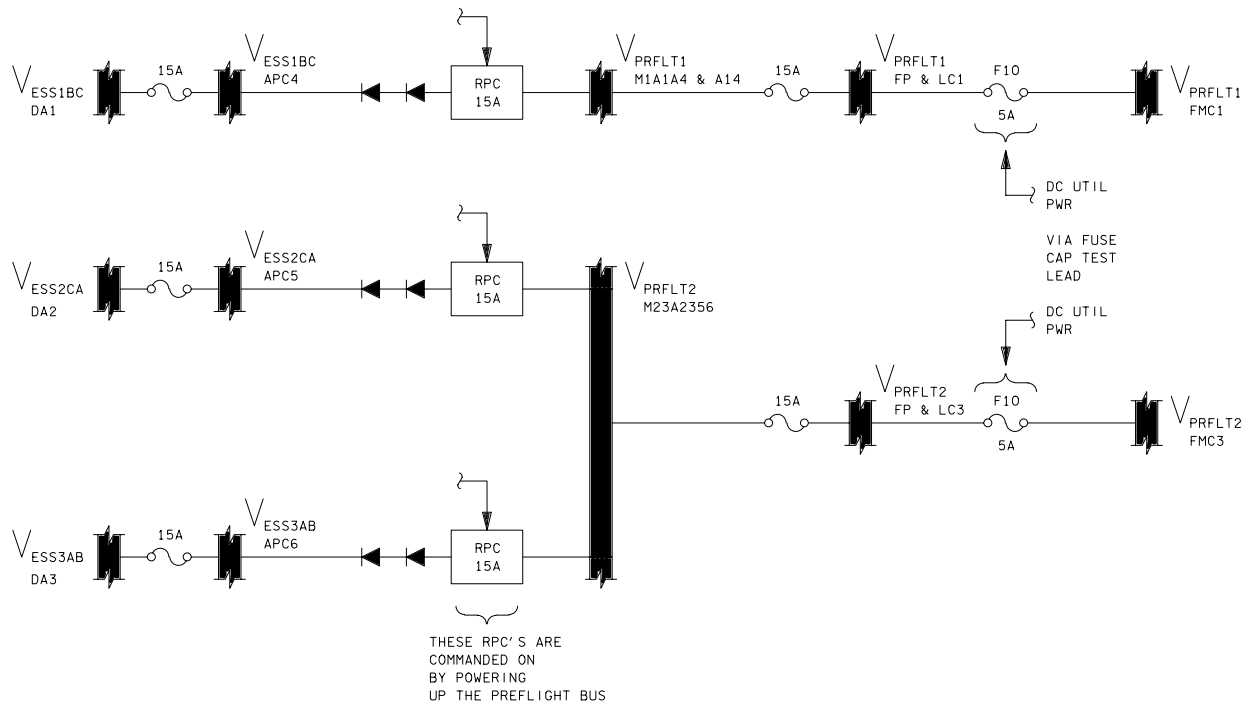


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**Figure 2.12-2. Fuel cell contingency powerup connection (fuel cell 1 shown)**

2.12-4

**Verify that this is the correct version before use**



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Figure 2.12-3. Fuel cell contingency powerup to ESS DA current path

**TITLE**

LF01 MULTIPLEXER/DEMULTIPLEXER (MDM) WORKAROUND

**BACKGROUND**

The orbiter Malfunction Procedures book contains a procedure (MAL SSR-202) to power the preflight test bus. It refers to the In-Flight Maintenance (IFM) Checklist, which contains a procedure (PREFLIGHT TEST BUS SETUP) to perform a contingency powerup of the fuel cell in the event that power is lost to a fuel cell ECU. The procedure uses the launch MDM LF01 ground-switching capability as a workaround. There are many more functions that could be performed by inserting proper plug and pin numbers. The following table lists some of the functions and associated plug-pin numbers that can be worked around using the LF01 MDM cables. Some items in the table require a specific preflight bus to be powered in addition to the LF01 input. These are identified in the bus power required column. Note that some functions require multiple commands. Other functions can be identified using the integrated schematics and wire lists for the LF01 MDM (81V72A32). Always double-check this table with the wire list when performing this IFM.

Input P+P	MS ID	Title	Bus power required
J02-026	V45K0109N	FCP 1 STOP-A	ESS1BC MPC1
J04-038	V45K0110N	FCP 1 STOP-B	ESS1BC MPC1
J02-015	V45K0112N	FUEL CELL NO 1 START	ESS1BC MPC1
J02-094	V45K0209N	FCP 2 STOP-A	ESS2CA MPC2
J04-108	V45K0210N	FCP 2 STOP-B	ESS2CA MPC2
J02-096	V45K0212N	FUEL CELL NO 2 START	ESS2CA MPC2
J06-094	V45K0309N	FCP 3 STOP-A	ESS3AB MPC3
J08-061	V45K0310N	FCP 3 STOP-B	ESS3AB MPC3
J06-096	V45K0312N	FUEL CELL NO 3 START	ESS3AB MPC3
J02-003	V45K0811N	FCP 1 PURGE VLVS MNL OPEN-A	MNA MPC1
J02-091	V45K0812N	FCP 1 PURGE VLVS MNL OPEN-B	MNA MPC1
J02-013	V45K0821N	FCP 2 PURGE VLVS MNL OPEN-A	MNB MPC2
J02-079	V45K0822N	FCP 2 PURGE VLVS MNL OPEN-B	MNB MPC2
J01-126	V45K0831N	FCP 3 PURGE VLVS MNL OPEN-A	MNC MPC3
J01-054	V45K0832N	FCP 3 PURGE VLVS MNL OPEN-B	MNC MPC3
J04-060	V45K1084N	PRSD O2 ECS PRI SPLY VLV-OPEN A	MNA MPC1
J04-050	V45K1088N	PRSD O2 ECS PRI SPLY VLV-OPEN B	MNA MPC1
J04-048	V45K1085N	PRSD O2 ECS PRI SPLY VLV-CLOSE A	MNA MPC1
J04-052	V45K1089N	PRSD O2 ECS PRI SPLY VLV-CLOSE B	MNA MPC1
J04-122	V45K1086N	PRSD O2 ECS SEC SPLY VLV-OPEN A	MNB MPC2
J04-117	V45K1090N	PRSD O2 ECS SEC SPLY VLV-OPEN B	MNB MPC2
J04-106	V45K1087N	PRSD O2 ECS SEC SPLY VLV-CLOSE A	MNB MPC2



<b>Input P+P</b>	<b>MS ID</b>	<b>Title</b>	<b>Bus power required</b>
J04-110	V45K1091N	PRSD O2 ECS SEC SPLY VLV-CLOSE B	MNB MPC2
J03-095	V45K1103N	PRSD O2 TANK 1 ANNULUS VAC-ON	PREFLT 1
J03-094	V45K1116N	PRSD O2 TK 1 HTR CUR SNSR-RESET	PREFLT 1
J03-096	V45K1117N	PRSD O2 TK 1 HTR CUR SNSR-TEST	PREFLT 1 or ESS 2CA FD
J02-017	V45K1121N	FCP 1 PUMP POWER	PREFLT 1 MPC1
J02-072	V45K1124N	FCP 2 PUMP POWER	PREFLT 2 MPC2
J06-072	V45K1127N	FCP 3 PUMP POWER	PREFLT 2 MPC3
J04-064	V45K1128N	PRSD O2 TANK 1 QUANTITY CHECK	PREFLT 1
J02-009	V45K1143N	PRSD O2 MANF 1 ISLN VLV-OPEN-A	ESS1BC MPC1
J06-087	V45K1171N	PRSD O2 MANF 1 ISLN VLV-OPEN-B	ESS1BC MPC1
J02-010	V45K1144N	PRSD O2 MANF 1 ISLN VLV-CLOSE A	ESS1BC MPC1
J06-088	V45K1173N	PRSD O2 MANF 1 ISLN VLV-CLOSE-B	ESS1BC MPC1
J02-087	V45K1148N	PRSD O2 MANF 2 ISLN VLV-OPEN A	ESS2CA MPC2
J04-051	V45K1176N	PRSD O2 MANF 2 ISLN VLV-OPEN-B	ESS2CA MPC2
J02-088	V45K1149N	PRSD O2 MANF 2 ISLN VLV-CLOSE-A	ESS2CA MPC2
J04-053	V45K1178N	PRSD O2 MANF 2 ISLN VLV-CLOSE-B	ESS2CA MPC2
J04-063	V45K1151N	PRSD FCP 1 REAC VLV-OPEN-A	ESS1BC MPC1
J02-018	V45K1166N	PRSD FCP 1 REAC VLV-OPEN-B	ESS1BC MPC1
J04-039	V45K1152N	PRSD FCP 1 REAC VLV-CLOSE-A	ESS1BC MPC1
J02-001	V45K1168N	PRSD FCP 1 REAC VLV-CLOSE-B	ESS1BC MPC1
J04-097	V45K1156N	PRSD FCP 2 REAC VLV-OPEN-A	ESS2CA MPC2
J02-073	V45K1181N	PRSD FCP 2 REAC VLV-OPEN-B	ESS2CA MPC2
J04-099	V45K1157N	PRSD FCP 2 REAC VLV-CLOSE-A	ESS2CA MPC2
J02-075	V45K1183N	PRSD FCP 2 REAC VLV-CLOSE-B	ESS2CA MPC2
J08-063	V45K1161N	PRSD FCP 3 REAC VLV-OPEN-A	ESS3AB MPC3
J06-073	V45K1163N	PRSD FCP 3 REAC VLV-OPEN-B	ESS3AB MPC3
J08-039	V45K1162N	PRSD FCP 3 REAC VLV-CLOSE-A	ESS3AB MPC3
J06-075	V45K1164N	PRSD FCP 3 REAC VLV-CLOSE-B	ESS3AB MPC3
J06-095	V45K1191N	PRSD O2 GAS SUPPLY VLV-OPEN	PREFLT 1
J06-082	V45K1196N	PRSD O2 GAS SUPPLY VLV-CLOSE	PREFLT 1
J03-018	V45K1203N	PRSD O2 TK 2 ANNULUS VAC-ON	PREFLT 2
J03-026	V45K1216N	PRSD O2 TK 2 HTR CUR SNSR-RESET	PREFLT 2
J03-015	V45K1217N	PRSD O2 TK 2 HTR CUR SNSR-TEST	PREFLT 2 or ESS 1BC FD
J04-098	V45K1228N	PRSD O2 TANK 2 QUANTITY CHECK	PREFLT 2
J03-076	V45K2103N	PRSD H2 TANK 1 ANNULUS VAC-ON	PREFLT 1
J04-042	V45K2128N	PRSD H2 TANK 1 QUANTITY CHECK	PREFLT 1
J08-036	V45K2191N	PRSD H2 GAS SUPPLY VLV-OPEN	PREFLT 1
J08-059	V45K2196N	PRSD H2 GAS SUPPLY VLV-CLOSE	PREFLT 1

<b>Input P+P</b>	<b>MS ID</b>	<b>Title</b>	<b>Bus power required</b>
J03-029	V45K2203N	PRSD H2 TANK 2 ANNULUS VAC-ON	PREFLT 2
J04-119	V45K2228N	PRSD H2 TANK 2 QUANTITY CHECK	PREFLT 2
J06-074	V45K2239N	PRSD H2 MANF 1 ISLN VLV-OPEN A	ESS1BC MPC1
J08-042	V45K2240N	PRSD H2 MANF 1 ISLN VLV-OPEN B	ESS1BC MPC1
J06-086	V45K2241N	PRSD H2 MANF 1 ISLN VLV-CLOSE A	ESS1BC MPC1
J08-054	V45K2242N	PRSD H2 MANF 1 ISLN VLV-CLOSE B	ESS1BC MPC1
J04-054	V45K2243N	PRSD H2 MANF 2 ISLN VLV-OPEN A	ESS2CA MPC2
J04-126	V45K2244N	PRSD H2 MANF 2 ISLN VLV-OPEN B	ESS2CA MPC2
J04-049	V45K2245N	PRSD H2 MANF 2 ISLN VLV-CLOSE A	ESS2CA MPC2
J04-116	V45K2246N	PRSD H2 MANF 2 ISLN VLV-CLOSE B	ESS2CA MPC2
*J01-115	V54K0003N	R REND RDR+WB COMM ANT DEPL CMD 1B	--
*J03-074	V54K0013N	R REND RDR+WB COMM ANT DEPL CMD 1A	--
*J01-098	V54K0004N	R REND RDR+WB COMM ANT DEPL CMD 2B	--
*J03-088	V54K0014N	R REND RDR+WB COMM ANT DEPL CMD 2A	--
J06-080	V58K0156N	HYD 1 H2O BLR CONT A&B AC PWR ON	PREFLT 2
J06-092	V58K0256N	HYD 2 H2O BLR CONT A&B AC PWR ON	PREFLT 2
J06-093	V58K0356N	HYD 3 H2O BLR CONT A&B AC PWR ON	PREFLT 2
J01-050	V61K2588N	CABIN FAN A-ON	PREFLT 2
J01-059	V61K2593N	CABIN FAN B-ON	PREFLT 2
J01-100	V61K2604N	H2O LOOP 1 PUMP A CONTROL-ON	MNA FMCA 1
J01-040	V61K2609N	H2O LOOP 1 PUMP B CONTROL-ON	MNB FMCA 2
J01-122	V61K2704N	H2O LOOP 2 PUMP CONTROL-ON	CNTL CA1 and switch in GPC
J01-105	V61K2773N	AVIONICS BAY 1 FAN A ON	PREFLT 1
J01-036	V61K2778N	AVIONICS BAY 1 FAN B ON	MNB FMCA 2
J01-106	V61K2783N	AVIONICS BAY 2 FAN A ON	PREFLT 2
J01-060	V61K2788N	AVIONICS BAY 2 FAN B ON	MNC FMCA 3
J01-097	V61K2793N	AVIONICS BAY 3 FAN A ON	PREFLT 2
J01-048	V61K2798N	AVIONICS BAY 3 FAN B ON	MNA FMCA 1
J01-124	V61K2865N	ARS IMU FAN A-ON	PREFLT 1
J01-062	V61K2866N	ARS IMU FAN B-ON	PREFLT 2
J05-062	V61K2867N	ARS IMU FAN C-ON	PREFLT 2
J05-050	V62K0613N	FIRE AGENT DISCHARGE-AV BAY 2	PREFLT 2
J03-017	V62K0633N	FIRE AGENT DISCHARGE-AV BAY 3	PREFLT 1
J03-025	V62K0811N	FIRE SUPPRESSION AV BAY 2 ARM	PREFLT 2
J05-059	V62K0812N	FIRE SUPPRESSION AV BAY 3 ARM	PREFLT 1
J03-072	V62K0818N	SMOKE DET RESET CMD-ALL	PREFLT 1
J07-074	V63K1114N	FCL 1 PUMP A-ON	PREFLT 1
J03-019	V63K1124N	FCL 1 PUMP B-ON	MNB FLC2

<b>Input P+P</b>	<b>MS ID</b>	<b>Title</b>	<b>Bus power required</b>
J03-010	V63K1314N	FCL 2 PUMP A-ON	PREFLT 2
J07-088	V63K1324N	FCL 2 PUMP B-ON	MNA FLC1
J02-008	V74K5080N	NSP 1 T-ZERO UMBILICAL ON	MNB FLC2
J02-095	V74K5081N	NSP 2 T-ZERO UMBILICAL ON	MNB FLC3
J04-059	V74K6652N	S-BAND FM XMTR NO 1 OFF	MNB FLC2
J04-115	V74K6653N	S-BAND FM XMTR NO 2 OFF	MNC FLC3
J07-072	V75K2107N	PCM MASTER 1 PWR ON A	MNA FPC1
J03-002	V75K2108N	PCM MASTER 1 PWR ON B	MNC FPC3
J07-082	V75K2109N	PCM MASTER 2 PWR ON A	MNA FPC1
J03-008	V74K2110N	PCM MASTER 2 PWR ON B	MNB FPC2
J01-107	V76K0107N	MAIN BUS A TIE BUS-ON	PREFLT 1
J01-116	V76K0108N	MAIN BUS A TIE BUS-OFF	PREFLT 1
J02-014	V76K0127N	MAIN BUS A CONTROL BUS AB1/CA1-OFF	MNA FLC1
J02-070	V76K0128N	MAIN BUS A CONTROL BUS AB2/CA2-OFF	MNA FLC1
J08-047	V76K0129N	MAIN BUS A CONTROL BUS AB3/CA3-OFF	MNA FLC1
J01-049	V76K0131N	MAIN BUS B TO ESS BUS-1BC-0N	MNB MPC2

\* This method works only for a failed "DEPLOY" switch position. To deploy, the switch must be in "GND" position.

J07-076	V76K0134N	MAIN BUS C TO ESS BUS-1BC-0N	MNC MPC3
J01-114	V76K0161N	FUEL CELL 1 TO MAIN BUS A-ON	PREFLT 1
J01-103	V76K0162N	FUEL CELL 1 TO MAIN BUS A-OFF	PREFLT 1
J01-063	V76K0207N	MAIN BUS B TIE BUS-ON	PREFLT 2
J01-037	V76K0208N	MAIN BUS B TIE BUS-OFF	PREFLT 2
J02-022	V76K0227N	MAIN BUS B CONTROL BUS AB1/BC1-OFF	MNB FLC2
J02-080	V76K0228N	MAIN BUS B CONTROL BUS AB2/BC2-OFF	MNB FLC2
J08-058	V76K0229N	MAIN BUS B CONTROL BUS AB3/BC3-OFF	MNB FLC2
J07-095	V76K0231N	MAIN BUS C TO ESS BUS-2CA-ON	MNC MPC3
J01-109	V76K0234N	MAIN BUS A TO ESS BUS-2CA-ON	MNA MPC1
J01-047	V76K0261N	FUEL CELL 2 TO MAIN BUS B-ON	PREFLT 2
J01-034	V76K0262N	FUEL CELL 2 TO MAIN BUS B-OFF	PREFLT 2
J07-073	V76K0307N	MAIN BUS C TIE BUS-ON	PREFLT 2
J07-085	V76K0308N	MAIN BUS C TIE BUS-OFF	PREFLT 2
J02-004	V76K0327N	MAIN BUS C CONTROL BUS BC1/CA1-OFF	MNC FLC3
J02-092	V76K0328N	MAIN BUS C CONTROL BUS BC2/CA2-OFF	MNC FLC3
J08-044	V76K0329N	MAIN BUS C CONTROL BUS BC3/CA3-OFF	MNC FLC3
J01-104	V76K0331N	MAIN BUS A TO ESS BUS 3AB ON	MNA MPC1
J01-051	V76K0334N	MAIN BUS B TO ESS BUS-3AB-ON	MNB MPC2
J07-094	V76K0361N	FUEL CELL 3 TO MAIN BUS C-ON	PREFLT 2
J07-096	V76K0362N	FUEL CELL 3 TO MAIN BUS C-OFF	PREFLT 2

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<b>Input P+P</b>	<b>MS ID</b>	<b>Title</b>	<b>Bus power required</b>
J02-024	V76K1510N	AC BUS 1 PH A/B/C-ON	PREFLT 1
J02-023	V76K1517N	AC BUS 1 PH A/B/C-OFF	PREFLT 1
J02-093	V76K1610N	AC BUS 2 PH A/B/C-ON	PREFLT 2
J02-081	V76K1617N	AC BUS 2 PH A/B/C-OFF	PREFLT 2
J08-034	V76K1710N	AC BUS 3 PH A/B/C-ON	PREFLT 2
J08-033	V76K1717N	AC BUS 3 PH A/B/C-OFF	PREFLT 2
J03-016	V76K1813N	ARRAY 1 MN BUS A TO PH A/B/C ON	ESS1BC FLC1
J03-009	V76K1814N	ARRAY 1 MN BUS A TO PH A/B/C OFF	PREFLT 1 & ESSIBC FLC2
J03-071	V76K1833N	ARRAY 2 MN BUS B TO PH A/B/C ON	ESS2CA FLC2
J03-087	V76K1834N	ARRAY 2 MN BUS B TO PH A/B/C OFF	PREFLT 2 & ESS2CA FLC2
J05-064	V76K1853N	ARRAY 3 MN BUS C TO PH A/B/C ON	ESS3AB FLC3
J05-052	V76K1854N	ARRAY 3 MN BUS C TO PH A/B/C OFF	PREFLT 2 & ESS3AB FLC3
J08-050	V45K2303N	PRSD H2 TK3 ANNULUS VAC-ON	PREFLT 2
J08-051	V45K2328N	PRSD H2 TK3 QUANTITY CHECK	PREFLT 2
J08-052	V45K2453N	PRSD H2 TK4 AND 5 ANNULUS VAC-ON	PREFLT 1
J08-053	V45K2478N	PRSD H2 TK4 AND 5 QUANTITY CHECK	PREFLT 1

## TITLE

DELTA AMPS MEASUREMENTS

## PURPOSE

To describe the rationale of the delta amps measurement, its relation to the fuel cell performance, and the console responsibilities in implementing the measurements use.

## BACKGROUND

The delta amps measurement was designed to provide insight into fuel cell performance when two operating fuel cells are bus tied. The delta amps measurement reveals the load-sharing characteristics through the bus tie, allowing the operator to monitor performance changes over an extended period of time. If the fuel cell is bus tied and experiencing either flooding or crossover, it will transfer load to the healthy fuel cell, causing the load between the tied fuel cells to diverge and resulting in significant changes in the delta amps. Based upon analytical studies, a 12-amp shift in the delta amps equates to: (1) a 300-mV degradation in one of the 96 cells, or (2) a 3-percent KOH concentration change in a fuel cell. Test data shows that a 300-mV degradation indicates crossover, a high KOH concentration indicates crossover, and low KOH concentration indicates flooding.

The delta amps measurement is also used to determine bus-loading actions in the case where a fuel cell has previously failed. If the measurement indicates severe load imbalances between the remaining two fuel cells, the crew will attempt to balance the load.

The delta amps measurement is an onboard GPC computation available to the crew on SPEC 69, and to the MCC on MSK FC\_EPDC display. It is calculated as follows:

FC1 delta amps (V92C2142C) = FC1 amps (V45C0101A) - FC2 amps (V45C0201A)

FC2 delta amps (V92C2143C) = FC2 amps (V45C0201A) - FC3 amps (V45C0301A)

FC3 delta amps (V92C2144C) = FC3 amps (V45C0301A) - FC1 amps (V45C0101A)

The delta amps computation has Fault Detection and Annunciation (FDA) to annunciate out-of-limit conditions to the crew. Under nominal conditions, the delta amps FDA limits will be set to Offscale High (OSH) (+500) and Offscale Low (OSL) (-500 amps) to avoid receiving nuisance alarms caused by normal load transients. For certain situations, the delta amps measurement FDA will be changed to alert the crew in the event of fuel cell condition changes.

## PROCEDURE

- A. Cell Performance Monitor (CPM) failure, CPM instrumentation failure (OI MDM), and Orbit Pocket Checklist (OPCL) FC Delta Volt procedure

The CPM detects cell changes by comparing both halves of a substack. Because all the cells in a substack operate at the same current, a significant voltage loss in any single cell will produce an identical voltage change in the substack delta volts measurement, and the fuel cell delta volts comp (actual - predicted volts). For the loss of an individual fuel cell CPM, the crew is directed to perform a main bus tie, which is used to monitor for a shift in the delta amps measurement between the two tied fuel cells. A shift of 12 amps is equivalent to approximately 300-mV degradation in one of the 96 cells. The magnitude of the performance change may indicate an internal cell problem. If allowed to continue, this could lead to crossover, which is potentially a catastrophic failure. Once bus tied, the MCC will monitor the delta amps measurement and subsequently determine new FDA limits. Limits will be selected after monitoring the range of values that the measurement cycles through. The new limits will equal the highest observed value +12 amps and the lowest observed value -12 amps. Once determined, the MCC will TMBU the new limits and notify the crew. If the crew experiences a loss of COMM, they will reset the limits to the present delta amps value  $\pm 40$  amps. The  $\pm 40$  amps value accounts for possible differences in the fuel cell V-I performance curve.

Certain known conditions will cause the delta amps to change. Fuel cell loads can cause the delta amps to change because of differences in the V-I performance curves between the two tied fuel cells. In addition, reactant pressure changes, temperature changes, or inerts can cause fuel cell load changes. Using the STS-44 predicted V-I end-of-life and beginning-of-life fuel cell curves, the delta amps variations due to load changes was computed. The total load changed from 10 kW to 19 kW, giving a delta amps change of 25 and 35 amps, respectively. To ensure that the load changes do not cause an alarm, a pad of 5 amps was added to the extreme case of 35 amps, resulting in the 40-amp limit.

If the crew receives the "S69 delta amps 1(2,3)" message, no COMM, or on MCC recommendations, they will safe the fuel cell. Otherwise, the measurements will continue to be monitored by the FDA software. For cases of loss of insight into the fuel cell, the buses will be untied prior to entry.

In addition to tying the main buses and monitoring the delta amps measurement, the Fuel Cell Monitoring System (FCMS) will be connected, and individual cell readings will be taken once per day to monitor fuel cell performance.

#### B. FC Stack T and FC Exit T procedures

The stack T and exit T procedures use the delta amps measurement to monitor fuel cell health, along with the fuel cell KOH concentration. A delta amps shift of  $\pm 12$  amps corresponds to a  $\pm 3$  percent KOH concentration change in a fuel cell. A high KOH concentration (>48 percent dry stack) and improved fuel cell performance signals O<sub>2</sub>/H<sub>2</sub> crossover. A low concentration (<26 percent, wet stack) and degraded performance signals flooding.

New delta amps FDA limits are required to monitor fuel cell performance for changing KOH concentrations. The MCC will determine and TMBU the new delta amps limits as described in the previous procedure. If the crew receives the "S69 delta amps 1(2,3)" message, no COMM, or on MCC recommendations, they will shut down the fuel cell. Otherwise, the measurements will continue to be monitored by the FDA software. The buses will be untied for entry.

C. FC cool P malfunction procedure

The FC cool P procedure uses the delta amps measurements to monitor fuel cell health and to receive any indications of fuel cell flooding. For the fuel cell to keep relieving water to the water supply system, there must be a 10-psid differential pressure (worst case) between the fuel cell stack pressure and the H<sub>2</sub>O supply system pressure. The FDA will annunciate any further changes in the pressure that would cause the fuel cell to flood.

A delta amps change of -40 amps indicates that a fuel cell is in a flooded condition. The 40-amp value resulted from the calculation of a 12 percent change in KOH from a normal fuel cell to a flooded fuel cell. A 12-percent change in KOH equates to a 0.384-volt change using an interface voltage of 0.032 V/ percent concentration. The analysis assumed a 10-kW load between two tied fuel cells and uses a stack resistance of 0.01 ohms. The circuit analysis resulted in a 40-amp difference between the two cells.

## TITLE

FUEL CELL MONITORING SYSTEM

## PURPOSE

To provide information about the design and operation of the Fuel Cell Monitoring System (FCMS).

## INTRODUCTION

The FCMS is a data system designed to provide insight into the single-cell voltages in the orbiter fuel cells. The FCMS is used in flight and during ground checkout/processing.

## BACKGROUND

The existing Cell Performance Monitor (CPM) works well, but there are some fuel cell failure modes that the CPM does not adequately detect. The CPM compares the first 16 cells in a substack to the second 16 cells and then returns the absolute value of the difference between these measurements. With this design, it is not possible to conclusively determine if a change in the CPM output is due to a single cell degrading or whether there are several cells slightly degraded.

Another fuel cell problem that could be masked in the current CPM is the case in which more than one cell is degrading or developing crossover, and the cells are on different halves of the same substack. In this case, if the cells were degrading at the same rate, the CPM reading would be unaffected and the problem would go undetected.

Several CPM design upgrade options were presented to the orbiter program over the years. Because of competing priorities, the excellent reliability of the fuel cells, and program budget constraints, none of the proposed upgrades has been implemented.

The capability of the CPM became an issue during the STS-83 mission. Shortly after lift-off, the FC2 CPM indicated a problem in the fuel cell. The Substack Delta Volts (SSDV) measurement for substack 3 was increasing. MN B was tied to MN C to provide additional monitoring of the fuel cell performance. The measurement continued to rise, but over time the rise rate slowed and appeared as if it might eventually stabilize. The bus tie (load-sharing) data indicated a healthy fuel cell, and there were no other indications of anything wrong with the fuel cell. Except for the SSDV measurement, all indications were that the fuel cell was healthy.

During STS-83, the available data did not allow for ground personnel to rule out the possibility of crossover in the fuel cell. Crossover is the inadvertent mixing of O<sub>2</sub> and H<sub>2</sub> in the stack of a fuel cell. The crossover reaction produces heat at the crossover point. The extra heat, in turn, helps to enlarge the size of the crossover path between the O<sub>2</sub> and H<sub>2</sub>. If left unchecked, crossover will result in a catastrophic fuel cell



rupture/fire and possible loss of the shuttle. With this in mind, the Mission Management Team (MMT) decided that the proper course of action was to safe the fuel cell and to execute a Minimum-Duration Flight (MDF) timeline.

The fuel cell was returned to the vendor, International Fuel Cells (IFC), for failure analysis. After some diagnostic tests and analysis work, crossover was ruled out. The fuel cell was successfully started and, after continued operation, the SSDV reading stabilized. The stack was subsequently torn down, and a series of analyses and laboratory tests were performed. The tests and analyses showed that there was slightly degraded performance spread across several cells. In the end, the vendor was not able to determine the exact cause of the degradation. The conclusion was that it would have been okay to continue using the fuel cell during STS-83. However, because the consequence of unchecked crossover is so severe, it was clear that with the data available during flight, the correct decision was made. It was also clear that if the vehicle was equipped with the capability to measure the individual cell voltages, the possibility of crossover could have been eliminated. The decision during flight would have been to continue FC2 operation and stay on orbit.

## **DESIGN PROCESS**

To preclude another incident of unnecessary early mission termination caused by lack of insight into the fuel cell single cells, a tiger team was formed in May 1997. The assignment for this team was to design, build, install, and fly a single-cell voltage measurement system on STS-87 in November 1997 and on all subsequent missions. This schedule required the first shipment of hardware to be delivered to KSC in mid-August, which gave the team 10 to 12 weeks to define requirements, design, build, test, and deliver flight hardware.

Several design options were investigated. Most designs, including those that interfaced with the onboard flight software and data system, were abandoned because of the schedule. During one meeting with the Shuttle Program Office, it was suggested that the deadline be moved out approximately 3 months to allow a solution that would incorporate the measurements into the real-time shuttle downlink telemetry. The Program Office reiterated that the first flight of STS-87 in mid-November 1997 was a requirement.

The team narrowed the possibilities down to two options, to record the data onboard and downlink via the Orbiter Communications Adapter (OCA) or to record the data onboard and downlink via a spare Ku channel, most probably channel 3.

The Ku option held the threat of delays that could be associated with required changes to downlink Telemetry Format Loads (TFLs). In addition, the proposed Ku- band channels are generally reserved for optional Payload (PL) services with which the team did not want to interfere. The team settled on the first option of recording the data onboard and then downlinking via the OCA.

At this point, the concept for the FCMS was complete. The cell voltages would be measured, an analog-to-digital conversion would be done, and the data would then be combined into a serial data stream to be displayed and recorded by an onboard Payload General Support Computer (PGSC).

With the short development time available, the team quickly recognized that designing a single-cell voltage-monitoring system from the ground up was not feasible, and a search began for commercially available data systems. Several manufacturers were considered. Some were disqualified based on schedule, and some could not meet the required specifications. Eventually, Aydin Vector was selected to build the FCMS hardware. The company indicated that they could meet our specifications and schedule. They also had previous experience building data systems for the SPARTAN and MISTI satellite programs, as well as experience in several other aerospace projects.

Boeing North American in Downey took the lead responsibility for the hardware development and engineering for vehicle modifications. JSC MOD assumed responsibility for developing the onboard and ground software applications and for building the necessary PGSC interconnect cables. KSC assumed responsibility for building systems to obtain the data during ground operations and for performing the vehicle modifications.

### **FCMS OPERATION AND CONSTRAINTS**

The FCMS consists of a master and two remote (or slave) Pulse Code Modulation (PCM) units. The master unit (PCM 1) handles the timing, control, and formatting of the data stream, inserts the orbiter Greenwich Mean Time (GMT) into the data stream, measures single-cell voltages on FC1, and provides the system outputs. The slave unit 1 (PCM 2) measures single-cell voltages from FC2, and slave unit 2 (PCM3) measures single-cell voltages from FC3. These voltages are sent to the master unit to be combined with FC1 voltages and GMT in the output data stream (See Figures 2.15-1 and 2.15-2).

The output serial data stream is encoded as biphase -L and runs at a rate of 4.095 kbps. Each frame consists of 300 12-bit words. Words 1 and 2 are frame sync words. Words 3 through 9 are the GMT timetag at the beginning of the frame. Words 10 thru 297 are the 288 cell voltages (96 cells times three fuel cells). Words 298 thru 300 are spare channels. The selected data rate of 4.095 kbps results in one full frame of data approximately every 0.88 seconds.

It should be noted that the individual cell voltages are not sampled at the same instant of time. The cell voltages are sampled sequentially, and there will be approximately 280 milliseconds between the 1st and the 96th cell measurement on each fuel cell. The GMT in each frame is the time that cell 1 on FC1 was sampled.

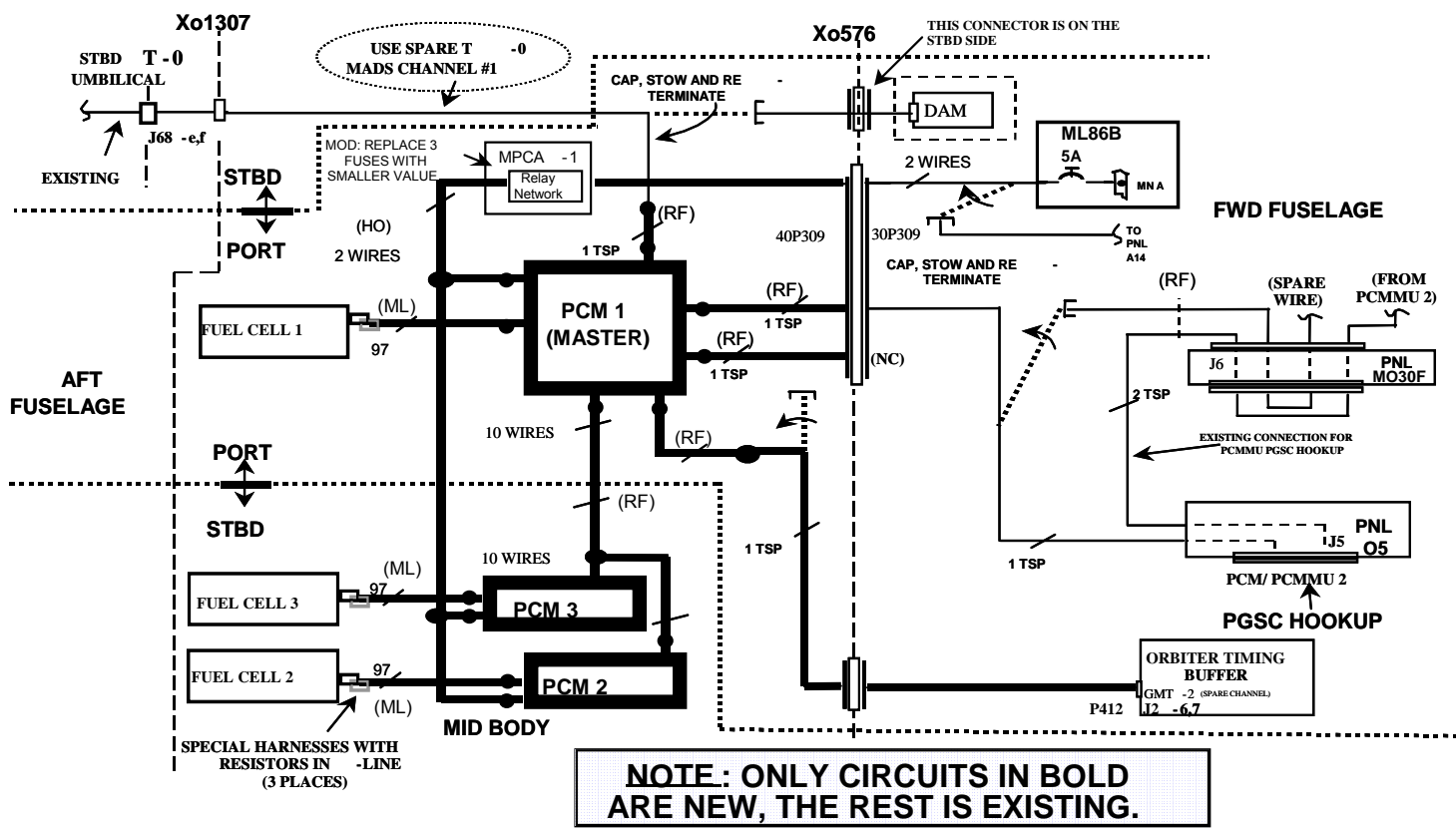


Figure 2.15-1. Single-cell monitoring circuit diagram

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2.15-4

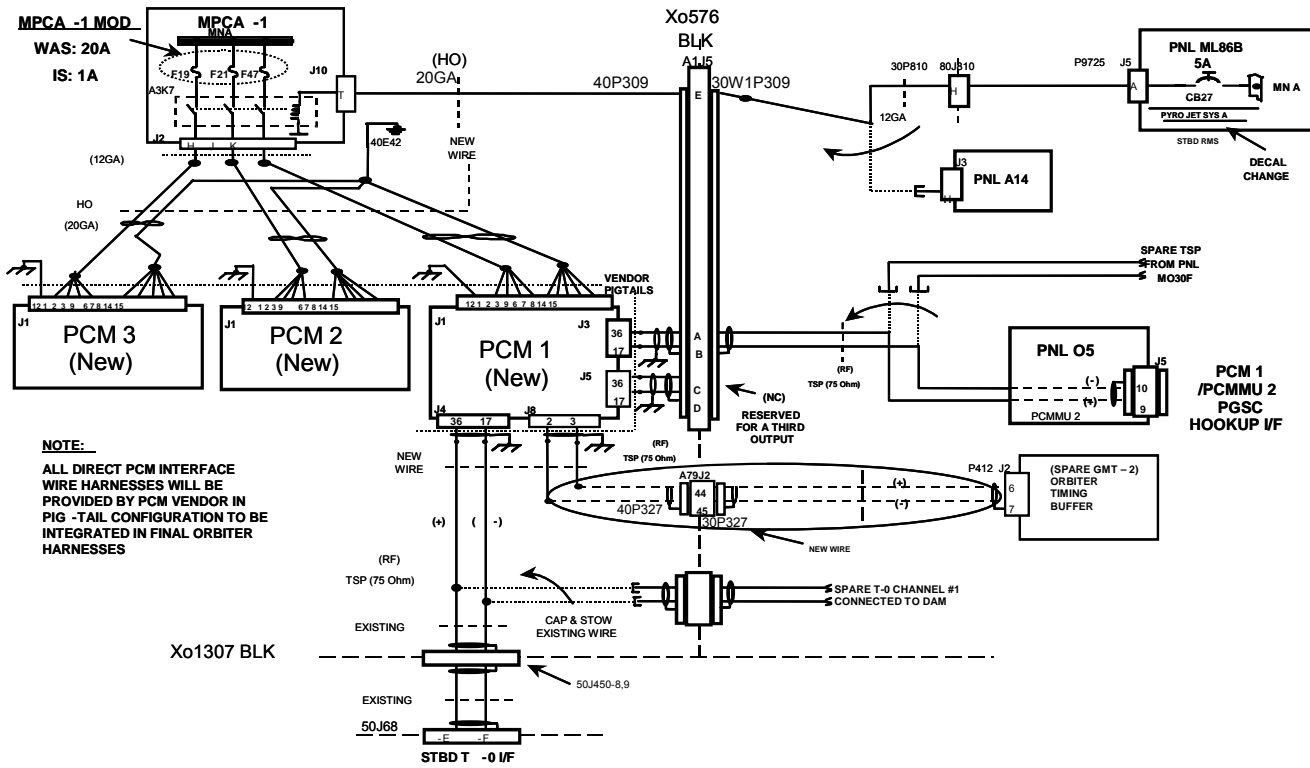


Figure 2.15-2. Detailed wiring configuration for PCM power, timing, and PCM output circuit

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The power for the FCMS is supplied from MN A MPC1. Power comes through fuses F47, F21, and F19 for the master unit, slave unit 1, and slave unit 2, respectively. Power to the units is controlled via three contacts of relay A3K7, one contact for each slave and master unit. The coil of the A3K7 relay is energized via CB27 on ML86B. This circuit breaker is rated at 5 amps and receives power from the MNA ML86B sub-bus. Because each card in each unit needs an individual power feed, this type of power arrangement was selected to minimize the number of splices required.

The master unit has three data output ports. Each of these ports puts out an identical data stream. The first output is connected to the Pulse Code Modulation Master Unit (PCMMU) 2 outlet on PNL O5. Spare pins (9 and 10) are utilized so that existing PCMMU capabilities are separate and unaffected. This output provides data to the onboard PGSC data system. When the crew wants PCMMU2 data, they hook up the PCMMU cable. When they want FCMS data, they use the FCMS cable.

The second output goes to a connector at the 576 bulkhead. Currently, nothing is connected to the other side of this bulkhead connector. This output was intentionally added for possible future use.

The third output is connected to the T-0 umbilical. This output is utilized prelaunch and during ground turnaround/processing activities (N<sub>2</sub> diagnostics, etc.).

During Electromagnetic Interference (EMI) testing at the Johnson Space Center, the FCMS hardware had some emissions that exceeded the STS SL-E-0002 specification for orbiter hardware. The test was done in a "worst case" configuration with several unterminated data lines and without the shrouds that are installed in the actual vehicle. Analysis was conducted to show that, for conducted emissions, there was a safety margin of ~42 dB and for radiated emissions, a safety margin of ~38 dB. A waiver was processed to allow operation of the FCMS system. The waiver was approved for on-orbit operations but not for ascent/entry. At present, the FCMS is deactivated during the prelaunch count just prior to closing the crew compartment hatch. Some discussion has taken place about revisiting the EMI testing to allow certification of the FCMS during ascent/entry. Because the crew does not have access to the data during these timeframes (PGSCs and cables are stowed), the decision was made to leave it as is.

## **ONBOARD SOFTWARE APPLICATIONS**

### **A. WINDECOM, FCMS**

The onboard PGSC implementation requires both the WINDECOM FCMS and FCMS applications to be running (see the diagram in the MAL PROCEDURES EPS SSR-1 fuel cell Monitoring System Operation). WINDECOM FCMS is a special WINDECOM configuration that was built specifically to decommutate the FCMS serial bit stream and format the data so that it can be easily read by the FCMS application. WINDECOM FCMS will have a display of the fuel cell single-cell voltages and the associated GMT; each fuel cell has its data in a series of vertical columns. The data are visible and valid but not particularly easy for the crew to read. The WINDECOM default display shows FC1 single-cell voltages. The second display shows FC2 and FC3 voltages. To toggle

between the FC1 display to the FC2 and FC3 displays, the crew can page up or down. If a situation arises in which only WINDECOM FCMS is available, the crew can still read the single-cell voltages.

## B. FCMS

The FCMS application display (Figure 2.15-3) shows the individual single-cell voltages and has options to record them into an ASCII data file(s). This application displays one fuel cell on each page. The default display comes up with FC1, but the crew can easily select FC2 or FC3.

The display is structured with the fuel cell broken into substacks. Each substack consists of two columns. The first column has the first 16 cells, and the second column has the second 16 cells. The displayed cell voltages are rounded to the nearest millivolt. At the bottom of each column is a summation of the 16 cells in the substack half. The absolute value of the difference between the halves of the substack is the mathematical reproduction of the SSDV measurement. The displayed value here is an absolute value, because the crew is used to seeing SSDV in this form. The bottom field under each column is the addition of the voltages from each half of the substack. This value is the mathematical reproduction of the total fuel cell volts. An option in the init file allows recording of data to the nearest tenth of a millivolt, but voltages to the nearest millivolt should be adequate in most circumstances.

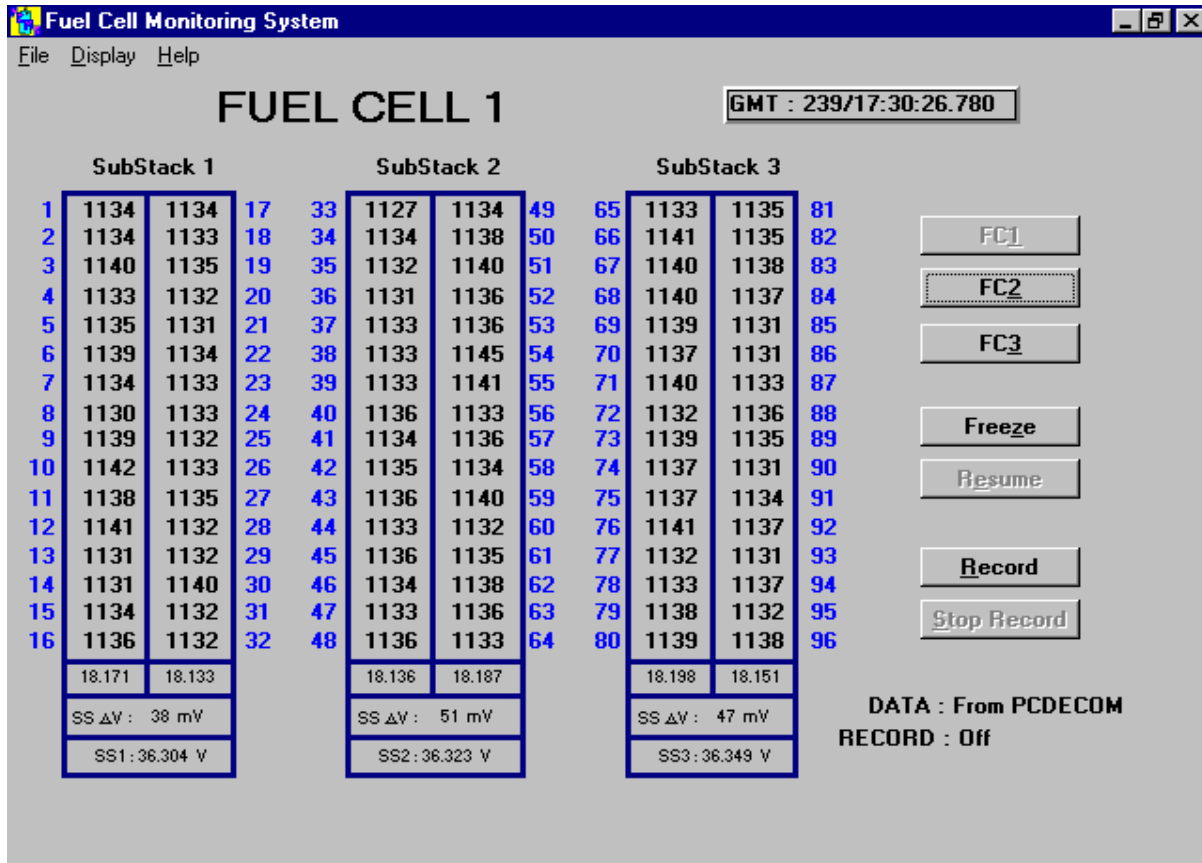
The crew has an option to record data. When the Record function is selected, two options are presented. Option 1 is to record full rate until the maximum file length is achieved. Option 2 is to record one sample every \_\_\_ minutes for \_\_\_ hrs.

If option 1 is selected, the FCMS application begins recording data until it reaches the maximum file length defined in the init file or until the crew selects Stop Record. The default maximum file length specified in the init file is 820 lines. The size was selected to ensure that the data file would always fit on a single 1.2-Mb floppy disk.

If option 2 is selected, the crew enters in the interval between samples and the total record time. The recording proceeds until the recording is complete, until the maximum file size is reached, or until the crewmember selects Stop Record. If the crew selects interval recording and selects an interval and time that exceeds the maximum file size, data will still be recorded, but the crew will receive a message advising that the file will record to maximum file size.

Because the single-cell voltages nominally vary depending on load, and since the vehicle load is constantly changing, the freeze option was built into the FCMS. The crew can select Freeze to freeze the data on the display. This freezes the data so that the crew can look at data from one time point (one possible use is the case in which OCA downlink is unavailable and we want the crew to report some values). The Freeze button affects only the display screen, not the record function. If files are being recorded, the recording continues in the background. To resume real-time data on the screen, the crew selects Resume.

The initialization file, or init file, contains default reconfigurable options for the FCMS application. If changes are required or desired, there are two options to accomplish this. The first is to have the crew open the init file and make the desired changes, and the second is to change the init file on the ground and uplink the new init file via the



OCA.

Figure 2.15-3. FCMS display

In either case, there are two ways for the FCMS application to use the new init file. The first is for the crew (from within the FCMS program) to select file and then select load new init file. The second method is to restart the FCMS application, and it will use whatever init file is currently in the FCMS directory. The init file is well commented, which makes reading and modifying a straightforward activity. The WordPad application works nicely for editing the init file. See Figure 2.15-4 for an example of the init file.

When data is recorded, the FCMS application builds two output data files. One is an ASCII data file. The other is a zip file, which contains the ASCII data file. The zip file is built to speed up downlink and to minimize file transfer time.

The ASCII data file contains one line for each frame of recorded data. Each line starts with the GMT and is followed by 288 cell voltages. A comma separates each of the cell voltages. Each line is terminated with a carriage return. The 288 cell voltages start with FC1 cell no. 1, followed by FC1 cell no. 2, progressing sequentially to FC3 cell no. 96. The number of lines in the file is the number of frames recorded.

The ASCII file names are based on the GMT of the first time point in the file. For example, a file in which the first time point is at GMT 325/14:02:37.601 will be named fc251402.fcv. The fc at the beginning indicates that the file contains data from all three fuel cells. If the file contained data only from FC1, 2, or 3, the first two letters of the file name would be f1, f2, or f3, respectively. The option to record data from only one fuel cell is selectable in the FCMS application initialization (init) file, but this is an option that will probably be seldom, if ever, used. The numerical part of the file name contains the second two digits of GMT day followed by minutes and then seconds. (The first digit of the GMT day was left off to keep the file name to eight characters because the entire fuel cell community did not have Windows 95 at the time this application was developed.) The .fcv extension stands for fuel cell volts.

### **DOWNLINKING FILE(S)**

The primary mode of operation for the FCMS on orbit is for the crew to record a data file and then downlink it via the OCA. After recording the data file, the next step is to get the file downlinked for MCC, engineering, and vendor analysis.

When an FCMS recording is initiated, the application creates the data and zip files and puts them in the FCMS directory on the hard drive of the machine being used. Under normal circumstances, only the zip file is downlinked. The FCMS procedure (EPS SSR-1 in the MAL PROCS) has the crew transfer the zip file to the ocadown directory on the OCA machine. This transfer or copy can be done via either floppy disk or the onboard network, depending on how the end user PGSC is networked with the OCA machine. When the crew reports that they put a copy of the FCMS file in the ocadown directory on the OCA machine, the Flight Activities Officer (FAO) Multipurpose Support Room (MPSR) personnel will downlink it. Currently, the downlinked file is placed on the MODM server in the u:\inbox\egil folder and then EGIL/EPC personnel are notified.



[INITIALIZATION]

```
; If set to True (1) the GMT will be read from PCDECOM
; If set to False (0) the GMT will be read from the
; system clock
READ_GMT_FROM_PCDECOM=1
```

```
; Upper/Lower limit settings in MV
VOLTAGE_LOWER_LIMIT=920
VOLTAGE_UPPER_LIMIT=1200
```

```
; Limits for ERROR conditions in MV - error text will display
VOLTAGE_LOWEST_LIMIT=0
VOLTAGE_HIGHEST_LIMIT=1250
```

```
; Error text for out of limits high and low
; Limited to 3 chars
LOW_ERROR_TEXT=OSL
HIGH_ERROR_TEXT=OSH
```

[RECORDING]

```
; The number of frames to record for each file for full rate recording
; Each line is approx. 498 bytes for 3 file mode - 1458 bytes in 1 file mode
; 1.2 MB of data=approx. 820 lines
; 1.2 MB=approx. 7 min if 820 lines at 1/2 sec rate
NUM_OF_RECORD_FILE_LINES=820
```

```
; Path location to record the data files in the form - (DRIVE):\PATHNAME\
RECORD_FILE_PATH=
```

```
; Recording mode is 1 file or 3 files
; (all data in one file or separate files for each fuel cell)
RECORDING_MODE=1
```

```
; For interval recording, record FRAME_RECORD number of frames at each
interval
FRAME_RECORD=1
```

```
; For interval recording, AUTO_STOP can be set to true(1) or false(0)
; to have the recording stop when NUM_OF_RECORD_FILE_LINES is reached or
; to continue recording for the entire time interval duration regardless
; of file size
AUTO_STOP=1
```

```
; Recording parms can be set to V for volts MV for millivolts
PARMS=MV
```

```
; File extensions used for recording
ONE_FILE_EXTENSION=.FCV
THREE_FILE_EXTENSION=.FCV
```

```
; Decimal places recorded can be set to 3 or 4
RECORD_DECIMAL_PLACES=3
```

```
; Create a zipped version of the recorded files (1=yes,0=no)
ZIP_THE_FILES=1
```

[DISPLAY]

**Figure 2.15-4. FCMS initialization file**

```
; Interval in which to update the display
; This interval is in 1/2 seconds.
DISPLAY_UPDATE_INTERVAL=2

; Display parms can be set to V for volts MV for millivolts
PARMS=MV
SUBSTACK_TOTALS=V
SUBSTACK_DELTAS=MV
SUBSTACK_GRAND_TOTALS=V

; Computed data for the display can be computed using
; 3 or 4 decimal places
COMPUTED_DATA_DECIMALS=3

; Error and Range limit color values
; RED, GREEN, YELLOW, BLUE, CYAN, WHITE, BLACK
ERROR_LOW_COLOR=RED
ERROR_HIGH_COLOR=RED
RANGE_LOW_COLOR=YELLOW
RANGE_HIGH_COLOR=YELLOW

[DEBUG]
CREATE_A_LOG_FILE=1

; If set to true(1), the data will be read from the FCMSDEMO.INI file
; for testing and demonstration purposes.
[DEMO]
DEMOMODE=0
```

**Figure 2.15-4. Concluded**

One additional note on the OCA downlink capability: Some onboard configuration activities must be performed onboard to allow downlink file transfer. These are generally transparent to the EGIL/EPS, but some upfront coordination with FAO and INCO may be helpful. Also, since the primary mode of OCA downlink uses the Ku-band system, Ku coverage is usually necessary to conduct OCA downlinks. The OCA can be configured to use S-band, but the file transfer in this mode is very slow compared to Ku-band operations. For this reason, FCMS files should be downlinked via S-band only in contingency situations.

## TITLE

HYDROGEN PUMP / H2O SEPARATOR

## PURPOSE

The purpose of this SCP is to describe the function for the Hydrogen Pump/H2O Separator.

## REFERENCES

Orbiter Fuel Cell Powerplant Review and Training Course (booklet and videotapes), International Fuel Cells, March 1999

Orbiter Fuel Cell Powerplant Review and Training Course (booklet), UTC Fuel Cells, June 2002

## DISUSSION

The Hydrogen Pump/H2O Separator is part of the fuel cell's water removal subsystem that is contained in the accessory section of the fuel cell. Water removal is necessary for a fuel cell to work properly. The water removal system is responsible for maintaining proper electrolyte concentration and preventing liquid water from entering the fuel cell stack and flooding the cells. The hydrogen pump (H2 pump) circulates the hydrogen and the water vapor mixture from the fuel cell stack through the condenser. The condenser and H2 pump separate the liquid water from the gas. The humidified hydrogen gas is then returned to the fuel cell stack. The liquid water is discharged into the shuttle's water system for crew use and vehicle cooling.

### A. The Water Removal Process (Refer to Figure 2.16 – 1)

#### Condenser

The condenser receives hydrogen gas saturated with water vapor from the fuel cell stack. After the condenser cools the mixture, water droplets precipitate out. The humidified hydrogen and water droplets flow into the H2 pump / separator section.

#### H2 Pump / Separator Section

The H2 Pump / Separator Section contains an AC motor, which drives an impeller attached to a stack of perforated plates. As the stack of plates spin (at 8000 rpm), the water droplets cling to the plates and are flung outward to form a rotating ring of water. The hydrogen, now stripped of its liquid water, proceeds through holes in the impeller rotor, collects in an annulus of the pump, and then returns to the fuel cell stack.

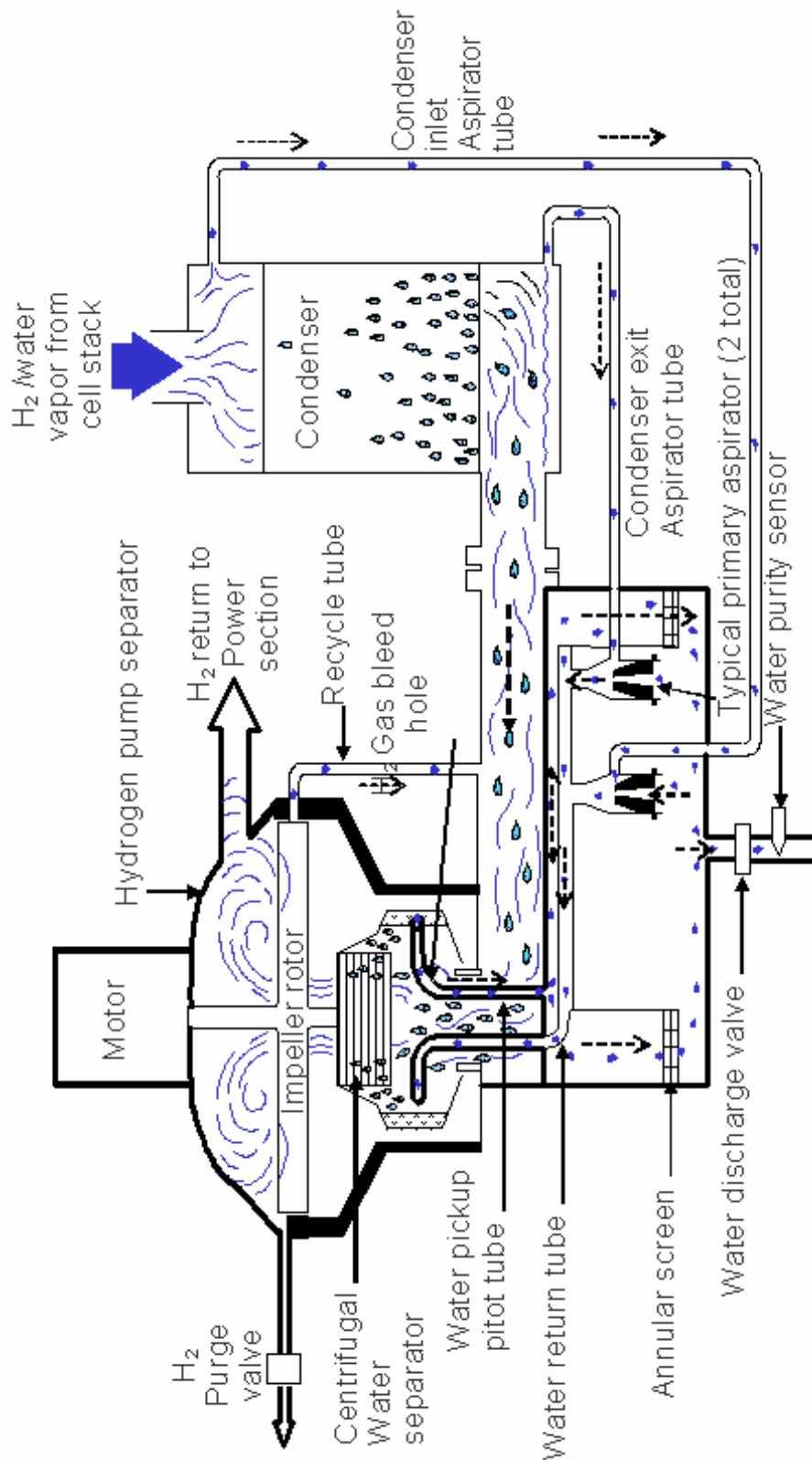


Figure 2.16-1. H2 Pump / Separator

2.16-2

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### Water Discharge Valve

To remove the water out of the H2 pump / separator section, the water discharge valve must open. The discharge valve opens when its diaphragm senses a pressure differential of 5 psi above the fuel cell's hydrogen system pressure. This is accomplished as the water builds up in the rotating ring, increasing the pressure applied to the water discharge valve via the pickup pitot tube. The pickup pitot tube's opening faces upstream against the rotating water. The differential pressure is needed because the valve is biased by a spring, hence acting as a backpressure regulator. When the differential pressure reaches 5 psi, the valve opens and allows the water in the H2 pump / separator section to flow into the Orbiter Water Storage system; then the valve shuts again. While a fuel cell is running, the water discharge valve constantly opens and closes. In an ideal world the valve would find an equilibrium position, and the water discharge flow would be constant. When the water flows out of the water discharge valve, it drops from 60 psia to 15 psia, and hydrogen bubbles appear as result of the dissolved hydrogen disassociating itself from the water. Before the water reaches the Supply Water Tanks, it flows through palladium separators downstream of the water discharge valve in an effort to remove as much entrapped hydrogen from the water as possible.

### H2 Gas Bleed Hole

To remove as much hydrogen from the water as possible before it leaves the fuel cell, a very small hole - about 0.0020 in diameter - is drilled (Labeled "H2 Gas bleed hole" on Figure 2.16-1) on the inside wall of the pickup pitot tube. Due to centrifugal force, the water will go to the outside of the curved tube and the hydrogen will stay to the inside and be expelled through the hole in the pitot tube. Then it will flow through the H2 pump / separator section again.

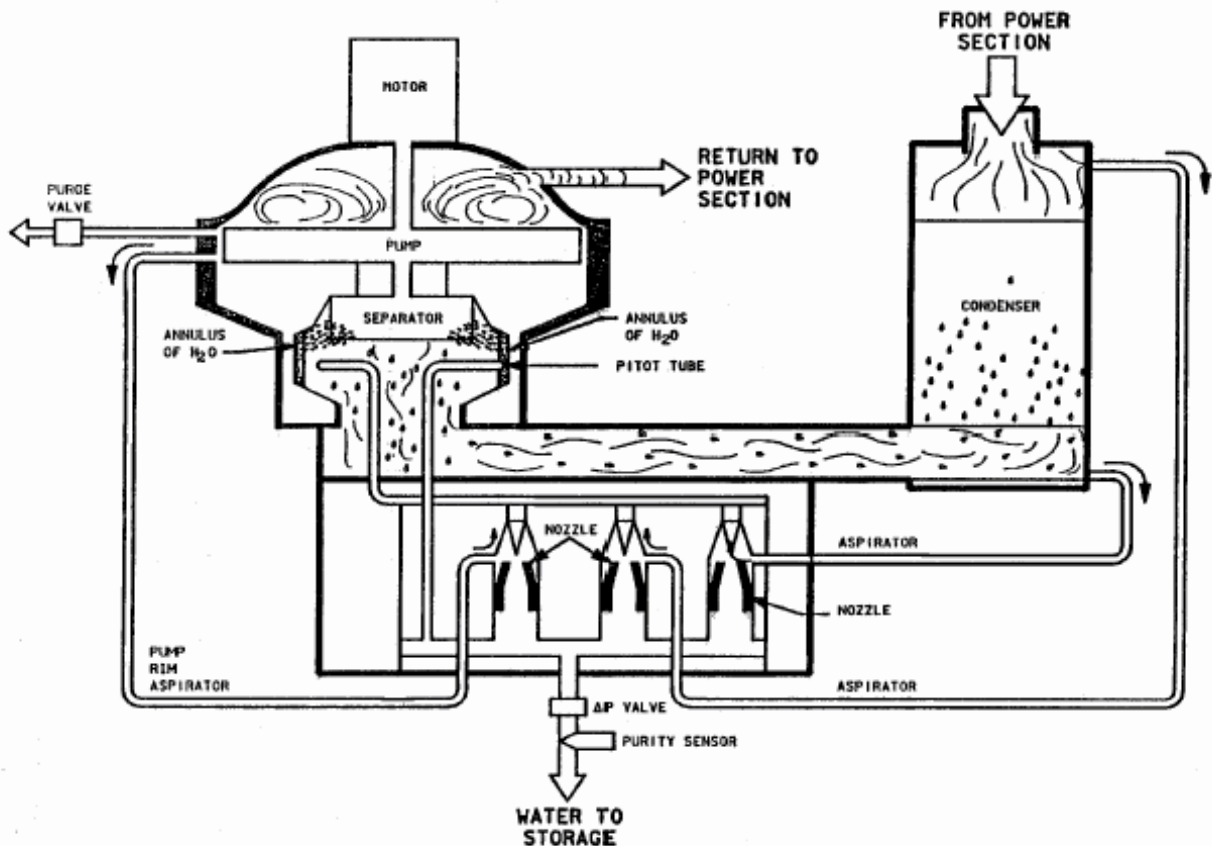
### Condenser Aspirator Tube / Nozzle System

Water pools in the 'cheeks' of the condenser in atmospheric pressure. To remove this water a condenser aspirator tube / nozzle system is in place. It is composed of two aspirator tubes placed on the condenser: one at the inlet and one at the exit. These tubes are routed to individual nozzles that lead back to the H2 pump / separator through the water return tube. The way the system works is some of the high-pressure water from the water pickup pitot tube (waiting to go through the water discharge valve) travels through the two nozzles back into the rotating cup of water in the H2 pump / separator through the water return tube. Due to the Bernoulli effect, the nozzle increases the water's velocity and decreases its pressure in the aspirator allowing the pooling water in the 'cheeks' of the condenser to flow into the H2 pump / separator. The side of the condenser the aspirator tubes are placed determines a right-hand vs. left-hand fuel cell on the orbiter. A retrofit kit allows field conversion of a right-hand fuel cell into a left-hand fuel cell.

Recycle Tube / STS-2 Failure

Under certain conditions condensed water makes its way through the H2 water separator impeller region. This is not the usual case, but during start up and certain cold conditions, liquid water can be found in the impeller-housing region. The ramification is that in the close clearance between the edge of the rotor and the housing is a thin film of water. This water has tremendous drag on the motor, and if allowed to exist the motor will stall because it is not strong enough to rotate at its nominal speed. The motor will not stop completely, but it will slow down to the point that it is basically ineffective.

The original solution was to have three aspirator tube nozzle systems (see Figure 2.16 - 2). The third aspirator was connected to the rim of the impeller rotor-housing region. On STS -2 the H2 motor flooded. The nozzle of the 3<sup>rd</sup> aspirator, which was made out of aluminum, corroded and became plugged, and the aspirator stopped suctioning water out of the impeller-housing region. Then the worst possible situation was present: a high-pressure area full of water had a direct path back to the rim of the impeller region.



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**Figure 2.16-2. STS-2 Fuel Cell Water Removal System.**

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To fix the problem, the 3<sup>rd</sup> aspirator was removed and replaced with a recycle tube that extends from the inlet of the pump (a low pressure area compared to the aspirator pumps) to the rim of the impeller-housing region (see Figure 2.16 - 1). This purposely recycles about 3% of the hydrogen flow down to the inlet of the pump. As a result any water that collects in the impeller-housing region will join back with the humidified hydrogen and water droplets and get directed back into the inlet of the pump for another pass through the H2 separator.

## B. The H2 Pump / Motor

The hydrogen pump is a 400 Hz 115 volt three-phase motor. It is also known as a drag pump because it depends on the friction caused by dragging the material with it which makes it inefficient. It is used because its performance is very consistent and flat. A centrifugal pump would work in this design but is not as easy to handle analytically, and its performance would not be as well known under all conditions. Therefore the inefficiencies of the drag pump are tolerated. It consumes about 60 watts but only does about 5 to 10 watts of useful work. The H2 motor was over designed (i.e. stronger than it needed to be) to overcome the inertia of the heavy wheel assembly during startup and to allow the motor to come up to speed in a reasonable amount of time.

The H2 pump is the only component that UTC Fuel Cells makes; everything else is purchased from an outside vendor - even the H2 motor. UTC Fuel Cells tried to find someone that could make the hydrogen pump when the design first came out but was unsuccessful due to the degree of precision needed.

The H2 motor is an integral part of the hydrogen pump. It is a canned motor; the windings of the motor are on the outside encased in a housing that resembles a 'can'. The interior of the motor, containing the pump impeller, is called a wet motor because the interior is flooded with the wet hydrogen.

## C. FC H2 Motor Status

The performance of the H2 Pump/H2O Separator is monitored by the FC H2 Motor Status indication on the EGIL\_FC\_EPDC display and the crew's Shuttle onboard display SM SPEC 69 (see Figure 2.16 - 3). SPEC 69 is only available to the crew in OPS 2 and 4. This performance monitor was added to the fuel cell after the failure of the H2 Pump on STS-2.

The voltage signal conditioner, that produces the H2 Motor Status, has a series of transformers that create voltages at points 1, 2, 3 and 4 whenever current flows through phases A, B, C or the neutral of the H2 motor (see Figure 2.16 - 4). The H2 Motor Status voltage is measured across points 5 and 6. For nominal 3-phase operation, current flows through phases A, B, and C. In a perfectly balanced system current flows in one phase and out another - no



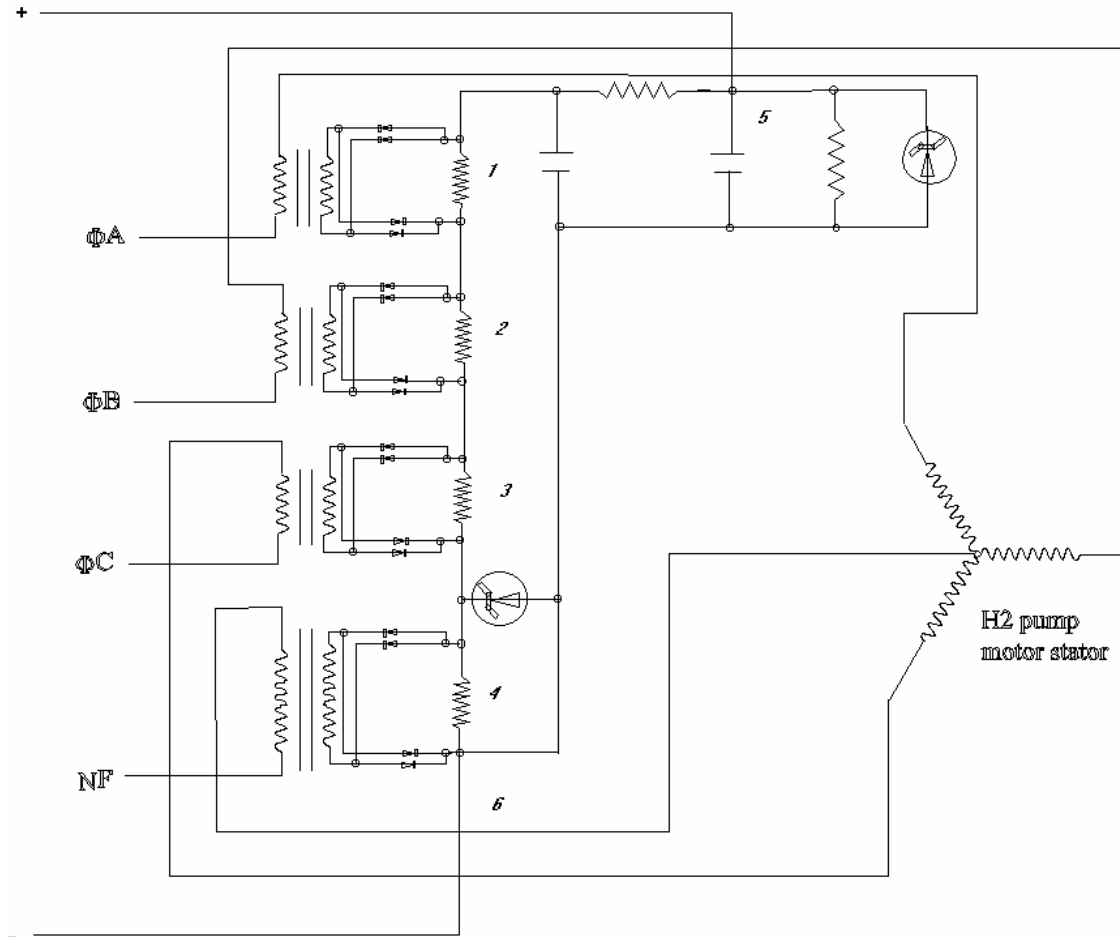
current flows down the neutral line. The H2 Motor Status voltage measured across points 5 and 6 is approximately 0.4 V.

The H2 Pump/H2O Separator can operate on two phases. However, the load is unbalanced so current flows down the neutral line; thus voltage is seen at point 4. The neutral transformer is much stronger than the phase transformers; therefore it produces a higher voltage reading for a given level of current. As a result the H2 Motor Status voltage changes from ~0.4 V to ~ 4 V for 2-phase ops.

In a stall condition, the phase transformers have more current going through them (stall currents are ~1.3 amps per phase vs. ~ 0.2 amps per phase) so the individual phase voltages increase thus increasing the total H2 Motor Status voltage to ~ 2.2 V for a 3-phase stall condition. However, in a 3-phase stall condition the extra voltage produced by the phase transformers still is not as much as the voltage produced by the neutral transformer during 2-phase ops.

000/000/069		FUEL CELLS			4 000/00:00:00	
		FC				
		1	2	3		
VOLTS		30.9	29.9	31.1	H2O RLF LINE T	79
AMPS		150	175	120	NOZ T A	177
					B	177
FLOW O2		3.1	3.6	2.8	HTR SW	A
H2		0.5	0.6	0.4	PURGE LN O2	125
REAC O2		OP	OP	OP	T H2	135
H2		OP	OP	OP	T1 T2	96
STACK T		+202	+206	+200	H2O LINE PH	
EXIT T		151	149	150		
COOL T		90	89	92		
P		60	60	60		
PUMP						
H2 PUMP		0.4	0.4	0.4	PH	
READY		RDY	RDY	RDY	ΔV SS1	2 20 20
					SS2	21 9 43
					SS3	73 22 22
H2O					Δ AMPS	- 25 + 55 - 30
PRI LN T		150	150	150		
VLV T		81	77	75		
ALT LN T		82	86	78		

Figure 2.16-3. SM 69 FUEL CELLS



**Figure 2.16-4. H2 Motor Status Electrical Schematic**

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-2	OV-102	11/12/1981	11/14/1981	Fuel Cell	Flowmeter	FC1 H2 Flowmeter	FC1 H2 Flowmeter reading was low. Many flowmeter failures occur. Flowmeter will be readjusted or replaced when fuel cell is rebuilt. Flowmeter serves no purpose other than an indicating device. Loss of this measurement will not effect the mission.
STS-2	OV-102	11/12/1981	11/14/1981	Fuel Cell	Flowmeter	FC2 O2 Flowmeter	FC2 O2 Flowmeter read OSH. FC2 and FC3 O2 Flowmeters read off scale. The flowmeters will not be replaced until fuel cells are replaced because of possibility of introducing contamination into accessory section. Fuel cells can be manually purged. Software change in work to allow auto purge regardless of flowmeter output.
STS-2	OV-102	11/12/1981	11/14/1981	Fuel Cell	pH sensor	FC1 pH High	Crew observed pH high event on FC1. The crew observed rapid loss of 0.75 V DC in FC1 output voltage. Water from FC1 showed a high pH content followed by loss of output voltage. FC1 was then shut down. The pump rim aspirator was blocked by a small foreign object. This caused progressive flooding of the fuel cell with resultant high pH and voltage loss. AC current data is now carefully monitored to detect any irregularities with the H2 pump. See SCP 2.17 for further information on this failure.

2.17-1

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-4	OV-102	06/27/1982	07/04/1982	Fuel Cell	TCE	FC1 thermal TCE shift	During prelaunch activities of STS-4, FC1 experienced an approximate 8° F downward shift in Thermal canister Experiment (TCE) control. The main TCE cartridge on the thermal control valve was verified out of calibration with entrapped FC-40 fluid (penetrating fluid) between the actuating piston and the boot. The cause of the fluid entrapment was determined through inspection of the piston fluid entrapment relief groove. Rounded corners on the groove near the tapered end of the piston were observed in photographic shadowgraphs. This condition allowed the rubber boot to conform into the groove, blocking fluid flow. A design change effective on three substack fuel cells has increased the number of fluid entrapment relief grooves from one to three. Prelaunch fuel cell procedures will be modified to operate the fuel cell at high power for approximately 30 minutes, as soon as possible after fuel cell activation.
STS-6	OV-99	04/04/1983	04/09/1983	Fuel Cell	Flowmeter	FC powerplant 2	During STS-6 OV-99, the fuel cell powerplant 2 flowmeter failed to the lower limit. The redesign flowmeters are incorporated into the new three-substack FCPs and will support flights in line with the three-substack fuel cell conversion.

2.17-2

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-6	OV-99	04/04/1983	04/09/1983	Fuel Cell	Coolant Pump	FC1 Coolant Pump	During postlanding checkout of STS-6, FC1 coolant pump delta pressure indicated on when FC1 start/stop switch was in stop. The delta P switch contacts (both sets) were verified closed. S/B open. The failure was caused by leakage of FC-40 coolant into the hermetic switch assembly (through defective weld) and subsequent thermal expansion of FC-40, causing the switch deformation. The failed unit on S/N 109 two-substack FCP supporting OV-99 has been replaced with a new switch, which was verified to be working properly. All vehicles incorporating three-substack FCPs either inline or conversion, will include leak-checked coolant pump delta pressure switches.
STS-9	OV-102	11/28/1983	12/08/1983	Fuel Cell	FC Water	FC confidence run	Excessive free hydrogen has observed in ECLSS potable water tank while accumulating water during the fuel cell confidence run before STS-9. Troubleshooting determined that FC2 and FC3 were responsible for the abnormal water tank condition. A significant quantity of GH2 was being discharged, along with product water. Excessive amount of H2 gas was found in the potable water systems. The source was determined to be a secondary water filter that was separating H2 gas from the circulating water flow stream and diverting it to

2.17-3

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							the water discharge valve. The filter is a two-stage filter and, if modified to eliminate second stage, will eliminate the H2 entrapment problem while maintaining necessary filtration. Corrective action consists of replacing the fuel cells with units demonstrating acceptable H2 content following installation of the filter modification.
STS-27	OV-104	12/02/1988	12/06/1988	Fuel Cell	FC ALT T	FC2 ALT H2O Line T	FC2 alternate H2O line erratic temperature. Investigation isolated the problem to an erratic thermostat, a leak in the alternate water line check valve, or effects of the flight thermal environment. Troubleshooting at KSC could not duplicate the problem with either the thermostat or valve. The "B" thermostat was removed, and it was tested within spec. The probable causes are that the vehicle was in a bottom Sun attitude for an extended period when this occurred, and the thermostat may have been installed loosely. From flight data, it was noted that when the line heaters were switched to the "B" circuit and the bondline temperature decreased below approximately 100° F, the line heaters cycled within the normal range. The subsequent flight (STS-30), with a more benign

2.17-4

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							environmental temperature and a new thermostat, resulted in normal operation.
STS-31	OV-103	04/24/1990	04/29/1990	Fuel Cell	Flowmeter	FC2 O2 Flowmeter	FC2 O2 flow rate high during purge. See SCP 2.16 for more detail.
STS-41	OV-103	10/06/1990	10/10/1990	Fuel Cell	Flowmeter	FC1 H2 Flowmeter	FC1 H2 Flowmeter static at 0.19. Shortly after FC1 starts, the H2 flowmeter drifted low and became static at a reading of 0.19. The output remained at 0.19 for the remainder of the mission. The fuel cell flowmeters have a history of failures such as this.
STS-41D	OV-103	08/30/1984	09/05/1984	Fuel Cell	CPM	FC1 CPM	During the first flight of OV-103 STS 41-D, the fuel cell performance monitor for FC1 failed low on the following measurements: V45V102A, V45V103A, and V45V104A. The cause of the flight problem was a shorted Q4 transistor which, in turn, burned resistor R10 and discolored R32. Also, transistor Q2 opened. Loss of CPM is detectable during flight, but noncorrectable. The main buses can be reconfigured to allow fuel cell operation. Loss of the CPM would not affect the mission or fuel

2.17-5

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							cell performance. (Failure of the CPM would only require the crew to tie the failed CPM fuel cell to another bus as accomplished on STS 41-D).
STS-48	OV-103	09/12/1991	09/18/1991	Fuel Cell	FC Reac Vlv Ducer	FC1 O2 Reac Vlv Ducer	FC1 O2 reactant valve indicated failed closed. On flight day 2, the FC1 reactant valve indicated a closed position. All further indications suggest a transducer failure. During presleep cryo reconfiguration on flight day 3, the valve indicated open again. Indication in both instances were on both the documented MSIDs and the R1 talkback.
STS-51J	OV-104	10/03/1985	10/07/1985	Fuel Cell	Flowmeter	Failure of Fuel Cell 3 O2 Flow Transducer	Fuel Cell 3 O2 flow transducer failed to Off-Scale Low (OSL) upon initiation of manual purge on Fuel Cell 3. There was no impact to the mission.
STS-61A	OV-99	10/30/1985	11/06/1985	Fuel Cell	FC Condenser	FC1 Condenser Exit T	FC1 condenser exit temperature became unstable during the OV-99 STS 61-A mission. A sticky condenser exit thermal control valve is suspect. This powerplant was stored dry for approximately 1 year since being rebuilt. Dry storage may have resulted in altered valve operation due to a change in the valve cartridge rubber boot characteristics. The degree of condenser exit temperature shift was

2.17-6

Verify that this is the correct version before use



Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							not great enough to warrant action by the crew. It was within allowable operating parameters.
STS-61B	OV-104	11/26/1985	12/03/1985	Fuel Cell	Fuel Cell	FC2 Voltage degradation	FCP voltage degradation noted in STS 61-B mission. The degradation in the powerplant output voltage was caused by the inability of the reactant regulator to provide an adequate purge of the power section. The less than adequate purge is the result of the duct feed valve being left cracked open due to a misseated valve spring. FC2 exhibited a degradation in performance during flight 2 of OV-104 (STS 61-B). The powerplant output voltage dropped roughly 0.5 volt throughout the mission. This condition is suspected to have been caused by a sticky dual-feed valve. A sticky valve would limit the amount of purge gas flow through the power section during purging operations. This would prevent the adequate removal of impurities within the power section. The problem was further compounded by the presence of an excess amount of He in the O2 cryo supply. Fuel cell powerplant integrity is last verified when the power plants are powered up during prelaunch operations.

2.17-7

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-61B	OV-104	11/26/1985	12/03/1985	Fuel Cell	Flowmeter	Fuel Cell Flow Ducer Fails	Preflight it was noticed that the FC1 H2 Flow Ducer (V45R0160A) was frozen at 0.18. Also FC3 O2 Flow Ducer (V45R0360A) failed OSL. The losses did not have any impact on the mission. At GMT 331/04:18, Fuel Cell H2 Flow Ducer recovered and continued to perform normally. A simular failure/recovery scenario was exhibited by this measurement on the last flight of this vehicle (51-J).
STS-61C	OV-102	01/12/1986	01/18/1986	Fuel Cell	Fuse	ESS1BC Fuel Cell 1 Feed	During prelaunch activities, it was noted the FC 1 volts transducer was erratic when the F9 meter was selected for FC1 volts and when the FC1 source for ESS1BC was enabled. Otherwise the FC 1 volts transducer displayed a bias of approx 1 volt low. Further testing at KSC showed that FC 1 did not feed the ESS1BC bus. It was confirmed, however, that MN Bus B and MN Bus C where each powering the ESS1BC bus. It is thought a high impedance exists between the 20 amp fues (F31) in the Main Distribution Box feeding FC 1 power to the ESS1BC bus and the ESS1BC-FC1 source switch on Panel R1. FC1 volts transducer is reading properly on orbit, but is considered suspect. As part of hte Post-Flight troubleshooting, the Main Distribution Box will be removed and examined. The ESS1BC Bus is redundantly powered via the MN Bus

2.17-8

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							B and MN Bus C feeds, so there was no impact. The FC1 volts transducer is considered unreliable, so the A/E system procedures and the ASCENT, ORBIT, and ENTRY POCKET CHECKLISTS were updated.
STS-28	OV-102	08/08/1989	08/13/1989	Fuel Cell	Flowmeter	FC1 H2 Flowmeter	Fuel cell 1 H2 flow measurement is drifted high during STS-28. The H2 cryo usage did not reflect high flow rate. Loss of FC1 H2 flow measurement was the impact. Fuel cell H2 leak detection was suspect. Possible false alarm could annunciate if the measurement exceeded onboard limit, if left unchanged. H2 flow can be calculated from fuel cell power usage. The cryo H2 usage will be relied upon to detect FC1 H2 leakage. The limit was TMBU'd to off-scale high. Problem tracking list #5C.

2.17-9

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-29	OV-103	03/13/1989	03/18/1989	Fuel Cell	H2O RLF VLV	FC1 H2O RLF VLV T	The crew configured the fuel cell H2O Relief Heaters to the B AUTO position per the heater reconfiguration on the morning of FD3. The B thermostat immediately turned the heater ON since its temperature was 70° F. The temperature rose to 130° F before a normal cooldown was seen of the H2O line. STS 26 data on this thermostat showed that the temperature never rose about 105° F during its cycling when OV-103 was in a cool attitude. Thermostat had been changed out post STS 26. B HTR cycles were higher than A HTRS. This thermostat/heater needs further troubleshooting. There is no impact to the mission. A recommendation was made to test the thermostat for proper set points. Problem tracking list number 16.
STS-42	OV-103	01/22/1992	01/30/1992	Fuel Cell	FC H2 MTR	FC2 H2 MTR Status	For about 7 seconds, Fuel cell 2 H2 MTR Status increased from about 0.6 volts to as high as 1.5 volts. AC2 phase A increased approximately 0.1 amps, phase B increased approximately 0.2 amps, and phase C decreased approximately 0.15 amps. There was no impact to the mission. This was considered an unexplained anomaly. In case this was caused by oxidation on the phase C circuit breaker, the crew cycled the circuit breaker open, then closed. No additional troubleshooting was

2.17-10

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							performed. MER tracking problem #1A, B.
STS-45	OV-103	01/22/1992	01/30/1992	Fuel Cell	FC CPM	FC3 CPM Anomaly	FC3 CPM SSDV remained at the self-test value (50 mV) at approximately GMT 084/14:30. Values would cycle between normal and self-test values each time a self-test was performed. CPM returned to normal operation at approximately GMT 084/16:40. A second occurrence of this failure occurred at approximately GMT 085/20:00 until 085/23:30. FC3 was bus tied to a good FC to ensure insight into fuel cell performance. (Bus tie performed for SPACELAB support anyway). A Main Bus B-C remained in place and FC delta amps was monitored. A CHIT was written to assess accuracy of delta volts values. CHIT asked for failure history/similarities. Response to CHIT #005 expressed confidence in the CPM delta volt data for this failure mode. MER tracking problem 4.

2.17-11

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-50	OV-102	06/25/1992	07/09/1992	Fuel Cell	Purge Valve	FC3 O2 Purge Vlv Anomaly	After the AUTO FC Purge, FC3 O2 Purge Vlv did not close completely and O2 flow rates remained high (about 70% of purge flow rate overboard). If valve remained partially open, it would significantly impact O2 consumables with a 2 lb/hr leak overboard. FC3 O2 Purge Vlv was manually opened for 10 seconds, then closed. This took care of hte excess flow. Purges will be minimized to reduce exposure to partially failed open valve MER problem tracking list number V07.
STS-52	OV-102	10/22/1992	11/01/1992	Fuel Cell	FC CPM	FC1 Suspect CPM	FC1 Substack 3 Delta Volts transitioned from 36 mV to 44 mV after self-test. Substack 3 maintained 44 mV after self-test. Substack 3 maintained 44 mV for varying amounts of time before returning to normal value of 36 mV. The transistions to 44 mV occur after each CMP self-test. (The same failure has been seen on STS 61-B). FC 1 was bus tied to a good fuel cell to ensure insight into fuel cell performance. Main Bus A and B were tied to monitor FC delta amps. MER problem tracking No. 6, PR FCP-2-14-0257.
STS-54	OV-105	01/13/1993	01/19/1993	Fuel Cell	FC ALT H2O LN	FC3 ALT H2O LN T Increase	At touchdown, FC3 ALT H2O LN Temperature (MSID V45T0382A) increased from 90° F to a peak of 127° F postlanding. This may be a result of an open ckeck valve which

2.17-12

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							normally isolates the ALT path from the fuel cell water. There is no mission impact. Possible turnaround impact of check valve is failed open. MER problem tracking list No. 7.
STS-55	OV-102	04/26/1993	05/06/1993	Fuel Cell	FC ALT H2O LN	FC2 ALT Line Temp	At approximately 0/04:00 MET, the FC2 Alternate Line temperature was seen to increase from its nominal 70°-90° F to 120°-130° F. Fuel Cells 1 and 3 Line temperatures remained normal. This is indicative of a leaky check valve on the Alternate H2O line and was also noticed during STS-52. At approximately 1/01:00 MET, the supply and alternate H2O lines depressed due to a leak in the water N2 common manifold and FC2 Alternate line temperatures returned normal indicating the Alternate H2O line check valve reseated. When the water tanks were repressurized, the fuel cell alternate line temperature increased. This confirms a leaky check valve. There was no impact to the mission.
STS-56	OV-103	04/08/1993	04/17/1993	Fuel Cell	Fuel Cell	FC Substack 3 Delta Volt Increase	During each FC Purge, the FC SS3 Delta Volt measurement (V45V0104A) increased by amounts greater than have been seen normally. During the first purge, SS3 Delta Volts increased by 8 mV and by 40 mV on the last purge (normal change is < 5 mV). This is indicative of uneven performance between the two halves of SS3 and may be

2.17-13

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							caused by O2 cell port plugging. There was no impact to the mission. Possible turnaround impact. The resolution was to avoid purging FC1 for the remaining of the flight. MER problem tracking list No. 12.
STS-63	OV-103	02/03/1995	02/11/1995	Fuel Cell	H2 MTR	FC2 H2 MTR Status	For about 6 seconds, FC2 H2 MTR Status increased from about 0.6 volts to as high as 0.83 volts. AC2 phase B increased ~ 0.2 amps, phase C decreased ~ 0.1 amps, and phase A showed no change. There was no impact to the mission. A similar anomaly occurred prelaunch on STS-42, OV-103, with FC2. Post STS-42 the fuel cell ECU was replaced. The cause of hte STS-42 anomaly is presently unknown.
STS-66	OV-104	11/03/1994	11/14/1994	Fuel Cell	FC ALT LN	FC2 H2O Flow Through ALT Path	Fuel cell 2 Alternate H2O Line temperature indicated flow down the alternate water path. At approximated 0/01 MET the Fuel Cell 2 Alternate H2O Line temperature (V45T0282A) rapidly increased from 82° F to 130°-135° F, where it has remained. Normal range of temperatures is 70°-90° F; higher temperature is indicative of flow through the alternate path. There was no impacts at the time. Possible nuisance FES shutdown if full FC 2 H2O flow, with significant hydrogen content, is experienced through the alternate path to supply H2O Tank B.

2.17-14

Verify that this is the correct version before use



Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							The temperatures were continued to be monitored throughtout the flight as well as the Supply H2O Tank B quantities to quantify amount of flow through the alternate path. MER problem tracking list No. V-03.
STS-66	OV-104	11/03/1994	11/14/1994	Fuel Cell	H2 MTR	FC2 H2 MTR Status Erratic	Fuel Cell 2 H2 MTR Status (V45V0214A) was erratic. At GMT 310:12:20, the parameter value took a step increase from 0.36 volts to 0.48 volts with no associated change in AC2 currents or FC2 performance. AT GMT 315:07:21 the parameter step changed back to 0.36 volts, again with no other associated AC2 changes, and agina to 0.48 volts at GMT 315:06:35. Typical parameter value is > 0.4 volts. The impact was possible loss of insight into Fuel Cell 2 H2 MTR performance, if the status failed and not biased. The parameter remained within limits of nominal H2 MTR performance. Changes in AC2 current and FC2 performance was used to verify the health of the H2 MTR. Main Bus B was already tied to Main Bus C for SPACELAB operations.

2.17-15

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-69	OV-105	09/07/1995	09/18/1995	Fuel Cell	FC Condenser	FC2 Condenser Exit Temp High	During FC2 startup, the condenser exit temp exceeded LCC limit of 160° F, FC2 was shut down when the exit temperature reached 184° F. The restart attempt yielded the same result. The launch was scrubbed due to loss of a FC.
STS-74	OV-104	11/12/1995	11/20/1995	Fuel Cell	FC CPM	FC3 CPM Funny	At MET 2/07:31, all three substack delta volt measurements (V450302(3,4)A) shifted by approximately 8 mV. There was no significant load change on Fuel Cell 3 at the time. Additionally, the CPM self test signal, which had been at a value of 48 mV, also shifted to a self-test value of 56 mV (2 mV away from self test failure). There was no impact to the mission. The shifted values still provided acceptable insight into FC3. The FC3 Substack 1, 2, 3 delta volts FDA was inhibited for crew sleep and rendezvous to prevent nuisance FDA in the event the CPM shifted again and failed the self-test. Further assessment was made the determine if hte FDA should remain inhibited. This was considered a "funny" versus an "anomaly" since the self test values remained within limit.

2.17-16

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-79	OV-104	09/16/1996	09/26/1996	Fuel Cell	Fuel Cell	FC2 pH	Fuel Cell 2 generated a pH on startup that remained for 15 minutes after connection to MN B. The pH was received during both fuel cell load adjusts, and the common pH indication was received each time. KSC performed a litmus test check at the galley which gave a result of 7 (nominal). Another pH was received at MECO, with the common pH indication following 4 minutes later. The pH remained on and intermittent for 20 minutes and then both indications went back to a nominal status. A bus tie, FES, and H2O tank reconfiguration was performed per the APCL procedure, FC pH High. EGIL requested that the crew perform the IFM procedure, FC H2O pH test, to ensure the Orbiter H2O supply did not have an excessive amount of KOH. At MET 5 hrs, the crew called down the results of the litmus test. There was no mission impact. The inflight maintenance procedure, FC pH test, p. W-13, was performed. The crew reported the litmus test had the following results: Initial 8-9, at 2 minutes: 7-8, at 3 minutes: 6-7, at 10 minutes: 6-7. FC2 performance remained steady throughout the mission as evidenced by the voltage, delta amps on the bus tie, and no anomalous H2 motor indications. The bus tie was maintained to monitor fuel cell performance and the busses

2.17-17

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							were untied before rendezvous. This FC was "out of family" for a new fuel cell when it comes to pH indications after startup.
STS-79	OV-104	09/16/1996	09/26/1996	Fuel Cell	Flowmeter	FC2 O2 Flow Transducer	At approximately 2/00:00 MET, the Fuel Cell 2 O2 Flow transducer (V45R0260A) began to slowly degrade and was no longer reflecting the fuel cell load. There was no impact to the mission. Other insight remained that could be used to monitor the fuel cell.
STS-81	OV-104	01/12/1997	01/22/1997	Fuel Cell	FC CPM	FC2 CPM Self-Test Anomaly	At 020/08:06 GMT, Fuel Cell 2 CPM performed a self-test and remained in self-test mode (all three Substack Delta Volts measurements read approximately 50 mV: V450203A, and V45V0203A, and V45V0204A) for 3.5 minutes versus the normal 2 to 3 seconds. This anomaly repeated itself for the next four successive self-tests (approximately every seven minutes). At 020/08:46, another self-test occurred which appeared to be nominal. Subsequent self-test also

2.17-18

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							appeared to be nominal.
STS-82	OV-103	02/11/1997	02/21/1997	Fuel Cell	FC ALT LN	FC3 H2O Flow Through ALT Path	Fuel Cell 3 Alternate H2o Line temperature indicated flow down the alternate water path. At approximately 001/16:14:00 MET the Fuel Cell 3 Alternate H2O Line temperature (V45T0382A) increased from 76° F to 126° F. Normal range of temperatures is 70°-90° F; higher temperature and small pressure spikes in the alternate line (V45P0187A) are indicative of flow through the alternate path. This is the first occurrence for the valve (S.N ED6607). At MET 001/17:07 MET, immediately following the On-Orbit NH Burn TIG, FC3 Alternate H2O Line temperature began dropping back to the normal temperature range of 70°-90° F. Indicating that the flow down the alternate line had stopped. There were indications that a small amount of H2O from FC3 was intermittently seeping down the alternate path. FC3 continued to relieve water through the primary path. H2O Supply Tank C was isolated for EMU recharges to avoid H2 contamination. A potential impact to the EMU water servicing from Tank

2.17-19

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							C initiated a concern since the water from the alternated lines does not pass through the hydrogen separators. To preclude the potential of hydrogen transfer to EMU's, water was dumped from Tank C using the FES and then was transfered from Tank A to Tank C. The Tank C water was then used for the EMU water servicing.
STS-83	OV-102	04/04/1997	04/08/1997	Fuel Cell	Fuel Cell	FC2 Substack Deltavolts Anomaly	During prelaunch (IPR-83V0139) and on orbit, Fuel Cell 2 substack 3 delta volts (V45V0204A) exhibited unusual begavior, trending toward the point where Flight Rules dictate the fuel cell be safed. The fuel cell did not exhibit any performance digradation, or any other confirming cue of a problem. On orbit, multiple fuel cell purges were performed with minimal effect on the trend. A reconfiguration of the main bus tie was performed in an effort to stabilize the substack trend. At that point, fuel cell 2 substack 3 delta volts appeared to stabilize at about 130 to 144 mV. As concern over fuel cell 2 health continued, the community decision was made to safe the fuel cell. Fuel Cell 2 was safed at 001/23:44 MET. Fuel Cell 2 was lost and Loss of 1 Fuel Cell

2.17-20

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							powerdown procedures were performed resulting in orbiter and payload powerdowns. A Minimum Duration Mission (MDF) was invoked. This substack trend is out of family. No definite conclusion on what caused the problem could be made by the Engineering and Flight Control community. The same trend was not seen on previous flights of this fuel cell. For further information reference SCP 2.16.
STS-83	OV-102	04/04/1997	04/08/1997	Fuel Cell	Reactant Valve	FC2 H2 Reactant Valve Failure	At MET 001/23:46:54 during Fuel Cell 2 Safing, the Fuel Cell Reactant Valves were closed. Indications were received that only the O2 REAC Valve had closed, and the the H2 REAC Valve (V45X2155E) remained open. The crew confirmed that the Panel R1 talkback also indicated the H2 REAC Valve was open. The crew was requested to attempt to close the valve via the Panel C3 Redundant Reac Valves circuit breaker and switch. The circuit breaker was closed and the switch taken to CLOSE with no success. The C3 swithc has held in the CLOSE position for an additional minute, again with no success. There was no impact to the FC safing. The Fuel Cell's regulator is designed to maintain a balance pressure within

2.17-21

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							the powerplant stack by allowing the excess reactants to vent overboard during the safing process. This can occur even with only one reactant valve closed. FC 2 was successfully safed. AT MET 002/06:03, a switch retention device was placed over the panel R1 switch, holding it in teh CLOSE position. The valve successfully closed in approximately 1 second of installation of the switch.
STS-84	OV-104	05/15/1997	05/24/1997	Fuel Cell	Flowmeter	FC3 H2 Flow Transducer Erratic	Following Fuel Cell 3 start-up, it was noticed that the H2 flow transducer (MSID = V45R0370A) was giving erratic readings. EGIL has inhibited FC3 H2 flow FDA via TMBU. Impacts included that the the SPEC 69 and TLM FC3 H2 flow readings are unreadable. Insight into FC3 and H2 system is reduced. Post-flight troubleshooting required.
STS-86	OV-104	09/25/1997	10/06/1997	Fuel Cell	Fuel Cell	FC2 Substack 1 Delta Volts Transient	During ascent the crew received 2 messages at MET 000/00:01:14 and 000/00:01:42 for the Fuel Cell 2 substack 1 delta volts measurement. The voltage started increasing from 6 millivolts, eventually reaching Off Scale High and after approximately 45 seconds settled back to 6 millivolts. The delta volts measurement then remained stable and the CPM continued to have

2.17-22

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							nominal self tests. There was no impact to the mission. Post MECO, Main Bus B was tied to Main Bus A to monitor fuel cell performance.
STS-91	OV-103	06/02/1998	06/12/1998	Fuel Cell	Overboard Relief	Fuel Cell Overboard Relief	FC3 relieving water through the overboard relief nozzle. Condition had also been observed pre-mission. When the supply H2O tanks were pressurized, approximately 100% of FC3 water was relieving overboard. When the tanks were depressed to 5 psig and 0 psig, percentast of FC3 water going overboard was about 50% and 30% respectively. During crew sleep on FD6, at approximately 5/04:30, FC3 appeared to have stopped relieving overboard while the tanks were depressed to 0 psig. This lasted for approximately 6 hours until the tanks were pressurized at crew wake. A survey of hte relief nozzoe using the RMS was performed on FD9. Small amounts of ice were observed to be forming and breaking off from the nozzle area. No ice formation was observed on the PLB doors or any other exterior Shuttle surfaces. The impact was that it reduced the amount of water going to the supply water tanks, resulting in less water available for transfer to MIR and for extension day deorbit

2.17-23

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							opportunities. Postflight inspection was recommended.
STS-91	OV-103	06/02/1998	06/12/1998	Fuel Cell	FCMS	Fuel Cell	The first set of FCMS data takes were initiated at a GMT 156:20:08. The Full rate data take was performed and completed successfully. The Interval recording (1 sample every 5 minutes for 10 hours) was initiated prior to sleep. At crew wakeup, the crew reported that the Interval recording was unsuccessful (only 1 2KB file was generated). The same data takes were attempted again (GMT 159/21:09) with similar results. The Full data rate completed successfully but hte Interval recording again suspended (18KB file size). The crew was give a go to restart the Interval recording, but the application suspended again (2 KB file size). The crew restared the FCMS application using an interval of 1 sample every 5 minutes for 5 hours.

2.17-24

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							<p>The crew reported that hte Record Complete status was bouncing around (going from 1% to 99% to 18%). The third attempt at data takes was performed at GMT 161/18:40. Both the End User PGSC and PCDECOM PGSC were rebooted prior to the Interval data take attempt. Once initiated, the crew reported that they saw the GMT clock on the display jumping from GMT 161 to 162 to 462. The crew exited the FCMS application and updated the FCMS.ini file to use the PGSC System Clock (versus the Orbiter Timing Buffer). The crew restarted the FCMS application, and reinitiated the Interval data take. Crew reported that the GMT was now updating properly. Prior to sleep, the crew reported that the GMT was still updating properly and the data file was 35% complete. At wakeup, the crew reported that hte GMT was still updating properly and the data file was 35% complete. At wakeup, the crew reported that hte Interval data take had completed successfully. The problem appears to be related to the GMT time in the FCMS data stream. It's unclear at this time if the problem is with the PGSCs, FCMS software, or with the vehicle hardware.</p>

2.17-25

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-94	OV-102	07/01/1997	07/17/1997	Fuel Cell	CPM	Fuel Cell 3 Cell Performance Monitor Suspect	At approximately MET 000/00:34, Fuel Cell 3 substack 2 Cell Performance Monitor (CPM) output (MSID V45V0303A) increased from 2 mV to a level of 34-36 mV over a 20 minute period. Per a memorandum from the Fuel Cell vendor, (International Fuel Cells memo IFC SIM 038), this signature could be caused be a failed resistor in the CPM circuitry. The memorandum states that if the CPM reading increases past 42 mV, the CPM would no longer be considered suspect. The impact was possible loss of insight to the Fuel Cell 3 substack 2 performance. A Main B to Main C bus tie was maintained to monitor laod sharing between FC 2 and FC 3, to gain insight into FC 3 performance. Beginning with FCS checkout, the FC 3 CPM showed readings of up to 46 mV. Data was pulled between 14/11 and 15/11 MET and indicated the FC3 SS DV2 reading to be nominal and reflecting FC performance. Therefore the EGIL discipline did not feel the CPM failed.
STS-96	OV-103	05/27/1999	06/06/1996	Fuel Cell	Flowmeter	Fuel Cell 3 H2 Flow Transducer	At 007/22:29 MET, the Fuel Cell 3 H2 Flow transducer (V45R0370A) failed OSL. There was no mission impact. These flow transducers have a history of failing. Other insight remains that can be used to monitor the fuel cell. FDA was inhibited for this parameter.

2.17-26

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-107	OV-102	01/16/2003	02/01/2003	Fuel Cell	FCMS	Suspect FCMS Data System	At GMT 18/14:03, the crew reported having problems with the Fuel Cell Monitoring System (FCMS) Data Take; they received a red error message: "Windecom Connection Could Not Be Made." The crew rebooted the PGSC and tried again and received the same error message. The crew verified the Windecom PGSC was configured correctly, then replaced the FCMS cable (part number SED39131027-301, serial number 1003) with the backup cable. After cable replacement, the FCMS Data Take worked nominally. Then at GMT 31/02:02, the crew reported the same problem with the backup cable (S/N 1004); they also tried rebooting the Windecom PGSC. All efforts ended with the same error message: "Windecom Connection Could Not Be Made." Due to crew time constraints, the second FCMS data take was cancelled. FCMS is now deamed unreliable and was not able to be used for Fuel Cell troubleshooting. No other FCMS data takes were planned for the flight. If Fuel Cell troubleshooting requires an FCMS data take, it will be attempted at that point (having in mind that it is more than like not to work).

2.17-27

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-109	OV-102	03/01/2002	03/12/2002	Fuel Cell	Faint Object Camera	Unexpected Fuel Cell 3 Spike during EVA4 Faint Object Camera (FOC) Removal	At approximately MET 5/23:07, the Orbiter Fuel Cells saw a spike of 30-32 amps. At approximately the same time the Fuel Cells saw this spike, the Direct Power Converters (DPCs) was analogous spikes. All current pather from the DPCs were eliminated as the casue of hte spike except for the path providing current to the HST work and Indicator lights. At the time of hte spike, this circuit was closed when the crew opened the A-Latch to remove the Faint Object Camera (FOC) from the Hubble Space Telescope (HST). Indicator ligts operated nominally after the spike. This circuit was interrupted when the Advanced Camera for Surveys (ACS) was installed and will not be used again during this flight. There was no impact to the mission.

2.17-28

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## TITLE

STS-2 FUEL CELL 1 FAILURE

## DISCUSSION

The failure mode of FC1 is very interesting. In training, fuel cell failures are cut and dried and readily apparent from watching data on EGIL display 605. In real life, the failure showed itself in several ways, all very subtle.

Before looking at the failure scenario, it is interesting to look at the failure itself. Figure 2.18-1 shows the fuel cell water removal system. Warm H<sub>2</sub> and water vapor flow through the condenser. See SSSH drawing 3.4 for overall fuel cell information. Also flowing through the condenser is FC-40, the fuel cell coolant loop. The coolant loop cools the H<sub>2</sub> and water vapor, thus enabling the rotating plates in the fuel cell water separator to separate the now free water droplets from the vapor. Inside the separator, a rotating annulus of water is thus formed. A pilot tube is positioned in this rotating annulus of water to create a high pressure. Thus the water is removed from the pump and from the inlet and outlet of the condenser and returned to the water separator via another tube that is not normally immersed in the rotating annulus of water. However, should the water cover this tube also, both tubes will reach a high pressure, and the water can no longer flow. At this point, a pressure buildup occurs on the aspirator side of  $\Delta P$  valve. When the  $\Delta P$  is greater than 5 psid, the valve opens, allowing only water into the product water line. When the tube is uncovered, the  $\Delta P$  again becomes small, the valve closes, and the cycle begins again.

The FC1 failure was initiated when a foreign particle lodged in the H<sub>2</sub> pump impeller nozzle exit. Subsequent testing duplicated STS-2 FC1 symptoms. Partial blockage of the nozzle exit caused

- A. Backflow to impeller
- B. Backflow of water through pump to power section (through H<sub>2</sub>O trap)
- C. AC current 0.2 to 0.4 amperes higher

Additional testing confirmed the following data analysis conclusions:

- A. Total blockage of any nozzle inlet - pump operated normally.
- B. Total blockage of pump impeller nozzle exit - pump stalled.

In the case of the FC1 failure, hindsight is 20/20. Before the first launch attempt of STS-2, fuel cell purges were performed on all three fuel cells. During these and subsequent purges, the AC1  $\phi A$ ,  $\phi B$ , and  $\phi C$  currents were high (Figure 2.18-2) by 0.3 to 0.4 amperes (seen as 1 millimeter on stripchart) before start of purge, and the current decreased by 0.3 to 0.4 amperes with purge initiation and again increased 0.3 to 0.4 amperes with purge completion. The astute observer would have seen this as the loading, unloading, and reloading of the H<sub>2</sub> pump for FC1 due to the water that the

blocked aspirator prevented from being removed. Only AC1 showed the characteristic traces. The H<sub>2</sub> pump is not designed to pump liquid, only vapor.

After the successful launch of STS-2, the symptoms should have become even more obvious to an observer looking at the AC currents on stripchart. Instead of the normal straight line current traces (Figure 2.18-3), AC1  $\phi$ A,  $\phi$ B, and  $\phi$ C currents were erratic. Less than 1 millimeter swings to begin with, but the difference between them and AC2 and AC3 was apparent. This and the purge signatures were adding up to a fuel cell problem. Without the purge data, the erratic AC current could have been caused by any of the equipment on AC1. As the flight continued, AC1 became steadily more erratic. Another parameter which could have been helpful was the FC1 condenser exit temperature. After looking at FC1, 2, and 3 condenser exit temperature plots from launch until FC1 shutdown, a difference in the traces was evident. FC1 exit temperature was more erratic than either FC2 or FC3. This was not obvious by looking at real-time digital data on EGIL display 605. As the failure progressed and the fuel cell flooded, the water in the fuel cell began to leach out KOH. Thus, the small amount of water still being removed from the fuel cell triggered the pH sensor. At this point, the AC1 currents became very erratic (relative to their normal straight line signature). The AC traces fluctuated by as much as 0.6 amps (Figure 2.18-4). The failed fuel cell began to offload itself, as seen in Figure 2.18-5.

When the fuel cell failure was identified by the EPS operator, FC1 became the first STS fuel cell to be shut down in "real time." Shortly after shutdown, it was suggested that the fuel cell be safed to remove the remaining reactants from within the stack. The triggered pH alarm was indicative of KOH presence within the fuel cell manifold. The only way that KOH can be present in the manifold is if it is extracted from the cell matrix. Deterioration of the cell matrix could result in the direct mixing of H<sub>2</sub> and O<sub>2</sub> within the stack (crossover). The STS-2 fuel cell was safed by initiating a start sequence without opening the reactant valves. The procedure for safing was written real time by the EPS operations. As the fuel cell was restarted, the parasitic internal heater package produced a load on the fuel cell and caused it to consume the remaining reactions in the stack. The fuel cell coolant pressure was monitored to determine when the reactants were evacuated. Since the coolant pressure is also a direct reading of the O<sub>2</sub> pressure in the stack, it decreased as the O<sub>2</sub> was consumed.



The following is a synopsis of the STS-2 coolant pressure as FC1 was safed.

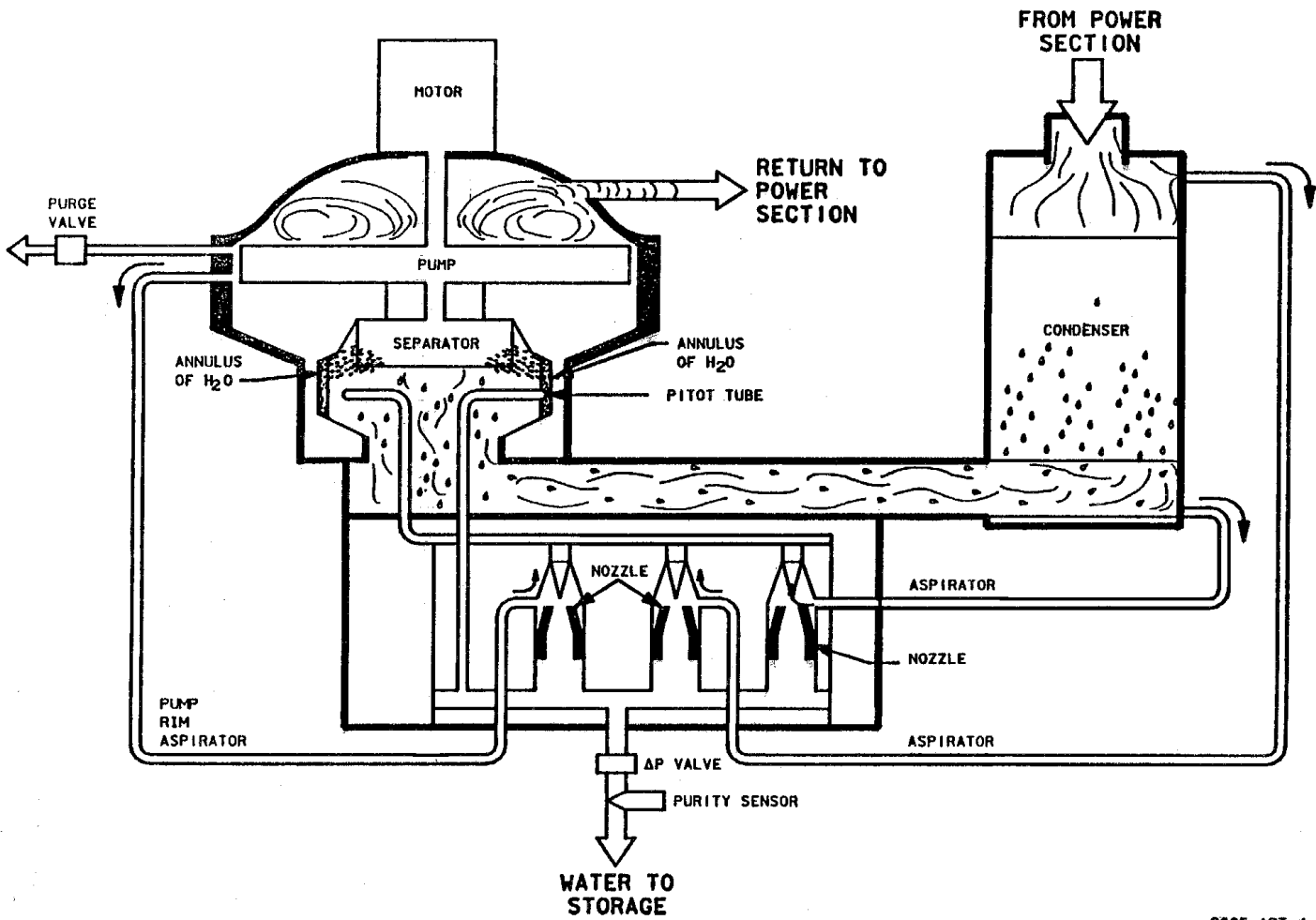
316:20:15 Fuel cell 1 shutdown  
316:23:03 Fuel cell 1 restarted  
316:23:08 Fuel cell 1 stopped (13.2 COOL P)

Time	Coolant pressure	AC1	$\phi$ A	$\phi$ B	$\phi$ C
23:02	62.4		3.8	3.7	3.6
23:03	39.4		5.4	5.4	5.3
23:04	13.6		5.4	5.3	5.2
23:05	13.6		5.4	5.4	5.2
23:07	13.6		5.3	5.3	5.1
23:08	13.2		N/A	N/A	N/A
23:09	13.2		3.8	3.7	3.6

Since the STS-2 failure, the pump rim aspirator has been removed from the H<sub>2</sub> pump to preclude the failure mode identified above. Before STS-26, an instrumentation package was added to allow monitoring of the current driving the H<sub>2</sub> pump. With this new instrumentation, the STS-2 failure can now be easily identified in its incipient stages. Test data indicates that under nominal 3 $\phi$  operations, the H<sub>2</sub> pump reading will be between 0.3 and 0.5. Under a stalled or degraded condition, the reading will range from 0.8 to 2.5. The current delta for each phase after fuel cell restart was approximately 1.7 amps. This is the sum of a normal coolant pump current (0.5 amps) and a stalled H<sub>2</sub> pump (1.2 amps) due to the pumping of liquid rather than vapor.

There are two important points to be learned from this failure besides the purely technical aspect of hardware failure. They are

- A. The EGIL position has some instrumentation points that demand almost constant attention. Unlike any other console position, small variations in some EGIL system parameters can be indicative of serious problems.
- B. Although simulated training covers a great many system failure modes, it can not possibly cover them all. All data must be watched very closely to ensure that some as yet unidentified problem does not exist.

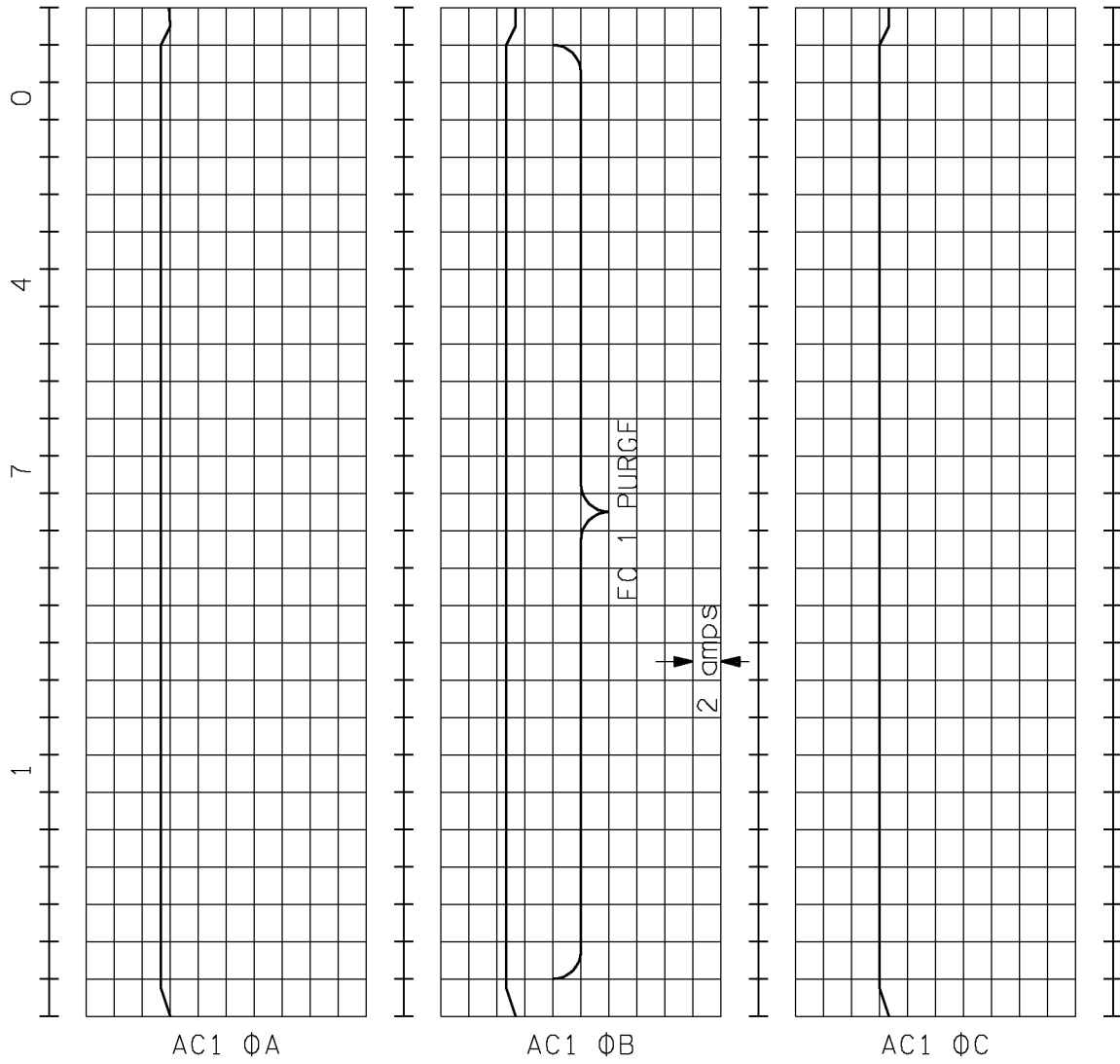


0685. ART, 4  
12830\_284

Figure 2.18-1. STS-2 fuel cell water removal system

2.18-4

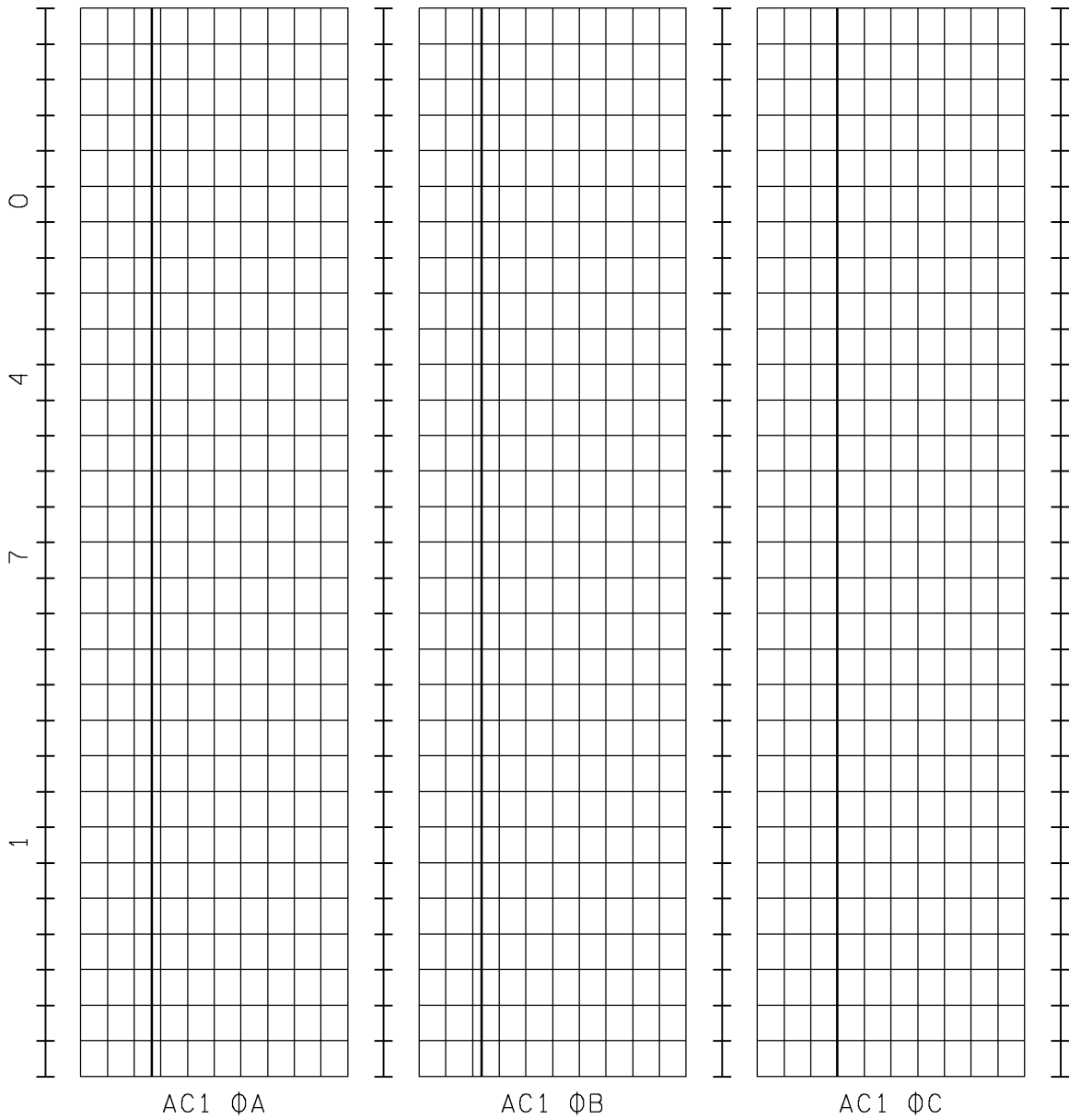
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0737. ART 2

j\_128305\_285

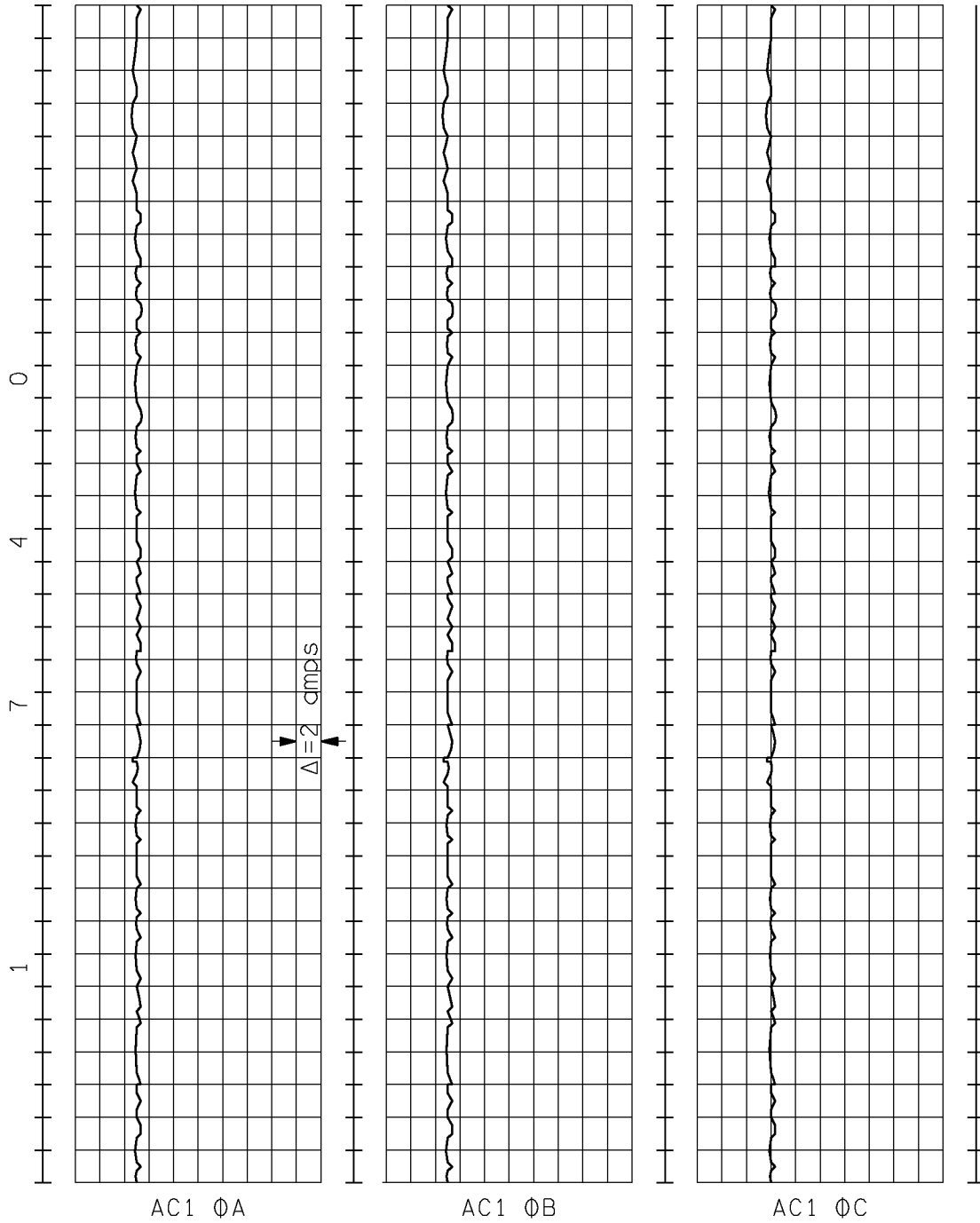
**Figure 2.18-2. Purge signatures**



0737. ART 2

j\_128305\_286

**Figure 2.18-3. Nominal straight line traces**



0737. ART § 2

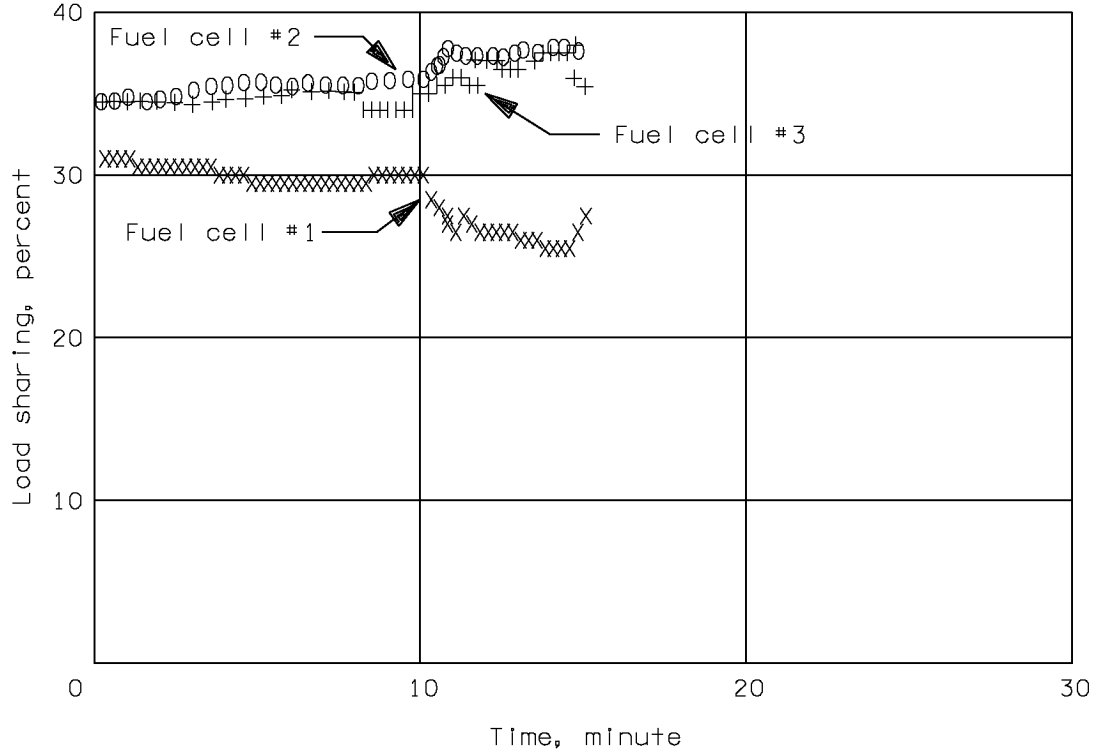
j\_128305\_287

**Figure 2.18-4. Erratic traces**

F/V 2/102 EGIL UP-20 P11820B

UDRATE 10 SEC POINT 89 SITE GDS NOM =  
FC1%LOAD FC2%LOAD FC3%LOAD  
M0111008C = XR M0211008C = OR M0311008C = +R

27.106 37.363 35.531



0686. ART # 2  
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**Figure 2.18-5. Percent load sharing**

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**TITLE**

**POWER REACTANT STORAGE AND DISTRIBUTION SYSTEM**

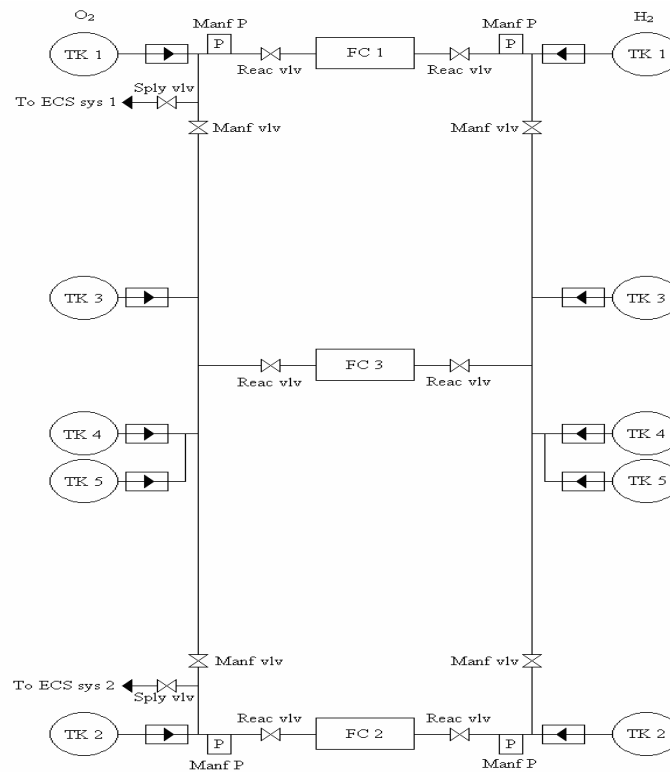
**PURPOSE**

The purpose of this SCP is to provide a brief overview of the power reactant storage and distribution (PRSD) system, some basic features of its operation, and a more detailed description of the major hardware components that comprise the system.

**A. System Description**

The PRSD system provides storage of cryogenic H<sub>2</sub> and O<sub>2</sub>, supplies these reactants to the fuel cells as demanded, and supplies metabolic O<sub>2</sub> to the environmental control and life support system (ECLSS).

Functional schematics of the PRSD systems are shown on drawings 3.2 (O<sub>2</sub>) and 3.3 (H<sub>2</sub>) of the Space shuttle Systems Handbook. A simplified schematic of the system is shown by figure 3.1-1. The O<sub>2</sub> and H<sub>2</sub> systems are essentially identical with only two principal exceptions, which will be mentioned later. Two tanks per system are the minimum configuration. However, three or more tanks will normally be flown. Figure 3.1-2 illustrates the location in the payload bay of five tank sets. The tanks are below the payload bay liner so that they do not impact the payload envelope.



**Figure 3.1-1. PRSD system schematic**



The H<sub>2</sub> and O<sub>2</sub> systems each contain two valve panels connected by a common manifold. The valve panels are line replaceable units (LRU) installed in the system using dynatube fittings. A manifold isolation/crossfeed valve on each panel permits isolation of any system leak with resulting loss of no more than a single fuel cell. Tank 1 is plumbed to valve panel 1, tank 2 is plumbed to valve panel 2, and tanks 3, 4 and 5 are plumbed into the common manifold between the isolation/crossfeed valves. Fuel cell 1 is fed through its reactant valve from valve panel 1, fuel cell 2 through its reactant valve from panel 2, and fuel cell 3 from the common manifold. However, the fuel cell 3 reactant valve is mounted on valve panel 2. In the past, the isolation/crossfeed valves were never closed so that flow from any tank was available to all fuel cells through the distribution manifold. However, because of concerns over a manifold leak possibly starving all three fuel cells before the crew can perform leak isolation, one valve will be closed for crew sleep. Reference SCP 3.5.

The horizontal drain provides the capability of detanking liquids while the vehicle is in a horizontal attitude. Detanking while in a vertical (launch) attitude is through the tank fill lines. The ground servicing equipment (GSE) supply lines provide reactants to the fuel cells via GSE between fuel cell startup (at approximately L-9 hours) and transfer to onboard reactants (at T-2 minutes, 35 seconds).

Reactant from each supply tank flows through an individual 5-micron cryogenic filter and check valve before entering the distribution manifold where it is subsequently distributed to the fuel cells and, in the case of O<sub>2</sub>, to the ECLSS. The check valves for tanks 1 and 2 are mounted on the corresponding valve panel. Check valves for oxygen tanks 3, 4 and 5 are mounted inline. Check valves for hydrogen are identical. Each tank also has its own relief valve/filter panel, which contains the filter, high pressure overboard relief valve, and two pressure transducers. The tank 1 and tank 2 panels also contain a second relief valve, which relieves manifold overpressure back to the respective tank. Manifold overpressure protection would only be required if the system were in an off-nominal configuration. Notice that if both isolation/crossfeed valves are closed, there is no manifold overprotection for the system volume between the isolation valves. For this reason, the fuel cell 3 reactant valves should never be closed if both manifold valves in a system are already closed. If this should become necessary to do for leak isolation, then it must be determined quickly whether a manifold or fuel cell leak exists. If the leak is in the fuel cell, then one manifold valve must be opened, as analytical and test data indicate that the pressure rise rate can be as high as 900 psi/min. There also exists analytical and test data which show that the manifold valves will relieve overpressures from manifold 3 to manifold 1 or 2. However, the pressure at which the valves relieve is a function of the downstream system operating pressure. The worst case is oxygen, where the manifold valves have demonstrated the ability to relieve at a delta pressure of ~1600 psi, some 550 psi above the certified system design pressure.

The reactants are stored at supercritical pressures so that they are always in a single-phase condition (no liquid/vapor interface) regardless of tank density. This is illustrated by the oxygen pressure-quantity curve in figure 3.1-3.

Tank pressures are maintained by internal heaters. O<sub>2</sub> and H<sub>2</sub> heaters in each tank are split into two independently controllable circuits with half of the heater power per circuit. Heater power in each tank can, therefore, be selected in increments of 0, 50, or 100 percent. The heaters are enabled by means of a crew-activated, three-position switch (OFF, ON, AUTO) with independent switches for the A and B heater circuits for each tank. Heater power, at 28V, 29V, and 30V dc, is summarized by the following table.

**Table 3.1-1. PRSD heater power in watts at 28V dc**

Bus Voltage	O <sub>2</sub>		H <sub>2</sub>	
	(2) Htr	(4) Htrs	(1) Htr	(2) Htrs
28V	440w	880w	98w	196w
29V	472w	950w	106w	211w
30V	506w	1020w	114w	227w

In the AUTO position, the heaters are cycled on and off automatically by the heater controllers based on a tank pressure input from the heater control pressure transducer. Heaters are cycled on when the tank pressure reaches the low limit of the control band by an ON signal from the controller to the logic. They are then cycled off by removal of the ON signal when the tank pressure reaches the high limit of the control band. The low and high ranges of the heater control band are as follows.

<u>O<sub>2</sub> Tanks 1 and 2</u>	<u>Tanks 3, 4, 5</u>
HTR ON = 803 to 819 psia	832 to 848 psia
HTR OFF = 838 to 854 psia	867 to 883 psia
<u>H<sub>2</sub> Tanks 1 and 2</u>	<u>Tanks 3, 4, 5</u>
HTR ON = 200 to 206 psia	217 to 223 psia
HTR OFF = 220 to 226 psia	237 to 243 psia

The heater control circuits are wired such that if both tanks 1 and 2 are being used, their heaters will always cycle together. The same applies for tanks 3 and 4 (and 5), on OV-105; however, tank 5 is isolated and does not operate in this paired logic.

Between logic paired tanks (such as tanks 1 and 2), if at least one heater switch per tank is in AUTO, an ON signal from both tanks is required before the heaters that are selected to AUTO will cycle on. An OFF (high pressure) from either tank

will then terminate operation of all circuits selected to AUTO in both tanks. In the switch ON position, the circuits selected are on at all times. Use of the ON position would occur only in a contingency situation and would require crew monitoring of tank pressures to cycle the heaters ON and OFF manually. Any combination of switch positions can be selected. If at least one circuit in each tank is selected to AUTO, automatic operation would be as described previously in the paragraph with any circuits selected to ON being on continuously regardless of tank pressure. If one or both circuits in tank 1, for example, are in AUTO and no circuits in tank 2 are in AUTO, then those circuits in AUTO are dependent only on the pressure in tank 1 for automatic operation.

One principal difference between the O<sub>2</sub> and H<sub>2</sub> systems is that each O<sub>2</sub> valve panel contains an additional valve for supplying metabolic O<sub>2</sub> to the ECLSS. A second principal difference between the O<sub>2</sub> and H<sub>2</sub> systems is the use of delta current sensors to protect the O<sub>2</sub> system against heater shorts internal to the tank. The sensors are located in the cryo control boxes. The sensors compare heater current into and out of the tank heater. A differential current of greater than 0.91 ampere, sensed by either of two redundant sensors, will result in automatic shutdown of the defective circuit in less than 5 milliseconds. A good circuit in the same tank will continue to operate. Associated with the delta current sensors is a momentary two-position (TEST, RESET) switch for each tank. In the TEST position, a tripping current of 1.5 amps is imposed on each sensor for that tank to verify proper operation. The RESET position removes the trip signal(s) from the logic and permits continued operation of the heater.

Once per flight, the crew will perform a cryo O<sub>2</sub> tank heater sensor check, to verify proper operation of the delta current detector. The test is performed with heaters active, to verify that a "trip" removes power from its respective heater. The test procedure is as follows:

1. In succession, for each O<sub>2</sub> tank flown, the crew will take both A and B heaters to ON and wait 5 seconds to verify heater operation. Monitor the cryo pressures on the EGIL CRYO display and RTPLOT to verify heater operation.
2. The crew will then take the TEST/RESET switch to "TEST" and verify that "TRIP" indications appear on the CRT. Monitor the EGIL CRYO display, ELOG, and OFS for four current sensor "TRIP" indications. Monitor the EGIL CRYO display and RTPLOT to verify the heaters turned OFF.
3. Following a successful current sensor test, the crew will return heater switches to previous (nominal heater plan) position. EGIL should monitor to ensure proper configuration.

4. Finally, the crew will take the TEST/RESET switch to RESET after a successful test in a tank. This action resets the trip logic circuitry to allow resumed operation of the cryo heaters in that tank.

Note that the crew waits 5 seconds after the heaters are taken to “ON” before taking a tank to “TEST.” This ensures that the EGIL console operator can verify that both heaters were disabled when the “TRIP” was annunciated. This is done either real time or with recorded data if the test takes place during loss of signal (LOS). Care should be taken that the procedure is executed without delays since a couple of the steps leave the vehicle with all O<sub>2</sub> heaters off. This is permissible for the expected length of time the test should take.

The procedure is performed once per flight, and is normally scheduled near the beginning of the mission, either on flight day 1 prior to crew sleep, or early on flight day 2. The rationale is that the most likely time for these circuits to get damaged is during ground processing or launch. Performing this test also fulfills an Orbiter Maintenance Requirement and Specification (OMRS) which calls for these circuits to be tested once per vehicle processing flow. Having the crew perform the procedure on-orbit ensures that all circuits are working properly when they are most needed, and also eliminates a maintenance task for KSC during ground turnaround.

Each tank has both a wide-range and a narrow-range pressure transducer. These are the two pressure transducers mounted on the tank relief valve/filter panel.

- The wide range (TK P) is 0 to 1200 psia for O<sub>2</sub> and 0 to 400 psia for H<sub>2</sub>.
- The narrow range (CNTRL P) is 515 to 1015 psia for O<sub>2</sub> and 145 to 305 psia for H<sub>2</sub>.

The O<sub>2</sub> and H<sub>2</sub> wide-range transducer pressures, O<sub>2</sub> and H<sub>2</sub> quantities, and O<sub>2</sub> heater temperatures are all displayed on dedicated meters located on D&C panel O2. The narrow-range transducer pressures (heater control pressures) and O<sub>2</sub> heater temperatures are input to the C&W system. All common measurements, such as O<sub>2</sub> heater control pressures, are OR'd together to a common light in the C&W matrix on D&C panel F7. C&W alarm (class 2) default limits are set as follows.

H <sub>2</sub> (all tanks)	153 psia $\geq$ P $\geq$ 294 psia	H <sub>2</sub> PRESS (C&W light name)
O <sub>2</sub> (all tanks)	540 psia $\geq$ P $\geq$ 985 psia	O <sub>2</sub> PRESS (C&W light name)
O <sub>2</sub> (all heater temps)	T > 349° F	O <sub>2</sub> HEATER TEMP (C&W light name)

However, examination of the above limits shows that the low limits do not protect the fluid “critical pressure” (ref. fig. 3.1-3 for O<sub>2</sub>) and provide relatively late insight into system leaks and heater malfunctions. On orbit, the class 3 SM alert limits are set on the wide-range tank pressure transducers. This limit sensing is available in SM OPS 2 and 4. A second limit set for each measurement is preconditioned in the software to be used only if one or both of the associated tank heater switches are in AUTO. If both heater switches are in ON or OFF, then the first limit set is used. The limit sets are summarized below:

<u>Fluid</u>	<u>Set</u>	<u>Precondition steering</u>	<u>Limit values</u>
H <sub>2</sub>	1	A and B switches in ON or OFF	165-283
H <sub>2</sub>	2	A or B switch in AUTO	189.8-283
O <sub>2</sub>	1	A and B switches in ON or OFF	575-960
O <sub>2</sub>	2	A or B switch in AUTO	740-960

The second limit set was created in lieu of simply raising the lower limit in set 1 to avoid nuisance alarms from sudden pressure collapse during tank destratification.

**B. Normal Operating Sequence Configuration**

The tanks are normally filled and pressurized at L - 45 hours. Filling is through the individual tank fill quick disconnects (QD) with the vapor being vented through the tank vent QDs. All fill and vent QDs are located on a panel behind the preflight umbilical access door. Pressurization is accomplished hydraulically by introducing high-pressure liquid into the tanks through the fill line. Initial pressurization levels are 725 to 735 psia for O<sub>2</sub> and 175 to 180 psia for H<sub>2</sub>. Following pressurization, the liquid trapped in the fill lines between the tanks and the panel QD will vaporize because of heat input to the line and raise the tank pressures above the initial value. Environmental heat leak will further contribute to a gradual increase in tank pressures. After the fill and pressurization operations are completed, the ground fill and vent lines are disconnected and the vehicle QDs are capped.

Fuel cell startup is performed using GSE reactant supply (ambient temperature gas) at approximately T-9 hours (L-13). During GSE operation, all manifold isolation/crossfeed valves, fuel cell reactant valves, and GSE supply valves are open. GSE reactants are supplied to the valve panels at a pressure of 905 to 955 psia for O<sub>2</sub> and 256 to 285 psia for H<sub>2</sub>. Since there is no flow demand from the tanks during GSE operation, the tank pressures will increase as described in the previous paragraph to equalize with the GSE pressure. Thereafter, the tank pressures and GSE pressure will remain equalized within the crack and reseal pressure band of the check valves unless there is a failure in the GSE supply system. Should the GSE pressure fall below the tank pressures, the check valves will open and the flow to the fuel cells will then be supplied by the onboard tanks.

Prior to launch, the tank 1 and 2 HTR A switches will be in the AUTO position. All other heater switches will be OFF. However, the GSE LPS commands configuring all heaters to the AUTO mode will be maintained until lift-off. At lift-off, the

configuration will be that of the panel switches. Only single heaters are used to minimize electrical power consumption during ascent. The A HTRS are used in lieu of B since loss of any main bus would cause loss of at least one heater string. Since the heaters are not essential for short durations such as ascent, and since loss of a fuel cell/main bus during ascent significantly reduces SRB interface voltages, it is desirable to lose as many cryo heaters as possible for fuel cell/main bus losses.

Transfer to internal reactants occurs at T-2 minutes 35 seconds. This is accomplished by closure of the GSE supply valves. All pressures should then begin to decay at approximately equal rates. At approximately T+15 minutes, the B heaters will be activated in tanks 1 and 2.

Normally, quantities in all tanks are kept balanced. The reasoning behind this is covered in detail in SCP 3.5.

The only other system configuration change that will normally be made during flight is to deactivate half of the O<sub>2</sub> tank heaters when the quantity is less than about 55 percent. This is necessary to preclude heater overtemperature at reduced quantity levels. Reconfiguration of the H<sub>2</sub> heaters is not required.

As a result of the heater operating characteristics in the AUTO mode (which is the normal operating mode), and the fact that heater power in the various tanks is not precisely balanced, a quantity imbalance may gradually develop between paired tanks. Oxygen tanks 1 and 2 are the most pronounced example of heater power imbalance (table 3.1-1). When O<sub>2</sub> tanks 1 and 2 are operating together in the AUTO mode, tank 2 will always attempt to pressurize slightly faster than tank 1 and will, therefore, supply slightly more outflow than tank 1 during the pressurization cycle. Over a period of time, a quantity imbalance will develop between the two tanks and some management of the heaters may be required to rebalance quantities. This phenomenon has been observed on previous flights.

## C. Component Hardware Description

### 1. Cryogenic storage tanks

Figure 3.1-4 shows a cutaway view of the cryogenic O<sub>2</sub> tank assembly. As shown, the assembly consists of an inner pressure vessel and an outer shell surrounded by a girth ring. Between the inner and outer shells is a blanket of multilayer insulation consisting of double silverized Kapton sheets separated by nylon net spacers. Suspended in the tank are two cylindrical heater surfaces and the capacitance-type quantity probe. The girth ring serves as the attach point for mounting braces and also as a surface for mounting various equipment such as the vac-ion pump and associated power supply, heater junction box, signal conditioner, and instrumentation junction box. Construction and assembly of the H<sub>2</sub> tanks is similar to the O<sub>2</sub> tanks with the exception that the H<sub>2</sub> tank has only one heater surface.

The function of the vac-ion pump is to establish and maintain a vacuum between the inner and outer shell during ground operations. It does not function during flight. The vacuum between the shells plus the blanket of multilayer insulation serves to minimize heat leak to the cryogenic fluid. The following table summarizes salient features of the tank assembly.

<b>Pressure vessel</b>	<b>O<sub>2</sub></b>	<b>H<sub>2</sub></b>
Material	Inconel 718	Al 2219
Inside diameter, in.	33.435	41.516
Wall thickness, in.	0.076	0.113
Tank volume, ft <sup>3</sup>	11.237	21.395
Maximum fill quantity, lb	809.1	96.30
Maximum heat leak, Btu/hr	21.0	6.6
<b>Cryogenic storage tank operational pressures (psia)</b>	<b>O<sub>2</sub> (w/meas error)</b>	<b>H<sub>2</sub> (w/meas error)</b>
Design limit (max)	1050 (1035)	335 (320)
Proof (1.2X first time/else 1.1X)	1260/1155 (1242/1138)	402/368.5 (384/352)
Burst (1.5X)	1575 (1552)	502.5 (480)
<b>Outer shell</b>	<b>O<sub>2</sub></b>	<b>H<sub>2</sub></b>
Material	Al 2219	Al 2219
Inside diameter, in.	36.8	45.50
Wall thickness, in.	0.062	0.071
<b>Girth ring</b>	<b>O<sub>2</sub></b>	<b>H<sub>2</sub></b>
Material	Al 2219-T62	Al 2219-T62
Outside diameter, in.	41.2	48.7
<b>Tank assembly</b>	<b>O<sub>2</sub></b>	<b>H<sub>2</sub></b>
Weight, lb	210.0	224.7

2. Tank heater assemblies

Each individual heater assembly (one per H<sub>2</sub> tank, two per O<sub>2</sub> tank) has its own temperature transducer. For O<sub>2</sub>, hardware and backup C&W limits ensure that the temperatures of the heater assemblies do not exceed 350° F. This number is based upon the autoignition temperature of Teflon (700°F) which may be loose in the tank, combined with a 200° F pad and 150° F allowance for measurement error (due to physical location of the sensor, lag time, and sensor error). The maximum heater temperature of the H<sub>2</sub> assembly should not be allowed to exceed 200° F because of potential damage to the tank structure. For both O<sub>2</sub> and H<sub>2</sub> tanks, the maximum fluid

temperature should not be allowed to exceed 160° F because of potential damage to the tank (see the OMRS).

Each O<sub>2</sub> tank has two heater surfaces, or assemblies. Each assembly contains two heater elements. For example, assembly 1 houses heater A1 and heater B1. Whenever the A (or B) heaters are energized, both the A1 and A2 (or B1 and B2) elements will receive power. Therefore, it is not possible to selectively power only one assembly at a given time. The heater surfaces are offset 5 inches from the tank centerline. Each H<sub>2</sub> tank has only one heater surface, also offset 5 inches from the tank centerline. The heating elements consist of Nichrome V wire sheathed in SiO<sub>2</sub> and 321 stainless steel, with the O<sub>2</sub> elements double sheathed. Details of the heater elements are shown by figure 3.1-5. The following table summarizes the pertinent physical features of the heater assemblies.

Parameter	O <sub>2</sub>	H <sub>2</sub>
Number of heater surfaces	2	1
Heater diameter, in.	3.5	3.5
Heater length, in.	27.0	35.0
Percent of heater surface removed by holes	10	14
Total heater weight, lb	3.55	3.04
Surface emittance	0.6	0.6
Heater offset from tank center line, in.	5	5

### 3. Unidirectional and bidirectional shutoff valves

The fuel cell reactant valves in both the H<sub>2</sub> and O<sub>2</sub> systems and ECLSS O<sub>2</sub> supply valves are unidirectional solenoid latching valves (fig. 3.1-6). The manifold isolation/crossfeed valves and GSE supply valves in both systems are bidirectional solenoid latching valves (fig. 3.1-7). Both types of valves are manufactured by Consolidated Controls Corporation. The unidirectional type valve has positive shutoff capability in the normal flow direction and relief capability in the opposite direction (outlet to inlet). The relief function occurs when outlet pressure exceeds inlet pressure by 35 psid. Bidirectional valves are advertised to provide positive shutoff in both directions. However, a test performed at Rockwell in 1978 (TR S134215) showed evidence that the manifold valves will actually relieve overpressure from inlet to outlet, although at pressures exceeding the designed burst pressure of the associated plumbing. Additional testing at JSC in 1988 confirmed this feature, as previously stated.

The O<sub>2</sub> valves are required to operate with an inlet pressure of 0 to 1035 psig, while H<sub>2</sub> valves operate at an inlet pressure of 0 to 320 psig. The valve



has a filter with an absolute rating of between 15 and 25 microns internal to the valve body at both the inlet and outlet.

A valve is opened by energizing the opening coil of the solenoid. The magnetic field thus generated raises the plunger, allowing the ball plug to unseat and reactant to flow through the valve. The plunger is maintained in the open position by the permanent magnets. It is not necessary to maintain a voltage on the opening coil. To close the valve, the closing coil is energized. The magnetic field produced by the closing coil neutralizes the field of the permanent magnet allowing the spring to reseat the ball and plunger. Response time to open or close is a maximum of 0.5 second.

An electrical switch arrangement is provided in the unit which makes or breaks an electrical circuit as a function of the valve poppet position. With the valve poppet in the closed (no flow) position, the switch is closed completing an electrical circuit. Actuation of the electrical switch is directly and positively dependent upon movement of the poppet. When operating from closed to open position, the switch remains closed until the valve poppet has reached the full open position. Likewise, when operating from the open to closed position, the switch remains open until the valve poppet has reached the full closed position.

4. Pressure relief valves

The pressure relief valves, used to relieve system overpressure in the oxygen (fig. 3.1-8) and hydrogen (fig. 3.1-9) systems, are manufactured by Parker-Hannifan Company. As shown by the figures, construction of the O<sub>2</sub> and H<sub>2</sub> valves is slightly different, as is the operating pressure range. All valves reference ambient pressure. Any excess pressure is vented overboard. H<sub>2</sub>/O<sub>2</sub> tanks use a common vent port. H<sub>2</sub> tanks 1, 2 and 4 have a different port than H<sub>2</sub> tanks 3 and 5. The following table summarizes the pressure, temperature, and flow performance of the relief valves.

Parameter	O <sub>2</sub>	H <sub>2</sub>
Minimum cracking pressure, psig	1005	302
Minimum reseat pressure, psig	987	296
Maximum full flow pressure, psig	1040	315
Maximum relief valve flow rate, lb/hr at 70° F	164	97
Fluid temperature, °F		
Minimum	-20	-20
Maximum	150	150

5. Check valve, O<sub>2</sub>/H<sub>2</sub>

A check valve (fig. 3.1-10) is installed on valve panels 1 and 2 to allow flow from storage tanks 1 and 2 to the fuel cells and to prevent flow back to the tanks. Check valves for tanks other than tanks 1 and 2 are mounted in-line (not on a panel) to isolate those tanks from the distribution manifold. The valve opens and allows flow when a differential pressure of 3 + 2 - 0 psi is applied across the valve in the direction of flow. Reseat occurs at 1 to 5 psid. Required operating conditions include pressures ranging from 0.01 psia to 1035 psig and fluid temperatures from -423° to 220° F. The unit contains an integral filter element at the valve inlet rated at 5 microns nominal, 12 microns absolute.

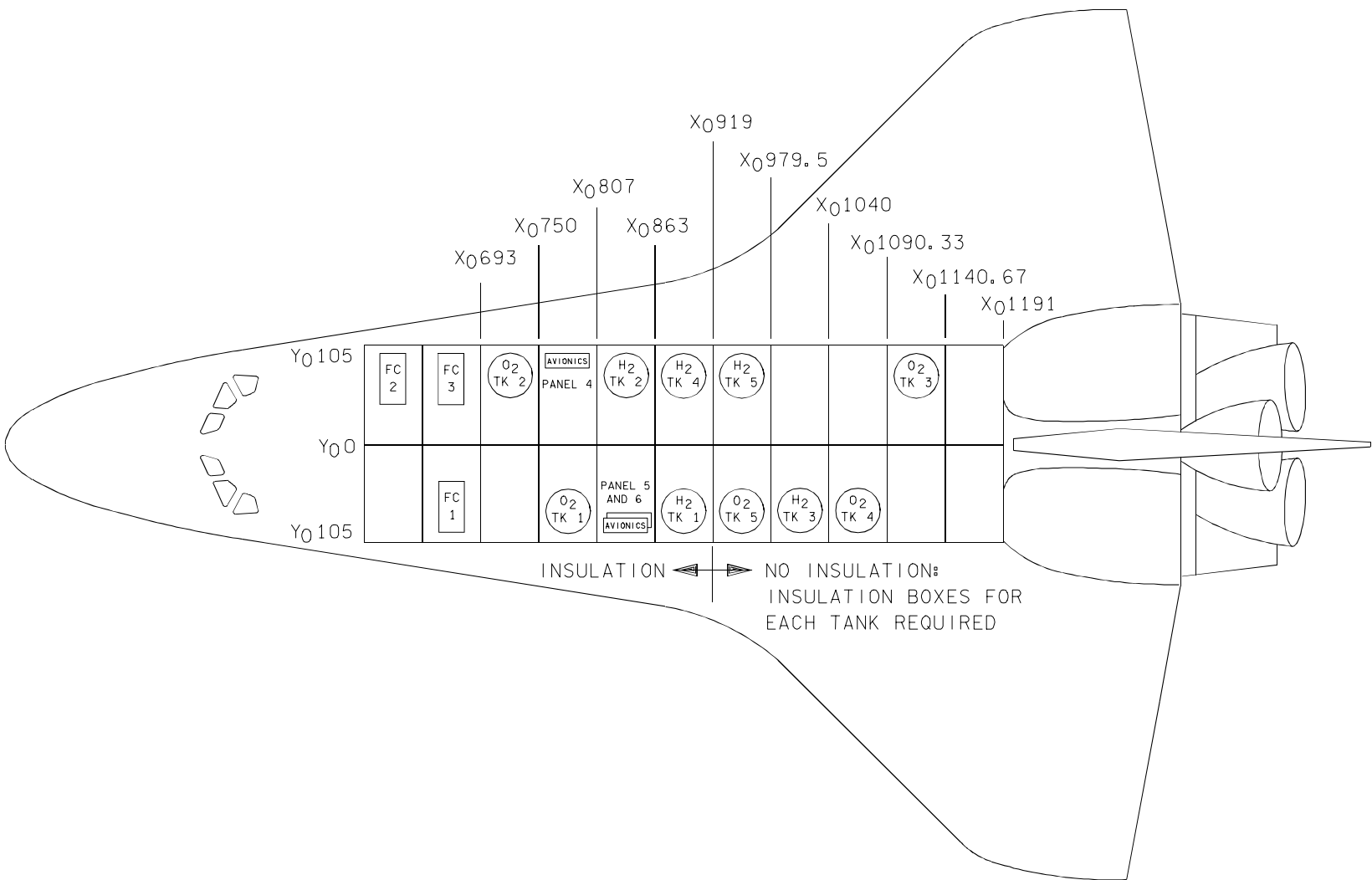
6. Cryogenic filter, O<sub>2</sub>/H<sub>2</sub>

The cryogenic filter (fig. 3.1-11), manufactured by Wintec Division of Brunswick Corporation, is located between the storage tanks and the valve panel to protect components on the valve panel from particulate matter. The unit has a replaceable filter element of 304 L CRES material having a rating of 5 microns nominal, 12 microns absolute. The element has a dirt holding capacity of 4 grams of particulate. It is anticipated that filter elements will be replaced at scheduled intervals, probably every 25 flights. Design maximum working pressure is 1050 psia but the element can withstand a differential pressure of 2100 psi without collapsing.

7. Valve panels and relief valve/filter panels

Figures 3.1-12 and 3.1-13 illustrate the physical layout of the oxygen left-hand (panel 1) and right-hand (panel 2) valve panels. Figures 3.1-14 and 3.1-15 show hydrogen valve panels 1 and 2. The valve panels are LRUs installed in the system dynatube fittings. Note that the lines and valve bodies on the hydrogen panels are insulated, whereas on the oxygen panels they are not. The hydrogen panels are insulated to prevent condensation of the nitrogen purge gas during ground operations.

Figure 3.1-16 shows a typical tank 1 or 2 relief valve/filter panel. There are four such panels - one each for O<sub>2</sub> TK 1, O<sub>2</sub> TK 2, H<sub>2</sub> TK 1, and H<sub>2</sub> TK 2. These panels are also LRUs. Components on the hydrogen panels are insulated. The oxygen panels are not insulated. Note that these panels include a relief valve back into the associated tank in the event of a manifold overpressure. Figure 3.1-17 shows a typical relief valve/filter panel for oxygen or hydrogen TKs 3, 4, etc. These panels have only one relief valve; i.e., the tank-to-overboard relief.



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Figure 3.1-2. Five tank set locations in mid fuselage

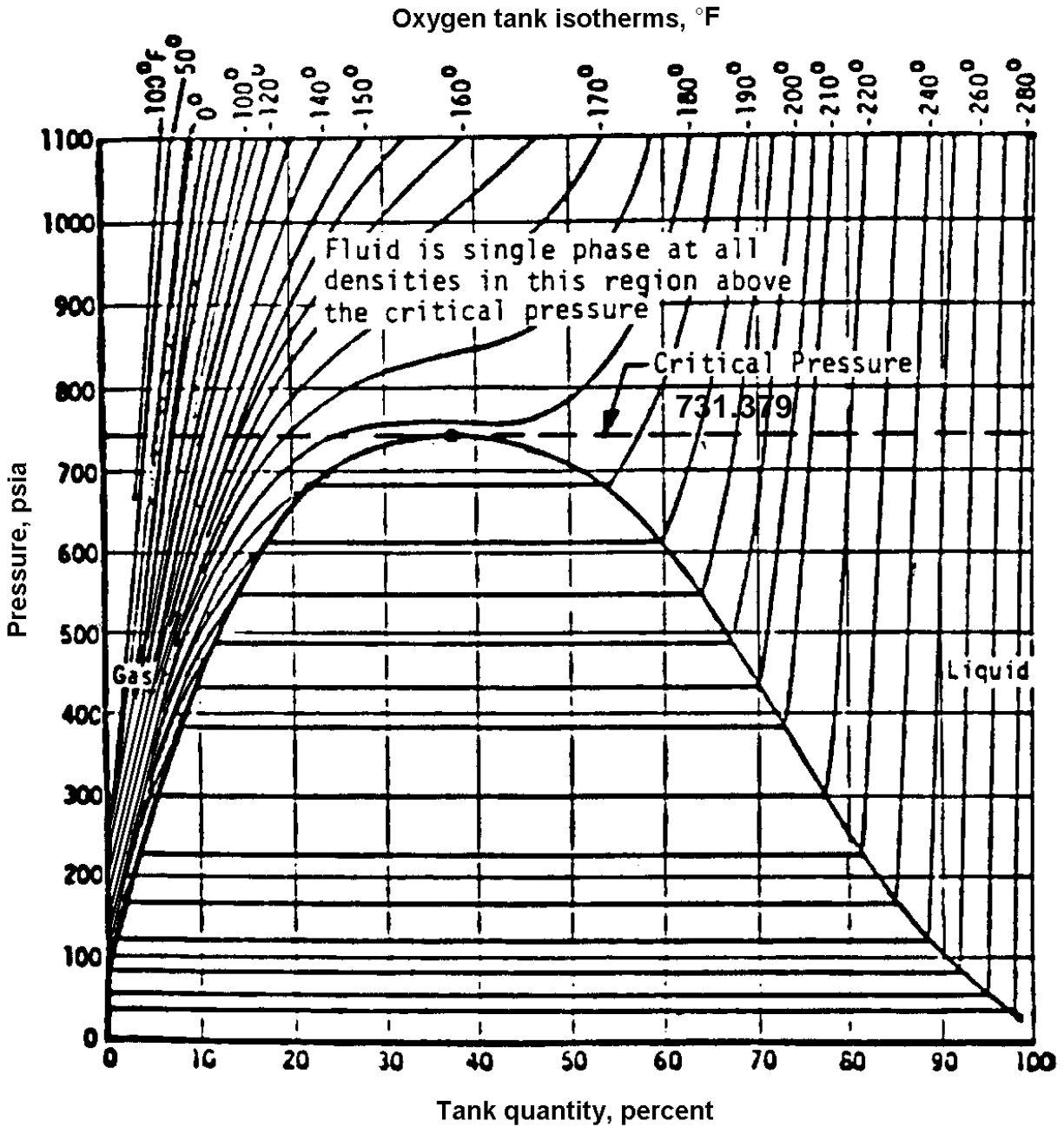
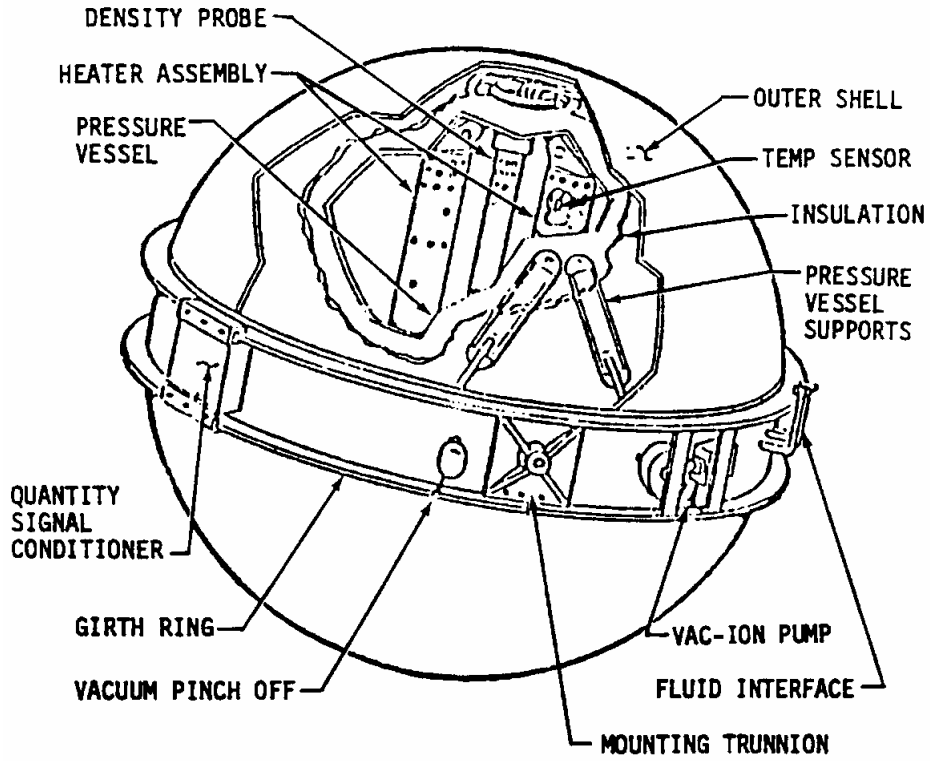
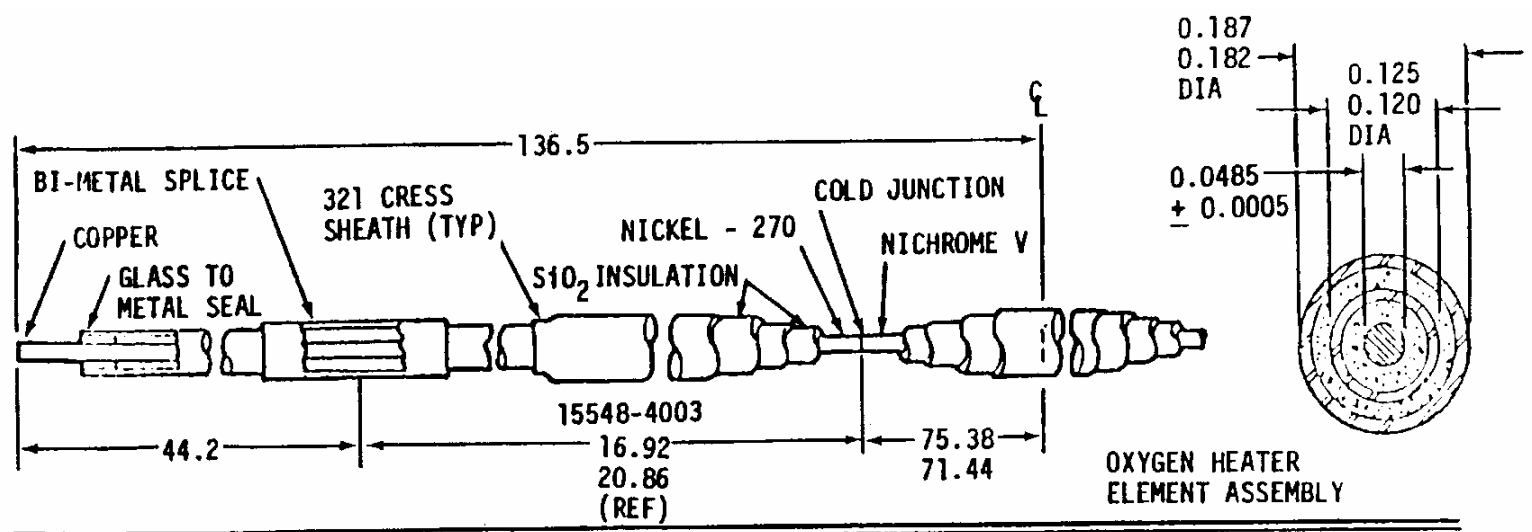


Figure 3.1-3. Oxygen pressure vs quantity diagram



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**Figure 3.1-4. Cutaway of cryogenic O<sub>2</sub> tank assembly**

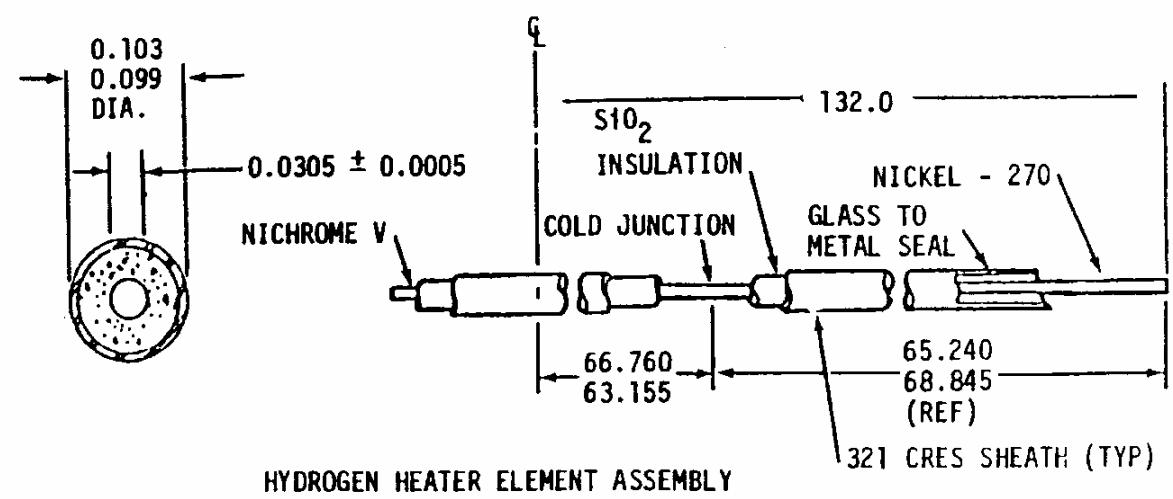


**OXYGEN**

- NICHROME V:  
0.048-0.049 DIA  
(16 GAGE)
- NICKEL - 270:  
0.048-0.0050 DIA  
(16 GAGE)
- COPPER:  
0.0383-0.0393 DIA  
(18 GAGE)

**HYDROGEN**

- NICHROME V:  
0.030-0.031 DIA  
(20 GAGE)
- NICKEL - 270:  
0.028-0.030 DIA  
(20 GAGE)

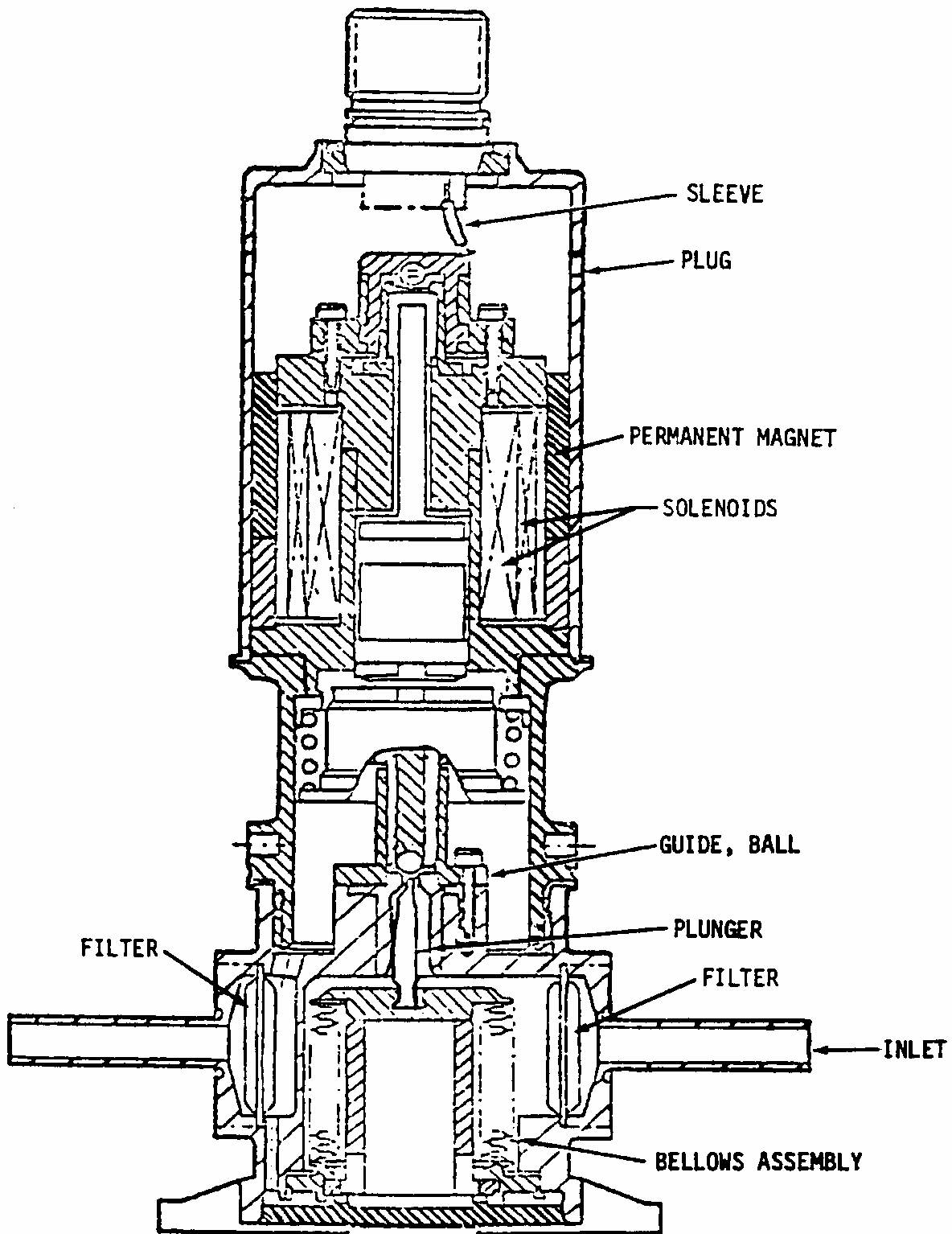


HYDROGEN HEATER ELEMENT ASSEMBLY

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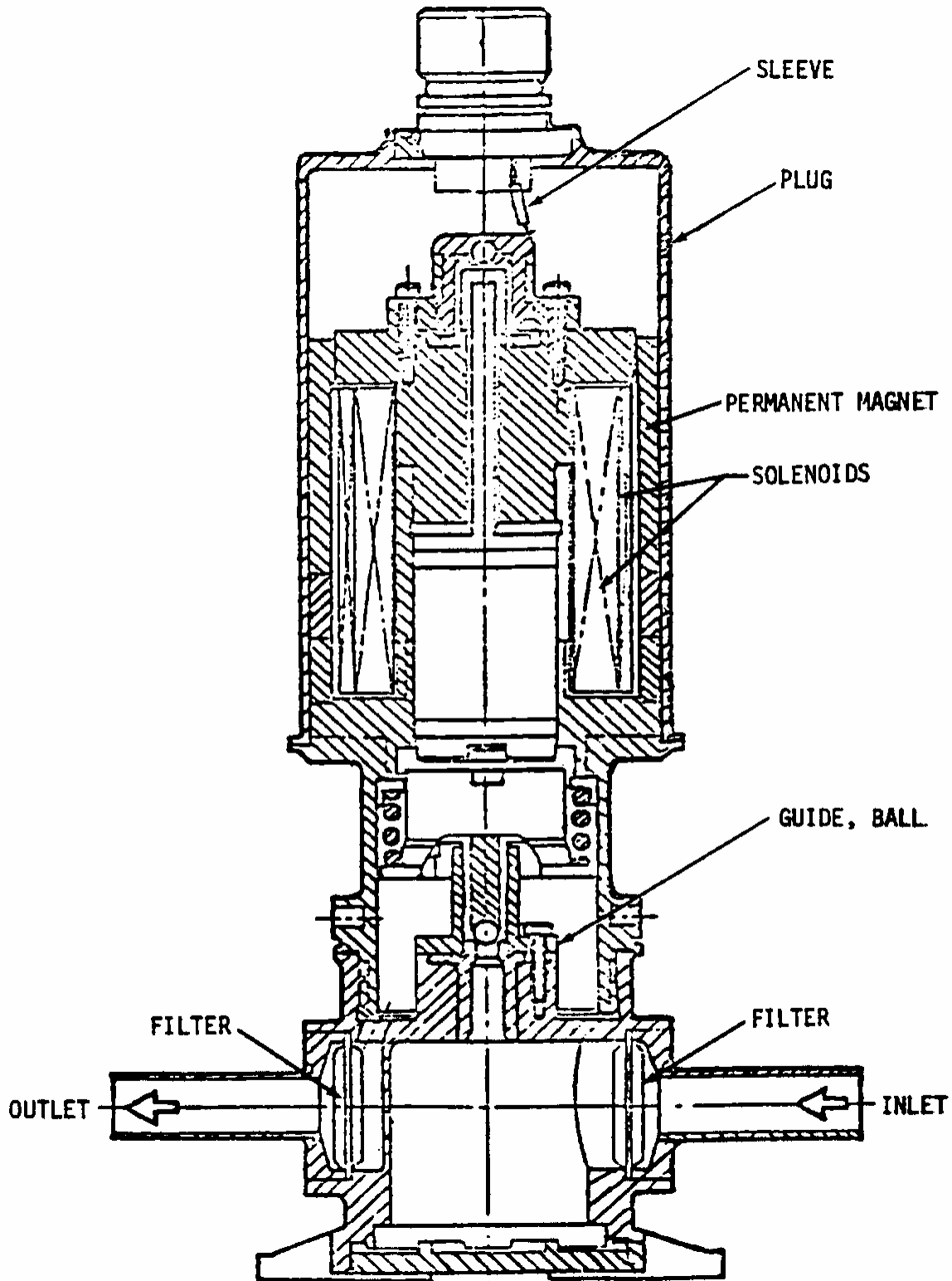
Figure 3.1-5. Heater elements detail

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3.1-15  
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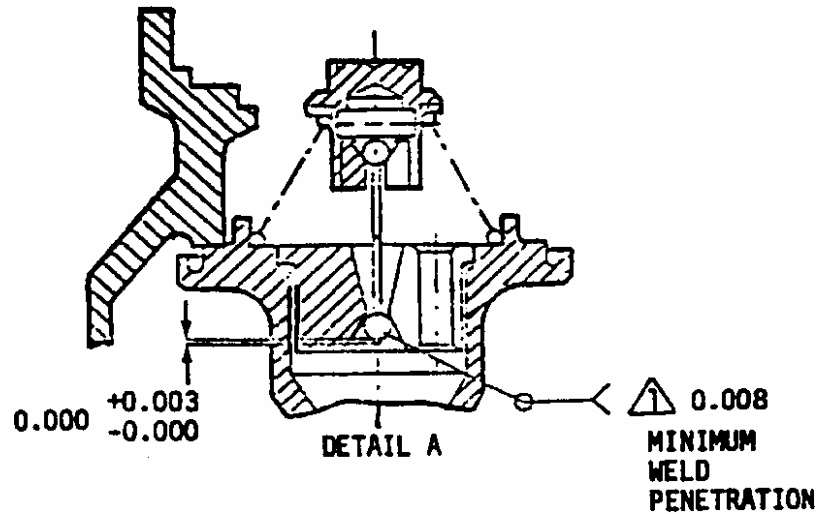
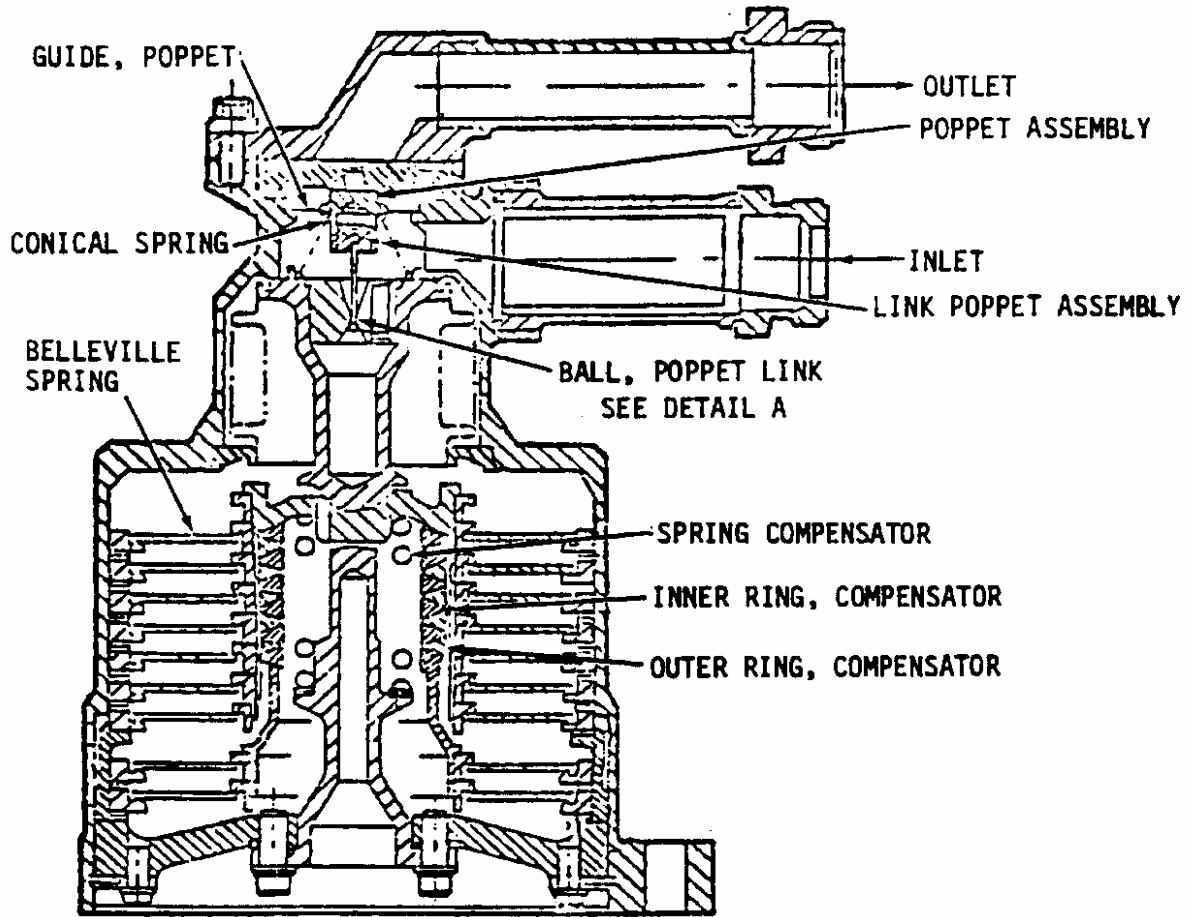
Figure 3.1-6. Unidirectional solenoid latching valves



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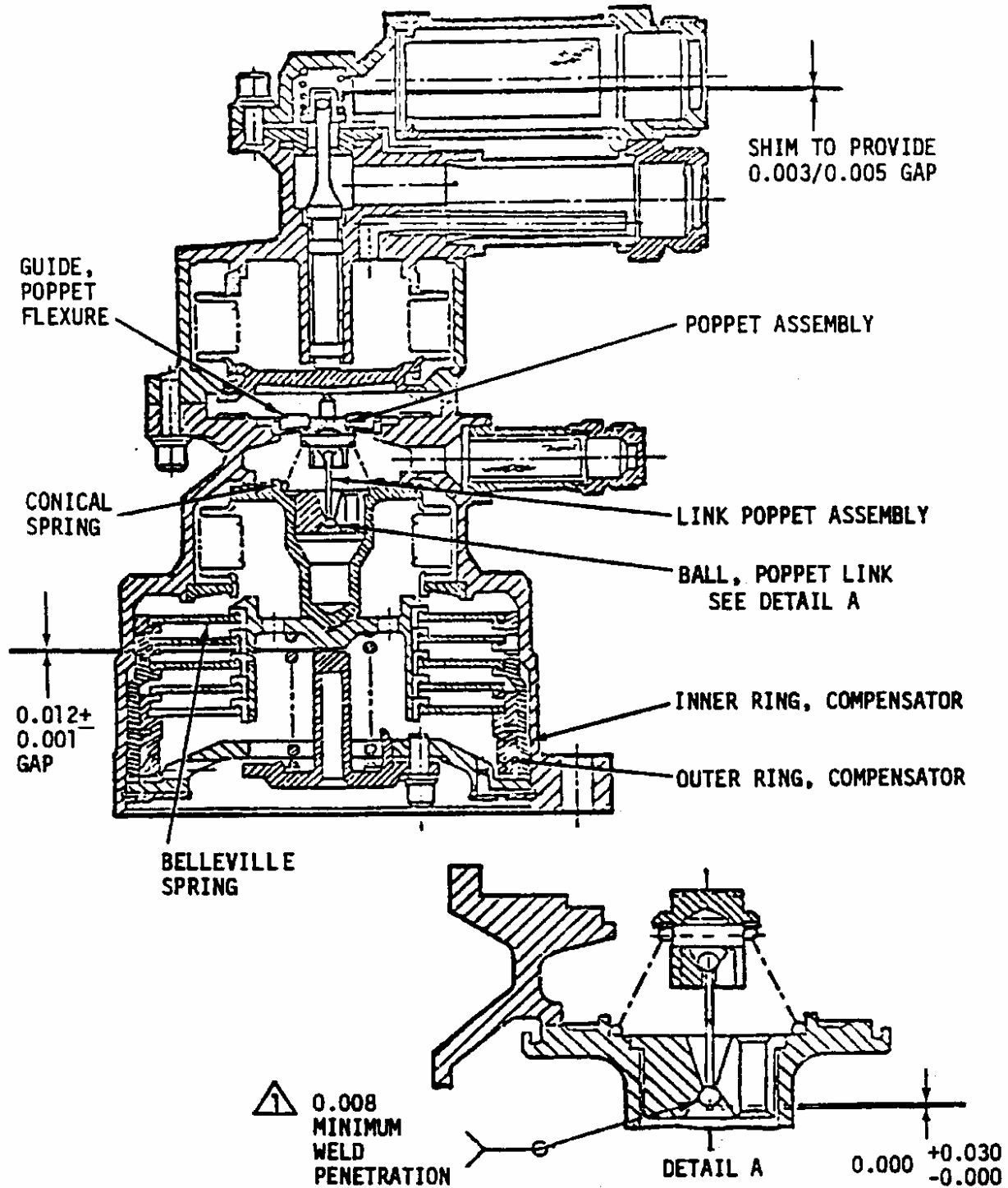
*Figure 3.1-7. Bidirectional solenoid latching valves*





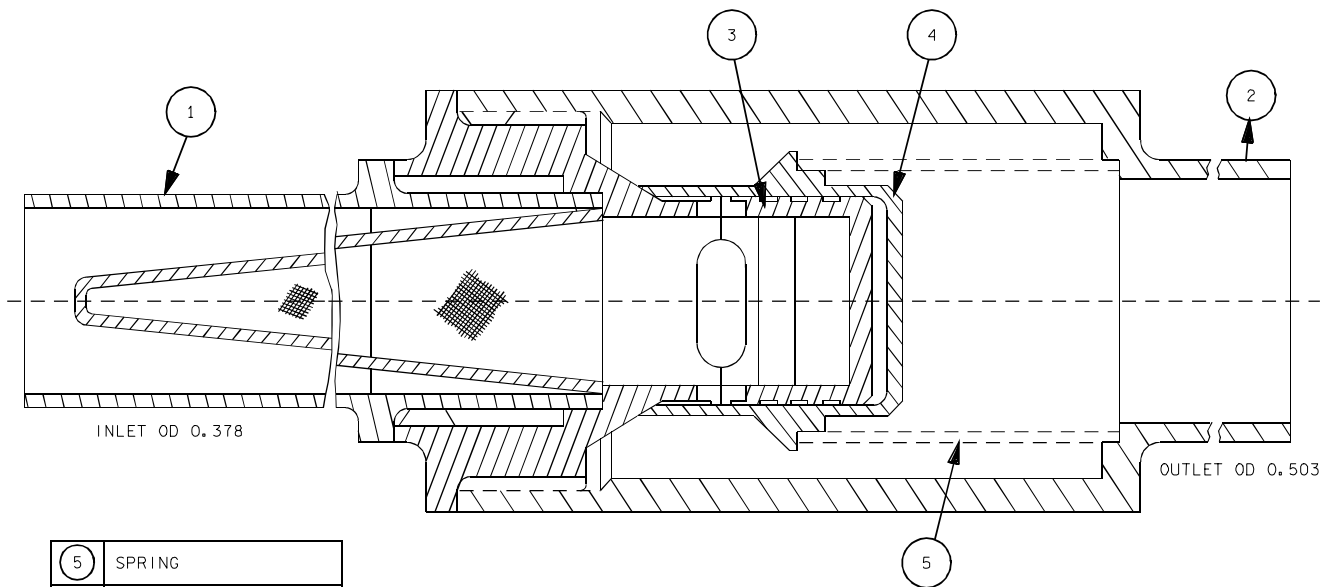
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Figure 3.1-8. O<sub>2</sub> pressure relief valve

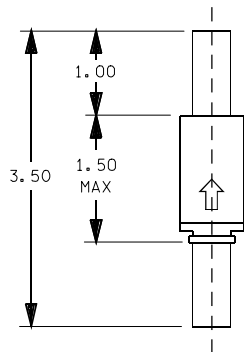


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Figure 3.1-9. H<sub>2</sub> pressure relief valve



5	SPRING
4	POPPET
3	HOUSING, INLET
2	HOUSING OUTLET
1	ASSY, WELD, INLET TUBE



- NOTES:
- HEIGHT: 0.125 LB MAX
  - OPERATING FLUIDS: N<sub>2</sub>, He, O<sub>2</sub>, AND H<sub>2</sub> LIQUID OR GAS
  - PRESSURES:
    - WORKING - ZERO TO 1035 PSIG
    - CRACK - 4.0 PSI MAX
    - RESEAT - 1.0 TO 5.0 PSI
    - PROOF PRESSURE - 1553 PSIG
    - BURST PRESSURE - 2070 PSIG MIN
  - LEAKAGE:
    - INTERNAL - 0.3 SCCS He MAX AT ZERO TO 1035 PSI REVERSE
    - EXTERNAL - 1 X 10<sup>-4</sup> SCCS He MAX
  - PRESSURE DROP: 7.5 PSI MAX, 100 LB/HR, GN<sub>2</sub>, 100 PSI INLET PRESSURE, +70°F TEMP
  - OPERATING TEMP: -423°F TO +220°F
  - OPERATING LIFE: 300,000 CYCLES MIN
  - INLET FILTER: 45 MICRONS ABSOLUTE, 20 MICRONS NOMINAL
  - ROCKWELL P/N MC284-0428-0410, MEETS REQUIREMENTS OF SPECIFICATION MC284-0428
  - ACCEPTANCE TEST PER T5-AT-3038-2

128304810. ART, 2

Figure 3.1-10. Check valve, O<sub>2</sub>/H<sub>2</sub>

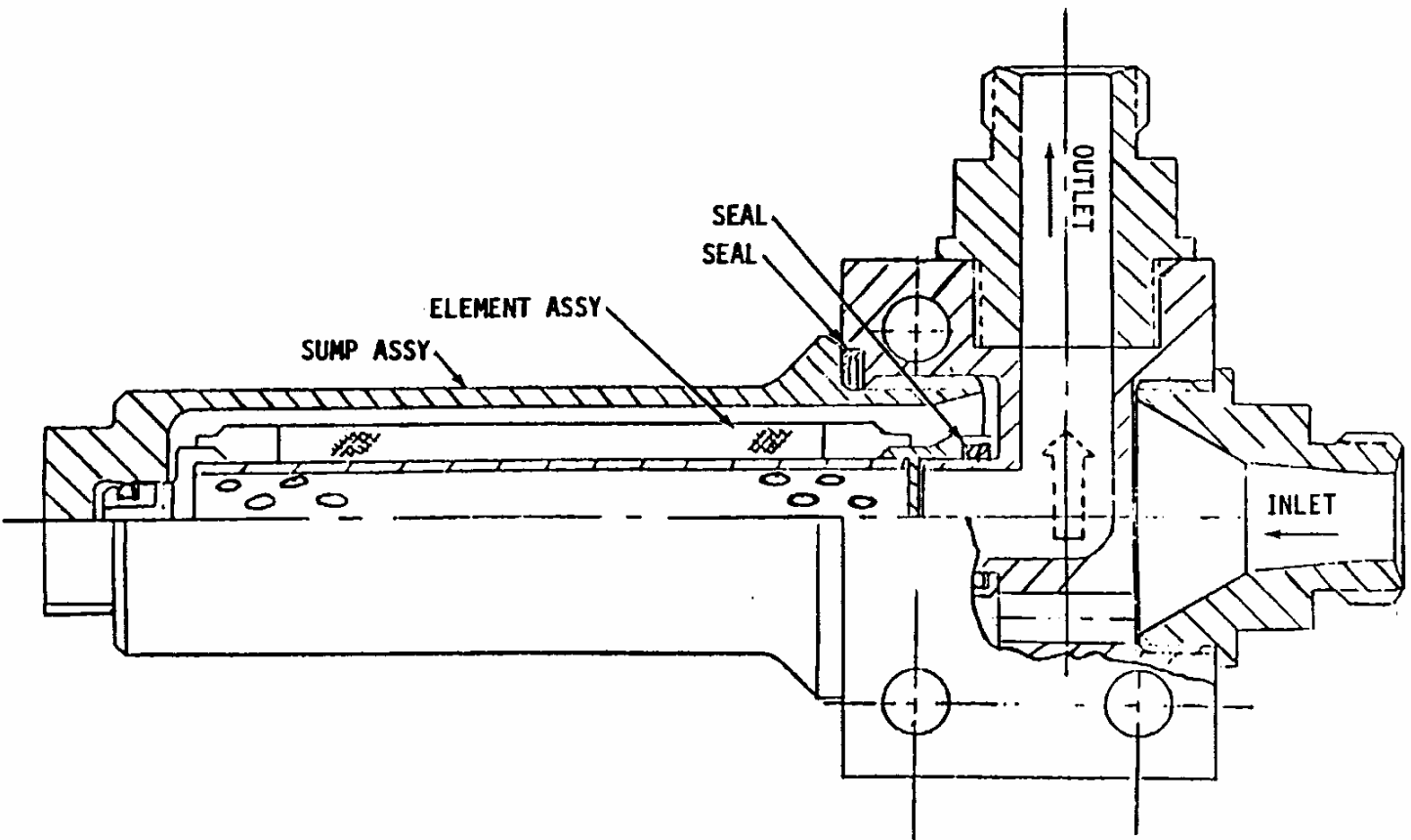
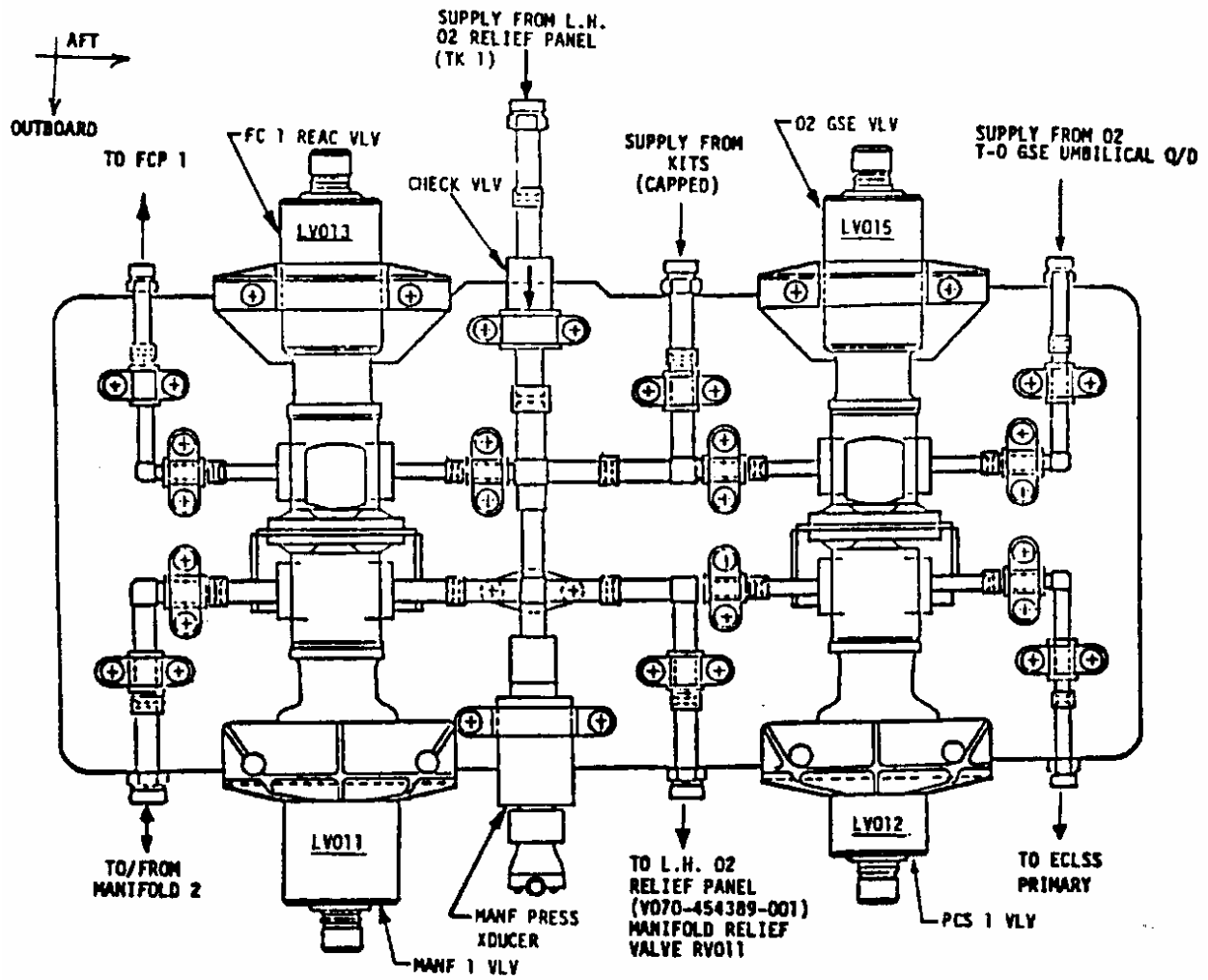


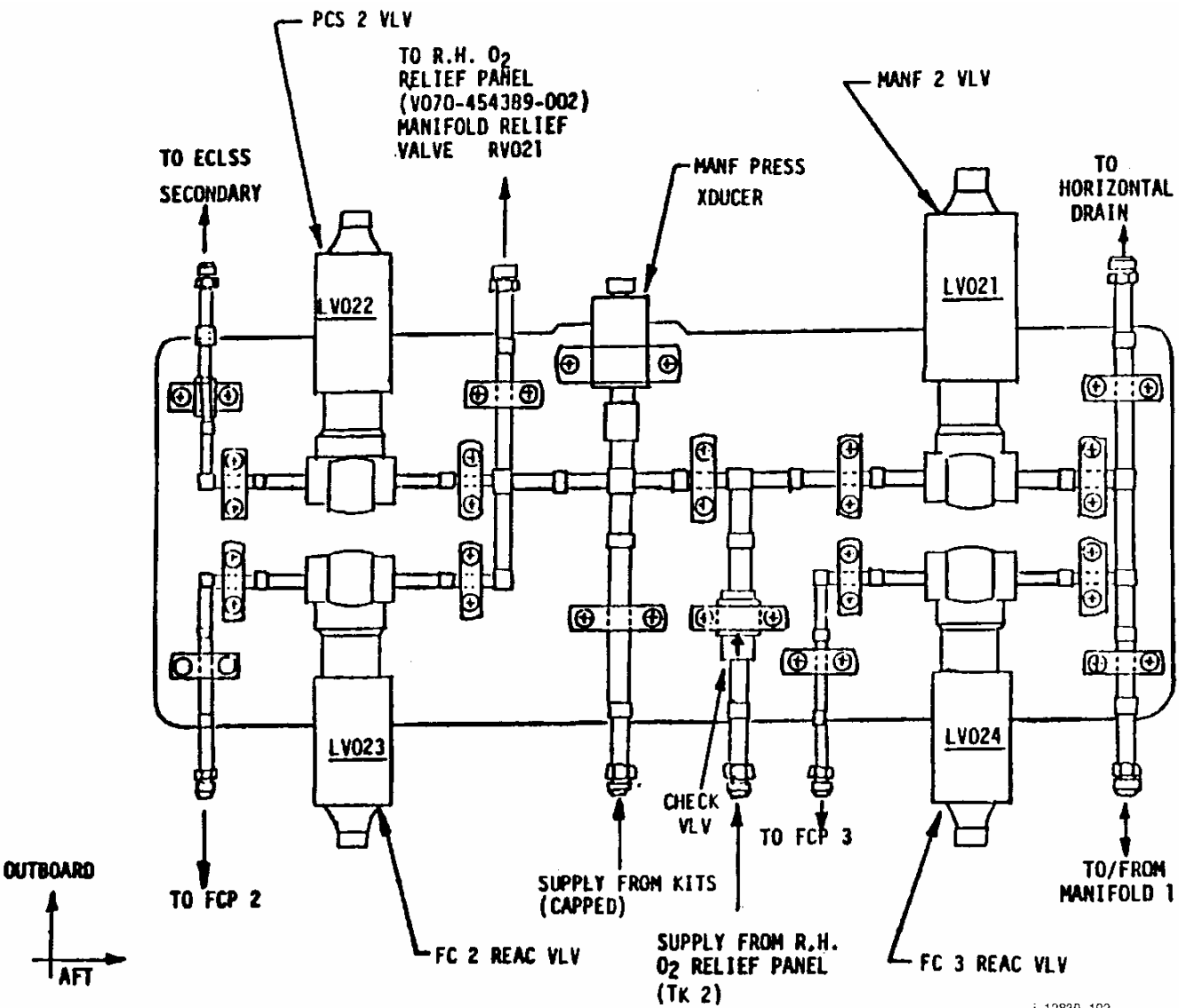
Figure 3.1-11. Cryogenic filter

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Figure 3.1-12. PRSD oxygen panel number 1, left-hand side



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3.1-23

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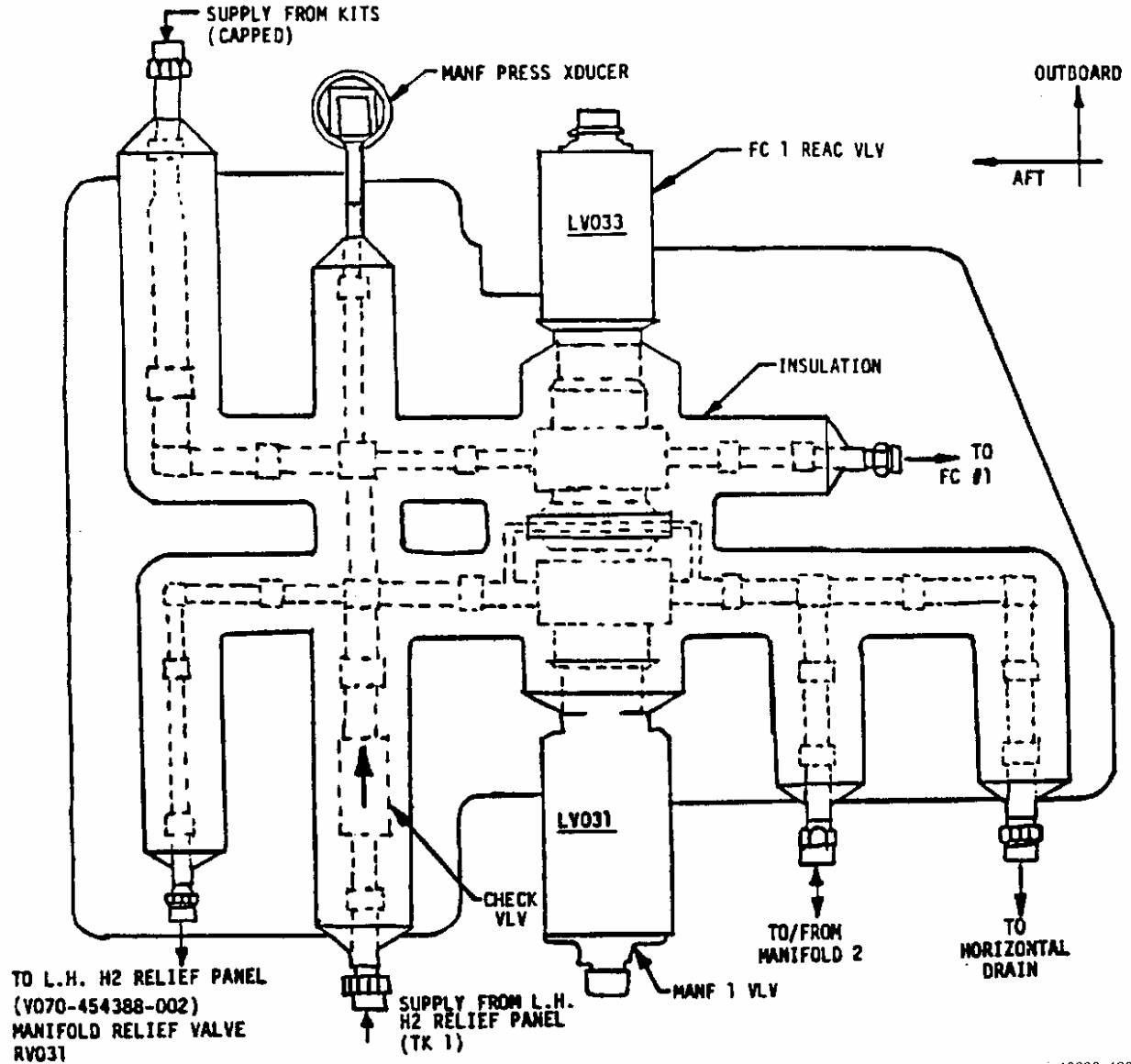
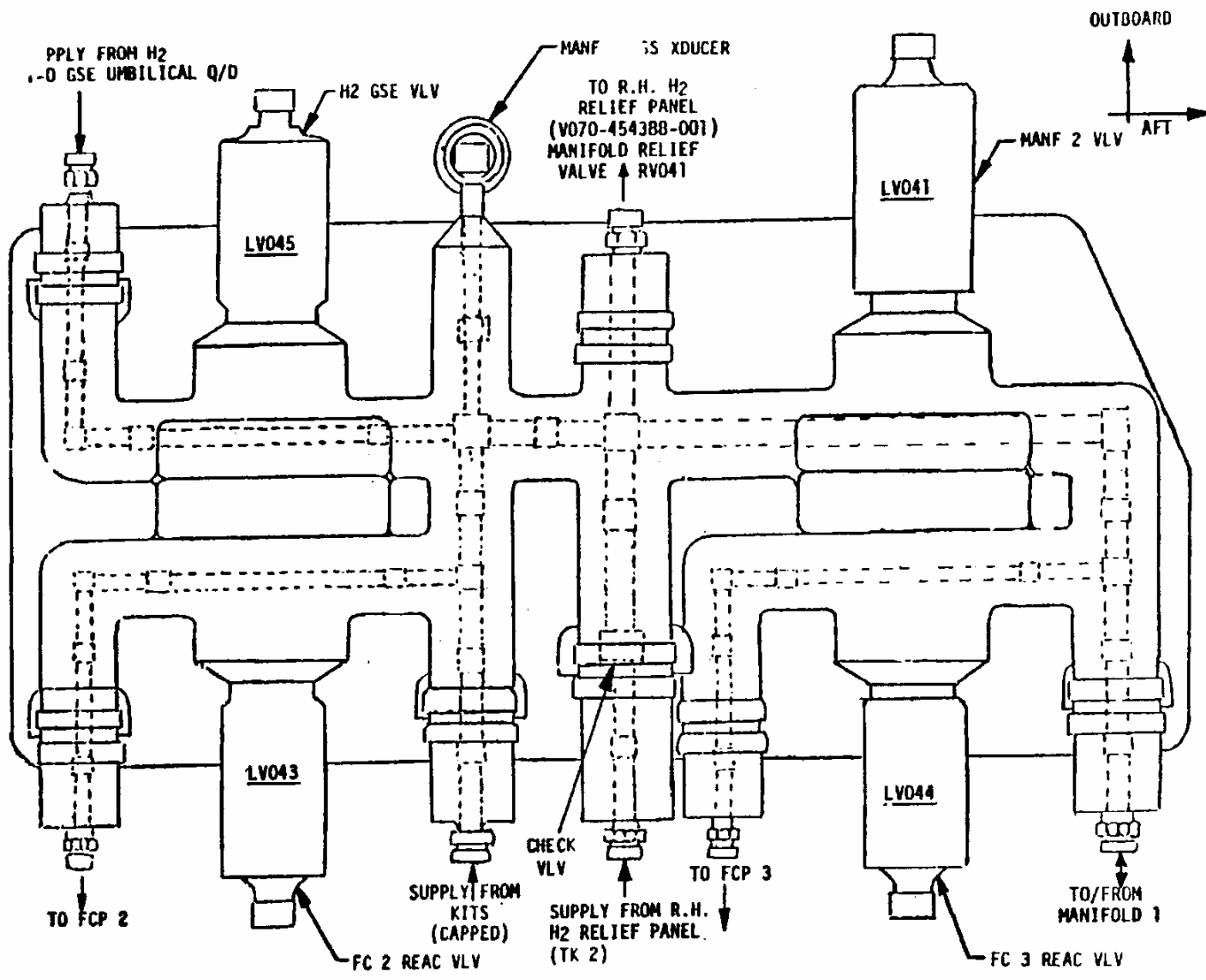


Figure 3.1-14. PRSD hydrogen panel number 1, left-hand side



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Figure 3.1-15. PRSD oxygen panel number 2, right-hand side

3.1-25  
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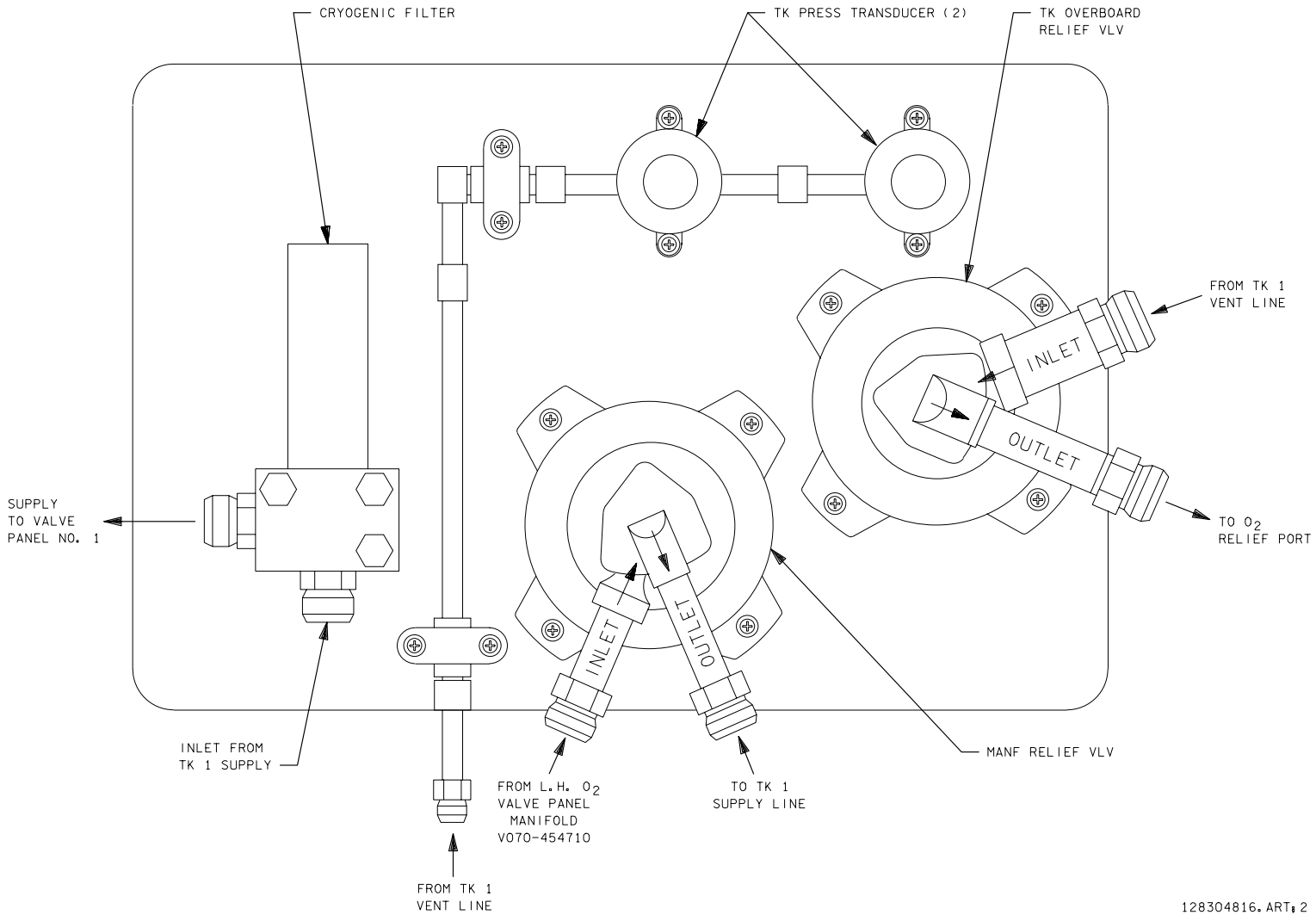


Figure 3.1-16. Typical tank 1 and tank 2 relief valve/filter panel

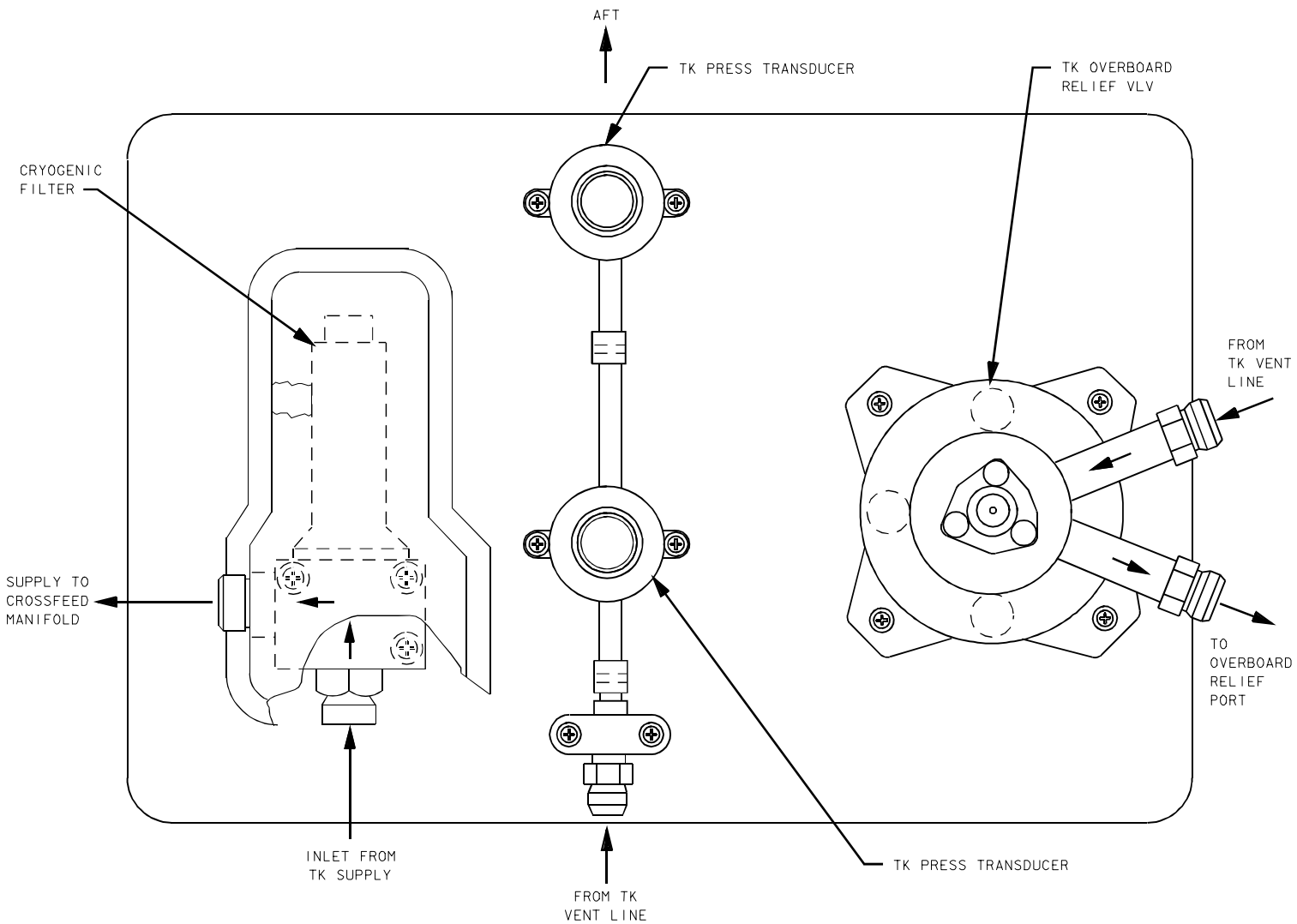


Figure 3.1-17. Typical relief valve/filter panel for tanks 3, 4

## TITLE

CRYO THEORY

## PURPOSE

The purpose of this systems brief is to provide flight controllers with an understanding of some of the fundamentals of cryogenic fluids. Topics to be covered will include

1. What is a cryogenic fluid?
2. How does it behave?
3. What does a shuttle flight controller need to know about cryogenic fluid?

## BACKGROUND

Cryogenics is defined in Webster's Dictionary as... "The science that deals with the production of very low temperatures and their effect on the properties of matter." The term "very low temperature" is arbitrary, but the workers at the National Bureau of Standards (NBS) in Boulder, Co. have chosen to consider the field of cryogenics as that involving temperatures of -240° F and below. The NBS was established by an act of Congress on March 3, 1901. The NBS conducts research and provides (1) a basis for the Nation's physical measurement systems, (2) scientific and technological service for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety.

Cryogenics temperatures are needed to liquefy the gases typically needed for space vehicles (O<sub>2</sub> and H<sub>2</sub> in our case). Liquids are needed to minimize the size of the containment vessel needed to carry a given mass of the element. Extraction of the liquid can be done several ways. The means which we use in the orbiter power reactant storage and distribution (PRSD) system is to add heat, which in turn raises the pressure and drives the fluid from the tank.

## FUNDAMENTALS

Before talking too much about cryogenics and supercritical fluids, a brief review of traditional thermodynamics is in order. In the traditional sense, elements are considered to exist in one of three states, solid, liquid, or vapor. Since we do not expect to store elements on the shuttle below their freezing point, solids will not be addressed in this discussion.

If a liquid is heated while maintained at a constant pressure, it will eventually start to form bubbles of vapor, or boil. The state (pressure, temperature, density) of both the liquid and vapor at this point are said to be at saturation (just started to boil). The state of the vapor defines a single point on a continuous line. The state of the liquid defines a single point on another continuous line. If the pressure is raised, the temperature at which the liquid would start to turn to vapor (boil) would be higher. This is why the cooling systems on cars have a cap, which keeps the water pressurized. The state of the liquid and vapor at this temperature and pressure would also be said to be at saturation, and yet another point on the continuous lines would be formed. The combination of states of all saturated vapor conditions will form the saturated vapor line. The combination of all states of all saturated liquids is called the saturated liquid line.

Since both the liquid and the vapor are coexisting, the temperature and pressure are the same. The only difference that sets them apart is their densities (lb/cuft). Reference figure 3.2-1,

where both lines can be seen. This plot is for water. Points in between the saturated liquid and vapor lines define states where liquid and vapor can coexist (2-phase saturated fluid). Points to the left of the saturated vapor line are said to be superheated vapor (the temperature of the vapor is higher than that required to keep it as a vapor). Points to the right of the saturated liquid line are said to define subcooled liquids (the temperature is below that which is required to keep the fluid as a liquid).

Let's take an example from figure 3.2-1. Suppose we have liquid water at 14.69 psia, and we have raised its temperature to 212° F, and the very first bubble has formed. There are two points which define the state of the water, one for the liquid at (59.8, 14.69) and one for the vapor at (.037, 14.69). What this means is that the water is a 2-phase fluid, 14.69 psia, 212° F, with a liquid density of 59.8, and a gas density of .037 lb/ft.

When the orbiter PRSD tanks are initially loaded, they are totally filled with low pressure liquid which has been stored at saturated conditions. Since there is only liquid (no gas) in the tank, the fluid is considered to be single phase. Now, analyze what would happen if we wanted to extract some of the fluid while it is being stored at these low pressures. Note that this is NOT an explanation of how it is really done.

Heat could be added by activation of the heater elements within the tank. At saturated liquid conditions, this heat added into the fluid would cause it to "boil," creating a 2-phase fluid where liquid and vapor coexist. This would not be a "rolling" boil but would be analogous to the onset of small bubbles in a pot of 212° F water on a stove. The creation of the first bubble in the PRSD tank would increase the pressure in the tank until the fluid was forced past the tank check valve and into the plumbing. If you continued to add heat and extract fluid from the tank, the amount of vapor bubbles in the tank would increase. The fluid would still remain at constant saturation conditions (pressure, temperature, and fluid densities), but the consumption of mass from the tank would be reflected as a larger SIZE bubble. The same phenomenon would be seen on your stove if you continued boiling the water; the pressure rise would raise the lid (check valve) releasing water until all that would be left in the pot would be vapor (steam). At the point where the last drop of liquid water was depleted from the pot, the steam would still be at saturated (212° F) conditions. If you continued to add heat, the temperature of the steam would now begin to increase, and the steam would be SUPERHEATED.

Although this method obviously works to drive fluid from the tank, it has major drawbacks. The characteristics of the fluid liquid and vapor states are dramatically different. For example, the thermal conductivity of a liquid is much greater than that of vapor; we all know that a hot object transfers heat and thus cools down much faster in liquid water than it does in the air. Since we add heat locally in the PRSD tanks, we must know that the complete heater assembly is immersed in fluid with a high density (liquid) rather than a low density (gas). Immersing all or part of the PRSD tank heater probe in low density gas would cause those parts of the probe to overtemp, since the heat transfer rate to the gas would be very slow. Additionally, quantity measurement in the tank is made by measuring the dielectric of the fluid with a capacitance probe. If the capacitance probe was immersed in a small pocket of vapor, it could falsely read that the tank was nearly empty, when in actuality it could be almost full.

If the plot in figure 3.2-1 was taken far enough, it could be seen that the saturated liquid and vapor lines converge to a single point. That point is called the CRITICAL POINT. The pressure at that point is called the CRITICAL PRESSURE. At all points above the critical pressure, the fluid no longer has the ability to create a sharp "boundary" between a liquid and vapor state. Fluids stored at pressures above the critical point are not called liquids or vapors, but instead are simply called SUPERCRITICAL FLUIDS. Although the properties of the fluid at a given

point (density, temperature, etc.) may closely resemble a liquid state, the fluid behaves much differently when exposed to a change.

Let's look at an example. If we take a pot of water at room temp (70° F) and start to add heat, its temperature will begin to rise. Since the pot is uncovered, its pressure will remain constant at 14.7 psia. Since the temperature of the water is below that which causes it to boil, its state will appear to the right of the saturated liquid line on figure 3.2-1 (in the subcooled liquid zone). The density of the water would be greater than 60 lb/ft<sup>3</sup>. If we continue adding heat, the water will reach 212° F, and its state will appear at the intersection of the 212° isotherm and the saturated liquid line. At this point, the density of the water would be about 60 lb/ft<sup>3</sup>. If the volume that it is occupying is 1 ft<sup>3</sup>, then there is 60 lb of water (all liquid). Let's consider this to be our starting point for our example. Now let's continue adding heat until all of the liquid water is gone. As we add heat, the temperature will now remain constant at 212° F, but the water will start to boil. The water vapor will have a density of about .04 lb/ft<sup>3</sup> (as seen from fig. 3.2-1). When all of the liquid is gone, we will have all saturated vapor (steam) at the density of .04 and a temp of 212° F. Now if we continue to add heat, we will raise the temp of the steam and lower its density. It is said that the steam is now superheated. This is an example of phase changes which can occur when a fluid is subcritical.

Let's repeat the example starting at the point where we just intersected the saturated liquid line. Now, instead of beginning to boil the water we placed a lid on the pot which did not "relieve" until above the critical point of water (3206 psia). As heat is added to the water, no phase change occurs. Instead, the density of the water would gradually decrease, and its temperature would gradually increase. Eventually, the water would have a very low density (much like a vapor), but it would have been a gradual transition. Throughout the entire depletion of the water, the density of all the water would be the same. There would be no "bubbles" of vapor as seen in the subcritical method of depletion.

This is the method that is used in the orbiter PRSD system. The tank pressure is normally run supercritical (>731.4 and 187.5 for O<sub>2</sub>/H<sub>2</sub>). This, to a great extent, guarantees that the fluid density is homogeneous throughout the tank. In actuality, heat transfer from the heater element in the center of the tank to the outside is sometimes slow, and with the lack of external mixing forces at times, causes significant temperature and density gradients. This phenomenon is called stratification and is explained in detail in another SCP.

The characteristics in figure 3.2-1 will be seen in O<sub>2</sub> and H<sub>2</sub> also. Specific graphs of their vapor domes and isothermal lines can be seen in figures 3.2-2a and 3.2-2b.

## PRESSURIZATION

The fundamentals discussed above relate to what the EPS and EGIL are concerned about - pressure predictions.

The pressurization of the fluid within a PRSD tank is caused by thermal expansion of the fluid due to heating. Since the volume of an ideal tank is fixed (no stretch), any expansion will cause the fluid pressure to rise. A full tank will have fluid with a high density, which will be hard to compress. Therefore, it will pressurize faster (under no-flow conditions) than a tank with lower density fluid.

On the other hand, mass flow from the tank causes the pressure to be relieved from the fluid faster if the density is high. These tradeoffs net a result which makes it easiest (least amount of

heat) to extract (boil) fluid from the tank at mid-densities, and harder at lower or higher densities.

The NBS has printed tables (fig. 3.2-3) which dictate thermodynamic constants which can be applied to determine

1. The rate at which fluid can be extracted from a fixed volume per unit of heat input (while maintaining constant pressure)
2. The pressure rise rate due to heat input into a fixed volume
3. The pressure decay rate due to mass flow out of a fixed volume

The constants that are used to determine the above are:

1. Specific Heat ( $\ominus$ ) - Units are in BTU/lbm. This is used to determine how much heat is needed to maintain constant pressure when a pound of fluid is extracted. This is also known as  $dQ/dM$  (figure 3.2-6d and 3.2-6e).
2. Energy Derivative ( $\oslash$ ) - Units are in psia \* cubic feet/BTU. If we divide by the tank volume in cubic feet, we have a constant called ( $\oslash/V$ ), with units of psia/BTU. We can use this constant to multiply by  $Q_{dot}$  (BTU/HR) to get the pressure rise rate (psia/BTU/HR). See figure 3.2-4a and 3.2-4b.

Multiplying both constants above yields another constant, with units of psia \* cuft/lbm. Dividing by the volume yields ( $\oslash\ominus/V$ ) with units of psia/lbm. This constant can be used with the mass flow rate (lbm/hr) to find the pressure decay rate in psia/hr. If flow is out of the tank,  $\oslash\ominus/V$  will be negative in sign.  $\oslash\ominus/V$  is essentially the theoretical equivalent of "K," talked about in other SCP's. "K" is a constant derived from flight data. Flight data differs from pure theoretical data by factors of tank stretch, environmental heat leak, etc.

Since these properties change with fluid state, the NBS tables define these constants based on isobars. Figure 3.2-3 is for H<sub>2</sub> at the 200 psia isobar. If we take a fluid density of 3 lb/cuft, we can see that the following conditions exist:

$$\begin{aligned}\ominus &= 139 \text{ BTU/lbm (also known as } dQ/dM) \\ \oslash &= 6.6 \text{ psia * cuft/BTU} \\ V &= 21.39 \text{ cuft (volume of a PRSD H}_2 \text{ tank)}\end{aligned}$$

Therefore:

$$\begin{aligned}\oslash/V &= 0.31 \text{ psia/BTU} = 0.31 \text{ psia/hr/BTU/hr} = 0.005 \text{ psia/min/BTU/hr} \\ &= 0.018 \text{ psia/min/watt}\end{aligned}$$

$$\begin{aligned}\oslash\ominus/V &= 42.8 \text{ psia/lbm} = 42.8 \text{ psia/hr/lbm/hr} \\ &= 0.71 \text{ psia/min/lbm/hr}\end{aligned}$$

Note that there is also a fudge factor curve (figure 3.2-7) which attempts to adjust the theoretical data with non-ideal conditions introduced from the "real world." The irregular shape of the O<sub>2</sub> curve is probably due to the error discussed below. Real-world conditions include such things as tank stretch and environmental heat leak. Figure 3.2-8a and 3.2-8b are the "K" curves which are derived strictly from flight data. The curves are accurate at some quantities, but have error

at others. Also, the “original K” curves match the SMS better, and have become known as “SIM” curves.

Part of the known error is caused by dispersion in the flight data points. The other part of the error is caused by an inaccurate curve fit at some quantities. It is recommended that the curves be updated to account for these problems.

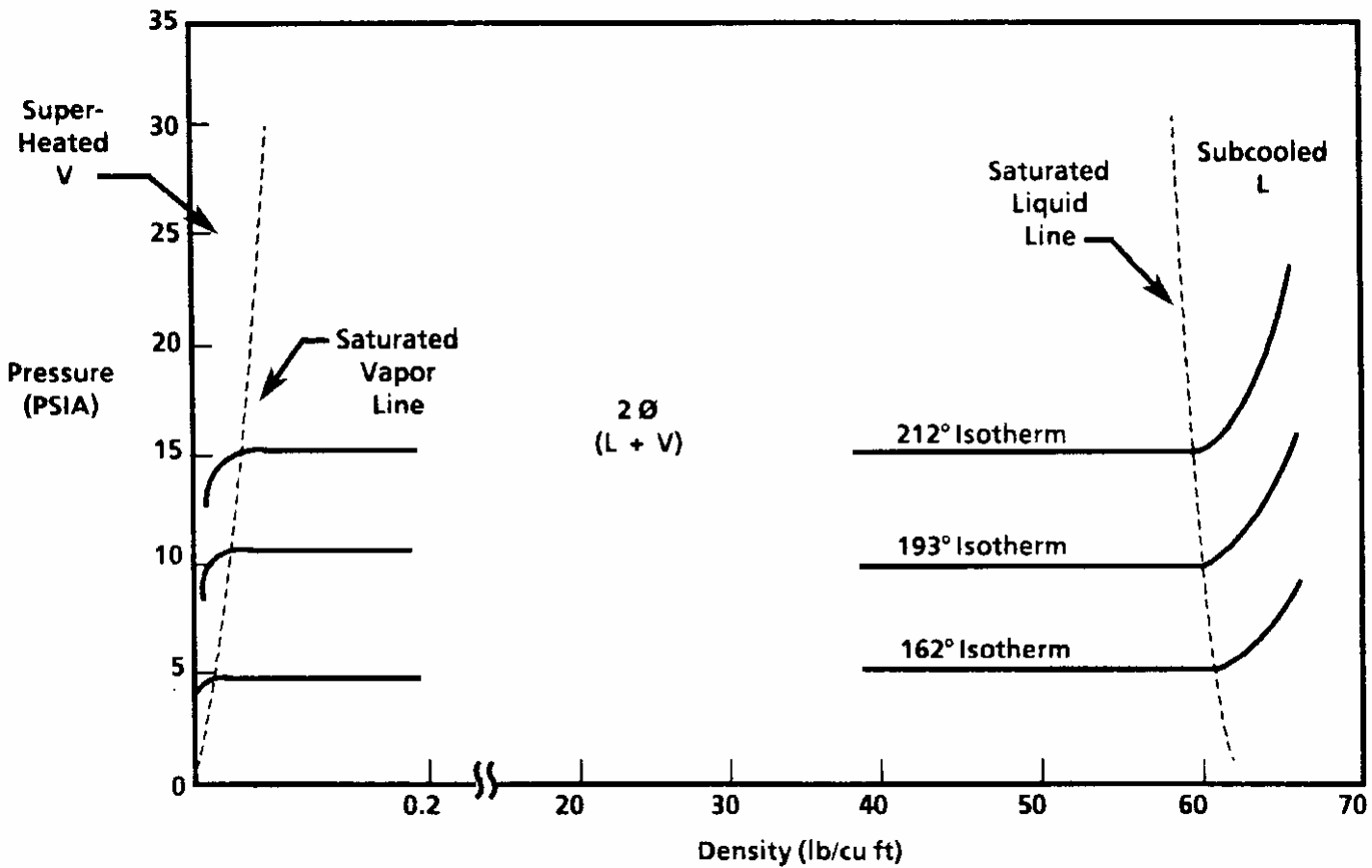
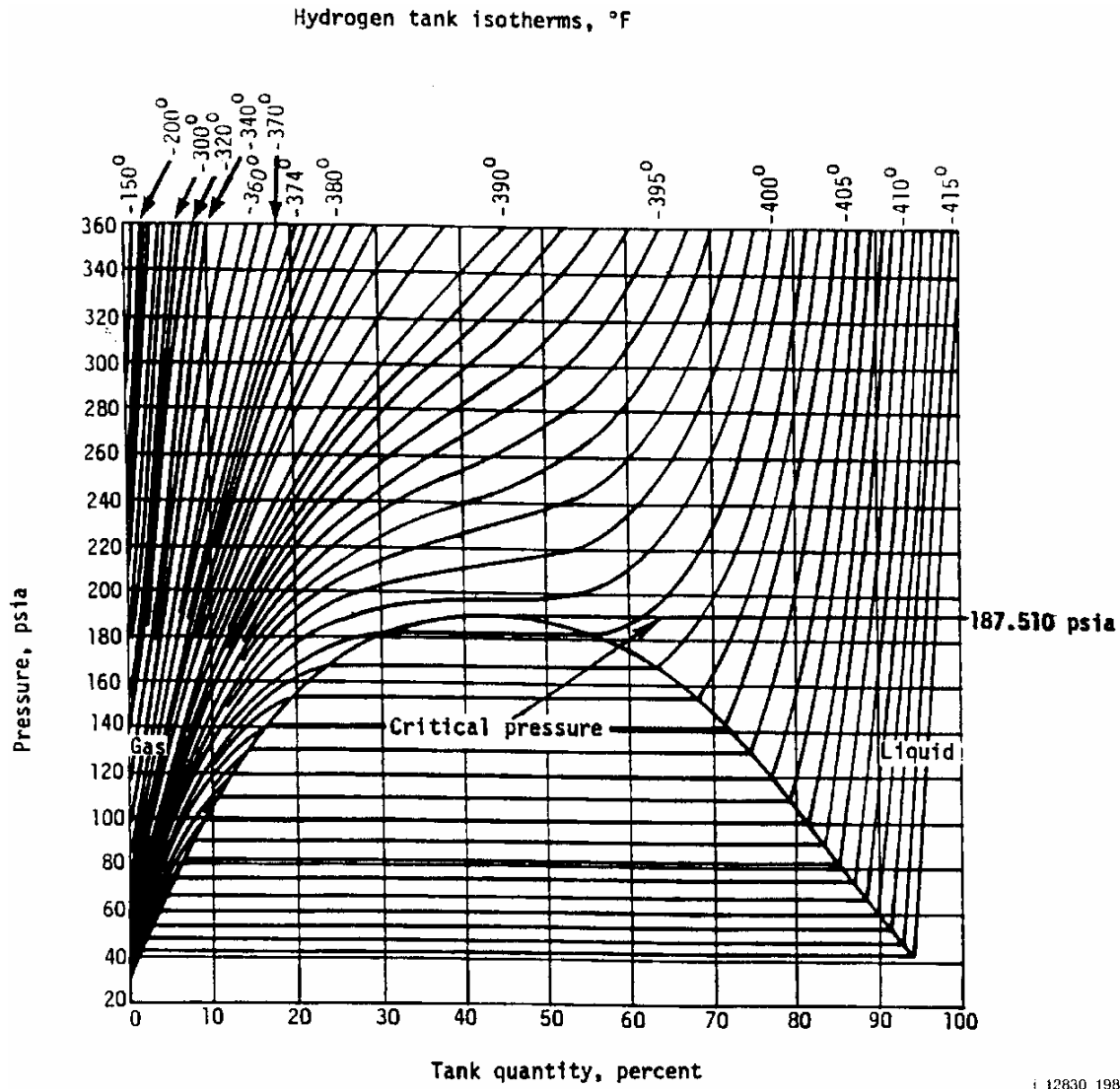


Figure 3.2-1. Water saturation conditions

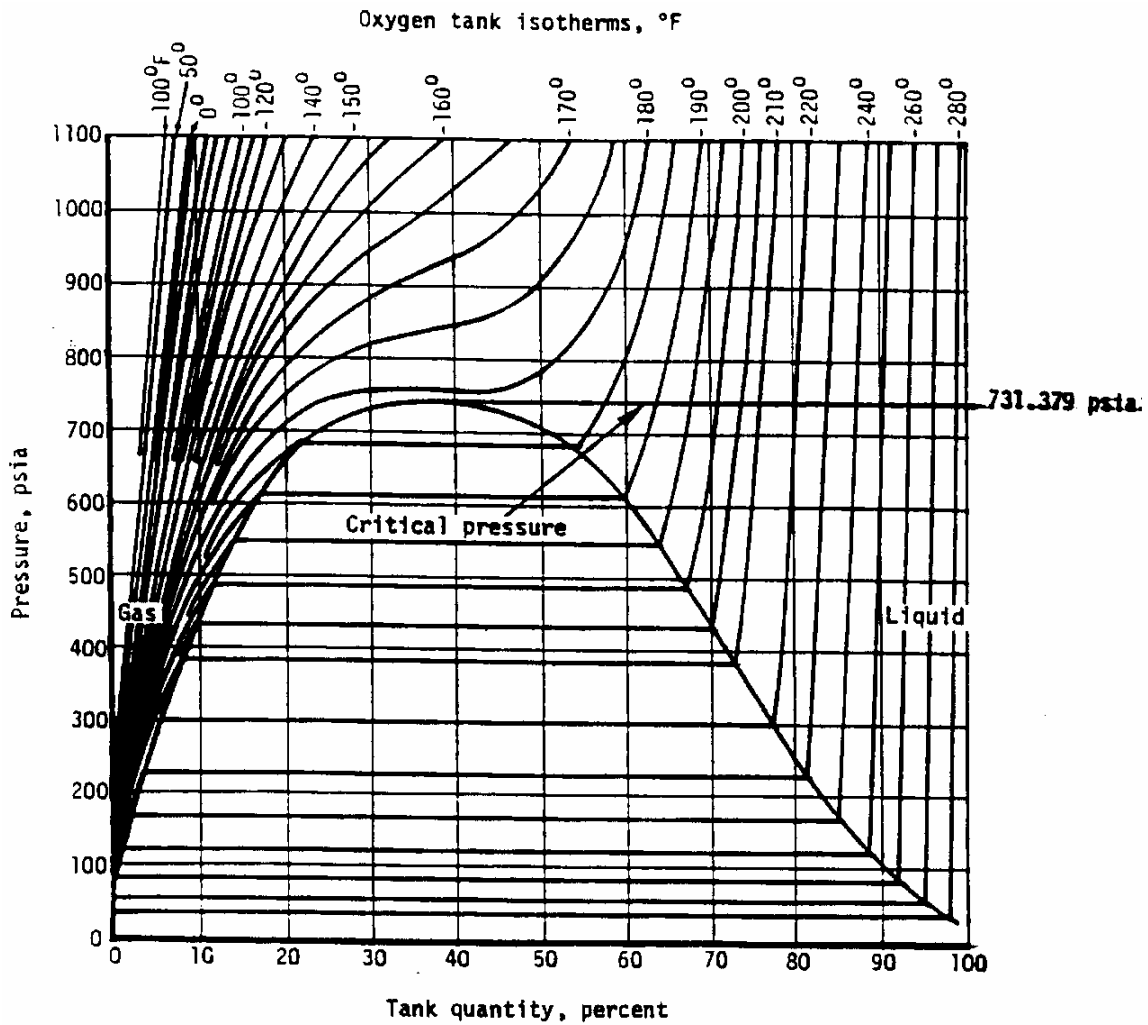
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Figure 3.2-2a. Hydrogen tank isotherms, °F



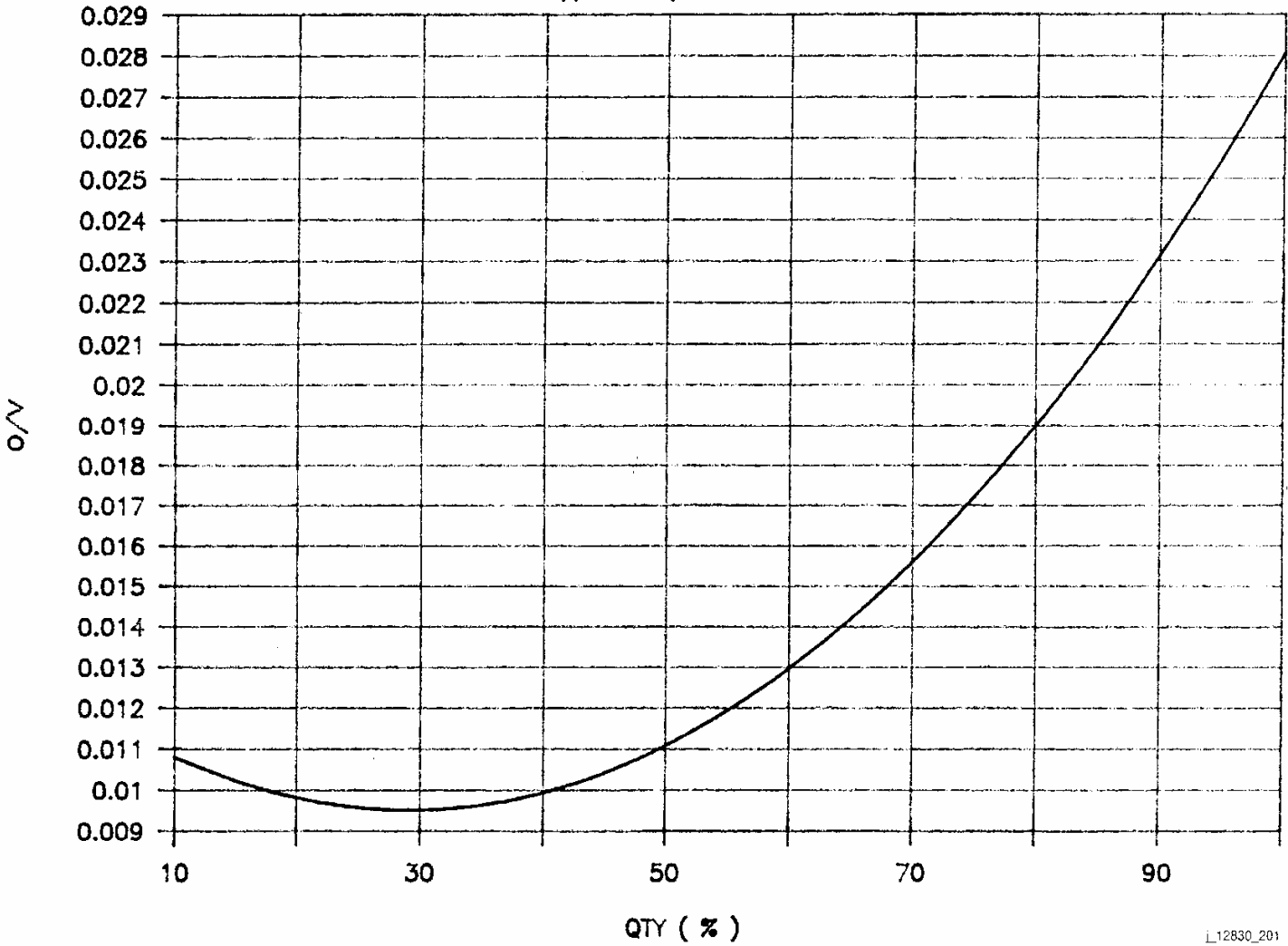
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Figure 3.2-2b. Oxygen tank isotherms, °F



# H2 ENERGY DERRIVATIVE

$$+dp/dt = 0/V * Watts * C$$

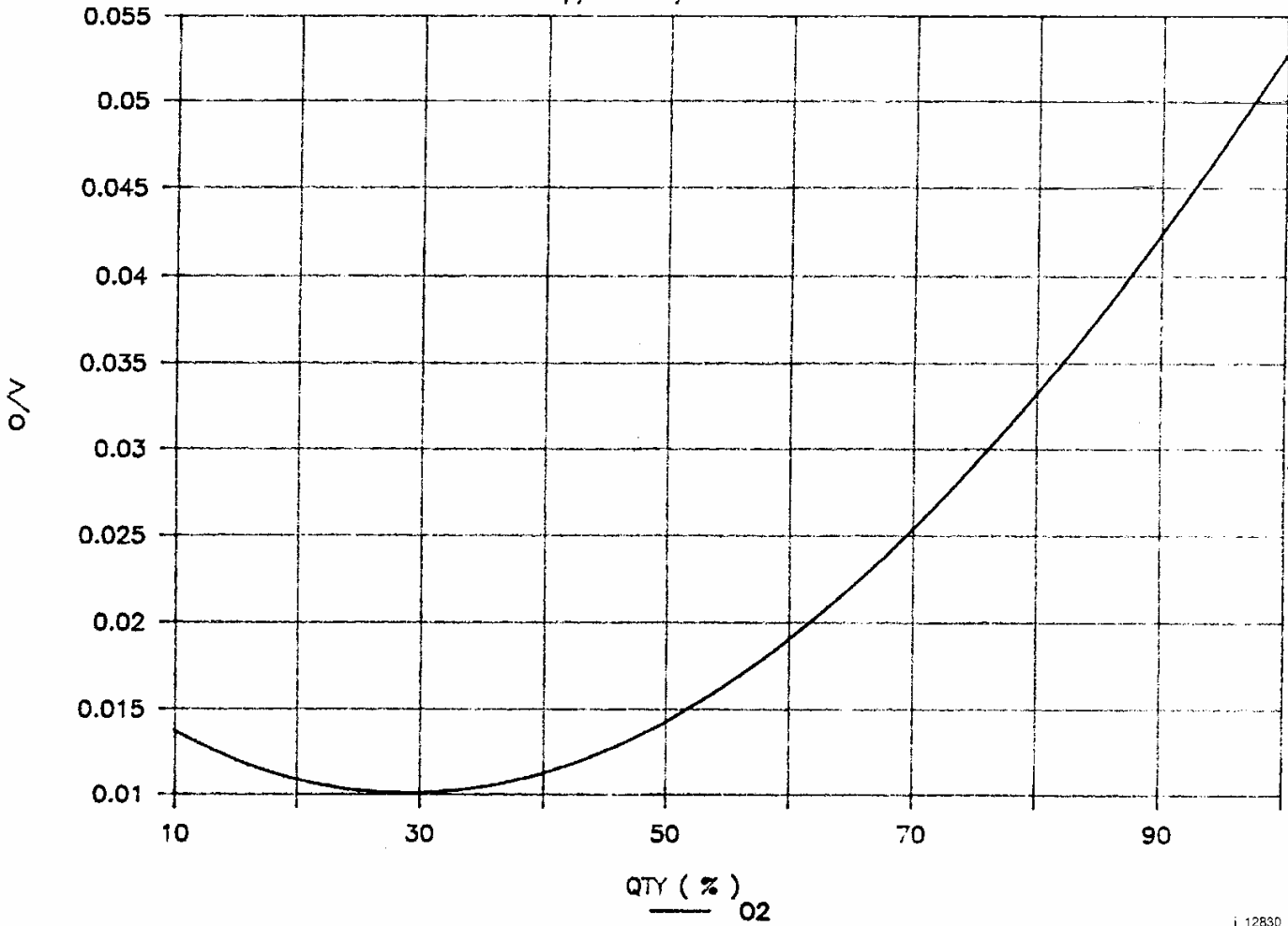


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Figure 3.2-4a. H<sub>2</sub> energy derivative

# O2 ENERGY DERRIVATIVE

$$+dp/dt = O/V * \text{Watts} * C$$

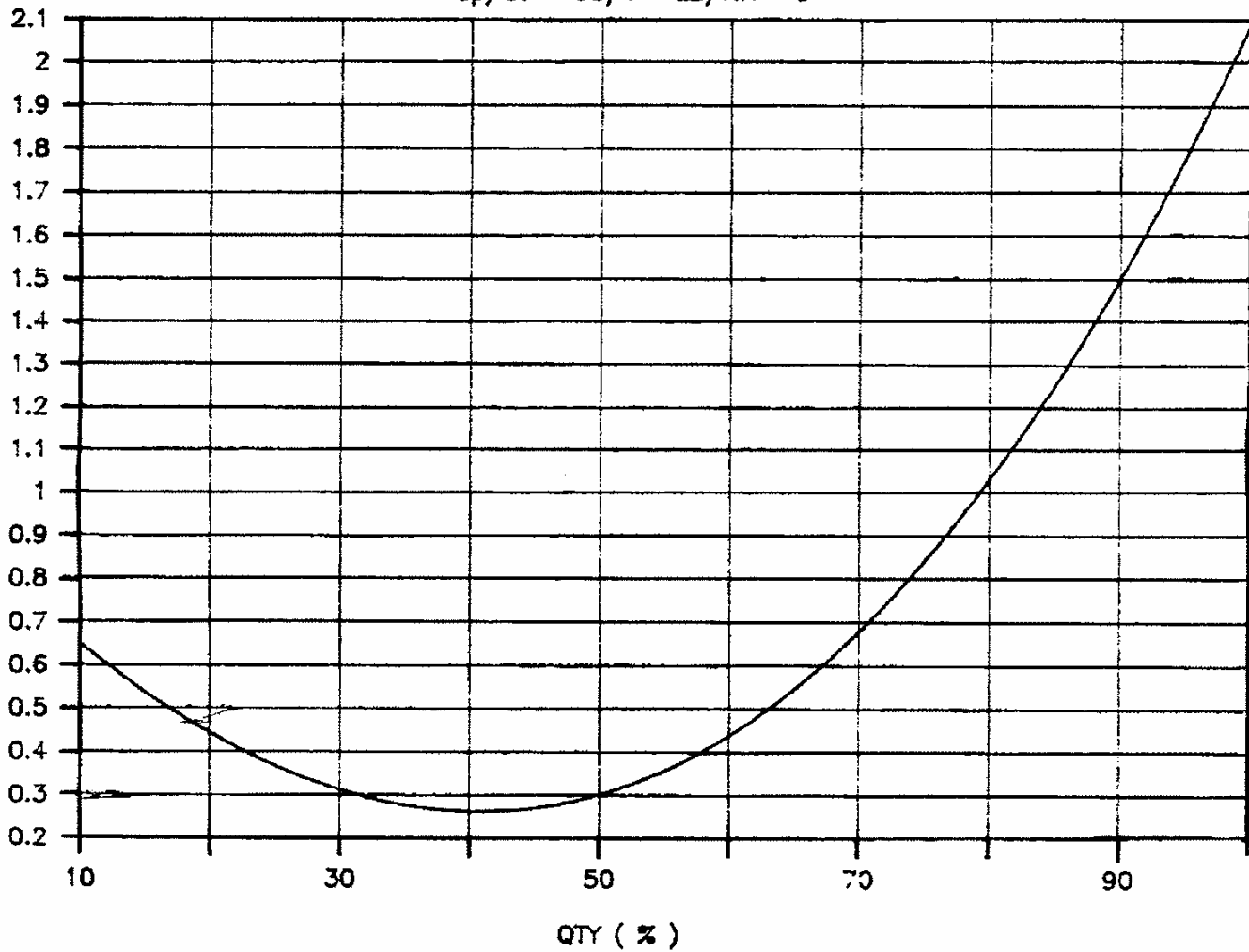


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Figure 3.2-4b.  $O_2$  energy derivative

# H2 PRESSURE DECAY

$$-dp/dt = 00/V * LB/HR * C$$

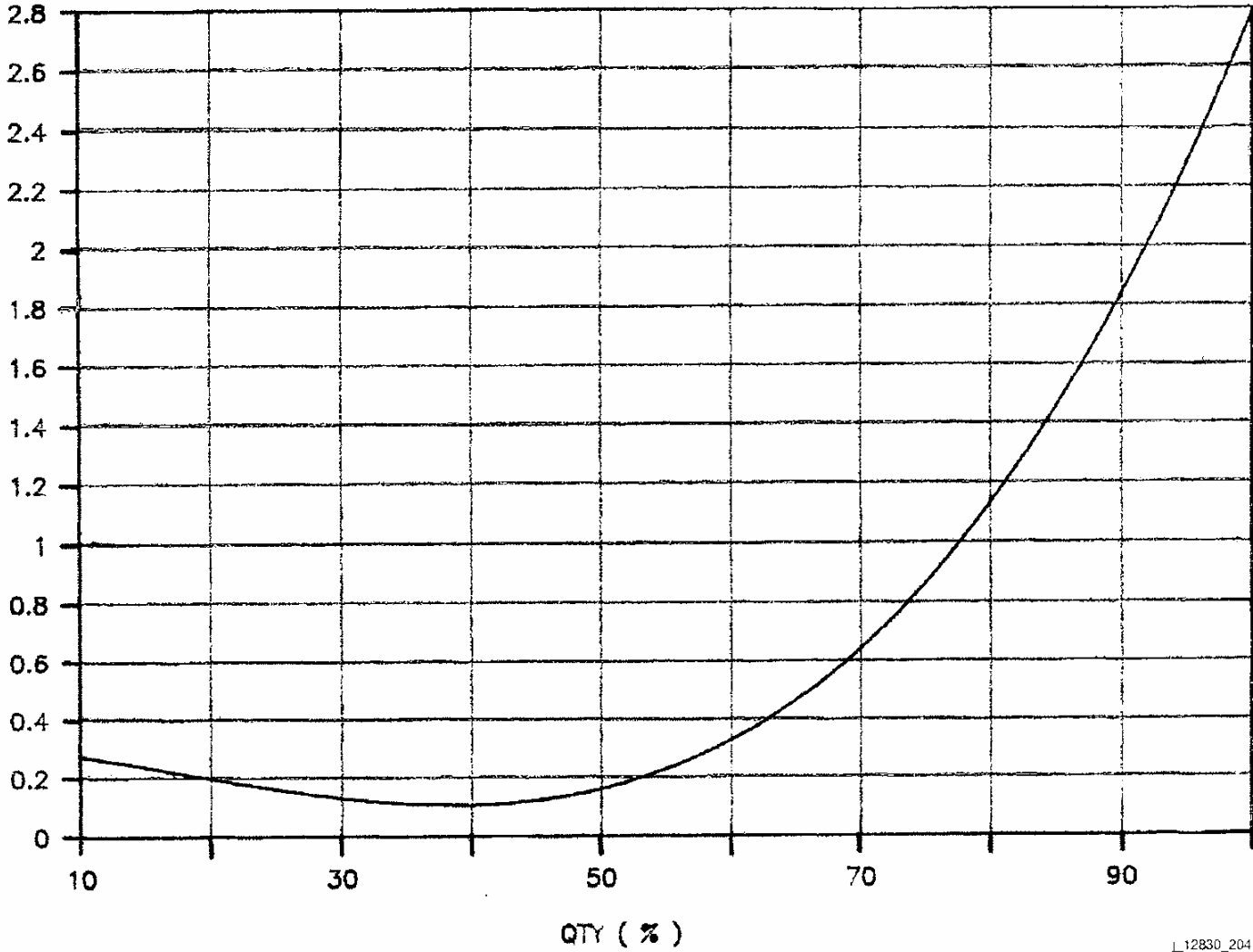


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Figure 3.2-5a. H<sub>2</sub> pressure decay

# O2 PRESSURE DECAY

$$-dp/dt = 00/V * LB/HR * C$$



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Figure 3.2-5b. O<sub>2</sub> pressure decay

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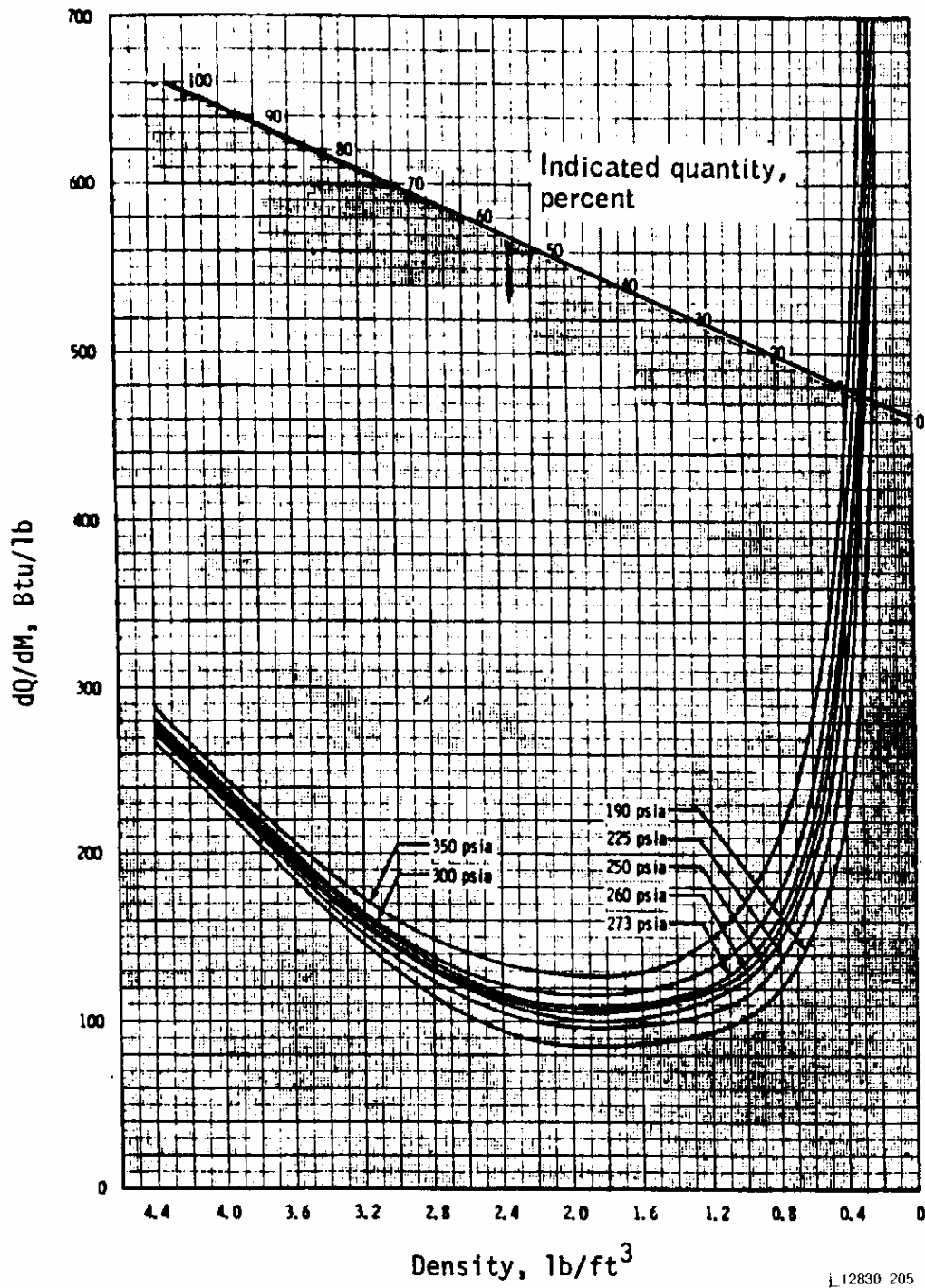
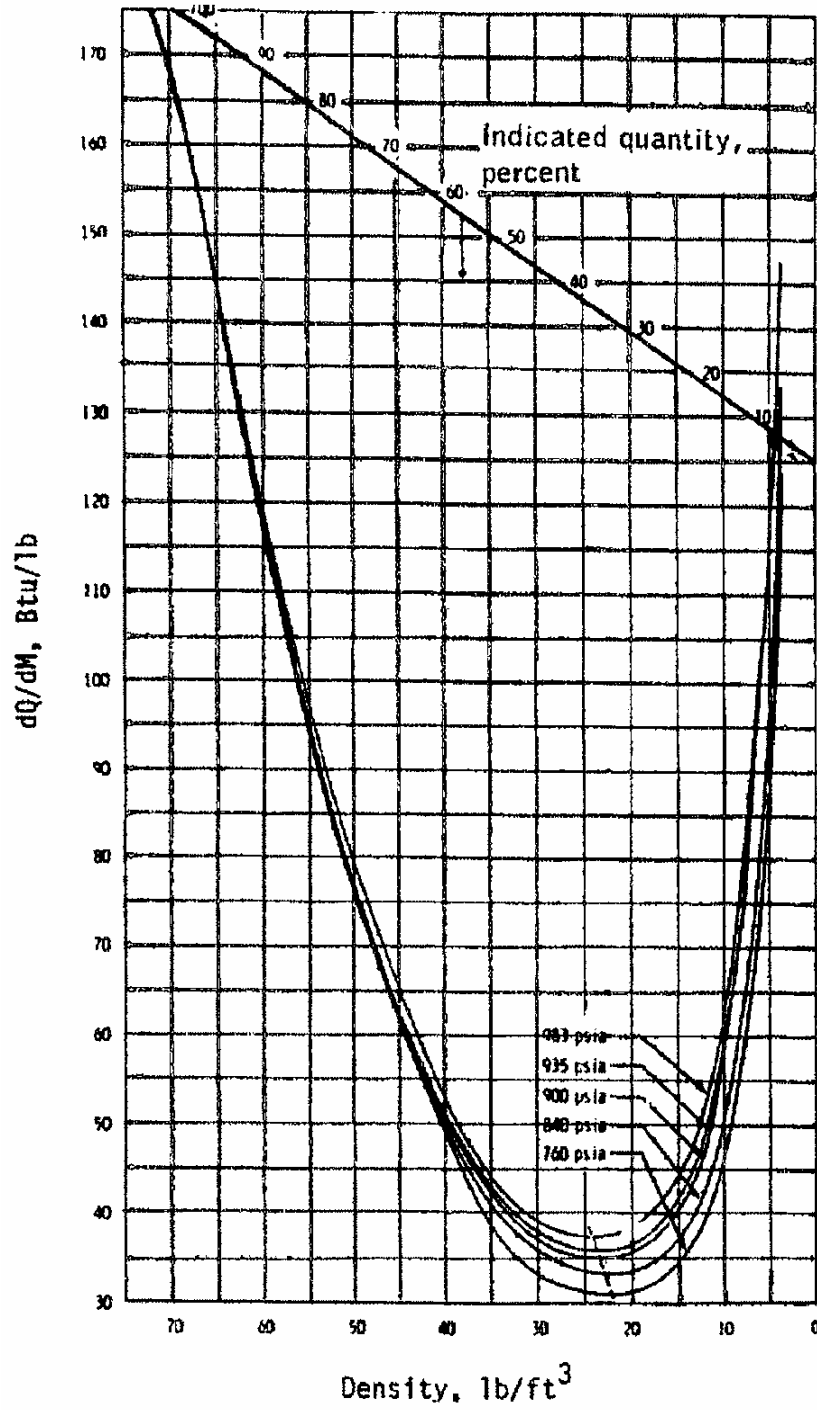


Figure 3.2-6a. Hydrogen tank  $dQ/dM$

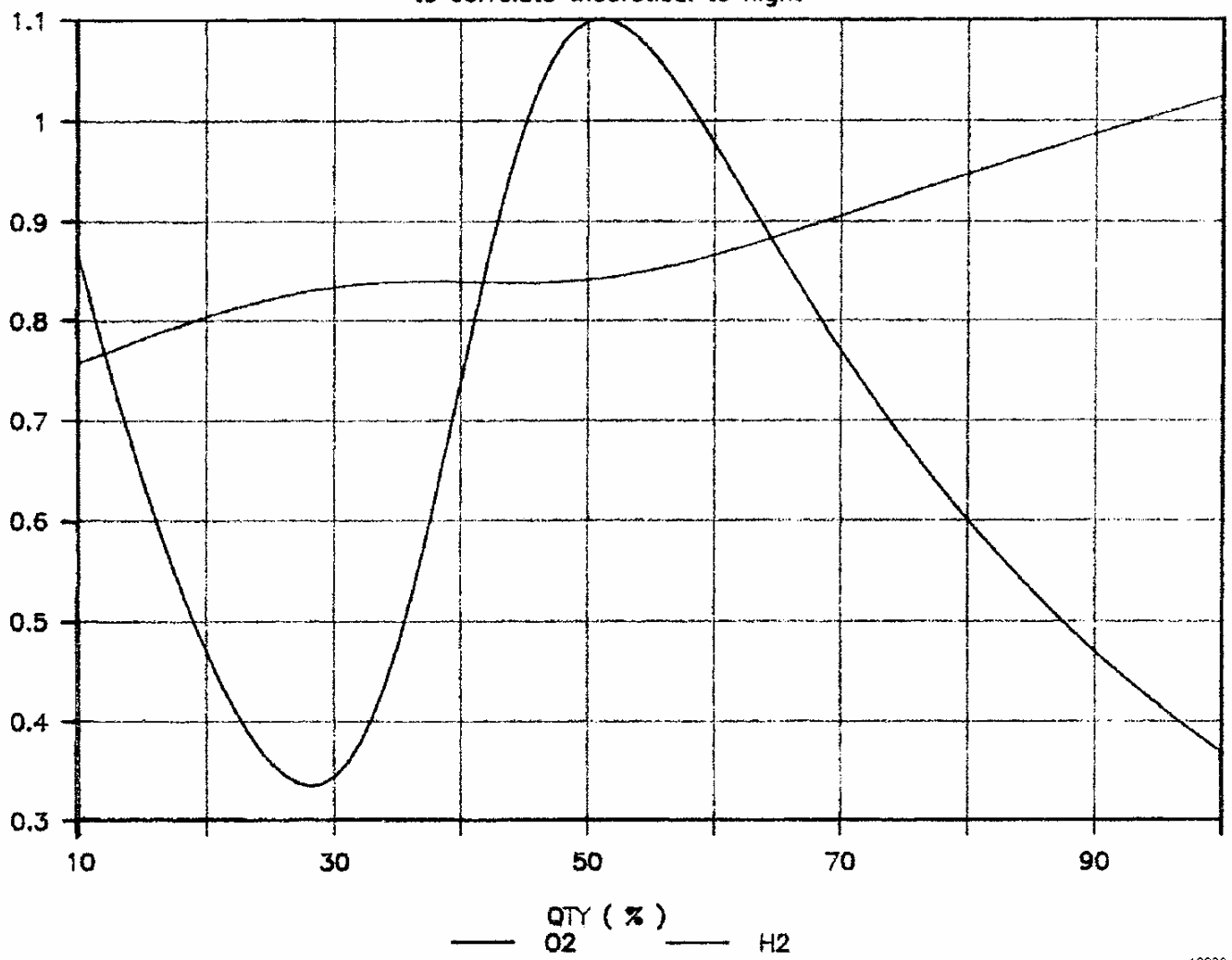




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Figure 3.2-6b. Oxygen tank  $dQ/dM$

### "C" Adjustment to correlate theoretical to flight



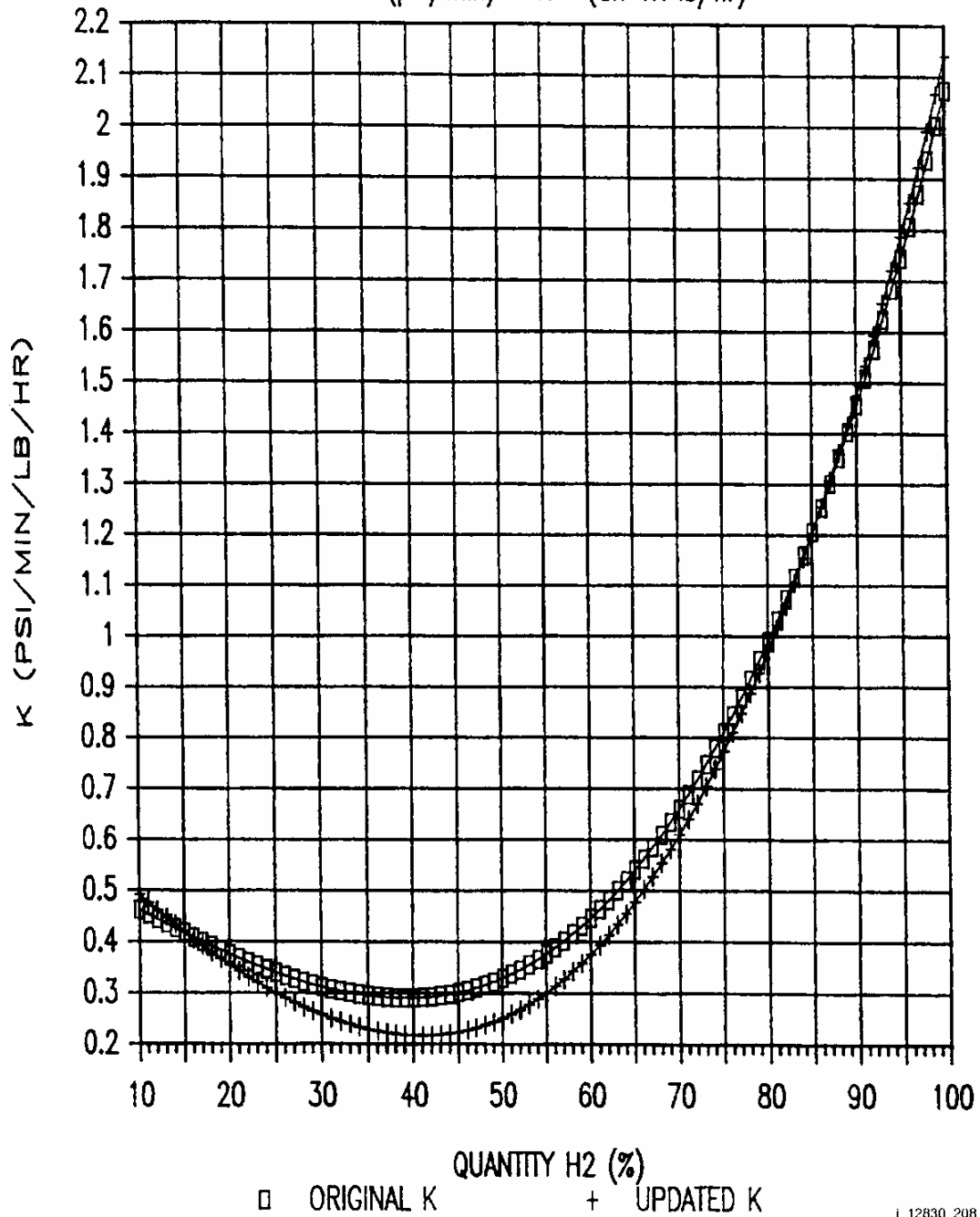
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Figure 3.2-7. "Fudge factor" curve

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# K vs. QUANTITY H2 COMPARISON

$$\text{DEC (psi/min)} = K * (\text{off TK lb/hr})$$



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Figure 3.2-8a. H<sub>2</sub> K curve

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# K vs. QUANTITY O2 COMPARISON

$$\text{DEC (psi/min)} = K * (\text{aff TK lb/hr})$$

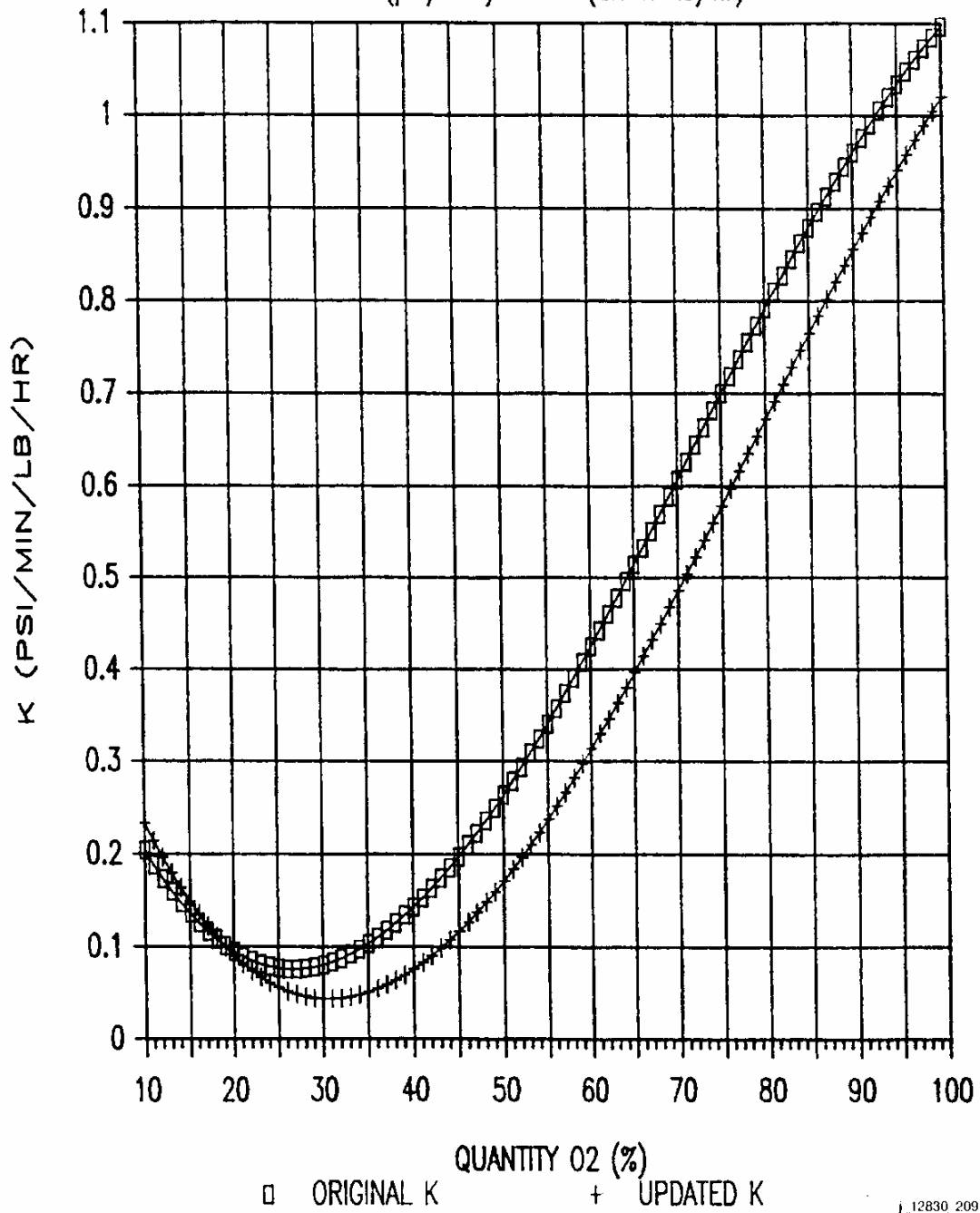


Figure 3.2-8b. O<sub>2</sub> K curve

## TITLE

STRATIFICATION/DESTRATIFICATION EFFECTS IN PRSD TANKS

## PURPOSE

This SB briefly discusses the phenomena of stratification and destratification. It also gives some specific examples and plots of these events.

## BACKGROUND

Stratification and destratification are phenomena that occur in the cryogenic PRSD tanks. Stratification and destratification produce quantity and pressure effects that may lead to (1) erroneous conclusion of a leak, (2) erroneous analyses of consumption rates, or (3) erroneous analysis of fluid density.

Stratification is the process of/state of a substance being formed into layers. Cryogenic tanks stratify when their associated heaters are enabled and begin to cycle. The cycling of the heaters, on and off, begin to form layers of different temperatures in the cryo tank. The more a heater cycles the more the tank stratifies. The fluid temperature of the cryo is greater closer to the heater, and as you move away from the heater towards the cryo tank wall the fluid temperature decreases. Since density is a function of temperature, the density increases as you move away from the heater. Stratification in a cryo tank is analogous to layering in an onion.

Since the heater surface is in close proximity to the quantity sensor (the quantity sensor actually measures the density of the fluid and converts it to quantity), stratification in a tank can cause erroneous low readings. The development of stratification in a cryo tank may be so gradual that the error in the quantity reading is not obvious. Dramatic decreases in quantity readings, on the order of 10% in a few minutes, have been observed in H<sub>2</sub> tanks. Large quantity decreases may initially be interpreted as leaks; however, an actual quantity loss of that magnitude would be accompanied by an abnormal pressure decay. Cryo tank stratification will not cause abnormal pressure decay.

The development of stratification is a function of heater duty cycle, tank quantity, vehicle acceleration level and direction, and vehicle maneuvers. However, it is most likely to occur with high heater duty cycles (high vehicle power levels and/or single tank operation), tank quantities in the range of about 30 to 80%, low vehicle accelerations (high altitudes), little or no maneuvering, or any combination of these variables. It is very likely that some degree of stratification will always exists in a tank, but the degree will be hard to predict.

Destratification occurs when a stratified tank is mixed. A cryo tank is mixed when a vehicle maneuver is performed. The vibrations of the maneuver shake the tank, mixing the fluid temperature layers into a more homogeneous state. Since temperature and pressure are proportional when the tank destratifies, the temperature decreases and

therefore the pressure decreases. However, during destratification, as the temperature and pressure decrease, the quantity of the tank increases.

The effects of stratification and destratification can be observed in offloaded O<sub>2</sub> tanks. When an O<sub>2</sub> tank is offloaded it is first filled to its normal capacity and then the heaters are used to boil off fluid until the desired quantity is reached. The use of the heaters causes some stratification in that tank; then at MECO the tanks are shaken thus causing them to destratify (O<sub>2</sub> tank pressure decreases as the quantity increases).

It has been found that the quantity effects of stratification/destratification are more pronounced in H<sub>2</sub> tanks, and the pressure effects are more pronounced in O<sub>2</sub> tanks. Several examples of stratification and destratification are discussed in the following paragraphs, with some description of the circumstances surrounding each event. The intent of these examples is to illustrate the variety of responses of the tank quantity and tank pressure that can occur under varying combinations of circumstances.

## FLIGHT RESULTS

The first example of shuttle stratification/destratification was observed on STS-2. It occurred immediately after the OMS-4 burn in O<sub>2</sub> tank 3. On STS-4 and STS-5 a DTO was conducted to try to observe stratification and destratification in a controlled environment. STS-41-D was the first flight of offloaded O<sub>2</sub> tanks. Tanks 3 and 4 were offloaded, and due to the use of their heaters during the offload the tanks became stratified. At MECO tanks 3 and 4 destratified. The quantity increased and the pressure dramatically decreased. The effects of offloading and stratification and destratification were also observed on STS-48.

Figures 3.3-1 and 3.3-2 are examples of stratification and destratification that was observed on STS-90 and STS-87.

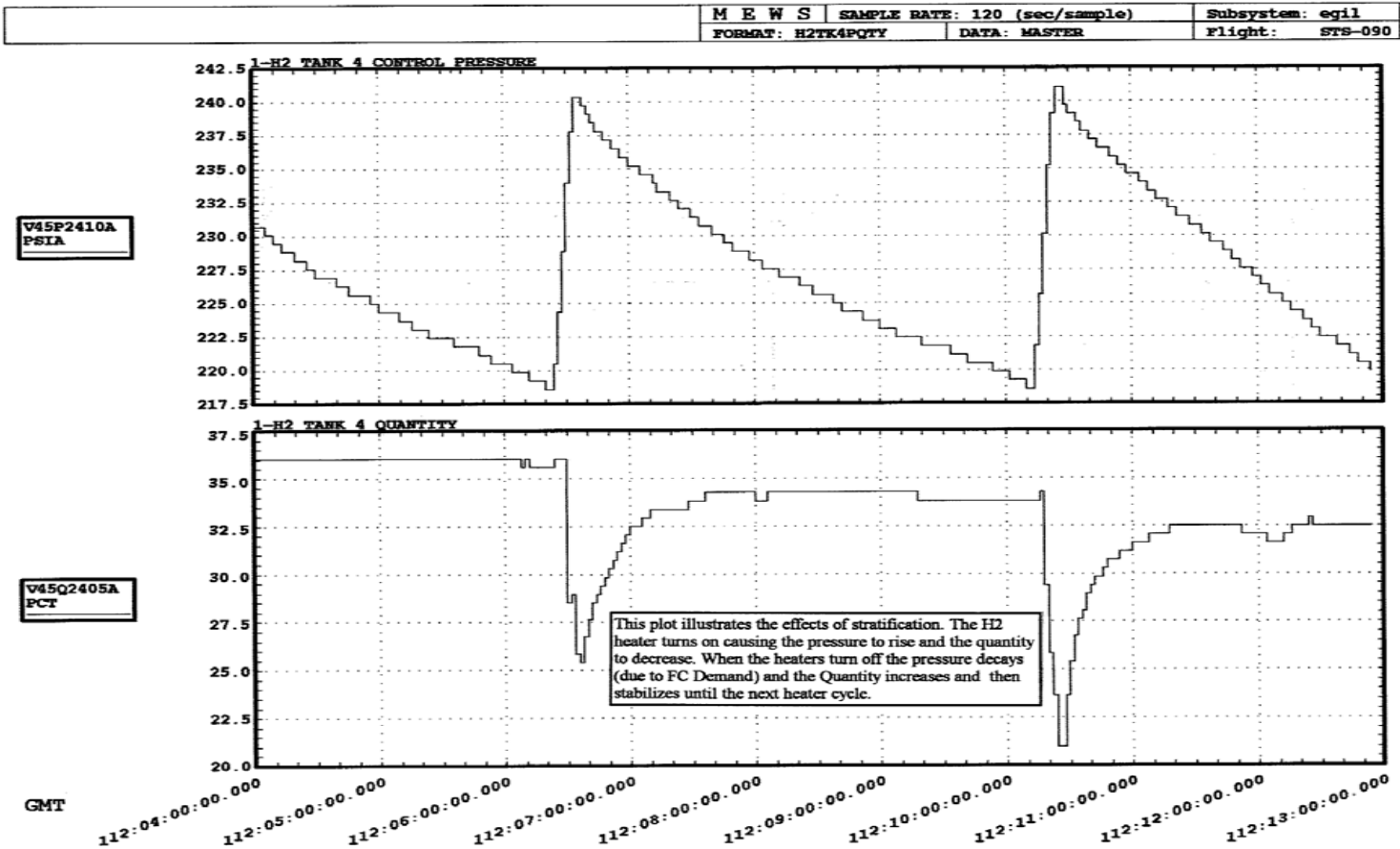


Figure 3.3-1. H<sub>2</sub> stratification

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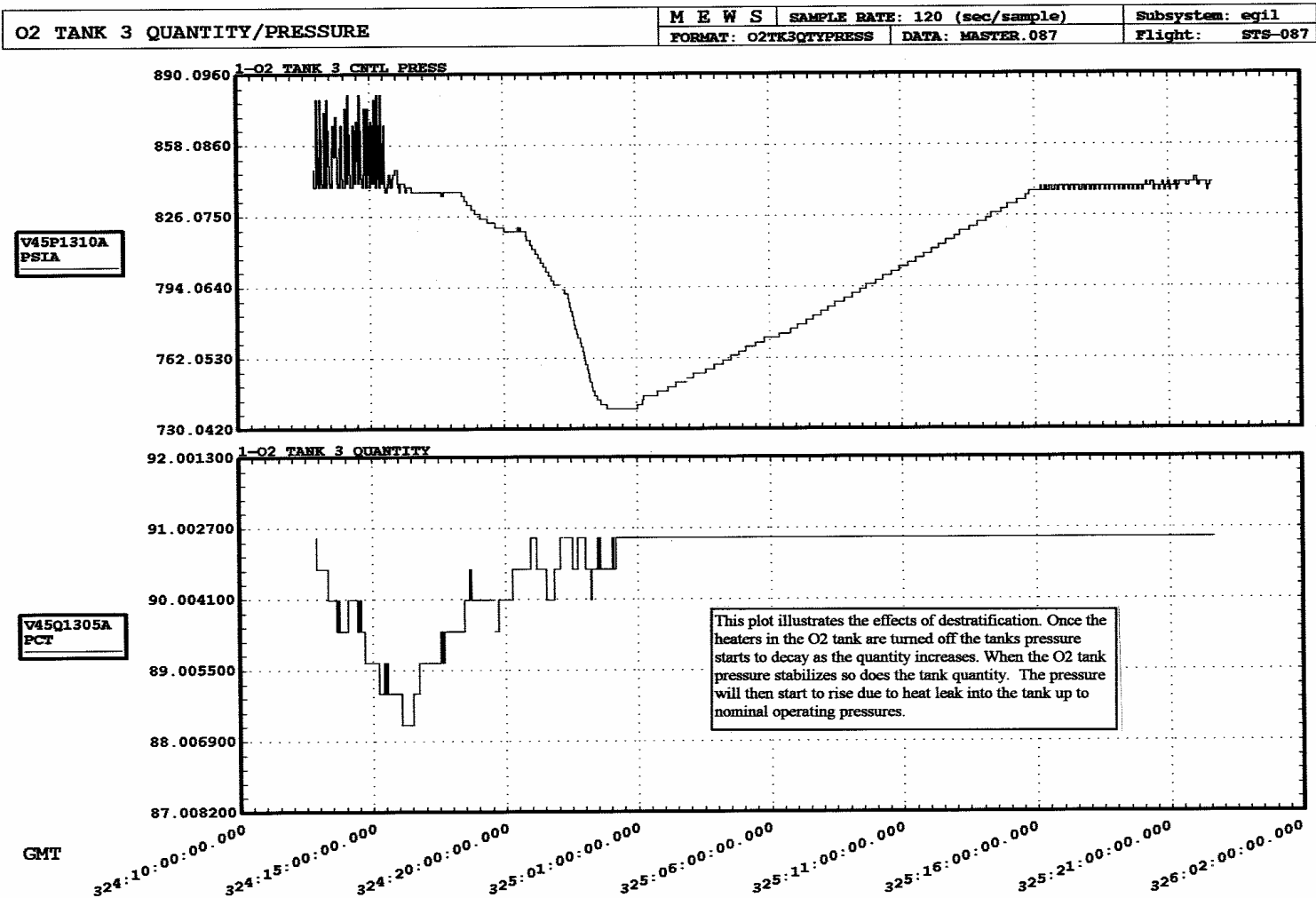


Figure 3.3-2. O<sub>2</sub> destratification

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**TITLE**

STANDARDIZED CRYOGENIC MANAGEMENT PLANS

**PURPOSE**

This brief will cover the guidelines for managing the oxygen and hydrogen cryogenics based on the number of tanks flown, and mission profile.

**BACKGROUND**

The cryogenic (cryo) tanks are managed to accomplish the following:

1. Minimize mission impact due to a tank loss.
2. Always keep cryo in tanks 1, 2, and a center manifold tank (preferably tank 3). The estimate is to have about 30 to 35% in tanks 1, 2, and manifold 3 at deorbit prep to allow supporting the extension days with a manifold valve failure. This allows cryo to be managed from panel R1 during entry.
3. Keep a manifold valve closed for single-shift sleep periods (protects a manifold for a catastrophic leak).
4. All tanks 4 and greater will be depleted first with the rest of the mission utilizing a standard three-tank set management plan.
5. Perform cryo tank heater/controller checkout as soon as practical (not ASAP).
6. Minimize the exposure to manifold spikes (usually during first day of flight).
7. Achieve equal quantities in tanks 1, 2, and 3 at end of mission (EOM).
8. Manage center of gravity (c.g.) and weights when required.
9. Minimize crew interaction.
10. Tanks 1 and 2 (if possible) will not be offloaded on a long single-shift mission.

Flight Rules used to determine cryo management:

- A9-251 Cryo Heater Management For Ascent
- A9-252 Cryo Heater Management For Orbit
- A9-254 Cryo Heater Management
- A9-256 Cryo O2/H2 Tank Quantity Balancing
- A9-252 Cryo Heater Management For Orbit (minimum quantity)

## MANIFOLD SPIKES

A manifold spike occurs when a high flow demand on a “full” tank causes cold slugs of dense cryogenic to flow into the manifold. Due to the heat leak into the lines, the cryo “boils off” more rapidly in the manifold causing a pressure spike. Engineering personnel are not concerned with the manifold spikes seen to date that do not cause the manifold relief valves to open (H<sub>2</sub> crack 290 psia/reseat 285 psia, O<sub>2</sub> crack 975 psia/reseat 950 psia). If for some reason the manifold relief valves crack, engineering personnel will write the paperwork to check them out post-flight (normal planned checkout every 12 months). The cryo management plans developed manage tanks to minimize exposure to manifold spikes.

Manifold spikes seen to date have occurred during the post-insertion timeframe (thermal impacts), during full single-tank operations (spikes intermittent, usually stop within 3-6 hours), and during 10.2-psia depress/repress operations. The only time the pressure has increased to the manifold relief valve crack limit was during STS-29.

Manifold spikes are not a major concern. They are seen quite often in smaller magnitudes, but the intent is to avoid them.

The following are guidelines to minimize exposure to manifold spikes (as best as possible) by minimizing high flow demands from a full single tank:

- Post insertion, use paired tanks versus a full single tank.
- When single full tank required, isolate a manifold to minimize demand.
- Fuel cell purges should not be performed during single full-tank operations (when tank first brought on-line)
- Fuel cell purges or any other cryogenic high-flow evolution should not be performed on FD01 to allow the manifold to stabilize at ‘on-orbit’ temperatures.
- Cabin depress/repress, O<sub>2</sub> transfer to ISS, and EMU recharge should be performed with manifold valves open and center tank(s) controlling to provide maximum cryo system volume/capability.

## CRYO MANAGEMENT

The cryo management plan thoroughly talked about and agreed upon by the section will minimize the potential of manifold spikes and check out all cryo tank heaters and controllers during the first 2 days of the mission. After the second day, the management plan continues managing the tanks to deplete all tanks above tank 3 and to balance the quantities between tanks 1, 2, & 3. Cryo

management for c.g. and any offloading will factor into the plan (Information on Offloading can be found in SCP 3.12).

For single-shift missions the manifolds will be closed in a 1-2-2-1-1-2-2-1-1-... fashion. Typically for single-shift missions, the cryo reconfiguration is performed 1 hour before and after the sleep period. This management plan minimizes tanks 1 and 2 heater reconfigurations while still maintaining tanks 1 and 2 quantities within a day's capacity from one another.

All management will account for going to tanks 1 and 2 at deorbit prep with only one system of heaters activated for the oxygen. This is due to the fact that at less than 50% (53% with instrumentation) quantity in an oxygen tank only 1 set of heaters will be operated. Usually this configuration is implemented at post sleep on entry day for a single-shift flight.

In the case of a dual-shift mission, there is normally no good reason to close a manifold valve from a cryo management standpoint. However, it is desirable to cycle the manifold valves once during the mission to fulfill an OMRS (OMRS V45DAO.030). Therefore, a manifold valve test is scheduled about 12 hours prior to deorbit prep. The test is scheduled later in the mission to protect for a valve failing closed during the test, that way there would be no adverse impact to the mission.

For single or dual-shift missions, it is also desirable to manage the cryo tanks in such a way that no cryo reconfigurations are required during critical phases of flight or during mission critical events such as EVA's, satellite deploys, Rendezvous, or Undocking. For example, cryo tank depletion will be avoided on mission days that involve EVA activities. Another instance is during the undocking timeline. Due to stratification/destratification in the tanks, a switch throw has been added to the RNDZ Checklist to configure tank 3 A heater to AUTO. Once separation is complete there is a callout to take the tank 3 A heater back to OFF. This ensures that all tanks with remaining cryo have heaters available in case destratification occurs and the pressure begins to drop.

## **STANDARD MISSION MANAGEMENT**

Note: For Dual-shift missions, use RED presleep and postsleep for cryo reconfigurations.

### **A. Three Tank Set**

- Ascent: Tanks 1 and 2 A heaters. At approximately MET 15 minutes (Post OMS 1 Steps in the Asc Cklist) the B heaters are activated.
- Post insertion: No change - Tanks 1 and 2, A and B heaters.
- First presleep: Single-shift mission - Tank 3 A and B heaters, manifold 1 closed and

(~5-11 hrs MET) Tank 2 heaters deactivated.  
Dual-shift mission - Tank 3 A and B heaters activated  
(Tanks 1 and 2 are in backup).

First postsleep: Single or Dual Shift missions - Deactivate Tank 3. Use  
Tanks 1 and 2  
(~19-24 hrs MET) in paired-mode with the manifolds open.

After first 2 days the following becomes the 'Standard 3 Tank mission  
management' plan.

Single-shift wake: Tanks 1 and 2

Single-shift sleep: Tank 3 and a manifold closed with its  
associated heater activated (manifold management  
assumes 1-2-2-1-1-2-2-...)

Dual shift: Tanks 1 and 2 for 24 hours, then tank 3 for 12 hours,  
tanks 1 and 2 for 24 hours, ...

#### B. Four Tank Set

Ascent: Tanks 1 and 2 A heaters. At approximately MET 15  
minutes (Post OMS 1 Steps in the Asc Cklist) the B  
heaters are activated.

Post insertion: Tanks 3 and 4, A and B heaters activated. (Tanks 1 and 2  
are in backup)

First presleep: Single-shift mission -Manifold 1 closed, Tanks 2 and 4  
deactivated.

(~5-11 hrs MET) Active heaters Tanks 1 and 3.  
Dual-shift mission - Tank 4 deactivated (Tank 3 active,  
Tanks 1 and 2 are in backup).

First postsleep: Single-Shift mission - Tank 4 activated, tank 3 deactivated,  
manifold 1 open (Tank 1 in backup)  
Dual-shift mission - Tank 4 activated, tank 3 deactivated  
(Tanks 1 and 2 in backup)

After first 2 days:  
Tank 4 will be used until depletion.

Single-shift wake: Tank 4 with either Tank 1 or 2 in backup,  
manifolds open.

Single-shift sleep: Tank 4 and a manifold closed with its associated heater activated (manifold management assumes 1-2-2-1-1-2-2-...)

Dual shift: Tank 4 with Tanks 1 and 2 in backup.

Once Tank 4 is depleted use the Standard 3 Tank mission management plan.

### C. Five Tank Set

Five Tank is identical to Four Tank management thru the First Postsleep.

Second presleep: Single-shift mission - Tanks 2 and 5 activated, Tanks 1 and 4 deactivated, Manifold 2 closed.  
Dual-shift mission - Tank 5 activated, tank 4 deactivated (Tanks 1 and 2 in backup)  
(Stay on Tk 5 for 24 hrs)

Third presleep: Single-shift mission - Tanks 2 and 4 activated, Tank 5 deactivated, Manifold 2 closed.  
Dual-shift mission - Tank 4 activated, tank 5 deactivated (Tanks 1 and 2 in backup)  
(Stay on Tk 4 for 24 hrs)

Fourth presleep: Single-shift mission - Tanks 1 and 5 activated, Tanks 2 and 4 deactivated, Manifold 1 closed.  
Dual-shift mission - Tank 5 activated, tank 4 deactivated (Tanks 1 and 2 in backup)

#### **Presleep Reconfigs required for SSPTS Flights**

Third presleep: Single-shift mission - Tanks 2 and 4 activated, Tank 5 deactivated, Manifold 2 closed.  
Dual-shift mission - Tank 4 activated, tank 5 deactivated (Tanks 1 and 2 in backup)  
(Stay on Tk 4 for 48 hrs)

Fifth presleep: Single-shift mission - Tanks 1 and 5 activated, Tank 4 deactivated, Manifold 1 closed.  
Dual-shift mission - Tank 5 activated, tank 4 deactivated (Tanks 1 and 2 in backup)

When reconfig goes back to Tk 5 (either 4th or 5th presleep), stay on this tank until depletion; then go back to Tk 4 until depletion.

Once Tanks 4 and 5 are depleted, the Standard 3 Tank mission management plan will be used.

#### D. Greater than Five Tanks - EDO Tank Set

Due to the Columbia accident an EDO Pallet no longer exists. If future flights manifest an EDO Pallet EGIL will determine the cryo management plan.

### **HISTORY**

The EGIL team decided on the current cryo management plan in a meeting that occurred on 11/20/03. During the meeting the EGIL team used the following guidelines to determine what cryo management plan to use:

- Cryo Management Flight Rules (listed above in Background)
- Crew Time (Extra switch throws)
- OV-102 Deletion
- EDO Plan (No longer exists)
- Ease of scheduling (Analyst impact to preflight analysis and EGIL Planning during the mission)
- Longer Docked (SSPTS) missions
- Failure modes of a tank (leak, controller loss, etc)
- Risk mitigation

The following management plans listed in Table 1 were looked at, along with their associated pros and cons. It should be noted that 4 and 5 tank management has changed over the years. Management plans have been everything from changing HTR/TK configurations ever 8 hours to the plan that we are currently using today (including everything in between).



Cryo Management Plans	Pros	Cons
Take Tk5 to 50%, Deplete Tk4, Deplete Tk5	<ul style="list-style-type: none"> <li>▪ Q Max <math>\Delta</math> – 40%</li> </ul>	<ul style="list-style-type: none"> <li>▪ Not as easy to schedule (would not be able to be at exactly 50%)</li> <li>▪ Higher quantity difference when tanks are full</li> </ul>
Swap between Tk4 and Tk5 every 24 hrs (This would occur at Pre Sleep everyday)	<ul style="list-style-type: none"> <li>▪ Q Max <math>\Delta</math> – 20%</li> <li>▪ Easy to schedule</li> <li>▪ Keeps tanks at closer quantities throughout depletion</li> </ul>	<ul style="list-style-type: none"> <li>▪ O2 and H2 Tks 4 and 5 deplete on same FD (for 113 case, 1 tk was depleted on the previous day 3 others on the same FD)</li> <li>▪ Does not incorporate flexibility for EGILs during real time flight ops to change depletion plan</li> <li>▪ Contains the most switch throws</li> </ul>
Swap between Tk4 and Tk5 every 24 hrs until the tks reach X.X% then deplete them	<ul style="list-style-type: none"> <li>▪ Q Max <math>\Delta</math> – 35%</li> <li>▪ Keeps tanks at closer quantities throughout depletion</li> </ul>	<ul style="list-style-type: none"> <li>▪ Hard to schedule</li> <li>▪ No good way to determine a quantity that is good for all cases. Only consistency is that you would have to be above the quantity that we would use for an average day. (~35%)</li> <li>▪ Cannot incorporate a standard for which tanks we deplete first (on one case Tk 4 was depleted first on another Tk 5)</li> </ul>
Deplete Tk5 then deplete Tk4 (current plan)	<ul style="list-style-type: none"> <li>▪ Easy to schedule - no change to the current process</li> <li>▪ Least amount of switch throws</li> <li>▪ Protects for CPC failures</li> </ul>	<ul style="list-style-type: none"> <li>▪ Q Max <math>\Delta</math> – 75%</li> <li>▪ Higher quantity difference when tanks are full</li> </ul>
Stay on Tk5 for 24 hrs go to Tk4 for 24 hrs then deplete Tk5 then Tk4	<ul style="list-style-type: none"> <li>▪ Q Max <math>\Delta</math> – 47% (happens when the tanks are at lower quantities)</li> <li>▪ Easy to schedule</li> <li>▪ Incorporates a depletion plan that does not change</li> </ul>	<ul style="list-style-type: none"> <li>▪ To maintain this for SSPTS we would have to add one more day of 24hr ops to Tk 4 and 5 until depletion</li> </ul>

**Table 1: Cryo Management Plan Options**

**Verify that this is the correct version before use**

During the meeting, it was decided that if the EDO was ever flown we would perform a cryo controller checkout for those tanks on FD3. (Single sleep mission config is shown, if it is a dual mission the manf vlvs would remain open and tks 1 or 2 would be in backup.)

Post Sleep FD3: Tks 2 and 6/7

Pre Sleep FD4: Tks 2 and 8/9 Manf 2 CI

Actual tank management past FD 3 will be determined at a later date if required.

Also of interest for EDO flights is the fact that C.G. Management (for EOM) normally had to be incorporated into the management plan; below is a short summary of how EDO flights were normally handled.

- Since OV-102 was the vehicle that flew the EDO pallet Tks 4 and 5 were depleted first.
- Then Tks 1, 2, and 3 were taken to 50%.
- Then the EDO pallet was used. The pallet tanks were not normally depleted. For most missions, this will result in tanks 1, 2, and 3 being at about 35% for deorbit prep. This will protect 1 and 2 for the extension days in case of a manifold failure. It should be noted that for weather wave-off days, go ahead and deplete the EDO pallet tanks. Since the forward H<sub>2</sub>O tanks will be down by about 200 pounds for the next deorbit prep opportunity, depleting the EDO tanks will be offset as far as c.g. concerns go. Deplete the EDO tanks to be able to factor out the measurement uncertainty and “any better” than residual depletion. This will allow a better estimate of mission margins since redlines will decrease.

	Post	3 Tank crvo							Deorbit to EOM			
	Ascent	X1	O1	X2	O2	X2	O2	X1....	X1...	O1...	O	
Tk1	Insertion										Tk1	Tk1
Tk2											Tk2	Tk2
	Tk3									Tk3		
	Tk4		Tk4			Tk4 for 24 Hours				Tk4 to Depletion →		
				Tk 5 for 24 Hours				Tk5 to Depletion →				

X - Manf CL  
O - Manf OP

\*Single shift Manifold closed 1-2-2-1-1-2-2-1.... with coresponding HTR active

**Figure 3.5-1. Cryogenic Management Plan**

3.5-9

Verify that this is the correct version before use

## TITLE

CRYO DEPLETION

## PURPOSE

To discuss the general EGIL philosophy with rationale when depleting a cryo tank.

## BACKGROUND

Cryo tank depletions happen on missions where four or more cryo tanks are flown. As the quantity of cryo in a tank nears depletion, it becomes more difficult for the tank heaters to pressurize the tank. This causes the heaters in the tank to remain ON for longer periods of time which results in increased heater assembly and fluid temperatures. Hence towards the end of a tank depletion the tank pressures might not reach the upper limit in the logic control band; therefore the heaters will never kick off and cool down. In some instances the heaters cannot keep up with the fuel cell demand; therefore the heaters will remain ON, but the pressure will not rise. Thus the heater and fluid temperatures can get close to reaching their maximum flight rule limit value during depletion. (Heater temperatures limits are: 350 °F for O2 and 200 °F for H2. Fluid temperature: 160 °F for both). This is more of an issue with O2 than H2; an H2 tank is usually depleted before its heater temperatures get close to 200 °F.

The minimum quantities expected to be obtainable prior to reaching maximum tank heater temperature limits are 6.5% for an O2 tank and 2.5% for an H2 tank. Note that two H2 tanks (Tank 1 and 2 nominally) will not be depleted past 4% because the heater flow capacity of an H2 tank with both its heaters activated is not great enough to keep up with entry fuel cell flow demands below 4%. These percentages represent the flight rule residual values. Many variables including the residual values, temperatures, mission events, etc. are involved in the cryo tank depletion process.

## DEPLETION PRACTICES

Factors to be considered when deciding what day the depletion of a cryo tank should be preformed.

- A. The depletion should be managed to occur during the crew day (not during sleep).
- B. Days in which EVAs or other major activities are being preformed should be avoided if possible.

When depleting a cryo tank the goal is to get the quantity at or below its residual value without violating the heater and fluid temperature limits. Depleting a cryo tank can be an all day process during which the temperatures and pressures will be frequently monitored. Determining when the tank is depleted depends on several variables which are listed below:

- A. How close are the quantities to the flight rule residual values?
- B. How close to are the heater temperatures and fluid temperatures to the maximum flight rule limit? (Heater Temps: 350 °F for O2 and 200 °F for H2. Fluid Temp: 160 °F for both O2 and H2).
- C. How fast are the heater/fluid temperatures increasing?

- D. Are the pressures in the tank still going up? Will the pressures reach the upper limit in the logic control band (allowing the temperatures to cool off before the next heater cycle) before to the temperatures reach their upper limit? If the pressures are not rising any more the tank is probably getting close to being depleted.
- E. Is the cryo coming out of the tank worth the additional power required to power the heaters in the tank being depleted?
- C. Is there sufficient cryo margin to support nominal mission objectives? Is there a need for additional margin? (Does the tank really need to be squeezed for every last drop?)
- H. Is it an O2 or an H2 tank? A leak in an H2 tank that is not depleted could cause the deorbit burn to be wave off a day in order to deplete the tank.
- I. Are there any upcoming LOS or unexpected LOS periods? (Will the temperatures remain below their limits during the LOS or will they exceed their limits?)
- J. How quickly can the tank depletion actions get on board and be preformed? (Preclude exceeding the temperature limit because it took longer than expected to get the actions on board. Consider the amount of time required for a flight note to be approved and then read up. Note: The Flight Note should be written well in advance.)

An O2 heater temperature of 300 °F has been accepted (as an EGIL philosophy) as a “hard limit” where the heaters need to be turned off when depleting an O2 tank due to possible temperature overshoot and the time needed to get the actions on board. This 300 °F limit should allow the heaters to be turned off before the temperatures reach 350 °F which will also preclude a master alarm and an FDA from ringing on board. Since reaching the upper Flight Rule limit is more likely when depleting an O2 tank than an H2 tank and the result of exceeding the upper limit for O2 is of greater consequence than H2 (igniting the Teflon vs. damaging the tank structure), a “hard limit” was only chosen for O2. An O2 heater temperature of 250 °F is good milestone to think about how much longer O2 depletion should continue. Keep in mind O2 tanks have depleted before the heater temperatures ever reached 250 °F. Therefore the variables involved during cryo tank depletions (A-J above) need to be frequently monitored throughout the depletion process.

After a tank is depleted the tank the quantity should remain stable and not rise; the quantity will sometimes increase by a bit flip or two and then stead out. The fluid temperature should remain steady and not rapidly decrease. For O2 depletions the pressures and heater/fluid temperatures slowly decrease after the heaters are deactivated, but for H2 depletions the pressures and heater/fluid temperatures will slowly increase.

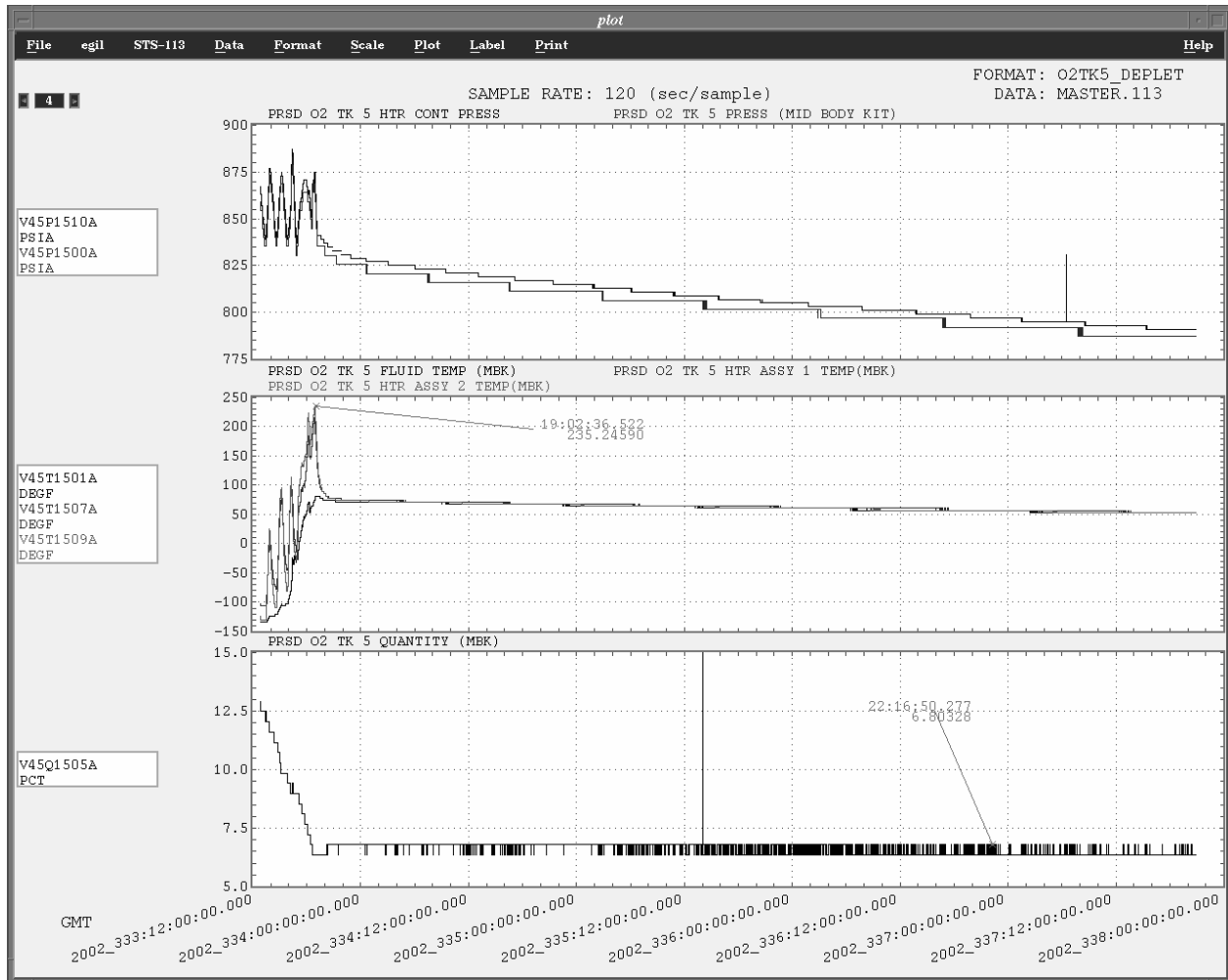


Figure 3.6-1. O<sub>2</sub> Tank 5 Depletion

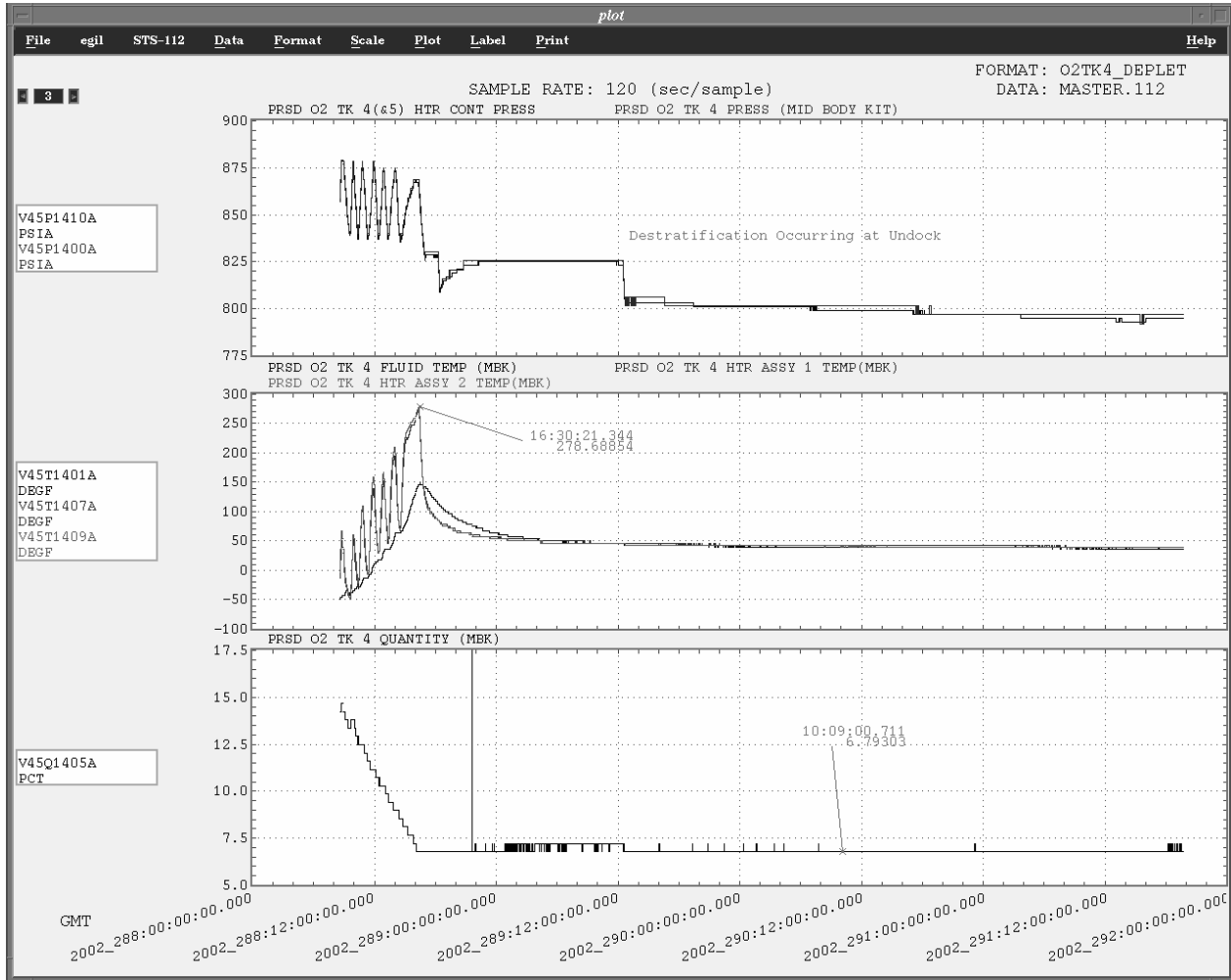


Figure 3.6-2. O<sub>2</sub> Tank 4 Depletion

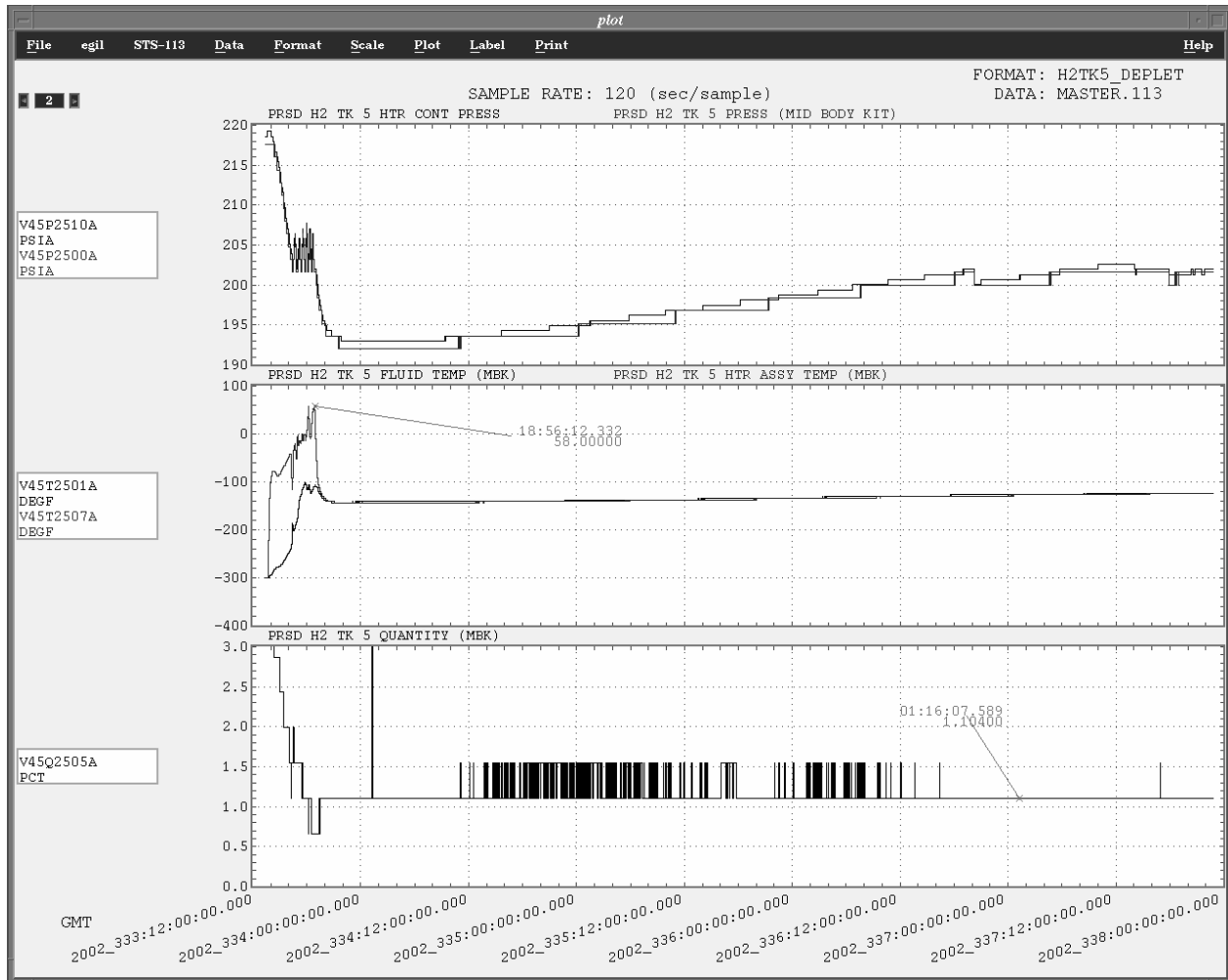
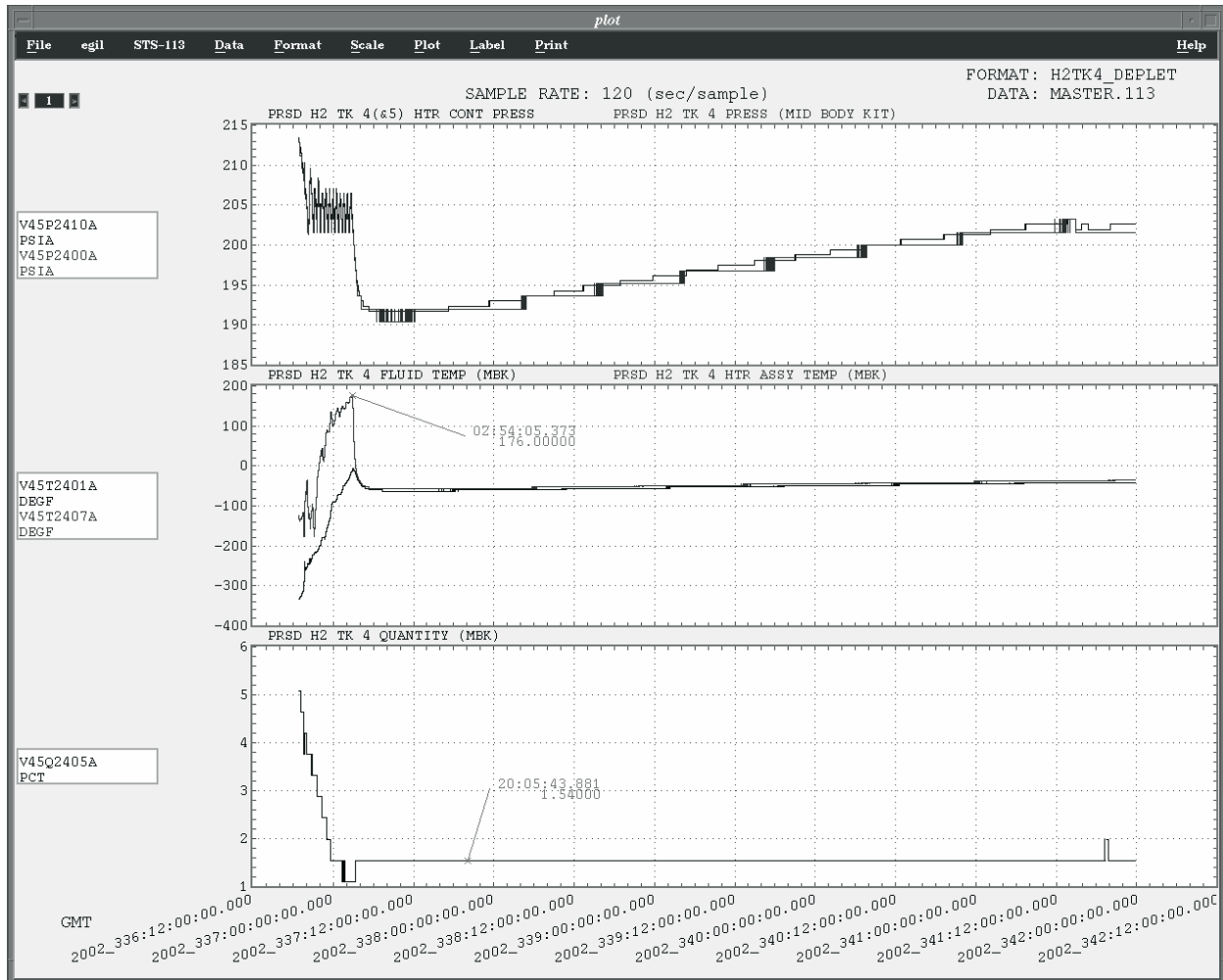


Figure 3.6-3. H<sub>2</sub> Tank 5 Depletion





**Figure 3.6-4. H<sub>2</sub> Tank 4 Depletion**

Assisted depletion is a method used to help deplete a cryo tank. Assisted depletion utilizes another tank's heaters to feed the fuel cell demand while the tank being depleted utilizes its heaters to pressurize itself - both tanks will feed the fuel cell demand during a portion of the decay cycle. If TK3 is assisting TK4's depletion the heaters will kick off in TK3 and TK4 once TK3's pressure reaches the upper pressure limit in the control band since their heater logic is paired; thus allowing TK4's heater/fluid temperatures to cool off while the pressures decay. Assisted depletion is typically not used during H<sub>2</sub> tank depletions because there is less concern that the H<sub>2</sub> tank heater and fluid temperatures will reach their upper limits. The downside to assisted depletion is if TK5 is being depleted its heater logic is not paired with another tank's, and therefore during assisted depletion the pressure in TK5 might not reach the upper limit to turn the heaters. Therefore less cryo will have been used out of TK5 since it was not feeding the full demand and the benefit of the heaters turning off will not have been met. Assisted depletion also extends the depletion of a tank.

Redline Determination: Redlines are the residual amount of cryo for every tank plus the total measurement uncertainty (MU). After a cryo tank is depleted, the (MU) for the depleted tank does not need to be protected anymore. For individual tanks this error is 2.6%. To obtain the total MU the individual tank error is RSS'ed (Root Summed Squared) for the number of tanks.

The total MU for 5 tanks is  $\sqrt{(2.6^2 + 2.6^2 + 2.6^2 + 2.6^2 + 2.6^2)} = 2.6\sqrt{5}$  percent. Once a tank has been depleted the  $MU = 2.6\sqrt{X}$ , where X is the number of undepleted tanks. The residual value of 6.5% or 2.5% also needs to be updated to the real value obtained in the SOCRATES case. If the depleted quantity is greater than defined residual value (> 6.5% O2 or 2.5% H2), then whether or not a good depletion was obtained becomes the determining factor. If a good depletion was obtained then the residual value will be updated to the quantity value greater than 6.5% or 2.5% and the MU does not need to be protected for that tank anymore. However, if a good depletion was not obtained then the residual value should stay at 6.5% or 2.5% and the MU for that tank still needs to be protected since some more cryo could potentially be obtained from the tank.

**TITLE**

PRSD H<sub>2</sub> AND O<sub>2</sub> REAL-TIME LEAK MONITORING

**PURPOSE**

This SCP describes the general approach to real-time monitoring of the PRSD cryogenic reactants for the purpose of leak detection. Techniques used to monitor the system and actions to be taken are described in detail.

Routine leak monitoring of the PRSD system consists of two major objectives. These are

- A. Comparison of actual quantity usage rates to the predicted. This is performed to evaluate system leakage and electrical power consumption over a relatively long period of time.
- B. Comparison of actual pressure decay rates to predicted for leak detection. This method of leak detection can give instantaneous indication of system leaks.

**DISCUSSION**

During prelaunch operations, the fuel cells are normally supplied with gaseous reactants from the GSE. The GSE supply is held at a pressure of 905-955 psia (O<sub>2</sub>) and 256-285 psia (H<sub>2</sub>). The pressure will normally remain constant somewhere in this range. Environmental heat leakage into the PRSD tanks will maintain their pressure equal to that of the GSE. Therefore, when the GSE supply is removed, the PRSD tank check valves will unseat and allow reactant flow from the tanks. The pressure in all "commonly manifolded" tanks will decay at the same rate.

To ascertain the relative health of the PRSD plumbing, two prelaunch system integrity checks are performed to ensure that no major leaks have been masked by GSE operation. The first check occurs at approximately L - 7 hours. At that time, a fuel cell performance calibration is performed per OMI S0007VL2. During this performance calibration, OMI V1040VL2 sequence 19-109 will be called to perform the PRSD integrity check. The orbiter O<sub>2</sub> and H<sub>2</sub> T-O GSE supply valves will be closed and the tank pressure decay rates measured for a period of 2 to 3 minutes. The T-O valves are then reopened. Table 3.7-1 shows the maximum tank pressure decay rates (in psi/min) allowable during the integrity check.

**Table 3.7-1. Maximum tank pressure decay rates**

	Number of tanks			
	2	3	4	5
Oxygen	28	25	23	22
Hydrogen	4	4	4	4

Because this is a very coarse check, it could be possible to pass the criteria established and launch a vehicle with a PRSD system leak. Because of this and the fact that leaks could develop after launch, one of the major tasks of the electrical power systems console operator is to monitor continuously for system leaks.

### Quantity Monitoring

At intervals of every 2 to 4 hours, the total O<sub>2</sub> (cryo O<sub>2</sub> TTL QTY) and total H<sub>2</sub> (cryo H<sub>2</sub> TTL QTY) quantities from MSK 649 are plotted on the console charts. The trend of the plotted data is then compared to the predicted profile. If the trend of both reactants closely parallels the predicted lines, actual average power is very close to predicted and no system leaks are indicated. If the slopes of both the O<sub>2</sub> and H<sub>2</sub> trends are steeper/lower than the predicted line, the average power is higher/lower than predicted. If only one actual trend exceeds the predicted slope, a leak in that system could be indicated.

Because very small leaks could go undetected for hours or even days by monitoring plot trends, the fuel cell reactant usage rates should be calculated and compared every time a new point is plotted on the charts. The quantity and time data available on MSK 649 can be used to compute the H<sub>2</sub> and O<sub>2</sub> usage rates as follows:

$$r_H = \frac{Q_{H1} - Q_{H2}}{t_1 - t_2} = \text{--- lb/hr} \quad (1A)$$

$$r_O = \frac{Q_{O1} - Q_{O2}}{t_1 - t_2} - (0.07) * (N) - 0.07 = \text{--- lb/hr} \quad (1B)$$

where: r = Consumption rate for electrical power (lb/hr)  
 Q = Total reactant quantity at given time (lb)  
 t = Time (hr)  
 0.07 = Crew metabolic O<sub>2</sub> use (lb/man-hr)  
 0.07 = Cabin O<sub>2</sub> leakage (lb/hr)  
 N = Number of crew

There are two pitfalls to be aware of when making comparisons such as described above. First, if the time interval is short, a bit count change can result in a significant difference in the comparison of relative consumption rates. Second, tank stratification can result in erroneous quantity readings (ref. SCP 2.11).

Dividing the results of equations 1A and 1B by the appropriate "conversion factors" (which we will call C<sub>H</sub> and C<sub>O</sub>) will convert the usage rates to equivalent average power. The conversion factors are dependent on fuel cell V-I performance characteristics (age) and actual power output. The appropriate conversion factors based upon the mission average power and fuel cell performance are normally supplied by the RSOC/Consumables Analysis Section with the final console charts. The units of the conversion factors are lb/kW-hr. If not specifically stated, the factors can easily be calculated from the premission predicted usages as shown below:

$$C_H = \frac{Q_H}{(P) * (t)} = \text{————— lb/kW-hr} \quad (2A)$$

$$C_O = \frac{Q_O - (0.07) * (N) * (t) - (0.07) * (t)}{(P) * (t)} = \text{————— lb/kW-hr} \quad (2B)$$

- where:
- C = Conversion factors (lb/kWh)
  - Q = Predicted quantity of reactant to be used (lb)
  - P = Predicted mission average power level (kW)
  - t = Mission duration (hr)
  - N = Number of crew
  - 0.07 = Crew O<sub>2</sub> metabolic consumption (lb/man-hr)
  - 0.03 = Cabin O<sub>2</sub> leakage (lb/hr)

If neither conversion factors nor predicted quantity usages are known, C<sub>H</sub> = 0.09 and C<sub>O</sub> = 0.72 can be used as approximations.

Using the appropriate conversion factors, the equivalent power can be calculated as follows:

$$P_H = \frac{r_H}{C_H} = \text{—— kW} \quad (3A)$$

$$P_O = \frac{r_O}{C_O} = \text{—— kW} \quad (3B)$$

- where:
- P = Equivalent power based on reactant usage (kW)
  - r = Reactant usage rates for electrical power (lb/hr)
  - C = Reactant conversion factor (lb/kWh)

Typically, P<sub>H</sub> will yield values several hundred watts higher than P<sub>O</sub>. This can be attributed to H<sub>2</sub> escaping from the fuel cells into the product water.

### Pressure Decay

Tank pressure decay rates during heater “off” cycles can be instrumental in determining mass flow out of a given tank. Converting the fuel cell power into mass flow (and combining with metabolic use for oxygen) and comparing that value to the mass flow indicated by the tank pressure decay rate can give immediate insight into significant system leaks.

Pressure decay rate in a given tank is controlled by two independent variables. Those are fluid density (tank quantity) and mass flow from the tank.

For constant mass flow from the tank, the decay rate decreases nonlinearly as tank quantity decreases, until the quantity reaches that corresponding to minimum dq/dm (quantity ≈40 percent). After that point, decay rate will begin to nonlinearly increase with decreasing tank quantity. This effect can be seen in Figures 3.7-1 through 3.7-4. For a

constant tank quantity, pressure decay rate increases linearly with increasing mass flow from the tank.

The decay rate will be the product of mass flow times a constant (which we will arbitrarily call K). The constant will be dependent on tank quantity alone. Figures 3.7-1 through 3.7-4 depict the value of these constants as a function of tank quantity. These are in-house curves derived from a third order polynomial curve fit of STS-9 and STS-32 flight data. The individual flight data points are plotted and compared to the curve fit data in Figures 3.7-5 and 3.7-6. As can be seen from the plot, a significant amount of dispersion does exist. Because of this, leak rates smaller than the normal consumption rate will be difficult to confirm using the pressure decay method. Comparison of the curve fits of the flight H<sub>2</sub> data to theoretical data curves given in the PRSD systems handbook (published by R&E) shows excellent agreement. Comparison of O<sub>2</sub> data is close, but flight data shows the theoretical values to be slightly high in the upper tank quantities.

Figures 3.7-3 and 3.7-4 are copies of those supplied to the crew in the Malfunction Procedures book for leak troubleshooting. The constants (K) are scaled to be used with equivalent fuel cell amps being supplied by the tank. The equation using the K values is also adjusted by a factor of 1000 (O<sub>2</sub>) or 10,000 (H<sub>2</sub>) to allow the values to be scaled as integers instead of decimal fractions. Fuel cell amps are used because it is most convenient (and accurate) for determining mass flow. This, of course, neglects flow for O<sub>2</sub> metabolic consumption (which is small except for when the Launch and Entry Suits (LESs) are in use).

Figures 3.7-1 and 3.7-2 have constants (K) scaled to be used in conjunction with mass flow values. These will be most useful during ascent when LES O<sub>2</sub> flow must be accounted for. If the figures using fuel cell amps are used, any metabolic flow must be converted to fuel cell amps. The equation for the conversion is

$$\text{AMPS} = (\text{O}_2 \text{ FLOW}) * (47.5) \quad (4)$$

The expected pressure decay can be calculated by using the equations stated on Figures 3.7-3 and 3.7-4. Different configurations will vary the exact steps required to calculate the expected rate. The easiest configuration to calculate decay rates for will be when a single tank is feeding a single fuel cell. To calculate the decay rate for this configuration, do the following:

- A. Read a K value from the Y-axis based on the individual tank quantity.
- B. Use this number in the equation specified with the particular figure in use. The result of the equation will be that tank's decay rate in psi/min (when the heaters are in an "off" cycle).

The easiest method to compare the actual pressure decay rate to what it should be is to overlay an expected decay rate background line on MCC UP MSKs 2718 and 2719 (cryo decay/leak program). The actual plot data can then be compared to the expected line(s). With manifold valves open, all tank decay rates would be equal. If the tank

quantities are unbalanced, the usage rate would split among the tanks in proportion to their constant values from Figures 3.7-1 through 3.7-4. This is analogous to current flow through parallel resistance in an electrical circuit. The voltage (potential) will be the same at the common points (as the pressure in the PRSD), but the total circuit current will divide based upon the ratios of parallel resistance values (just like the mass flows will do in the PRSD). If a mass flow in a given leg has to be split among only two tanks, then equation 6 can be used to compute the flow split. The subscript “X” denotes the tank for which the flow is being calculated. The subscript “O” denotes the other tank sharing the flow contribution. If there are more than two tanks which are commonly manifolded and activated (will be sharing the flow demand), the equivalent K value for the parallel combination of the other tanks that are commonly manifolded with the tank being analyzed must be calculated first. This is done using equation 5. The results of equation 5 are then fed into equation 6.

The equation to be used for computing the equivalent K value for the “other” tanks in the same common manifold is

$$\frac{1}{K_o} = \sum_{i=1}^N \frac{1}{K_i} \quad (5)$$

- where:  $K_o$  = The equivalent K value of the combination of all other active tanks commonly manifolded with one being analyzed
- $N$  = Number of tanks commonly manifolded with the one being analyzed
- $K_{1..N}$  = The individual tank values of all tanks in the common manifold, not including the one being analyzed. Could be tanks (1 and 2) or (2, 3, and 4), etc.
- $K_x$  = The individual tank K value for the tank being analyzed

The equation for the flow contribution of one individual tank when more than one tank will be supporting a common flow demand is

$$AMPS_x(FLOW_x) = \frac{K_o}{K_o + K_x} * TOTAL AMPS (TOTAL FLOW) \quad (6)$$

For example, three O<sub>2</sub> tanks (let us assume tanks 1, 2, and 3) are feeding a common fuel cell demand (requires tank pressures to be equal) of 600 amps, and tank 1, 2, and 3 quantities are 50, 60, and 70 percent, respectively. Normally, ascent is the only time period where tank 3 pressure is equal to tanks 1 and 2. From Figure 3.7-3, the constants K are 3.5, 6.5, and 10, respectively. Using equations 5 and 6,

For tank 1:

$$\frac{1}{K_o} = \frac{1}{6.5} + \frac{1}{10} \quad \text{therefore } K_o = 3.94$$

$$\text{AMPS}_{\text{TANK1}} = \frac{3.94}{3.94 + 3.5} * 600 = 317.7$$

For tank 2:

$$\frac{1}{K_o} = \frac{1}{3.5} + \frac{1}{10} \quad \text{therefore } K_o = 2.59$$

$$\text{AMPS}_{\text{TANK2}} = \frac{2.59}{2.59 + 6.5} * 600 = 171.0$$

For tank 3:

$$\frac{1}{K_o} = \frac{1}{3.5} + \frac{1}{6.5} \quad \text{therefore } K_o = 2.28$$

$$\text{AMPS}_{\text{TANK3}} = \frac{2.28}{2.28 + 10} * 600 = 111.4$$

Using the equation stated on Figure 3.7-3, it can be seen that multiplying each corresponding tank amp and K value and then dividing by 1000, the decay rate in all tanks is 1.11 psi/min, even though the flow rates are different.

As shown in the example calculation, the tank with the lowest K value will contribute the most. Therefore, its quantity will be depleted at a faster rate than the other tanks. Since we normally operate the tanks at quantities >40 percent, any tank quantity imbalances between paired tanks will accelerate, until the first tank reaches minimum dq/dm ( $\approx$ 40 percent) quantity. This demonstrates the value of quantity balance between logically paired tanks.

Let us repeat the above example, except under the assumption that both manifold valves in the O<sub>2</sub> system are closed. Now, the mass flow out of each tank will be dependent only on the demand from each individual fuel cell. Therefore, since the tank quantities are different, one might expect that the individual tank pressure decay rates would be significantly different. Let us make a further assumption that the 600-amp total fuel cell demand is split up as 190, 200, and 210 amps for fuel cells 1, 2, and 3, respectively. From the equation stated on figure 3.7-3, the tank pressure decay rates are 0.67, 1.30, and 2.10 psi/min for tanks 1, 2, and 3, respectively.

Since the rates in all the tanks are significantly different, then all three rate lines need to be plotted onto the background of UP 2719.



Let us complicate things even further. Let us assume the same quantity and load values as above, but with a new orbit configuration which has manifold valve 1 closed, with the tank 1 and 3 heaters enabled. The decay rate for tank 1 will be 0.67 as calculated above. However, now tank 3 will be the sole source for supplying reactants to fuel cells 2 and 3. Therefore, the decay rate for tank 3 will be  $10 \times 410 / 1000 = 4.10$  psi/min.

As seen above, the pressure decay rate depends on a number of circumstances. Those are

- Tank quantity
- Fuel cell load distribution
- Metabolic O<sub>2</sub> consumption
- Manifold valve/heater configuration
- Number of tanks flown

Since there are so many variables used in computing the decay rates, it is the intent of this SCP to give the EPS console operator the basic knowledge necessary to compute these values for any PRSD configuration in real time. Once the expected decay rates are calculated, the appropriate background line(s) should be drawn on MSKs 2718 and 2719.

Remember that the above methods are used for computing decay rates with the heaters in an off cycle. Normally, when the heaters are receiving power, they will overcome the mass flow demand and cause the pressure to rise. The only exception to this is in the O<sub>2</sub> system when several LESs are in use and/or the direct O<sub>2</sub> valve is open. During all other times, if the heaters are receiving power and the pressure is decaying, then a leak is indicated.

### **UP Pressure Decay Background Lines**

The methods used above for calculating pressure decay rates will yield a value with units of "psi/min." Since the UPs are configured to plot pressure vs. time, then the decay rate calculated above will be the slope of the required background line.

To draw reference lines on the UPs, either a blank V41 MED menu is used with the appropriate flight and UP numbers inserted or you may use the workstation application. The V41 menu allows construction of UP background lines based on (X,Y) end points. The menu will accept 15 data point pairs which define slope changes on a single continuous line. This means that one continuous line is drawn on the UP, changing direction at each end point. If two background slopes are to be drawn, the end points must be positioned in the grid and axis lines. This is done to hide the unwanted lines connecting the end points of the reference lines. The Y-axis intercept (Y<sub>i</sub>) of a decay line will be the upper control range of the tank(s) that are operating. The following chart has the appropriate Y-axis intercepts for each specific tank's decay line.

		Y-axis Intercept (Y <sub>i</sub> )	
		O <sub>2</sub> .....	H <sub>2</sub>
Ascent			
All cryo tanks	.....	940	260
Orbit/entry			
Tank 1/2	.....	840	220
Tank 3/4/5	.....	875	240

The X-axis intercept for a line is determined by the decay rate of the tank(s) and the minimum Y-axis value on the UP. For the oxygen pressure UP, the usual range of pressures plotted on the Y-axis is from 700 to 900 psi and for H<sub>2</sub> it is from 100 to 300 psi. So the Y-axis minimum (Y<sub>min</sub>) is 700 for O<sub>2</sub> and 100 for H<sub>2</sub>. These numbers may change for off-nominal operations of the cryogenic tank heaters (manual operation requires a larger control range). The equation to find the X intercept (X<sub>i</sub>) is:

$$X_i = \frac{Y_i(\text{psi}) - Y_{\min}(\text{psi})}{\text{Decay rate (psi / min)}} \quad (7)$$

The number generated by this equation is in minutes. The two end points for this line are (O, Y<sub>i</sub>) and (X<sub>i</sub>, Y<sub>min</sub>). Check the X<sub>i</sub> value with the time spread on the X-axis. If X<sub>1</sub> is larger than the time spread (X<sub>max</sub>), then the reference line will intercept the right-hand Y-axis instead of the X-axis. Therefore the end point of the line will be (X<sub>max</sub>, RY<sub>i</sub>), where

$$RY_i = Y_i - \left( \text{Pressure decay rate} * X_{\max} \right) \quad (8)$$

This condition will be evident with hydrogen plots only when the quantity approaches min dq/dm (when the pressure decay in response to flow out of the tanks is very small). This effect can be seen in Figure 3.7-7.

To draw just one line on the UP, plug the paired numbers in the V41 menu for data point pairs 01 and 02. Transmit unprotected and verify the reference line is on the UP. If two lines need to be drawn, the procedure is a little more complicated. Develop X and Y end points for both lines. Insert the first data pair (O, Y<sub>i1</sub>) for 01 and the other pair (X<sub>i1</sub>, Y<sub>min</sub>) or (X<sub>max</sub>, RY<sub>i1</sub>) for 02. Since there is only one continuous line, the line that connects the two reference lines has to be hidden in the axis or grid lines. Therefore, data point 03 has to be on the same grid line as data point 02. Refer to figure 3.7-8 and the line between points 2 and 3. Plug in the data pairs for line 2 (X<sub>i2</sub>, Y<sub>min</sub>) or (X<sub>max</sub>, RY<sub>i2</sub>) for point 03 and (O, Y<sub>i2</sub>) for point 04. Transmit unprotected and verify that there are no stray lines on the UP. If one of the two lines ends on the X-axis and the other ends on the Y-axis, a stray line will be drawn connecting those end points. If elimination of this stray line is desired, point 03 should be (X<sub>max</sub>, Y<sub>min</sub>) and the two points defining the second line would be 04 and 05.

For example, let us assume that a pressure decay of 5.55 psi/min was determined for O<sub>2</sub> tanks 1 and 2 if they are being used and 11.2 psi/min for tank 3 if it is in use. From the chart shown earlier, the control pressures can be determined and two points developed.

$$\text{Tanks 1, 2} \quad (X, Y) = (0, 840) = (0, Y_{i1})$$

$$\text{Tank 3} \quad (X, Y) = (0, 875) = (0, Y_{i2})$$

Now using the equations given for determining the X intercept, the other end points can be found.

For tanks 1,2:

$$X_{i1} = \frac{840 - 700 \text{ psi}}{5.55 \text{ psi/min}} = 25.23 \text{ min}$$

$$Y_{min} = 700 \text{ psi}$$

For tank 3:

$$X_{i2} = \frac{875 - 700 \text{ psi}}{11.2 \text{ psi/min}} = 15.63 \text{ min}$$

$$Y_{min} = 700 \text{ psi}$$

Figure 3.7-9 has the V41 menu with the data pairs inserted. Once the data is transmitted, the Mission Operations Computer (MOC) will draw one continuous line from data point 01 to 02 to 03 to 04. Therefore, points 01 and 02 draw the decay line for tanks 1 and 2. The line drawn from data point 02 to 03 is hidden in the X-axis line and cannot be seen. Data points for tank 3 are numbers 03 and 04. Figure 3.7-8 shows the result of the V41 menu inputs with the data points numbered as they are inserted in the V41 menu. The sawtooth curve is tank 1 and 2 control pressure (SMS data) vs. time. The slope of the decay during the heater "off" cycles roughly parallels the line drawn from point 01 to 02. If only tank 3 was supplying the demand, its plot would roughly parallel the line drawn from point 03 to 04.

This adjustment of the reference lines on the CRYO MSKs should be executed for every change of 5 to 10 percent cryo quantity or a change in manifold valve or heater reconfiguration. For certain situations there are needs to draw one or two lines. If cryo tanks 1 and 2 are feeding the fuel cells with both manifold valves open, one line would be appropriate. Two lines could be drawn on the UP, one for the present quantity and one for 5 percent less in quantity to save time when the quantity decreases. If one manifold valve is closed, then two lines would be needed to track both tank 1 (or 2) and tank 3. If both manifold valves are closed, two or three lines are needed, one for tank 3 and one (or two if the tank quantity or fuel cell load imbalance was significant) for tanks 1 and 2.

### Quantification of Leak Size Using Pressure Decay

As can be seen from Figures 3.7-1 through 3.7-4, using pressure decay analysis can provide a reasonable amount of accuracy in detecting PRSD system leaks. Once a leak is identified, it is also possible to approximate the leak size by analyzing the amount of excess pressure decay. The excess pressure decay is defined by:

$$XDECAY = ACTDECAY - PREDECAY \quad (\text{if the tank heaters are not receiving power}) \quad (9A)$$

or

$$XDECAY = ACTDECAY \quad (\text{if the tank heaters are receiving power}) \quad (9B)$$

where:

- XDECAY = Excess dp/dt (positive in sign for decaying pressure)
- ACTDECAY = The actual dp/dt observed in realtime (positive in sign for decaying pressure)
- PREDECAY = The predicted dp/dt based on tank quantity and flow from the tank (positive in sign for decaying pressure)

The leak size can then be estimated using Figures 3.7-10 and 3.7-11. These figures depict curves that show the individual tank leakage rates in lb per excess psi/min.

To approximate the leak size if the heaters are not receiving power

- A. Determine by how much the actual pressure decay rate is exceeding the predicted for that tank using equation 9A.
- B. Locate the tank quantity on the X-axis.
- C. Move vertically until the line intersects the curve.
- D. Move horizontally and read the value of K on the Y-axis.
- E. That value is the excess decay rate for each lb/hr leakage out of that tank.
- F. Divide the excess decay rate by the K value to obtain the leakage rate in lb/hr for that tank.
- G. If multiple tanks are feeding a leak, repeat the process for all affected tanks.
- H. The summation of all individual tank leak values is the total system leak.

For example, let us use the previous example values for O<sub>2</sub> tanks 1, 2, and 3 of 50, 60, and 70 percent quantities, respectively, with all manifold valves open and feeding a common fuel cell demand of 600 amps. As computed before from Figure 3.7-3, the

3.7-10

**Verify that this is the correct version before use**

expected decay rates should be 1.11 psi/min in all three tanks. However, let us say that the actual data is showing a 5 psi/min pressure decay in all tanks. This is an excess pressure decay rate of 3.38 psi/min in each tank. From Figure 3.7-10, it can be seen that each tank is feeding a leak of 12.52 lb/hr (3.38/.27), 8.05 lb/hr (3.38/.42), and 5.63 lb/hr (3.38/.6) for tanks 1, 2, and 3, respectively. This adds up to a total system leak of 26.2 lb/hr, which could be leaking from a fuel cell, manifold, or PCS system. Again, these methods assume that the heaters are in an off cycle.

If the heaters are receiving power, the leak can be quantified by the following method:

- A. Determine the heater mass flow capacity from Figures 3.7-11 and 3.7-13 based on the amount of heat being input.
- B. Determine the additional mass flow from the tank using Figures 3.7-10 and 3.7-11. The excess decay rate is the actual decay rate being observed, as given by equation 9B.
- C. Add the values obtained in 1 and 2 above to obtain the total flow rate from the tank.
- D. Subtract the fuel cell/metabolic flow from the value computed in C. Note that if only one tank is affected out of a commonly manifolded set, and its pressure is decreasing, its check valve will backseat, stopping all flow from the tank except for the leak flow.

In equation form, the above computation for when tank heaters are receiving power is

$$\text{LEAK} = (\text{DMDQ} * \text{Q}) + (\text{XDPDT} / \text{K}) - \text{R} \quad (10)$$

- where:
- LEAK = The approximate leakage in lb/hr
  - DMDQ = The heater flow capacity per watt from Figures 3.7-12 and 3.7-13
  - Q = The heat being input to that tank in watts
  - XDPDT = The excess dp/dt calculated in equation 9B
  - K = Constant read from Figures 3.7-10 and 3.7-11
  - R = The reactant use rate (lb/hr) from that tank to support fuel cell load plus metabolic

For example, if heater A only in O<sub>2</sub> tank 1 was in an “on” cycle, the pressure was continuing to decay at a rate of about 4 psi/min, the tank was feeding a fuel cell and metabolic demand of 14 lb/hr (the tank pressure had not dropped below the manifold pressure), and the tank quantity was 100 percent, then

$$\begin{aligned} \text{LEAK} &= (0.022 * 500) + (4 / 1.1) - 14 \\ &= 0.6 \text{ lb/hr} \end{aligned}$$

This indicates that there is probably no leak in the system. If, in the above example, we were seeing a decay of 20 psi/min, the leak rate becomes

$$\begin{aligned}\text{LEAK} &= (0.022 * 500) + (20 / 1.1) - 14 \\ &= 15.2 \text{ lb/hr}\end{aligned}$$

This indicates a system leak of approximately 15 lb/hr. If, in the above example, we were seeing an increasing pressure of 4 psi/min (negative in sign) when both tank heaters were on, the leak rate becomes

$$\begin{aligned}\text{LEAK} &= (0.022 * 1000) + (-4 / 1.1) - 14 \\ &= 4.4 \text{ lb/hr}\end{aligned}$$

### Leak Reconfiguration

The normal crew alert for system leaks will be for low pressure alarms due to the inability of the tank heaters to feed the combination of normal demand and the leak itself. This is the premise behind all the crew procedures for ascent and entry. This is not to say that PRSD system leaks in which the heaters can maintain the pressure require no action. The larger leaks are simply the only ones to which by the crew will be automatically alerted. If on orbit, ORB PKT, EPS, CRYO O2(H2) LEAK procedure should be used for troubleshooting cryo leaks.

Once leak isolation is complete, multiple reconfiguration options may be available. Flight Rule A9-260 should be consulted for specific leak isolation and reconfiguration options.

For leaks when heaters will be deactivated and the pressure allowed to bleed down, the pressures will probably bleed down to the two-phase saturation pressure for the reactant at the given tank density (quantity) quickly. However, its decay rate after that point will be slower as liquid begins to boil.

If the tank quantity is on the “gas” side of the vapor dome, the tank pressure will track down the saturated vapor boundary line until the tank is depleted. This effect can be seen in Figure 3.7-14.

If the tank quantity is on the “liquid” side of the vapor dome, the pressure decay rate should change noticeably when the pressure reaches the saturated liquid line (liquid begins to boil). Continuing decreases in tank quantity would lower the fluid pressure below the vapor pressure at that temperature, causing liquid to boil and raise the pressure in the tank back up to the vapor pressure at that temperature. Therefore, in theory, continuing decreases in tank quantity would not lower the pressure, but rather would convert more liquid to gas. This stabilization in tank pressure could take on the appearance that the leak had stopped or slowed. However, as a fluid undergoes sudden expansion, its temperature decreases. Therefore, this cooling effect would tend to lower the fluid temperature, which would in turn lower the vapor pressure. Due to evaporative cooling, it is expected that the pressure would be decaying to correspond to the new lower vapor pressure at the cooler temperature. The quantitative rate at which this cooling would lower the vapor pressure is beyond the scope of this SCP. If the tank quantity continues to decrease, the saturated vapor line on the vapor dome may eventually be encountered and the pressure will then begin to track down the slope of

the vapor dome (saturated vapor line) until the tank is depleted. This effect can be seen in Figure 3.7-15. For more background on this subject, consult SCP.

If the leak is found to be in a tank and it is predicted that the tank heaters can maintain a stable pressure (if required to feed the leak and all fuel cells), then the manifold valves should be opened and the other tank heaters deactivated (except for a leak in tanks 3, 4, and 5, where the tank 1 and 2 heaters should be left in AUTO). This will maximize usage out of the affected tank before it is depleted due to the leak. Before even attempting this configuration, the EPS console operator should first verify that the total fuel cell demand plus the leak flow rate is within the tank heater capacity as stated in Figures 3.7-12 and 3.7-13. If this configuration is used (and the affected tank heaters can support the leak plus all fuel cell demands), the new maximum time to a nominal end of mission with the current power level is given by

$$t = \frac{Q_{\text{aff}} - Q_R}{r + L} + \frac{Q_{\text{rem}} - U}{r} = \text{_____ hr} \quad (11)$$

If a touchdown time is given instead of the fuel cell load, and the EPS console operator is requested to compute a maximum fuel cell usage rate which can be allowed and still support the landing time plus redline (extension days + unusables), the equation becomes:

$$r = \frac{b + \sqrt{b^2 + 4ac}}{2a} = \text{_____ lb/hr} \quad (12)$$

- where:
- b = (t) \* (L) - Q<sub>aff</sub> - Q<sub>rem</sub> + U + Q<sub>R</sub>
  - a = t
  - c = (L) \* (Q<sub>rem</sub> - U)
  - Q<sub>aff</sub> = The total amount of reactant in the tank which is leaking (in lb)
  - Q<sub>rem</sub> = The total amount of reactant in the tank(s) which will be deactivated (in lb)
  - Q<sub>R</sub> = Tank residuals  
Normal values: 47 lb (O<sub>2</sub>) or 2.3 lb (H<sub>2</sub>) each  
If a tank quantity (> residual levels) will be reached where the tank heater(s) cannot meet the fuel cell + leak demand, then that tank quantity should be used for QR.
  - U = The reactant redline (in lb). Includes a fixed usage rate for the extension day(s)
  - r = The average reactant use rate for electrical power (and for metabolic O<sub>2</sub>) in (lb/hr)
  - t = Time to a new nominal End-of-Mission (EOM) touchdown (in hours)
  - L = Reactant leak rate (in lb/hr)

If the leaking tank heaters cannot support the leak rate plus the fuel cell demand, or if the leak is in the manifold, then the option exists to isolate the tank to a single fuel cell by closing manifold valve(s). This should be attempted only if Figures 3.7-12 and 3.7-

13 show that the affected fuel cell flow rate plus leak flow rate is within the heater capacity for that tank. If this configuration is opted for, then the equations for the maximum time to a new EOM are given by

$$t_{\text{leak}} = \frac{Q_{\text{aff}} - Q_{\text{R}}}{r_{\text{aff}} + L} \quad (13)$$

$$t = \frac{Q_{\text{rem}} - (r_{\text{rem}})(t_{\text{leak}}) - U}{R_{\text{aff}} + r_{\text{rem}}} + t_{\text{leak}} \quad (14)$$

- where:
- $Q_{\text{aff}}$  = The total amount of reactant in the tank which is leaking (in lb)
  - $Q_{\text{rem}}$  = The total amount of reactant in the other tank(s) other than the one which is leaking (in lb)
  - $Q_{\text{R}}$  = Tank residuals  
Normal values: 47 lb ( $\text{O}_2$ ) or 2.3 lb ( $\text{H}_2$ ) each  
If a tank quantity ( $>$  residual levels) will be reached where the tank heater(s) cannot meet the fuel cell + leak demand, then that tank quantity should be used for QR.
  - $U$  = The reactant redline (in lb). Includes a fixed usage rate for the extension days
  - $r_{\text{aff}}$  = The reactant use rate for electrical power (and for metabolic  $\text{O}_2$ ) for the affected tank (in lb/hr)
  - $r_{\text{rem}}$  = The reactant use rate for electrical power (and for metabolic  $\text{O}_2$ ) for the tank(s) which are not leaking (in lb/hr)
  - $t$  = Max time to a new nominal EOM touchdown (in hours)
  - $t_{\text{leak}}$  = Time required to deplete the leaking tank(s) (in hours).  
If  $t_{\text{leak}} >$  the time to a nominal EOM, then  $t_{\text{leak}} =$  time to a nominal EOM
  - $L$  = Reactant leak rate (in lb/hr)



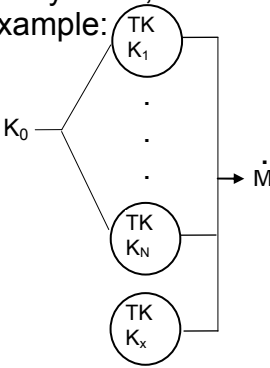
### **Disclaimers**

All the above leak/time equations assume a constant leak rate. Since there are no guarantees that the leak cannot get bigger, some consideration should be given to increasing leak sizes when evaluating mission duration.

### **Summary**

For quick reference, Table 3.7-2 summarizes the equations from this SCP needed to troubleshoot using pressure decay rates.

**Table 3.7-2. Equations for troubleshooting using pressure decay rates**

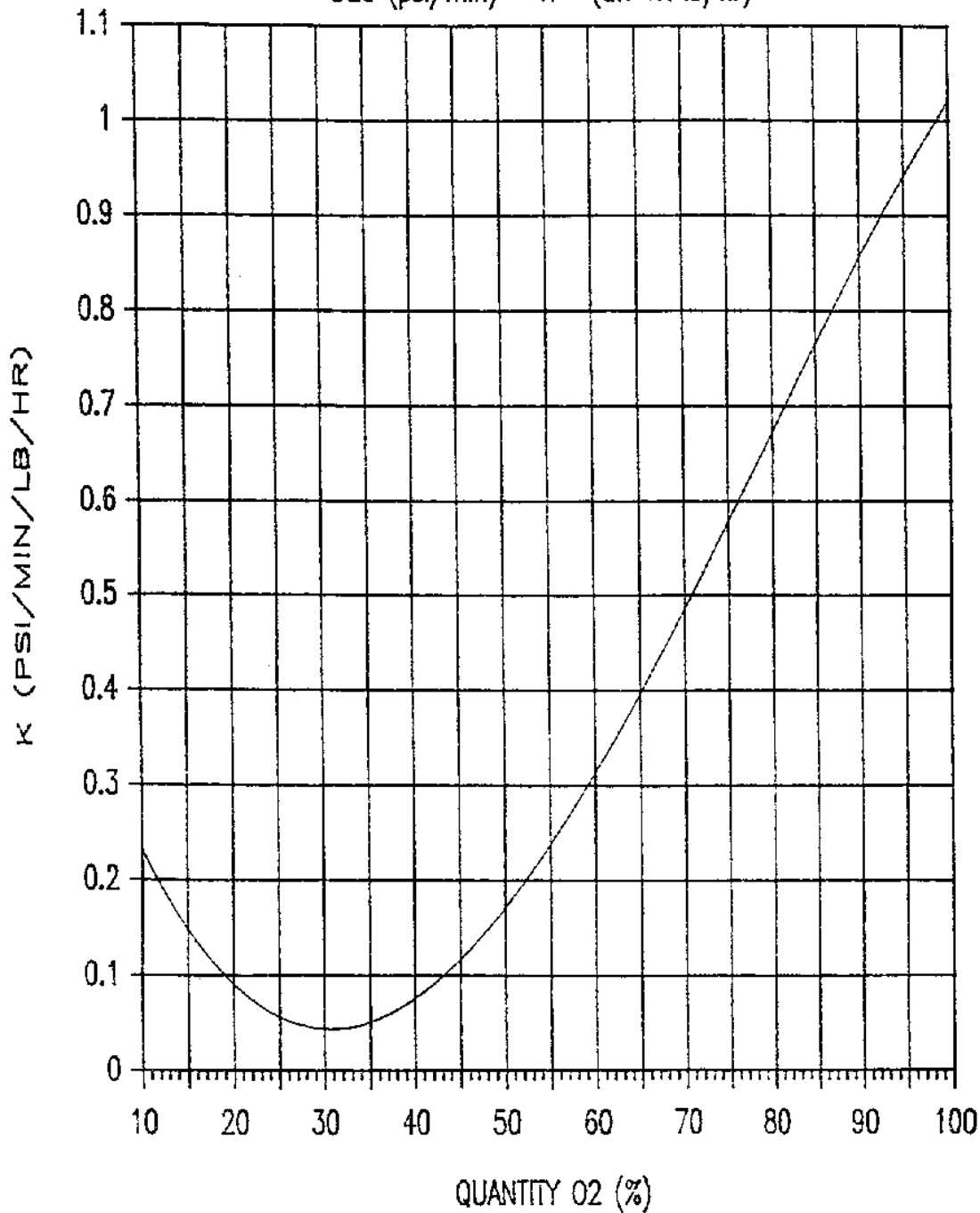
<p>Expected pressure decay rates; example:</p>  <p>Tank being analyzed</p>	<ol style="list-style-type: none"> <li>1. Read individual values of K from Figures 3.7-1, 3.7-2, 3.7-3, or 3.7-4; <math>K_x</math> is for the tank being analyzed</li> <li>2. If multiple tanks are feeding a common flow:             <math display="block">\frac{1}{K_o} = \sum_{i=1}^N \frac{1}{K_i}</math> <p>(do not include <math>K_x</math> in summation)</p> <math display="block">AMPS_x(FLOW_x) = \frac{K_o}{K_o + K_o} * TOT AMPS \quad (TOTFLOW)</math> </li> <li>3. Expect decay<sub>x</sub> = <math>K_x * FLOW_x</math>      Figures 3.7-1 and 3.7-2              Expect decay<sub>x</sub> = <math>(K_x/1000) * AMPX_x</math>      (O<sub>2</sub>), Figure 3.7-3              Expect decay<sub>x</sub> = <math>(K_x/1000) * AMPX_x</math>      (H<sub>2</sub>), Figure 3.7-4</li> </ol>
<p>MED V41 UP background lines</p>	<ol style="list-style-type: none"> <li>1. Initial point = <math>(0, Y_1)</math>  <math>Y_1 = 940</math> (Asc O<sub>2</sub>), <math>260</math> (Asc H<sub>2</sub>)  <math>= 840</math> (E/O O<sub>2</sub> TK 1/2), <math>220</math> (E/O H<sub>2</sub> TK 1/2)  <math>= 875</math> (E/O O<sub>2</sub> TK 3/4/5), <math>240</math> (E/O H<sub>2</sub> TK 3/4/5)</li> <li>2. End point = <math>(X_i, Y_{min})</math>  <math display="block">X_i = \frac{Y_i - Y_{min}}{\text{expected decay rate}}</math> <p>or if <math>X_1 &gt; X_{max}</math>, then              end point = <math>(X_{max}, RY_i)</math>  <math>RY_i = Y_i - (\text{expected decay rate} * X_{max})</math></p> </li> </ol>
<p>Leak size for an individual tank</p>	<ol style="list-style-type: none"> <li>1. If the tank heaters are not receiving power...             <ol style="list-style-type: none"> <li>a. <math>XDECAY = ACTDECAY - PREDECAY</math></li> <li>b. Read K from Figures 3.7-10 or 3.7-11</li> <li>c. <math>LEAK</math> (ind tank) = <math>XDECAY / K</math></li> </ol> </li> <li>2. If the heaters are being powered...             <ol style="list-style-type: none"> <li>a. Read DMDQ from Figures 3.7-12 or 3.7-13</li> <li>b. Read K from Figures 3.7-10 or 3.7-11</li> <li>c. <math>XDPDT</math> = Actual dp/dt being observed (pos in sign for decaying pressure)  <math>R</math> = Fuel cell cell (plus metabolic) consumption <u>from that tank</u>  <math>Q</math> = dependent on number of heaters powered                      100 watts/H<sub>2</sub> heater string                      500 watts/O<sub>2</sub> heater string (2 elements)  <math>LEAK</math> (ind tank) = <math>(DMDQ * Q) + (XDPDT / K) - R</math></li> </ol> </li> </ol>

**Table 3.7-3. Actions to be taken for known leaks**

<p>Leak size for multiple commonly manifolded tanks, all at approx the same quantities</p>	<p>Assumption is that all tanks are decaying at the same rate</p>
	<p>1. If no tank heaters are receiving power:</p> <ul style="list-style-type: none"> <li>a. N = number of tanks</li> <li>b. XDECAY = ACTDECAY - PREDECAY</li> <li>c. Read K from figures 3.7-10 or 3.7-11</li> </ul> <p>TOTAL LEAK = (XDECAY/K) * N</p> <p>2. If any tank heaters are receiving power:</p> <ul style="list-style-type: none"> <li>a. Read DMDQ from Figures 3.7-12 or 3.7-13</li> <li>b. Read K from Figures 3.7-10 or 3.7-11</li> <li>c. XDPDT = Actual dp/dt being observed (pos in sign for decaying pressure)</li> </ul> <p>R = <u>Total</u> fuel cell (plus metabolic) consumption  Q = <u>Total</u> heater watt input  100 watts/H<sub>2</sub> heater string  500 watts/O<sub>2</sub> heater string (2 elements)</p> <p>TOTAL LEAK = (DMDQ * Q) + N * (XDPDT/K) - R</p> <p>For example: 3 tank ascent  O<sub>2</sub> TK1 and 2 A HTRS cycled on  All tanks 100% qty  15 LB/HR fuel cell flow  15 LB/HR metabolic flow</p> <p>TOTAL LEAK = (0.022 * 1000) + 3 * (XDPDT/1.1) - 30  = 22 - 30 + (3/1.1) * XDPDT</p> <p>TOTAL LEAK = 2.73 XDPDT - 8</p> <p>If the observed decay with the heaters cycled on is 20 psi/min  (in all 3 tanks), then:</p> <p>TOTAL LEAK = (2.73) * (20) - 8  = 47 lb/hr</p>

# NORMAL O<sub>2</sub> PRESS DECAY RATE

$$\text{DEC (psi/min)} = K * (\text{off TK lb/hr})$$

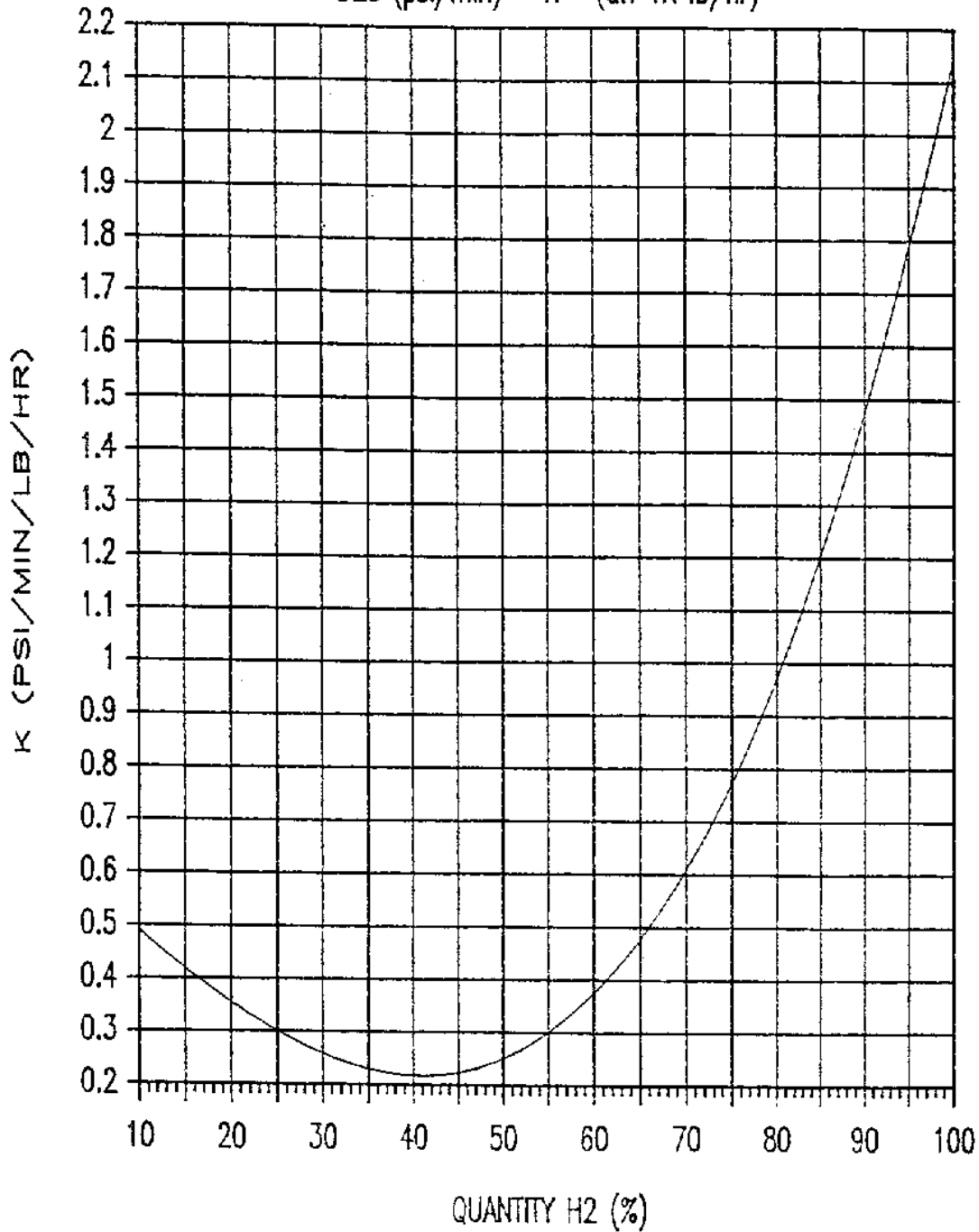


330\_004

Figure 3.7-1. Normal O<sub>2</sub> pressure decay rate (decay per tank lb/hr)

# NORMAL H<sub>2</sub> PRESS DECAY RATE

$$\text{DEC (psi/min)} = K * (\text{off TK lb/hr})$$



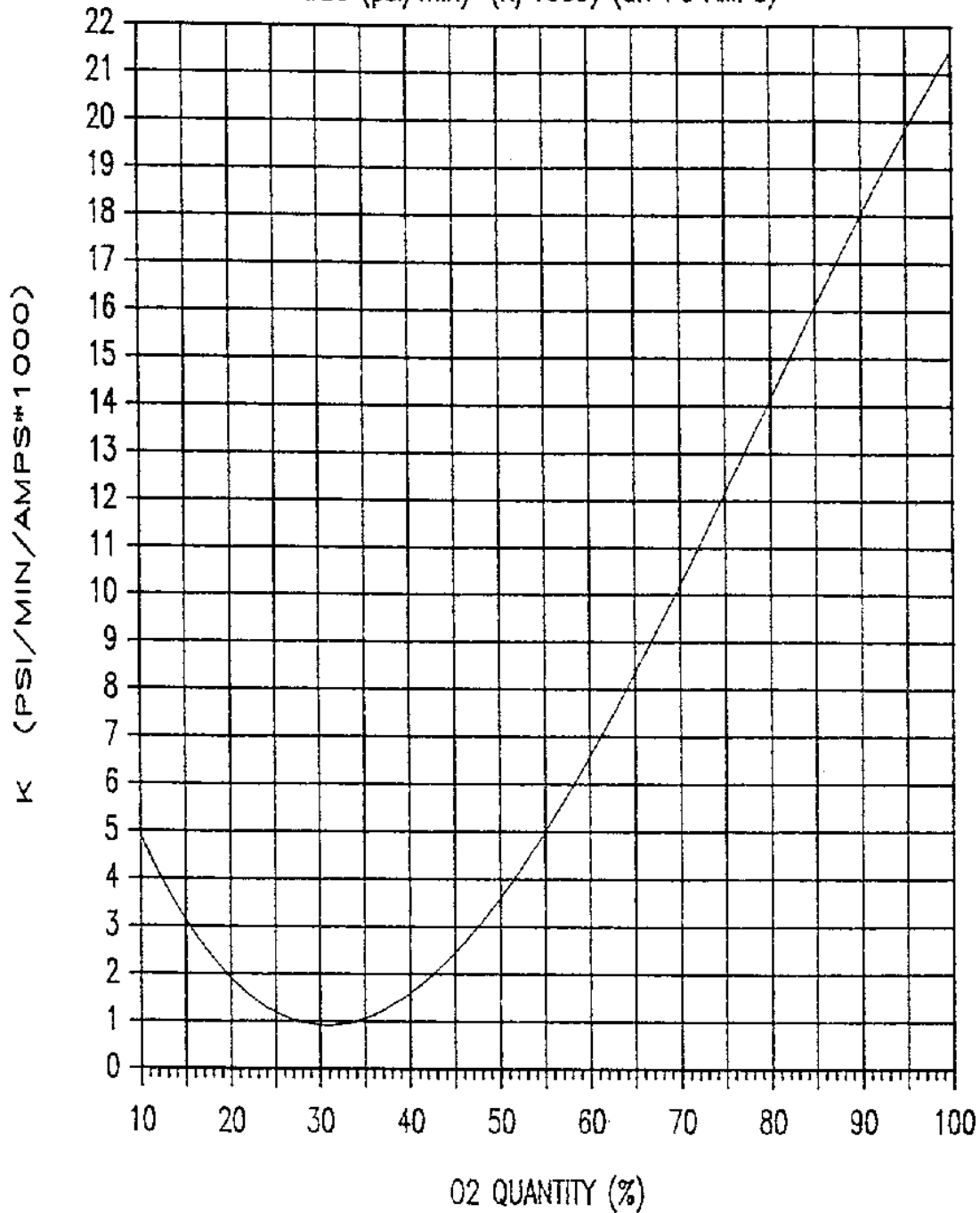
330\_005

**Figure 3.7-2. Normal H<sub>2</sub> pressure decay rate  
(decay per tank lb/hr)**

**Verify that this is the correct version before use**

# NORMAL O<sub>2</sub> PRESS DECAY RATE

$$\text{DEC (psi/min)} = (K/1000) * (\text{off FC AMPS})$$



830\_006

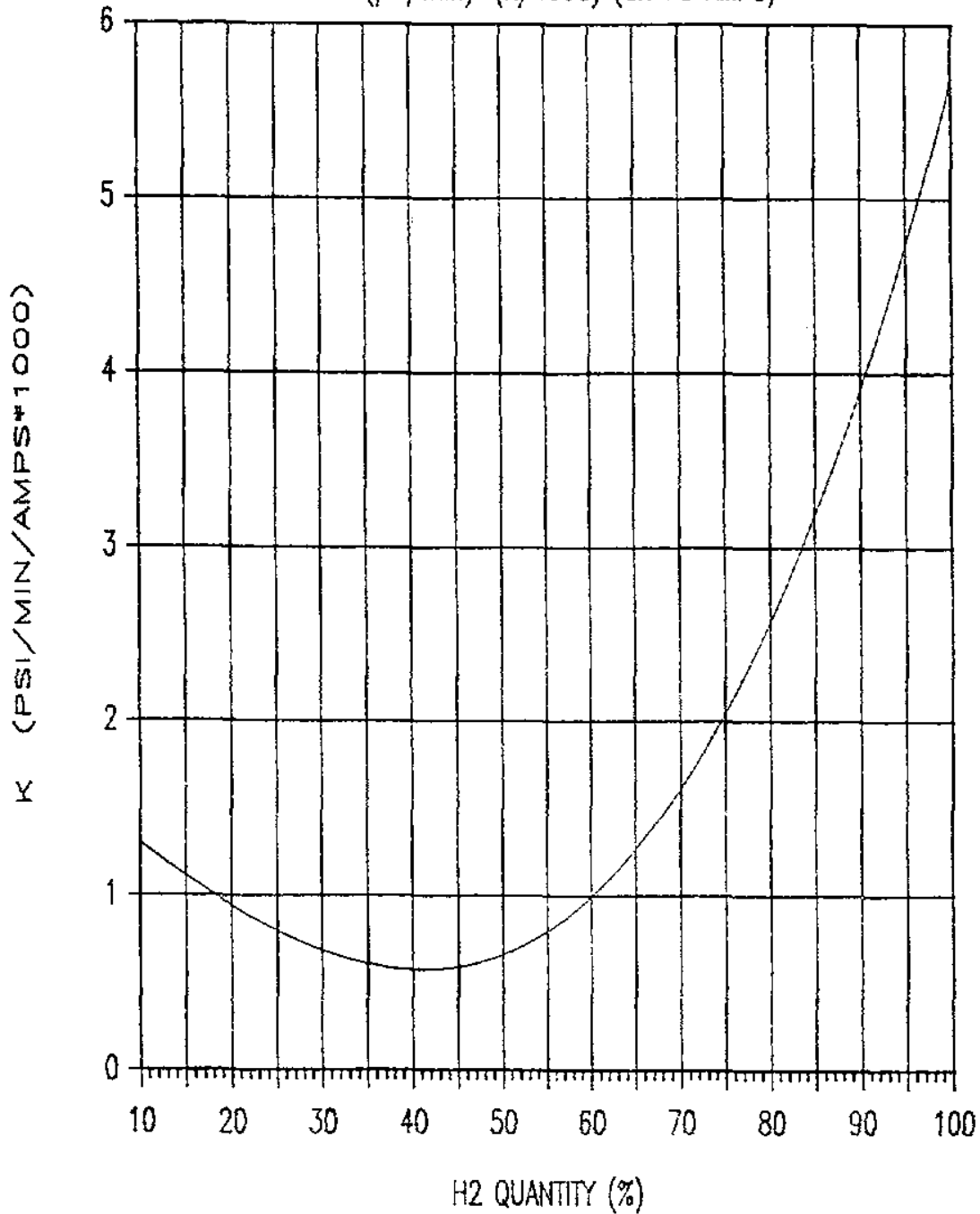
**Figure 3.7-3. Normal O<sub>2</sub> pressure decay rate  
(decay per 1000 amps)**

3.7-20

**Verify that this is the correct version before use**

# NORMAL H<sub>2</sub> PRESS DECAY RATE

$$\text{DEC (psi/min)} = (K/1000) * (\text{off FC AMPS})$$



30\_007

**Figure 3.7-4. Normal H<sub>2</sub> pressure decay rate  
(decay per 10,000 amps)**

3.7-21

**Verify that this is the correct version before use**

# O<sub>2</sub> CURVE FIT to FLIGHT comparison

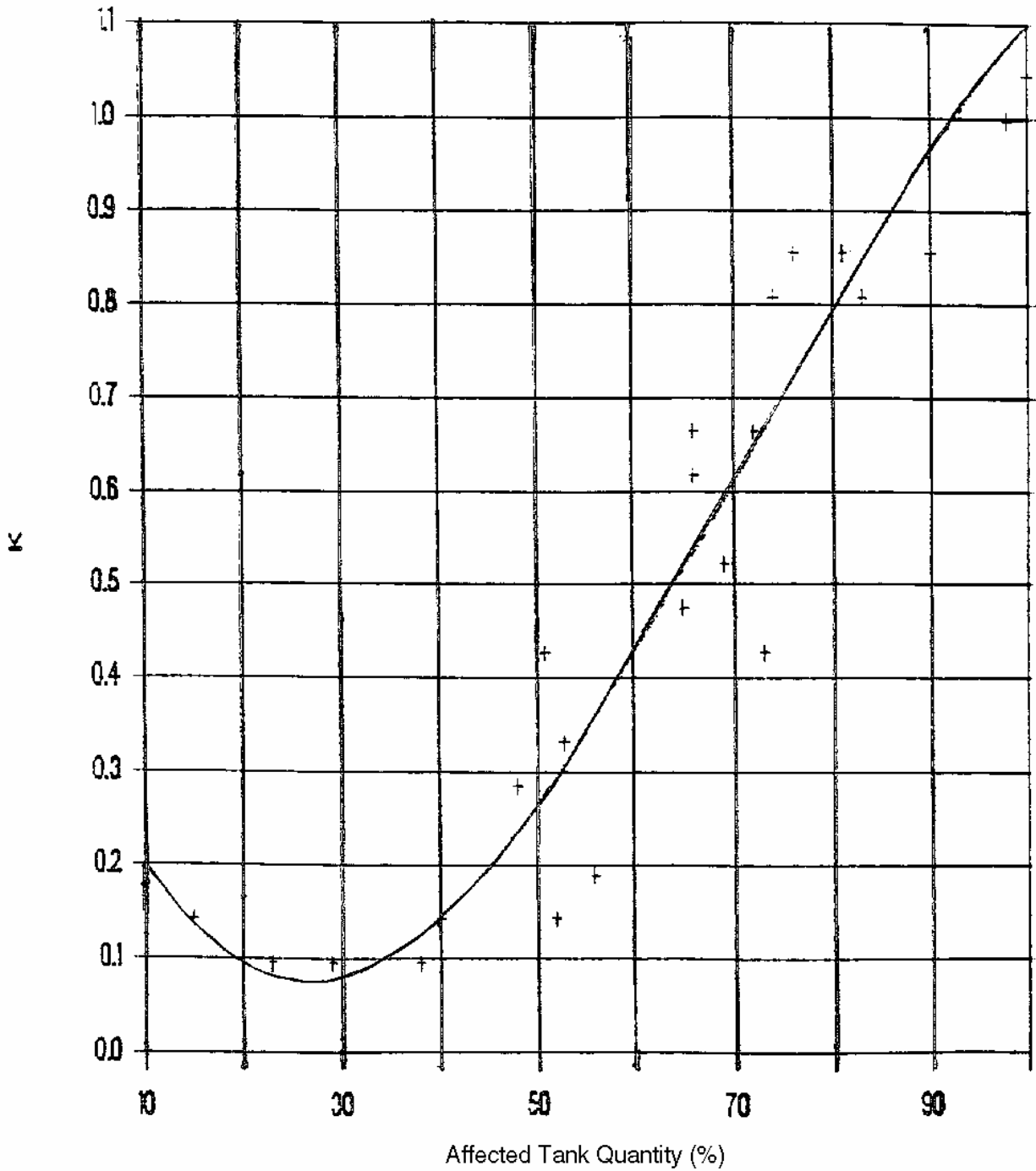


Figure 3.7-5. O<sub>2</sub> curve fit to flight comparison

Verify that this is the correct version before use



## H<sub>2</sub> CURVE FIT to FLIGHT comparison

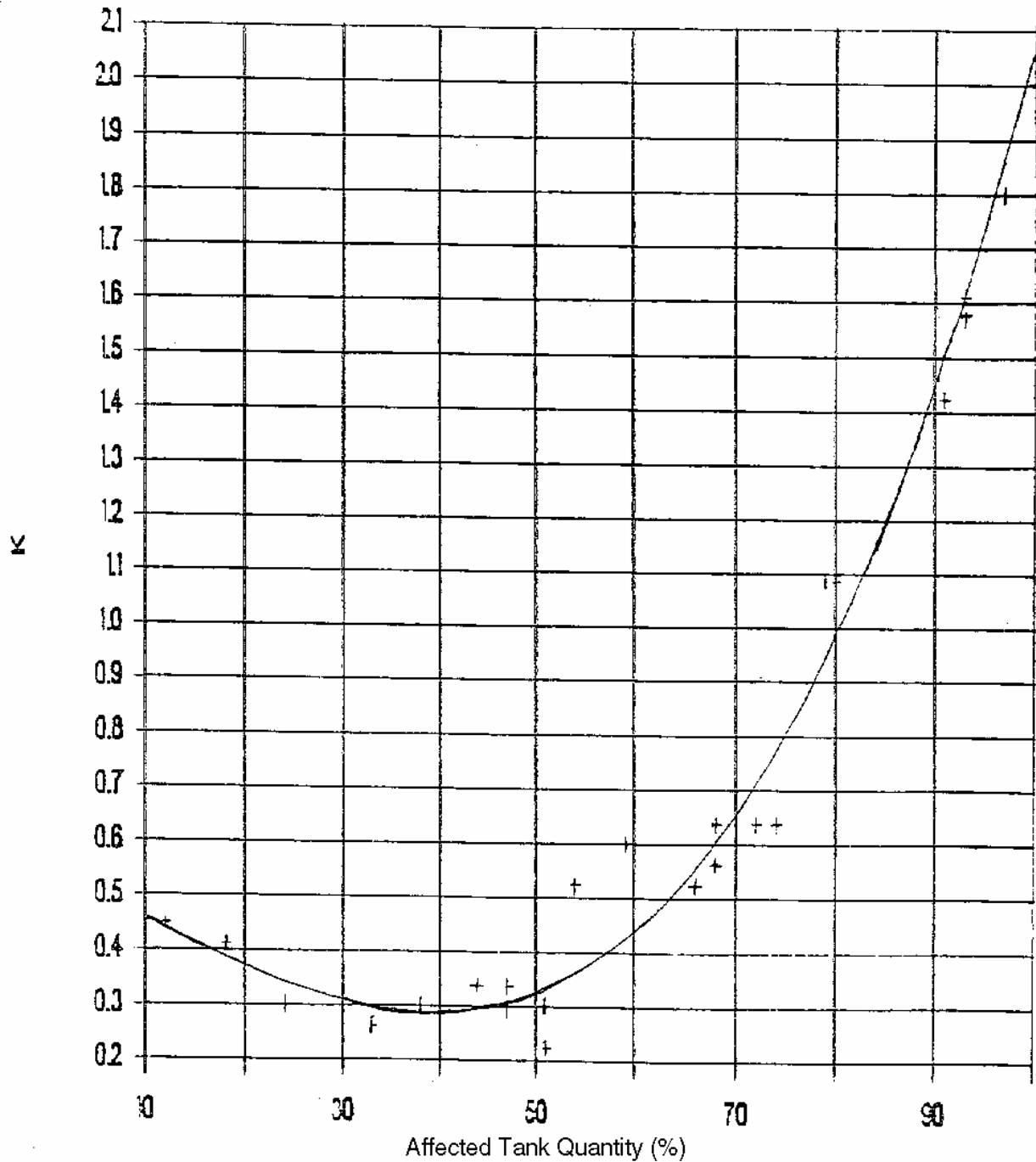
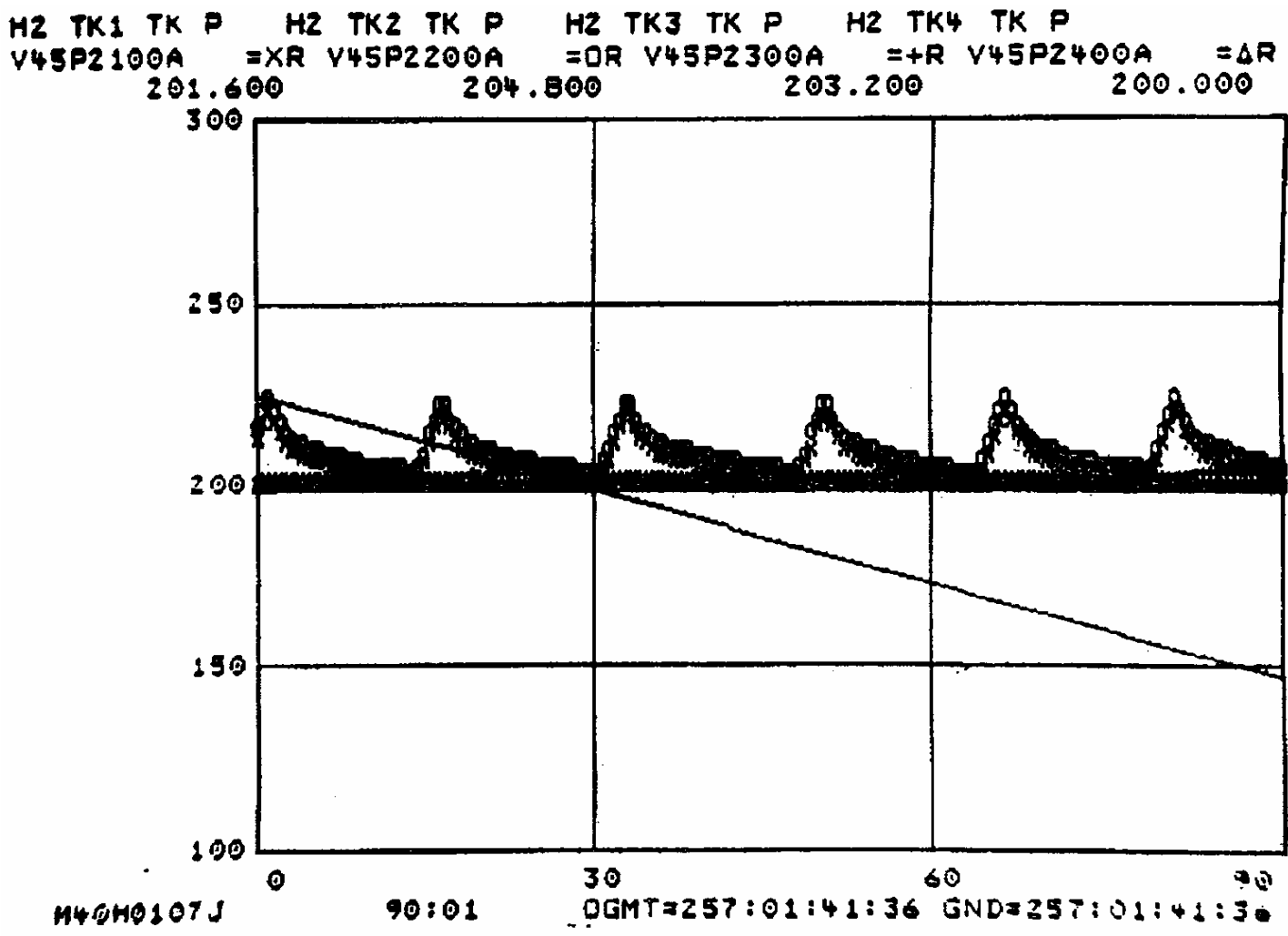


Figure 3.7-6. H<sub>2</sub> curve fit to flight comparison



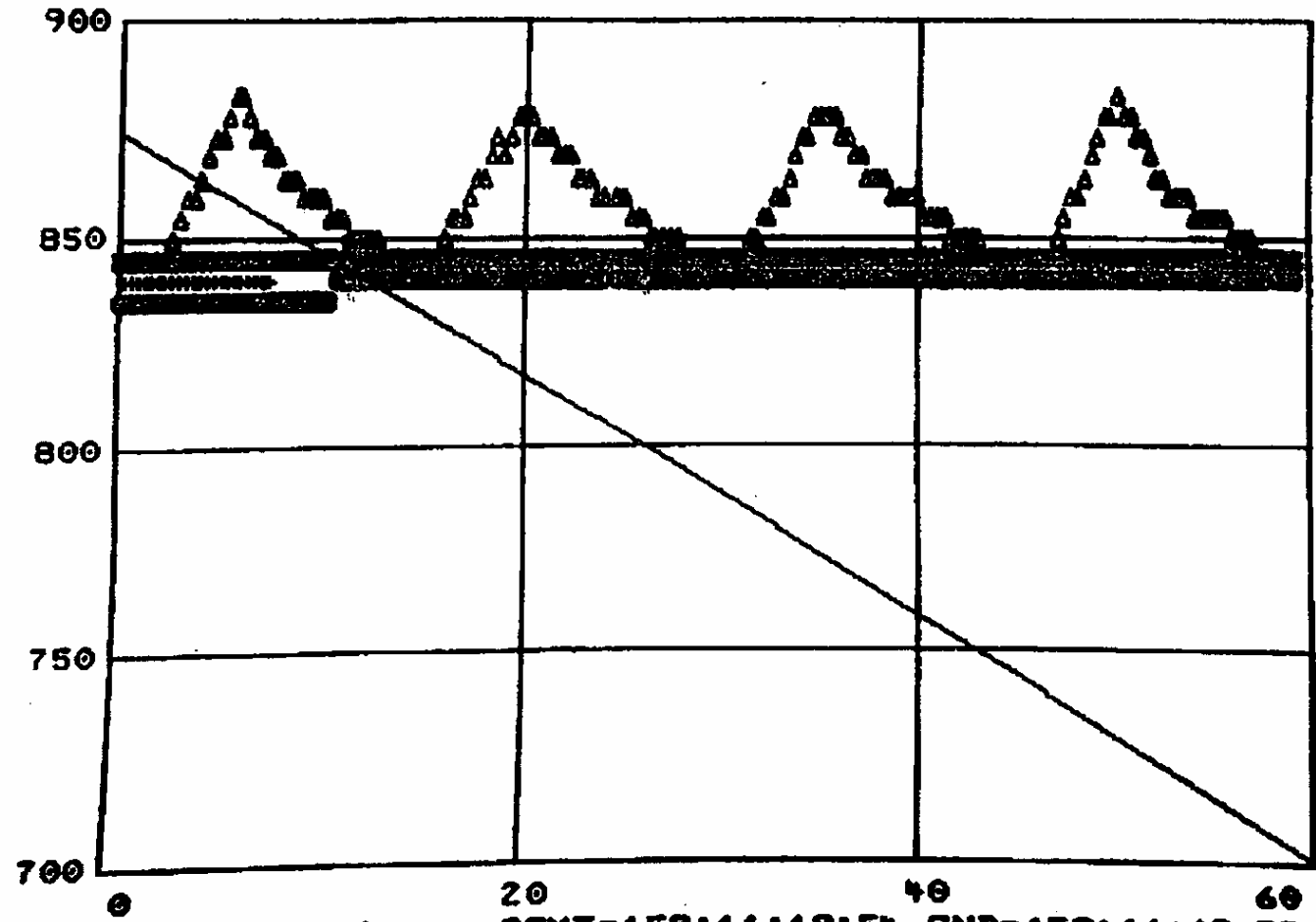
L12830\_010

Figure 3.7-7. Hydrogen pressure display

3.7-24

Verify that this is the correct version before use

O2 TK1 TK P    O2 TK2 TK P    O2 TK3 TK P    O2 TK4 TK P  
V45P1100A    =XR V45P1200A    =OR V45P1300A    =+R V45P1400A    =ΔR  
844.800            840.000            840.000            844.800



140M0107J

59:21

OGMT=158:11:18:54

GND=158:11:18:55

L12830\_011

Figure 3.7-8. Oxygen pressure display

3.7-25

Verify that this is the correct version before use

V41#

002/RT TLM UNIVERSAL PLOT(NOMINAL DATA) MENU MSK 18 \_\_\_\_\_ ,  
SCALE (L/R/D/C) \_\_ , L/R = ADD NOMINALS; D = DEL NOMINALS; C = CHG NOMINALS  
NOTE: IF X PARAMETER IS A TIME; INPUT X POINTS IN MINUTES

DATA POINT PAIRS

NO	X VALUE	Y VALUE	NO	X VALUE	Y VALUE
01 /	0	840	02	25	700
03 /	16	700	04	0	875
05 /			06		
07 /			08		
09 /			10		
11 /			12		
13 /			14		
15 /					

OR: UP TO 6 COEFFICIENTS FOR A 1ST TO 5TH DEGREE POLYNOMIAL.

COEFFICIENT A(0) / \_\_\_\_\_ , COEFFICIENT A(1) \_\_\_\_\_ ,  
COEFFICIENT A(2) / \_\_\_\_\_ , COEFFICIENT A(3) \_\_\_\_\_ ,  
COEFFICIENT A(4) / \_\_\_\_\_ , COEFFICIENT A(5) \_\_\_\_\_ / \$

\_\_\_\_\_ ENTER PM FOR PERMANENT MED

**Figure 3.7-9. V41 menu**

# O<sub>2</sub> PER TK LEAK RATE from EXCESS DP/DT

$$\text{LEAK (lb/hr)} = (\text{EXCESS DP/DT})/K$$

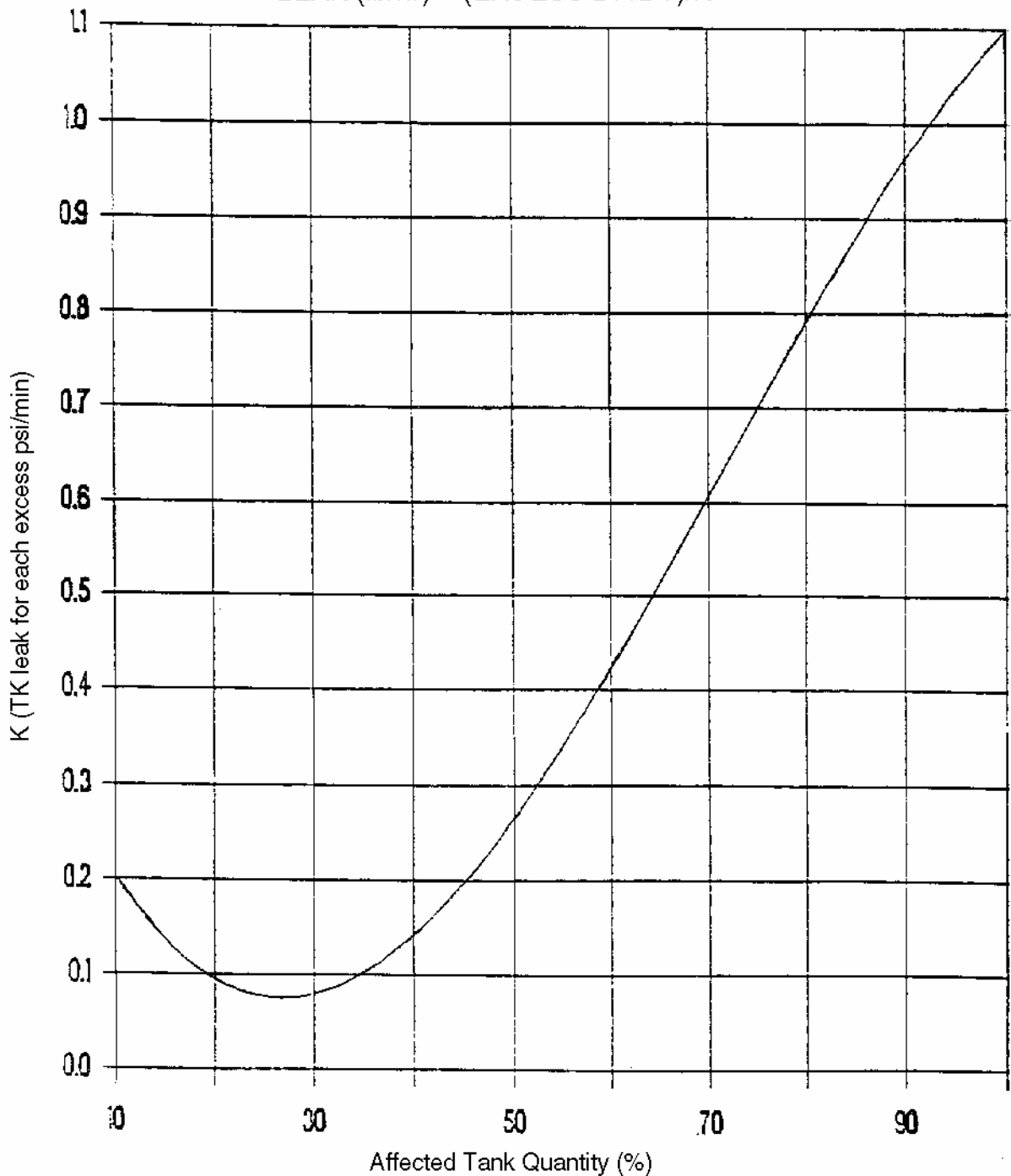


Figure 3.7-10. O<sub>2</sub> per tank leak rate from excess dP/dt

# H2 PER TK LEAK RATE from EXCESS DP/DT

$$\text{LEAK (lb/hr)} = (\text{EXCESS DP/DT})/K$$

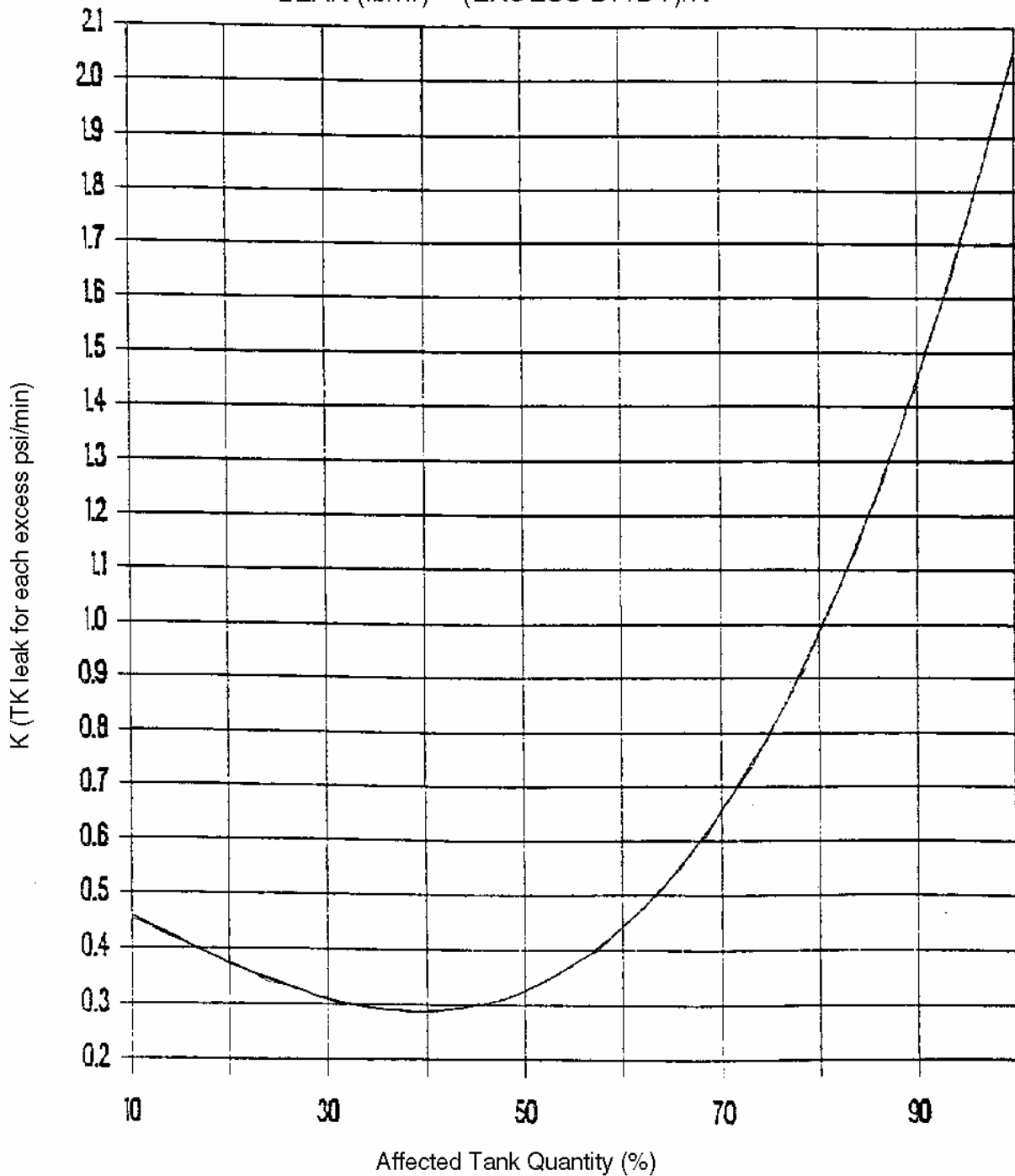


Figure 3.7-11. H<sub>2</sub> per tank leak rate from excess dP/dt

Verify that this is the correct version before use

# O<sub>2</sub> FLOW CAPACITY per watt

to maintain stable pressure

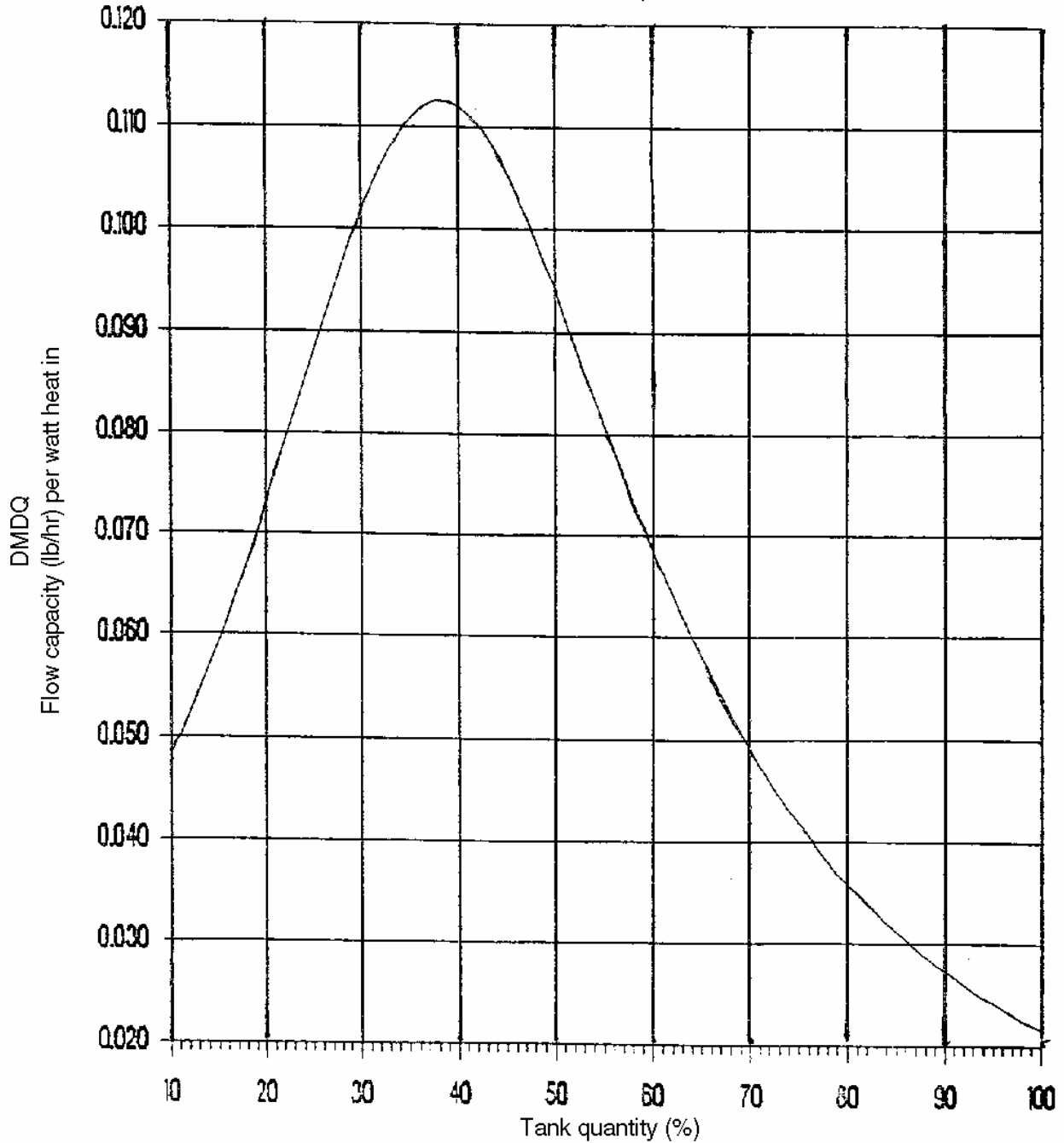


Figure 3.7-12. O<sub>2</sub> flow capacity per watt

## H2 FLOW CAPACITY per watt to maintain stable pressure

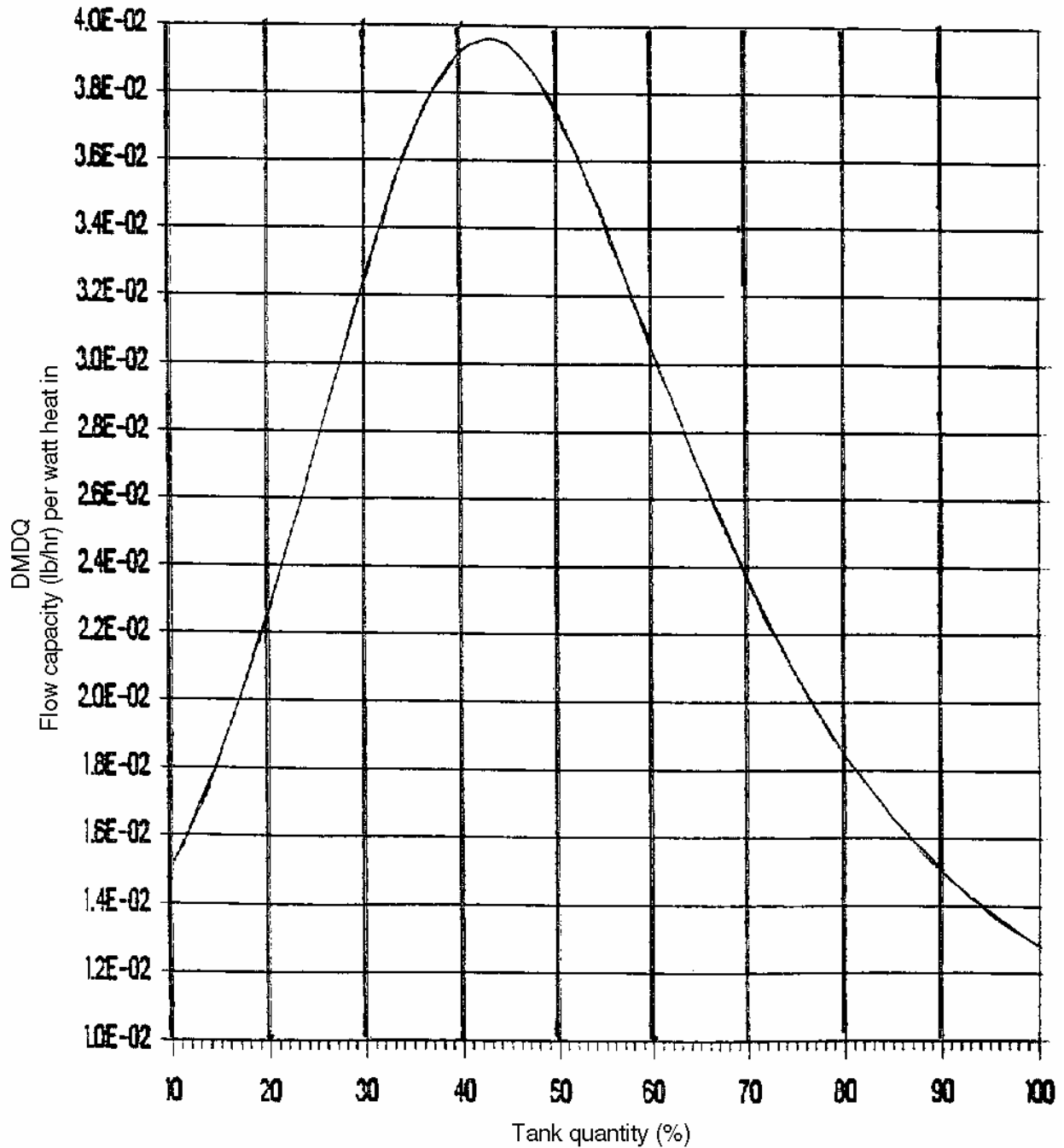


Figure 3.7-13. H<sub>2</sub> flow capacity per watt



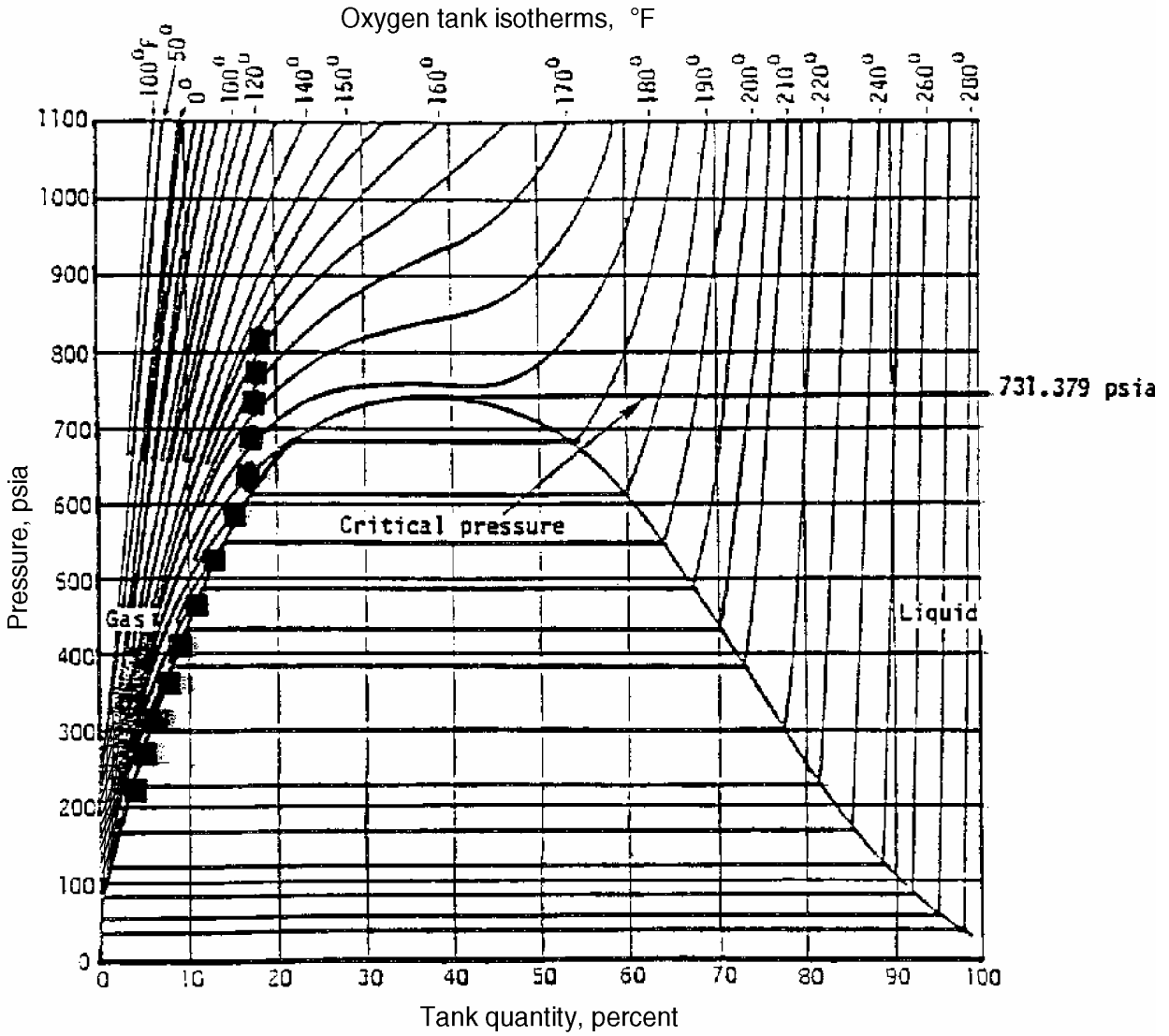


Figure 3.7-14. O<sub>2</sub> leak (low quantity)

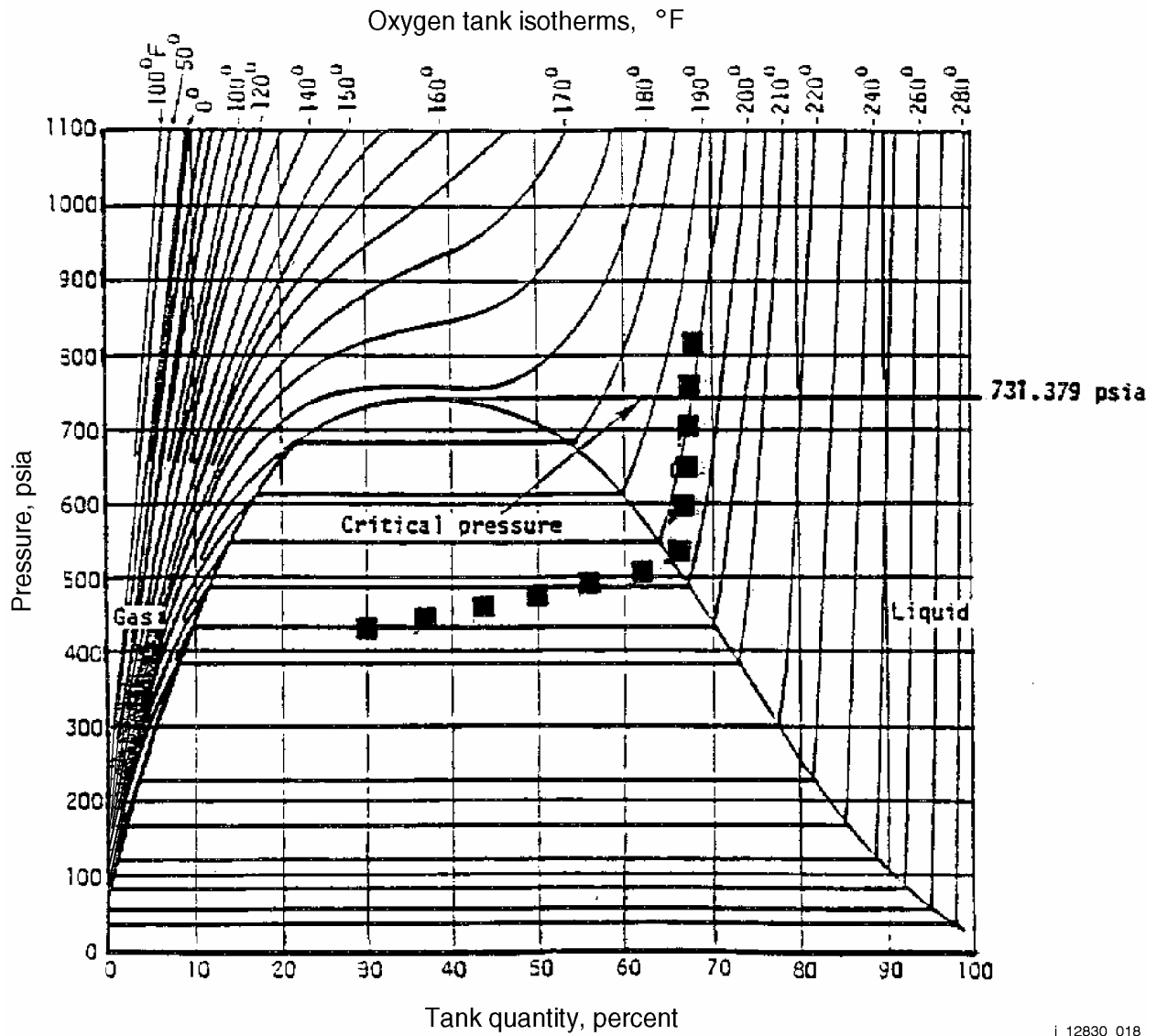


Figure 3.7-15. O<sub>2</sub> leak (high quantity)

I 12830 018

## TITLE

PRSD MANUAL HEATER OPERATION

## PURPOSE

This SCP outlines a basic procedure to be used for on-orbit manual operation of PRSD heaters, identifies constraints to be observed during manual operation, and presents data from the only flight where manual operation has actually been required.

## BACKGROUND

There are specific failures, primarily bus losses or loss of AUTO operation capability, that may require manual operation of the PRSD heaters in some tanks for extended periods of time, depending upon the particular circumstances at the time of the failure. The primary objective of the manual management plan is to minimize the time impact to the crew while still keeping the system pressures within an appropriate operating range.

Several methods are available, either individually or in combination, to minimize crew time impact during manual operations.

- A. Widening the pressure operating range from the normal AUTO mode on/off bands of about 35 psi (O<sub>2</sub>) and 20 psi (H<sub>2</sub>) lengthens the time between heater cycles in direct proportion. For example, an on/off range of 70 psi instead of 35 for O<sub>2</sub> results in the time between heater cycles being twice as long. Likewise, widening the range to 140 psi results in a time between heater cycles four times greater than that at the 35 psi pressure band. This assumes a constant power level and a constant number of tanks involved in the manual procedure.
- B. A maximum of two tanks would be required to be operated in manual due to any single failure. However, under certain conditions, it may be advantageous to operate more than two tanks with the same heater control range simultaneously to lengthen the heater duty cycle even more. For example, operating four tanks, assuming all are at the same quantity level, will double the depressurization portion of the heater cycle but will not necessarily have a significant effect on the pressurization period. If the tanks are at different quantity levels, the time-multiplying factor may be more or less than twice, depending on the particular tank quantities.
- C. By operating only 50 percent heaters per tank instead of 100 percent heaters, the pressurization period of the cycles will be at least doubled.

By combining the methods discussed in 1, 2, and 3 above, maximum heater cycle periods and, thus, minimum crew involvement can be achieved. Certain restrictions must be considered in developing the manual plan, however. These are discussed in the following paragraphs.

## CONSTRAINTS

The following constraints should be observed when developing a manual heater operating plan. Rationale is provided for each constraint.

- A. The peak-to-peak pressure excursion must not exceed 375 psi for oxygen or 150 psi for hydrogen.

Rationale: Pressure excursions of greater than these values represent a structural pressure cycle on the tank. The tanks are designed to accommodate a lifetime total of 300 such pressure cycles. With a total life requirement of 125 flights, only three (3) structural cycles can be experienced per flight, on the average, without reducing the useful life of the tank. One structural cycle is automatically incurred on every flight during initial loading and pressurization. The other two cycles per flight are intended for any required ground testing or checkout.

- B. The maximum absolute pressure of the manual cycle range should be such that the manifold relief valves do not crack. Crack pressures are 975 psig for oxygen and 290 psig for hydrogen. Recommended maximum planned operating pressures are approximately 920 psia for oxygen and 260 psia for hydrogen to allow some margin for pressure overshoot and crew response.

Rationale: If the manifold relief valves open in flight, a retest is required before the next flight. This is not a normally planned test. Also, a failure of the relief valve in the OPEN position results in uncontrollable quantity management in the affected tank.

- C. The minimum absolute pressure of the manual cycle range should not be lower than the critical pressure of each system (731.4 psia for oxygen and 187.5 psia for hydrogen, as shown on the oxygen and hydrogen isotherms in Figures 3.8-1 and 3.8-2).

Rationale: Flight data from STS 51-D show that a two-phase condition existed in a tank during manual operation of the heaters (destratification on STS-42 caused one tank to drop below the critical pressure and again showed conditions consistent with two-phase). The expected condition of the fluid in the tank, based on quantity and pressure, indicated a single-phase condition. Two-phase fluid possibly existed because the heaters boiled the liquid around the elements faster than the pressure rise could keep the fluid liquified. The danger of this is that some areas of the heater surface may be in gaseous region, and localized overtemperature could occur that would not necessarily be indicated by the heater temperature transducer. For this reason, operating heaters in this condition for long periods of time is unacceptable. Overtemperature in the O<sub>2</sub> tank could result in ignition of the Teflon in the tank. Overtemperature in the H<sub>2</sub> tank could result in structural tank damage. Maintaining super-critical pressurization ensures that the fluid

is single-phase at any temperature or density.

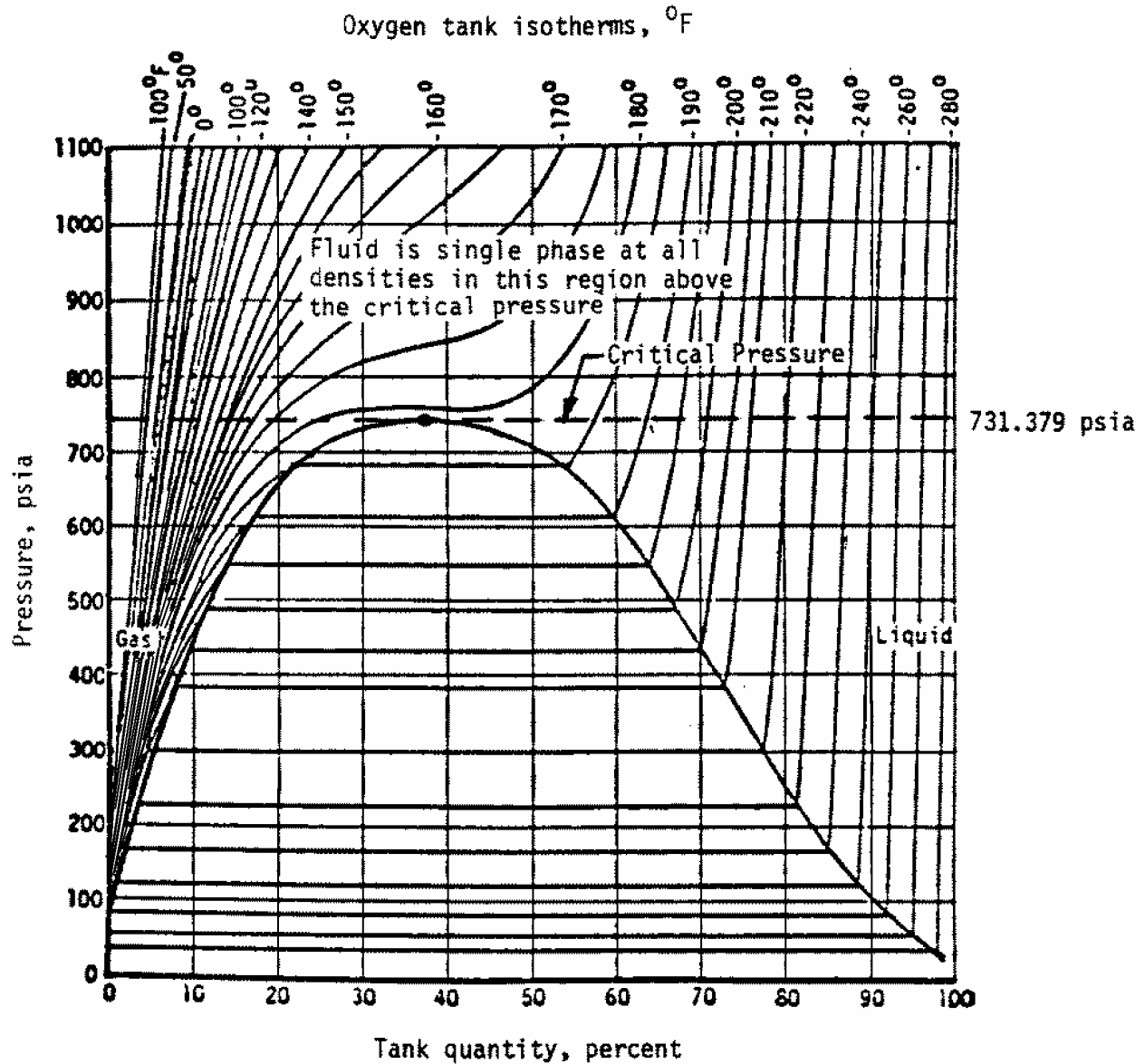
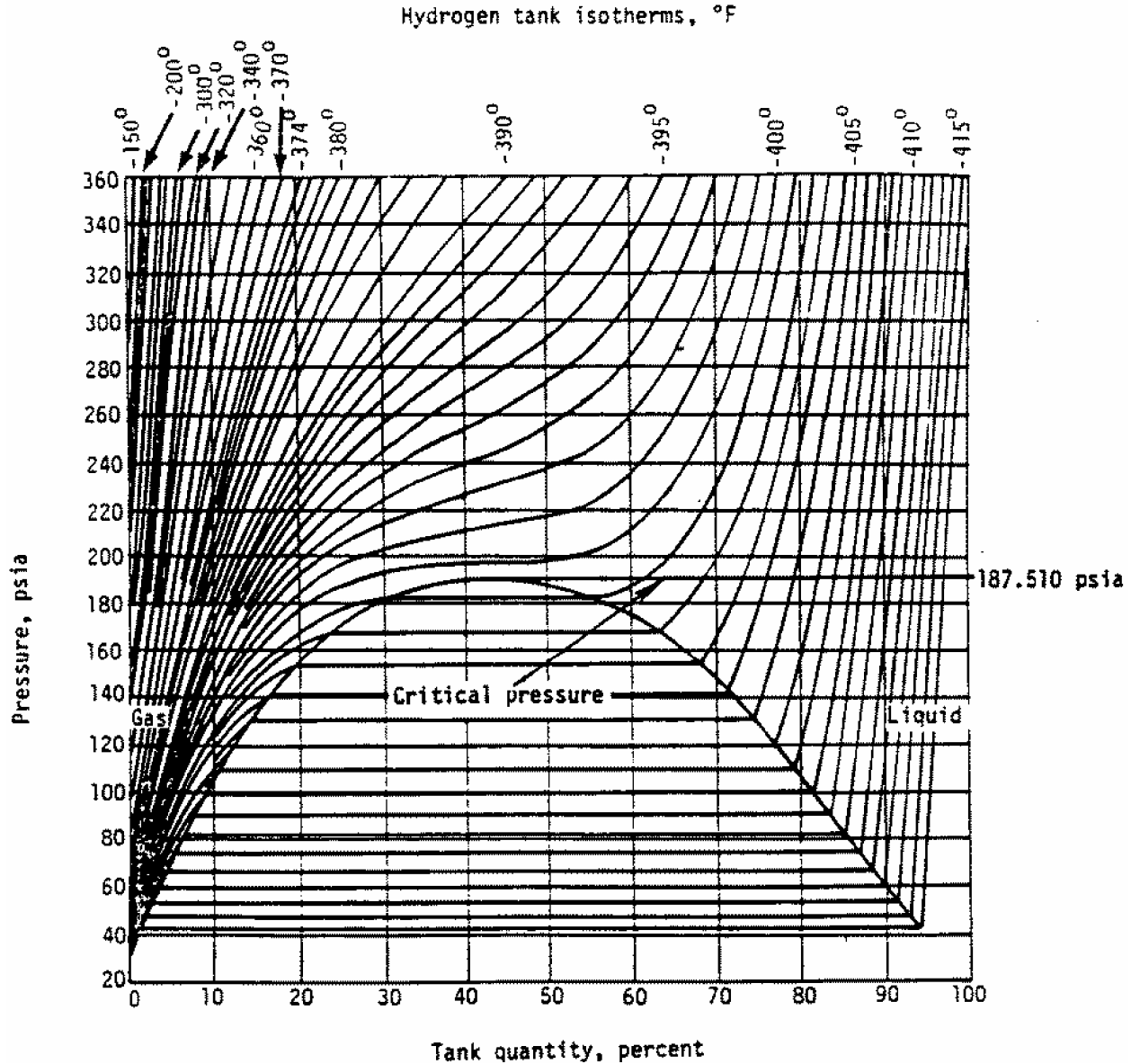


Figure 3.8-1. Oxygen pressure vs. quantity diagram  
(from SODB)



**Figure 3.8-2. Hydrogen pressure vs. quantity diagram (from SODB)**

- D. If the tank pressure falls below the two-phase saturation pressure (refer to Figures 3.8-1 and 3.8-2 for the O<sub>2</sub>/H<sub>2</sub> saturation domes), the heaters must be disabled until normal heat transfer into the tank raises the pressure above the two-phase saturation pressure. The heaters may be operated only in a contingency situation.

Rationale: When the pressure falls below the two-phase saturation pressure, two-phase fluid is located throughout the tank. The amount could be considerably more than the situation in constraint C. The reason for the deactivation is the same as constraint C, except that greater risk is thought to be involved.

**MANUAL MANAGEMENT PROCEDURE**

The manual procedure is a very simple three-step procedure.

- A. Based on the constraints outlined in the previous paragraph and the particular situation that exists at the time, determine the desired operating pressure band. If the failure that created the need for manual management occurs during a long LOS, the crew may already have set up the configuration according to EPS SSR-201 in the malfunction procedures, CRYO HTR MANUAL OPS.
- B. Reset the FDA pressure limits (one per tank) to alert when heater cycling is required. Normally, use the tank pressure as the primary indicator. The heater control pressure should be used only if a tank pressure transducer is lost. The heater control pressures are the hardwire C&W and B/U C&W and should normally be left at their preset values to act as a backup alarm to the class 3 FDA (O<sub>2</sub>/H<sub>2</sub> limits are set at 540, 985 and 153, 293.8, respectively). The applicable measurement numbers are

Tank number	Primary tank pressure		Backup heater control pressure	
	O <sub>2</sub>	H <sub>2</sub>	O <sub>2</sub>	H <sub>2</sub>
1	V45P1100A	V45P2100A	V45P1110A	V45P2110A
2	V45P1200A	V45P2200A	V45P1210A	V45P2210A
3	V45P1300A	V45P2300A	V45P1310A	V45P2310A
4	V45P1400A	V45P2400A	V45P1410A	V45P2410A
5	V45P1500A	V45P2500A	V45P1410A	V45P2410A

- C. Heater A is activated (turned ON) in the affected tank. When the pressure in the affected tank reaches the high limit and annunciates the alarm ('S68 O<sub>2</sub> (H<sub>2</sub>) TK P' or 'S68 O<sub>2</sub> (H<sub>2</sub>) CNTRL P'), turn all applicable O<sub>2</sub> or H<sub>2</sub> switches to OFF. When the alarm is annunciatted again, the procedure verifies whether the pressure is high, low, or OK. If the pressure is high, half heaters are sufficient to cycle the pressures and will be used for the rest of the operation. If the pressure is low, a single heater is not sufficient and heater B is turned ON to support. If the pressure is somewhere between the alarm limits, troubleshoot the alarm using the appropriate malfunction procedure.
  - 1. For situations in which the tank pressure goes below the critical pressure but is still above the two-phase saturation pressure, heaters may be used (dual heaters preferred) to raise the pressure back above the critical pressure.
  - 2. If the tank pressure falls below the two-phase saturation pressure, the heaters will be disabled until normal heat transfer into the tank raises the pressure above the two-phase saturation pressure. The heaters may be operated only in a contingency situation.

## FLIGHT DATA (STS 51-D)

Manual heater management has been implemented only one time during flight. On STS 51-D, the PRSD oxygen tank 1 heater controller experienced a failure in the AUTO circuitry so that O<sub>2</sub> TK1 could not be operated in the AUTO mode. The consumables budget was such that the flight, as originally planned, could have been completed on only three tank sets. As a result, the initial plan was to operate tanks 2, 3, and 4 in AUTO and not use tank 1 to avoid manual operations. Subsequent payload problems resulted in planning a mission extension of at least 1 day. Consequently, it became necessary to use some reactant from O<sub>2</sub> tank 1. This scenario resulted in the exclusive operation of O<sub>2</sub> tank 1 in the manual mode for two crew-awake periods.

The manual management plan was set up to cycle O<sub>2</sub> tank 1 pressures between 920 psia and 580 psia (the O<sub>2</sub> tank 1 quantity was initially about 100 percent) the peak-to-peak pressure range did not violate constraint A, and the selected maximum pressure did not violate constraint B. Constraint C does seem to be violated, but this constraint was developed after flight STS 51-L based on data from STS 51-D manual heater management.

Figures 3.8-3 and 3.8-4 show plots of the pressures in all tanks of the oxygen system for about 3 hours prior to the start of the first day of manual operation and about 9 hours of manual operation thereafter. Three features are obvious from the figures:

- A. The pressure decay rate with all four tanks involved illustrates the advantage of operating as many tanks as possible in the manual plan. In this particular case, it was necessary to maximize use from tank 1, so a multiple tank plan was not feasible.
- B. The widening of the pressure band reduced the heater duty cycle to only about once per hour with only one tank operating vs. six times per hour with two tanks operating in the normal AUTO mode pressure range.
- C. Further review of this management plan after the flight revealed other interesting facts. Operating with such a wide band that does not exceed the pressure excursion limit might cause the tanks not being used to exceed that limit due to destratification. This condition almost existed with O<sub>2</sub> tanks 3 and 4, as shown in Figure 3.8-5. Figure 3.8-6 shows manual cycles of the tank when half heaters were used. Each cycle at around the critical pressure of oxygen (about 731.5 psia) plateaus for a short period of time. Earlier when dual heaters were used to raise the pressure, no plateau is evident (refer to Figure 3.8-4). This prompted constraint C as previously defined in this SCP and prompted the use of dual heaters when the pressure does dip below the critical pressure due to either destratification or a late crew response.



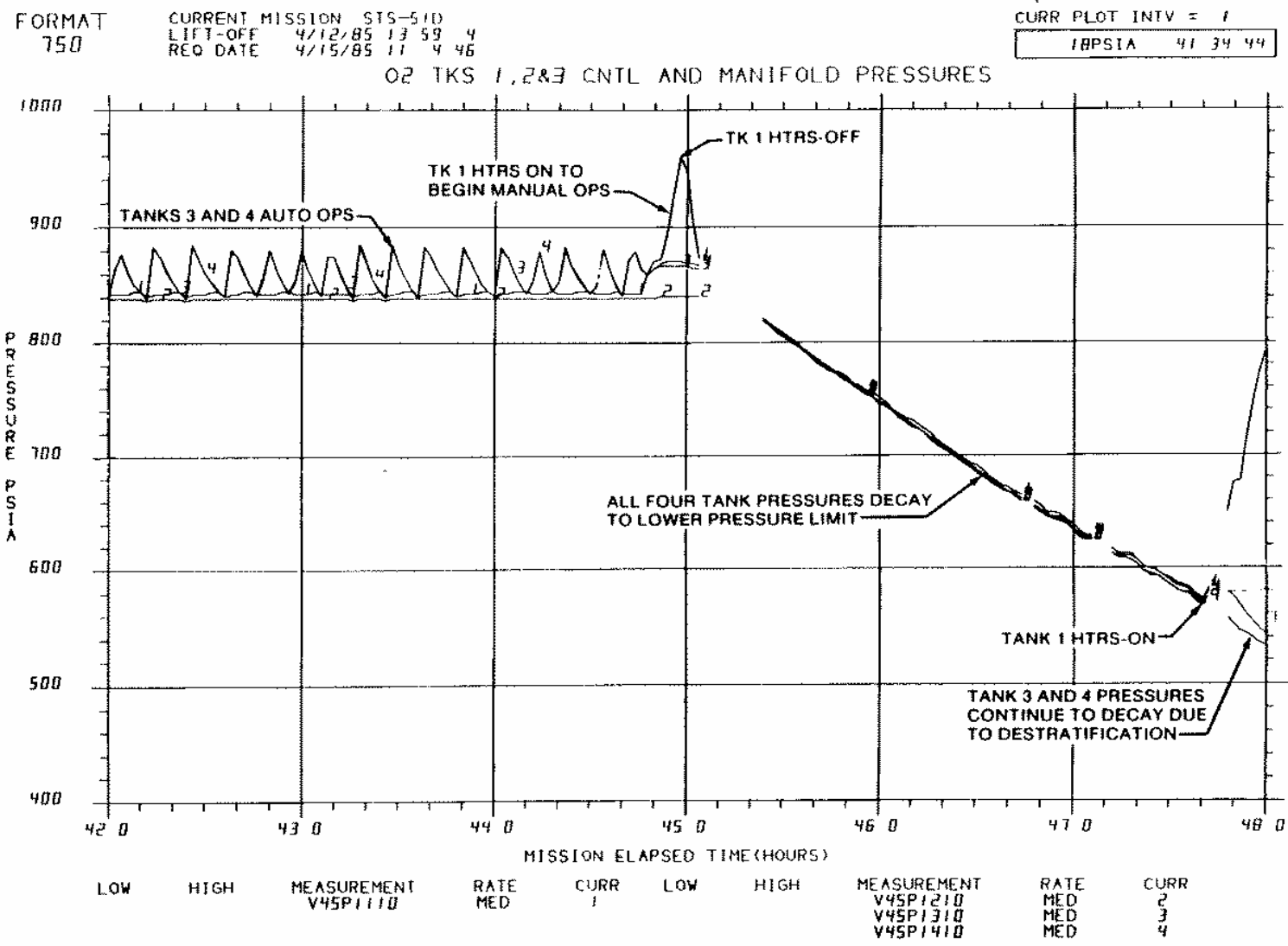


Figure 3.8-3. Initialization of oxygen tank 1 manual operation (STS 51-D)

3.8-7

Verify that this is the correct version before use

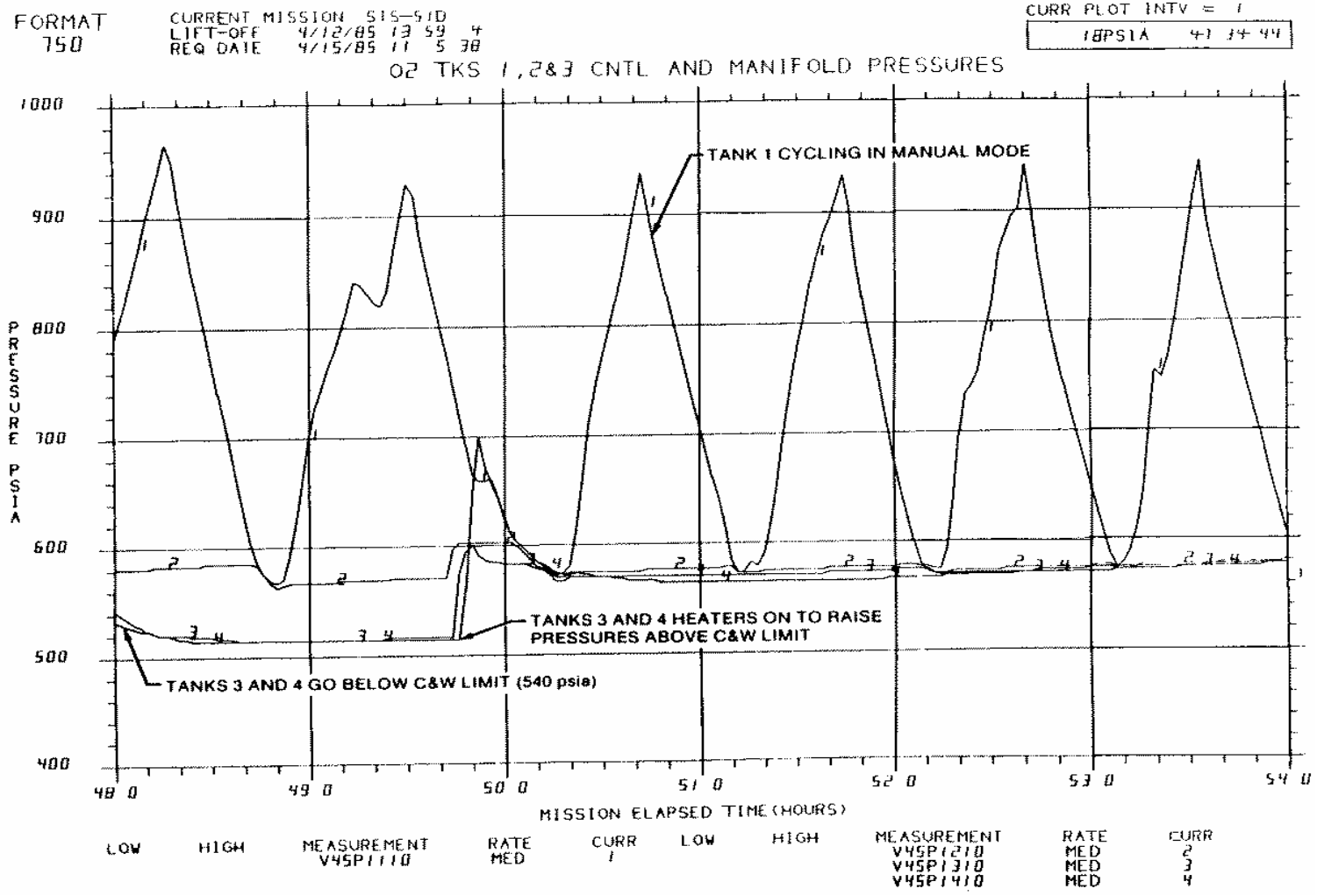


Figure 3.8-4. Continuation of oxygen tank 1 manual operation (STS 51-D)

3.8-8

Verify that this is the correct version before use

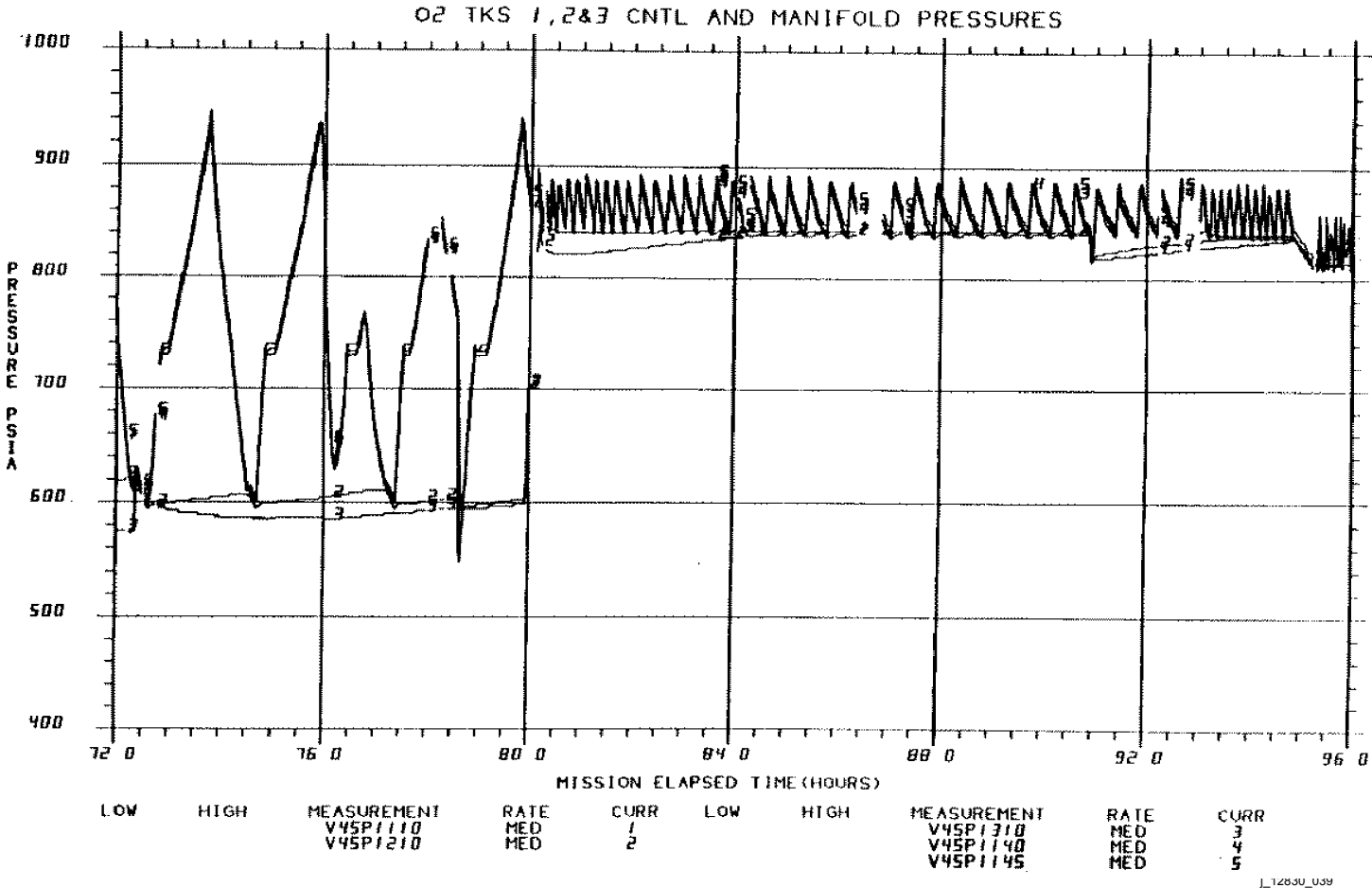
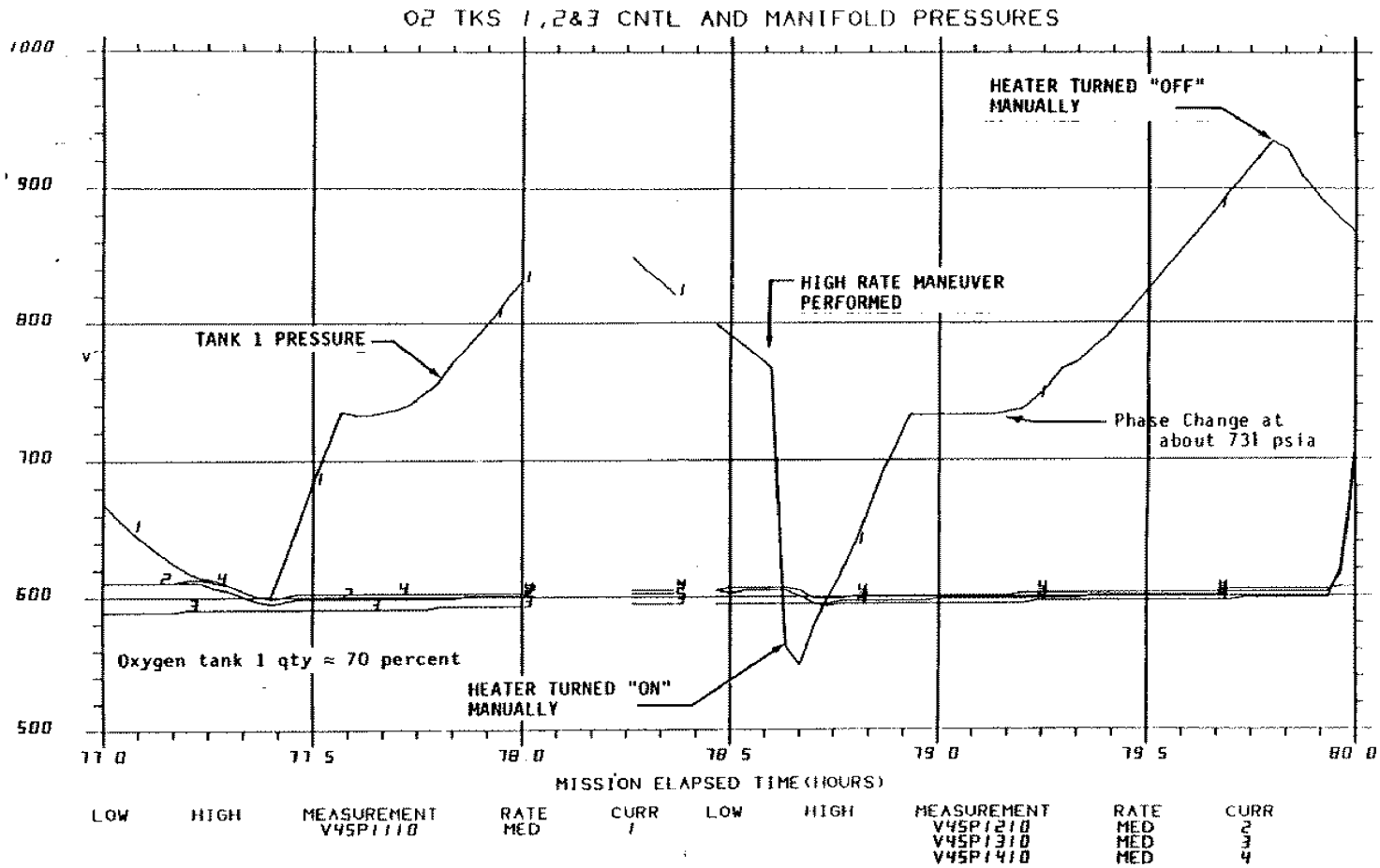


Figure 3.8-5. Manual heater management using single heaters (STS 51-D)

3.8-9

Verify that this is the correct version before use



**Figure 3.8-6. Manual heater management showing the plateau due to phase change (STS 51-D)**

3.8-10

Verify that this is the correct version before use

## TITLE

PRSD O<sub>2</sub>/H<sub>2</sub> QUANTITY MANAGEMENT WITH LOSS OF A QUANTITY SENSOR

## PURPOSE

The purpose of this SCP is to present suggested PRSD tank management schemes when the quantity sensor in a tank is lost, along with methods to estimate current quantity. Basically, the alternate tank management plans allow the console operator to more accurately infer the quantity in the tank with the failed sensor. Additional methods of estimating quantity that can be used as an effective backup or double check on the management plan are also discussed.

## DISCUSSION

There have been several anomalies on orbiter flights to date involving temporary or permanent loss of a quantity sensor reading. On other flights, quantity transducers have become erratic as the tank neared depletion. The following is a list of flights that have a documented quantity transducer anomaly:

STS-3	H2 TK 2 ( <i>EGIL post-mission report, engineering web</i> )
STS-4	H2 TK 2 ( <i>EGIL post-mission report</i> )
STS-9	O2 TK 3 ( <i>EGIL post-mission report</i> )
STS-38	H2 TK 3 ( <i>Eng Web page</i> )
STS-58	H2 TK 9 (prelaunch only) ( <i>EGIL post-mission report</i> )
STS-60	O2 TK 2 ( <i>EGIL post-mission report</i> )
STS-62	O2 TK 7 ( <i>Eng Web page</i> )
STS-66	H2 TK 4 ( <i>Eng Web page</i> )
STS-82	O2 TK 3 ( <i>EGIL Log</i> )
STS-87	H2 TK 4 ( <i>Eng Web page</i> )

Loss of a quantity sensor requires estimation of quantity in the tank with the lost sensor. Modification of the standard heater management plan may be required to increase reliability in tracking the quantity in the tank with the lost sensor.

Several methods of estimating quantity in a tank with a failed sensor are available.

- A. SOCRATES, Cryo System Pressure (CRYSP) model.
- B. Utilizing fuel cell-amp hours to hand-calculate quantity.

- C. Monitor fluid and heater temperatures to determine tank depletion.
- D. Pressure decay rates of the tank.

Each of these methods will be discussed in detail in a later section of this SCP.

### **CRYO MANAGEMENT GUIDELINES**

The following discussion is a general guideline for all flights when a tank quantity sensor has failed.

If the quantity sensor has failed in tanks 4 to 9, expedite depletion of the tank. For tanks 1 to 3, deplete the tank until nominal end of mission plus two extension days can be maintained. For single-shift missions, the ability to keep a manifold valve closed during sleep must also be taken into account.

Mission margin must also be considered when deciding how to manage the cryo. For missions with plenty of margin, it may not be necessary to expedite depletion of the tank. If the estimated tank quantity at end of mission plus 2 extension days is 30 percent or greater, with margin to spare, than the nominal cryo management plan can be followed. On the other hand, for missions with little margin, an evaluation of next worse failures will need to be done to ensure that each manifold is left with sufficient quantity to sustain itself for an emergency landing (next PLS). Although missions to date have had plenty of cryo at landing, on a cryo-tight mission that is forced to stay on orbit for the 2 mission-contingency days, cryo quantities could be extremely low and unable to sustain a manifold leak.

It is highly recommended to refer to the generic flight rules for the most current section philosophy and guidelines for cryo management.

### **PRELAUNCH QUANTITY DETERMINATION**

If the quantity transducer is failed even before the tanks have been loaded prelaunch, quantity determination can be more difficult. The tank temperature cannot be used as a reliable method because the tank is chilled down to its minimum temperature long before the tank is full. Each tank fills at a different rate, so waiting until all other tanks indicate being full does not ensure that the affected tank is full, too. In fact, once a tank is full, continuation of the filling process can cause the loss of quantity in the tank. As it turns out, when a tank approaches full quantity, there is a rise in the tank pressure. Up to that point, the pressure is fairly constant (Figure 3.9-1). Note in the figure that the rapid rise from 30 psia to >120 psia is from the hydraulic pressurization of the tanks following the fill valve closure. Following this technique, it is assumed that the tank is full; however, a 5-percent error margin can be subtracted from the assumed quantity. Boiloff rates should be assumed to be the same as experienced by the other tanks and periodically subtracted from the affected tank.

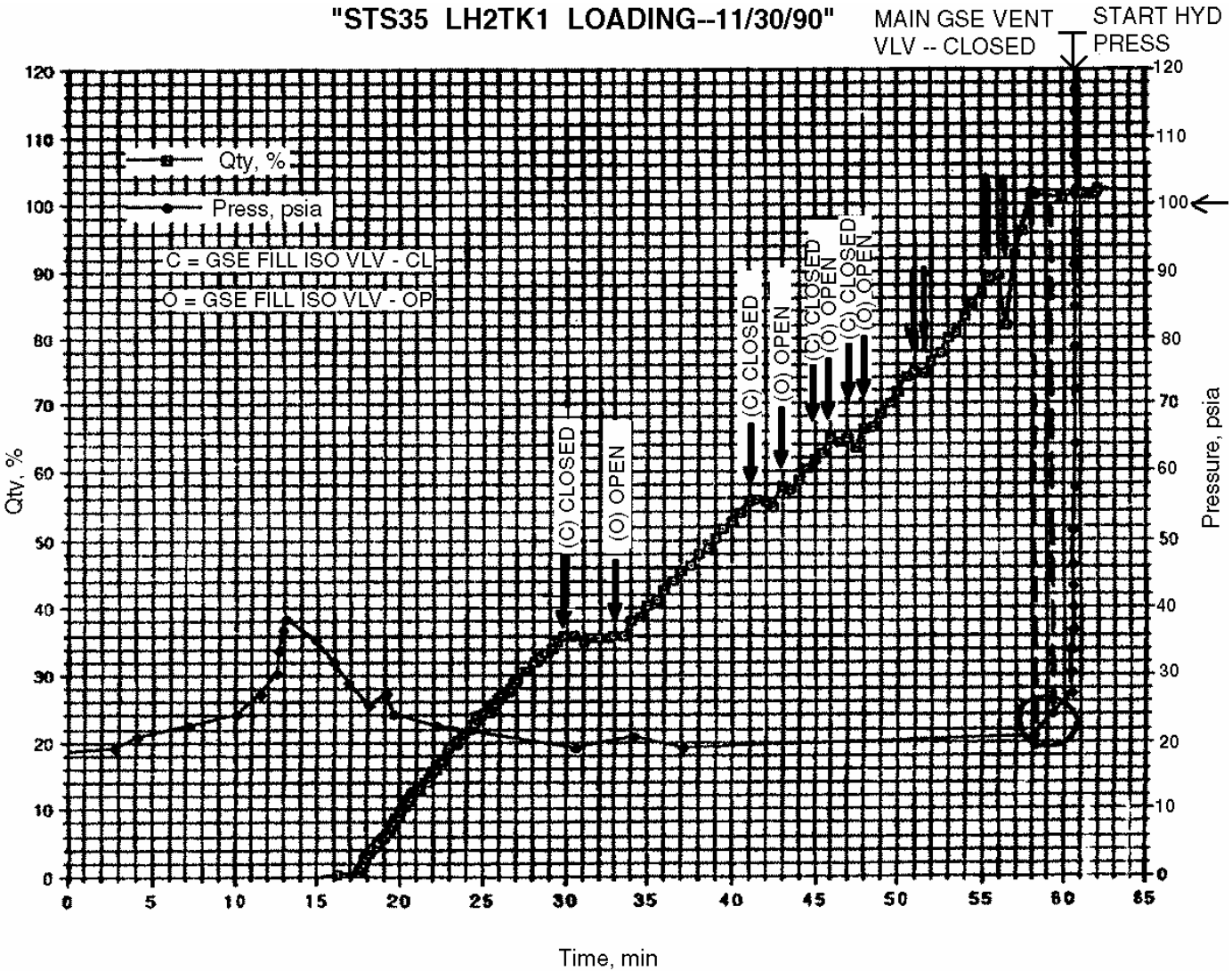


Figure 3.9-1. Tank pressure

3.9-3

Verify that this is the correct version before use.

## FOUR METHODS TO DETERMINE TANK QUANTITY

This section thoroughly discusses each option for determining tank quantity. In all the methods described below, as the tank approaches depletion (residual quantities remaining in the tank), the tank temperatures will begin to rise. When any tank fluid temperature reaches 150° F, or heater temperature reaches 250° F, the tank heaters must be deactivated.

### A. CRYSP

The most accurate method for determining tank quantity utilizes the SOCRATES program, CRYSP, to generate estimates of quantity and depletion time of the tank. The CRYSP program in SOCRATES models cryogenic usage and pressures and is utilized to develop preflight and real-time mission cryo plans. CRYSP takes into account power, environmental, and natural boiloff requirements. Tank pressure, manifold pressure, and tank quantity data can be plotted or generated in a table format.

The model will also mark the tank depletion time in the case's timeline. All the tank depletions can be found in the timeline by doing a filtered search on the keyword 'resid.' This will cause only the cryo reconfiguration points for depleted tanks to appear.

The time and last accurate quantity reading can be obtained by pulling ODRC data. The current SOCRATES case being utilized can be modified with this information by inserting a Cryo Tanks Reset event into the timeline. Five percent should be subtracted from the last known quantity for conservatism. As cryo resets are performed as the mission progresses, a '-1' should be inserted into the fields relating to the tank with the failure. (A '-1' will cause SOCRATES to ignore the data in this field.) This will cause CRYSP to calculate the tank's depletion based on the last known tank quantity. Both the EPRAC and CRYSP model should be run twice to get the most accurate picture of tank depletion time, pressure, and heater cycles. When a tank is depleted during the CRYSP run, the program will ask if heaters need to be reconfigured. The depletion time should be noted after each cryo reset and subsequent regeneration of cryo data is performed.

The flight control team should also reevaluate the case's power profile and ensure that it is as accurate as possible. Any over- or under-predictions for payload power estimates should be reflected in the timeline. This will improve the accuracy of both the tank's projected quantity and estimated time of depletion.

Figure 3.9-2 is a detailed procedure for obtaining the initial projected depletion time of a tank that has lost a quantity transducer. Please refer to the DF73 web page for the most current version.



1. Obtain the most recent time (GMT or MET) and accurate quantity reading for the tank. ODRC data is preferred, but history tab can be used, if necessary.
2. Bring up SOCRATES and the current case being utilized.
3. On the EPRAC main menu, select Edit, timeline (Fn-T).
4. After timeline comes up, select eVents, New (Ctrl-n).
5. In the New Event window, select either Cryo Tanks Reset Orbiter for tanks 1 to 5 or Cryo Tanks Reset EDO 1 for tanks 6 to 8. Press OK.
6. In the Cryo Tanks reset Orbiter window, fill in the following information, and then press INSERT:
  - a. Put in the time for the last good quantity reading.
  - b. Select GMT or MET, depending on the time point you selected.
  - c. In Comment field, designate this reset as the last quantity point for the tank. Example: Last data point for the H2 TK4 Qty (72.3%)
  - d. Insert the quantity data for the tank in lbs.
7. In the New Event window, select DONE.
8. On the TLEDIT window, select Utilities, Filter.
9. On the Event Filter window, click on Filter On.
10. Insert 'resid' in the Show all events which contain:, and click OK.
11. Highlight all the events listed. (Note: All should have 'residuals reached' in the comment column.)
12. On TLEDIT menu, select Edit and Delete.
13. When warning message, 'You are about to delete [#] event(s) from the timeline! Continue?.' Appears, click on OK. This will clean up the timeline prior to running CRYSP.
14. Save the timeline and exit the editor.
15. On the EPRAC main menu, select Run, EPRAM.

**Figure 3.9-2. SOCRATES timeline modification for loss of tank quantity sensor**

16. On the Run EPRAM Model, select Run.
17. When EPRAM has completed, on the EPRAC main menu, select Run, CRYSP.
18. On the CRYSP window, click on Detailed Output and then Click on Start.
19. Follow the preflight cryo management plan to determine heater selection as tanks deplete. Make a note of the time when the tank with the lost sensor depletes for future reference.
20. If the CRYSP model runs successfully, save the results.
21. Go back to the timeline and input a generic comment by the tanks cryo reset stating the depletion estimate.

**Figure 3.9-2. Concluded**

B. The fuel cell amp-hour method

This option hand calculates quantity depletion with a failed sensor by computing expected quantity usage based on orbiter fuel cell amp-hours consumed from the tank. The cryo consumed is directly proportional to the fuel cell amp-hours provided, regardless of the fuel cell voltage (47.5 amp-hour per lb O<sub>2</sub>, 377 amp-hour per lb H<sub>2</sub>). Therefore, it is important to use amp-hours, not kW-hours, because calculation errors may grow due to changes in the fuel cell volts. Computing quantity usage from the time of failure can also provide a time estimate of when to expect a tank to approach depletion.

First, the fuel cell amp-hours taken from the affected tank must be measured, converted to pounds of cryo consumed, and subtracted from the previously known quantity. Again, an additional 5 percent (4.6 lb H<sub>2</sub>, 39 lb O<sub>2</sub>) should be subtracted from the calculated quantity from the tank without the quantity transducer to provide some margin for error. Once the quantity measurement has been lost, fuel cell amp-hours, tank(s) feeding the fuel cells along with duration, and tank quantities should be recorded to calculate and verify the amount of cryo consumed from each tank.

Because roundoff errors can be great for calculations based upon a short time interval, a running total of the fuel cell amp-hours consumed from each tank should be maintained. This total should be based upon the fuel cell amp-hours consumed since the last time the manifolds, heater configuration, or tank pressure caused a tank to begin/end supplying cryo or supplying cryo to different fuel cells or Pressure Control System (PCS). Minimizing calculation roundoff error is also enhanced by taking data readings 4 or more hours apart. To aid the user, it is suggested that display hard copies be taken whenever the cryo management changes. History tab can also be utilized. Table 3.9-1 for H<sub>2</sub> and Table 3.9-2 for O<sub>2</sub> can be used to record required data and maintain accurate calculated quantities.

**Table 3.9-1. H<sub>2</sub> tank quantity calculation tracking sheet (example)**

MANF/TK CNTLR change	MET	FC A-HR			A-HR/TKS affected (since last TK reconfig)						H <sub>2</sub> consumed-calc			New TK qty-calc (actual)			New TK 3 qty (less 4.6 lb)	
		FC1	FC2	FC3	FC1/TK		FC2/TK		FC3/TK		TK1	TK2	TK3/4/5	TK1	TK2	TK3/4/5		
X	1/21+11	10	10	11	////	////	////	////	////	////	////	////	////	69.3	71.0	70.2	65.6	
	1/22+41	257	257	275	247	1,2	247	1,2	264	1,2	1	1	0	68.3 (68.5)	70.0 (69.8)	70.2	65.6	
	2/02+05	825	833	846	815	1,2	823	1,2	835	1,2	3.3	3.3	0	66 (66.1)	67.7 (67.3)	70.2	65.6	
					Consumed since MAN VLV 2 closed									.5	66 (66.1)	67.7 (67.3)	69.7	65.1
X	2/03+37	1090	1102	1107	1080	3	1092	2	1096	3	4.1	4.1	0	65.2 (65.3)	66.9 (66.5)	69.7	65.1	
	2/04+00	1157	1171	1175	67	3	69	2	68	3	0	0.18	0.36	65.2 (65.3)	66.7 (66.5)	69.34	64.7	
	2/04+56	1312	1331	1331	222	3	229	2	224	3	0	0.61	1.18	65.2 (65.3)	66.3 (66.1)	68.52	63.9	
	2/05+30	1412	1432	1430	322	3	330	2	323	3	0	0.87	1.71	65.2 (65.3)	66.0 (65.7)	68.0	63.4	
①		②						③				④			⑤		⑥	
① = When manifold V/V or TK P indicates TK start/stop supply cryo. ② = Time/FC amp-hr on MSK 649. ③ = Δ between present FC A-hr and FC A-hr at time of lost MANF/TK config change. ④ = H <sub>2</sub> consumed = Δ FC A-hr total per TK/377 A-hr/lbH <sub>2</sub> . ⑤ = New TK Qty = TK Qty at last TK config change - Qty consumed. ⑥ = For TK without Qty ducr, take calculated TK Qty - 4.6 lb.																		

Verify that this is the correct version before use.

3.9-7

**Table 3.9-1. H<sub>2</sub> tank quantity calculation tracking sheet (example) (concluded)**

MANF/TK CNTLR change	MET	FC A-HR			A-HR/TKS affected (since last TK reconfig)						H <sub>2</sub> consumed-calc			New TK qty-calc (actual)			New TK 3 qty (less 4.6 lb)
		FC1	FC2	FC3	FC1/TK		FC2/TK		FC3/TK		TK1	TK2	TK3/4/5	TK1	TK2	TK3/4/5	
					////	////	////	////	////	////	//////	//////	//////				

Verify that this is the correct version before use.

**Table 3.9-2. O<sub>2</sub> tank quantity calculation tracking sheet**

MANF/ TK CNTLR change	MET	FC A-HR			A-HR/TKS affected (since last TK reconfig)						H <sub>2</sub> consumed-calc			New TK qty-calc (actual)			New TK 3 qty (less 4.6 lb)
		FC1	FC2	FC3	FC1/TK		FC2/TK		FC3/TK		TK1	TK2	TK3/4/5	TK1	TK2	TK3/4/5	
					////	////	////	////	////	////	////	////	////	////	////		

\* Tank supply PCS O<sub>2</sub> must include: number of crew x 0.073 lb/hr/crew x number of hours last TK reconfig.

Verify that this is the correct version before use.

3.9-9

SHUTTLE OPS  
EGL/JSC-12830

ORIG: C. A. SWEITZER  
01/31/02: REV. F PCN-1

PRSD MGMT  
SCP 3.9

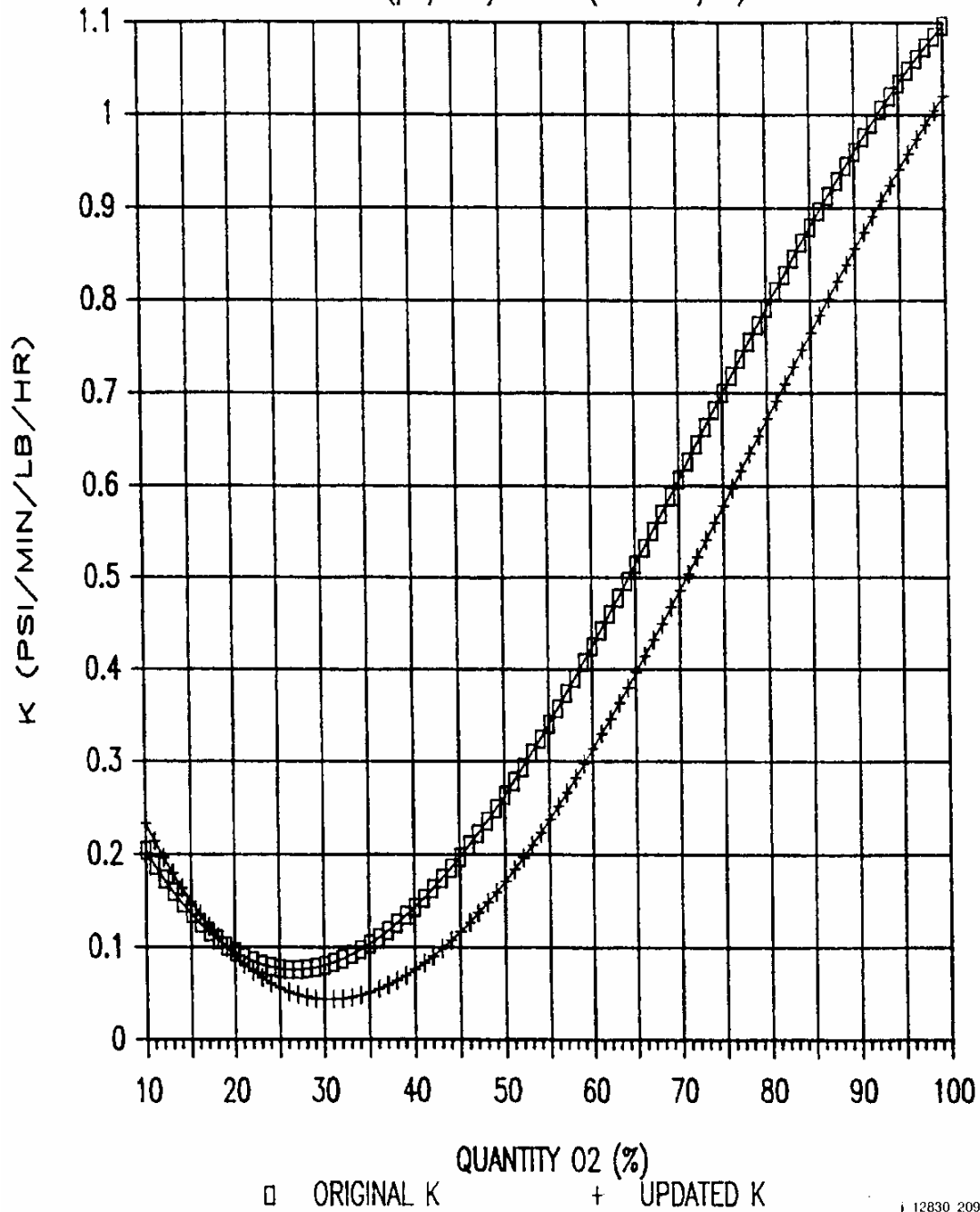
Although a tank is not being actively consumed from, it still loses quantity due to heat leak. Based on previous flight data, the H<sub>2</sub> leak rate is 0.4 percent/8 hours or 0.37 lb/8 hours. The operator can confirm this number by looking at how the tank quantities change while not actively being used. Measurements of the fuel cell amp-hours when the tank pressure indicates cryo is being consumed from the tank, as well as when the heaters have been reconfigured, should be taken. Depending upon tank pressures and quantities, it may be an hour or more before cryo is consumed from the newly selected tanks.

C. The tank pressure decay method

This method is a modification of the process normally used to detect cryo system leaks from the pressure decay cycles. Not only can it be used to determine tank quantity, but it can also be utilized for leak detection. By utilizing the pressure decay cycle of the affected tank and the cryo demand from the tank for the fuel cells and PCS (if O<sub>2</sub>), the "K" value can be calculated. Once this has been completed, the quantity can be determined by finding the corresponding quantity required by the "K" value. From this value, the quantity can be determined using Figures 3.9-3 and 3.9-4. Note that for some values of "k" two quantities can be possible; however, since the measurement times are relatively short, the user should use some common sense to know which quantity is accurate. An example of this method is demonstrated in Figure 3.9-5. This method, however, can be flawed due to stratification and destratification in the tank. Therefore, this is the least desirable method to utilize.

# K vs. QUANTITY O2 COMPARISON

$$\text{DEC (psi/min)} = K * (\text{off TK lb/hr})$$



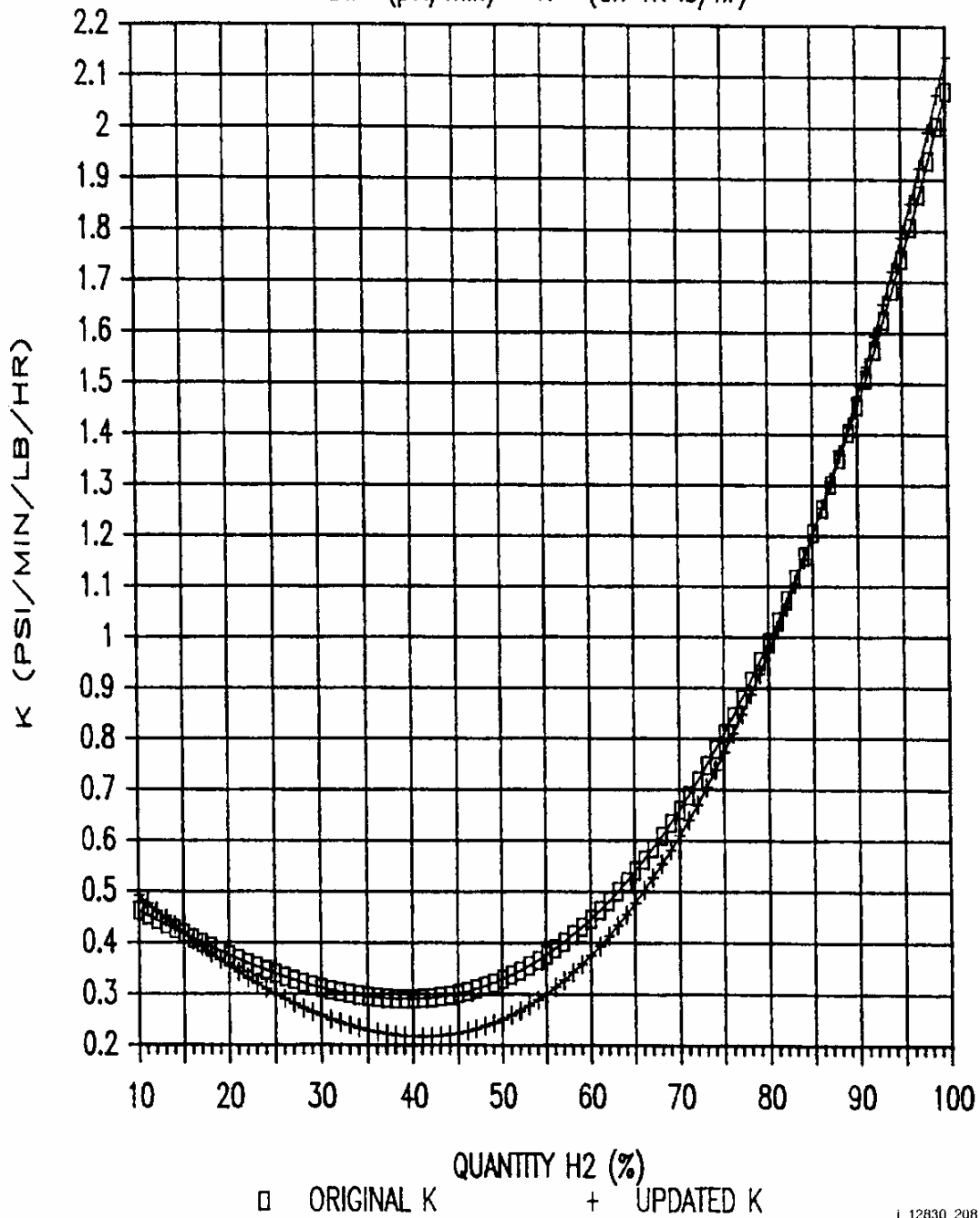
J 12830 209

Figure 3.9-3. O<sub>2</sub> K curve

Verify that this is the correct version before use

# K vs. QUANTITY H2 COMPARISON

$$\text{DEC (psi/min)} = K * (\text{off TK lb/hr})$$



12830\_208

Figure 3.9-4. H<sub>2</sub> K curve

Verify that this is the correct version before use



F/V 37/104 EGIL 2718 RR2718D CH083  
 UDRATE 30 SEC POINT 30 SITE TDR NOM=R  
 H2 TK1 TK P H2 TK2 TK P H2 TK3 TK P H2 MANF P 1  
 V45P2100A =R V45P2200A =OR V45P2300A =+R V45P2140A =ΔR  
 212.500 217.600 224.000 222.400

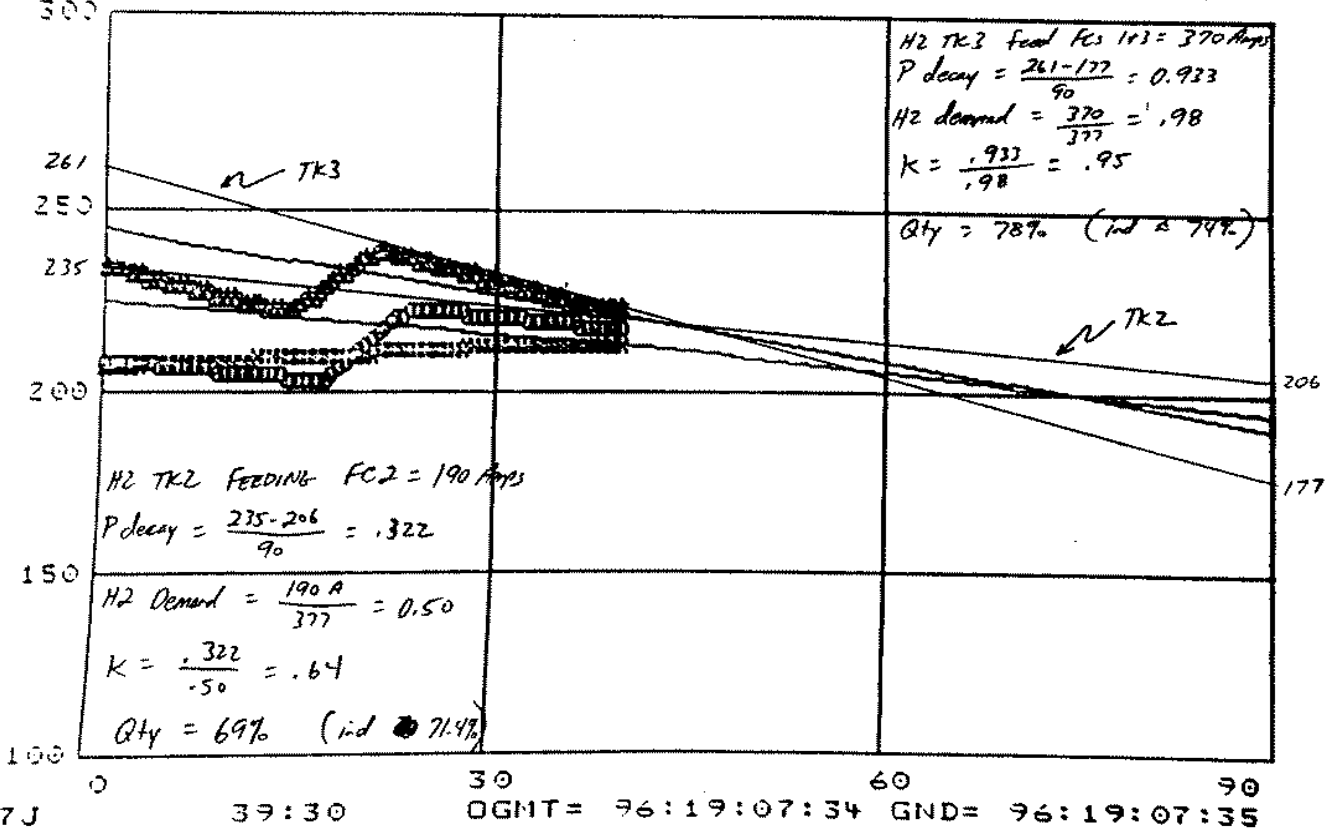


Figure 3.9-5. Quantity calculation using pressure decay

Verify that this is the correct version before use.

3.9-13

I\_12830\_048

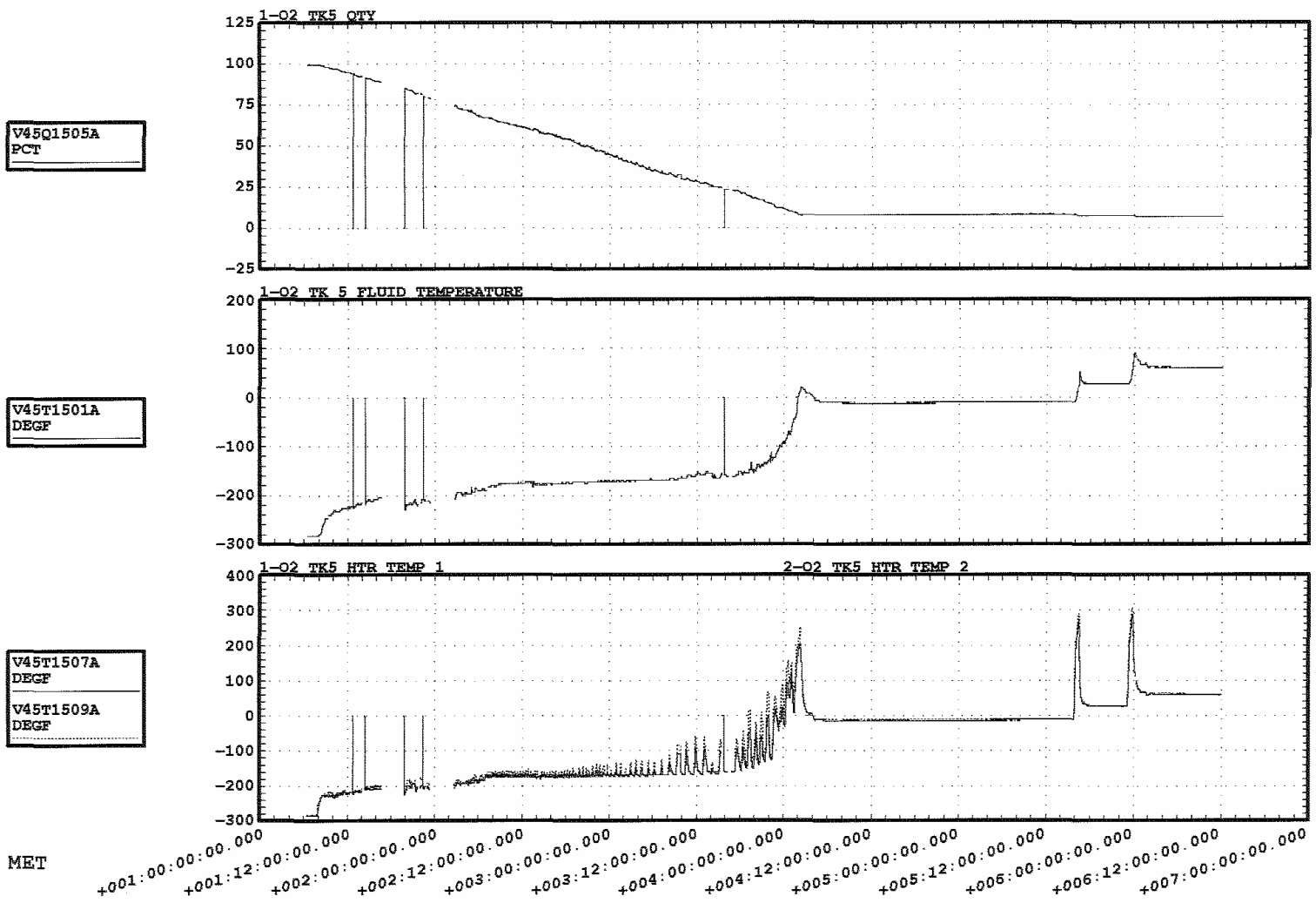
D. The tank fluid/heater temperature method

This method uses the thermodynamic properties of the fluid to infer density and, therefore, a quantity as a function of fluid bulk temperature. Figures 3.9-6 and 3.9-7 show the variation of tank quantity with bulk fluid temperature at operating pressure for oxygen and hydrogen, respectively. Because of the nature of the quantity-temperature curves, this method of quantity verification is largely ineffective over most of the quantity range, particularly in the case of hydrogen. For example, in the mid-quantity range a single bit count error of 3.5° in temperature amounts to an error in quantity for about 6 percent in the case of oxygen and over 20 percent in the case of hydrogen. A maximum allowable temperature transducer error of 45° F (+5 percent of full scale) renders this technique totally useless over most of the quantity range. It can be effective at very low quantities, however, to determine when a tank is nearing depletion.

Below about 20 percent quantity, the bulk temperature increases exponentially as the quantity decreases. In the exponential range of the curve, relatively large temperature errors can be tolerated without a significant error in inferred quantity. Heater surface temperature will also increase exponentially because of the increasing fluid bulk temperature surrounding them and the reduced heat transfer from the heater surface because of the reduced fluid density. The rapidly increasing bulk temperature and heater surface temperatures are an excellent method of monitoring operations in the low quantity region. Ultimately, high heater surface temperature becomes the criterion for deactivating oxygen heaters. In the case of hydrogen, the heater temperature does not approach over-temperature until such low quantities that the tank is essentially depleted anyway. Furthermore, the heaters are not able to keep the pressures up in the tank. Figures 3.9-8 and 3.9-9 show heater surface temperatures and fluid bulk temperatures for oxygen and hydrogen as the tanks near depletion.

This method is by far the easiest to use; however, as mentioned earlier, it is far less accurate than the other methods until the tank quantities are low. To implement this method, use the temperature of the fluid or heater in the tank, preferably just prior to a heater cycle to allow maximum heat dispersion from the previous heater cycle, and see Figures 3.9-8 and 3.9-9 to find the tank quantity for O<sub>2</sub> and H<sub>2</sub>.

O2 TK5 QUANTITY VERSUS TEMPERATURE	M E W S	SAMPLE RATE: 120 (sec/sample)	Subsystem: egil
	FORMAT: O2TK5QTY TEMP	DATA: MASTER	Flight: STS-095



V45Q1505A  
 PCT

V45T1501A  
 DEGF

V45T1507A  
 DEGF  
 V45T1509A  
 DEGF

Figure 3.9-6. O<sub>2</sub> tank quantity vs. temperature

3.9-15

Verify that this is the correct version before use.

H2 TK 5 QUANTITY VERSUS TEMPERATURE	M E W S	SAMPLE RATE: 120 (sec/sample)	Subsystem: egil
	FORMAT: H2 TK5_Q_VS_T	DATA: MASTER.091	Flight: STS-091

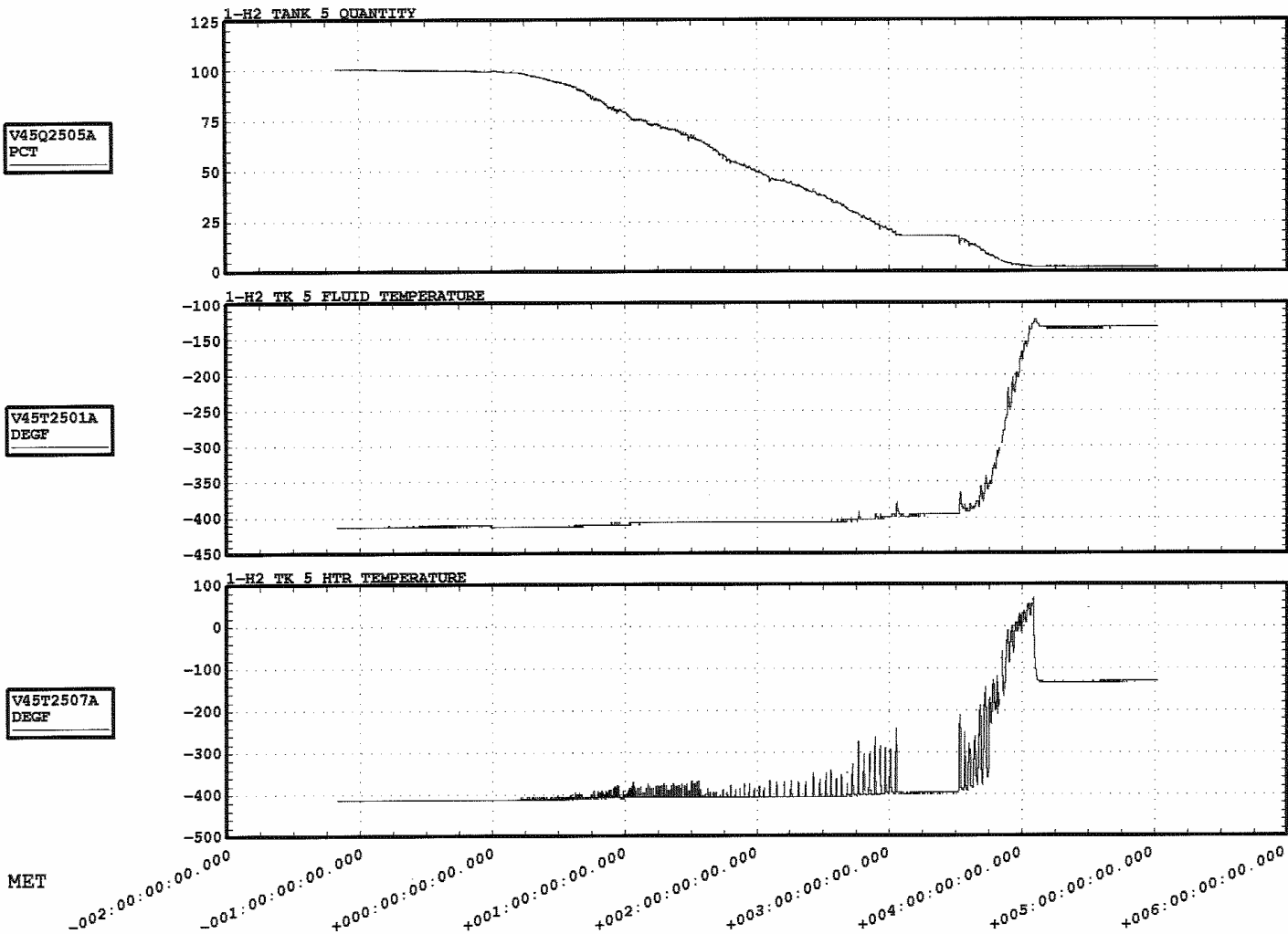


Figure 3.9-7. H<sub>2</sub> tank quantity vs. temperature

Verify that this is the correct version before use.

3.9-16

O2 TK5 QUANTITY VERSUS TEMPERATURE	M E W S	SAMPLE RATE: 120 (sec/sample)	Subsystem: egil
	FORMAT: O2TK5QTY_TEMP	DATA: MASTER	Flight: STS-095

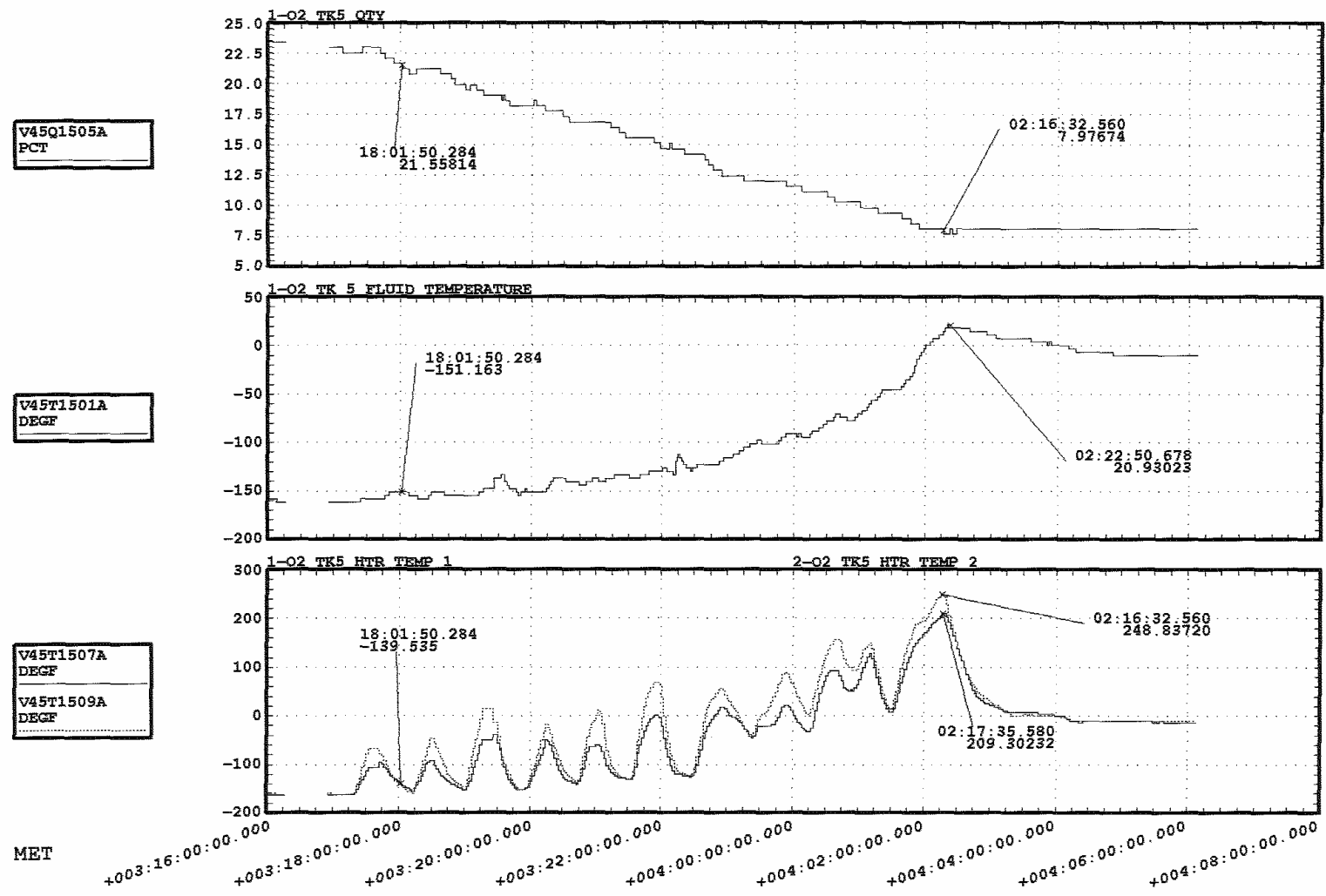
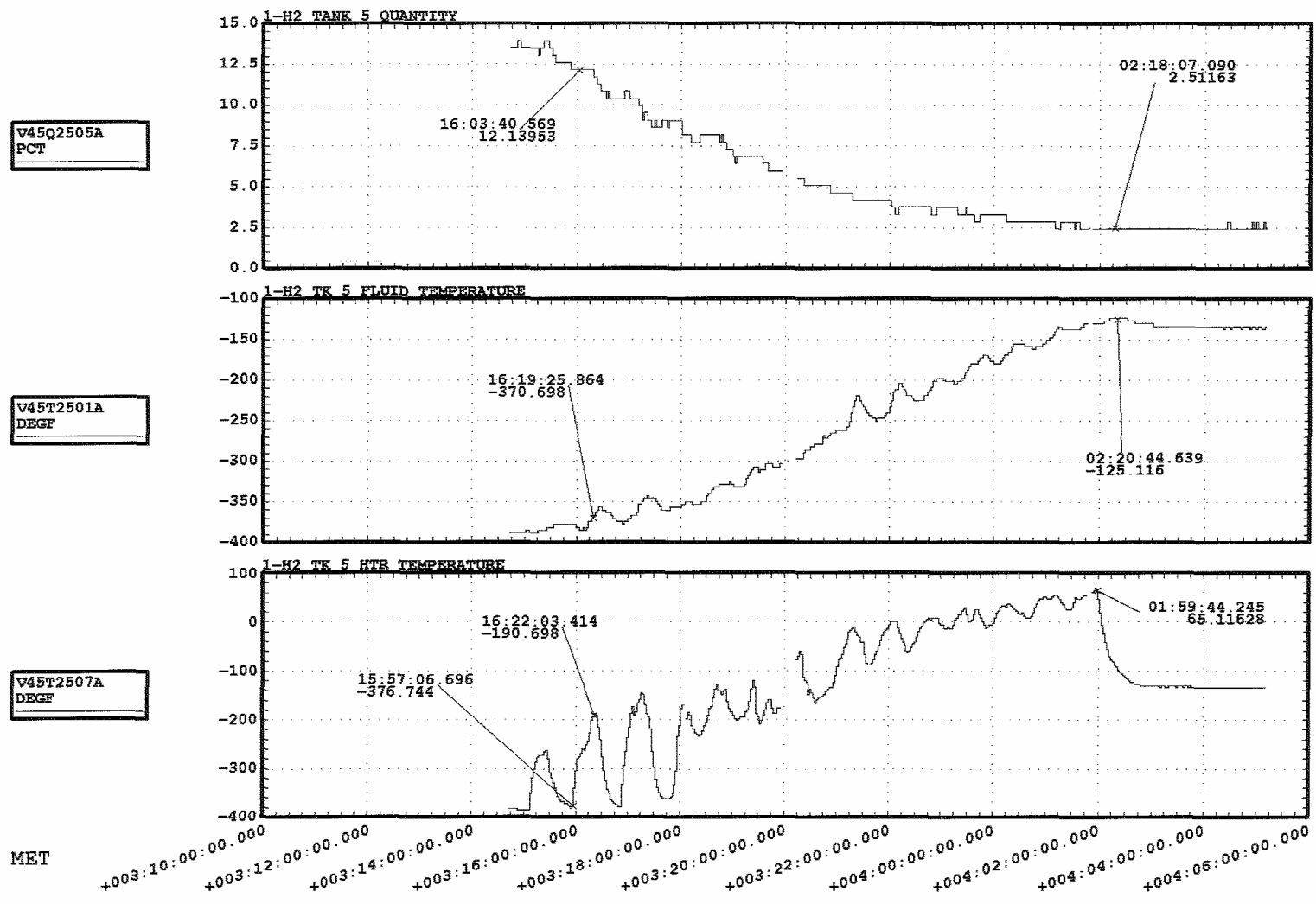


Figure 3.9-8. O<sub>2</sub> tank depletion, temperature vs. quantity

Verify that this is the correct version before use.

3.9-17

H2 TK 5 QUANTITY VERSUS TEMPERATURE	M E W S	SAMPLE RATE: 120 (sec/sample)	Subsystem: egil
	FORMAT: H2 TK5 Q VS T	DATA: MASTER.091	Flight: STS-091



V45Q2505A  
PCT

V45T2501A  
DEGF

V45T2507A  
DEGF

MET

Figure 3.9-9. H<sub>2</sub> tank depletion, temperature vs. quantity

Verify that this is the correct version before use.

3.9-18

## TITLE

NON-STANDARDIZED CRYO HEATER MANAGEMENT FOR ORBIT

## PURPOSE

The purpose of this SCP is to familiarize the flight controller with the method on how to modify the predicted cryo management plan after a single heater on an O<sub>2</sub> or H<sub>2</sub> tank has failed.

## INTRODUCTION

A number of failure modes exist which can cause an O<sub>2</sub> or H<sub>2</sub> heater to fail. The failure of a single O<sub>2</sub> or H<sub>2</sub> heater exposes the tank to a ZFT condition. The loss of both heaters in a tank would result in the inability to extract the remaining cryo from the tank. The impact of losing a cryo tank is mission dependent, depending on cryo consumables margin, and could result in a shortened mission.

A cryo heater that is defined as lost will be deactivated by placing the affected heater in the OFF position. The cryo management plan will be modified to expedite the depletion of the affected tank until nominal end of mission plus two extension days can be supported. The tank will be depleted by using the remaining good heater. For specific cases, see the guidelines described later in the SCP.

## BACKGROUND

The failure of an H<sub>2</sub> or O<sub>2</sub> tank heater exposes the tank to a single heater failure that could cause loss of the tank, possibly resulting in a shortened mission depending on current consumables margin. The tank would be lost due to the inability to extract cryo from the affected tank. A number of failure modes exist which can cause the remaining heater assembly to fail.

A cryo heater is defined lost when the heater temperature cannot be maintained below 350° (O<sub>2</sub>), 200° (H<sub>2</sub>), an O<sub>2</sub> current sensor trips while the heater is receiving power, or both current sensors to the heater are lost (reference Flight Rule A9-204). A cryo heater that is defined as lost will be deactivated by placing its corresponding switch in the "OFF" position (reference Flight Rule A9-252:D). If possible, cryo management will be modified to expedite depletion of the affected tank until nominal mission duration plus two extension days can be accomplished.

Tank management guidelines for tanks 3-5, tank 3 of a three-tank set mission, and tanks 1 & 2 are discussed in the following section.

## GUIDELINES

The following guidelines should be implemented after a single heater assembly of O<sub>2</sub> or H<sub>2</sub> fails. Reference Flight Rule A9-252 Cryo Heater Management for Orbit. Remember the next worst failure would result in the loss of the tank.

1. Failure occurs in tank 3-5: If more than three tank sets flown, then the affected tank will be immediately depleted to the point that the nominal end of mission plus two extension days can be supported.
2. Failure occurs in tank 3 (three-tank mission only): Tank 3 depleted until nominal end of mission plus two extension days can be supported, or until a minimum quantity is reached that will support its associated fuel cell/main (FC/MN) bus in a next PLS situation.
3. Failure occurs in tank 1 or 2:
  - a. Maintain minimum quantity to guarantee usage to support its associated FC/MN bus for a next PLS in the event that its manifold becomes isolated.
  - b. Maintain minimum quantity which will allow closure of one manifold valve during crew sleep for the nominal mission duration plus two extension days, if required. If tank 1 or 2 is the affected tank, if possible its associated manifold valve will not be closed for sleep periods.
  - c. Deplete affected tank until the quantity remaining in the tank can support nominal end of mission plus two extension days.

#### PROCEDURE

1. Establish a new "redline" for the affected tank (O<sub>2</sub> or H<sub>2</sub>). The new redline is essentially the margin over and above the requirement for a nominal mission duration plus two extension days. It also includes the residual quantity and the measurement uncertainty of the affected tank. The redline is not constant since it assumes that we may have to power down to save consumables.
2. Use the affected tank as quickly as possible until the quantity reaches below the new redline.
3. Establish a modified cryo management plan to keep the affected tank as close to the redline as possible.
4. Utilize SOCRATES to update the margins (PCM - projected consumables margin). SOCRATES can be used (real time) to input a leak or heater string failure that will affect the margin. Once changes in the timeline have been made, a PCM form can be generated that will reflect the changes in the margin.

#### Example: STS-43 (OV-104)

During STS-43, H<sub>2</sub> tank 1, heater B failed off. This failure caused change in the normal heater management plan for the flight. All variables required for the analysis are listed as follows:



Variables

Number of tanks = 4

H<sub>2</sub> margin = 23 lbm (per PCM)

Tank 1 residual = 4% of tank quantity

Measurement uncertainty = [100% tank quantity \* 2.6 \* SQR (number of tanks)]/100

Group B powerdown = 2 kW

End of mission (EOM) = 215 hr

Deorbit prep time = 4 hr

Mission elapsed time (MET) of the failure = 57 hr

Calculation of H<sub>2</sub> tank 1 Redline:

One major factor that needs to be considered is to maximize the CRYO H<sub>2</sub> quantity in the affected tank. The reason for this is to reduce the time of the tank depletion which, in turn, reduces the risk of losing the tank. This quantity is utilized to support FC1/MNA bus for next PLS in the event that the manifold becomes isolated.

To calculate the maximum quantity of H<sub>2</sub> in the affected tank, add the H<sub>2</sub> margin available, the residual of the affected tank, the measurement uncertainty, and the projected 2 kW of the group B powerdown, if the remaining heater fails (loss of tank).

$$[23 \text{ lb (margin)} + (4\% * 92 \text{ lbm (residual)}) + (\text{measurement uncertainty all tanks} - \text{measurement uncertainty of unaffected tanks})] = \underline{29.1 \text{ lbm}}$$

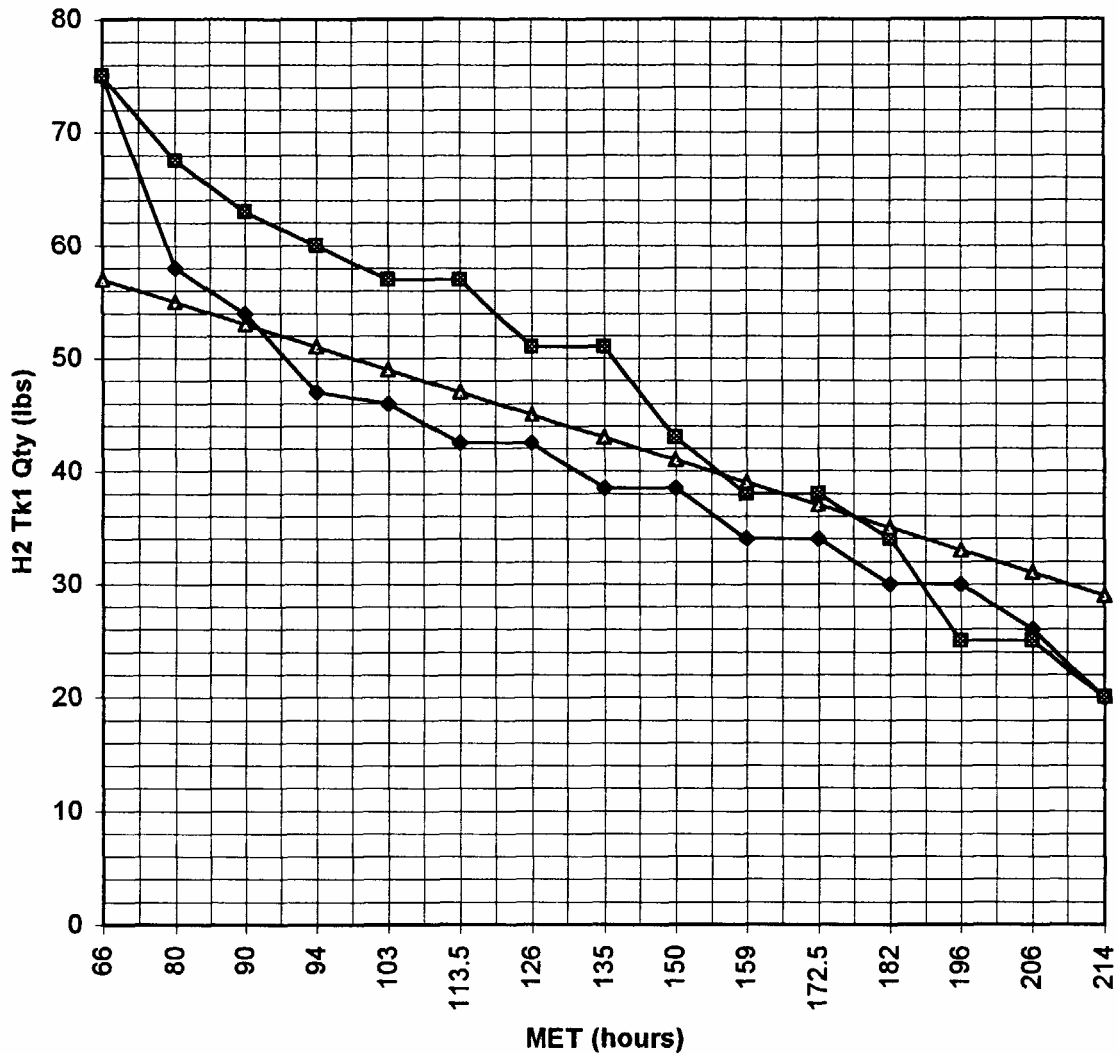
To calculate the amount of cryo that would be saved using the powerdown after the second heater assembly failure in tank 1, use the following equation:

$$[(2 \text{ kW (pwr)} * 0.0867 \text{ lb/kW-hr (H}_2 \text{ usage factor)}) * [215 \text{ hr (EOM)} - 4 \text{ hr (D/O prep time)} - 57 \text{ hr (MET)})] = \underline{26.7 \text{ lbm}}$$

So, at MET 57 hr the powerdown would save an additional 26.7 lbm of H<sub>2</sub>, and at 215 hr the powerdown would save zero lbm of H<sub>2</sub>. Now add the total quantities that have been calculated above to maximize the total quantity of H<sub>2</sub> in the affected tank.

$$29.1 \text{ lbm} + 26.7 \text{ lbm} = \underline{55.8 \text{ lbm}} \text{ (maximum quantity of H}_2\text{)}$$

Figure 3.10-1 illustrates the modified H<sub>2</sub> tank 1 quantity management plan.



- ◆ Modified H<sub>2</sub> Tk1 quantity management plan (lb)
- Permission quantity management plan
- △ H<sub>2</sub> Tk1 maximum quantity that maintains a 9+2 capability if tank lost.  
(Also assumes a Group B Pwrdrn for a 2.0 kW power savings.)

**Figure 3.10-1. Modified H<sub>2</sub> tank 1 quantity management plan**

## TITLE

### TIG CONSUMABLES AND QUANTITIES

#### Determination of estimated cryo quantities at deorbit burn Time of Ignition (TIG)

## PURPOSE

On each flight day, EGIL/EPS is asked to provide the Flight Dynamics Officer (FDO) mass properties that are a real-time update of the estimated cryogenic O<sub>2</sub> and H<sub>2</sub> tank quantities at the time of a given deorbit burn (TIG = 0). The deorbit burn is typically the burn time required to provide the primary landing for the next day. These quantities are used by the FDO to refine the vehicle mass properties and the center of gravity location on the vehicle used in flight dynamics calculations, which are required for vehicle entry. The purpose of this SCP is to discuss methods used to obtain the cryo mass properties, factors affecting these values, and to explain the process by which the data is delivered to the FDO.

## BACKGROUND

The fuel cell's consumption of O<sub>2</sub> and H<sub>2</sub> over time is a function of the average power over that time interval. Crew metabolic consumption, vehicle leak rates, and volume represses also affect the amount of O<sub>2</sub> consumed. The configuration of both the cryo system and the Pressure Control System (PCS) will determine from which tanks the cryo is being consumed. Refer to SSSH drawing 3.1 for a cryo system overview.

The SOCRATES preflight analysis provides a mission power profile that is used to predict the fuel cell power requirements and the configuration of the cryo system during the mission. The SOCRATES software provides the EGIL/EPS flight controller with the necessary tools to determine the mass properties for any time requested by FDO. For missions on which the preflight predicted power levels significantly differ from the actual power levels (>500 watts) a daily cryo reset is required to ensure that the SOCRATES profile is updated with actual cryo tank quantities. The cryo reset will ensure that the values provided to the FDO are up to date.

## MASS PROPERTIES

When EGIL mass properties are requested for a given TIG time by the FDO, the EGIL/EPS flight controller is required to provide the estimated O<sub>2</sub> and H<sub>2</sub> quantities in pounds for all the cryo tanks at that specific time. From the MCC workstations on the Display Navigation (DNAV) menu, the controller should select Shuttle: FDO: Paperless Mass Properties: EGIL Mass Properties. This will launch the spreadsheet application where the tank quantities should be recorded. The first row of the spreadsheet contains the various TIG times for the mission; quantities are entered in the column below the requested time.

The EPRAC software application is used to obtain the desired tank quantities. A cryo reset should always be done to ensure that values obtained are the most recent. Select

the mass properties icon from the tool bar or from the output menu to retrieve the data. Enter the correct MET or Greenwich Mean Time (GMT) into the time slot and select the retrieve button; the tank quantities will be updated for the time selected. The cryo quantities are then entered into the spreadsheet. The values entered should always be double checked and then verified using the O<sub>2</sub> and H<sub>2</sub> total quantities listed at the bottom. After the spreadsheet has been updated, it is saved and the FDO is informed that the mass properties are complete.

### COMPUTATION PROCEDURE

Configuration changes in the cryo system will change the O<sub>2</sub>/H<sub>2</sub> tanks that are being utilized to supply the fuel cell demand. When hand calculating the mass properties, it is necessary to divide the mission average power into configuration periods. The average power should be estimated for each configuration period. A configuration period is defined to begin when the manifold values are operated or when cryo heaters are either activated or deactivated and ends when the next switch throw occurs. The energy for each period is determined in kilowatt-hours (kWh); the time in each configuration is multiplied by the average power level for that time period.

Tabulate the number of kWh each tank contributes for each of the configuration periods. Consider the tanks that are active (in AUTO) and the number of fuel cells they are supplying, based on the manifold valve configuration. Use the conversion factors from the preflight analysis O<sub>2</sub>/H<sub>2</sub> budget tables to convert the energy (kWh) used into pounds required. If the flight-specific values are not available, default values of 0.695 lbm/kWh for O<sub>2</sub> and 0.0875 lbm/kWh are sufficiently conservative and commonly used for console analysis.

Calculate the additional O<sub>2</sub> metabolic and cabin leak usage by multiplying the combined rates found on the preflight budget table by the configuration time period. If both PCS valves are open, assume that they each supplied one-half the required O<sub>2</sub>. If the usage rates are not available, use 0.07 lb/hr/crew and 0.08 lb/hr cabin leak.

Subtracting the calculated total usage in each tank from the current time to the required TIG time for both H<sub>2</sub> and O<sub>2</sub> tanks yields the TIG quantities. These values are then entered into the spreadsheet under the appropriate column and row, and FDO is notified that the mass properties have been updated.

## TITLE

PRSD OFFLOADING GUIDELINES AND CONSIDERATIONS

## PURPOSE

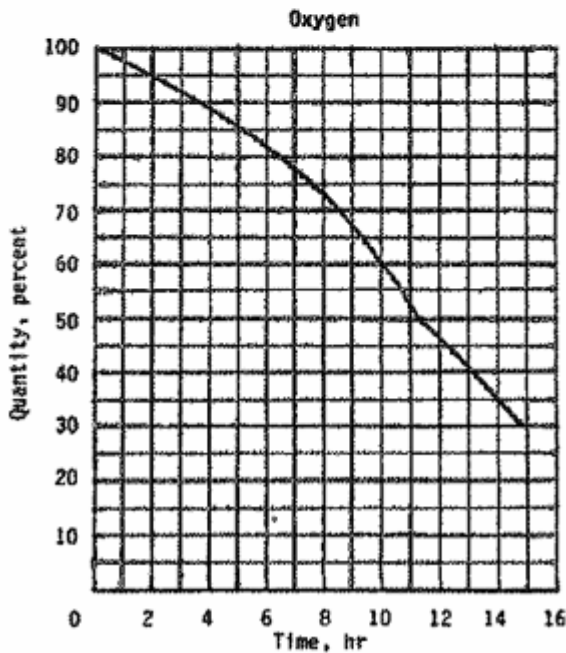
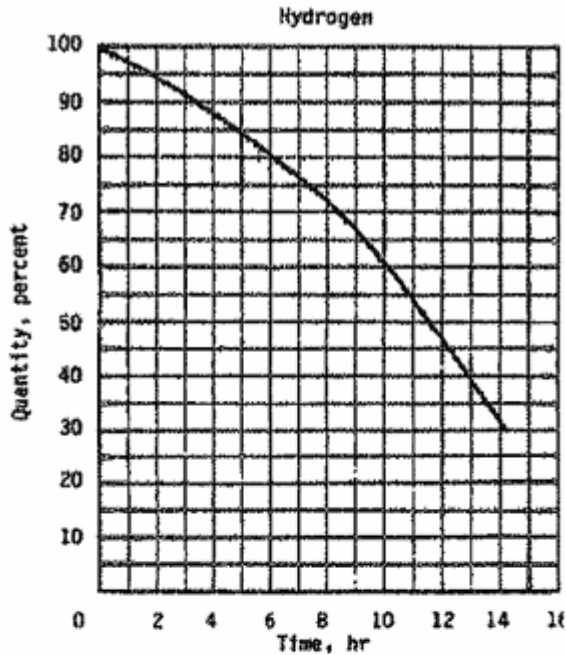
The purpose of this SCP is to present and discuss guidelines and constraints that apply to planning an offloaded Power Reactant Storage and Distribution (PRSD) system configuration.

## BACKGROUND AND CONSTRAINTS

The PRSD tanks can be offloaded (loaded to less than capacity) when the fully loaded tank capacity is not required to achieve planned mission duration, and there are other reasons for reducing total vehicle weight. The other reasons typically include negative or marginal ascent performance, excess abort landing weight, abort center of gravity management, or a combination of these. Offloading was even considered once for EOM c.g. management, but that is not considered a viable reason for offloading. Offloading is an acceptable method of solving some performance problems and will undoubtedly be utilized for that purpose many times in the future. There are, however, certain guidelines and criteria that should be observed when planning an offloaded configuration. The principal constraining factors around which the guidelines have evolved are (1) Kennedy Space Center (KSC) timeline impact and (2) tank structural integrity and lifetime.

- A. KSC timeline impact - The PRSD offloading is performed by loading all tanks full, pressurizing to normal operating pressures, and then offloading, as required, by turning on the tank heaters to boil off reactant to the desired level. This method is used because of the design of the quantity gauges. The gauges are capacitance-type gauges that must be fully immersed for predictable accuracy. Where tanks are only partially filled at ambient pressure, the indicated quantity can be highly inaccurate. Also, hydraulic pressurization requires that the tanks be full. Figure 3.12-1 shows the time required to offload O<sub>2</sub> and H<sub>2</sub> tanks using this method.

Safety requirements at KSC preclude conducting certain other activities in parallel with cryogenic loading or offloading. Therefore, time that is required for offloading delays other activities that could be taking place. KSC has determined that they can absorb about 10 hours of offloading without significantly restructuring their launch preparation timeline. As shown by Figure 3.12-1, in 10 hours of offloading, tank quantities can be reduced to about 60 percent; i.e., an offload of 40 percent. Any number of tanks can be offloaded simultaneously. Any situation that may require an offload of more than 40 percent should be coordinated with KSC well in advance. However, the general rule is that offloading should not exceed 40 percent per tank unless absolutely necessary.



L12830\_220

**Figure 3.12-1. PRSD tank offloading times using tank heaters**

- B. Tank structural integrity and lifetime - Launch vibrations induced on the cantilevered heater and quantity probes are normally dampened by the surrounding fluid. For oxygen, a fluid with a density of at least 30 percent of the maximum fill density is required to provide adequate dampening. For hydrogen,

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200 psia ambient temperature gas is sufficient (approximately 2 percent tank quantity). Although a tank can be flown at these reduced quantities, it is still put through extra stress. For this reason, a tank can be offloaded no more than 25 times in its useful lifetime of 125 flights. A tank is considered to be offloaded if it is launched with a quantity of <90 percent.

C. Offload guidelines

1. Oxygen tank quantities must be >30 percent at lift-off.
2. Tank offloads of >40 percent (60 percent indicated quantity) should be avoided. If necessary, advance coordination with KSC is required.
3. Hydrogen tanks will not normally be offloaded because of the small reduction in weight. However, if weight reduction is required, flying empty hydrogen tanks may be considered.
4. Normal offloads will consist of equal amounts from tanks 1 and 2.

D. Stratification/destratification effects

Offloading results in significant stratification during and following the offloading procedure. The stratification typically persists until launch. The operator should be prepared for the destratification phenomena, which then occur in the offloaded tanks following MECO. These are discussed in detail in SB 4.10.

E. Effect of offloading on center of gravity location

The mass properties group did an analysis at one time that indicated the following approximate values for c. g. movement due to offloading (or managing a quantity differential between tank sets). A positive value indicates c.g. movement in the aft (-x) direction.

- O2 Tank 1 = +0.13 inch per 100 lb offloaded
- O2 Tank 2 = +0.16 inch per 100 lb offloaded
- O2 Tank 3 = -0.003 inch per 100 lb offloaded
- O2 Tank 4 = +0.016 inch per 100 lb offloaded

## TITLE

MANIFOLD VALVE TEST FOR DUAL-SHIFT MISSIONS

## PURPOSE

This brief describes the requirement and the operations required to test the PRSD O<sub>2</sub> and H<sub>2</sub> manifold valves for a dual-shift shuttle mission.

The shuttle requirement, OMRS V45DAO.030, states that manifold valve operation will be verified once per flow. Typically, this requirement is satisfied with the normal on-orbit operations of the Power Reactant Storage and Distribution (PRSD) systems. For a single-shift mission, the manifold valves (either 1 or 2) are required to be closed for crew sleep. Alternating between manifold valves one and two, per the standard cryo tank management plan, will verify manifold valve performance throughout the mission. However, for dual-shift missions, the manifold valves are not required to be closed because there is a crewmember awake at all times. This is why the manifold valve test must be performed on dual-shift missions.

The test is scheduled near End of Mission (EOM) to preclude a failed-closed valve (failed closed during the test) from impacting mission duration.

## PROCEDURE

For reference, a sample flight note for this procedure has been included (Figure 3.13-1). This default flight note is located in the "S:\Divisions\Private\DF73\Egl\_aids" folder. For dual-shift missions, we will schedule three parts (1, 2, and 3) for one crewmember at 2-hour intervals. The default flight note assumes that the current (pretest) cryo configuration is O<sub>2</sub>/H<sub>2</sub> tanks 1, 2, and 3 in Auto (just the A heaters for the O<sub>2</sub> side), with both manifolds open. As you can see from part 1, we reconfigure to close manifold valve 1 for both O<sub>2</sub> and H<sub>2</sub>. With the manifold valve closed, we will be monitoring the manifold and tank pressures on both sides of the closed valve to verify a good closed manifold. The 2-hour interval is typically the time required to adequately verify the performance of the manifold valves. For typical EOM quantities, the ON/OFF tank pressure cycles can be greater than 1 hour. If enough data are collected to satisfy the manifold valve performance prior to the 2-hour interval, a call can be made to reconfigure to the other manifold or to the nominal orbit configuration for completion of the test. The test can be incorporated into either the postsleep or the presleep activity for convenience (not entry-day postsleep). The default flight note can be modified to accommodate the current (pretest) cryo configuration or the ending (i.e., presleep) cryo configuration. Exact steps will be submitted via flight note for inclusion in an uplink message or read up by the Capsule Communicator (CAPCOM). For scheduling purposes, each part will take about 5 minutes of crew time.



MCC FLIGHT NOTE

Vehicle ID: OV 103      Flight ID: STS-96      Date: 05/31/01      Time: 0/03:22 MET  
TO: FLIGHT/FAO/CAPCOM      FROM: EGIL  
Flight Note Title: Cryo Manifold Valve Test  
Status: Open      Revision:      Action Req by: 0/07:22 Vehicle ID: OV ISS

Update To?    Update Title?    Update Status?    Revise Note?    Action Chg?

- 1 The following Cryo Manifold Valve Test procedure is required to verify the operation of the H2/O2
- 2 manifold valves:
- 3
- 4 Part 1: (At approx. xxx/yy:zz MET)
- 5
- 6 **R1 CRYO O2 TANK 2 HTR A - OFF**
- 7 **H2 TANK 2 HTRS A, B (two) - OFF**
- 8 **O2,H2 MANF VLV TANK1 (two) - CL (tb - CL)**
- 9
- 10 Wait approximately 2 hours to verify the performance of the tank 1 manifold valves or on MCC call
- 11 perform part 2.
- 12
- 13 Part 2: (At approx. xxx/yy:zz MET)
- 14
- 15 **R1 CRYO O2,H2 MANF VLV TANK 1 (two) - OP (tb - OP)**
- 16 **O2 TANK 2 HTR A - AUTO**
- 17 **H2 TANK 2 HTRS A, B (two) - AUTO**
- 18 **O2 TANK 1 HTR A - OFF**
- 19 **H2 TANK 1 HTRS A, B (two) - OFF**
- 20 **O2, H2 MANF VLV TANK 2 (two) - CL (tb - CL)**
- 21
- 22 Wait approximately 2 hours to verify the performance of the tank 2 manifold valves or on MCC call
- 23 perform part 3.
- 24
- 25 Part 3: (At approx. xxx/yy:zz MET)
- 26
- 27 **R1 CRYO O2, H2 MANF VLV TANK 2 (two) - OP (tb - OP)**
- 28 **O2 TANK 1 HTR A - AUTO**
- 29 **H2 TANK 1 HTRS A, B (two) - AUTO**
- 30
- 31
- 32
- 33
- 34
- 35 EPS/G. Peck
- 36 MET – XXX/XX:XX
- 37
- 38

Figure 3.13-1. MCC Flight Note

Verify that this is the correct version before use

## TITLE

POWER AND MISSION DURATION ANALYSIS

## PURPOSE

The purpose of this SCP is to present the two basic methods used for performing mission duration analysis. The first method applies a set of two basic equations to determine either (1) the possible mission duration based upon a given power level or (2) the average power level that will satisfy a given mission duration. The second method will utilize the flight model created in the EPRAC/EPRAM software application.

## REFERENCES

Shuttle Operational Data Book (SODB), JSC-08934, Volume 1, Rev. F, Aug. 1995, Sections 4.4.1.3 and 4.4.1.4.

## DISCUSSION

The electrical power systems console operator is often asked during simulations and missions to provide either the projected cryogenic consumables margin available in terms of time at projected power levels or possibly the maximum average power level that will allow the cryogenic consumables to reach EOM. This SCP will provide a standardized set of equations for determining the impact that the consumables have on each of these factors, as well as a brief discussion on the software application that is currently used on console to determine the PCM. For detailed information on the use of EPRAC/EPRAM, consult the application users guide.

The equations used for both mission duration and power level analysis are derived from the chemical equations used to explain the reaction that is occurring inside the fuel cell power plant. The power supplied by a fuel cell is measured in kilowatts and is the product of the current supplied by the fuel cell and the voltage level at which the current is supplied ( $P = VI$ ). The amount of hydrogen and oxygen required to produce a given amount of current, which is measured in amperes, is always constant. The voltage magnitude  $V$ , at which this current is supplied, depends upon electrical losses that are present within the electrical system. A fuel cell's losses will continually increase throughout its life; this is reflected in the voltage degradation of the fuel cell. When determining the amount of hydrogen and oxygen required to provide a given amount of energy (kWh), a conversion factor is used based on the fuel cell voltage degradation.

The conversion factor was developed for easy hand calculations of cryo usage. The conversion factor is a function of power demand on the fuel cells and the life of the fuel cells; a fuel cell's  $V-I$  characteristics are not linear. For quick-look analysis, the values 0.0875 lbm  $H_2$ /kWh and 0.695 lbm  $O_2$ /kWh are sufficiently conservative and commonly used for console analysis. The Shuttle Operations Data Book (SODB) states that the  $H_2$  consumed by a fuel cell is 0.002653 lbm/amp-hr (376.9 amp-hr/lbm), and the  $O_2$  consumed is 0.02106 lbm/amp-hr (47.5 amp-hr/lbm). As the power demand on a fuel cell increases, the current (amps) increases, causing more  $O_2/H_2$  to be consumed. A

newer fuel cell has a better V-I characteristic. Therefore, it will consume less O<sub>2</sub>/H<sub>2</sub> to deliver the same amount of power to a constant power load; it will supply more power to a resistive-type load.

A study was done by M. Shepard from the McDonnell Douglas Aeronautics Company (MDAC) (2/13/85) which approximated beginning-of-life fuel cell and end-of-life fuel cell H<sub>2</sub> consumption curves. In addition, an average fuel cell V-I performance characteristic and corresponding consumption curve was developed from the new and Launch Commit Criteria (LCC) fuel cell V-I curves. The study compared these three consumption curves to the maximum consumption curves provided in the SODB (ref. 1). Table 3.14-1 shows a comparison of H<sub>2</sub>/kWh conversion factors for each of these types of fuel cells, as well as showing what the effect of fuel cell demand is on the conversion factor. To obtain the corresponding O<sub>2</sub> lbm/kWh conversion factor, a factor of 7.94 lbm O<sub>2</sub>/lbm H<sub>2</sub> (0.002653/0.02106) should be multiplied by the equivalent H<sub>2</sub> conversion value.

### **POWER LEVEL**

The preflight analysis's premission analysis will provide a conversion factor for each cryogen, which will be based on the average predicted mission power level and the specific fuel cell V-I curves for the fuel cells being flown on the mission. The redlines, as defined in Flight Rule A9-257, include tank residuals, the measurement uncertainty, and the protection for a 2-day mission extension; these will also be part of the preflight analysis. The environmental use rate, which includes crew and animal metabolic use rate, cabin leak rate, spacehab leak rate, and any other usage that may occur over time, as well as additional O<sub>2</sub> usage in lbm to account for planned EVAs or other vehicle represses, will also be a part of the preflight analysis.

By placing all the variables into the power equations, the total possible mission average power level is obtained; this number will not reflect the extension-day power level, because these quantities were taken out.

After locating the H<sub>2</sub> conversion factor for the predicted average power level on Table 3.14-1, one can determine a rough percentage average degradation (average LCC curve) for the combined fuel cells being flown. Knowing the approximate degradation of the fuel cells is useful when a powerup or powerdown is required. When the average power level is changed due to a powerup/powerdown, a new conversion factor can be obtained by moving up or down the table to the new fuel cell average power level. Extrapolation can be done to achieve more accuracy, if desired. This new conversion factor should be used when determining the possible mission duration at the new power level.

The general equations for determining the maximum average power level for a given mission duration are:

$$P = \frac{Q_g - R}{t(C_{H_2})} \quad (H_2)$$

$$P = \frac{Q_g - R - t(ECS)}{t(C_{O_2})} \quad (O_2)$$

where

- P = Mission average power level, kW
- Q<sub>g</sub> = Total current gauged quantity in all tanks, lbm
- R = Redlines (residuals, measurement uncertainty, and extension day
- ECS = Environmental use rate, lbm/hr
- t = Remaining mission time, hr
- C = Conversion factor, lbm/kWh

Redlines (R) are defined in Flight Rule A9-257. They include tank residuals, measurement of uncertainty, and protection for 2 weather extension days. Residual is the amount that cannot be removed from the tank. The residual amount for an O<sub>2</sub> tank is 6.5 percent of a full tank (781 lbm); for H<sub>2</sub>, it is 4.0 percent in the first two tanks and 2.5 percent of all remaining tanks (92 lbm). The individual tank uncertainty measurement error is 2.6 percent of a full tank, and the total error is the square root of the number of tanks times the individual measurement error (0.026 x lbm x (no. of tanks)<sup>1/2</sup>). The redlines will also include protection for 2 extension days for weather wave off. If there are contingency requirements for equipment to be on that is normally off (e.g., circ pump, Inertial Measurement Unit (IMU), General Purpose Computer (GPC)), the amount of cryo used by this equipment will also have to be subtracted from the tank quantities. On extension days, the orbiter will be in a group C powerdown, and payloads will be at survival power levels. The total average power on extension days, including deorbit prep, should be between 13 and 16 kW, depending on payload survival power levels.

The Environmental Control System (ECS) use rate includes any O<sub>2</sub> that is being delivered to the PCS. The PCS supplies oxygen for maintaining the cabin atmosphere. The use rates include crew and animal metabolic rates, EVA use amounts, a cabin leak rate, and other uses, such as a Mir represses. The crew metabolic rate is 0.07 lbm/hr/crewmember, and an approximate cabin leak rate is 0.08 lbm/hr. Conversion factor values that are typically used for defaults are 0.69 lbm/kWh for O<sub>2</sub> and 0.087 lbm/kWh for H<sub>2</sub> when doing a quick calculation.

## MISSION DURATION ANALYSIS

If we solve the average power level equations for time, the resultant equations can be used to determine the maximum mission duration.

$$t = \frac{Q_g - R}{P(C_{H_2})} \quad (H_2)$$

$$t = \frac{Q_g - R}{P(C_{O_2}) + ECS} \quad (O_2)$$

Using the same inputs as stated previously for unusable allowances and conversion factors, we can solve the above equations for mission duration given an average mission power level. Both the hydrogen and oxygen equations should always be evaluated to determine which is the limiting consumable. The consumable with the lower power level or the shortest time is always the limiting consumable.

## SOCRATES PCM PAD

The SOCRATES EPRAC application has an option to do a projected consumables margin (PCM PAD). This software application will allow the user to do either mission duration or power level analysis using real-time data. When using the reset Real Time (R/T) option, the current tank quantities and MET are retrieved and all power calculations are done using the mission power profile model provided by the preflight analysis. The results generated will include the mission duration, as well as the mission average power level and extension day average power.

The power level analysis can also be done by using the override mission kW option. A simple calculation can be done which will result in a fairly close approximation of the average power level possible, using the results acquired from the mission duration analysis. The margin available in kWh divided by the time remaining in the nominal mission will give the net change to the average power that is possible. Using the new average power number to override the mission kW in the PCM PAD application should yield close to zero margin. Since the fuel cells are operating at a different power level, the usage rate has changed and margins are not exactly zero. When either the O<sub>2</sub> or H<sub>2</sub> margin is zero, the override mission power number will be the average power level that will satisfy the given mission duration.

**EXAMPLES**

Mission duration:

Given 5 tanks O<sub>2</sub> and H<sub>2</sub> - 100 percent full  
 18 kW - mission average power  
 7 - crew  
 15 kW - extension day power  
 40 percent - degraded fuel cells

Find: Maximum mission duration

Tank redlines:

O <sub>2</sub>	$\text{MU} = (2.6 \text{ percent})(781 \text{ lbm})(5 \text{ tanks})^{1/2} = 45.4 \text{ lbm}$ $\text{Residuals} = (6.5 \text{ percent})(781 \text{ lbm})(5 \text{ tanks}) = 253.8 \text{ lbm}$ $\text{Ext day use} = (48 \text{ hr})(15 \text{ kWh})(7.94)(0.0862) = \frac{492.8 \text{ lbm}}{792.0 \text{ lbm}}$
----------------	--

H <sub>2</sub>	$\text{MU} = (2.6 \text{ percent})(92 \text{ lbm})(5 \text{ tanks})^{1/2} = 5.35 \text{ lbm}$ $\text{Residuals} = (4.0 \text{ percent})(92 \text{ lbm})(2 \text{ tanks})$ $(2.5 \text{ percent})(92 \text{ lbm})(3 \text{ tanks}) = 14.26 \text{ lbm}$ $\text{Ext day use} = (48 \text{ hr})(15 \text{ kWh})(0.0862) = \frac{62.06 \text{ lbm}}{81.67 \text{ lbm}}$
----------------	---

ESC	$\text{Crew metabolic} = (7 \text{ crew})(0.07 \text{ lbm/crew/hr}) = 0.49 \text{ lbm/hr}$ $\text{Cabin leak rate} = \frac{0.08 \text{ lbm/hr}}{0.57 \text{ lbm/hr}}$
-----	---

$$t_{O_2} = \frac{(5 \text{ tks})(781 \text{ lbm}) - (792 \text{ lbm})}{(18 \text{ kW})(7.94)(0.0871) + (0.57)} = 239 \text{ hr}$$

$$t_{H_2} = \frac{(5 \text{ tks})(92 \text{ lbm}) - (81.67 \text{ lbm})}{(18 \text{ kW})(0.0871 \text{ lbm/kWh})} = 241 \text{ hr}$$

Because the O<sub>2</sub> calculations produce the shorter mission duration, it will be the limiting consumable, and 239 hours is the possible mission duration.

Assuming that in the above case the mission duration is 11 days, what is the required on-orbit powerdown to achieve this, and what will the new conversion factors be?

$$P_{O_2} = \frac{(5 \text{ tks})(781 \text{ lbm}) - (792 \text{ lbm}) - (264 \text{ hr})(0.57 \text{ lbm/hr})}{(264 \text{ hr})(7.94)(0.0871 \text{ lbm/kWh})} = 16.23 \text{ kW}$$

$$P_{H_2} = \frac{(5 \text{ tks})(92 \text{ lbm}) - (81.67 \text{ lbm})}{(264 \text{ hr})(0.0871 \text{ lbm/kWh})} = 16.45 \text{ kW}$$

Powerdown required = 18kW - 16.23 kW = 1.77 kW on-orbit powerdown

Because the O<sub>2</sub> maximum average power is smallest, this determines the required powerdown. The new conversion factor can now be determined using the average fuel cell power from Table 3.14-1.

Average fuel cell power = (16.23 kW)/(3 fuel cells) = 5.41 kW

$$\frac{(6 \text{ kW}) - (5.41 \text{ kW})}{(6 \text{ kW}) - (5 \text{ kW})} = \frac{(0.0871 \text{ lbm/kWh}) - (C_{H_2})}{(0.0871 \text{ lbm/kWh}) - (0.0862 \text{ lbm/kWh})}$$

$$C_{H_2} = \mathbf{0.0866 \text{ lbm/kWh}}$$

$$C_{O_2} = (7.94)(0.0866) = \mathbf{0.688 \text{ lbm/kWh}}$$

If we use these new conversion factors to calculate the powerdown requirement, we get the following:

$$P_{O_2} = \frac{(5 \text{ tks})(781 \text{ lbm}) - (792 \text{ lbm}) - (264 \text{ hr})(0.57 \text{ lbm/hr})}{(264 \text{ hr})(7.94)(0.0866 \text{ lbm/kWh})} = 16.32 \text{ kW}$$

$$P_{H_2} = \frac{(5 \text{ tks})(92 \text{ lbm}) - (81.67 \text{ lbm})}{(264 \text{ hr})(0.0866 \text{ lbm/kWh})} = 16.55 \text{ kW}$$

Powerdown required = 18kW - 16.32 kW = **1.68 kW** on-orbit powerdown

Several iterations of this calculation may be done, depending on the level of accuracy required.

**Table 3.14-1. Hydrogen consumption per kilowatt-hour (lbm/kWh)**

**H<sub>2</sub> CONVERSION FACTORS**

FC power (kW) per FC	20 LCC	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1 NEW
2	.0849	.0847	.0845	.0844	.0842	.0840	.0838	.0836	.0835	.0833	.0831	.0829	.0827	.0826	.0824	.0822	.0820	.0818	.0816	.0815
3	.0863	.0861	.0860	.0858	.0856	.0854	.0852	.0851	.0840	.0847	.0845	.0843	.0842	.0840	.0838	.0836	.0834	.0833	.0831	.0829
4	.0875	.0873	.0871	.0869	.0868	.0866	.0864	.0862	.0860	.0858	.0856	.0854	.0852	.0851	.0849	.0847	.0845	.0843	.0841	.0839
5	.0886	.0884	.0882	.0880	.0878	.0876	.0874	.0872	.0870	.0868	.0866	.0864	.0862	.0860	.0858	.0856	.0854	.0852	.0850	.0848
6	.0897	.0895	.0893	.0890	.0888	.0886	.0884	.0882	.0879	.0877	.0875	.0873	.0871	.0869	.0866	.0864	.0862	.0860	.0858	.0855
7	.0908	.0905	.0903	.0900	.9898	.0896	.0893	.0891	.0889	.0886	.0884	.0881	.0879	.0877	.0874	.0872	.0870	.0867	.0865	.0862
8	.0918	.0915	.0913	.0910	.0908	.0905	.0903	.0900	.0897	.0895	.0892	.0890	.0887	.0885	.0882	.0880	.0877	.0874	.0872	.0869
9	.0928	.0925	.0923	.0920	.0917	.0914	.0912	.0909	.0906	.0903	.0901	.0898	.0895	.0892	.0890	.0887	.0884	.0881	.0879	.0876
10	.0938	.0935	.0932	.0929	.0927	.0924	.0921	.0818	.0915	.0912	.0909	.0906	.0903	.0900	.0897	.0894	.0891	.0888	.0885	.0882
11	.0948	.0945	.0942	.0939	.0936	.0933	.0930	.0926	.0923	.0920	.0917	.0914	.0911	.0908	.0904	.0901	.0898	.0895	.0892	.0889
12	.0959	.0955	.0952	.0948	.0945	.0942	.0938	.0935	.0932	.0928	.0925	.0922	.0918	.0915	.0912	.0908	.0905	.0902	.0898	.0895

**O<sub>2</sub> CONVERSION FACTORS**

FC power (kW) per FC	20 LCC	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1 NEW
2	.675	.674	.673	.671	.670	.669	.667	.666	.664	.663	.662	.660	.659	.657	.656	.655	.653	.652	.650	.649
3	.685	.684	.682	.681	.680	.678	.677	.675	.674	.673	.671	.670	.668	.667	.665	.664	.663	.661	.660	.658
4	.694	.693	.691	.690	.688	.687	.685	.684	.682	.681	.679	.678	.676	.675	.673	.672	.670	.669	.667	.666
5	.703	.701	.700	.698	.696	.695	.693	.692	.690	.688	.687	.685	.683	.682	.680	.678	.677	.675	.674	.672
6	.711	.710	.708	.706	.704	.703	.701	.699	.697	.696	.694	.692	.690	.688	.687	.685	.683	.681	.680	.678
7	.720	.718	.716	.714	.712	.710	.708	.707	.705	.703	.701	.699	.697	.695	.693	.691	.689	.687	.686	.684
8	.728	.726	.724	.722	.720	.718	.716	.714	.712	.710	.708	.706	.704	.702	.699	.697	.695	.693	.691	.689
9	.737	.734	.732	.730	.728	.726	.723	.721	.719	.717	.715	.712	.710	.708	.706	.704	.701	.699	.697	.695
10	.745	.743	.740	.738	.736	.733	.731	.728	.726	.724	.721	.719	.717	.714	.712	.710	.707	.705	.702	.700
11	.753	.751	.748	.746	.743	.741	.738	.736	.733	.731	.728	.726	.723	.721	.718	.716	.713	.711	.708	.705
12	.762	.759	.756	.754	.751	.748	.746	.743	.740	.738	.735	.732	.730	.727	.724	.722	.719	.716	.713	.711

3.14-7

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## **TITLE**

POWERDOWNS

## **INTRODUCTION**

The powerdown procedures were developed to reduce orbiter thermal loads or to reduce orbiter electrical loads. There are three types of powerdowns; two types are retained in the Orbit Pocket Checklist (OPCL), and the third is retained in the Payload Powerdown book. Powerdowns discussed in Section 10.0 of the OPCL are performed in response to specific orbiter failures after troubleshooting actions are completed. An early deorbit is usually associated with these types of failures. The priority powerdowns in Section 11.0 of the OPCL are nominal powerdowns that can be used on each flight, in addition to contingency powerdowns utilized at the discretion of the MCC. The Payload Powerdown book is a flight-specific book that contains the payload-specific powerdown and payload safing procedures for a flight. This book is utilized with the OPCL when performing powerdowns.

## **REFERENCES**

SYS AOA (JSC-22728).

OPCL (JSC-48033).

CD/O (JSC-48007).

Flight Procedures Handbook, Vol. II (JSC-16873), Sections 10 and 11.

APCL (JSC-48003).

EPCL (JSC-48021).

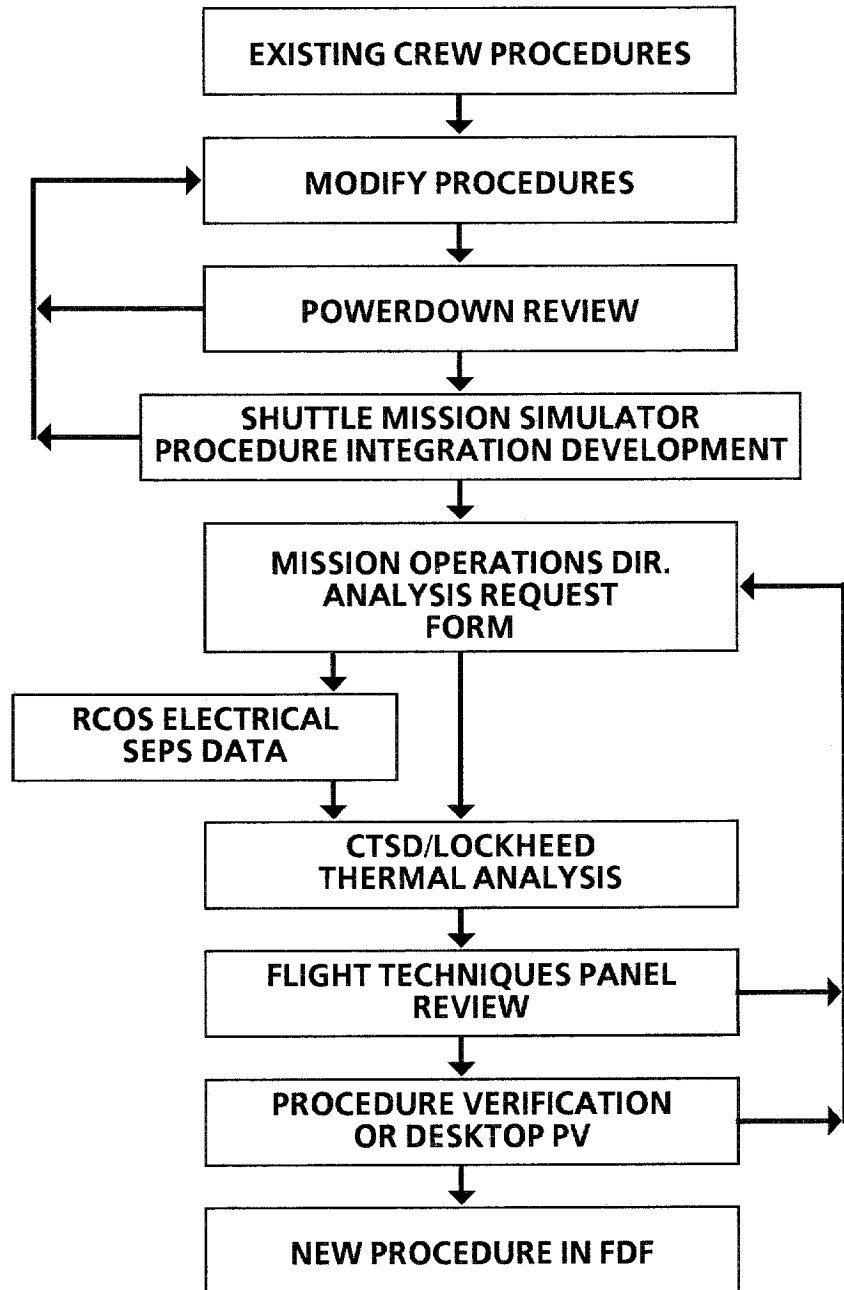
Payload Powerdown (JSC-48097-XX, where XX is the flight number).

## **BACKGROUND**

The original powerdown procedures were written prior to STS-1. In 1987, Mission Operations Directorate (MOD) began a 2-year exhaustive review of the powerdown procedures and their assumptions. This review was performed by a group of 30 engineers comprising astronauts, flight directors, flight controllers, trainers, and Rockwell and Lockheed engineers.

The updated procedures take into account larger crews, new test and analysis data, and flight experience. The review process involved powerdown working group meetings, splinter group meetings, procedure verification in the Shuttle Mission Simulator (SMS) (230 hours), electrical analyses, and thermal analyses and culminated in 15 flight techniques special topics meetings. A general diagram of the review process is shown in Figure. In light of the thoroughness of the review and the severely

off-nominal orbiter configurations, changes to the procedures are discouraged without extensive shuttle community review.



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*Figure 3.15-1. Powerdown procedures review process*

## PRIORITY POWERDOWNS

The priority powerdowns were written for nominal on-orbit situations (lettered powerdowns) and for generic failures not covered in Section 10 of the OPCL (numbered powerdowns). Group A is the standard orbiter configuration after the Post Insertion checklist is completed. Group B is an additional benign powerdown, which is utilized for additional consumables savings. Group C, which includes numbered powerdowns 1 and 2, is the agreed-to powerdown for mission extension days. The numbered powerdowns 3 through 7 are used for contingency purposes.

Note that all priority powerdown steps are in order, based on level of criticality, redundancy, and ease of backing out. Therefore, if a partial powerdown or repower is required, it is best to use the step order to decide which gear to power/unpower unless there is a specific real-time need to change the order.

1. Group A is the standard configuration for on-orbit operations. It is mainly utilized for mission events, such as rendezvous or deploy, and when consumables conservation measures are not required. It is never called procedurally and is listed for documentation purposes only.
2. Group B is used for power-critical missions to conserve consumables and is available for real-time implementation when consumable conservation measures are required. It is a standard practice in premission analyses to utilize a Group B to obtain 96 hours of launch hold. It was written with an average orbiter power level goal of 12 kW (payload power not included). Since then, a Multiplexer/Demultiplexer (MDM) powerdown has been deleted from the Group B steps. Also, Haynes Inertial Measurement Units (IMUs), which replaced the original type of IMUs flown, require more power. Actual flight data has shown an average orbiter power level of 12.5 to 13 kW. Orbiter lighting can be the major power delta for a Group B. On cryo-critical missions, it is good practice to get with the crew prior to flight and encourage them to be frugal with lights and other equipment. On STS-64, the estimated crew power savings was 300 W because of close management of lights (140 W) and other Line Replaceable Units (LRUs), such as the Thermal Impulse Printer System (TIPS) and the galley. On STS-90, when the crew performed an initial lighting powerdown in the Spacelab, a 160-W power delta was seen.
3. Group C is used for mission extension days and is written with a goal of 10.8 kW. Typical flight data shows an average orbiter power level of 11 kW and is the power level utilized for preflight analysis. Again, Groups 1 and 2 are considered apart from Group C.
4. Groups 1 through 7 are for contingency use. Usage of any numbered powerdowns assumes sequential inclusion of all lower-numbered groups (i.e., Group 4 assumes that Groups 1, 2, and 3 have already been performed). Note that powerdowns in Groups 1 and 2 have a very close configurational similarity with powerdowns in Groups B and C, respectively.

5. Groups PP3A and PP3B are solely for payload powerdowns. Group PP3A powers down all payloads that are considered recoverable. Payloads are recoverable if powering them down does not impact data from before or after the powerdown is performed or backed out of. Refer to the Payload Powerdown book for a current flight for an example of this type of powerdown.
6. Group 3B is a total powerdown that may cause payload operations to be nonrecoverable. Again, this type of powerdown resides in the Payload Powerdown book.

For more information on the priority powerdowns, look in the OPCL, Priority Powerdown Procedural Notes.

The Payload Powerdown book contains payload powerdown and safing procedures for a specific flight and includes the PP3A and PP3B powerdowns. The book is divided into different phases of flight, including ascent, entry, and on orbit. Powerdowns that call for use of the Payload Powerdown book are HI LOAD EVAP, loss of one Freon loop, loss of one fuel cell, and loss of the Flash Evaporator System (FES). The MN BUS Undervolts/fuel cell Volts procedure in the OPCL also calls for steps in the Payload Powerdown book; the steps called are dependent on whether the PRI PL bus is recoverable. Powerdowns that call for the use of the payload safing procedures are loss of two cabin fans, two H<sub>2</sub>O loops, cabin press, second fuel cell, and two Freon loops.

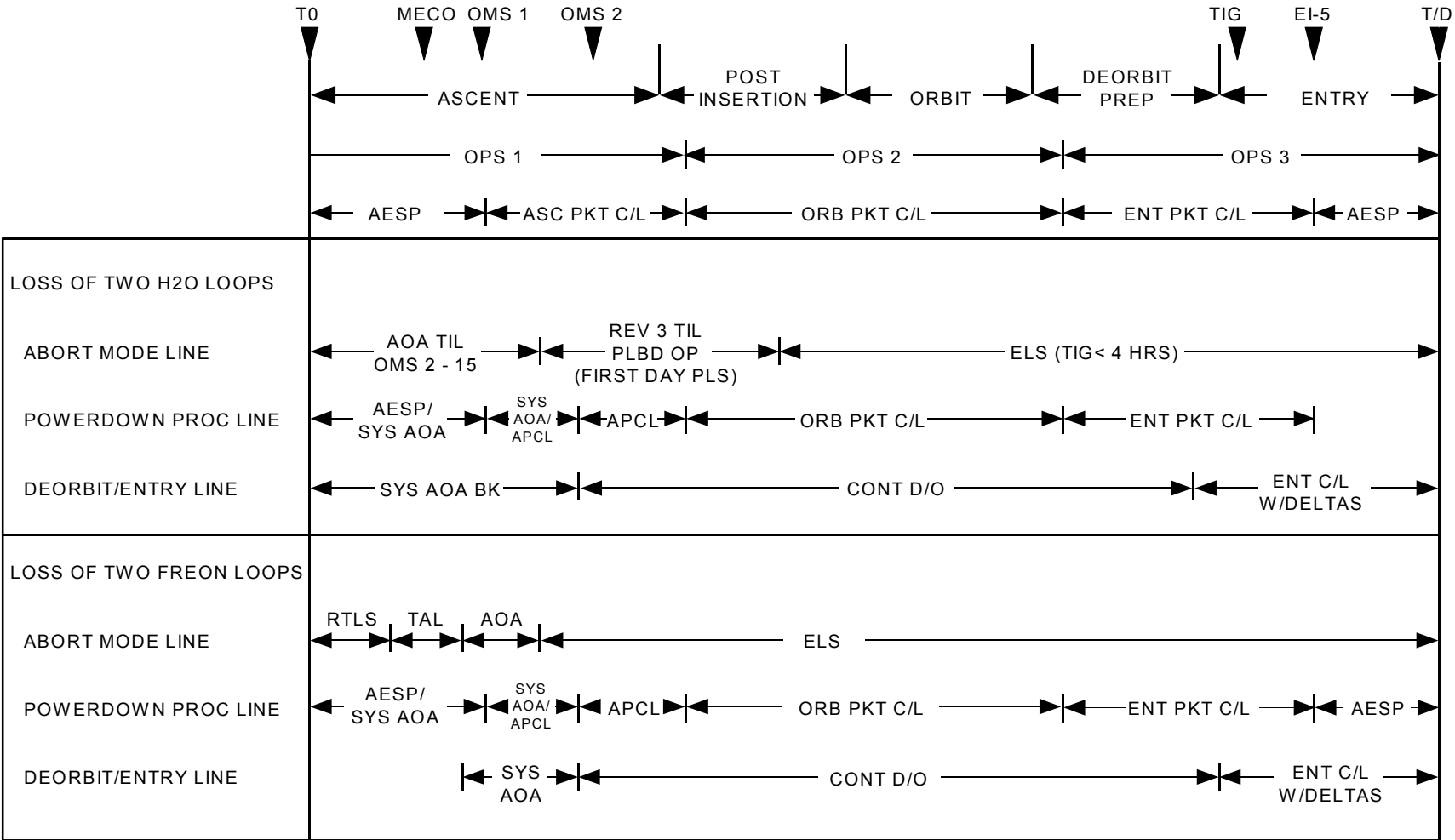
## **EGIL OPS NOTES FOR POWERDOWNS**

### **A. Loss of two Freon loops**

When two Freon loops are lost, the most probable subsequent catastrophic failure is loss of all fuel cell power because of overheating, which could cause the fuel cell Norel plates to deform and the tie rods to loosen, ultimately resulting in a loss of stack pressure. Therefore, the powerdown is written to put the orbiter in a zero-fault-tolerant operational, and sometimes nonoperational, configuration for most equipment to minimize orbiter power. Exceptions to this powerdown should be made only if loss of crew or vehicle is imminent and the exceptions will expedite the powerdown process. Also, the crew initiates a constant manual fuel cell purge to all three fuel cells simultaneously for the water removal and cooling effects. If the crew is unable to initiate the fuel cell purge from onboard, a TMBU command will be uplinked to turn on PRG heaters and to open all three sets of purge valves simultaneously. The TMBU must be completed before the payload MDMs are unpowered. An overview of procedural flow for loss of two Freon loops is shown in Figure 3.15-. Average estimated total orbiter power may drop as low as 5.2 kW after the powerdown, 7.4 kW for the deorbit burn, 8 kW at Entry Interface (EI), and 10 kW at Touchdown (TD).

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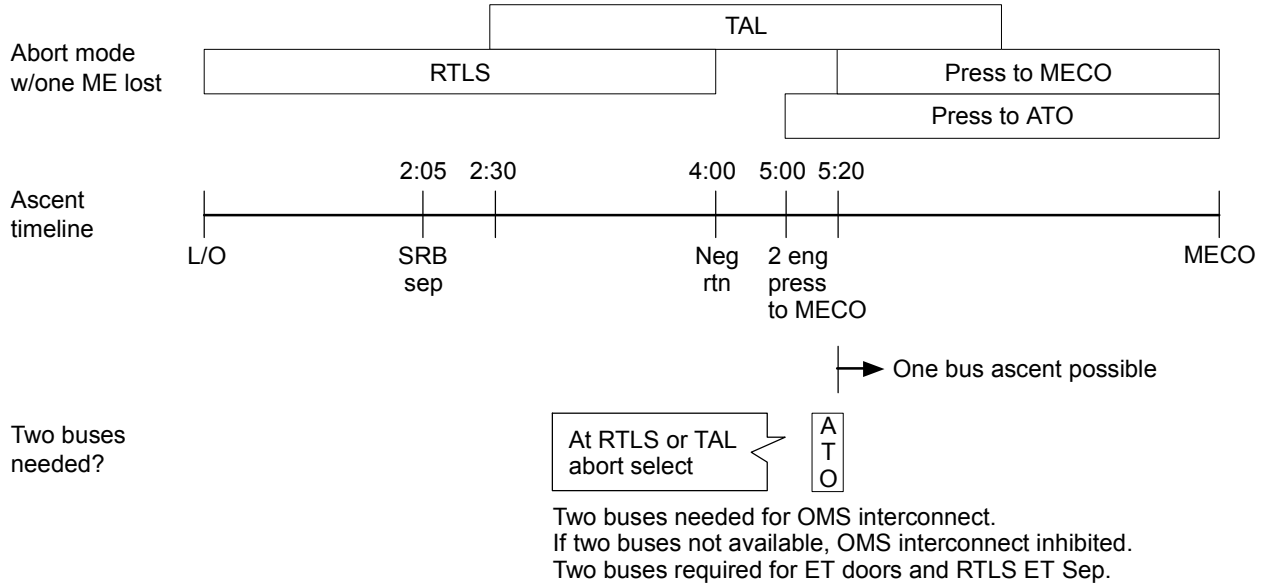
3.15-5



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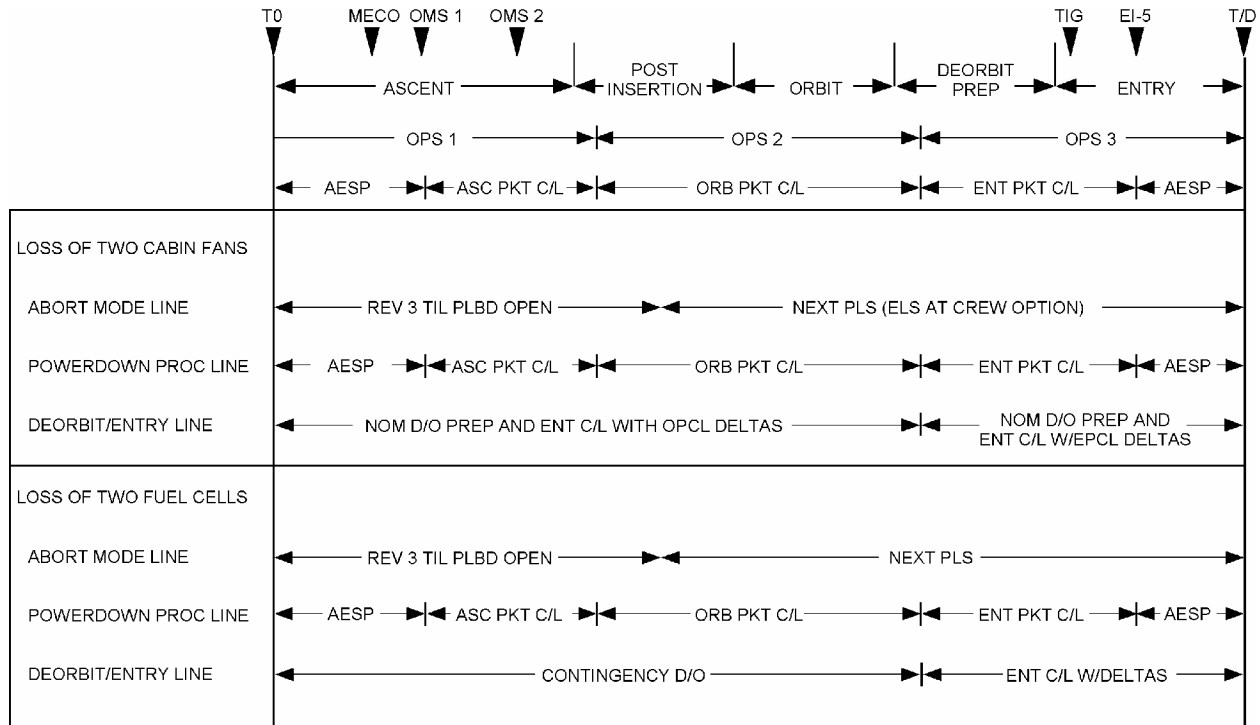
Figure 3.15-2. Procedural flow for loss of two H<sub>2</sub>O loops/two Freon loops

- B. Loss of two H<sub>2</sub>O loops
  - 1. Results in loss of all cooling to cabin air-cooled and water-cooled equipment (includes AC inverters, all forward power, load and motor controllers, interior lighting, Annunciation Control Assemblies (ACAs), and C/W).
  - 2. For the on-orbit wait case (TIG >2.5 hours), circ pumps may have to be operated to prevent main bus overvoltage because of lightly loaded main buses.
  - 3. An overview of procedural flow for loss of two H<sub>2</sub>O loops is shown in Figure 3.15-.
- C. Loss of two fuel cells
  - 1. A safe, one-fuel-cell entry can be performed at reduced orbiter power levels (2 to 12 kW continuous, 12 to 13 kW for 4 hours, 16 kW for 15 min) with possible undervoltage on specific sub-buses during high-power events (i.e., Payload Bay Door (PLBD) closing, etc.).
  - 2. Loss of second fuel cell results in the loss of a main bus. The crew recovers the lost bus (if not shorted) late in the powerdown when the electrical load is low enough for one fuel cell to support all three main buses. If the second fuel cell loss occurs in the EPCL timeframe, the main bus remains unpowered because there is not enough time to sufficiently power down, reconfigure systems, and regain the bus.
  - 3. Ascent cue card - Perform powerdown as soon as possible to avoid dropping two main buses or to regain second main bus quickly. See Figure 3.15-3 for an example of abort modes with loss of two main buses (one main engine).
- D. For loss of two cabin fans, cabin pressure, or FES procedural flow versus failure time, refer to Figure 3.15-4 and Figure 3.15-.
- E. For thermal analysis results for all powerdown cases, refer to Figure 3.15-6.



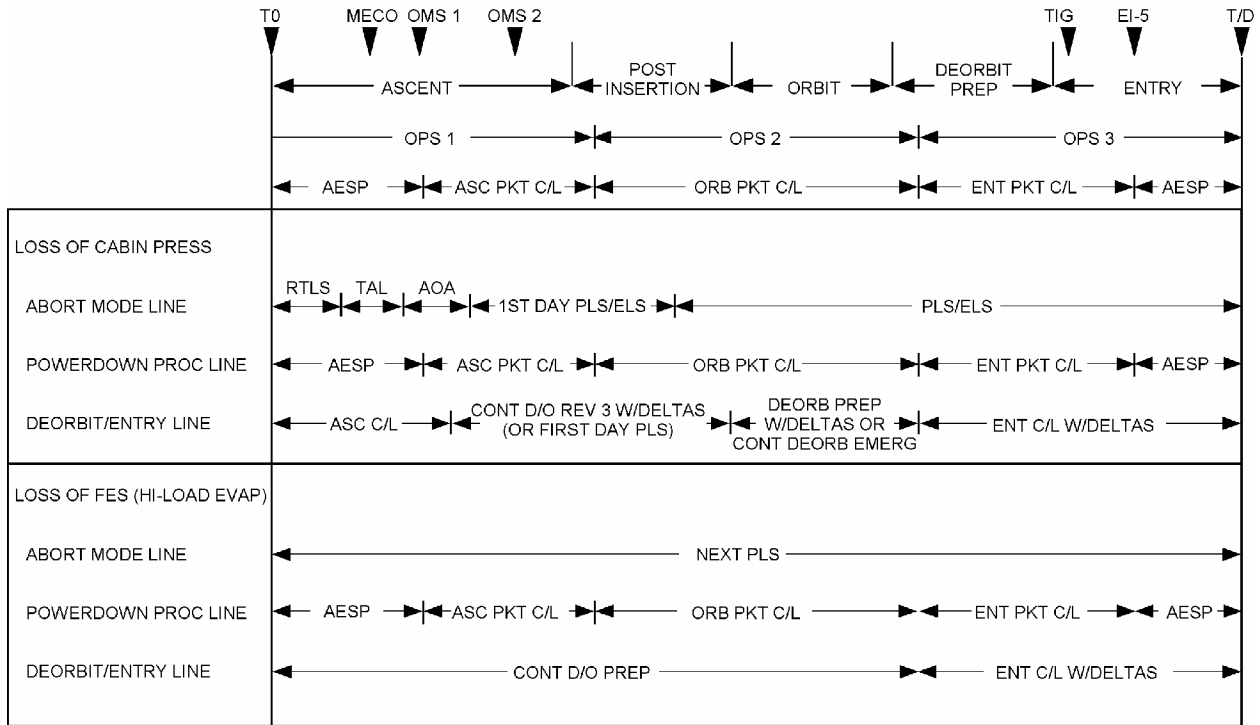
j\_12830\_078.cnv

**Figure 3.15-3. Abort modes with loss of two fuel cells and two main buses (one ME)**



j\_12830\_509.cnv/tif

**Figure 3.15-4. Procedural flow for loss of two cabin fans and two fuel cells**



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**Figure 3.15-5. Procedural flow for loss of cabin pressure and FES**



TITLE	TIME OF FAILURE 1	TIME OF FAILURE 2	CABIN PARAMETERS						AVIONICS SUPPLY AIR TEMPS			FUEL CELL HX	IMU TEMPS		
			PRIOR TO TD	PRIOR TO TD	TEMP	DEWPOINT	RH	P	PPCO2	PPO2	BAY 1	BAY2	BAY 3A	FC-49 RETURN TEMP	INLET
UNITS	HR:MIN	HR:MIN	°F	°F	%	PSIA	MM HQ	PSIA/%	°F	°F	°F	°F	°F	°F	°F
								H 30%							
LIMIT @ 14.7 PSI			95	61	95	Δ15.5	7.6	L 2.2 P	95	95	95	140	95	130	
LIMIT @ 8 PSIA			73						73	73	73		73		
LIMIT @ 4 PSIA			64						64	64	64		64		
LOSS OF 1 FCL-TOPPING FES AFO	5:00	4:30		85	100										
LOSS OF 1 FCL-REV 3	4:54	-		72											
2FCL FAILED AOA	1:48	1:44	94	94	100	-			101		104			135	
2FCL FAILED AFO	3:16	3:13	104	102	100	-					98		104		
2FCL FAILED ENTRY	1:48	1:43	101	94	100	-					100		101		
2FCL FAILED AOA	1:46	1:44	97	97	100	-									
2WCLAFO TIG>2.5	5:35	5:30	115	103	100	-			125	114	126		115		
2WCLAFO TIG<2.5	3:12	3:07	108	103	100	-			105	122	118			136	
2WCL FAILED ENTRY	1:51	1:46	106	98	100	-	11.9		121	130	114				
LOSS OF CABIN FANS REV 3	4:55	4:55	97	97	100	-	33.5								
LOSS OF CABIN FANS AFO	21:00	21:00	104	104	100	-	7.6								
LOSS OF CABIN FANS ENTRY	4:00	3:00	93	93	100	-									
2FC FAILED ASCENT	:01 FROM LIFT-OFF	:05 FROM LIFT-OFF		86		-									

Figure 3.15-6. Thermal analysis for all powerdown cases

3.15-9

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TITLE	TIME OF FAILURE 1	TIME OF FAILURE 2	CABIN PARAMETERS						AVIONICS SUPPLY AIR TEMPS			FUEL CELL HX	IMU TEMPS		
			PRIOR TO TD	PRIOR TO TD	TEMP	DEWPOINT	RH	P	PPC02	PP02	BAY 1	BAY 2	BAY 3A	FC-49 RETURN TEMP	INLET
2FC FAILED AFO REV 3	4:00	3:45		69		-									
2FC FAILED AFO TIG>5.5	9:00	8:30		66											
2FC FAILED AFC TIG<5.5*	3:00	2:45		56								153			
2FC FAILED ENTRY	3:00	2:30		62											
LOSS OF FES DEORBIT	3:45	3:45		70	100										
LOSS OF FES ENTRY (@ TIG-:45)	1:45	1:45		90	100				105	104	103				
LOSS OF FES ENTRY (@ TIG-:15)	1:15	1:15		55	100			0.4	105	104	102				
LOSS OF FES AOA	ANALYSIS	IN PROGRESS													
LOSS OF CABIN P AOA (4 PSI)	1:40	-	78					0.7							

Note: Due to model limitations, the above data should not be interpreted as a precise prediction of the cabin environment. The data should be used only to indicate when the potential for a problem exists.  
 Note: Limit violations indicated.  
 Note: AFO = Abort From Orbit.

Figure 3.15-6. Continued

3.15-10  
Verify that this is the correct version before use

TITLE	TIME OF FAILURE 1	TIME OF FAILURE 2	CABIN PARAMETERS						AVIONICS SUPPLY AIR TEMPS			FUEL CELL HX	IMU TEMPS		
			PRIOR TO TD	PRIOR TO TD	TEMP	DEWPOINT	RH	P	PPCO2	PPO2	BAY 1	BAY2	BAY 3A	FC-49 RETURN TEMP	INLET
UNITS	HR:MIN	HR:MIN	°F	°F	%	PSIA	MM HQ	PSIA/%	°F	°F	°F	°F	°F	°F	°F
								H 30%							
LIMIT @ 14.7 PSI			95	61	95	Δ15.5	7.6	L 2.2 P	95	95	95	140	95	130	
LIMIT @ 8 PSIA			73						73	73	73		73		
LIMIT @ 4 PSIA			64						64	64	64		64		
LOSS OF 1 FCL-TOPPING FES AFO	5:00	4:30		85	100										
LOSS OF 1 FCL-REV 3	4:54	-		72											
2FCL FAILED AOA	1:48	1:44	94	94	100	-			101		104			135	
2FCL FAILED AFO	3:16	3:13	104	102	100	-					98		104		
2FCL FAILED ENTRY	1:48	1:43	101	94	100	-					100		101		
2FCL FAILED AOA	1:46	1:44	97	97	100	-									
2WCLAFO TIG>2.5	5:35	5:30	115	103	100	-			125	114	126		115		
2WCLAFO TIG<2.5	3:12	3:07	108	103	100	-			105	122	118			136	
2WCL FAILED ENTRY	1:51	1:46	106	98	100	-	11.9		121	130	114				
LOSS OF CABIN FANS REV 3	4:55	4:55	97	97	100	-	33.5								
LOSS OF CABIN FANS AFO	21:00	21:00	104	104	100	-	7.6								
LOSS OF CABIN FANS ENTRY	4:00	3:00	93	93	100	-									
2FC FAILED ASCENT	:01 FROM LIFT-OFF	:05 FROM LIFT-OFF		86		-									

Figure 3.15-6. Concluded

Verify that this is the correct version before use

3.15-11

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-3	OV-102	03/22/1982	03/30/1982	PRSD	Quantity Transducer	Cryo H2 Tk 2 QTY Offscale High	Cryo H2 Tank 2 Quantity transducer failed (Off-Scale High)
STS-3	OV-102	03/22/1982	03/30/1982	PRSD	Cryo Heater	Cryo H2 TK 1 HTR B Fail ON in AUTO	Cryo H2 TK 1 HTR B stayed ON continuously when in AUTO mode. It was traced to a failed ON RPC (RPC 2 in H2/O2 CNTRL Box 1). The alternate RPC is powered directly from MNC. The management plan was as follows: (1) All HTRS OFF at L/O (2) At L/O + 2'30" - Tank 1 & 2 HTRS to A AUTO (both H2 and O2) (3) At approximately L/O + 15' (OPS 105) - Go to A & B HTRS for O2. Stay on A HTRS for H2. Changes were made to DEORBIT PREP, pg 5-13, Switch matrix for ENTRY. Changes were made to all ASCENT C/L & Cue Card FDF.
STS-3	OV-102	03/22/1982	03/30/1982	PRSD	Cryo Heater	Cryo O2 TK False AUTO Trip	Cryo O2 Tank had a TRIP indication on HTR A. Suspect sensor or instrumentation failure. Crew tried resetting. At L/O + 3 H 02 M the crew reset the trip switch and everything is now operating nominally.
STS-4	OV-102	06/27/1982	07/04/1982	PRSD	Quantity Transducer	H2 TK2 Quantity Transducer Shift	H2 Tank 2 Quantity transducer appears to have shifted down from approximately 95% to approximately 43%. Tank 1 quantity was used to estimate the remaining quantity in Tank 2.
STS-4	OV-102	06/27/1982	07/04/1982	PRSD	Cryo Heater	H2 TK4 Heater A failure	H2 Tank 4 Heater A was not working. HTR A was turned OFF and HTR HTR B was taken to AUTO.
STS-4	OV-102	06/27/1982	07/04/1982	PRSD	Cryo Heater	H2 TK2 Heater B failure	Cryo H2 Tank 2 Heater B failed OFF. Tanks 1 & 2 A Heaters were taken to AUTO and the B heaters were taken

3.16-1

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
							OFF.
STS-8	OV-99	08/30/1983	09/05/1983	PRSD	Quantity Transducer	H2 TK3 Quantity Transducer	Biased during heater ops
STS-8	OV-99	08/30/1983	09/05/1983	PRSD	O2 Current Sensor	O2 TK2 Current Sensor 1A	Slow to reset
STS-9	OV-102	11/28/1983	12/08/1983	PRSD	Quantity Transducer	O2 TK3 Quantity Transducer	At GMT 340+16+05, Cryo O2 Tank 3 QTY transducer failed to 37%. The tank quantity prior to failure read 58%. The resolution was to deplete Tank 3 on half heaters.
STS-61C	OV-102	01/24/1985	01/27/1985	PRSD	O2 Current Sensor	O2 TK3 Current Sensor 1A	Failed to hold "TRIP" status
STS-51C	OV-103	01/24/1985	01/27/1985	PRSD	O2 CPC	O2 Tk2 Control Press Fail	O2 Tk2 controll press failed OSL
STS-51D	OV-103	04/12/1985	04/19/1985	PRSD	Cryo Heater	O2 TK Cryo Pressure Controller	Failed to work in AUTO mode, MAN heaters required
STS-29	OV-103	03/13/1989	03/18/1989	PRSD	Cryo H2 Tank	S68 Cryo H2 PRES Message Anomaly	At MET 00/1+57, a S68 Cryo H2 PRESSURE message was observed. A C/W Read revealed that H2 Tk4 CNTL PRESSURE H/W C/W (Channel 80) was tripped. After checking with the crew, they reported that when configuring PNL ML86B, they momentarily pushed in ESS 1BC CRYO CNTLR H2 TK 4 cb and then released it. An NRT request verified this scenario. Whe the cb was pushin IN, the measurement becasue active at a value above the lower limit. The cb was opened, the vlue went below the lower limit and triggered the C&W. The noise filter is 2 counts on H2 TK4 Control Pressure. No further postflight action is

3.16-2

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
							required.
STS-34	OV-104	10/18/1989	10/23/1989	PRSD	Cryo Valve	Cryo O2 Manifold VLV Tank 2 Failure	At MET 01/09+36, the crew attempted to close the Cryo O2 Manifold Tank 2 VLV on Panel R1 per the presleep cryo configuration plan. The crew reported that they held the switch for approximately 5 seconds with no change observed on the associated talkback. The swithc discrete (V45X1146E) also remained unchanged. At MET 004/23:41, the crew successfully re-opened the O2 Manifold VLV TK2 on the first attempt. MOD had requested the valve be re-opened to prevent workarounds to cryo de-tanking procedures postlanding. Possible causes include corroded switch contacts, driver failure, open circuit in electronics, valve failed open. At MET 001:19:34, O2 Manifold Valve Tank 2 was cycled close to test whether the valve would change position. On the first attempt, the valve closed. To protect against the valve failing open, the valve was left closed until EOM. Heater

3.16-3

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
							operations consisted of TK1, 2 in AUTO during crew days and TKS 2, 3 during crew sleeps. The intent was to avoid manual heater operations which impacts crew workload. The valve was requested to be checked prior to the next flight of OV-104.
STS-32	OV-102	01/09/1990	01/20/1990	PRSD	Cryo Valve	H2 Manf 2 Valve Leak	Leak was below "spec" limit
STS-41	OV-104	10/06/1990	10/10/1990	PRSD	Check Valve	O2 TK1 Check Valve	Sticky valve, required 20 psid to relieve
STS-38	OV-104	11/15/1990	11/20/1990	PRSD	Quantity Transducer	H2 TK3 Quantity Transducer	Failed OSH, failed signal conditioner
STS-33	OV-103	11/22/1990	11/27/1990	PRSD	Check Valve	O2 TK1 Check Valve	Sticky valve, twice required 20 psid to relieve
STS-35	OV-102	12/02/1990	12/11/1990	PRSD	Quantity Transducer	H2 TK2 Quatity Transducer Bias	At approximately 2/00:00 MET, Cryo H2 TK2 quantity rose by approximately 1.2%. Normal heat leak into the tank should have caused it to drop by approximately 1.5% over this time period. This apparent transducer bias remained in the TK2 quantity measurement since that time.

3.16-4

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-37	OV-104	04/05/1991	04/11/1991	PRSD	Cryo Valve	O2 Manifold Valve TK2 Failed to Close	During the FD2 Pre-sleep cryo configuration, the crew tried to close the O2 MANF VLV TK2. This valve did not close. During FD4 Post-sleep cryo configuration, the crew was able to close O2 MANF VLV 2 on the first attempt. O2 MANF VLV2 was remained closed for the remainder of the flight.
STS-40	OV-102	06/05/1991	06/14/1991	PRSD	Cryo Heater	Cryo H2 TK3 Heater A Failed	Fuse failed, thermal cycling = fatigue. Troubleshooting steps verified the heater was lost in both the 'AUTO' and 'ON' switch positions.
STS-43	OV-104	08/02/1991	08/11/1991	PRSD	Cryo Heater	H2 TK1 HTR B Failure	Fuse failed. At the end of the first sleep period, H2 TK1 HTR B failed OFF. Pressure rise rate in the tank confirmed that only one of the two heaters was operating. Troubleshooting confirmed that the heater could not be operated in the AUTO or manual mode.
STS-43	OV-104	08/02/1991	08/11/1991	PRSD	Cryo Valve	Cryo H2 MANF VLV TK1 Failed to Close	During FD7 pre-sleep cryo configuration, H2 MANF VLV TK1 failed to close (ie, remain open). The switch positions attempted were close, close, open, close. Impact was possible loss of MANF VLV 1 isolation. Closure of the H2 MANF VLV TK1 will only be attempted for leak isolation. If the valve were closed and failed to reopen, a normal 9+2 mission would not be possible with the present H2 TK1 quantity. The mission would be shortened unless FC1 were placed in Standby or Shutdown.
STS-48	OV-103	09/12/1991	09/18/1991	PRSD	Cryo Valve	FC1 O2 Reac false-close	False CLOSE indication, S/N 44

3.16-5

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-45	OV-104	03/24/1992	04/02/1992	PRSD	Cryo Heater	Cryo O2 Tank 3 Control Press Bias	O2 Tank 3 Control Press biased high approximately 15 psi. Since the transducer provides input to the controller and telemetry is via the output from the controller, it is not possible to tell if the problem is in the transducer or controller. However, since O2 Tank 3 and 4 are controlling low (827-868), it is not a telemetry problem. The only impact is that the O2 tanks 3 and 4 operated approximately 10-15 psi below there normal control band.
STS-49	OV-105	05/07/1992	05/16/1992	PRSD	Cryo Valve	O2 MANF VLV 1 Fail Open	During FD1 Pre-sleep, when the crew attempted to close O2 Manifold Valve 1, the valve did not close. A second attempt to close the valve also failed. At GMT 136:23:38 the crew attempted to close the O2 Manifold VLV TK 1. Again the valve did not close. Cryo management plan changes were required: for all sleep periods, O2 manifold valve 2 was closed per Flight Rule 9-166C. There was no mission duration impact. Post flight testing is required.
STS-50	OV-102	06/25/1992	07/09/1992	PRSD	Check Valve	Cryo O2 Tank 7 Check Valve	Cryo O2 Tank 7 Check Valve stuck in the open position. At GMT 190:14:20 the check valve appeared to operate normally again. O2 Tank 7 pressure will rise and fall with the O2 manifold (and tank isolation is lost) when check valve is ope. The tank was not used for the remainder of the mission.

3.16-6

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-50	OV-102	06/25/1992	07/09/1992	PRSD	Cryo O2 Tank	Cryo O2 Tank 2 Leak	Cryo O2 Tank 2 developed about a 1 lb/hr leak. There was no impact to the mission duration or entry at that leak rate. O2 management plan consumed 125 lbs from TK2 when ensured 13+2 day capability on remaining tanks.
STS-50	OV-102	06/25/1992	07/09/1992	PRSD	Cryo Heater	The Cryo O2 Tank 2 Heater A2 Fail	Cryo O2 Tank 2 heater A2 has been experiencing intermittent poser drop-outs. Loss of 1 or 2 A heater elements in Tank 2. The O2 Tank 2 "A" HTR was unpowered for the remainder of the flight.
STS-50	OV-102	06/25/1992	07/09/1992	PRSD	Cryo Tank	Cryo O2 TK3 Rapid Pressure Cycles	Cryo O2 TK3 experienced abnormally requent pressure cycles during which all cryo demand was met by TK 3 even though its tank pressure was below the manifold pressure during 2/3 of each cycle. Since the phenomenon has not been seen on previous missions, it is considered possible that this phemonenon was related to the O2 TK 7 Check Valve anomaly.
STS-50	OV-102	06/25/1992	07/09/1992	PRSD	Cryo Tank Quantity Ducer	Cryo O2 TK 3 QTY XDCR	At 189/17:35 GMT, Cryo O2 Tank 3 QTY measurement V45Q1305A started shifting erratically from 80% to OSH. The reading establized back to the nominal quantity. There was no impact to the mission. Troubleshooting is required postflight.

3.16-7

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-47	OV-105	09/12/1992	09/20/1992	PRSD	Cryo Heater	Cryo O2 TK 4 CNTLR Problem	At GMT 256/15:21, O2 TK 4 CNTL PRESS indicated OFF SCALE LOW (OSL). The crew checked the O2 TK 4 CNTLR circuit breaker (ML86B) and found it closed. They cycled the circuit breaker ten times, but the controller output could not be recovered. A test of the O2 TK 4 controller at GMT 257/17:55 revealed that the failure is in the pressure sensor circuit nad the O2 Tk4 cannot be operated by itself in the AUTO mode. However, O2 TK4 does work wit hte O2 TK 3 as a paired set. Five minutes before touchdown the Control Pressure suddenly started working properly.
STS-52	OV-102	10/22/1992	11/01/1992	PRSD	Cryo Heater	Cryo O2 TK2 HTR A2 Intermittent	When O2 Tank 2 heaters were placed to AUTO for the sleep period, the A2 heater did not indicate ON at the beginning of the heater cycle, but came on about midway through. This has occurred during every heater cycle since. The fuel cell amps data indicates that the A2 heater is late coming ON. There is no impact. For future O2 TK2 use, only the B heater will be used except for testing the A heater, if required.
STS-54	OV-105	01/13/1993	01/19/1993	PRSD	Cryo Valve	O2 Manf 1 Valve	Failed to close, S/N 29
STS-56	OV-103	04/08/1993	04/17/1993	PRSD	Cryo Valve	FC1 O2 Reac false-close	False CLOSE indication, S/N 44
STS-57	OV-105	06/21/1993	07/01/1993	PRSD	Cryo Valve	FC3 H2 Reac	Failed to close, S/N 84

3.16-8

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-57	OV-105	06/21/1993	07/01/1993	PRSD	Cryo Valve	O2 Manf 1 Valve	Failed to close, S/N 29. During pre-sleep - FD01, O2 MANF VLV TK1 failed to go close during the cryo reconfig. The crew tried again to close the valve, holding the switch for approximately 1.5 seconds, with no success. At GMT 180:04:03, another attempt to close the valve was successful. the valve was then reopened successfully. The O2 and H2 Manifold 2 Valve was closed for crew sleep.
STS-60	OV-103	02/03/1994	02/11/1994	PRSD	Cryo Quantity Ducer	O2 TK2 QTY XDCR Erratic	Cryo O2 Tank 2 Quantitiy sensor measurement V45Q1205A was erratic. The sensor reading occasionally read high and has been offscale high (>104% QTY). There was no impact to the mission. Further troubleshooting may be required post landing.
STS-62	OV-102	03/04/1994	03/18/1994	PRSD	Cryo Heater	H2 TK6 Heater A failure	Failed to energize
STS-62	OV-102	03/04/1994	03/18/1994	PRSD	Quantity Transducer	O2 TK7 Quantity Transducer	Failed OSH
STS-62	OV-102	03/04/1994	03/18/1994	PRSD	Cryo heater	Cryo H2 TK6 "A" HTR Fail	At MET 002:08:09, it was noticed that the H2 TK6 "A" HTR dicrete (V45X4106E) was missing indicating that the "A" HTR had failed during paired operations with the H2 TK7 (both A nd B heater switches in AUTO position). This was verified by the H2 TK6 pressure rise rate. At GMT 066:10:45, troubleshooting on the H2 TK6 heater confirmed that the A heater was lost for both the AUTO and Manual ON configurations. The nominal cryo management plan was used using H2 TK6 "B" heaters. The H2 TK6 "A" heaters were lost.

3.16-9

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-62	OV-102	03/04/1994	03/18/1994	PRSD	Cryo Quantity Ducer	O2 TK7 Quantity Measurement Failure	At GMT 075:08:09, just after the OMS 5 burn, the O2 TK7 quantity measurement (V45Q3205A) failed to OFF-SCALE HIGH. There was no impact to the mission. The O2 TK7 quantity was calculated by using the FC power usage.
STS-59	OV-105	04/09/1994	04/20/1994	PRSD	Check Valve	H2 Tank 5 Check Valve Fail to Seat	Failed to seat, sudden seating caused manifold spike. Cryo H2 Tank 5 check valve failed to seat. At MET 002:12:00, Tank 5 heaters were deactivated and Tank 4 Heaters taken to AUTO mode. As the pressure in Tank 4 cycled with the heater operation, pressure in Tank 5 tracked that in Tank 4. At GMT 103:21:47 the cryo config was switched to allow H2 TK5 to feed FC demand in an attempt to clear any contaminants that may be preventing the check valve from closing. This config was maintained for 1 Hr with a FC AUTO Purge performed during the time to add additional demand on H2 TK5. H2 TK5 check valve remained failed open post troubleshooting ops. During a cryo heater cycle at 105:03:48 had gone closed. Review of MEWS data showed that the check valve closed after a pressure spike (254 psia) occurred in the H2 manifold (manifold spike was caused by a sticky H2 TK2 check valve coming open). There was no impact to the mission. H2 Tank 5 depletion was delayed.

3.16-10

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-59	OV-105	04/09/1994	04/20/1994	PRSD	Check Valve	Sticky Cryo H2 TK2 Check Valve	Sticky valve, three times. At GMT 105:00:00, Cryo H2 Tank 1 and 2 usage began after Tank 4 depletion. These tanks had not been used since post insertion. During four of the first seven pressure cycles, H2 Tank 2 check valve remained closed until a pressure differential of approximately 15 psi over the H2 manifold developed. There was no impact to the mission. A small H2 manifold pressure spike was caused. H2 Tank 2 check valve operated normally since the manifold pressure spike.
STS-59	OV-105	04/09/1994	04/20/1994	PRSD	Check Valve	O2 TK1 Check Valve	Sticky valve, required 20 psid to relieve
STS-68	OV-105	09/30/1994	10/11/1994	PRSD	Check Valve	H2 TK 2 Check Valve	Sticky valve, same as on STS-59
STS-66	OV-104	11/03/1994	11/14/1994	PRSD	Quantity Transducer	H2 Tank 4 QTY XDCR Problem	At GMT 314:00:11, H2 Tank 4 QTY XDCR started to increase from 2.1% and reached 10.% QTY. Data indicated no change in temperature or pressure. QTY measurement was erratic. This quantity transducer experienced problems preflight. There is no impact to the mission. H2 Tank 4 was considered depleted. Further troubleshooting may be required postlanding.
STS-67	OV-105	03/02/1995	03/18/1995	PRSD	Cryo	O2 System He Contamination	Residual He = prelaunch performance degrade

3.16-11

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-71	OV-104	06/27/1995	07/07/1995	PRSD	Cryo Temp	Erratic O2 Tank 5 Heater Temperature	At 188/14:53:14 GMT a Master Alarm was received onboard with no associated Fault Summary Message or F7 light. Postlanding checkout of R13 tripped parameters showed C&W channel 81, PRSD O2 TK5 HTR T 1 (MSID V45T1507A) had gone out of limits at some time during the mission, which was not expected. Data review showed erratic data on this parameter at about the same time as the Master Alarm. Although the downlist data did not show an exceedence of hte alarm limit, the onboard sample rate of the H/W C&W system is greater than the downlist data, and any exceedence could have been missed in the downlist data. The impact is erratic data on the effect MSID, which could result in loss of the only H.W C&W heater temperature measurement o the O2 Tank 5 (HTR 2 is not sampled by the H/W C&W), and loss of hte ability ot monitor the affected temperature during O2 tank depletion on subsequent missions.
STS-71	OV-104	06/27/1995	07/07/1995	PRSD	Cryo Valve	H2 MANF VLV TK1 Failed OPEN	Failed to close, broken wire. During FD1 Presleep cryo config, H2 MANF VLV TK1 failed to close (failed open). The switch was held in the closed position for ten seconds and the valve did not respond. H2 MANF VLV TK2 will be closed for sleep periods. Additional attempts to close the H2 MANF 1 VLV was performed during the mission.

3.16-12

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-71	OV-104	06/27/1995	07/07/1995	PRSD	Cryo Valve	H2 Manifold Valve 1 Microswitch Failure	False CLOSE indication, S/N 20. At GMT 182/01:34, the H2 Manifold valve discrete went to the CLOSED position with an associated message. The crew checked the talkback and confirmed a CLOSED indication. The crew was asked to hold the H2 MANF 1 VLV open for 10 seconds with no joy. The pressure in H2 trnak 1 stayed steady at 208 psi and manifold pressure matched the tank 5 pressure, which was feeding at the time, indicating the problem was a microswitch failure. At GMT 182/11:06 the H2 manifold valve indication transistion back to OPEN. The crew verified an OPEN talkback indication on board. After the initial occurance, the valve indication toggled several more times during the remainder of the mission. There was no impact to the mission. A TMBU was sent to inhibit the H2 MANF 1 CL FDA.
STS-73	OV-102	10/20/1995	11/05/1995	PRSD	Cryo Valve	H2 Manifold Valve TK1 Failed Open	Failed to close, S/N 8. During the cryo manifold valve test on RED FD16, the H2 MANF VLV TK1 failed OPEN (failed to go CLOSED). The crew reported that they attempted to close the valve twice with no joy. The ground had the crew hold the switch in the open position for ten seconds. The valve remained in the OPEN position. H2 Manifold 1 isolation capability was lost.

3.16-13

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-74	OV-104	11/12/1995	11/20/1995	PRSD	Cryo Valve	H2 Manifold Valve 1 Microswitch Failure	False CLOSE indication, S/N 20. AT 324/12:39 GMT (just after start of D/O prep), the H2 Manifold Valve 1 discrete toggled to the CLOSE position, generating the associated FDA alarm. The crew confirmed the CLOSED indication. Ground asked the crew to take the valve switch to open; no joy on the valve indication. Ground data indicated this was an instrumentation problem only. The crew, referencing EPS MAL 7.6e, cycled the valve switch to close, then back to open and the indication returned to OPEN. This failure originally occurred on STS-71, and was unable to be recreated on the ground. Failure was closed out as an unexplained anomaly. There was no impact to the mission. Further ground testing is recommended.
STS-74	OV-104	11/12/1995	11/20/1995	PRSD	Cryo Valve	Cryo O2 Manifold Tank 1 Valve Failed Open	Failed to close, S/N 29. During the FD4 Presleep cryo config (MET 3/06:23), Cryo O2 Manifold Tank 1 Valve failed to close when commanded. The crew attempted to close the valve a few times, with no success. The crew was requested to command the valve open for ten seconds in an attempt to warm the valve by deeping the open solenoid energized - again, the valve would not close. The valve was successfully closed during the FD1 cryo presleep configuration. This value has failed on three previous missions while on OV-105 (STS-49, -54, & -57). Ability to isolate O2 Cryo Manifold

3.16-14

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
							Tank 1 was lost. Cryo O2 Manifold Tank 2 Valve was closed during sleep periods for the remainder of the mission. Sufficient cyro remained in O2 Tank 2 to support atleast NEOM + 3 with that plan.
STS-72	OV-105	01/11/1996	01/20/1996	PRSD	Cryo Heater	H2 TK4 Heater A failure	Broken fuse

3.16-15

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-75	OV-102	02/22/1996	03/09/1996	PRSD	Cryo Heater	H2 TK4 Heater Failure	At approximately 055/10:00 GMT, the quantities of Cryo H2 Tanks 4 & 5 began to diverge while in "paired" operation. Quantity divergence continued while both tanks were in operation until, by approximately 058/14:00, the quantity divergence had reached 20%. At this time the heaters were deactivated. Fuel Cell 3 current data indicated that the H2 TK4 A heater ceased to operate at the same time the quantity divergence between H2 Tanks 4 and 5 began. There was no impact to the mission. Oxygen is the limiting cryogenic, even if H2 Tanks 4 and 5 were not used again. The B heater for O2 TK4 may be operated. However, since one panel switch controls the B heater in both H2 Tanks 4 and 5, once Tank 5 is depleted, both tanks will be deactivated. The B heaters were reactivated to use as much H2 out of the tanks as possible. The result was that H2 Tanks 4 and 5 were depleted down to 2.4% and 2.0% respectively.

3.16-16

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-78	OV-102	06/20/1996	07/07/1996	PRSD	Cryo Heater	Cryo H2 Tank 4 B Heater Failure	Broken fuse. On OV-102, H2 Tanks 4 and 5 operate in paired configuration only and at approximately 175:11:49 GMT, the quantities in Tanks 4 and 5 (V45Q2400A, V45Q2500A) began to diverge. From the subsequent quantity data, it was suspected that Tank 4 was operating on a single heater element. Further troubleshooting procedures consisted of operating the A and B heaters separately to determine if a heater element had failed. There was no impact to the mission. The A heater in Tanks 4 and 5 were still operational. When the B heaters were operated in AUTO mode, and with the A heaters OFF, it was evident from heater temperatures that the Tank 4 B Heater had failed. Post-flight troubleshoot was required.
STS-79	OV-104	09/16/1996	09/26/1996	PRSD	Cryo Heater	Cryo H2 TK3 B Heater Failure	Broken fuse, had over 2300 cycles. Cryo H2 Tank 3 nominal configuration for Flight Day 10 crew sleep is A and B heaters in AUTO. At GMT 268/18:12:13 the heaters automatically cycled, however only the A heater discrete indicated ON; the B heater discrete (V45X2308E) failed to indicate ON. Subsequent data analysis clearly indicated H2 TK3 was operating on a single heater element. A slower pressure rise rate as compared to a previous cycle confirmed the heater B had failed OFF. H2 Tank 3 depletion was expedited to protect against next worst failure of losing the A heater. Post-flight troubleshooting was required to

3.16-17

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
							determine exact failure mode of H2 TK3 heater B.
STS-79	OV-104	09/16/1996	09/26/1996	PRSD	Cryo Valve	H2 Manifold Valve 1 Microswitch Failure	False CLOSE indication, S/N 20. At 266/17:42 GMT, the H2 MANF VLV 1 discrete toggled to the CLOSE position. It was determined that the valve was actually open based on pressure data. The associated FDA alarm was not generated because it had been inhibited on flight day 1 to avoid nuisance alarms. The crew was asked to confirm the Panel R1 talkback indication after they woke up. This failure occurred on STS-71 and STS-74. This failure could not be reproduced during ground testing. The previous failures were closed out as unexplained anomalies. There was no impact to the mission. Further ground testing required.

3.16-18

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-81	OV-104	01/12/1997	01/22/1997	PRSD	Cryo Valve	H2 Manifold Valve 1 Microswitch Failure	False CLOSE indication, S/N 20. At 17/01:12 GMT, the H2 Manifold Valve 1 discrete toggled to the CLOSED position. It was determined that the valve was actually open based on pressure data. The associated FDA alarm was not generated because it was inhibited on Flight Day 1 to avoid nuisance alarms. The crew confirmed the Panel R1 talkback indication showed closed. This failure occurred on STS-71, STS-74, and STS-79. This failure could not be reproduced during ground testing. There was no impact to the mission. The valve was removed during the next OMDP cycle.
STS-83	OV-102	04/04/1997	04/08/1997	PRSD	Cryo Valve	FC2 H2 Reac	Failed to close, S/N 66
STS-94	OV-102	07/01/1997	07/17/1997	PRSD	Check Valve	O2 TK2 Check Valve	Sticky valve, required 12 psid to relieve
STS-87	OV-102	11/19/1997	12/05/1997	PRSD	Quantity Transducer	H2 Tank 4 Quantity Measurement Failure	Failed OSH, recovered at depletion. At approximately 5/08:01 MET, the H2 Tank 4 quantity measurement (V45Q2405A) failed off-scale high. H2 tanks 4 and 5 were in AUTO and in the middle of a heater pressure. There was no impact to the mission. H2 tanks 4 and 5 were kept in AUTO (paired logically) through depletion of those tanks. H2 Tk4 quantity was estimated based on pressure, fuel cell usage, and relative H2 TK5 quantity. H2 tank 4 and 5 were depleted together, based on fluid and heater temperature levels (nominal method of depletion).

3.16-19

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-101	OV-104	05/19/2000	05/29/2000	PRSD	Cryo Heater	Cryo O2 TK4 A HTR Anomaly	Flight Day 2 Post Sleep Cryo Reconfiguration at GMT 141/00:01:24 the O2 TK4 heaters A and B were placed in AUTO. The first heater cycle at GMT 141/00:01:49 of this tank was nominal. During the second cycle at GMT 141/00:11:35 and subsequent cycles the O2 TK4 A heater did not cycle. There was no impact to the mission. Cycling of hte O2 TK4 A heater switch at GMT 141/16:11:39 to the OFF position and then back to AUTO regained the functionality of this heater.
STS-107	OV-102	01/16/2003	02/01/2003	PRSD	Cryo Heater	O2 Tank 7 Heater A Failure in ON Position	During the EDO Pallet Cryo O2 Tank Heater Sensor Check on FD2, when the Cryo O2 Tank 7 Heater switches were taken to the "ON" position at GMT 2003/017/13:25:50, the heaters failed to turn ON and the A RPC ON discretes (V45X3206E and V45X3211E) were not present. The A heater switch ON indication (V45S3231E) was present. Approximately ten minutes later, the crew performed the sensor check agian on O2 TK6 with the same results. There was no impact to the mission. At GMT 2003/018:04:08, the A heater on O2 TK7 was taken to AUTO. The A heater switch ON indication and the A RPC ON discretes were received. A full cycle of hte heater was observed and verified operational with the A heater switch in AUTO.

3.16-20

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## TITLE

DC POWER DISTRIBUTION AND CONTROL

## INTRODUCTION

The Direct Current (DC) power generated by the fuel cells is provided to the orbiter via the Electrical Power Distribution and Control (EPDC) system. The EPDC system provides distribution and control of all electrical power to the orbiter. This brief will cover the DC bus system only.

The shuttle electrical system consists of a three-bus system that distributes electrical power to the forward, mid, and aft sections of the orbiter. The EPDC system consists of wires, circuit breakers, resistors, fuses, diodes, remote switching devices, and bus bars.

This section describes the distribution of electrical power from the fuel cell to the various areas of the orbiter. The components and controls that manage the routing and distribution are addressed, as well as the crew procedures required. Refer to Shuttle Systems Handbook, drawing 2.2 (two pages), for detailed DC power distribution information. Figure 4.1.1-1 shows a simplified representation of the DC power distribution system.

## ORBITER ELECTRICAL BUSES

The power generated by the fuel cells is distributed throughout the orbiter via electrical buses. Each bus is protected from its sub-bus by some type of circuit protection.

All components receiving power from the orbiter are qualified to operate between 24 and 32 volts. However, components powered by the essential bus must be able to operate at near fuel cell open-circuit voltage (38 volts). Because of line losses, each bus voltage will be slightly different. The DC bus voltage will be maintained as follows:

- A. Main bus volts >27.0 (27.2) V DC or <32.0 (31.8) V DC
- B. Control bus volts >24.8 (25.0) V DC or <32.0 (31.8) V DC
- C. Essential bus volts >25.5 (25.7) V DC or <38.0 (37.8) V DC
- D. Forward PCA volts >26.2 (26.4) V DC or <32.0 (31.8) V DC
- E. Aft PCA volts >26.1 (26.3) V DC or <32.0 (31.8) V DC

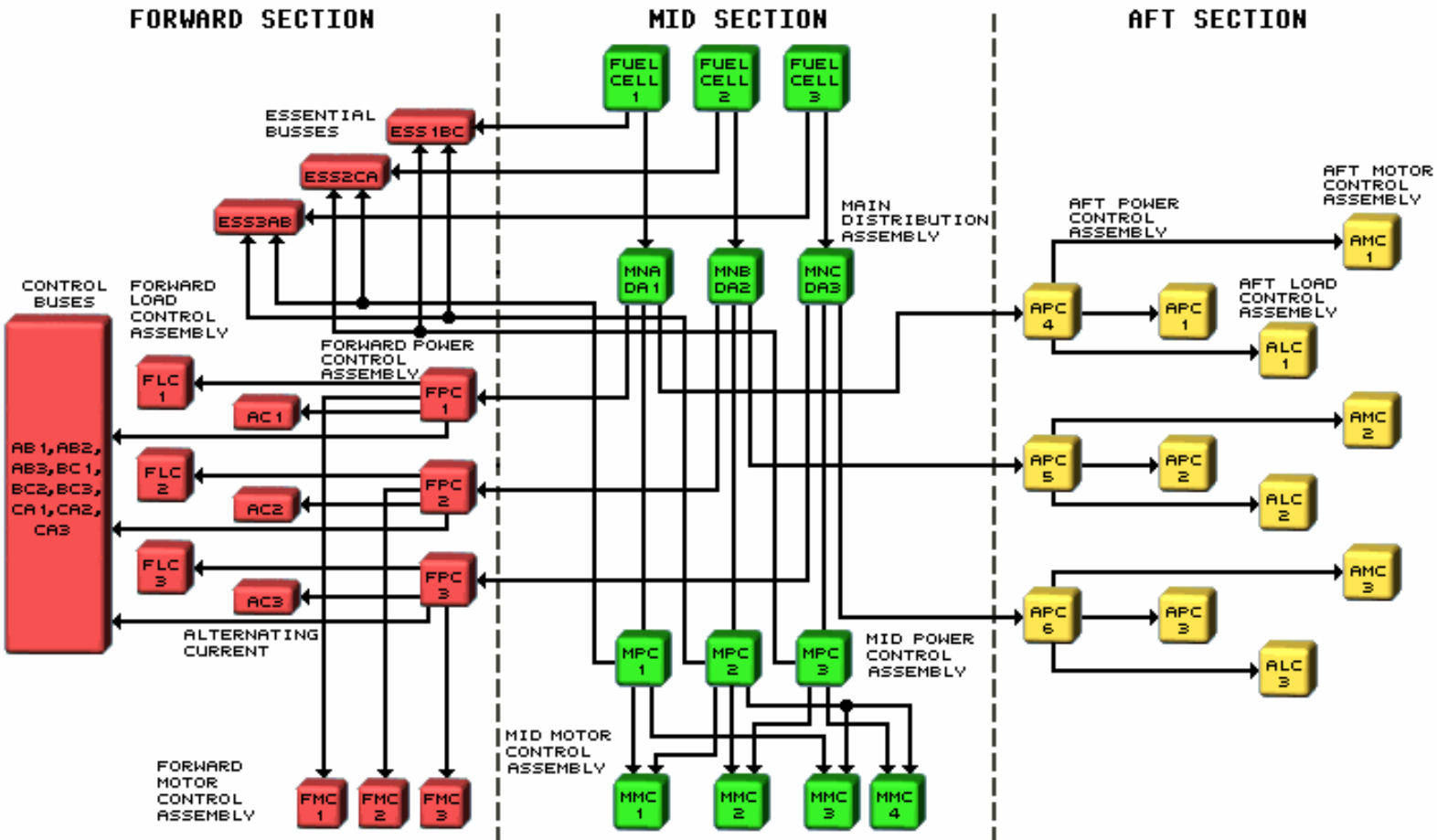


Figure 4.1.1-1. The DC power distribution

4.1.1-2

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Listed below are the types of DC buses used on the orbiter.

A. Main buses

The DC power generated by the fuel cells is routed to three main (MN) buses. FC1 supplies MNA, FC2 supplies MNB, and FC3 supplies MNC. The three main buses are the prime source of DC power for orbiter electrical loads. The MN distributes power to its associated sub-buses.

B. Essential buses

Each essential (ESS) bus is redundantly powered by three power sources. The three essential buses (ESS1BC, ESS2CA, and ESS3AB) are used to supply control power to electrical loads that are deemed essential (e.g., fuel cell and General Purpose Computer (GPC) switches).

C. Control buses

Control (CNTL) buses are used to supply control power to equipment with crew switch controls. There are nine control buses (CNTLAB1, 2, 3; CNTLBC1, 2, 3; and CNTLCA1, 2, 3).

D. Payload buses

The EPDC system provides DC power to flight-specific payloads via the following buses: primary payload (PRI PL), cabin payload (CABIN PL), aft payload (AFT PL), the auxiliary payload (AUX PL), and the orbiter utility panels.

## REMOTE SWITCHING DEVICES

The type of remote switching device used is determined mainly by the power requirement of its associated load.

A. Hybrid circuit drivers

Hybrid circuit drivers are solid-state switching devices used as logic switches for low-power electrical loads (less than 5 amps). When used as a logic switch, several control inputs are required to turn on a load. Hybrid circuit drivers are current-protected by internal fusible links.

B. Remote Power Controllers (RPCs)

An RPC is a solid-state device that supplies an output current equal to its input current, as long as a "control" signal is applied to a separate "control" input on the device. The control signal acts to enable or "turn on" the device. Removal of either the control signal or the input power results in zero output current. Figure 4.1.1-2 shows a schematic representation of an RPC. RPCs are used for loads requiring current in a range of 3 to 20 amps. They have a current-limiting capability whereby they limit the output current from 125 to 150 percent of rated value for 2 to 3 seconds. Within 3 seconds, the RPC "trips," which removes the

output current. To restore power to the load, the RPC must be reset by removing and reapplying the control signal. RPCs are also current-protected by fusible links.

If multiple control inputs are required before an RPC is turned on, hybrid circuit drivers usually are used as the logic switch that drives the control input of the RPC.

C. Relays and power contactors

A relay is typically used as a switch to connect a power source to a load. The power source usually resides as a sub-bus in a power or motor control assembly. The relay is opened and closed by applying a control signal to the relay coils. The control signal is made up of current from a control bus and controlled by a mechanical switch in the crew module. The magnetic field generated by the control power causes the contacts to open or close, which controls the passage of high current from one side of the contacts to the other.

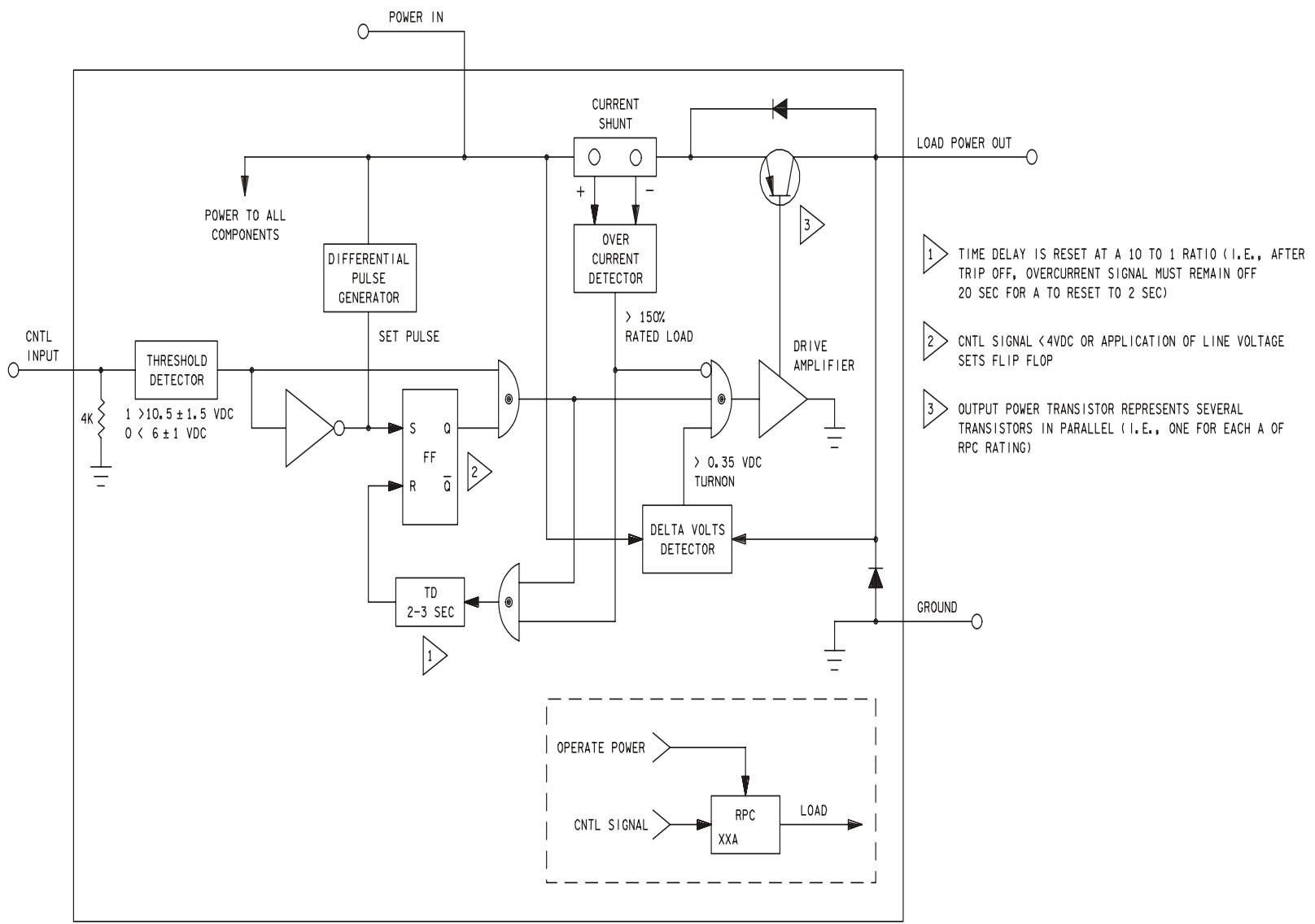
Power contactors differ from relays in size and current-carrying capability. Motor-driven power contactors are used for connecting fuel cell to MN and MN bus tie by mechanically forcing a large pin(s) into a cylindrical receptacle. The length of each pin is 0.5 feet, and the diameter is 0.5 inch. Connection of the fuel cell/MN bus and MN bus ties requires excellent surface contact (therefore, a tight fit) between the pin and receptacle. A great amount of force is required to drive the pin into the receptacle, ensuring the necessary surface contact.

D. Hybrid relays

Hybrid relays are four-pole nonlatching relays with a solid-state logic circuit for opening/closing the contacts. They are used to switch three-phase Alternating Current (AC) power to motors and are rated at 4 amps inductive.

## ASSEMBLIES

The orbiter DC power distribution system was designed to minimize wire lengths (hence line loss) by placing the sub-buses near respective major loads in the forward, mid, or aft sections of the orbiter. The sub-buses are manufactured as self-contained units (Line Replaceable Units (LRUs)), called sub-bus assemblies. Sub-bus power to the loads is always available but isolated by remotely controlled switches (most often RPCs). The control signal necessary to activate the control device is turned on and off with cabin panel switches that receive power from the control buses. The four types of assemblies used include Main Distribution Assembly (MN DA), Power Controller Assembly (PCA), Load Controller Assembly (LCA), and Motor Controller Assembly (MCA).



4.1.1-5

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Figure 4.1.1-2. Schematic representation of an RPC

A. Main A (B,C) Distribution Assemblies (DAs 1(2,3))

Each DC main DA receives power from a fuel cell. The DAs provide circuit protection and power distribution to the forward and aft fuselage avionics and the payload. The location of the main DAs is in the mid-fuselage adjacent to the fuel cell that powers the assemblies. The placement reduces the wire run length between the fuel cell and the DA to save weight and to reduce line losses. The only switching devices in the distribution assemblies are power contactors. Other internal components include connectors, 500-A, 50-mv shunt, resistors, diodes, fuses, and holders. The DA and its components include the following:

1. Main bus bar (Main A DA1, Main B DA2, Main C DA3).

Connected to the main bus are all the sub-buses powering the components assigned to that distribution system. Each sub-bus is protected by either a fuse or an RPC. Power to the main bus from the fuel cell is applied through a zero-gauge, nonfuse-protected feeder by closing the FC/MAIN BUS switch on panel R1. The normal main bus voltage should be between 27 and 32 volts.

2. Essential bus bar (ESS 1BC, 2CA, 3AB).

Connected to this bus are those circuits used for critical equipment control power (e.g., cryo pressure control and fuel cell operation). Each circuit is fuse-isolated. Power to the ESS bus is supplied directly from the fuel cell by closure of the ESS BUS SOURCE FC 1 (2,3) switch on panel R1. In addition to the fuel cell power source, the ESS bus is also powered by two MN DA sub-buses via RPCs by closure of the ESS BUS SOURCE MN B/C (C/A, A/B).

3. Motor-driven contactors

- a. Main bus-to-main bus tie connection
- b. Fuel cell-to-main bus connection
- c. Main B(C)-to-PRI P/L bus
- d. FC3-to-PRI P/L bus

4. Current shunt for fuel cell current readout on panel F9, crew display, and to TM (V45C0101A, V45C0201A, V45C0301A).

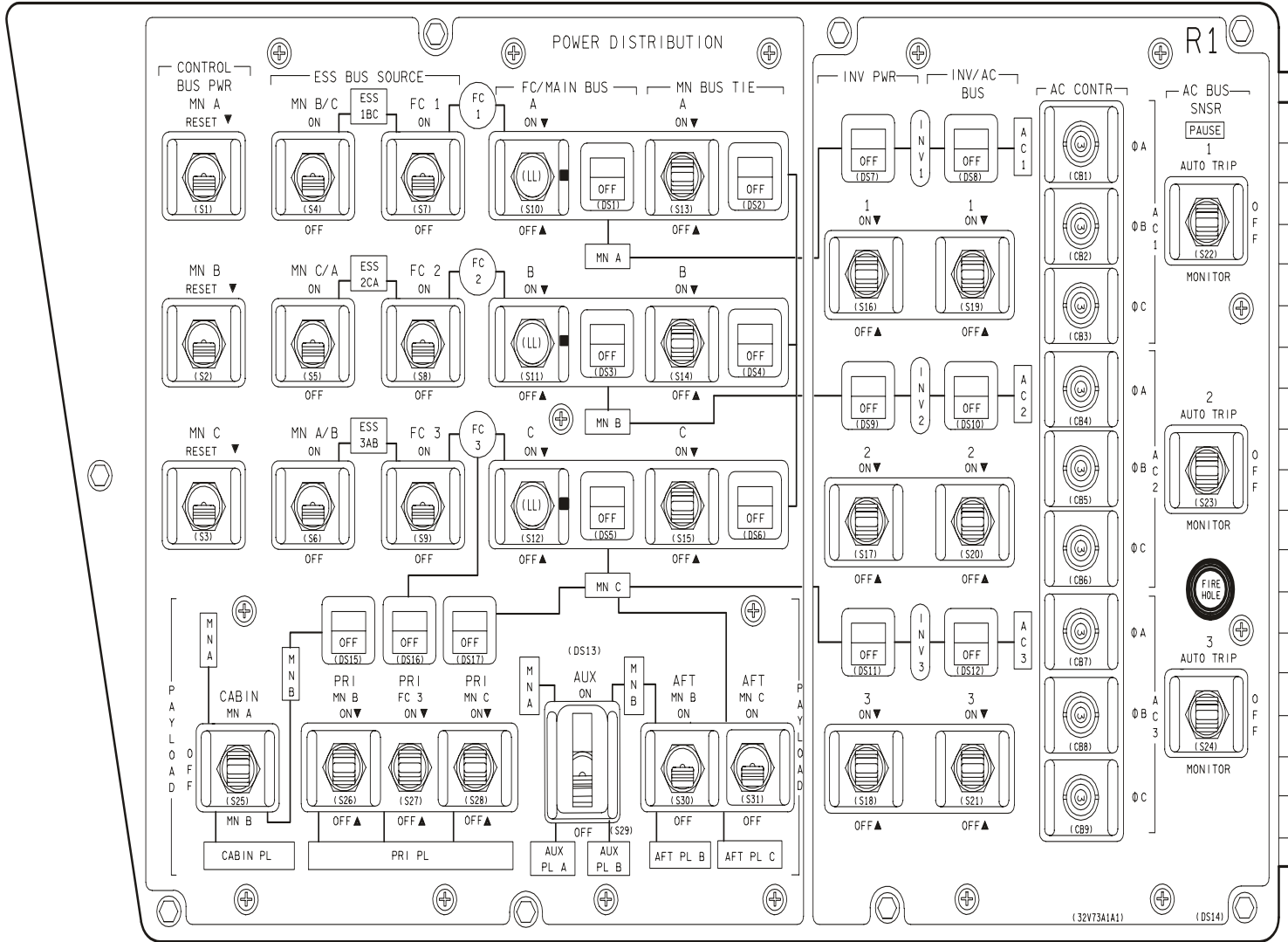
5. Voltage readout circuit of fuel cell volts for readout on panel F9, crew display, and to TM (V45V0100A, V45V0200A, V45V0300A).

6. Voltage readout circuit of main bus volts for readout on panel F9, crew display, and to TM (V76V0100A, V76V0200A, V76V0300A).

7. A separate voltage sensor supplies a signal to the Caution and Warning (C&W) system (main bus undervolts).
8. Crew controls to the DA are all on panel R1 and consist of the following switches (see Figure 4.1.1-3):
  - a. Fuel cell/main bus connection with talkback (tb)
  - b. ESS bus source FC1 (2,3)
  - c. ESS bus source MN B/C (C/A, A/B)
  - d. MN bus tie with tb
  - e. PRI FC3 (to primary payload bus) with tb
  - f. PRI MN B (to primary payload bus) with tb
  - g. PRI MN C (to primary payload bus) with tb



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4.1.1-8



128304113. PNL 1

Figure 4.1.1-3. Panel R1

B. Power control assembly

The forward, mid, and aft PCAs (1, 2, 3) supply DC power to components located in those areas. The PCA is located so that its bus is near the components to be served in order to reduce wire runs so that weight can be saved and line losses reduced. The location of each PCA is listed below:

1. Forward power control 1 (FPC 1) - AV bay 1
2. Forward power control 2 (FPC 2) - AV bay 2
3. Forward power control 3 (FPC 3) - AV bay 3
4. Midpower control 1 (MPC 1) - Midbody CP
5. Midpower control 2 (MPC 2) - Midbody CP
6. Midpower control 3 (MPC 3) - Midbody CP
7. Aft power control 1 and 4 (APC 1 and 4) - Aft AV bay 4 CP
8. Aft power control 2 and 5 (APC 2 and 5) - Aft AV bay 5 CP
9. Aft power control 3 and 6 (APC 3 and 6) - Aft AV bay 6 CP

The FPCs are water cooled, and all other PCAs are cooled by the orbiter Freon coolant loops.

Each PCA contains main bus RPCs and relays for remote switching. The PCAs serve as power control and switching centers for power being supplied by the DA. The crew has control over RPCs and relays within the PCA by operating panel switches within the crew cabin.

1. Forward Power Control Assemblies (FPCAs 1,2,3)

Power from MNA (B,C) DA 1 (2,3) is applied directly to the FPC bus by a fuse-protected feeder that is 3-wire, zero-gauge, and 150 amps. A current sensor wound around the feeder measures forward amps (V76C3075A, V76C3076A, V76C3077A). The sensor is powered by the DA.

The MN FPCs provide power to the following buses:

- a. AC power-generating system using three RPCs controlled by the INV PWR 1 (2,3) switches on panel R1.
- b. Six of the nine control buses using three RPCs. These RPCs are normally powered but, if tripped, can be reset by the CONTROL BUS PWR RESET switches on panel R1. The reset drivers for the RPCs are physically located in the Forward Load Control Assembly (FLCA 1,2,3).

- c. The Forward Motor Control Assemblies (FMCAs 1,2,3), which apply main bus power through relay drivers to motors, valves, pumps, etc.

In addition to the above listed circuits, the FPCAs contain additional RPCs and solenoid-driven relays to control power to various applications (e.g., Reaction Control System (RCS), Inertial Measurement Unit (IMU), and Data Processing Systems (DPS) switches).

## 2. Midpower Control Assemblies (MPCAs 1,2,3)

An MPCA is physically located near its associated fuel cell and DA. Main DA bus power is routed to main bus MPC 1 (2,3) by a 100-amp, fuse-protected, 2-gauge feeder and a return. A current sensor powered by the DA is wound around the fused feeder and measures mid amps (V76C3085A, V76C3086A, V76C3087A). The MPCA contains relay drivers and solenoid-driven relays to control power to various components and applications, such as motors, valves, heaters, etc.

MPC 1,2,3 powers directly the Midmotor Control Assemblies (MMCAs) that supply main bus power to payload bay door motors, latch drives, etc. Voltage requirements at the main MPC bus should be between 27 and 32 volts.

## 3. Aft Power Control Assemblies (APCAs 1,2,3,4,5,6)

The APCAs provide power and circuit protection for the aft fuselage, AV bay equipment, the SRB, and the controls for Ground Support Equipment (GSE) distribution. The APCA main bus APC 4,5,6 buses are powered directly from the main bus DA by two 200-amp, fuse-protected, zero-gauge feeders. A current sensor wound around these wires, powered from the DA, measures aft amps (V76C3095A, V76C3096A, V76C3097A).

Because of the large demand for power in the aft area and the need for a large number of RPCs and relay drivers, three additional APCAs are installed: APC1 powered by APC4, APC2 powered by APC5, and APC3 powered by APC6. The APC 4(5,6) bus powers the APC 1(2,3) directly through a zero-gauge, 150-amp, fuse-protected feeder with a return.

APCAs 4, 5, and 6 are essentially identical in design and contain RPCs and relay drivers. APCAs 1, 2, and 3 are somewhat different in that they contain a varying number of RPCs and relay drivers. They also contain solenoid-driven relays for large load demands.

## C. Load Control Assemblies (LCAs)

The LCAs are all located in the same areas as the PCAs to reduce PCA-to-LCA line losses and to save weight.

No midload control assemblies are required, because the MPCAs contain all the necessary RPCs and relay drivers to manage the midbody loads.

1. Forward Load Control Assemblies (FLCAs 1,2,3)

The FLCAs are powered directly from the main bus FPC 1, 2, and 3 via an 8-gauge, 35-amp, fuse-protected feeder and return.

2. Aft Load Control Assemblies (ALCAs 1,2,3)

The ALCAs are powered directly from the main bus APC 4,5,6 via a zero-gauge, 100-amp, fuse-protected feeder. A voltage measurement on the feeder downstream of the fuse reads APC of aft voltage (V76V3091A, V76V3092A, V76V3093A).

D. Motor Control Assemblies (MCAs)

The MCAs are located in the same area as their associated DA, PCA, etc. Each MCA contains a main DC bus and one or more AC buses. Control bus power from switches or Multiplexer/Demultiplexer (MDM) commands turns on a relay driver that applies main bus power to a set of relays. The relay contacts route AC power to the appropriate motor. MCAs contain hybrid relays, which are the remote switching devices for switching the AC power to the electrical loads.

Three forward MCAs contain the three main buses: MNA FMC1, MNB FMC2, and MNC FMC3. Each Forward Motor Control (FMC) also has three AC buses powered directly from the AC buses. The RCS has its own AC sub-bus. The FMCAs supply power to the forward vent doors, star tracker doors, and air data probe doors. The RCS AC bus supplies power to the forward RCS manifold and tank isolation valves.

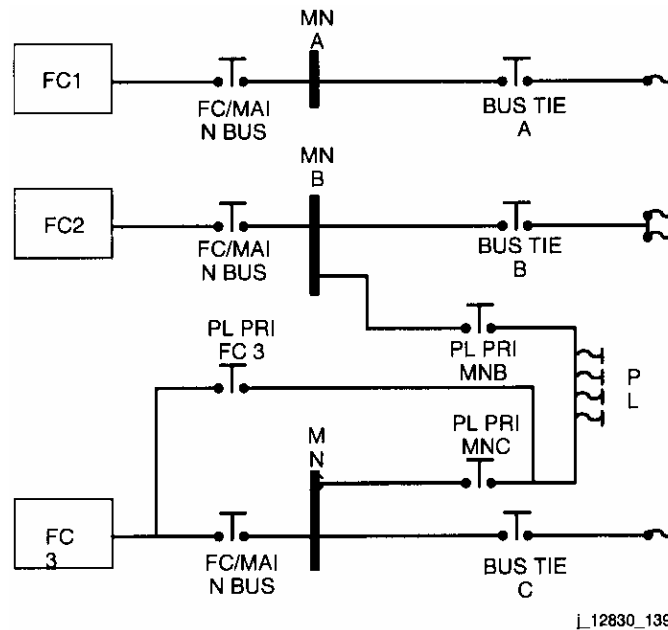
Four MMCAAs are used in the mid area. Each MMCA contains two main buses and two AC buses. MMCAAs 1 and 3 (MMC 1 and MMC 3) are powered by MNA and MNB, AC1, and AC3; MMCAAs 2 and 4 (MMC2 and MMC4) are powered by MNB and MNC, AC2, and AC3. Payload bay door and latch motors are typical loads in the midsection.

The Aft Motor Control Assembly (AMCA) consists of three MCAs, each containing a main bus (MNA AMC1, MNB AMC2, MNC AMC3) and a corresponding AC bus. The Orbital Maneuvering System/Reaction Control System (OMS/RCS) also contains its own main and AC sub-buses. Typical loads powered by the AMCAAs are the aft vent doors and the external tank centerline latches and doors. The OMS/RCS AC bus powers the aft OMS/RCS manifold tank isolation and crossfeed valves.

## BUS TIE

Main buses are normally isolated from one another so that a main bus short will not affect another main bus. However, the capability exists to electrically connect the main

buses (in any combination) with an electrically controlled motor switch. For example, if MNA is “tied” to MNB, this effectively makes both tied distribution systems one system powered by one or both FCs. The tie bus is composed of three zero-gauge, 150-amp, fuse-protected feeders between the tie switches. Figure 4.1.1-4 shows the configuration of buses, the tie bus, and the bus tie switches.



**Figure 4.1.1-4. Bus tie, switch, and bus configuration**

Main buses are typically tied for the following situations:

1. To support the high-power Spacehab loads on the primary payload buses, MNB and MNC may be tied.
2. To maintain three main bus integrity prior to a fuel cell being shut down, its main bus is tied to another main bus.
3. To regain insight into a fuel cell performance because of suspected or failed instrumentation.
4. In performance of malfunction procedures to minimize load transients on the fuel cells (i.e., electrical load >18 kW).
5. If concern exists that the health of a fuel cell is in jeopardy, the fuel cell main bus is tied to another healthy main bus (i.e., OPCL-COOL P).

## ESSENTIAL BUS DISTRIBUTION AND CONTROL

As the name implies, essential bus power is used for very critical applications, such as restoring power to a fuel cell, AC system, or GPC. Essential bus power is also used to

power switching discretely to MDMs. Because of its criticality, each essential bus is powered by three independent power sources: ESS1BC is powered by FC1 and main buses B and C; ESS2CA is powered by FC2 and main buses A and C; and ESS3AB is powered by FC3 and main buses A and B.

The fuel cell-to-main bus connection is made from panel R1 by placing the ESS bus source/FC1 (2,3) switch to ON. Main bus power activates two 20-amp RPCs, which then connect main bus power from the two main buses not associated with the system to the essential bus via a 16-gauge dual wire, 20-amp, fuse-protected feeder. Diodes in both the fuel cell and main bus feedlines are diode-protected to prevent power feedback between the fuel cell and the main buses.

### **CONTROL BUS DISTRIBUTION AND CONTROL**

Control bus power is used as switching power to enable a driver or RPC to supply main bus power to a component. It is generally not used to supply operational power to loads. The control bus allows the number of wire runs for control and power to be reduced. In addition, the control wire can be made of a smaller gauge.

There are nine control buses, each powered by three main bus sources for redundancy. Each control bus receives power from two RPCs and a 10-amp, fuse-protected circuit breaker. The labeling includes the two main RPC power sources and the number of the bus. For example, control bus AB1, AB2, and AB3 are three buses powered by both the main A and main B RPC. Three RPCs located in the forward power control assemblies route main bus power to the appropriate control buses. For example, main A RPCs 1, 2, and 3 route main A power to control buses AB1, AB2, AB3, CA1, CA2, and CA3.

Control buses are located only in the flight and middeck areas behind the Display and Control (D&C) panels. No crew action is required to power these buses except to reset a tripped RPC via the control bus PWR MN A (B,C) RESET switch on panel R1.

### **PAYLOAD BUS POWER**

Panel R1 shows in schematic form how the payload power distribution is designed and controlled. The buses as shown on panel R1 are as follows:

- A. Primary payload - The primary electrical interface for payloads. It is located in the midsection of the payload bay. The primary payload bus receives power from the following:
  - 1. FC3 - By placing the PRI FC3 switch to the ON position and verifying the bus on. FC3 can supply up to 8 kW continuous at 27.2 V DC to the primary payload bus.
  - 2. MNB - By placing the PRI MNB switch to the ON position and verifying the bus on. The MNB source can supply up to 7 kW continuous.

3. MNC - By placing the PRI MNC switch to ON and verifying the tb on. MNC can supply up to 7 kW continuous to the primary payload bus.

The FC3/MNB/MNC-to-PRI PL BUS connection is via a zero-gauge, fuse-protected feeder. Refer to SSSH, drawing 2.2, sheet 2 of 2, for details.

MNC is the normal source of power to the primary payload bus. Although the FC3 source has the same power constraints as the MNC source, MNC is the preferred power source to the payloads. The MNB source does not have the power capabilities of the other sources because of the fuse sizing between the MNB bus and the primary payload bus. FC3 and MNB or MNB and MNC are never used simultaneously via the primary payload bus, because that would effectively bus tie two main buses. This method of bus tying is used only if the normal tie method is unusable.

B. Aft payload

Power is provided in the aft section of the payload via the aft payload buses B and C by placing either switch on panel R1 to the ON position. These buses are located near X1307 and supply 1.5 kW average (2 kW maximum) at 25.2 V DC.

C. Auxiliary payload

The auxiliary payload A and the auxiliary payload B, located in the mid-payload bay area (X645), can supply a total of 0.4 kW from main A and main B buses. Because the two sources are diode protected, both sources can be used simultaneously.

D. Cabin payload

The payload cabin switch provides MNA or MNB power to patch panels located in the aft flight deck under the payload specialists and mission specialists stations. Three-amp RPCs in the MPCA route FPC1 and FPC2 power via 3- to 12-gauge feeders to these buses.

E. Fuel cell structure return

The FC3 structure return switch on panel A11, which provided the capability to isolate FC3 from the orbiter structure for payload purposes, is not operational. The switch was disabled because there was some concern that fuel cell damage could occur.

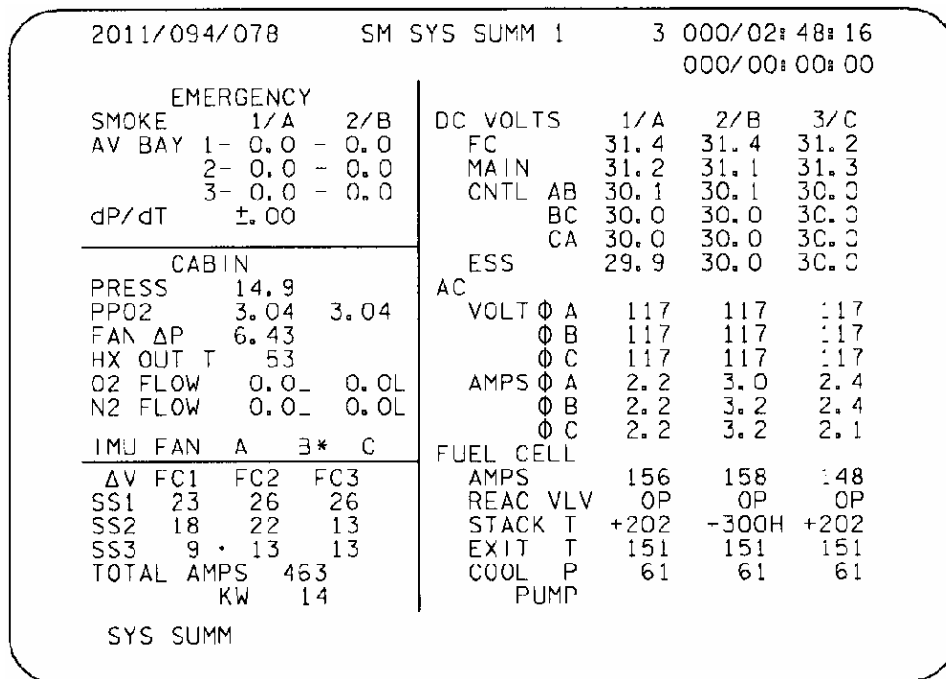
F. DC utility outlets

The DC outlets are located on the flight deck (panels A15A1, F1, A11, A1, and 019) and middeck (panels M013Q, M052J, and M030F). These outlets operate at 28 V DC and are protected by 10-A circuit breakers. Refer to SCP 4.4.1 for more information on utility outlets.

**CREW AND GROUND DISPLAYS**

Onboard CRT displays for monitoring the EPDC include SM OPS 2 SYS SUMM 1, BFS SYS SUMM 1, and SM OPS 2 S67 ELECTRIC (see Figure 4.1.1-5, Figure 4.1.1-6, and Figure 4.1.1-7).

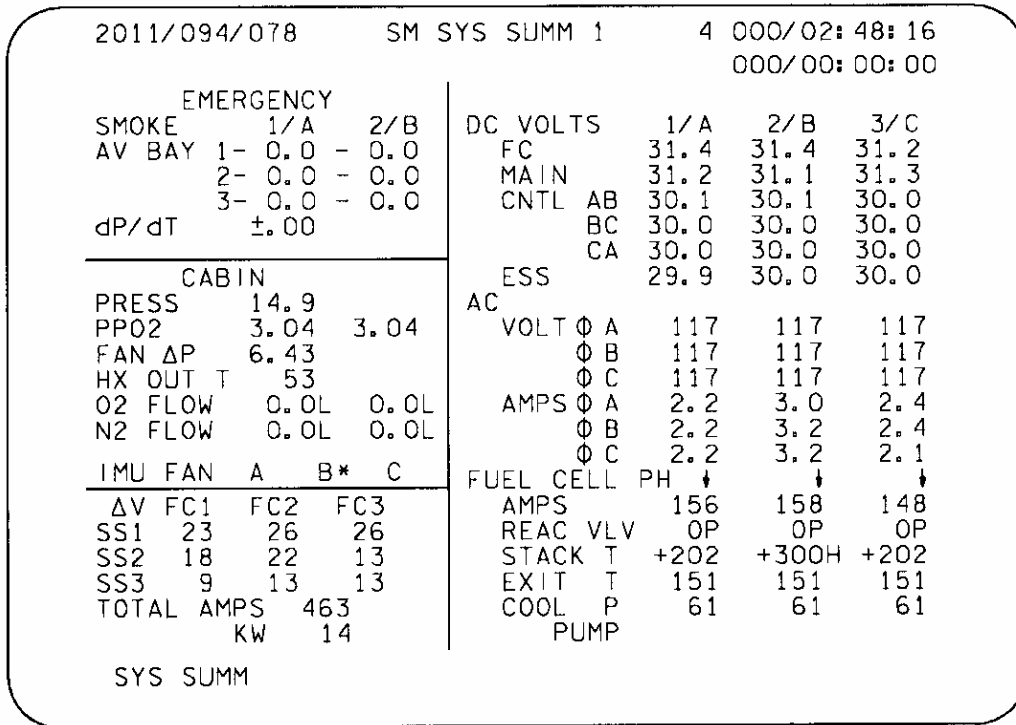
The EGIL\_FC\_EPDC (Figure 4.1.1-8) is the primary console display for monitoring EPDC parameters; DC volts and amps are shown for the various buses in the upper left-hand corner of this display. The status of the bus tie switch is also shown. Additionally, the status of the CNTL and ESS RPCs are shown. Parameters for monitoring payload power are shown on the CRYO\_5TK\_ORB display (see Figure 4.1.1-9).



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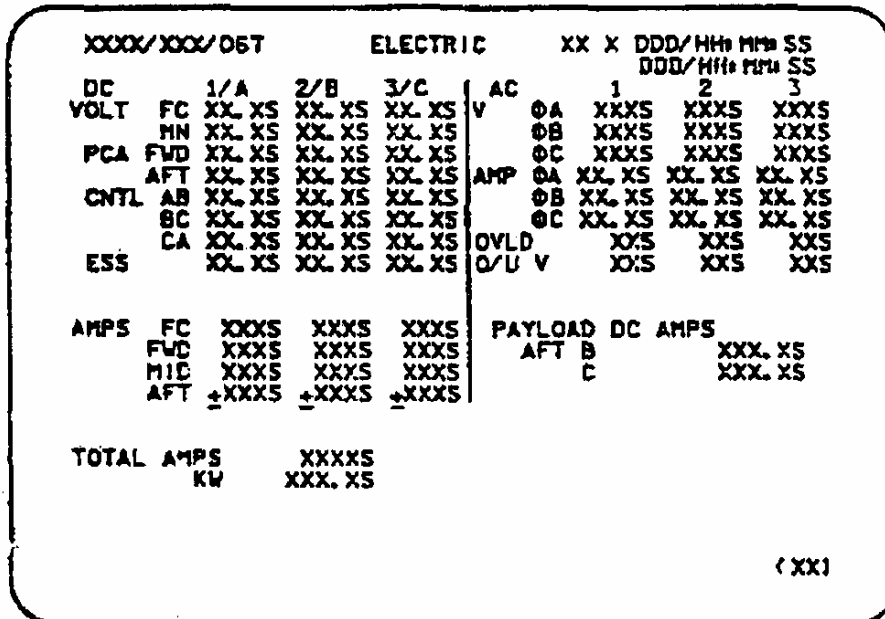
**Figure 4.1.1-5. EPDC parameters on SM OPS 2 SYS SUMM 1 CRT display**





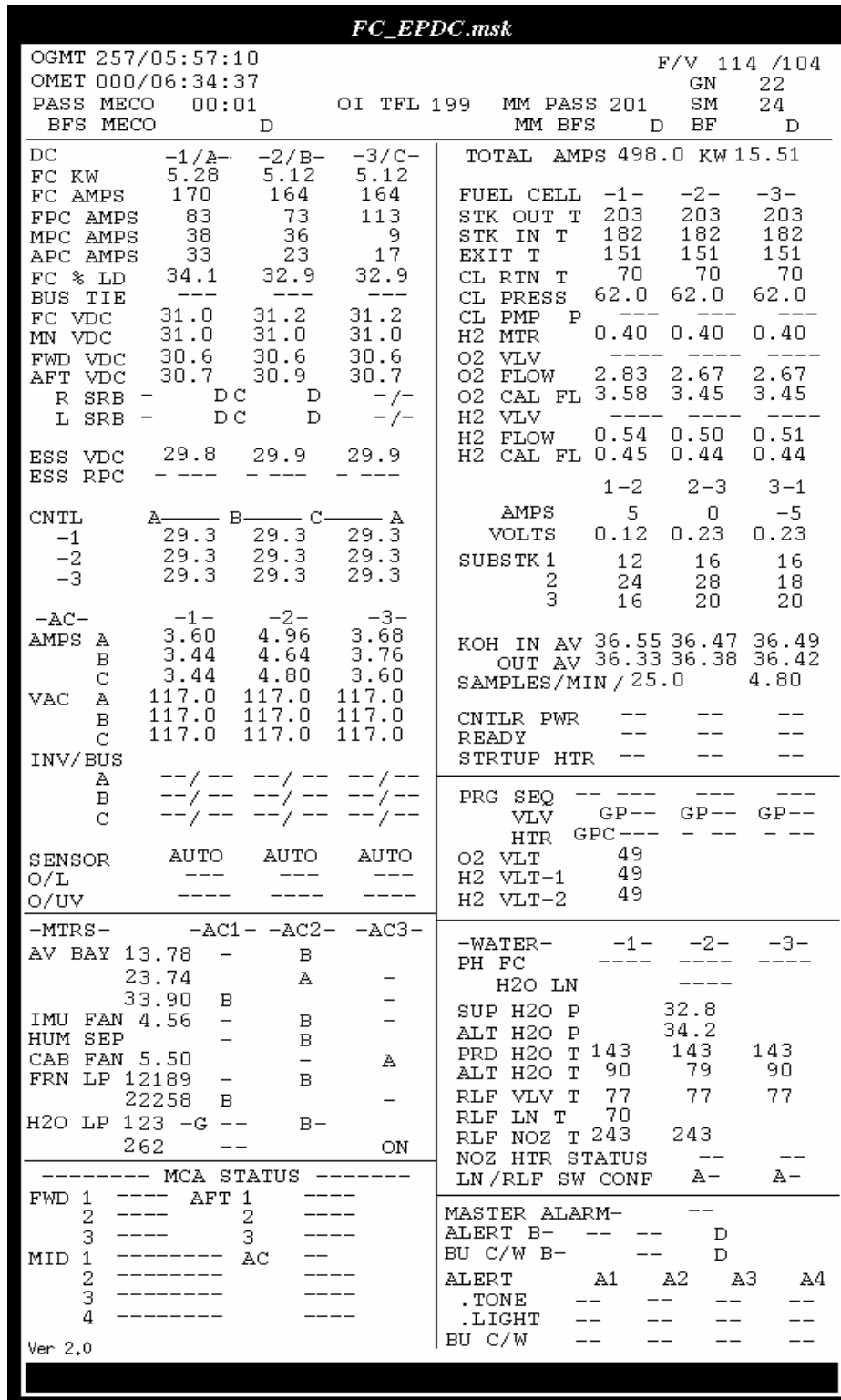
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Figure 4.1.1-6. EPDC parameters on BFS SM SYS SUMM 1 CRT display



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Figure 4.1.1-7. SM OPS 2 ELECTRIC CRT display



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Figure 4.1.1-8. EGIL\_FC\_EPDC display

CRYO_ORBIT.msk									
F/V 114 / 104		OGMT 256/23:20:25			OMET 256/23:20:25				
CRYO O2		1	3	4	5	2			
TANK P		950	950	950	950	950			
CNTL P		949	951	951	951	949			
MANF P-VLV		950	- OP			OP - 950			
PCS VLV/P		OP / 948				OP / 948			
Q(%)		99.6	99.6	99.6	99.6	99.6			
FLUID T		-250	-250	-250	-250	-250			
HTR 1 T		-250	-257	-257	-257	-250			
HTR 2 T		-250	-257	-257	-257	-250			
HTR A1/B1		-- / --	-- / --	-- / --	-- / --	-- / --			
HTR A2/B2		-- / --	-- / --	-- / --	-- / --	-- / --			
SNSR 1 A/B		- / -	- / -	- / -	- / -	- / -			
SNSR 2 A/B		- / -	- / -	- / -	- / -	- / -			
HTR SW A		-- AUTO	-- ----	-- ----	-- ----	-- AUTO			
HTR SW B		-- ----	-- ----	-- ----	-- ----	-- ----			
CRYO H2		1	3	4	5	2			
TANK P		249	249	249	249	249			
CNTL P		249	249	249	249	249			
MANF P-VLV		248	- OP			OP - 248			
Q(%)		99.3	99.3	99.3	99.3	99.3			
FLUID T		-416	-416	-416	-416	-416			
HTR T		-416	-416	-416	-416	-416			
HTR A/B		-- / --	-- / --	-- / --	-- / --	-- / --			
HTR SW A		-- AUTO	-- ----	-- ----	-- ----	-- AUTO			
HTR SW B		-- ----	-- ----	-- ----	-- ----	-- ----			
PAYLOAD POWER				TOTAL: O2 3890.21		KW-H 18.61			
FC3	MNA	MNB	MNC	H2 456.56		AMP-H 600.48			
PRI	--	--	--	CABIN P	14.7	-1-	-2-		
AUX	--	--	--	AIRLOCK P	0.2	EMU VOLTS	0.0 0.0		
CABIN	--	--	--	CABIN A/L dP	0.0	AMPS	-0.22 -0.22		
AFT P/L	--	--	--	CABIN dP/dT	0.0	EVAP OUT T	41 41		
AFT AMPS		0.0	0.0	PPO2 A	3.2				
AFT KWH		0.00	0.00	B	3.2				
PL/MNC GND			MNC	C	3.2				
				EVLSS PRESS	948				
Ver 2.0									

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Figure 4.1.1-9. CRYO\_5TK\_ORB display

## TITLE

MCA DISTRIBUTION

## PURPOSE

The purpose of the MCAs is to supply 3 $\phi$  AC power to various noncontinuously operating motors. MCAs are located in the forward, mid, and aft sections. The MCAs are normally referred to by their location and MCA number in that area. As an example, the no. 1 MCA in the aft end of the orbiter is referred to as AMCA1. We currently have a total of 10 MCAs in the orbiter, three in the forward, four in the mid, and three in the aft sections.

Typical applications for each group of MCAs are listed below.

<u>FMCAs</u>	<u>MMCAAs</u>	<u>AMCAAs</u>
RCS valves	PLBD open/close	OMS/RCS valves
Vent doors	Vent doors	Vent doors
ADTA probe deploy	RAD deploy	ET doors
Star tracker doors	RMS retention	
	PL retention	
	Ku-band antenna deploy	

## OPERATION

MCAs control motor-operated valves, latches, and positioning mechanisms. To ensure safe operations, some provision must be made to turn these motors off when the mechanism reaches its desired position. This is accomplished with the MCAs. For example, an MCA will receive a command from either a panel switch or MDM discrete and will buffer the command with the position feedback switches. The output will be set high only if the device in question is not already in the desired position. The output drives an amplifier that is connected to a relay solenoid. When energized, three AC poles on its associated relay close, while opening a fourth pole to indicate operational status.

The three phases of the AC source are circuit protected by individual circuit breakers, one for each phase of the AC bus, or by means of a 3 $\phi$  "ganged" circuit breaker assembly. If an overcurrent exists on any phase, the ganged circuit breaker assembly will open, interrupting power from all three phases of the AC source.

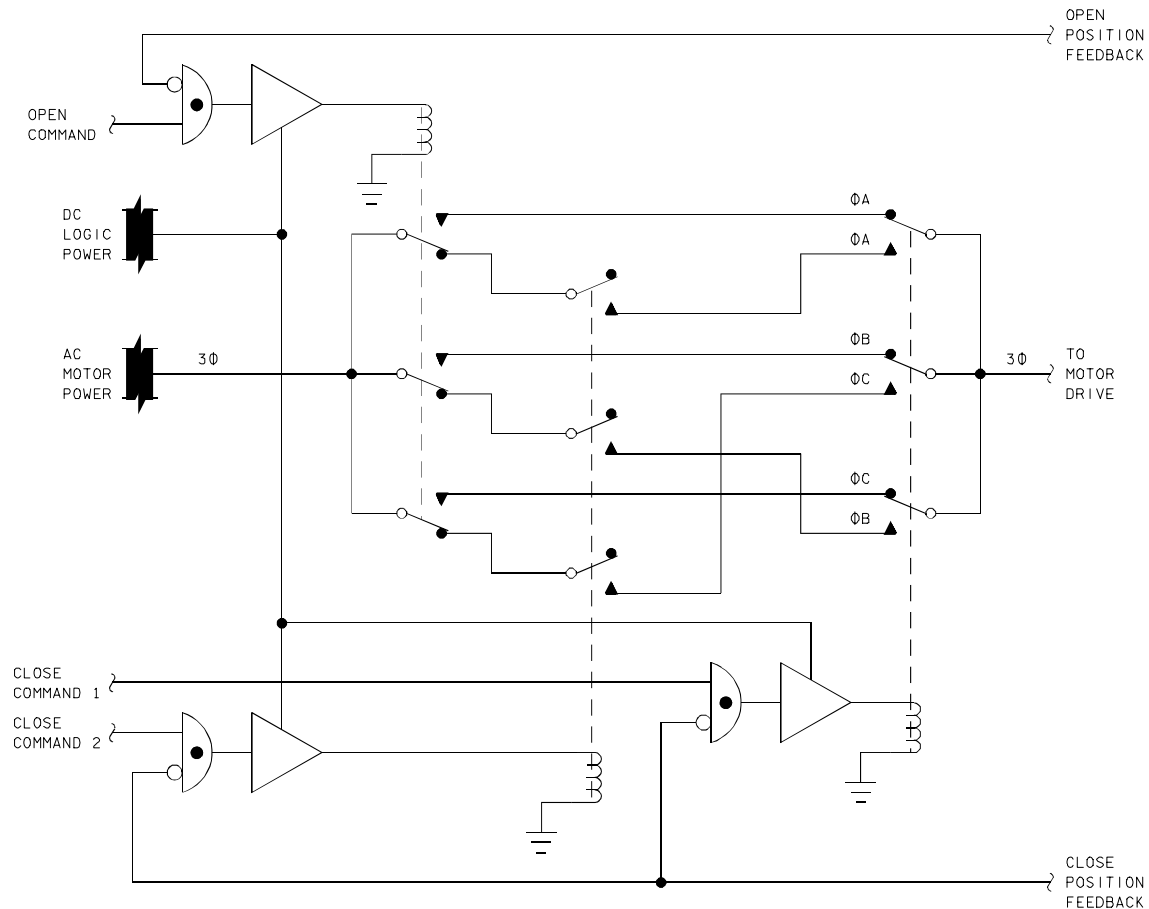
When the relay closes, AC power will be transmitted to the appropriate motor, and it will begin to run. As the motor runs, it drives an associated mechanical mechanism. Once the mechanism reaches its desired state, it will activate a microswitch, which will send a signal back to the command amplifier, causing its output to go low. The solenoid will now be powered off, and the three AC contacts will transition to their normally open position, while the fourth operational status contact transitions back to its normally closed position.

To drive the mechanical device back to its original state, a separate command is issued, which energizes a different relay solenoid. The relay contacts associated with this solenoid connect the same AC source to the motor, except that phases B and C will be reversed. This will cause the motor to run in the reverse direction.

The purpose of the fourth relay contact on a given relay is for telemetry monitoring. The fourth contact on many relays in a given MCA are connected together in series. This configuration is often referred to as a “daisy chain.” The input to this daisy chain is a 28 V DC signal. The output of the daisy chain is referred to as a status bit and will be monitored through an MDM. A typical MCA illustrating basic MCA design is shown in Figure 4.1.2-1. Aft and forward MCAs contain four status bits, and mid MCAs contain eight status bits.

It is sometimes difficult to determine what mechanical device is being driven by scanning the MCA status bits. Because many devices have redundant commands for a particular action, multiple MCA status bits will be interrupted when that action is being taken. The pattern of MCA bits generated during a particular operation is a valuable key to the EPS operator in trying to determine what operation is being done. The MCA status bits can be viewed on MSK FC\_EPDC. A section is published in this handbook (MCA Status vs. Function) that gives the associated operation as a function of MCA status bit pattern. Consult that SCP, along with the appropriate systems handbook drawings for reference.

Since several operations will generate the same pattern of MCA status bits, it is sometimes necessary to use other factors to determine what operation is being done. These include AC bus current signatures as displayed on console, A/G and flight loop transmissions, and particular activities that can be referenced in documents such as the Flight Plan.



128304301, SCH# 1

**Figure 4.1.2-1. Basic MCA design**

## POWER

Both AC and DC power are supplied to the MCAs.

As explained previously, the AC power can be circuit protected by individual circuit breakers or ganged circuit breakers. The use of these ganged circuit breakers could present a problem in the case of an AC bus short. Supplying two-phase power to the motors through ganged circuit breakers would cause the transformer effect of the motors to couple energy back through the unpowered phase and into the short, causing the ganged breaker to open, thus removing all power from the motor. The malfunction procedures, therefore, require the action to open all of the 3 $\phi$  ganged circuit breaker assemblies connected to a single-phase bus short. It is important to realize that opening these ganged breakers, in effect, causes loss of associated MCA AC sub-buses. Flight rules and malfunction procedures then must be performed for a total loss of the sub-buses themselves. It should be noted that several of these sub-bus losses necessitate a next-PLS entry.

In most cases, AC power is run directly from its circuit breakers on panel MA73C and into the MCA, where it becomes immediately available for use by the motor relays. However, there are some exceptions to this in the MMCAs.

In case of the Payload Bay Doors (PLBDs), the AC buses first pass through relays that are configured closed via software commands. These relays enable the AC PLBD buses in the MMCAs. The drivers for these relays were originally powered through the same switches (panel MA73C) that provide control (logic) power to the MMCAs. Since this logic power is always enabled, a malfunctioning GPC could send a command to these drivers engaging power to the PLBD motors (causing the doors to open/close) at an inappropriate time. This could result in loss of crew and vehicle.

To work around this problem, two switches were installed (PL BAY DR SYS 1 and SYS 2) on panel R13A2. The circuitry was changed so that the drivers on the ac PLBD buses will be enabled through these new switches and not from the same switches that provide control power to the MMCAs. Thus, the relays associated with each of the motors will engage power only if the drivers are armed through the PL BAY DR enable switches and the appropriate commands are sent from an MDM.

One problem with the new circuitry is the fact that six control buses (AB1, BC1, CA1, AB2, BC2, and CA2) provide power to the new switches. The loss of one of these six control buses takes out the three-phase power to one set of the PLBD motors and the redundant set of any motors powered from the AC PBM buses. Without a redundant set of motors for these operations, the mission will be terminated and the next PLS will be utilized. In addition, since the three remaining control buses (AB3, BC3, and CA3) provide the MN bus power to the MCA logic, the mission would be NEXT PLS for the loss of any one of the nine control buses.

There is also another set of AC buses that must be enabled prior to driving certain motors. These are the AC PBM buses. These buses are enabled by the PL BAY MECH PWR SYSTEM 1 and SYSTEM 2 switches on panel R13. These switches close relays that enable AC power to pass to relays for controlling operation of certain motors in the payload bay, such as for the payload retention latches, RAD deployment, Ku-band antenna deploy motors, and RMS latch mechanisms. Status bits associated with the AC-enable relays can be viewed on MSK FC\_EPDC.

In the MCAs, DC power is used for several functions:

- A. It is required as logic power for the logic and amplifiers to function.
- B. It is used to power the position-sensing microswitches on the mechanical devices.
- C. It is used as source power for the daisy-chained status poles on the individual relays.

The DC power is provided by circuit-protected power control assembly (PCA) 28 V DC. The circuit protection is performed by Remote Power Controllers (RPCs) located in the PCAs. These RPCs are turned on or off by logic switches on panel MA73C. The output

of a given RPC will be referred to as an MCA dc sub-bus. For example, the DC power supplied to FMC1 is called MNA FMC1. If the RPC should open, whether it be from an overcurrent or intentionally turned off, several operational status bits will transition to their low states in the MCA. Bus loss can be detected by trying to match the appropriate status bits to a common RPC power source. If so desired, the RPC can be reset by cycling its control switch on panel MA73C.

#### **LOCATION**

The location of the FMCAs, MMCAs, and AMCAs can be seen in Figures 4.1.2-2, 4.1.2-3, 4.1.2-4, and 4.1.2-5, respectively.



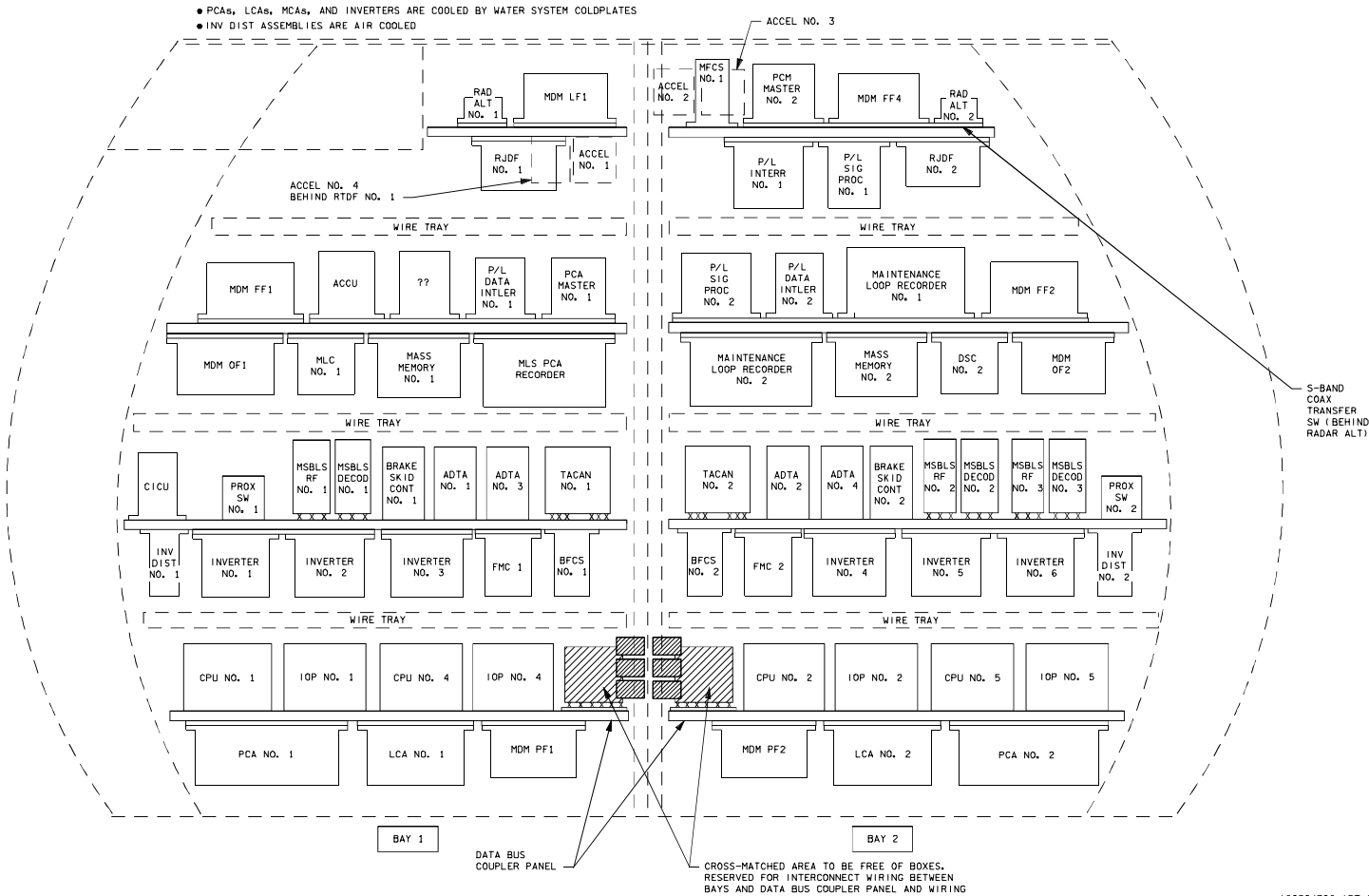


Figure 4.1.2-2. Forward avionics bay 1 and bay 2

128304302, ART. 2

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4.1.2-6

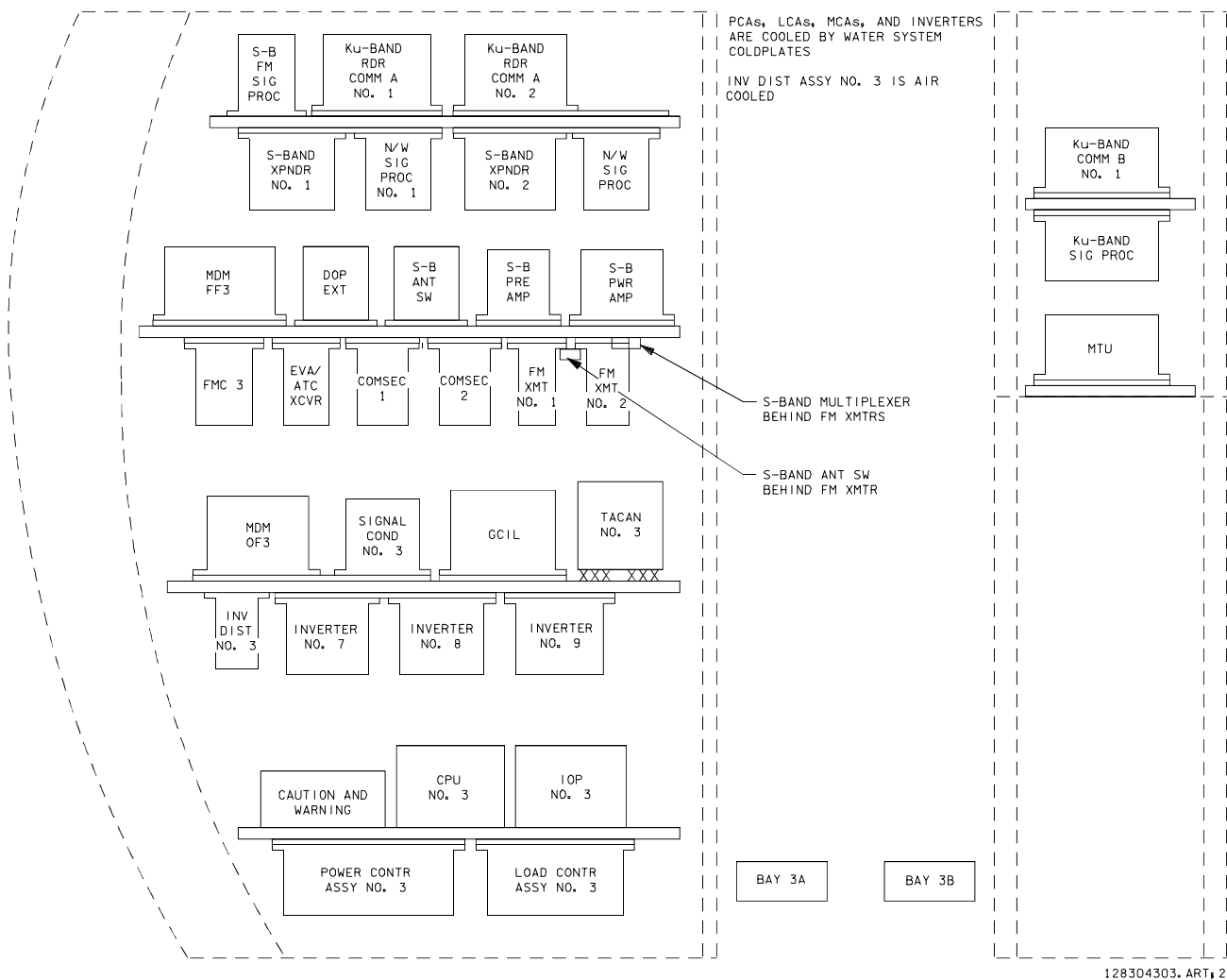


Figure 4.1.2-3. Forward avionics bay 3A and bay 3B

4.1.2-7

Verify that this is the correct version before use.

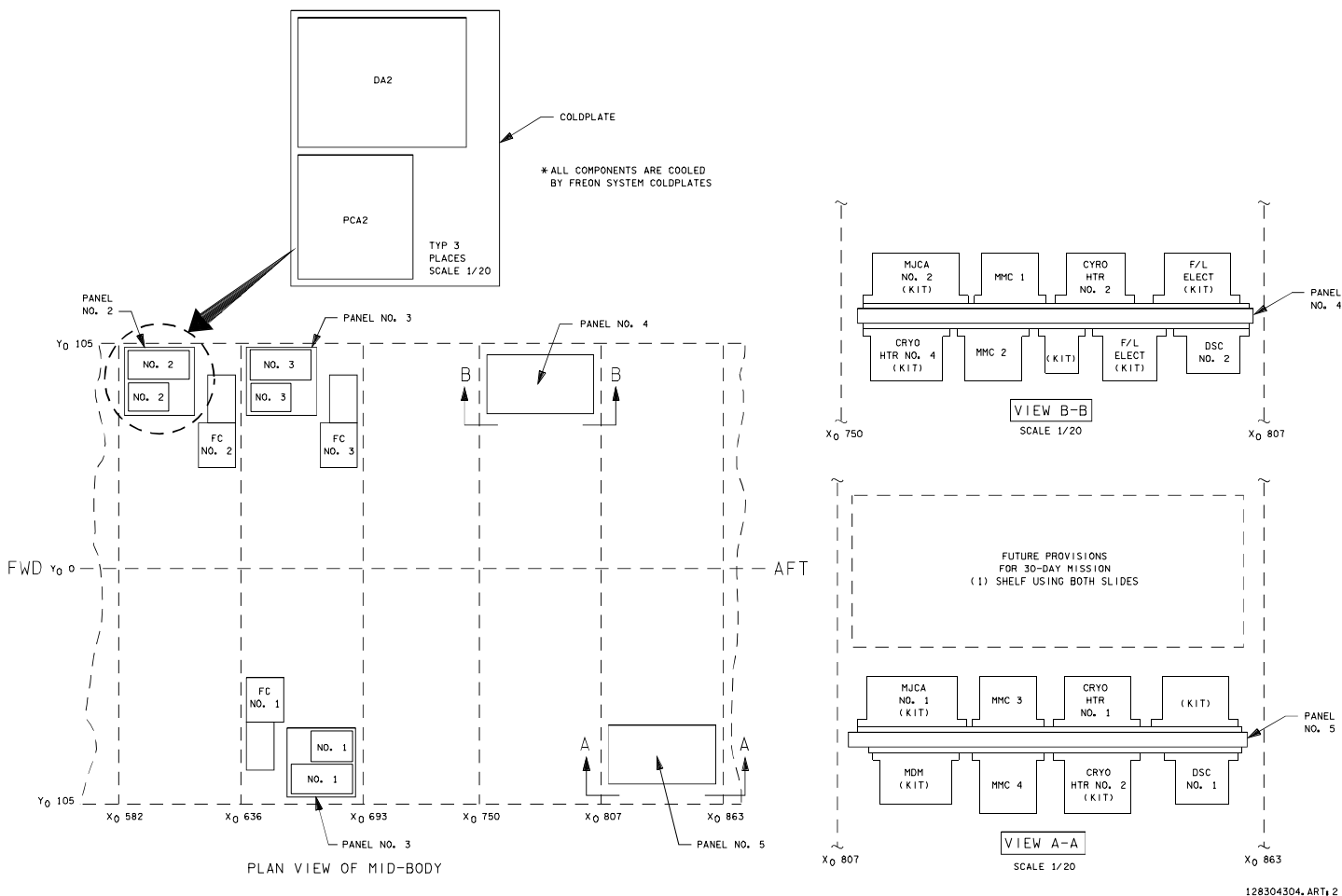
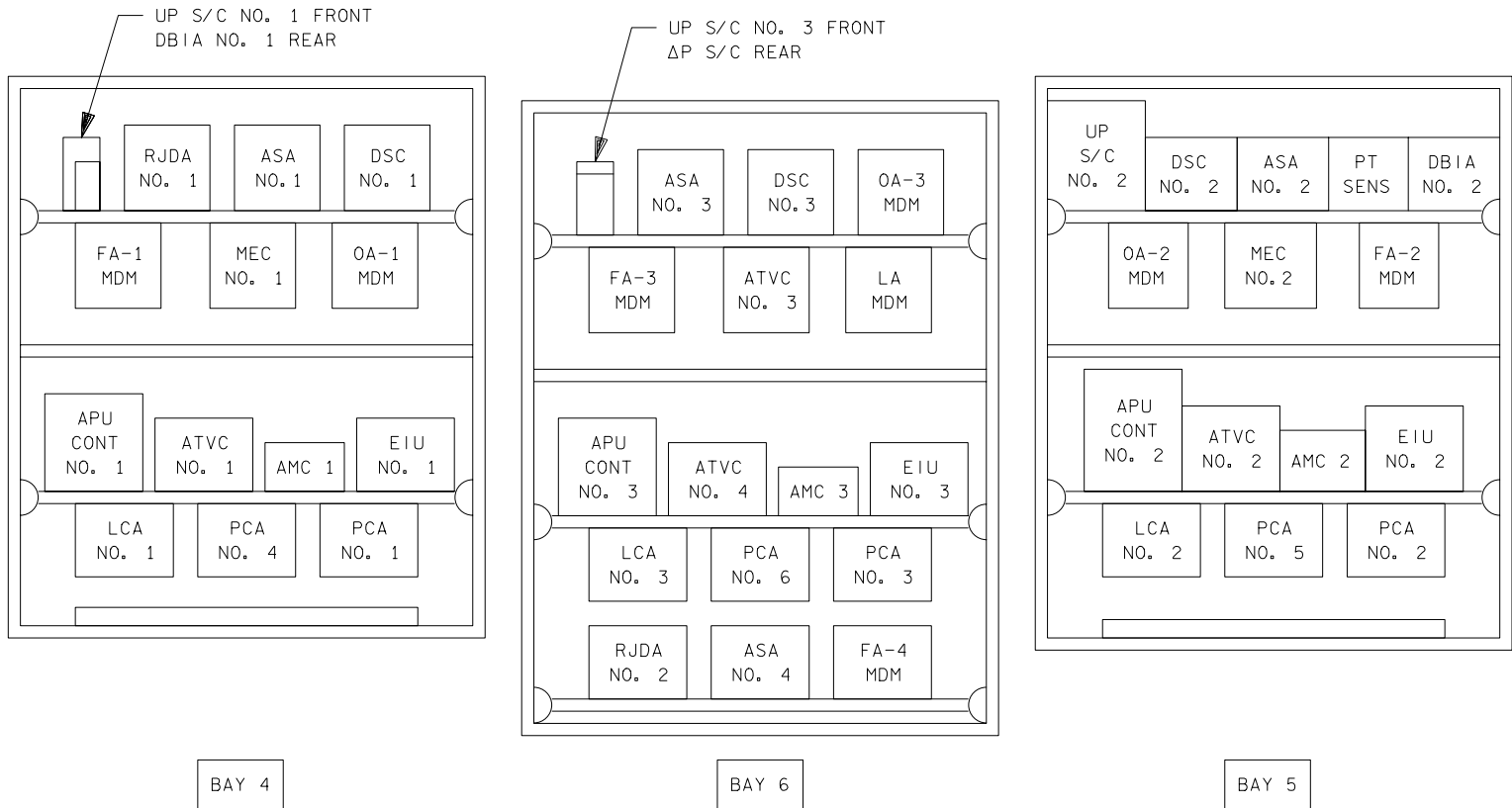


Figure 4.1.2-4. Midbody components

4.1.2-8

Verify that this is the correct version before use.

ALL COMPONENTS ARE COOLED BY FREON SYSTEM COLDPLATES



128304305. ART, 1

Figure 4.1.2-5. Aft avionics bays 4, 5, and 6

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4.1.2-9

**TITLE**

MCA STATUS VERSUS FUNCTION

**PURPOSE**

The purpose of this section is to provide the Electrical Power System (EPS) operator with a listing of associated operations as a function of MCA status bit pattern.

**DESCRIPTION**

The various mechanical operations that take place on the orbiter can be viewed by the EPS operator through the MCA status bits on the FC\_EPDC display. Different "patterns" represent different operations; however, several operations generate the same pattern of MCA status bits.

ACTIVITIES AFFECTING THE FORWARD MOTOR CONTROLLER ASSEMBLY

=====				=====			
*FWD RCS MANF ISOL:		OPEN*		*FWD RCS MANF ISOL:		CLSD*	
FWD	1 -- 3 -	AFT	1 ----	FWD	1 1 ---	AFT	1 ----
	2 -- 3 -		2 ----		2 1 ---		2 ----
	3 1 2 --		3 ----		3 -- 3 4		3 ----
MID	1 - - - - -	AC	--	MID	1 - - - - -	AC	--
	2 - - - - -		----		2 - - - - -		----
	3 - - - - -		----		3 - - - - -		----
	4 - - - - -		----		4 - - - - -		----
=====				=====			
*FWD RCS TANK 1/2 ISOL:		OPEN*		*FWD RCS TANK 1/2 ISOL:		CLSD*	
FWD	1 - - - -	AFT	1 ----	FWD	1 - - - -	AFT	1 ----
	2 - - - -		2 ----		2 - - - -		2 ----
	3 1 2 --		3 ----		3 1 2 3 4		3 ----
MID	1 - - - - -	AC	--	MID	1 - - - - -	AC	--
	2 - - - - -		----		2 - - - - -		----
	3 - - - - -		----		3 - - - - -		----
	4 - - - - -		----		4 - - - - -		----
=====				=====			
*FWD RCS TANK 3/4/5 ISOL:		OPN*		*FWD RCS TANK 3/4/5 ISOL:		CLS*	
FWD	1 1 -- 4	AFT	1 ----	FWD	1 1 2 3 4	AFT	1 ----
	2 - - - -		2 ----		2 - - - -		2 ----
	3 - - - -		3 ----		3 - - - -		3 ----
MID	1 - - - - -	AC	---	MID	1 - - - - -	AC	--
	2 - - - - -		----		2 - - - - -		----
	3 - - - - -		----		3 - - - - -		----
	4 - - - - -		----		4 - - - - -		----
=====				=====			

ACTIVITIES AFFECTING THE FORWARD MOTOR CONTROLLER ASSEMBLY (continued)

=====				=====					
*AIR DATA PROBE LEFT: DPLY*				*AIR DATA PROBE LEFT: STOW*					
FWD	1	1 2 --	AFT 1	----	FWD	1	-- 3 4	AFT 1	----
	2	1 - 3 -	2	----		2	- 2 - 4	2	----
	3	----	3	----		3	----	3	----
MID	1	-----	AC	--	MID	1	-----	AC	--
	2	-----		----		2	-----		----
	3	-----		----		3	-----		----
	4	-----		----		4	-----		----
=====				=====					
*AIR DATA PROBE RIGHT: DPLY*				*AIR DATA PROBE RIGHT: STOW*					
FWD	1	----	AFT 1	----	FWD	1	----	AFT 1	----
	2	1 - 3 -	2	----		2	- 2 - 4	2	----
	3	1 2 --	3	----		3	-- 3 4	3	----
MID	1	-----	AC	--	MID	1	-----	AC	--
	2	-----		----		2	-----		----
	3	-----		----		3	-----		----
	4	-----		----		4	-----		----
=====				=====					
*AIR DATA PROBES BOTH: DPLY*				*AIR DATA PROBES BOTH: STOW*					
FWD	1	1 2 --	AFT 1	----	FWD	1	-- 3 4	AFT 1	----
	2	1 2 3 4	2	----		2	1 2 3 4	2	----
	3	1 2 --	3	----		3	-- 3 4	3	----
MID	1	-----	AC	--	MID	1	-----	AC	--
	2	-----		----		2	-----		----
	3	-----		----		3	-----		----
	4	-----		----		4	-----		----
=====				=====					
*STAR TRACKER DOORS: PWR -Y,-Z ON*				*STAR TRACKER A&B DOORS OPN*					
FWD	1	1 ---	AFT 1	----	FWD	1	1 2 --	AFT 1	----
	2	1 -- 4	2	----		2	1 2 3 4	2	----
	3	1 ---	3	----		3	1 2 --	3	----
MID	1	----	AC	--	MID	1	-----	AC	--
	2	-----		----		2	-----		----
	3	-----		----		3	-----		----
	4	-----		----		4	-----		----
=====				=====					

ACTIVITIES AFFECTING THE FORWARD MOTOR CONTROLLER ASSEMBLY (concluded)

```

=====
*STAR TRACKER A&B DOORS:  CLS*
FWD  1  -- 3 4      AFT  1  ----
      2  1 2 3 4      2  ----
      3  -- 3 4      3  ----
MID  1  -----      AC  --
      2  -----      ----
      3  -----      ----
      4  -----      ----
=====

```

ACTIVITIES AFFECTING THE AFT MOTOR CONTROL ASSEMBLY

```

=====
*ET UMB C/L LATCHS:      DPLY*
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  1 2 --
      3  ----      3  1 2 --
MID  1  -----      AC  --
      2  -----      ----
      3  -----      ----
      4  -----      ----
=====

```

```

=====
*ET UMB C/L LATCHS:      STOW*
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  -- 3 4
      3  ----      3  -- 3 4
MID  1  -----      AC  --
      2  -----      ----
      3  -----      ----
      4  -----      ----
=====

```

```

=====
*ET UMB UPLOCK LATCH:    RLS*
FWD  1  ----      AFT  1  1 2 --
      2  ----      2  1 - 3 4
      3  ----      3  1 2 --
MID  1  -----      AC  --
      2  -----      ----
      3  -----      ----
      4  -----      ----
=====

```

```

=====
*ET UMB UPLOCK LATCH:    LCH*
FWD  1  ----      AFT  1  -- 3 4
      2  ----      2  1 2 - 4
      3  ----      3  -- 3 4
MID  1  -----      AC  --
      2  -----      ----
      3  -----      ----
      4  -----      ----
=====

```

```

=====
*ET UMB DOORS:          OPEN*
FWD  1  ----      AFT  1  -- 3 -
      2  ----      2  1 ---
      3  ----      3  -- 3 4
MID  1  -----      AC  --
      2  -----      ----
      3  -----      ----
      4  -----      ----
=====

```

```

=====
*ET UMB DOORS:          CLOSE*
FWD  1  ----      AFT  1  1 ---
      2  ----      2  -- 3 -
      3  ----      3  1 2 --
MID  1  -----      AC  --
      2  -----      ----
      3  -----      ----
      4  -----      ----
=====

```

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY  
RCS ISOLATION VALVES

=====				=====			
*MANF 1 LEFT FU/OX:		OPEN*		*MANF 1 LEFT FU/OX:		CLSD*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 1---		2 ----		2 -2--
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	--	MID	1 -----	AC	--
	2 -----		----		2 -----		----
	3 -----		----		3 -----		----
	4 -----		----		4 -----		----
=====				=====			
*MANF 1 RIGHT FU/OX:		OPEN*		*MANF 1 RIGHT FU/OX:		CLSD*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 --3-		2 ----		2 ---1
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	--	MID	1 -----	AC	--
	2 -----		----		2 -----		----
	3 -----		----		3 -----		----
	4 -----		----		4 -----		----
=====				=====			
MANF 2 LEFT FU/OX:		OPEN*		*MANF 2 LEFT FU/OX:		CLSD*	
FWD	1 ----	AFT	1 --3-	FWD	1 ----	AFT	1 ---4
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	--	MID	1 -----	AC	--
	2 -----		----		2 -----		----
	3 -----		----		3 -----		----
	4 -----		----		4 -----		----
=====				=====			
*MANF 2 RIGHT FU/OX:		OPEN*		*MANF 2 RIGHT FU/OX:		CLSD*	
FWD	1 ----	AFT	1 1---	FWD	1 ----	AFT	- 2--
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	--	MID	1 -----	AC	--
	2 -----		----		2 -----		----
	3 -----		----		3 -----		----
	4 -----		----		4 -----		----
=====				=====			



ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY

```

=====
*MANF 3 LEFT FU/OX:          OPEN*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  1 ---
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*MANF 3 LEFT FU/OX:          CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  -2 --
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*MANF 3 RIGHT FU/OX:         OPEN*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  --3 -
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*MANF 3 RIGHT FU/OX:         CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ---4
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
MANF 4 LEFT FU/OX:           OPEN*
FWD  1  ----      AFT  -  ----
      2  ----      2  ----
      3  ----      3  -2--
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*MANF 4 LEFT FU/OX:          CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  1 ---
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
MANF 4 RIGHT FU/OX:          OPEN*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ---4
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*MANF 4 RIGHT FU/OX:         CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  --3 -
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (continued)

=====				=====			
TANKS 1 /2 LEFT FU/OX:		OPEN*		*TANKS 1 /2 LEFT FU/OX:		CLSD*	
FWD	1 - - - -	AFT	1 - - - -	FWD	1 - - - -	AFT	1 - - - -
	2 - - - -		2 - - - -		2 - - - -		2 - - - -
	3 - - - -		3 1 2 3 4		3 - - - -		3 1 2 3 4
MID	1 - - - - - - -	AC	--	MID	1 - - - - - - -	AC	--
	2 - - - - - - -		- - - -		2 - - - - - - -		- - - -
	3 - - - - - - -		- - - -		3 - - - - - - -		- - - -
	4 - - - - - - -		- - - -		4 - - - - - - -		- - - -
=====				=====			
TANKS 1 /2 RIGHT FU/OX:		OPEN*		*TANKS 1 /2 RIGHT FU/OX:		CLSD*	
FWD	1 - - - -	AFT	1 - - - -	FWD	1 - - - -	AFT	1 - - - -
	2 - - - -		2 - - - -		2 - - - -		2 - - - -
	3 - - - -		3 1 2 3 4		3 - - - -		3 1 2 3 4
MID	1 - - - - - - -	AC	--	MID	1 - - - - - - -	AC	--
	2 - - - - - - -		- - - -		2 - - - - - - -		- - - -
	3 - - - - - - -		- - - -		3 - - - - - - -		- - - -
	4 - - - - - - -		- - - -		4 - - - - - - -		- - - -
=====				=====			
TANKS 3/4/5A LEFT FU/OX:		OPEN*		*TANKS 3/4/5A LEFT FU/OX:		CLSD*	
FWD	1 - - - -	AFT	1 1 - 3 -	FWD	1 - - - -	AFT	1 - 2 - 3
	2 - - - -		2 - - - -		2 - - - -		2 - - - -
	3 - - - -		3 - - - -		3 - - - -		3 - - - -
MID	1 - - - - - - -	AC	--	MID	1 - - - - - - -	AC	--
	2 - - - - - - -		- - - -		2 - - - - - - -		- - - -
	3 - - - - - - -		- - - -		3 - - - - - - -		- - - -
	4 - - - - - - -		- - - -		4 - - - - - - -		- - - -
=====				=====			
TANKS 3/4/5A RIGHT FU/OX:		OPEN*		*TANKS 3/4/5A RIGHT FU/OX:		CLSD*	
FWD	1 - - - -	AFT	- 1 - 4	FWD	1 - - - -	AFT	1 1 - 3 -
	2 - - - -		2 - - - -		2 - - - -		2 - - - -
	3 - - - -		3 - - - -		3 - - - -		3 - - - -
MID	1 - - - - - - -	AC	--	MID	1 - - - - - - -	AC	--
	2 - - - - - - -		- - - -		2 - - - - - - -		- - - -
	3 - - - - - - -		- - - -		3 - - - - - - -		- - - -
	4 - - - - - - -		- - - -		4 - - - - - - -		- - - -
=====				=====			

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (continued)

```

=====
TANKS 3/4/5B LEFT FU/OX:    OPEN*
FWD  1  ----      AFT  -  ----
      2  ----      2    1 - 3 -
      3  ----      3    ----
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*TANKS 3/4/5B LEFT FU/OX:    CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2    - 3 - 4
      3  ----      3    ----
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
TANKS 3/4/5B RIGHT FU/OX:   OPEN*
FWD  1  ----      AFT  -  ----
      2  ----      2    - 2 - 4
      3  ----      3    ----
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*TANKS 3/4/5B RIGHT FU/OX:   CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2    1 - 3 -
      3  ----      3    ----
MID  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*LEFT RCS XFEED MANF - /2 FU/OX:
                                OPEN*
FWD  1  ----      AFT  1  ----
      2  ----      2    ----
      3  ----      3    1 2 3 4
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*LEFT RCS XFEED MANF - /2 FU/OX:
                                CLSD*
FWD  1  ----      AFT  - 1  ----
      2  ----      2    ----
      3  ----      3    1 2 3 4
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*RIGHT RCS XFEED MANF - /2 FU/OX:
                                OPEN*
FWD  1  ----      AFT  -  ----
      2  ----      2    ----
      3  ----      3    1 2 3 4
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

```

=====
*RIGHT RCS XFEED MANF - /2 FU/OX:
                                CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2    ----
      3  ----      3    1 2 3 4
MID  1  - - - - -      AC  --
      2  - - - - -      ----
      3  - - - - -      ----
      4  - - - - -      ----
=====

```

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (continued)

```

=====
*LEFT RCS XFEED MANF 3/4/5 FU/OX:
                                OPEN*
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  ----
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

```

=====
*LEFT RCS XFEED MANF 3/4/5 FU/OX:
                                CLSD*
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  ----
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

```

=====
*RIGHT RCS XFEED MANF 3/4/5 FU/OX:
                                OPEN *
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  ----
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

```

=====
*LEFT RCS XFEED MANF 3/4/5 FU/OX:
                                CLSD *
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  ----
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

```

=====
*LEFT OMS XFEED FU/OX:      OPEN A*
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  ----
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

```

=====
*LEFT OMS XFEED FU/OX:      CLSD A*
FWD  1  ----      AFT  1  1 2 3 4
      2  ----      2  ----
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

```

=====
*LEFT OMS XFEED FU/OX:      OPEN B*
FWD  1  ----      AFT  1  ----
      2  ----      2  1 2 3 4
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

```

=====
*LEFT OMS XFEED FU/OX:      CLSD B*
FWD  1  ----      AFT  1  ----
      2  ----      2  1 2 3 4
      3  ----      3  ----
MID  1  - - - - -      AC  --
      2  - - - - -
      3  - - - - -
      4  - - - - -
=====

```

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (continued)

=====				=====			
*RIGHT OMS XFEED FU/OX: OPEN A*				*RIGHT OMS XFEED FU/OX: CLSD A*			
FWD	1	----	AFT 1	----	FWD	1	----
	2	----	2	----		2	----
	3	----	3	1 2 3 4		3	1 2 3 4
MID	1	-----	AC	--	MID	1	-----
	2	-----		----		2	-----
	3	-----		----		3	-----
	4	-----		----		4	-----
=====				=====			
*RIGHT OMS XFEED FU/OX: OPEN B*				*RIGHT OMS XFEED FU/OX: CLSD B*			
FWD	1	----	AFT 1	----	FWD	1	----
	2	----	2	1 2 3 4		2	1 2 3 4
	3	----	3	----		3	----
MID	1	-----	AC	--	MID	1	-----
	2	-----		----		2	-----
	3	-----		----		3	-----
	4	-----		----		4	-----
=====				=====			
*LEFT OMS ISOL VLV FU/OX: OPEN A*				*LEFT OMS ISOL VLV FU/OX: CLSD A*			
FWD	1	----	AFT 1	1 2 3 4	FWD	1	----
	2	----	2	----		2	----
	3	----	3	----		3	----
MID	1	-----	AC	--	MID	1	-----
	2	-----		----		2	-----
	3	-----		----		3	-----
	4	-----		----		4	-----
=====				=====			
*LEFT OMS ISOL VLV FU/OX: OPEN B*				*LEFT OMS ISOL VLV FU/OX: CLSD B*			
FWD	1	----	AFT 1	----	FWD	1	----
	2	----	2	----		2	----
	3	----	3	1 2 3 4		3	1 2 3 4
MID	1	-----	AC	--	MID	1	-----
	2	-----		----		2	-----
	3	-----		----		3	-----
	4	-----		----		4	-----
=====				=====			

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (continued)

=====				=====			
*RIGHT OMS ISOL VLV FU/OX: OPEN A*				*RIGHT OMS ISOL VLV FU/OX: CLSD A*			
FWD	1	----	AFT 1 1 2 3 4	FWD	1	----	AFT 1 1 2 3 4
	2	----	2 ----		2	----	2 ----
	3	----	3 ----		3	----	3 ----
MID	1	-----	AC --	MID	1	-----	AC --
	2	-----	----		2	-----	----
	3	-----	----		3	-----	----
	4	-----	----		4	-----	----
=====				=====			
*RIGHT OMS ISOL VLV FU/OX: OPEN B*				*RIGHT OMS ISOL VLV FU/OX: CLSD B*			
FWD	1	----	AFT 1 ----	FWD	1	----	AFT 1 ----
	2	----	2 ----		2	----	2 ----
	3	----	3 1 2 3 4		3	----	3 1 2 3 4
MID	1	-----	AC --	MID	1	-----	AC --
	2	-----	----		2	-----	----
	3	-----	----		3	-----	----
	4	-----	----		4	-----	----
=====				=====			

ACTIVITIES AFFECTING THE MID MOTOR CONTROLLER ASSEMBLY  
PAYLOAD BAY DOORS

=====				=====			
*CL LATCHES - 4 & - 3-- 6 REL*				*CL LATCHES - 4 & - 3-- 6 LATCH*			
FWD	1	----	AFT 1 ----	FWD	1	----	AFT 1 ----
	2	----	2 ----		2	----	2 ----
	3	----	3 ----		3	----	3 ----
MID	1	-----	AC 00	MID	1	-----	AC 00
	2	1--4----	0000		2	-34-----	0000
	3	---4----	0000		3	--3-----	00--
	4	-----6--	0000		4	-----7-	0000
=====				=====			
*CL LATCHES 5-8 & 9-- 2 REL*				*CL LATCHES 5-8 & 9-- 2 LATCH*			
FWD	1	----	AFT - ----	FWD	1	----	AFT 1 ----
	2	----	2 ----		2	----	2 ----
	3	----	3 ----		3	----	3 ----
MID	1	--2-----	AC 00	MID	1	---4----	AC 00
	2	-----8	0000		2	-----7-	0000
	3	-----6--	00--		3	----0---	00--
	4	-----8	0000		4	----5---	0000
=====				=====			

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (continued)

```

=====
*STBD BLKHD LATCHES:      REL*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  1-----      AC  00
      2  -2-----      0000
      3  -----      00 --
      4  --4--7-      0000
=====

```

```

=====
*STBD BLKHD LATCHES:      LATCH*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  -2-----      AC  00
      2  1-----      0000
      3  -----      00 --
      4  1-----7-      0000
=====

```

```

=====
*PORT BLKHD LATCHES:      REL*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  ---4-----      AC  00
      2  -----6--      0000
      3  -2-----      00 --
      4  -2-----      0000
=====

```

```

=====
*PORT BLKHD LATCHES:      LATCH*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  --3-----      AC  00
      2  -----5---      0000
      3  1-----      00 --
      4  -2-----      0000
=====

```

```

=====
*STBD PAYLOAD DOOR PDU:    OPEN*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  ---5---      AC  00
      2  -----      0000
      3  -----      00 --
      4  1-----      0000
=====

```

```

=====
*STBD PAYLOAD DOOR PDU:    CLSD*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  -----6--      AC  00
      2  -----      0000
      3  -----      00 --
      4  ---4-----      0000
=====

```

```

=====
*PORT PAYLOAD DOOR:        OPEN*
FWD  1  ----      AFT  -  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  -----      AC  00
      2  1-----      0000
      3  -----      00 --
      4  ---5---      0000
=====

```

```

=====
*PORT PAYLOAD DOOR:        CLOSE*
FWD  1  ----      AFT  1  ----
      2  ----      2  ----
      3  ----      3  ----
MID  1  -----      AC  00
      2  -2-----      0000
      3  -----      00 --
      4  -----8      0000
=====

```

ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (continued)

=====				=====			
*KU BAND ANT A:		DEPLOY		*KU BAND ANT A:		STOW*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	00	MID	1 -----	AC	00
	2 ---4 5---		0000		2 -- 3 -- 6--		0000
	3 -----		0000		3 -----		0000
	4 - 2 3-----		0000		4 1-- 4 ----		0000

\*NOTE: KU-BAND ANT B circuitry is spare. Reference SSSH 2.4-3.

=====				=====			
*FREON RAD: PORT LATCHES		RELEASE*		*FREON RAD: PORT LATCHES		LATCH*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 1---5---	AC	00	MID	1 - 2 --- 3--	AC	00
	2 -----		0000		2 -----		0000
	3 -----		0000		3 -----		0000
	4 - 2 --- 6--		0000		4 -- 3 - 4 ---		0000

=====				=====			
*FREON RAD: PORT PDU		DEPLOY*		*FREON RAD: PORT PDU		STOW*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 -- 3 4-----	AC	00	MID	1 1---5---	AC	00
	2 -----		0000		2 -----		0000
	3 -----		0000		3 -----		0000
	4 ---- 5 - 6 -		0000		4 ---- 6 - 7		0000

=====				=====			
*FREON RAD STBD LATCHES:		REL*		*FREON RAD STBD LATCHES:		LATCH*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	00	MID	1 -----	AC	00
	2 - 2 3-----		0000		2 1-----		0000
	3 - 2 -- 3---		00 --		3 1---- 6--		00 --
	4 -----		0000		4 -----		0000



ACTIVITIES AFFECTING THE AFT MOTOR CONTROLLER ASSEMBLY (concluded)

=====				=====			
*FREON RAD STBD PDU:		DEPLOY*		*FREON RAD STBD PDU:		STOW*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	00	MID	1 -----	AC	00
	2 ----- 6 7 -		0000		2 --- 4 5 ---		0000
	3 1-2-----		00 --		3 -2-4-----		00 --
	4 -----		0000		4 -----		0000
=====				=====			
*REMOTE MANIPULATOR/PORT: MRL REL*				*REMOTE MANIPULATOR/PORT:		MRL LATCH*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 --3-----	AC	00	MID	1 ---4-----	AC	00
	2 1-----6 --		0000		2 -2-----8		0000
	3 -----5---		0000		3 -----6--		0000
	4 -2-----8		0000		4 --3---7-		0000
=====				=====			
REMOTE MANIPULATOR/PORT:		MPM DPLY*		*REMOTE MANIPULATOR/PORT:		MPM STOW*	
FWD	1 ----	AFT	1 ----	FWD	- ----	AFT	- ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 -----	AC	00	MID	- -----	AC	00
	2 1-----		0000		2 -2-----		0000
	3 -----		0000		3 -----		0000
	4 -----8		0000		4 -----6-		0000
=====				=====			
*PYLD RETENTION POS - :		REL*		*PYLD RETENTION POS - :		LATCH*	
FWD	1 ----	AFT	1 ----	FWD	1 ----	AFT	1 ----
	2 ----		2 ----		2 ----		2 ----
	3 ----		3 ----		3 ----		3 ----
MID	1 ----- 5 6 --	AC	00	MID	1 ----- 5 6 --	AC	00
	2 -----		0000		2 -----		0000
	3 1 2 3 - 5 -- 8		0000		3 1 2 - 4 5 - 7 -		0000
	4 -----		0000		4 -----		0000
=====				=====			

ACTIVITIES AFFECTING THE MID MOTOR CONTROLLER ASSEMBLY

```

=====
*PYLD RETENTION POS 2:          REL*
FWD  1  ----          AFT  1  ----
      2  ----          2  ----
      3  ----          3  ----
MID  1  12-----          AC  00
      2  -----          0000
      3  -234-67-          0000
      4  -----          0000
=====

```

```

=====
*PYLD RETENTION POS 2:          LATCH*
FWD  1  ----          AFT  1  ----
      2  ----          2  ----
      3  ----          3  ----
MID  1  12-----          AC  00
      2  -----          0000
      3  --3--6-8          0000
      4  -----          0000
=====

```

```

=====
*PYLD RETENTION POS 3:          REL*
FWD  1  ----          AFT  1  ----
      2  ----          2  ----
      3  ----          3  ----
MID  1  --34-----          AC  00
      2  -----          0000
      3  1--45-67          0000
      4  -----          0000
=====

```

```

=====
*PYLD RETENTION POS 3:          LATCH*
FWD  1  ----          AFT  1  ----
      2  ----          2  ----
      3  ----          3  ----
MID  1  --24-----          AC  00
      2  -----          0000
      3  1--4--5-          0000
      4  -----          0000
=====

```

ACTIVITIES INVOLVING THE VENT DOORS

```

=====
* ALL:                          OPEN*
FWD  1  12--          AFT  1  12--
      2  1234          2  1234
      3  12--          3  12--
MID  1  12345678          AC  --
      2  12345678          ----
      3  12345678          ----
      4  12345678          ----
=====

```

```

=====
* ALL:                          CLOSED*
FWD  1  --34          AFT  1  --34
      2  1234          2  1234
      3  --34          3  --34
MID  1  12345678          AC  --
      2  12345678          ----
      3  12345678          ----
      4  12345678          ----
=====

```

\*- ,2,8,9 LEFT OPEN: 3-7 RT/LEFT:

```

=====
                                CLSD*
FWD  1  ----          AFT  1  12--
      2  -2-4          2  --34
      3  12--          3  ----
MID  1  -----          AC  --
      2  -----          ----
      3  -----          ----
      4  -----          ----
=====

```

## TITLE

CONTROL BUS SHORT TROUBLESHOOTING

## PURPOSE

This brief documents the procedures used on console to determine a control bus short, the approximate location of the short, and the actions necessary to unpower a control bus in the event of a short, per EPS Flight Rule 9-34.

## SYSTEM DESCRIPTION AND CONSOLE TOOLS

(Refer to SSSH drawing 2.2-1 for a detailed view of the control bus layout.)

There are nine control buses, each powered by three main bus sources for redundancy. Main bus power to each control bus is fed via a 5-amp RPC at each end of the control bus and a 5-amp fuse downstream of a 10-amp circuit breaker in the center of the control bus (Figure 4.1.4-1). Each RPC provides power to two separate control buses (Figure 4.1.4-2). The RPC status telemetry nomenclature indicates which two control buses the RPC is feeding (i.e., AB1/CA1). The control bus power RESET switch resets main bus power (A, B, or C) to three RPCs, each feeding two control buses. The center feed cb provides the third main bus power source for the control bus. The MNC cb provides the MNC source for control buses AB1, AB2, and AB3. A 5-amp fuse is located downstream of the cb for each control bus.

Control bus voltages and RPC discrettes can be monitored on display EGIL\_FC\_EPDC (Figure 4.1.4-3). The voltage is an analog value with a transducer range of 0.0 to 40.0 V DC. Nominal control bus voltage should be between 27 and 29 V DC. As discussed above, each RPC provides power to two separate control buses. If an RPC trips off, an asterisk is displayed between the bus voltages of the two affected control buses in the appropriate column (A, B, C). Notice that a main A RPC asterisk appears on both ends to signify the two affected control buses (i.e., AB1 and CA1).

Other console operator tools include limit manager, E-LOG, RTPLOT, and CRANS.

## BACKGROUND

Previously, it was thought that a control bus short would open all three power sources (both RPCs and the fuse). However, after further analysis and laboratory testing (LEMSCO-25658, Summary of the Control Bus Repower Test, May 1988), it was determined that, worst case, a short could open only two sources (an RPC and the fuse) and that a short could cause loss of only one (or even no) source. This characteristic of the control buses is unique among all orbiter buses and is caused by lengthy cable routing to numerous flight deck panels. Each control bus consists of several hundred feet of small-gage wire (22 and 24 gage). Two hundred feet of 22(24)-gage wire has a resistance of 3.24 (5.16) ohms. If a 1-ohm short occurred 200 feet away from a 28 V DC power source, the current through 24-gage wire would be 4.5 amps, an insufficient current to trip a 5-amp fuse. Because of this, a short would

result in a partial loss of the control bus. The philosophy then was that the affected portion of the control bus would be determined and declared lost, and that the bus would remain powered. However, after further control bus testing (Lockheed #EP5-M10-215, Shuttle Control Bus Kapton Wire Arc Tracking Test Summary, Oct. 12, 1990), this philosophy has been changed.

These tests indicate that arc tracking (a sustained propagating arc) can be initiated as soon as the short starts. If the control bus is left powered, energy is still fed to the short, causing localized heating. If arc tracking did not start initially, localized heating or subsequent arc tracking at the short location could cause additional insulation damage to adjacent wires. This may also cause arc tracking to initiate some time after the short initially occurred.

Critical function wires are located in the same bundles and/or harnesses as the control bus power wires. Referencing the Wire Harness Assembly List (Rockwell V070-773402), it can be seen that fuel cell reactant valves power, Caution and Warning (C&W) power supply, OMS engine drivers, fire suppression, essential bus, and other control bus power wires are some of the critical functions that are routed in the same bundle with a given control bus wire.

Because of the possibility of wire bundle/harness damage caused by arc tracking, the control bus short philosophy was changed to limit exposure to this risk. During dynamic flight (L-O to MECO, and EI to wheelstop), a shorted control bus will remain partially powered unless smoke or fire indications are present (indicating that arc tracking is most likely taking place). This partial power attempts to maintain maximum control power redundancy during these important flight phases. During other flight phases or if fire/smoke are detected, a control bus will be rapidly unpowered by powering off the remaining good sources. This would leave the other control buses in an operational but zero-fault-tolerant condition (because of common RPC and RPC reset switches). If the failure occurs during the on-orbit phase of flight, an In-Flight Maintenance (IFM) procedure will then be performed to inhibit only the appropriate RPC(s) on the shorted control bus. The IFM procedure would accomplish not only the unpowering of the shorted control bus, but would also restore redundancy to the other control buses. This strategy is discussed in more detail in the following text.

## PROCEDURE

A control bus short can be initially recognized in several ways. If the short opens the RPC on the "front end" of the bus (RPC closest to the voltage transducer), an asterisk (on display FC\_EPDC) indicates that the RPC has opened, and the associated control bus voltage should read approximately zero. If a short opens the RPC on the "back end" of the bus, only the asterisk will indicate that the RPC has opened. There is no voltage transducer at this end of the bus to confirm a short. Inputs from the crew and/or other MCC operators can identify lost equipment and reveal which D&C panels are affected by a suspected control bus short. Shorts can also be confirmed (if they happened at Acquisition of Signal (AOS)) by inspecting the plots of the appropriate FPC bus amps

and the appropriate fuel cell amps, because main bus power to the control bus RPCs comes from the FPCs and, in turn, the fuel cells.

If a short does not take out either RPC, there are a couple of events that may be observed. There may be a small drop (as much as 12.7 volts) in the bus voltage, depending on the size and location of the short; a short “signature” may be seen on fuel cell amps plots; or there may be only the reports from the crew and/or other disciplines about equipment or functions lost on a common control bus.

A short that did not open either RPC may have occurred toward the center of the control bus and may possibly have opened the 5-amp fuse on the center feed. Again, a short of this nature could be confirmed by a slight voltage drop, a plot signature on the appropriate FC amps, or reports of equipment/functions lost.

Depending on the location and resistance of the short, there is also the possibility of a short on the control bus that does not open any of the circuit protection devices. A smaller, more localized short (possibly only one panel) such as this may be detected only by loss of equipment or functions on a common control bus panel or panels.

In the past, it was more of a concern to find out exactly which control bus panels were affected by the short, because the bus was going to be left powered. Now, the main concern is to power off a shorted control bus.

Once the MCC determines that the control bus has a short, the control bus will be powered off to prevent further damage caused by localized heating and/or possible arc tracking. The control bus will be powered off according to the “type” of short that occurred.

If a short causes the loss of a control bus RPC, the control bus center power source cb (on panel R14) will be opened, and the remaining RPC will be disabled by continuously activating (with a switch retention device) the control bus RPC reset switch (on panel R1) until an IFM procedure is performed to power off the desired RPC (the reset switch powers off three RPCs). This action will cause four other control buses to lose one of three power sources, and two other control buses to lose two of three power sources. After the IFM procedure is performed to power off the good RPC on the affected bus, two RPCs will be regained by releasing the RPC reset switch. This will result in one control bus (the one with the short) with no power sources, four control buses with two of three power sources, and all others with all three power sources.

If a control bus short does not cause the loss of an RPC, the center source 5-amp fuse (downstream of the 10-amp cb) is probably open. The only quick method of removing the other two power sources is to use the two associated RPC reset switches. This action will cause six other control buses to lose one of three power sources and two other control buses to lose two of three power sources. After an IFM procedure is performed to power off the appropriate RPCs, four RPCs will be regained by releasing the RPC reset switches. This results in one control bus (the one with the short) with no power sources, two control buses with two of three power sources, and all others with all three power sources.

The IFM procedure will power off individual RPCs using the Launch Forward (LF) MDM cable. Using the IFM breakout box, a +28 V signal is sent via the appropriate LF MDM cable pin. This +28V signal will inhibit the driver that applies the control signal to the control bus RPC, thus powering off the RPC. The IFM does not power the LF MDM or the preflight test bus. This IFM procedure is located in the IFM Checklist as "Control Bus Power Down."

Consideration will be given to reset a control bus RPC that failed because of a short in an attempt to position valves or relays (powered by the control bus through momentary switches) when the attempt is considered mandatory to prevent loss of crew and vehicle. An RPC reset will be performed only during ground coverage on Mission Control Center (MCC) request.

Consult the Flight Rules to see the mission duration impacts caused by a control bus loss. In general, loss of any single control bus causes the loss of multiple latch gang redundancy on the payload bay doors and is considered a Primary Landing Site (PLS) condition. An IFM procedure has been developed that restores control bus power downstream of the payload bay door system switches on panel R13 (PLBD CNTL Bus Repower). This will remove the PLS condition for the loss of control buses AB1, AB2, BC1, BC2, CA1, and CA2. Other IFM procedures may be developed to eliminate PLS conditions for the loss of AB3, BC3, and CA3. This would involve restoring functionality to the mid MCA logic circuits at panel MA73C.

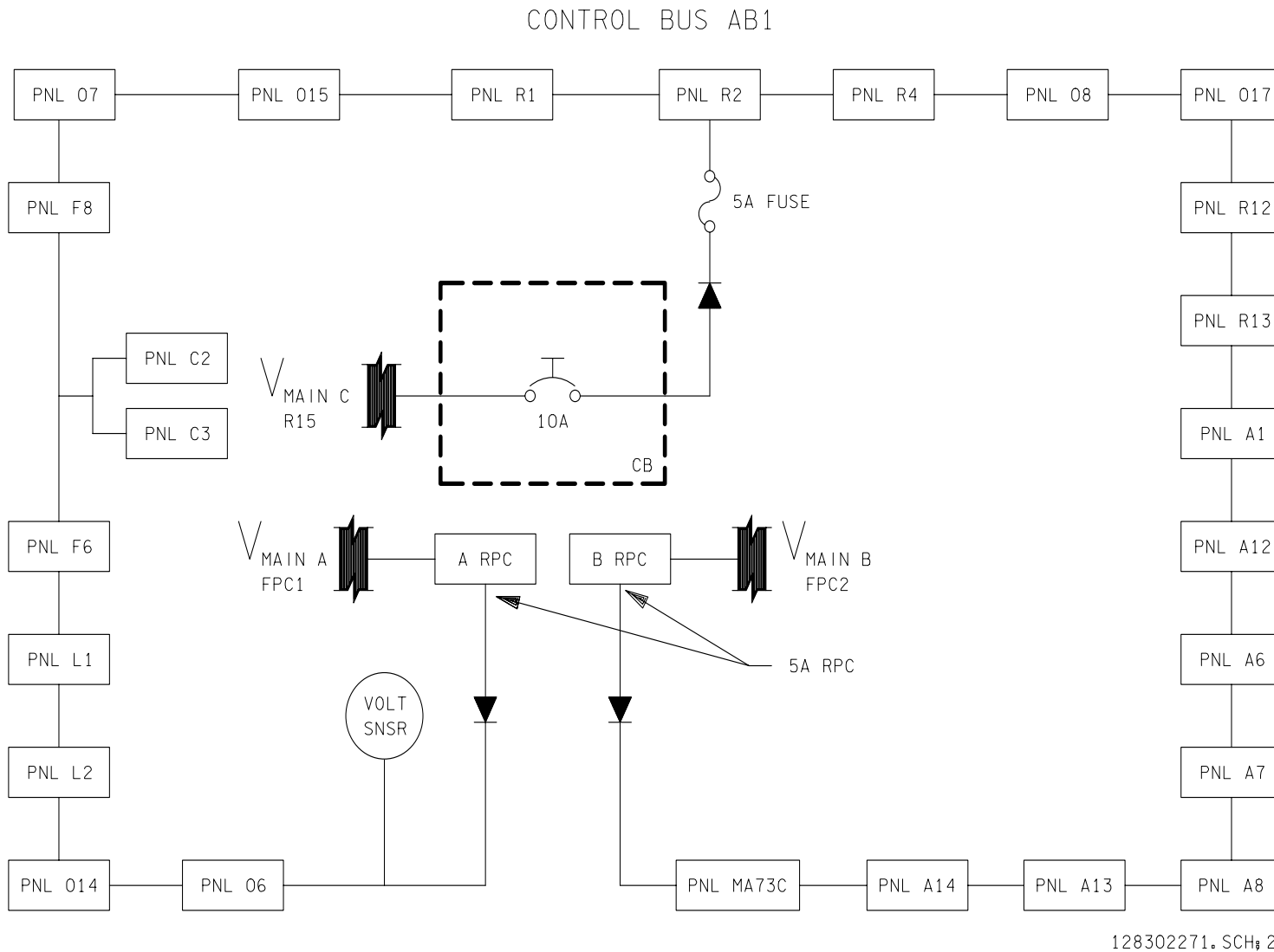
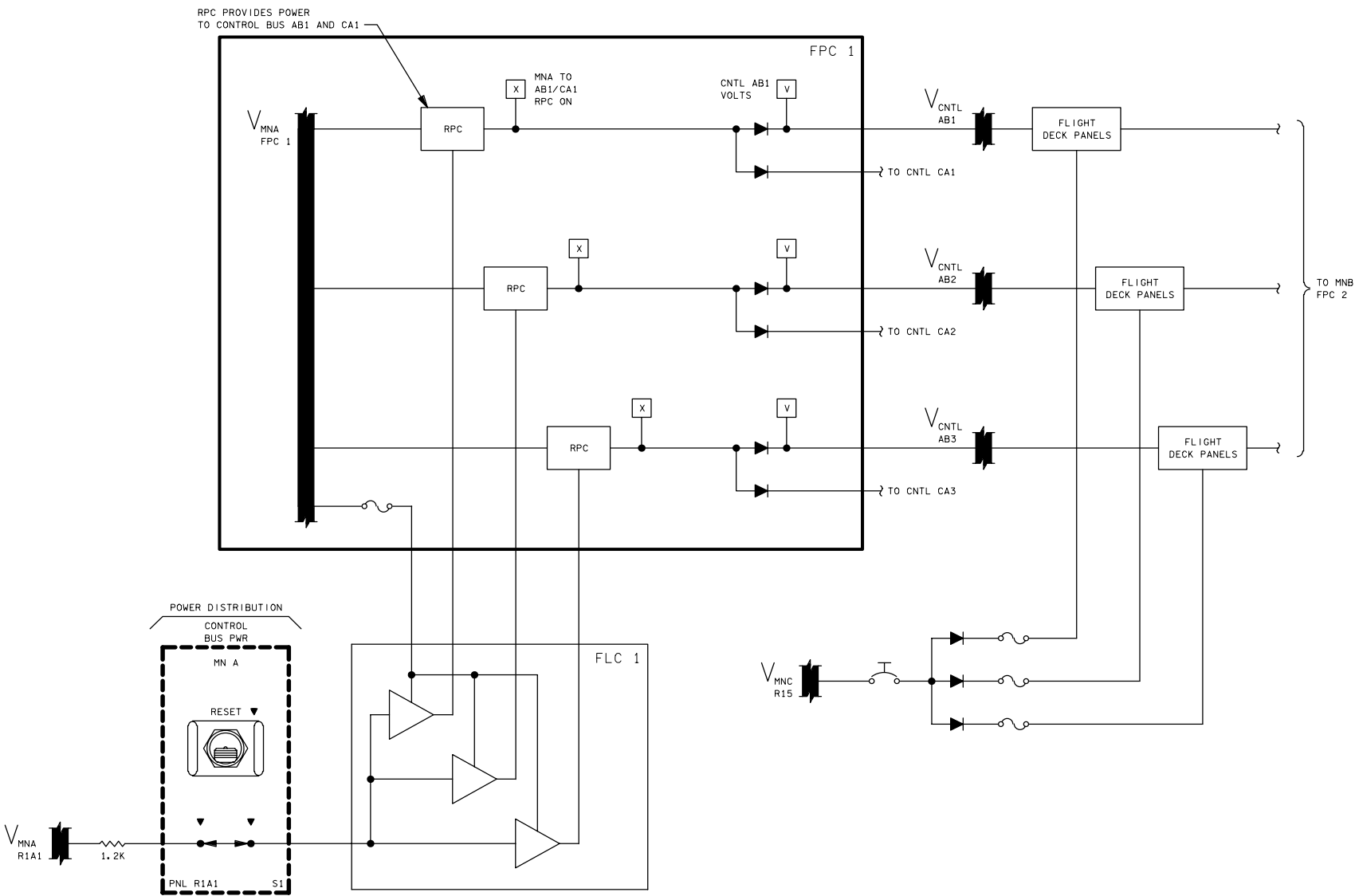


Figure 4.1.4-1. Typical control bus layout

4.1.4-5  
Verify that this is the correct version before use



128302227.SCH 1

Figure 4.1.4-2. Typical control bus RPC interface

4.1.4-6

Verify that this is the correct version before use



FC_EPDC.msk									
OGMT 257/05:57:10					F/V 114 /104				
OMBT 000/06:34:37					GN 22				
PASS MECO 00:01					OI TFL 199 MM PASS 201 SM 24				
BFS MECO D					MM BFS D BF D				
DC	-1/A-	-2/B-	-3/C-		TOTAL AMPS 498.0 KW 15.51				
FC KW	5.28	5.12	5.12		FUEL CELL -1- -2- -3-				
FC AMPS	170	164	164		STK OUT T 203 203 203				
FPC AMPS	83	73	113		STK IN T 182 182 182				
MPC AMPS	38	36	9		EXIT T 151 151 151				
APC AMPS	33	23	17		CL RTN T 70 70 70				
FC % LD	34.1	32.9	32.9		CL PRESS 62.0 62.0 62.0				
BUS TIE	---	---	---		CL PMP P ---				
FC VDC	31.0	31.2	31.2		H2 MTR 0.40 0.40 0.40				
MN VDC	31.0	31.0	31.0		O2 VLV ---				
FWD VDC	30.6	30.6	30.6		O2 FLOW 2.83 2.67 2.67				
AFT VDC	30.7	30.9	30.7		O2 CAL FL 3.58 3.45 3.45				
R SRB	-	DC	D -/-		H2 VLV ---				
L SRB	-	DC	D -/-		H2 FLOW 0.54 0.50 0.51				
ESS VDC	29.8	29.9	29.9		H2 CAL FL 0.45 0.44 0.44				
ESS RPC	---	---	---		1-2 2-3 3-1				
CNTL	A	B	C A		AMPS 5 0 -5				
-1	29.3	29.3	29.3		VOLTS 0.12 0.23 0.23				
-2	29.3	29.3	29.3		SUBSTK 1 12 16 16				
-3	29.3	29.3	29.3		2 24 28 18				
					3 16 20 20				
-AC-	-1-	-2-	-3-		KOH IN AV 36.55 36.47 36.49				
AMPS A	3.60	4.96	3.68		OUT AV 36.33 36.38 36.42				
B	3.44	4.64	3.76		SAMPLES/MIN /25.0 4.80				
C	3.44	4.80	3.60		CNTLR PWR -- -- --				
VAC A	117.0	117.0	117.0		READY -- -- --				
B	117.0	117.0	117.0		STRUP HTR -- -- --				
C	117.0	117.0	117.0		PRG SEQ -- -- --				
INV/BUS					VLV GP-- GP-- GP--				
A	---/---	---/---	---/---		HTR GPC--- ---				
B	---/---	---/---	---/---		O2 VLT 49				
C	---/---	---/---	---/---		H2 VLT-1 49				
SENSOR	AUTO	AUTO	AUTO		H2 VLT-2 49				
O/L	----	----	----		-WATER- -1- -2- -3-				
O/UV	----	----	----		PH FC ----				
-MTRS-	-AC1-	-AC2-	-AC3-		H2O LN ----				
AV BAY	13.78	-	B -		SUP H2O P 32.8				
	23.74	-	A -		ALT H2O P 34.2				
	33.90	B	-		PRD H2O T 143 143 143				
IMU FAN	4.56	-	B -		ALT H2O T 90 79 90				
HUM SEP	-	-	B -		RLF VLV T 77 77 77				
CAB FAN	5.50	-	A		RLF LN T 70				
FRN LP	12189	-	B -		RLF NOZ T 243 243				
	22258	B	-		NOZ HTR STATUS -- --				
H2O LP	123	-G --	B-		LN/RLF SW CONF A- A-				
	262	--	ON		MASTER ALARM-- --				
					ALERT B- -- -- D				
					BU C/W B- -- -- D				
					ALERT A1 A2 A3 A4				
					.TONE -- -- --				
					.LIGHT -- -- --				
					BU C/W -- -- --				
----- MCA STATUS -----									
FWD 1	----	AFT 1	----						
2	----	2	----						
3	----	3	----						
MID 1	-----	AC	--						
2	-----		----						
3	-----		----						
4	-----		----						
Ver 2.0									

Figure 4.1.4-3. Display FC/EPDC

## TITLE

HYDRAULIC CIRCULATION PUMP TRANSIENT DATA

## PURPOSE

The purpose of this SCP is to provide an overview of tests conducted to determine hydraulic circulation pump startup transient effects on orbiter and payload electrical equipment.

## BACKGROUND

Several tests have been conducted to measure the hydraulic circulation pump (circ pump) startup transient to aid in determining its possible effects on orbiter and payload electrical equipment. Two of the tests were ground orbiter tests that utilized test equipment plugged into the dc utility outlets. Another test was a breadboard setup that used power supplies that simulated two substack FC's. All loads for this test were resistive; the capacitance of the orbiter LRU input filters would yield lower voltage transients. The most accurate test consisted of verification flight instrumentation (VFI) recording of circ pump-induced transients in the Spacelab module during STS-9. The VFI equipment had the capability to record frequencies up to 20K Hz.

The results of the STS-9 data were published in two Notes of Interest (NOI's). Instead of trying to paraphrase the NOI's, they are included as attachments 1 through 3. In addition to the test results NOI's, a briefing that analyzes the circ pump startup transient and its effects during ascent is included as attachment 4. Some of the attachments to the NOI's were not included for brevity.

Only one payload, Spacelab, has approved documentation restricting starting a circ pump on an orbiter bus that powers the PRIPL bus. (A running circ pump is not restricted.) The core payload, ICD 2-19001 (Attachment 1 to Volume XIV of the NSTS 07700 Document), has included requirements that the payloads be designed to withstand the payload bus voltage transients induced by a circ pump startup. Following is a summary of the ICD requirements and the test results:

### A. PRIPL, AUXPL, and CABPL Buses

1. PL ICD - The payload shall accommodate sawtooth oscillations of 4 V peak-to-peak at a base frequency between 500 and 700 Hz. The transient voltage oscillates around the steady state voltage from -2.5 V to +1.5 V for up to 250 ms, then tapers to  $\pm 0.2$  V ripple by 300 ms.
2. VFI TEST - Test data indicated a sawtooth oscillation less than 1 V peak-to-peak at 440 to 580 Hz with a startup time of about 200 ms.
3. BREADBOARD TEST - Test data indicated a sawtooth oscillation of 2.5 V peak-to-peak with a startup time of about 150 ms.

### B. AFTPL Buses

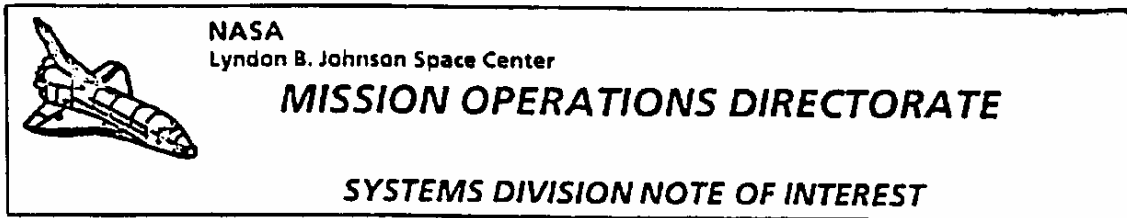
1. PL ICD - The payload shall accommodate sawtooth oscillations of 11 V peak-to-peak at a base frequency between 500 and 700 Hz. The transient voltage oscillates around the steady state voltage from -7 V to +4 V for up to 250 ms, then tapers to  $\pm 0.8$  V ripple by 300 ms.

2. VFI TEST - The AFTPL buses were not tested with the VFI equipment.
3. BREADBOARD TEST - Test data indicated a sawtooth oscillation of 13 V peak-to-peak with a startup time of about 150 ms.

A list of attachments with a brief description follows:

- Attachment 1: STS-9 Circ Pump Test Summary using the SL VFI data (DF NOI No. 184)
- Attachment 2: Breadboard Tests Summary (DF NOI No. 150)
- Attachment 3: Circ Pump Power and Bus Tie Options for SL Flights (DF NOI No. 169)
- Attachment 4: Presentation on Effects of Circ Pump Startup Transient during Ascent

ATTACHMENT NO. 1



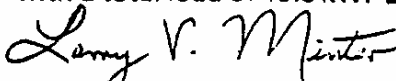
DF NOI #184  
REFER TO: DF7/84-103 (ALL MISSIONS)

MAY 29 1984

To: Distribution  
From: DF7/L. V. Minter  
Subject: STS-9 Circ Pump Test

To aid in determining hydraulic circulation pump startup transient effects on the payload buses, a circ pump test was performed during STS-9 prior to deactivation of the Spacelab systems. With Orbiter main buses B and C bus tied, circ pump 2 was started on MNB, then circ pump 3 was started on MNC. Circ pumps 2 and 3 were then unpowered and MN B and MNC untied. Circ pump 3 was then started on MNC, the sole source of power for the PRI PL bus. The voltage data of several Spacelab buses was recorded on the Spacelab verification flight instrumentation (VFI) system, a high resolution FM-FM data system capable of recording transient frequencies to 2500 Hz.

This NOI contains a summary of the VFI circ pump data received to date. The data in this report was obtained by analysis of VFI oscillographs, and the voltage values listed should be accurate within 0.1 V. During the test, Spacelab power was 4.8 kW. Prior to circ pump activation, the Spacelab main bus was at 30.4 V and the Orbiter main bus C was at 31.0 V with a total load of 15.6 kW. Each circ pump required 2 kW steady-state power.

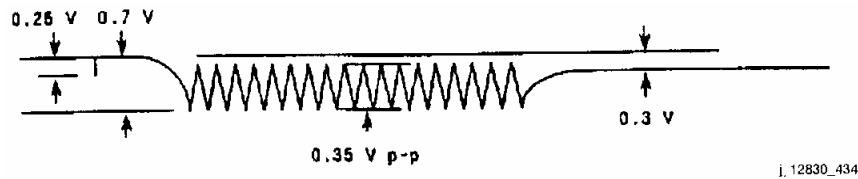
  
Larry V. Minter

DF7/LVMinter:prg:5/17/84:3161

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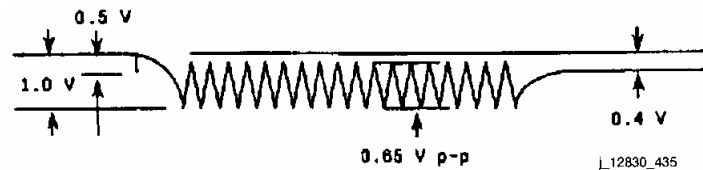
CIRC PUMP 2 ON MNB, MNB AND MNC BUS TIED

A. Data for SL Buses Powered by MNC



1. Voltage spike (drop) due to initial inrush current was 0.25 V.
2. Thirty ms after initial spike, bus voltage had 0.35 V p-p startup ripple, between 440 and 495 Hz for 105 ms.
3. Maximum voltage drop from prestart steady-state voltage during startup ripple was 0.7 V.
4. Total startup time was about 170 ms.
5. After startup was complete, bus voltage was 0.3 V below the prestart steady-state voltage.

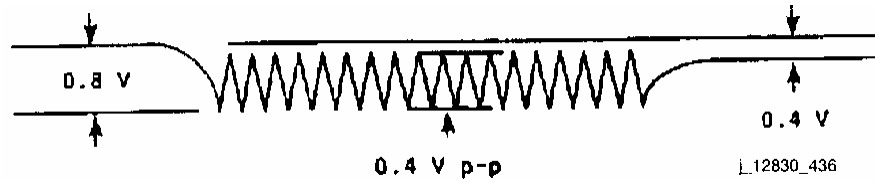
C. Data for SL Buses Powered by MNB (AUX PL B)



1. Voltage spike (drop) due to initial inrush current was 0.5 V.
2. Thirty ms after initial spike, bus voltage had startup ripple for 105 ms. Insufficient test data to determine ripple p-p voltage or frequency.
3. Maximum voltage drop from prestart steady-state voltage during startup ripple was 1.0 V.
4. Total startup time was about 170 ms.
5. After startup was complete, bus voltage was 0.4 V below the prestart steady-state voltage.

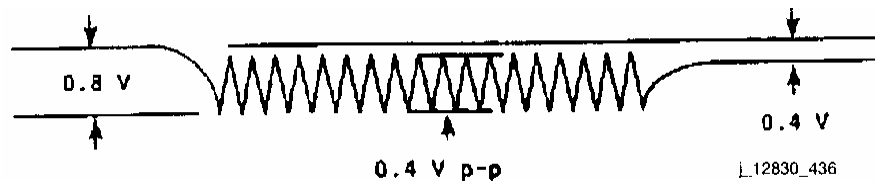
CIRC PUMP 3 ON MNC, MNB, AND MNC BUS TIED

A. Data for SL Buses Powered by MNC



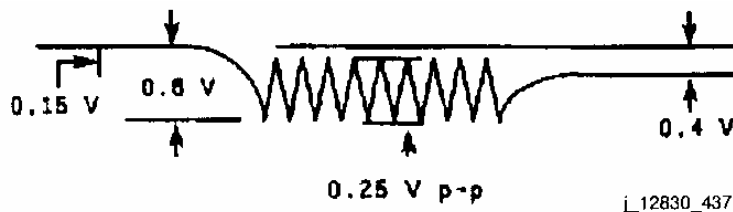
1. No discernible voltage spike due to initial inrush current.
2. 0.4 V p-p startup ripple between 495 and 570 Hz for 145 ms.
3. Maximum voltage drop from prestart steady-state voltage during startup ripple was 0.8 V.
4. Total startup time was about 230 ms.
5. After startup was complete, bus voltage was 0.4 V below the prestart steady-state voltage.

B. Data for SL Buses Powered by MNB (AUX PL B)



1. Voltage spike (drop) due to initial inrush current was 0.15 V.
2. Forty-five ms after initial spike, bus voltage had 0.25 V p-p startup ripple, between 500 and 570 Hz for 145 ms.
3. Maximum voltage drop from prestart steady-state voltage during startup ripple was 0.6 V.
4. Total startup time was about 200 ms.
5. After startup was complete, bus voltage was 0.4 V below the prestart steady-state voltage.

CIRC PUMP 3 ON MNC, NO BUSES TIED



1. Voltage spike (drop) due to initial inrush current was 0.4 V.
2. Forty ms after initial spike, bus voltage had 0.6 V p-p startup ripple, between 540 and 580 Hz for 100 ms.

3. Maximum voltage drop from prestart steady-state voltage during startup ripple was 1.3 V.
4. Total startup time was about 200 ms.
5. After startup was complete, bus voltage was 0.6 V below the prestart steady-state voltage.

## ATTACHMENT 2

DF NOI #150 (STS-9)

~~JUN 9 1989~~

DF7/83-36

TO: Distribution

FROM: DF7/R. T. Brown

SUBJECT: Orbiter Main Bus Voltage During STS-9 Hydraulic Circulation Pump Operation

Background: During STS-9 Spacelab operations, it is planned to configure the Orbiter so that each fuel cell is connected to its main bus. Main bus B is bus tied to main bus C and the Spacelab main bus is connected to Orbiter main bus C. Since some Orbiter loads are powered via diodes from more than one Orbiter main bus, any load change on any bus will usually be reflected in load changes to all three fuel cells. The main bus C voltage fluctuations will appear on the Spacelab main bus and may affect Spacelab equipment operations.

Of the Orbiter equipment that may be operated during Spacelab operations, the hydraulic system circulation pumps will cause the greatest transient and voltage ripple on the Orbiter main buses. Depending on hydraulic system temperatures and pressures, these pumps may be intermittently turned on one at a time. This note will estimate the expected STS-9 main bus C voltage fluctuations during Spacelab operations.

Discussion: There is no data to show what the bus voltage fluctuations will be when operating hydraulic circulation pumps with main buses powered by the three substack fuel cells. However, figures 1, 2, 3, 4, 5, and 6 show some oscilloscope picture and wave analysis data taken during Orbiter electrical system breadboard tests using power supplies and cabling designed to simulate two substack fuel cells and Orbiter main bus wiring. Figure 7 is a copy of a strip chart recording of fuel cell 2 and fuel cell 3 voltages and currents during a typical hydraulic circulation pump operation on STS-2. A close look at the two pictures in figure 1 shows an initial 1 millisecond current spike that peaks at 220 amps in about 500 microseconds. The next 200 milliseconds show the average current build to 160 amps and return to 70 amps steady state load with current oscillations building to 220 amps peak to peak and returning to 15 amps peak to peak ripple.

During the breadboard tests for figures 1, 2, 4, 5, and 6 all loads were resistive except the hydraulic circulation pump. Figure 2 shows the frequency spectrum of the ripple which peaks at about 2.2 KHz. Figure 3 shows that this peak to peak ripple voltage magnitude was reduced 60 percent by connecting a 3,000 microfarad capacitor across the aft bus. Figure 4 shows that cooling the hydraulic fluid increases the peak to peak ripple voltage by 50 percent. Therefore, a cold Orbiter attitude can be expected to increase the bus voltage ripple while operating other equipment with input capacitive filters will tend to reduce the bus voltage ripple. Figure 5 shows high frequency aft main bus

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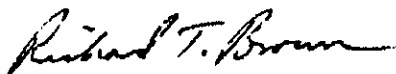


voltage ripple during pump start of 13 volts peak to peak and figure 6 shows this is reduced to 2.5 volts peak to peak at the midbody main bus distributor.

A strip chart recording of fuel cell 2 and 3 voltage and currents during STS-2 hydraulic circulation pump operations is shown in figure 5. The pump number 3 load was applied to main bus C which was connected to fuel cell 3. Fuel cell 1 had failed and fuel cell 2 was connected to main bus A and main bus B. With pump 3 connection to main bus C, fuel cell 3 current jumped from 275 amps to 370 amps during pump start, then fluctuated between 305 and 320 amps until pump 3 shutdown when the current changed from 310 to 270 amps. Fuel cell 2 current jumped from 330 amps to 380 amps during pump 3 start, then fluctuated between 330 and 345 amps until pump 3 shutdown when it changed from 345 to 320 amps. These 50 samples per second traces indicate a total start load of 145 amps with a running load of 65 amps. Voltage and current ripple appear to be undetectable (less than .32 volts and less than 4 amps which represent 2 PCM counts). Other load changes during this period were primarily associated with STS-2 payload operations (SIR-A in particular).

Even though the bus voltage ripple was undetected by fuel cell voltage and current PCM measurements, some other measurements were affected, such as aft payload main bus B amps (shown in figure 7) and main bus amps to midbody power control assemblies (not shown). These measurements became noisy and unusable during circulation pump operations. These are all current sensors with 0 to 75 or 0 to 100 amp ranges and the specific cause of their abnormal behavior has not been defined.

Conclusion: All of the above data has been associated with two substack fuel cell operations with load sharing via loads that are diode connected from more than one bus. The proposed Spacelab operations configuration will have two, three substack fuel cells connected together such that the main bus equivalent source impedance should be approximately halved. Spacelab and Orbiter LRU filter capacitors coupled with wiring inductance will add significant filtering. It is expected that Spacelab main bus voltage fluctuations due to Orbiter loads will be less than half the fuel cell voltage fluctuations seen to date. Based on predicted three substack fuel cell voltage--current performance--the 220 amps peak to peak current of figure 1 should cause less than 1 volt fluctuation at the Spacelab main bus. This is within the Orbiter bus voltage transient specification. However, like the Orbiter, Spacelab may have some measurement sensors that could be sensitive to the particular ripple voltage caused by hydraulic circulation pumps. We will probably not know this answer until we fly and operate the systems together.



Richard T. Brown

Enclosures 

DF7/RTBrown:msh:6/3/83:6327

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**T.S.2.2.7.3 - RIPPLE REDUCTION ~ HYDRAULIC  
RECIRCULATION PUMP.**

**Test Data From Oscilloscope Pictures.**

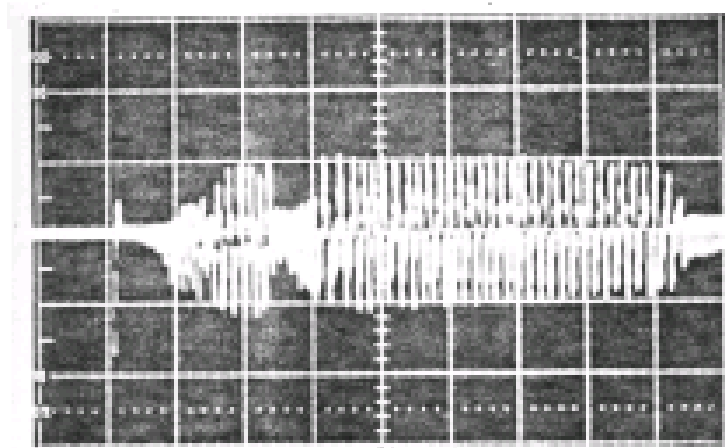
**Date 11-6-78**

**TEST #IIa RUN #1**

**EVENT: PUMP START-UP**

**TRACE: MAIN TO RTN. APCA-1 VOLTAGE. (MRA1)**

↑  
**5.0V/DIV**  
↓



←20 msec/DIV→

**AC COUPLED**

**T.S.2.2.7.3 - RIPPLE REDUCTION ~ HYDRAULIC  
RECIRCULATION PUMP.**

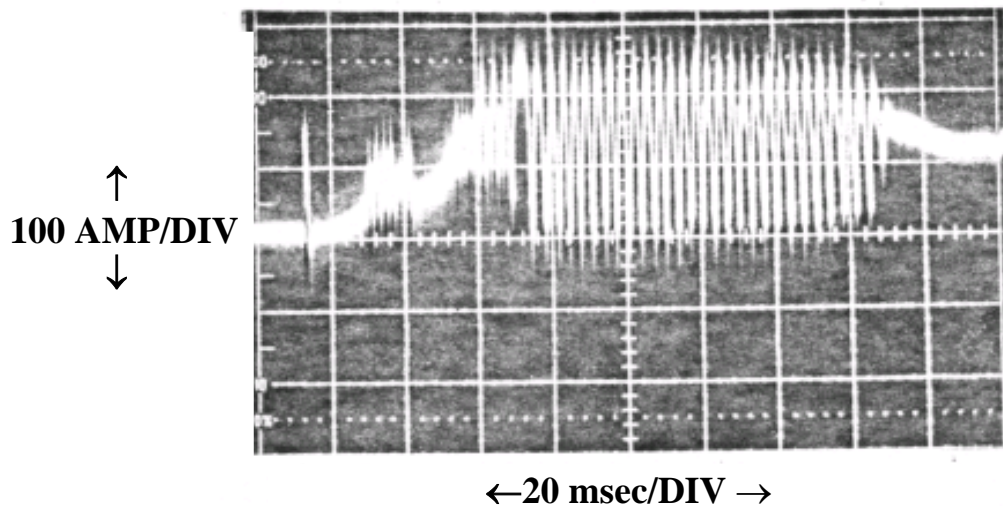
**Test Data From Oscilloscope Pictures**

**Date 11-6-78**

**TEST # IIb RUN # 1**

**EVENT: PUMP START-UP**

**TRACE: PUMP CURRENT**



**DC COUPLED**

**T.S.2.7.3 - RIPPLE REDUCTION ~ HYDRAULIC  
RECIRCULATION PUMP.**

**Test Data From Oscilloscope Pictures.**

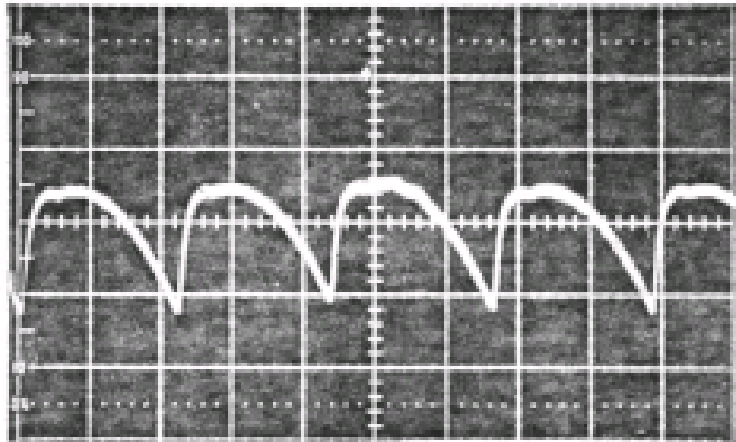
**Date 11-6-78**

**TEST # IIc RUN # 1**

**EVENT: STEADY-STATE PUMP OPERATION**

**TRACE: MAIN TO RTN. APCA-1 RIPPLE VOLTAGE.  
MRA1)**

↑  
**0.5 V/DIV**  
↓



←0.2 msec/DIV→

**AC COUPLED**

ATTACHMENT 3

DF NOI #169 (STS-9 and Subs)

NOV 15 1983

DF7/83-147

TO: Distribution

FROM: DF7/L. V. Minter

SUBJECT: Circ Pump Operations/SL Power

**1. STS-9 CIRC PUMP OPERATIONS** - No circ pump operations are expected on-orbit for STS-9 except possibly during the 24-hour cold attitude test. During the cold attitude test, if the hydraulic operating line temperatures are projected to reach -35°F or to reach -10°F on the 1307 bulkhead based on real-time data, the circ pumps will be sequentially cycled manually one time for about 15 minutes each to warm the hydraulic fluid. If this occurs, or if a hydraulic system problem occurs that necessitates cycling a circ pump, the bus tie configuration and the pump power source selection will be called to the crew by the MCC. An exception would be a failure case that required quick reaction time to prevent losing a hydraulic system.

If a hydraulic system problem occurs that necessitates cycling a circ pump, the pump will be manually cycled ON/OFF if it is required no more than two or three times per day. For problems that require more frequent pump operation, the circ pump(s) will be operated in the SM timer mode. The SM timer mode requires that two circ pumps be alternately cycled. Again, the bus tie configuration and the circ pump power source selections will be called to the crew by the MCC except for failures that require quick reaction time.

**2. CIRC PUMP STARTUP TESTS** - Vehicle testing indicated that during circ pump 2 startup on MN B (powered by fuel cell 2 with no buses tied), the initial inrush current caused a momentary MN B voltage drop of 2.35 volts (from 31.1 to 28.75 volts; SL lower limit is 26.6 volts). The startup lasted about 300 ms and consisted of 400 Hz, 2.5 volts peak-to-peak ringing on MN B.

A previous test indicated that the initial inrush current caused a voltage increase of about 6 volts, with startup ringing of 8 volts peak-to-peak. The data from this test is suspect, and the test equipment is being tested.

**3. CIRC PUMP POWER OPTIONS** - No valid data exists to indicate that a circ pump startup on MN B or MN C would affect SL equipment. (SL is powered from MN C with MN B and MN C bus tied.) Normally, circ pump 1 would be powered by MN A, 2 by MN B, and 3 by MN C. Circ pump 1 power source may be selected to MN A or MN B, 2 to MN B or MN C, and 3 to MN C or MN A.

Since insufficient test data exists to verify that a circ pump startup transient on a main bus which powers SL would not adversely affect SL equipment, a real-time workaround will be accomplished if circ pump operations are required. To operate circ pump 1 and/or 3, their power source should be selected to MN A. Since circ pump 3 is power source selected to MN C prelaunch, a real-time call will be made post-insertion for STS-9 to select MN A in case circ pump 3 needs to be powered quickly.

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To operate circ pump 2 would require bus tying MN A (all three buses would be momentarily tied), then untying MN B. SL would then be powered by MN A and MN C, and circ pump 1 and 2 would be power source selected to MN B. This bus tie configuration would remain as long as circ pump 2 operations were required.

If periodic circ pump 2 and 3 operation would be required, fuel cell 3 would power SL in the dedicated mode to prevent reconfiguring the bus ties between cycles.

Refer to the following table for a summary of the required bus configuration for all combinations of possible circ pump operations:

CIRC PUMP(S) TO OPERATE	0	1 <sup>Ⓞ</sup>	2 <sup>Ⓞ</sup>	3 <sup>Ⓞ</sup>	1&2	1&3	2&3	1,2&3
CIRC PUMP 1 MODE SW	OFF	CYC ON/ OFF	OFF	OFF	GPC	GPC	OFF	GPC
2	OFF	OFF	CYC ON/ OFF	OFF	GPC	OFF	GPC	GPC
3	OFF	OFF	OFF	CYC ON/ OFF	OFF	GPC	GPC	GPC
CIRC PUMP 1 PWR SOURCE 2 3 <sup>Ⓞ</sup>	A B A	A B A	B B A	A B A	B B A	A B A	A B A	A B A
BUSES TIED PL PWR SOURCE	B&C MNC	B&C MNC	A&C MNC	B&C MNC	A&C MNC	B&C MNC	B&C FC3	B&C FC3

- NOTES:**
- Ⓞ Single circ pump cycling must be done manually.
  - Ⓞ The prelaunch power source selection for circ pump 3 is MN C. A real-time call will be made post-insertion to select MN A in case circ pump 3 is required quickly to prevent loss of a hydraulic system.

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4. PROCEDURES FOR CIRC PUMP OPERATIONS - (Nominal bus tie configuration is assumed prior to entering each procedure.)

CIRC PUMP(S) TO OPERATE	CREW PROCEDURES
1 (MANUAL)	(A12) ● HYD CIRC PUMP PWR 1,3 (TWO) - MNA (R2) ● HYD CIRC PUMP 1 - ON/OFF AS REQ'D
2 (MANUAL)	(R1) ● MN BUS TIE A - ON (TB - ON), B - OFF (TB - OFF) (A12) ● HYD CIRC PUMP PWR 1,2 (TWO) - MNB (R2) ● HYD CIRC PUMP 2 - ON/OFF AS REQ'D
3 (MANUAL)	(A12) ● HYD CIRC PUMP PWR 1,3 (TWO) - MNA (R2) ● HYD CIRC PUMP 3 - ON/OFF AS REQ'D
1&2 (AUTO)	(R1) ● MN BUS TIE A - ON (TB - ON), B - OFF (TB - OFF) (A12) ● HYD CIRC PUMP PWR 1,2 (TWO) - MNB (R2) ● HYD CIRC PUMP 1,2 (TWO) - GPC
1&3 (AUTO)	(A12) ● HYD CIRC PUMP PWR 1,3 (TWO) - MNA (R2) ● HYD CIRC PUMP 1,3 (TWO) - GPC
2&3 (AUTO)	(R1) ● PL PRI FC3 - ON (TB - ON) ● PL PRI MNC - OFF (TB - OFF) ● FC/MN BUS C - OFF (TB - OFF) (A12) ● HYD CIRC PUMP PWR 1,3 (TWO) - MNA (R2) ● HYD CIRC PUMP 2,3 (TWO) - GPC
1,2&3 (AUTO)	(R1) ● PL PRI FC3 - ON (TB - ON) ● PL PRI MNC - OFF (TB - OFF) ● FC/MN BUS C - OFF (TB - OFF) (A12) ● HYD CIRC PUMP PWR 1,3 (TWO) - MNA (R2) ● HYD CIRC PUMP 1,2,3 (THREE) - GPC
1,2&3 (MANUAL SINGLE CYCLE)	(A12) ● HYD CIRC PUMP PWR 1,3 (TWO) - MNA (R2) ● HYD CIRC PUMP 1 - ON FOR 15 MIN, THEN OFF ● HYD CIRC PUMP 3 - ON FOR 15 MIN, THEN OFF (R1) ● MN BUS TIE A - ON (TB - ON), B - OFF (TB - OFF) (A12) ● HYD CIRC PUMP PWR 1,2 (TWO) - MNB (R2) ● HYD CIRC PUMP 2 - ON FOR 15 MIN, THEN OFF (R1) ● MN BUS TIE B - ON (TB - ON), A - OFF (TB - OFF) (A12) ● HYD CIRC PUMP PWR 1,3 (TWO) - MNA

*Larry V. Minter*

Larry V. Minter

DF7/LVMinter:msh:11/7/83:6327

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## ATTACHMENT 4

Presentation of effects of circ pump startup transient during ascent

### BACKGROUND

- Hydraulic circulation pump startup being considered for APU failures during ascent
- Issue raised over orbiter dc bus voltage transient caused by pump motor startup

### STARTUP TRANSIENT DATA (SODB FIGURE 4.2.4-4) (REF. FIGURE 1)

- Current transient is combination dc/ac
- Dc component » 150 amps
- Ac component » 220 amps peak-to-peak  
Frequency  $\approx$  220 - 400 Hz  
Time duration  $\approx$  150 <sub>M</sub>S
- Highest total peak  $\approx$  150 + 0.5 (220)  $\approx$  260 amps

### ORBITER EPDC TRANSIENT VOLTAGE DROP DUE TO CURRENT RIPPLE (REF. FIGURE 2)

- Resistive loss (simplistic analysis)

$$V_{DROPR} = I_{PEAK} * R_{LN} + 74 * I_{PEAK} * R_{FC}$$
$$\approx 150 * .005 + .74 * 150 * .007$$
$$\approx 0.75 \text{ V} + 0.78 \text{ V} = 1.5 \text{ V}$$

- Reactive loss (complex analysis)

Function of line inductance and capacitance

Since capacitance is variable (line routing, LRU configuration), assume capacitance = 0 (worst cast)

$$V_{DROPL} = IAC * 2II * F * L$$
$$\approx 110 * 2P * 400 * 30 * 10^{-6}$$
$$\approx 8.3 \text{ V}$$

$$V_{DROPCR} = 110 * .055 + .74 * 110 * .007$$
$$= 110 * 2II * 400 * 30 * 10^{-6}$$
$$= .55 + .57 = 1.1 \text{ V}$$

$$V_{DROPCR} = 1.1 + j8.3$$



$$= 110 \times 2 \times 10^{-6} \times 400 \times 30 \times 10^{-6}$$

$$= 8.4 \text{ V}$$

- Total voltage drop

Resistive + reactive loss

$$1.5 + 8.4 \approx 10 \text{ volts (worst case for } \sim 150 \text{ } \mu\text{S)}$$

- EPDC breadboard test performed in 1978 (LEC PDS-2449-158)

Voltage transient at aft PCA (resistive bus loading + pump load)

Single negative spike of » 12 volts, followed by

Ac transient of » 13 volts peak-to-peak

500 Hz frequency

“Valleys” are » 8-volt drop from steady-state

Dampens out in ~ 150 MS

Additional testing performed with impedances added to simulate aft dc bus loads

Voltage ripple transient not significantly reduced

- Another EPDC breadboard test performed in 1978 (LEC PDS-5109-032)

Purpose was to study effects of additional combinations of resistance, inductance, and capacitance on reducing the ripple transient

Applicable test to EPDC system was capacitor added in parallel with pump

Will cause same type of effect as other orbiter LRU's on aft bus

Transient reduction was logarithmic function of capacitance added

With 25,000  $\mu\text{F}$  capacitor

Initial transient spike reduced to » -4 volts, followed by

$\approx$  4.5-volt peak-to-peak ripple (-2.5-volt drop from steady-state)

Additional capacitance would show little improvement

## CONCLUSION

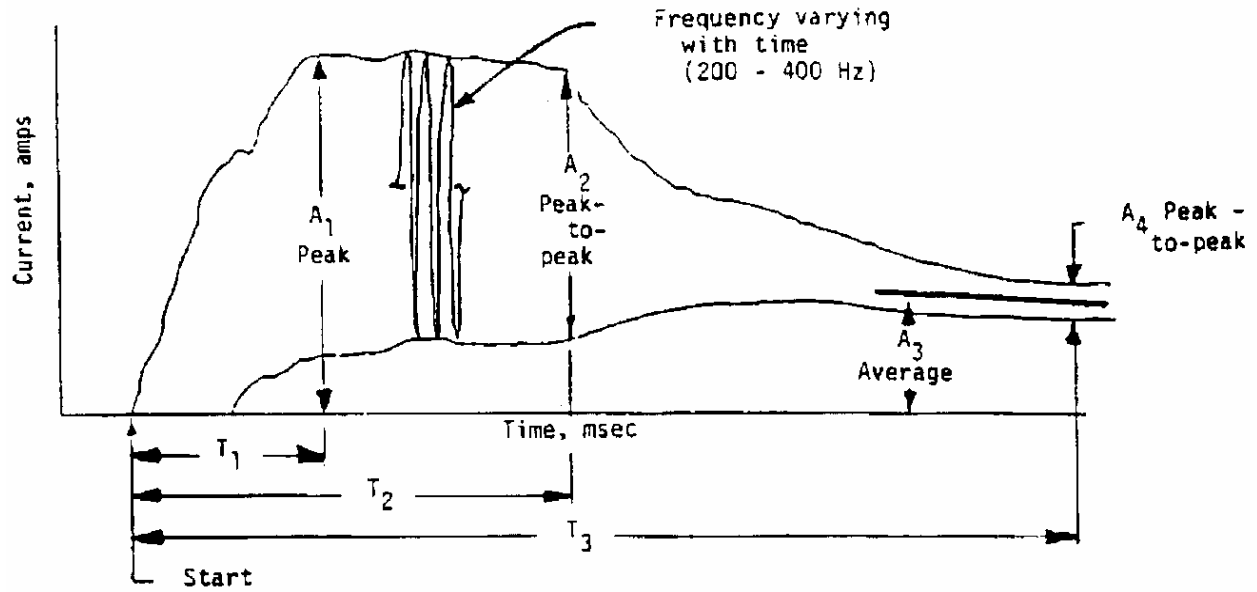
- Copper wire inductance causes substantial voltage loss from ac current

$\sim$  8-volt drop from steady-state (worst case) for 150 MS (calculated data indicated  $\sim$  10-volt drop)

- This voltage loss would violate aft PCA steady-state limits  
Aft PCA normally » 29 volts (new FC's) during ascent  
Steady-state redline = 26.1 volts (SODB table 3.4.5.6-2)  
Negative 5-volt margin at ripple wave "valleys" for ~ 150 MS (calculated data indicated ~ 7-volt negative margin)
- Simulated aft LRU capacitance had little effect on suppressing transient
- 25,000  $\mu$ F capacitance required to substantially reduce transient
- Actual LRU capacitance transient suppression unknown
- Orbiter and SRB LRU transient sensitivity unknown

#### RECOMMENDATION

- No circ pump ops during ascent  
Protecting double failure  
Activating pump creates potential problem without another failure
- If circ pump ops during ascent is direction, then first:  
Conduct integrated STS test  
Test must be performed with orbiter on fuel cell power (e.g., WCDDT)  
Add aft PCA oscilloscope instrumentation  
Record voltage transient  
Analyze or test all SRB and orbiter aft avionics for sensitivity margin  
Verifies that procedure is safe for all vehicles/fuel cells

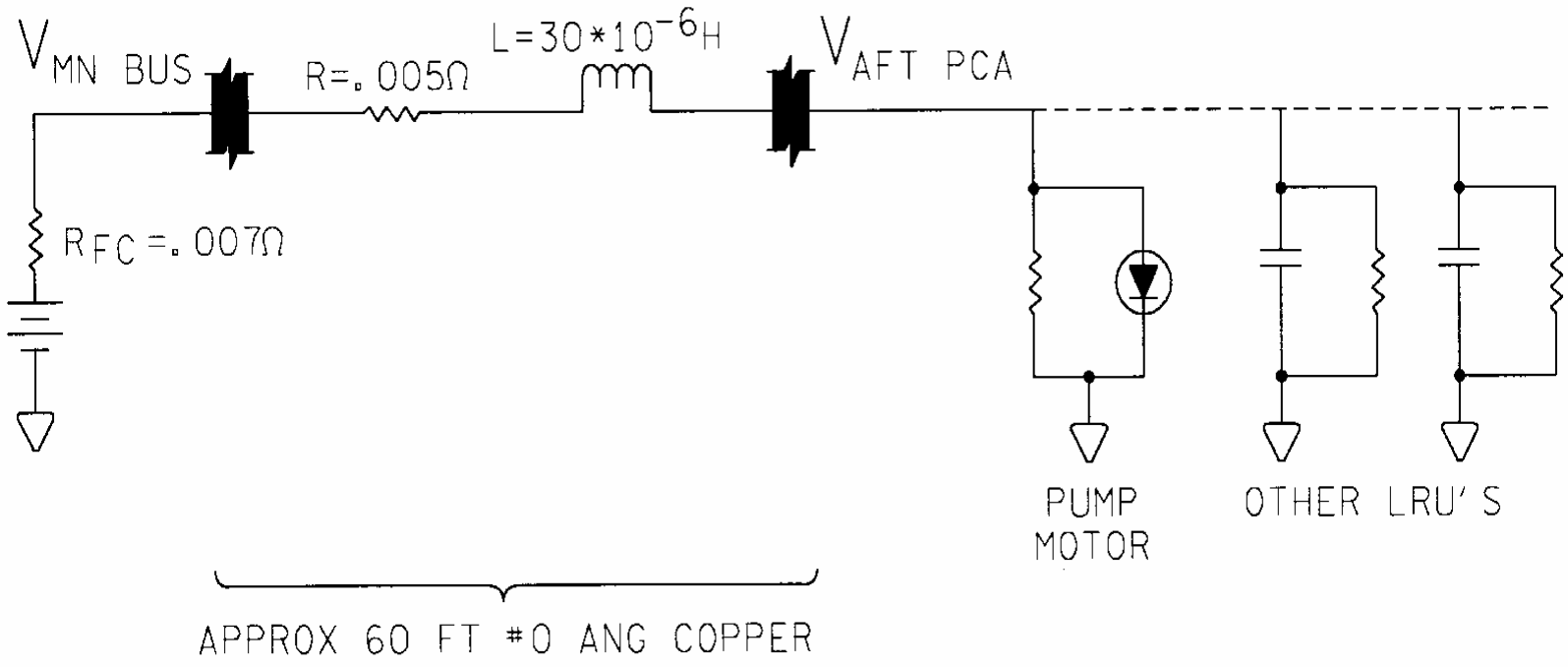


Temp °F	Nominal Start						$T_2$ msec		$T_3$ msec	
	Volts, dc	$A_1$ Amps	$A_2$ Amps	$A_3$ Amps	$A_4$ Amps	$T_1$ msec	n <sup>a</sup>	ss <sup>b</sup>	n <sup>a</sup>	ss <sup>b</sup>
25	28	280	242	140	120	70	380	2500	500	3000
35	28	255	235	115	60	75	230	1000	325	1500
50	28	255	230	100	30	50	170	170	340	500
70	28	255	214	72	30	60	140	140	290	290
70	24	222	185	82	20	65	85	85	300	300
70	32	253	215	75	30	45	230	2500	450	3000

<sup>a</sup> "n" indicates nominal start  
<sup>b</sup> "ss" indicates slow start

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Figure 4.1.5-1. Circulation pump start current vs time



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Figure 4.1.5-2. Orbiter aft dc bus circuit

Verify that this is the correct version before use  
4.1.5-19

## TITLE

BUS TIE TECHNIQUES

## PURPOSE

This brief describes the bus tie capabilities and limitations for the Main Bus Tie, the Back Door Bus Tie, the Back Door Fuel Cell Connect, and the techniques for applying the bus tie.

## BUS TIE

### Main Bus Tie

The Main Bus Tie is used to connect an unpowered/affected main bus to a powered main bus through the tie bus bar. This is accomplished by connecting the affected main bus to a tie bar with a motor contactor through remote switches on Panel R1. A powered main is then connected to the same tie bar with another motor contactor. To protect the main busses against excessive loads (ex. shorts) there are sets of fuses between the motor contactor and the tie bar.

### Reasons for a Main Bus Tie: (See FR A9-107)

1. To regain insight into a Fuel Cell due to loss of instrumentation
2. To maintain three main busses due to loss of a Fuel Cell
3. To minimize load transients on the Fuel Cells in performance of malfunction procedures
4. For extended on orbit operations of payloads requiring > 4KW (ie: SpaceHab)

### Comments:

*Do not bus tie a shorted bus!*

A shorted bus should not be connected to another healthy bus through the tie bar, or any other means of bus tie, to avoid feeding the short and dragging down the healthy bus. (i.e. potential loss of two main busses.)

*Do not bus tie three main busses!*

A bus tie that connects all three main buses at one time is not desirable. A single failure/short in this configuration could result in all three mains failing simultaneously. This is more critical during the Ascent phase of flight. There are situations (i.e. high loading using the Bus Tie cue card, Loss of 2<sup>nd</sup> FC Powerdown, Bus Tie reconfiguration) where this can be done. In a failure

scenario, it is an acceptable practice to temporarily tie three across during bus tie reconfiguration to keep from dropping a main bus. In most cases, if three main busses are connected through the Bus Tie due to the failure scenario, a powerdown must be performed (i.e. one FC cannot support all three mains without significant powerdowns). Operational philosophy is to keep Main Busses isolated, as long as it is possible, to offer the most redundancy to systems.

#### *Bus Tie Philosophy*

The standard main bus tie philosophy is to tie the bad bus to a good bus using this convention: MN A to MN B, MN B to MN C, and MN C to MN A. Although this is the standard convention, any combination of bus ties is possible, depending on the failure scenario.

#### **Hardware:**

The switches that operate the remote Bus Tie motor contactors are located on Panel R1. The motor contactor themselves are located in the MN DA, which is located in the forward end of the payload bay, adjacent to their respective Fuel Cell. For more information, refer to Section 4.1, DC Power Distribution and Control.

#### MN A - MN B bus tie

Both MN A and the MN B bus tie connections have (3) 0 gauge 150 amp fuse protected feeders and there is a 450 amp capability across the tie bar.

#### MN B - MN C bus tie

Both MN B and the MN C bus tie connections have (2) 0 gauge 200 amp fuse protected feeders with a 400 amp capability across the tie bar.

#### MN A - MN C bus tie

The MN A to MN C bus tie connection is unique in that it requires all the MN A - MN B and MN B - MN C connections, leads, and fusing. MN A is connected to the tie bar through a motor contactor and (3) parallel 150 amp fuses. This allows 450 amps to be carried to/from MN A. However, the MN A to MN C bus tie is made through the (6) 150 amp fuses that connect MN A to MN B and the (4) 200 amp fuses that connect MN B to MN C (see Fig. 4.1.6-1). MN C is then connected to the tie bar through its respective motor contactor and (2) parallel 200 amp fuses. Therefore, a 400 amp limitation exists with the MN C connection. This should not be a problem during most normal loading conditions of any flight phase.

Power to the motor contactors comes from its associated Main Controller circuit or bus (SSSH, Drawing 2.2, Sheet 1-3). The Main Controller circuit is redundantly powered by an ESS Bus and a MN Bus (see Fig. 4.1.6-2: MN

Controller Circuit). The MN A CONTR circuit is powered by ESS 1BC and MN B O15. The MN B CONTR circuit is powered by ESS 2CA and MN C O16. The MN C CONTR circuit is powered by ESS 3AB and MN A O14. Each power source is protected with a diode and a 5 amp circuit breaker. Both power sources are available under normal circumstances, however, only one power source is sufficient to operate the motor contactor. The MN CONTR circuits also provide power to the FC/MN Bus power contactors, PRI Payload power contactors, Docking System control power, EDO Pallet control power, and the ODS Vestibule Depress Valves.

**Back Door Bus Tie (MN C to MN B):**

**Reasons for a back door bus tie:**

Failed MN B - MN C Bus tie (Failed motor contactor or switch, tie bus short, failed tie bus fuses)

In the event of a failed bus tie for the reasons stated above, a normal bus tie through the main bus tie bar would be impossible. An alternative method for bus tying is available through the use of the Primary Payload bus. MN B and MN C can be connected to the Primary Payload bus thus creating the "Back Door" bus tie. If this method is required and there is a powered payload on the Primary Payload bus, a powerdown may be required due to the limitations on the Fuel Cell carrying both main busses and the primary payload bus, due to the fusing limitations.

**Comments:**

FC1 does not have the capability to connect to the Primary Payload Bus.

**Hardware:**

MN B to MN C

MN C (assuming no MN C short) can be connected to the Pri PL bus. MN B can then be connected to the Pri PL bus to share power. MN B is connected to the Pri PL bus through a motor contactor and a series of two sets of (2) 0 gauge 150 amp fuse protected feeders in parallel. This allows 300 amps to be carried between MN B and the Pri PL bus. There is no such fuse restrictions on the MN C connection (direct connections exist). The fuses limit the power that can be transferred to MN B through the back door bus tie technique. This should not be an issue under normal loading conditions. This configuration also has the effect of limiting the power that can be supplied to the Pri PL bus (during normal operations) by MN B.

**Back Door FC Connect (FC3 to MN C or FC3 to MN B):**

**Reasons for a back door FC connect:**

FC3 to MN C disconnect  
Nontransient hardware failure  
MN C Short (Loss of MN C) and a FC2 disconnect

Loss of a main bus due to a shorted motor contactor or a non-transient FC disconnect cannot be corrected for any main bus. However, FC3 can be used to recover MN C for some failure scenarios using the Pri PL bus. If MN C was lost due to a short, FC3 can still be used to power the primary payload bus and, therefore, can power MN B through the primary payload bus should a failure occur in the motor contactor for FC2 to MN B.

**Comments:**

*Do not connect a FC to a shorted main bus.*  
Nothing is gained by feeding the shorted bus. Further, excessive load will reduce the life of an FC.

**Hardware:**

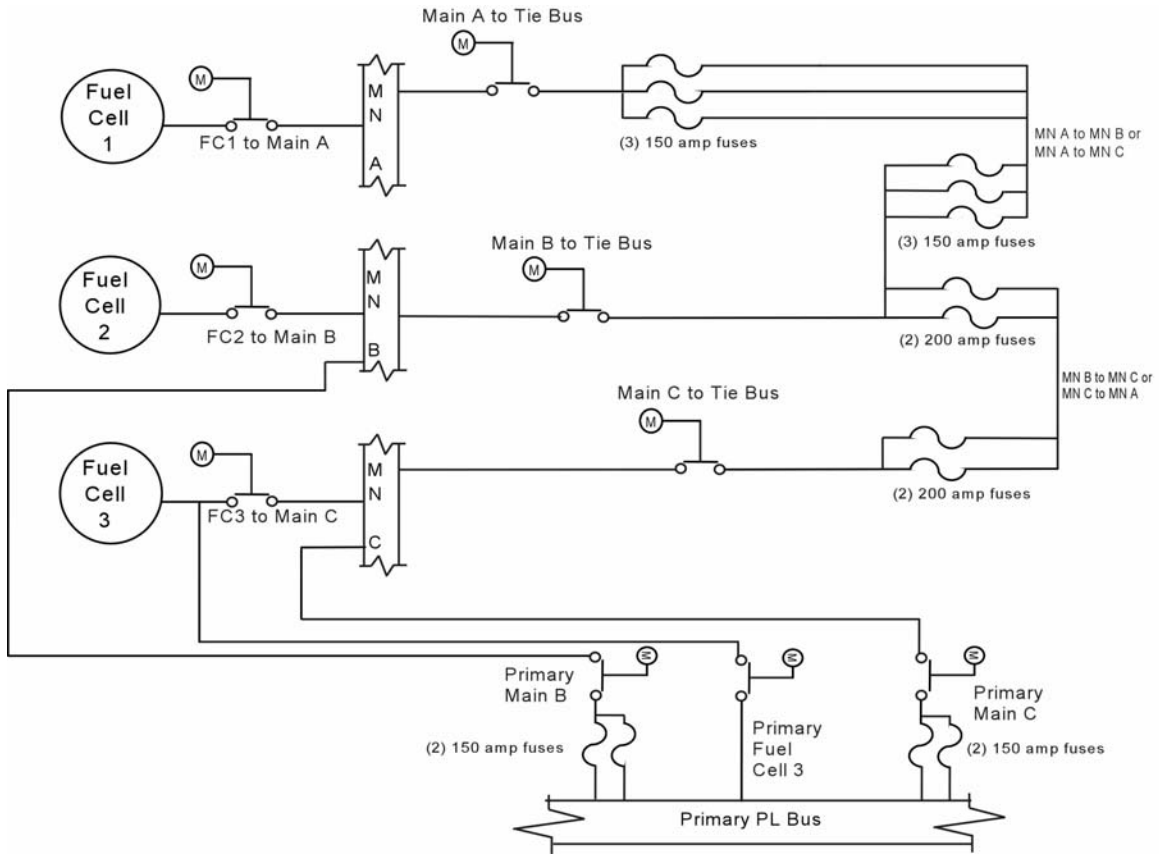
FC3 to MN C  
FC3 can be connected to the Pri PL bus using the switch on Panel R1. MN C can also be connected to the Pri PL bus via a switch on Panel R1. The result is MN C being powered by FC3 through the Pri PL bus rather than the Distribution Assembly. There are no fuse limitations in either connection.

FC3 to MN B (MN C is shorted)  
MN C is the only shorted main bus that does not necessarily result in the loss of its associated FC for load sharing. After completion of an AC power transfer (see Section 4.2.3), FC3 can be restarted. FC3 can then be connected to the primary payload bus. The MN B can also be connected to the Pri PL bus to allow load sharing with FC3. It is important to note that even though MN B can be repowered, there is a limitation as to what can be repowered. In order to restart FC3, the AC Power Transfer Cable would need to be installed to repower AC3. In this case, let's say AC1 was connected to AC3. The AC Power Transfer Cable is limited to 3 amps per phase due to the cb limitations of the utility outlet used. Serious thought must go into using FC3 to repower MN B in this case to avoid exceeding the limitation of the AC Power Transfer Cable, and essentially AC1, since AC1 would be carrying all the AC busses.

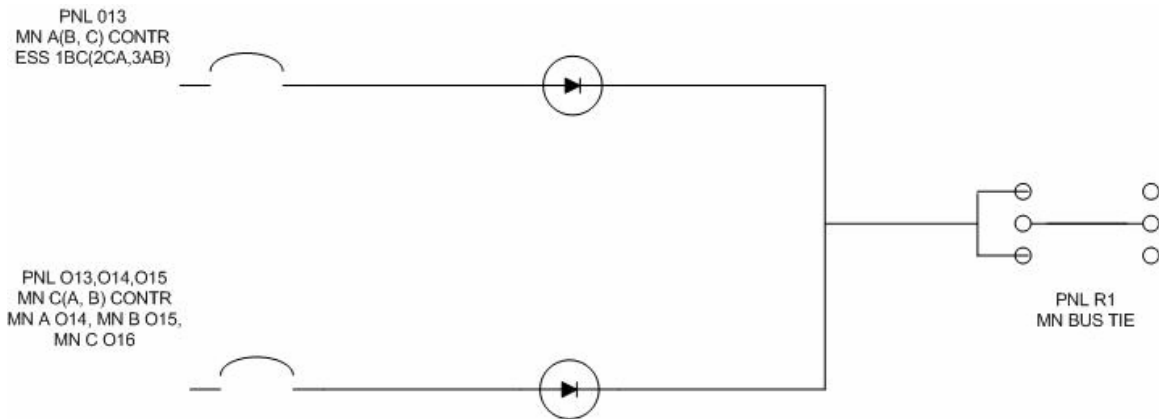
MN B recovery (FC2 to MN B disconnect)  
Both MN A and MN B can be recovered in the event of an FC disconnect using the normal bus tie procedure. However, MN B could be recovered with either the



back door bus tie (discussed earlier) or with the back door bus FC connect procedure even with failures to the main bus tie hardware.



**Figure 4.1.6-1. Bus Tie Configurations**



**Figure 4.1.6-2. MN Controller Circuit**

4.1.6-6

**Verify that this is the correct version before use**

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-4	OV-102	06/27/1982	07/04/1982	EPDC	H2 Cryo Heater Control Assembly	Fuse Failure	Fuse opened without the presence of a short. This cartridge fuse failed because it was overstressed. Repetitive thermal cycles on the fuse that was not properly derated caused the fuse to mechanically open (Kaymen-halsey Effect).
STS-4	OV-102	06/27/1982	07/04/1982	EPDC	FES HTR	FES HTR Short Circuit	A 15 - 20 amp spike on MN A was observed. It was due to either Heater A transient or is related to FES High-Load Inboard Duct HTR B. The heater shorted and was lost. There was no impact to the mission.
STS-6	OV-99	04/04/1983	04/09/1983	EPDC	Humidity Separator	AC short (AC2,AC3)	An AC short circuit occurred in a cable providing 3-phase AC2 power to the humidity separator and single-phase AC3 power to the humidity separator. The short was isolated when all four associated AC circuit breaker opened up. Postflight inspection showed that all six conductors were melted through, evidence of arcing (not to structure), scorched insulation, and Teflon wrap. The exact cause of the short was not apparent, but was probably a result of the wire bundle being hit with a hard metal object, forcing the bundle against the frame cap.

4.1.7-1

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-28	OV-102	08/08/1989	08/13/1989	EPDC	Teleprinter	A15 Utility Outlet	On STS-28, a short circuit occurred on a 20-gage cable powering the teleprinter through the A15 utility outlet. The crew had reported seeing sparks and glowing embers coming from the cable at the panel. The utility outlet circuit breaker did not open to isolate the short because of the low amount of energy of the short. Data showed that the short continued to propagate for 1.5 seconds. Inspection of the damaged cable revealed that both the power and the return were melted into two pieces at the connector, and 3/4 of an inch of the Gortex cover was melted. The wiring was melted to 1.2 inch from the wire tie on the strain relief up to the connector until the two wires were no longer touching; evident arcing had taken place. The connectors were exposed when the wires from a straight connector were bent at 90 degrees to fit into the recessed area, cracking the Kapton insulation.
STS-31	OV-103	04/24/1990	04/29/1990	EPDC	ADTA3 cb	Circuit Breaker Failure	On STS-31, during the powerup for FCS checkout, ADTA3 circuit breaker was closed but showed no signs of power. The circuit breaker was cycled five times. Three of these times, the LRU showed power, but following final closure, the power was off. The circuit breaker was cycled an additional five times, and ADTA3 regained power and functioned nominally the remainder of the flight.

4.1.7-2

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-38	OV-104	11/15/1990	11/20/1990	EPDC	Vacuum Cleaner	Vacuum Cleaner Short Circuited	During first attempt to power on the vacuum cleaner (to perform filter cleaning), the vacuum cleaner short circuited internally causing the L4:B UTIL PWR A15/MO13Q AC3 circuit breaker to open. AC data indicated a possible short in the vacuum cleaner. There was no impact to the mission. The crew continued filter cleaning using gray tape to remove lint from filters. No further use of the vacuum cleaner was planned. The vacuum was stowed and postmission inspection and repair will be performed.
STS-39	OV-104	04/28/1991	05/06/1991	EPDC	FC3/MNC	Fuel Cell 3 / Main C Bus Current	A 25 amps spike was seen on Fuel Cell 3, and with load sharing an addition 10 amps were seen on Fc1 and 2 for a total of 35 amps, for approximately 20 ms. The spike was not seen on the FWD, MID, or AFT amps. Coordination with STS-39 Payload and INCO officers revealed payload commanding coincident with the spike periods. Payload officer Jean Costlow was able to identify ALFE as the commanded payload for each of the 4 periods. The investigation was then focussed on ALFE as the prime suspect. Possible impacts include a short opening 3 or 5 amp fuse or cb's powered from MNC. Survey of FCR operators (systems, payloads) found no problems at the time of the reported spike. A list of open circuit breakers will be provided by postlanding team.

4.1.7-3

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-61C	OV-102	01/12/1986	01/18/1986	EPDC	FC1	ESS1BC Fuel Cell 1 Feed	During prelaunch activities, it was noted the FC1 volts transducer was erratic when the F9 meter was selected for FC1 volts and when the FC1 source for ESS1BC was enabled. Otherwise the FC1 volts transducer displayed a bias of approx 1 volt low. Further testing at KSC showed the FC1 did not feed the ESS1BC bus. It was confirmed, however that MN Bus B and MN Bus C were each powering the ESS1BC bus. It is thought a high bus C were each powering the ESS1BC - FC1 source switch on panel R1. FC1 volts transducer is reading properly on orbit, but is considered suspect. As part of the post-flight troubleshooting, the main distribution box will be removed and examined. Presently, the ESS1BC bus is redundantly powered via the MN bus B and MN bus C feeds, so there is no impact. The FC 1 volts transducer is considered unreliable, so the A/E system procedures and the ASCENT, ORBIT, and ENTRY POCKET CHECKLISTS have been updated.
STS-73	OV-102	10/20/1995	11/05/1990	EPDC	ET Doors	AC1 2-phase motor ops	On STS-73, during External Tank (ET) doors closure, AC1, phase B, did not supply power to any of the four motors supported by this circuit, as is evident by current traces. Further data review showed that the left vent doors 8/9 motor 1 had also not been powered by AC1, phase B, prior to launch. Postlanding, the circuit breaker, CB 4 on MA73C, was cycled approximately five times and the current path was restored. No further action was

4.1.7-4

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
							taken.
STS-75	OV-102	02/22/1996	03/09/1996	EPDC	H2 Cryo Heater Control Assembly	Fuse Failure	Fuse opened without the presence of a short. This crtridge fuse failed because it was overstressed. Repetitive themal cycles on the fuse that was not properly derated cuased the fuse to mechanically open (Kaymen-halsey Effect).
STS-78	OV-102	06/20/1996	07/07/1996	EPDC	H2 Cryo Heater Control Assembly	Fuse Failure	Fuse opened without the presence of a short. This crtridge fuse failed because it was overstressed. Repetitive themal cycles on the fuse that was not properly derated cuased the fuse to mechanically open (Kaymen-halsey Effect).
STS-79	OV-104	09/16/1996	09/26/1996	EPDC	H2 Cryo Heater Control Assembly	Fuse Failure	Fuse opened without the presence of a short. This crtridge fuse failed because it was overstressed. Repetitive themal cycles on the fuse that was not properly derated cuased the fuse to mechanically open (Kaymen-halsey Effect).
STS-80	OV-102	11/19/1996	12/07/1996	EPDC	H2 Cryo Heater Control Assembly	Fuse Failure	Fuse opened without the presence of a short. This crtridge fuse failed because it was overstressed. Repetitive themal cycles on the fuse that was not properly derated cuased the fuse to mechanically open (Kaymen-halsey Effect).

4.1.7-5

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-81	OV-104	01/12/1997	01/22/1997	EPDC	H2 Cryo Heater Control Assembly	Fuse Failure	Fuse opened without the presence of a short. This crtridge fuse failed because it was overstressed. Repetitive themal cycles on the fuse that was not properly derated cuased the fuse to mechanically open (Kaymen-halsey Effect). Since this failure, a design change has been made implemented that replaced the 5-amp fuses with 10-amp fuses.
STS-93	OV-102	07/22/1999	07/27/1999	EPDC	Primary MEC/Secondary MEC	AC short	A short circuit occurred in the AC system during ascent that caused the loss of the primary main engine controller on the center engine and the secondary controller on the left engine. Postmission inspection found a damaged wire in one of the payload bay wire trays. The failure analysis revealed that the conductor was exposed because of mechanical impact, something striking the wire harness against a screw that had raised burrs on the head. As a result of this failure, extensive vehicle wiring inspections were performed. As a result of hte inspections, many other incidents of damaged wires and improperly portected wire harnesses were found on each of the vehicles.
STS-84	OV-104	05/15/1997	05/24/1997	EPDC	Aft PL Amps ducer	Aft PL MNC Amps transducer fail	During the STS-84 mission, OV-104, at GMT 135/09:32:00, aft PL MNC amps measurement (V76C2822A) read zero. During subsequent PL operation on that bus, it continued to read 0 through aft PL MNC deactivation at 143/03:54:00. Loads up to 5 amps were expected. This caused some electrical insight to be lost on the bus. Repair was performed postflight.

4.1.7-6

Verify that this is the correct version before use



Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-97	OV-105	11/30/2000	12/11/2000	EPDC	APCU	APCU 2 Trip	At GMT 339/12:51, APCU 2 tripped off. Review of Shuttle and ISS data has shown nothing off nominal at the time of the trip. The APCU 2 trip status voltage (P50V9013V) transitioned from -4.69 to -1.53 volts indicating an input undervoltage and output undervoltage condition. Orbiter GPC System Maintenance Software annunciated two Fault Summary Messages: 200 APCU2 TRIP and 200 APCU2 VOLT LMT. The impact was temporary loss of ISS DDCU-3B loads and ISS channel 4B. The APCU 2 converters were repowered with the output relay opwn to verify nominal converter output voltage. APCU 2 was then reactivated at GMT 339/14:39. APCU 2 has remained stable since it was repowered.
STS-97	OV-105	11/30/2000	12/11/2000	EPDC	APCU	APCU 1 Dropoff	At GMT 339/16:48 both APCU 1 converters shut down. APCU 1 converters output voltage both high and low resolution (P50V9000V and P50V9001V) transitioned from there nominal 140 volt state to the unpowered level. Converter A and B output currents (P50C9003V and P50C9003V) also dropped off at the same time. The orbiter GPC system maintenance software annunciated a "200 APCU 1 VOLT LMT" fault summary messag. The APCU 1 trip indication (P50V9006V) remained at it's untripped state of -4.74 volts. After approximately 10 seconds, all APCU 1 outputs returned to nominal levels.

4.1.7-7

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-101	OV-104	05/19/2000	05/29/2000	EPDC	F9 Meter	F9 Meter Fluctuations	At GMT 141/00:44 the crew reported that during Ascent the panel F9 meter - DC AMPS & signal strength was fluctuating by approximately plus & minus 200. The crew reported that the meter was in signal strength during ascent and that the readings settled out after MECO. Since being on orbit, the F9 meter reading appear accurate, but fluctuate for about one minute before stabilizing whent he selector switch is moved. There was no impact to the mission. The crew minimized the use of the F9 meter and they allowed the meter reading fluctuations to settle out before reading.
STS-106	OV-104	09/08/2000	09/20/2000	EPDC	MNB APC5	MNB APC5 Bus Transient	At GMT 252/12/54:35 (MM104 transistion) a 60 amp transient was seen on MNB APC5. All equipment on the bus was investigated to determine the possible culprit for the transient. The transient last for 160 milliseconds. The OMS B crossfeed heaters have been identified as a possible culprit and a consideration is being made to not repower these heaters; to avoid possibly repowering into a short.

4.1.7-8

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
STS-109	OV-102	03/01/2002	03/12/2002	EPDC	FOC	Unexpected Fuel Cell 3 Spike during EVA4 Faint Object Camera (FOC) Removal	At approximately MET 5/23:07, the Orbiter Fuel Cells saw a spike of 30-32 amps. At approximately the same time the Fuel Cells saw this spike, the Direct Power Converter (DPCs) saw analogous spikes. All current paths from the DPCs were eliminated as the cause of hte spike except for the path providing current to the HST work and indicator lights. At the time of hte spike, this circuit was closed when the crew opened the A-Latch to remove the Faint Object Camera (FOC) from the Hubble Space Telescope (HST). Indicator Lights operated nominally after the spike. This current was interrupted when the Advanced Camera for Surbeys (ACS) was installed and will not be used again during this flight.
STS-110	OV-104	04/08/2002	04/19/2002	EPDC	Op-Stat	Postlanding MCA Op Stat Funny	During Post Landing operations, just prior to the transition to OPS 9, at GMT 109/16:38 the following MCA OP STAT showed open MID 1 STAT 1, MID 2 STAT 1, MID 2 STAT 7, MID 3 STAT 4, MID 4 STAT 5. At GMT 109/17:09 MCA OP STAT MID 1 STAT 7 and MID 1 STAT 8 showed open in addition to the loss of Left Vent Door 5 Open 2 microswitch telemetry (V59X3465X). No commonality could be found, therefore Vent Door Purge Positioning was not performed. The eight MA73C:C, D MID MCA LOGIC MCA POWER 3-phase AC circuit breakers were opened to preclude the possibility of a phase-to-phase short. At GMT 109/17:49 the ASP reported the MA73C:A MCA

4.1.7-9

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Brief Description
							LOGIC MNB MID 1 switch was in the OFF position. The MNB MID 1 switch in the OFF position explains the MID 1 STAT 7, the MID 1 STAT 8, and the Vent Door microswitch showing open. It was concluded that the MNB MID 1 switch was most probably bumped OFF during crew egress.

4.1.7-10

Verify that this is the correct version before use

## TITLE

ORBITER AC SYSTEMS

## INTRODUCTION

The AC power system onboard the space shuttle is a three-phase, 4-wire, Y-connected power system. The system consists of three AC buses, with each bus having three phases and a neutral (return) bus. The AC system provides the capability to operate three-phase induction motors with neutrals connected, and other single-phase line-to-neutral loads.

Each phase of an AC bus receives its power from an inverter designed to transform DC voltage (24 to 32 V) to 117 V (rms), 400-Hz AC power. The inverters receive DC power from the fuel cells via the Forward Power Control Assemblies (FPCAs) (Figure 4.2.1-1). The shuttle AC system contains nine inverters. Three AC buses each consist of three inverters (one per phase) and a neutral bus connected in a three-phase array. Each phase of the bus is offset by 120° (Figure 4.2.1-2). Each AC inverter is capable of delivering 6.41 amps continuously (100 percent rated), 9.62 amps for 30 minutes (.7 < pf ≤ .8 lagging) / 8 hours (pf > .8 lagging) (150 percent rated), or 12.8 amps for 2 minutes (200 percent rated). These values are strictly the inverter output capability. For reasons to be discussed later in this brief, the bus current telemetry may read lower than the actual inverter output current. The capability based on bus current telemetry (and associated instrumentation error) is 6.12 amps continuously (100 percent rated), 9.32 amps for 30 minutes (.7 < pf ≤ .8 lagging) / 8 hours (pf > .8 lagging) (150 percent rated), or 12.5 amps for 2 minutes (200 percent rated). Reference EGIL Flight Rule A9-155, Paragraph B, for more details on the AC inverter limits. Also reference SODB 4.5.6.3.1.8.

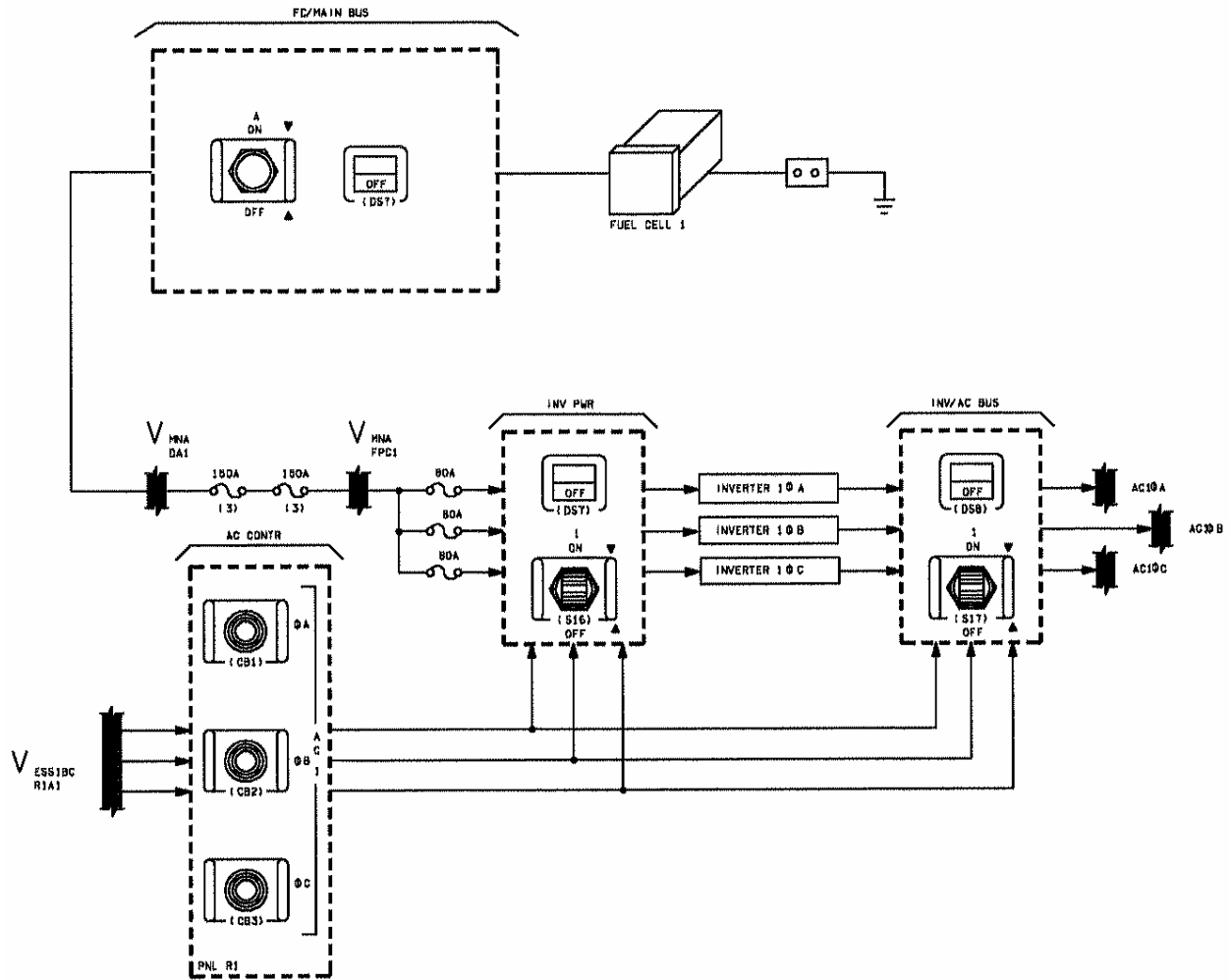
The AC system is used to power single-phase loads, such as lights and signal conditioners, as well as three-phase loads, such as pumps and fans.

### A. Inverters

The shuttle AC inverters are shown schematically on Space Shuttle Systems Handbook (SSSH) drawing 2.3-1. Refer to this drawing for the following discussion on AC inverter operation.

The inverters receive their DC power from the FPC. An inline 80-amp fuse is located between the FPC and the AC inverter. This fuse serves as a circuit protection device (to protect the FPC bus) for shorts within the inverter assembly (upstream of the inverter output). When the inverter power switch (INV PWR on panel R1) is taken to the ON position, power is applied to the 7.5-amp RPC in the inverter control box. At the same time, the 1-second (1.125) time delay is started. The 7.5-amp RPC provides the DC input through a diode to the AC phase inverter. The DC input must be  $>11 \pm 2$  V DC (voltage across the capacitor bank) to allow

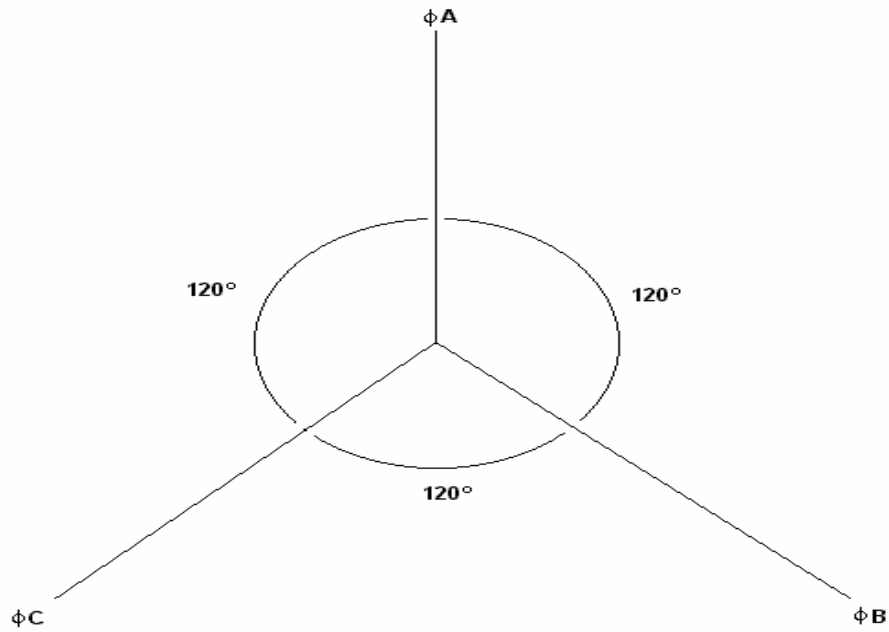
the inverter DC-DC converter to supply the control power to enable the inverter circuitry. (The DC input must be  $<9 \pm 2$  V DC for the inverter to turn off.)



1226. ART 2

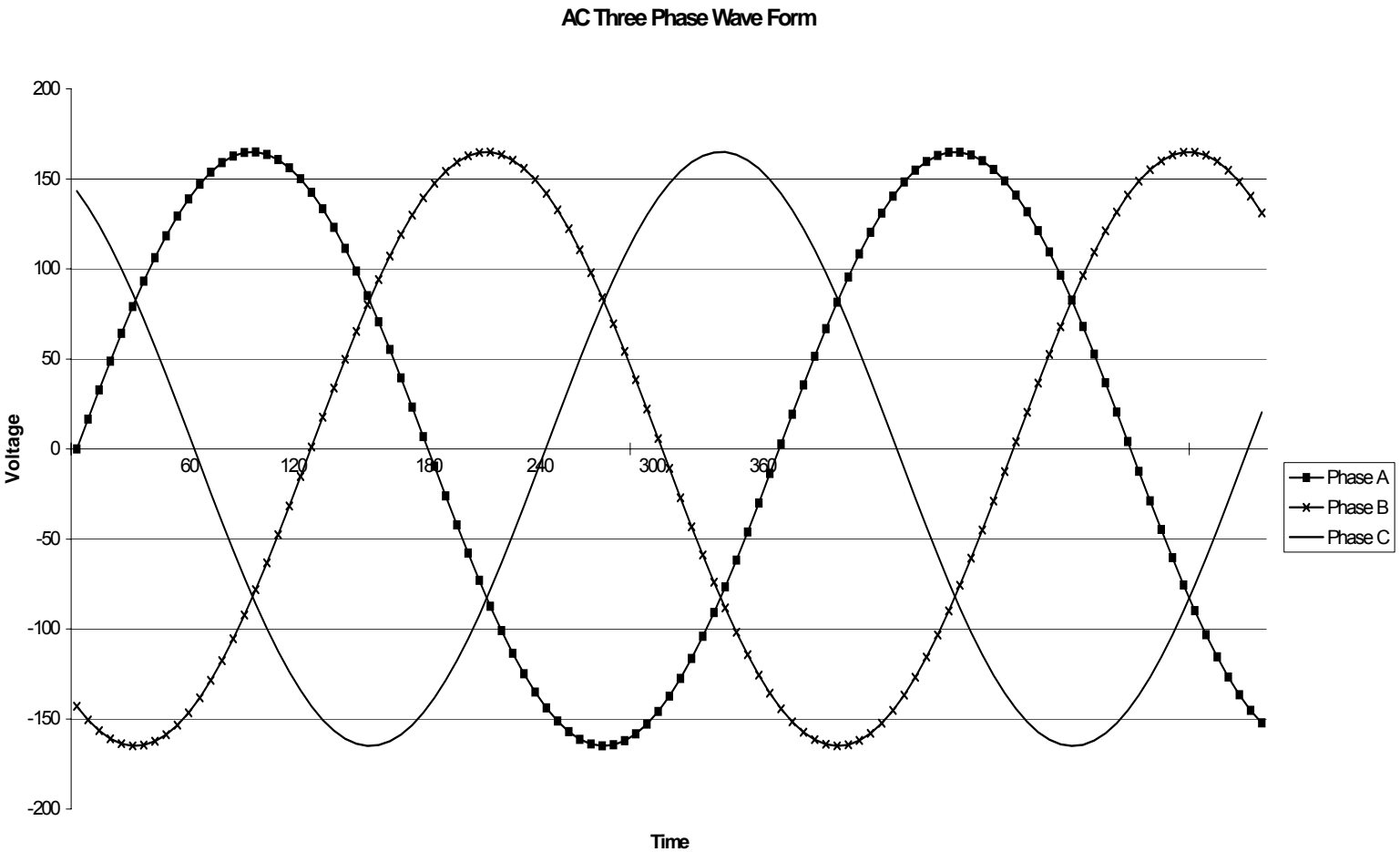
1\_12830\_145

Figure 4.2.1-1. AC-1 power control



(a) Bus phase offset

*Figure 4.2.1-2. AC bus phase displacement*



(b) AC three-phase wave form

Figure 4.2.1-2. Concluded

4.2.1-4

Verify that this is the correct version before use



The capacitor bank requires approximately 0.1 second to charge up, which is enough time for it to charge before the 1-second time delay in the inverter input control box times out, causing the inverter power relays to close. This closes the path from the FPC bus to the inverter, bypassing the 7.5-amp RPC which, until now, has been operating in its current-limiting mode. The INV PWR talkback returns to its unpowered state when all three inverter power relays are powered ON, so the talkback now indicates ON.

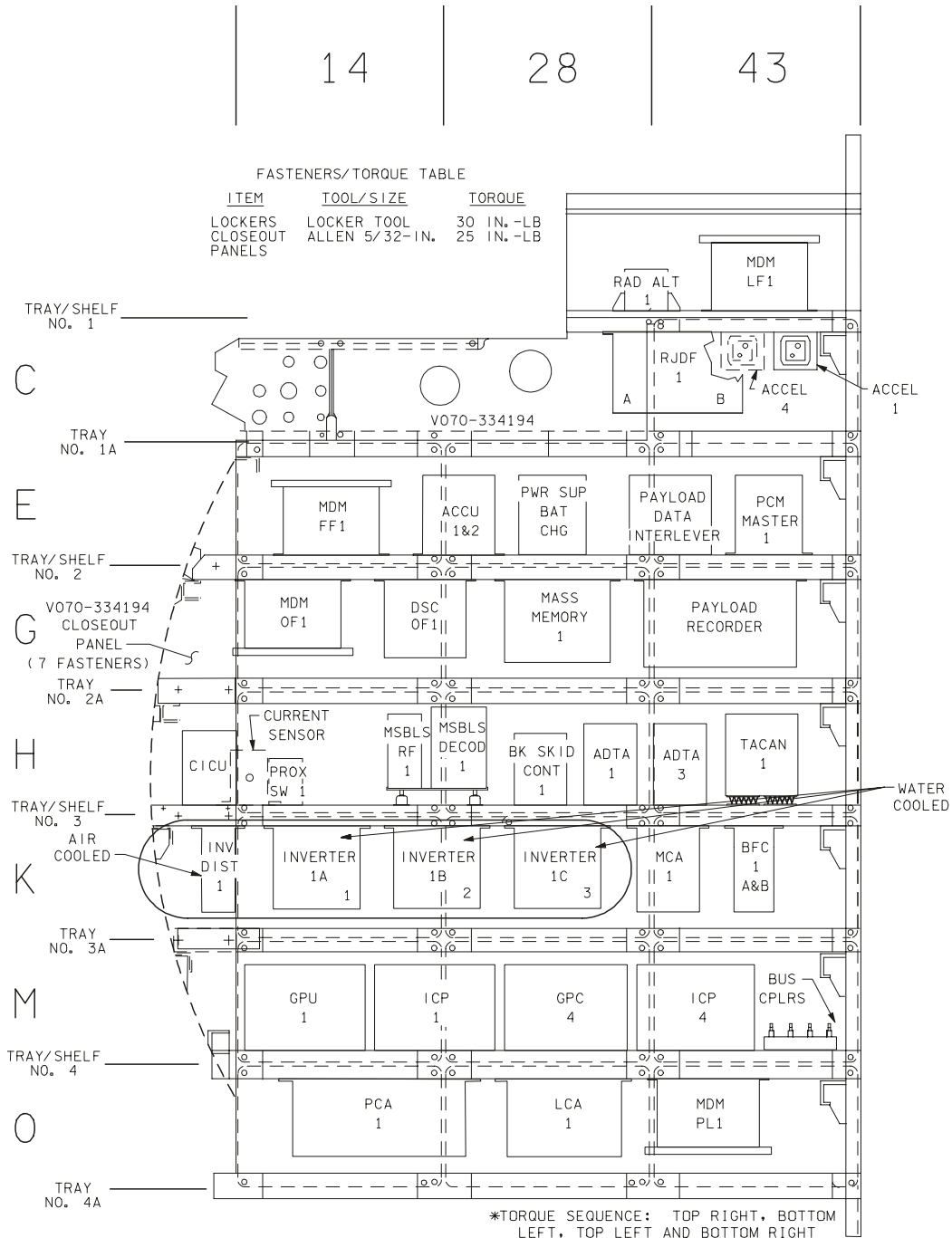
Applying power to the inverters through the 7.5-amp RPC limits the capacitor bank charging current to approximately 11 amps (150 percent + 11.25 amps) per inverter (30 amps for three inverters). Without the RPC, the current could exceed 600 amps for the three inverters. Once the inverter power relay is ON, however, the main bus current is no longer limited to 10 amps per inverter, and the current necessary to support AC loads can be supplied to the inverter. For the inverter powerup to work properly, the inverter output must be disconnected from the AC loads (INV/AC bus switch to OFF). If AC loads are connected to an inverter when the DC input power is applied, the inverter attempts to power its loads before the 7.5-amp RPC has been bypassed. When this occurs, the capacitor bank is depleted of its charge with the 7.5-amp RPC still in saturation. When the 7.5-amp RPC is bypassed, the inrush of current to the capacitor bank and the inverter could cause an undervoltage on the main bus. Feeding the DC voltage through the inductor and capacitor bank at the input to the inverter creates a high frequency Electromagnetic Interference (EMI) filter, but does not prevent large startup transients from being reflected back on the main bus. From the FPC, the power flows through the EMI filter (inductor and capacitor bank) to the power conversion circuits where two Controlled Current Feedback Transformers (CCFTs) chop the signal at a rate of ~9.6 kHz. This process creates a 400-Hz pulse width modulated waveform, which is smoothed by a reference filter to provide a 400-Hz sine wave output.

The AC inverters also have an internal clock circuit to provide synchronization between the phases of a three-phase AC bus. The internal clock is designed to control the output frequency at  $400 \pm 7$  Hz. The output from the inverter sync mixer is "daisy-chained" to the inverter sync separator of the following phase: A to B, B to C, C to A. The 400-Hz sync signal out of the inverter sync separator resets the ÷24 counter to zero. The 9600-Hz signal out of the inverter sync separator in each inverter synchronizes the internal oscillator. Phase displacement is determined by external jumpers (+12 V DC), which control count sequences used to synthesize a reference 400-Hz inverter sine wave voltage. This reference voltage is compared with and used to control the output voltage. The resulting inverter output is a 117-volt rms AC sine wave at 400 Hz. The three-phase array outputs three such sine waves, each displaced by  $120^\circ$  from the other.

#### 4.2.1-5

The phase displacement is determined by external jumpers. The phase A inverter is actually designated by there being no jumper input; phase B and phase C are determined by jumper input in specific locations (see SSSH drawing 2.3-1, zone O, 5).

The nine AC inverters on the shuttle are located in avionics bays 1, 2, and 3A, respectively (Figures 4.2.1-3, 4.2.1-4, and 4.2.1-5). Each group of three inverters is located next to its Inverter Distribution and Control Assembly (IDCA). Each avionics bay has four boxes. The inverters are water cooled (each located on a coldplate), and the IDCA is air cooled (avionics bay fan airflow).



128304213. ART# 1

**Figure 4.2.1-3. Component locations – bay 1**

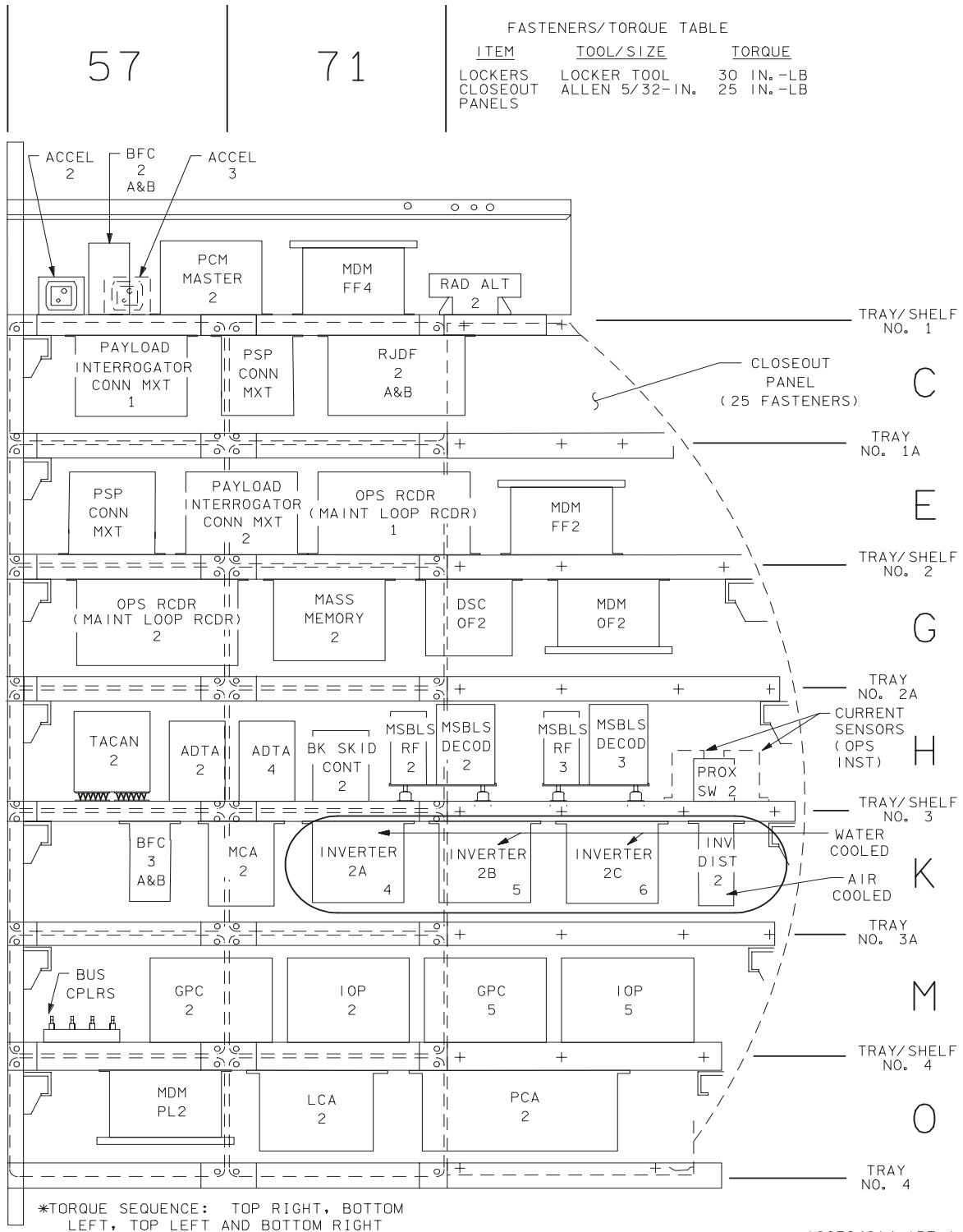


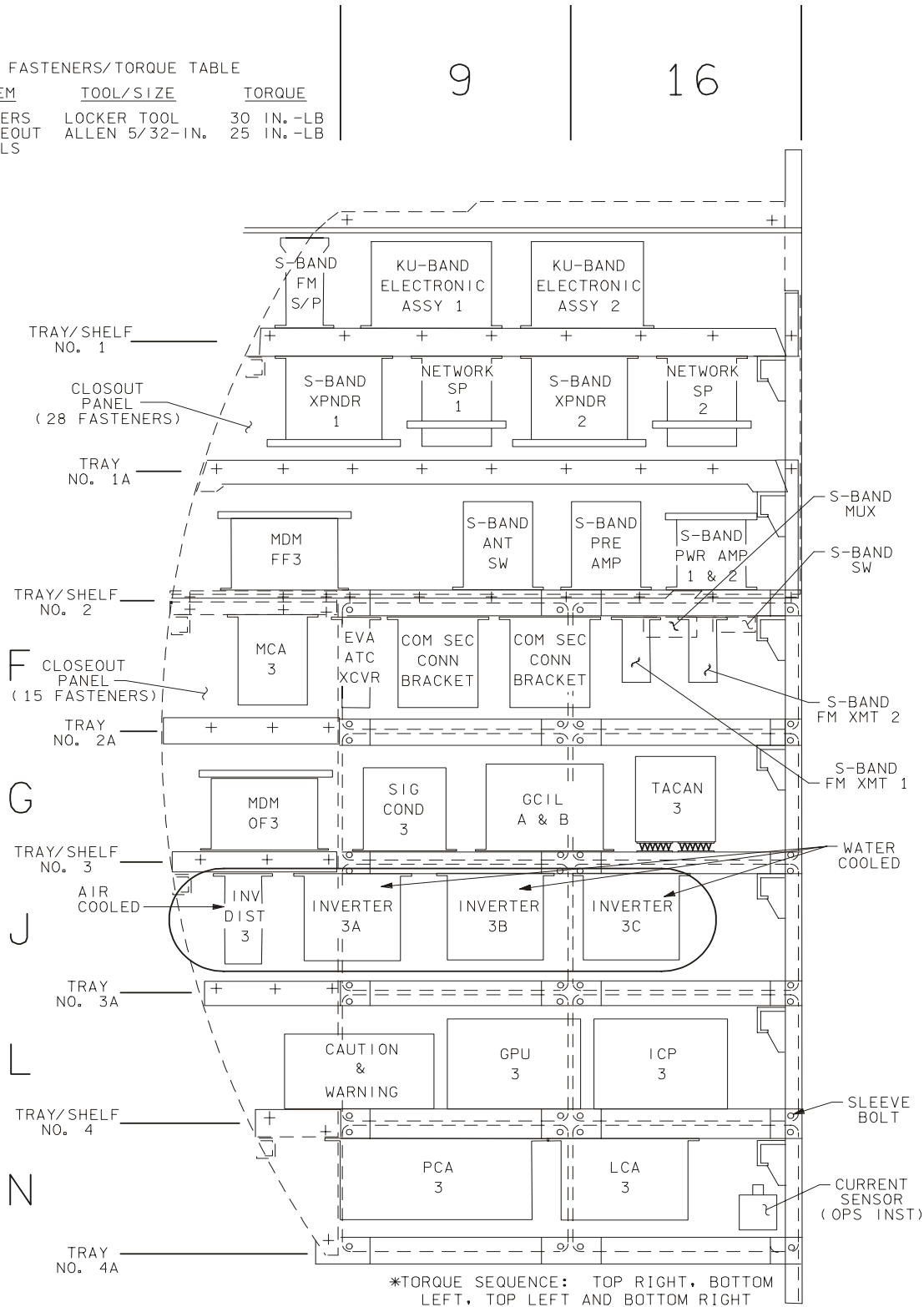
Figure 4.2.1-4. Component locations – bay 2

4.2.1-8

Verify that this is the correct version before use

FASTENERS/TORQUE TABLE

ITEM	TOOL/SIZE	TORQUE
LOCKERS	LOCKER TOOL	30 IN.-LB
CLOSEOUT PANELS	ALLEN 5/32-IN.	25 IN.-LB



128304215. ART 1

Figure 4.2.1-5. Component locations – bay 3A

4.2.1-9

Verify that this is the correct version before use

B. AC sensors

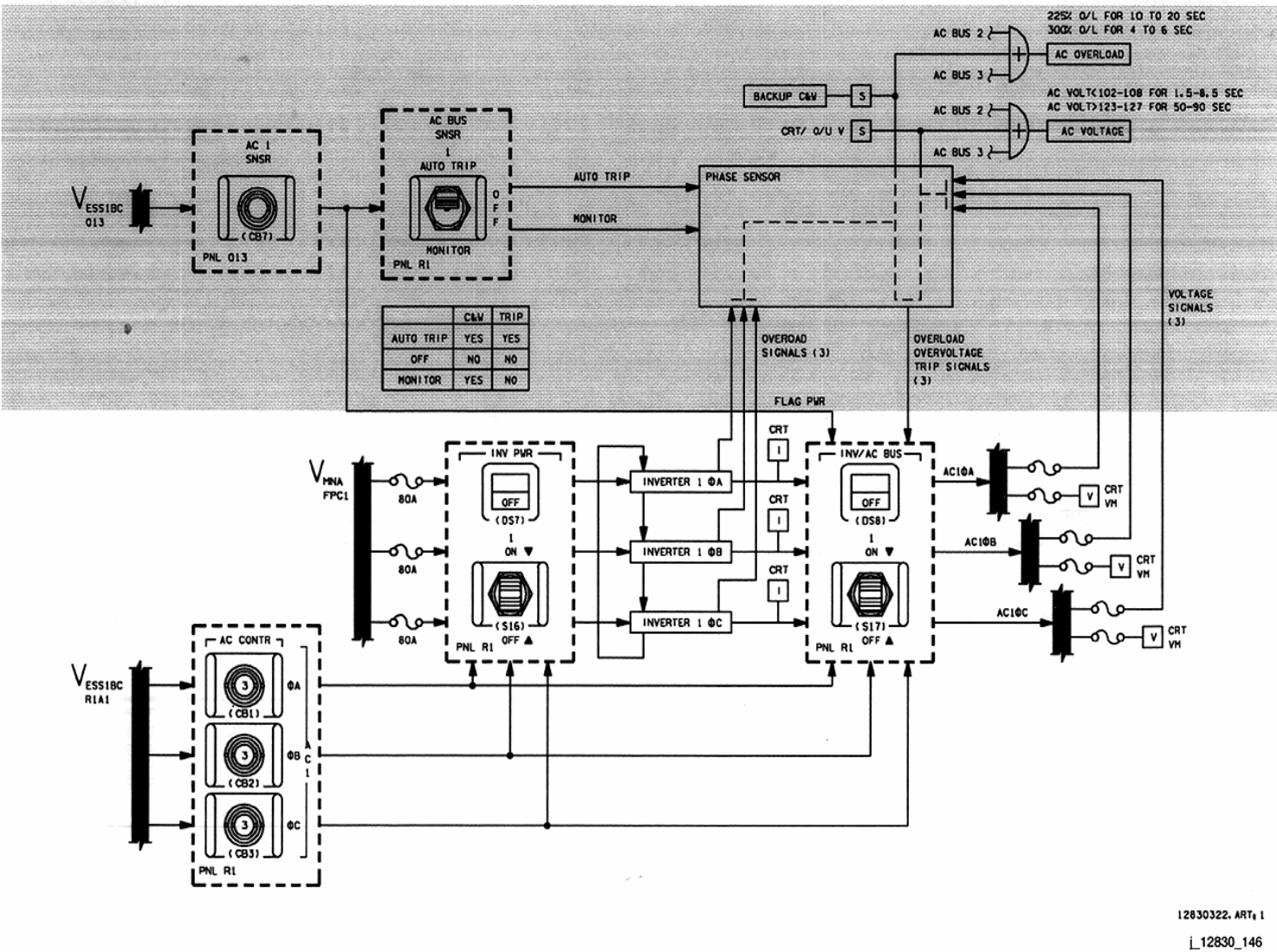
Each AC bus has an AC bus sensor to provide downstream circuit protection and failure annunciation. The sensors monitor AC voltage and current to detect and respond to an Overload (OL) and Overvoltage or Undervoltage (O/UV) condition.

Power to the AC bus sensors is provided by the essential buses via circuit breakers on panel O13 (Figure 4.2.1-6). The essential buses are also used to power the onboard INV/AC bus tb's; therefore, an essential sub-bus loss or an open cb causes loss of the AC bus sensor (loss of AC O/UV and OL sensing and trip-off capability) and causes the INV/AC BUS tb to indicate OFF. The backup (software) C&W capability will remain (software monitoring for voltage and current limit violations).

The AC bus sensor switches are located on panel R1 (see Figure 4.2.1-7 and SSSH drawing 2.3-1, zone M, 5). These switches are three-position switches.

1. AUTO TRIP - The AUTO TRIP position provides OL and O/UV protection. In case of an OL or OV condition, the sensor lights the corresponding C&W panel F7 light (AC VOLTAGE or AC OVERLOAD), generates a MASTER ALARM, and disconnects (trips off) the affected AC bus from its inverter. For a UV condition, the sensor lights the appropriate C&W panel F7 light (AC VOLTAGE) and generates a MASTER ALARM, but does not trip off the affected bus. The sensor does not trip off the bus because there is less concern and less risk of equipment damage for UV conditions as opposed to OL or OV conditions.
2. MONITOR - When the sensor switch is in the MONITOR position, the sensor monitors the inverter and bus for OL and O/UV conditions. The sensor annunciates the associated C&W for any of these conditions (F7 light and MASTER ALARM), but it does not trip off the bus. The sensor is flown in the MONITOR position for ascent to protect the AC bus from an inadvertent bus trip-off. An inadvertent bus trip-off during ascent would cause the loss of main engine controller redundancy (reference EGIL Flight Rule A9.1.4-2 for more details).
3. OFF - With the sensor switch in the OFF position, there is no monitor (no C&W lights or alarms) and no trip-off capability (i.e., there is no OL, OV, or UV sensing). The backup (software) C&W capability remains (software monitoring for voltage and current limit violations).

If an OL condition is present while the sensor is in OFF or MONITOR, taking the sensor to AUTO TRIP does not cause the bus to trip off. The sensor logic must see the positive leading edge of the OL signal (i.e., the sensor must sense the transition of the current from a non-OL state to an OL state). Conversely, if an OV condition is present while the sensor is in OFF or MONITOR, taking the sensor to the AUTO TRIP position causes the bus to trip off.



12830322. ART. 1  
i\_12830\_146

Figure 4.2.1-6. AC-1 sensor schematic

4.2.1-11

Verify that this is the correct version before use

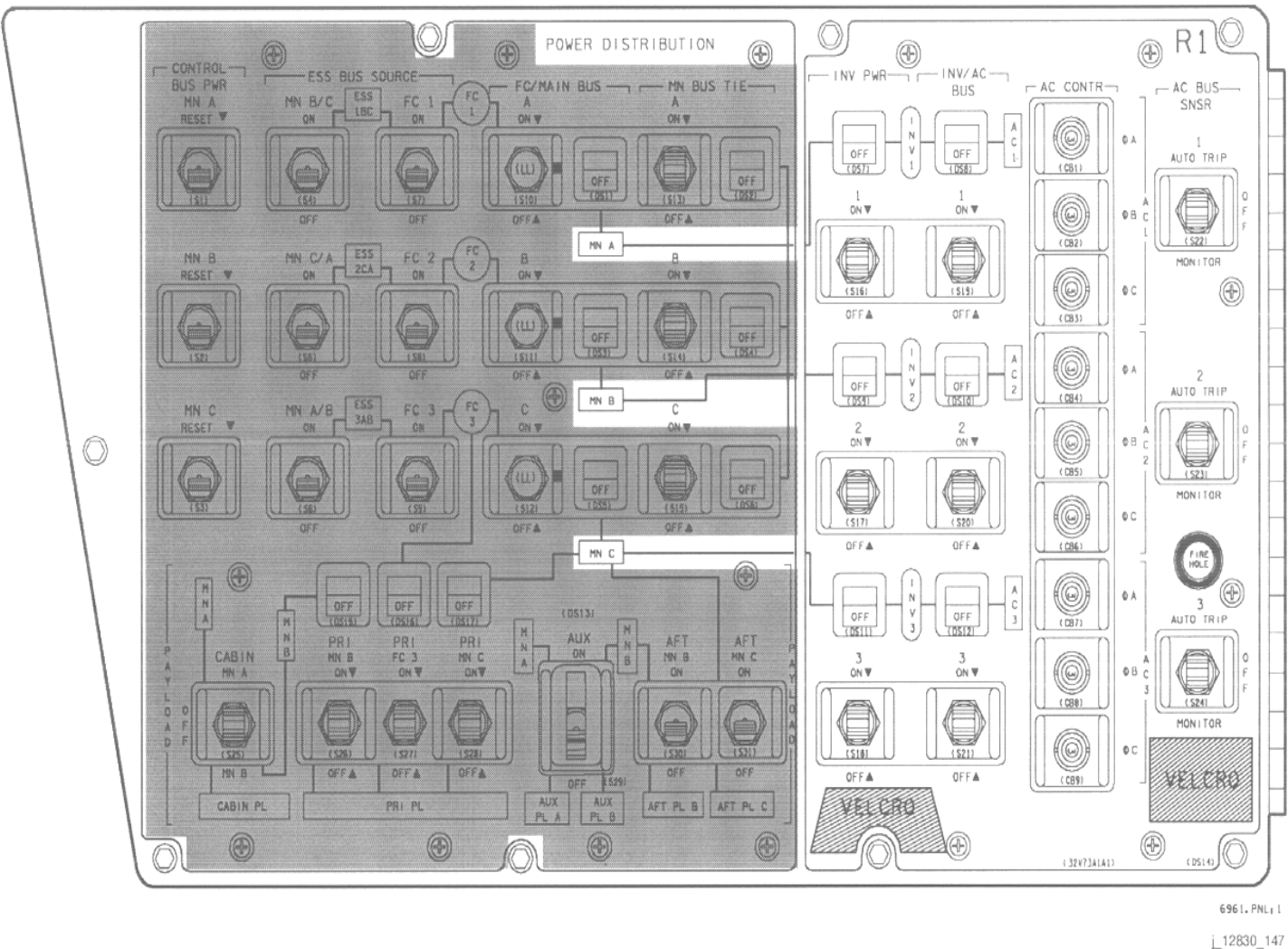


Figure 4.2.1-7. AC bus controls (panel R1)

4.2.1-12

Verify that this is the correct version before use



The OFF sensor position is used as a reset between the AUTO TRIP and MONITOR positions. When going from the OFF position to the AUTO TRIP position, or vice versa, the crewmember should stop in the OFF position for at least 1 second to allow for an adequate reset of the sensor logic circuits (flip-flops).

To monitor OL conditions, the current is sensed directly at the output of the inverter; the voltage is sensed at the output of the AC bus. An Overload (OL) condition is defined as amps >14.5 (225 percent of rated load) for 10 to 20 seconds or 17.3 to 21.1 amps (300 percent of rated load) for 4 to 6 seconds. An AC Undervoltage (UV) is defined as voltage <102 to 108 V for 6.5 to 8.5 seconds. An AC Overvoltage (OV) is defined as voltage >123 to 127 for 50 to 90 ms. Any AC overload or AC voltage condition annunciates an F7 light for either condition. Reference Figure 4.2.1-8 for a picture of the panel F7 matrix and the hardware C&W limits that drive these indicators. The following are the assigned hardware C&W channels that drive the AC OVERLOAD and AC VOLTAGE lights for each of the AC systems:

AC OVERLOAD	CH 63 (AC1)	AC VOLTAGE	CH 33 (AC1)
	CH 73 (AC2)		CH 43 (AC2)
	CH 83 (AC3)		CH 53 (AC3)

The AC VOLTAGE light is on when

Any AC phase bus voltage <102 to 108 volts for 6.5 to 8.5 seconds

Any AC phase bus voltage >123 to 127 volts for 50 to 90 milliseconds

The AC OVERLOAD light is on when

225 percent overload for 10 to 20 seconds (14.45 A)

300 percent overload for 4 to 6 seconds (17.3 to 21.1 amps)

The BACKUP C/W ALARM light is on when

Any AC phase bus voltage  $\leq$ 108 V AC

Any AC phase bus voltage  $\geq$ 123 V AC

Any AC phase bus overload condition (as described above)

O <sub>2</sub> PRESS	H <sub>2</sub> PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O <sub>2</sub> HEATER TEMP	MAIN BUS UNDERVOLT (R)	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H <sub>2</sub> O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS (R)	RIGHT RCS (R)
_____ (R)	LEFT RHC (R)	RIGHT AFT RNC (R)	LEFT OMS (R)	RIGHT OMS (R)
PAYLOAD WARNING (R)	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	_____
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

(34V73A7A2)

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**Figure 4.2.1-8. The AC voltage, AC OL, and backup C/W alarm lights**

C. AC inverter operations under failure conditions

A number of tests were performed on the shuttle AC inverters by the Aerospace Electrical Division of the Westinghouse Electrical Corporation in Lima, Ohio. A report (report LY21018) of the test results was published in April 1980. The report includes data gathered as a result of tests on inverter ops under 150 percent overload conditions for extended periods of time and under loss of coolant conditions at various loads. The following is a brief summary of the tests and the test results.

The inverter used for the tests was standard space shuttle AC inverter; i.e., the inverters convert an 18 V DC input to single-phase 117 V AC at 400 Hz. The inverter was rated at 750 VA continuous operations, 1125 VA for 30 minutes. Power factors range from -0.7 to +0.9.

The test results include the following data:

1. 150 percent overload for 8 hours

With adequate cooling, the inverter can handle this load. However, the lifetime and reliability of the inverter are affected if this load is maintained indefinitely.

2. Loss of coolant with 225 VA, -0.85 PF

At this load, the inverter was thermally stable and cooler than at no bus load, because of less heat generation.

3. Loss of coolant with 375 VA, -0.85 PF

This is also a stable operating condition, with no temperatures at or near the failure point.

4. Loss of coolant with 600 VA, -0.85 PF

This operating point is near the end of the thermally stable operating range. The inverter heat rejection reaches the maximum dissipation of 128 watts.

5. Loss of coolant with 750 VA, -0.85 PF

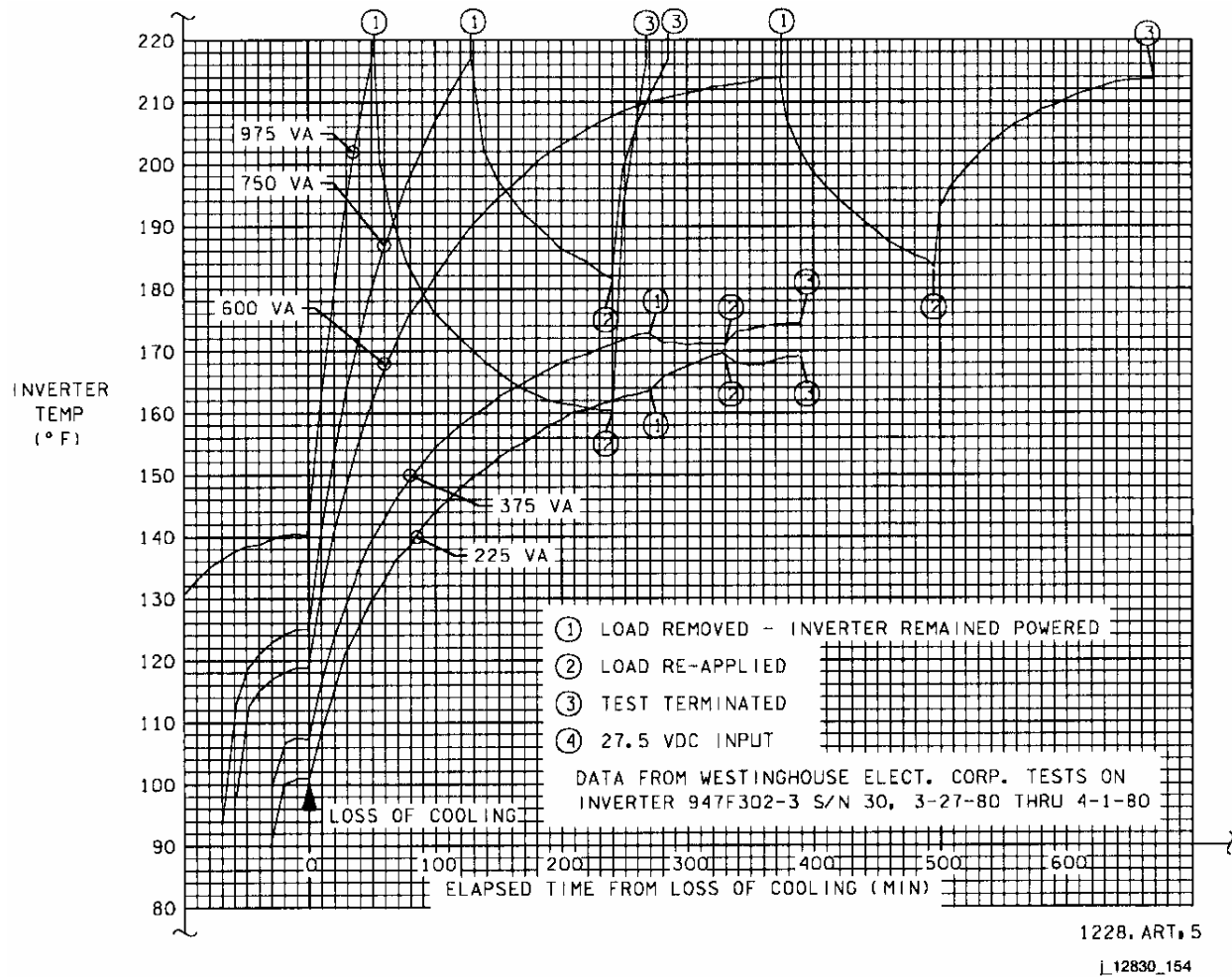
The inverter reaches redline at this load after ~2 hours of operation. Failure of the inverter occurs after approximately 3.5 to 4 hours of operation at this load. After this load is removed, inverter cooldown is very slow.

6. Loss of coolant with 975 VA, -0.85 PF

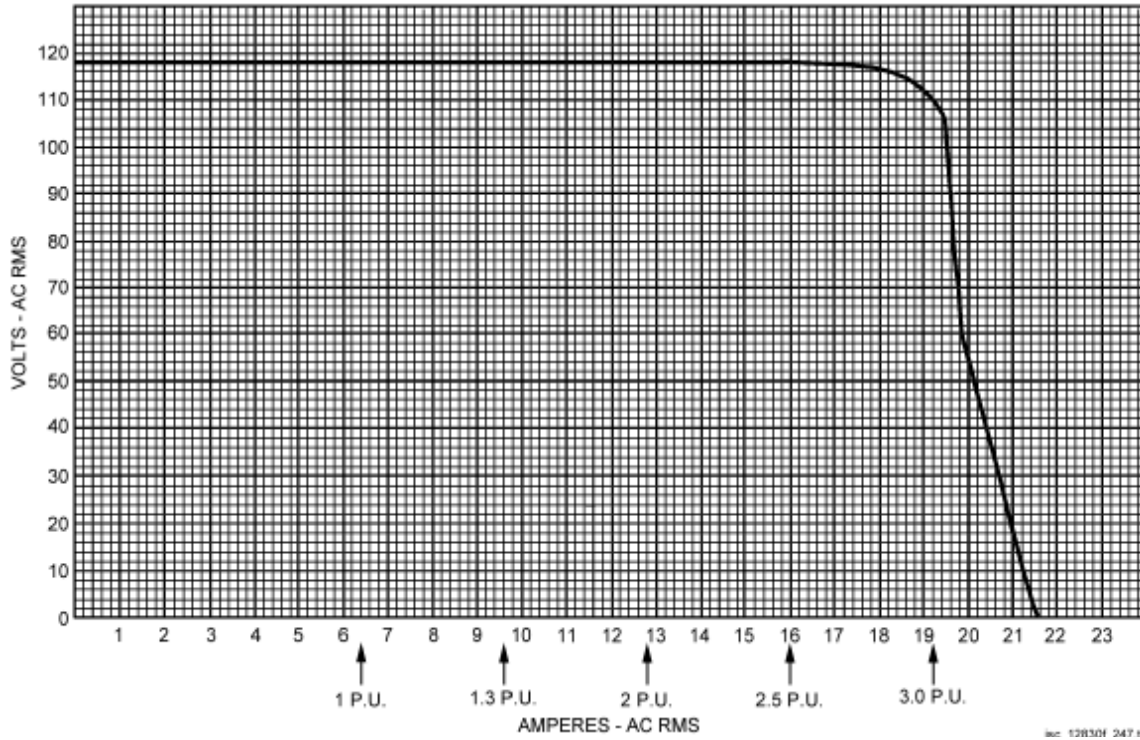
The inverter has ~1 hour of operating time after reaching thermal stabilization with this load and with cooling. Cycling the inverter at this load after 3 hours of no bus load allows for an additional 0.5 hour of operation (see Figure 4.2.1-9).

7. Output voltage vs. current

This test shows that the inverter has full output capability (>114 V) up to ~18.6 amps. At higher loads (current >18.6 amps), the inverter output voltage drops off rapidly (see Figure 4.2.1-10). This characteristic serves as a current limiting feature of the inverter.



**Figure 4.2.1-9. Orbiter inverter temperature vs. time with loss of cooling for various loads at 0.85 PF lagging**



**Figure 4.2.1-10. Output voltage vs. output current shuttle inverter S/N 44**

D. Onboard displays, control, and monitoring

In addition to the F7 matrix, the crew can monitor the AC system by various means. On orbit (OPS 2), AC information is available on crew displays SYS SUMM 1 and SPEC 67 ELECTRIC (see Figure 4.2.1-11 and Figure 4.2.1-12 for views of these two onboard displays). The SPEC 67 display shows AC voltages and currents, as well as OL and O/UV discretes. (The sensor output signals that drive the F7 lights also provide these OL and O/UV discretes.) The SYS SUMM 1 display, which is available during ascent/entry (OPS 1 and OPS 3) and on orbit (OPS 2), shows only the AC voltage and current information. The AC voltage for each of the nine AC buses is also available on a panel F9 meter (Figure 4.2.1-13). This is an analog meter with a range of 90 to 130 V. A rotary dial allows the crewmember to select which AC bus and phase voltage the meter is displaying. On the AC voltmeter, the range from 115 to 119 is indicated by a green band on the meter. The upper and lower limits of 123 and 108 are indicated by a red band at those respective levels.

Located on panel R1 are tb's for the inverter power (INV PWR) on/off status and for the inverter to AC bus (INV/AC BUS) connection on/off status (see Figure 4.2.1-7). Each AC bus (AC1, AC2, AC3) has only one set of switches. Individual phase control is performed by closing the desired AC CONTR circuit breaker and then using the INV PWR and INV AC BUS switches to power the inverter and connect it to the bus. One, two, or all three phases can be controlled at the same time by closing the desired circuit breakers.

Backup (software) C/W is also available for onboard monitoring of the AC system. Onboard Fault Summary (OFS) messages are sent for voltage, current, OL, and O/UV limit violations. The crew receives an S67 AC VOLTS 1 (2,3) fault message whenever the AC voltage for any phase is >123 V or <108 V. The crew receives an S67 AC CURRENT 1 (2,3) fault message whenever the AC current for any phase is >10 amps. The crew receives an S67 AC OVLD 1 (2,3) fault message for an OL condition on any phase (same criteria as used for OL). The generation of any of the messages also causes the BACKUP C/W ALARM light to illuminate on panel F7.

- E. The MCC workstation display used by the EGIL/EPDC controllers to monitor the AC system is the EGIL\_FC\_EPDC display (Figure 4.2.1-14). Data for the AC system is located in the middle left-hand side of this display. Available on the display are AC current (AC AMPS), voltage (VAC), inverter power and inverter-to-AC bus connection (INV/BUS), bus sensor switch position (SENSOR), OL indication (O/L), and O/UV indication (O/UV). The inverter power and inverter-to-AC bus indications are shown as “—”; the ON indications are shown as “---.” For an OL or O/UV condition, the display shows an “O/L” or an “O/UV,” respectively.

0 0 0 1 / / 0 7 8				S M S Y S S U M M 1				5				0 0 1 / 1 4 : 3 5 : 0 2							
								B F S				0 0 0 / 0 1 : 3 0 : 0 0							
S M O K E				1 / A		2 / B		D C V O L T S				1 / A		2 / B		3 / C			
C A B I N				0 . 0				F C				2 9 . 7		2 9 . 9		2 9 . 9			
L / R F D				0 . 0		0 . 0		M A I N				2 9 . 7		2 9 . 8		2 9 . 8			
A V B A Y 1				0 . 0		0 . 0		C N T L A B				2 9 . 8		2 9 . 8		2 9 . 8			
				2		0 . 0		B C				2 9 . 8		2 9 . 7		2 9 . 7			
				3		0 . 0		C A				2 9 . 8		2 9 . 7		2 9 . 7			
								E S S				2 9 . 6		2 9 . 8		2 9 . 8			
C A B I N								A C											
P R E S S				1 4 . 6				V O L T $\phi$ A				1 1 7		1 1 7		1 1 7			
d P / d T				+ 0 . 0				$\phi$ B				1 1 7		1 1 7		1 1 7			
B U / E O				+ 0 . 0		+ 0 . 0		$\phi$ C				1 1 7		1 1 7		1 1 7			
P P O 2				3 . 7		3 . 7		A M P $\phi$ A				4 . 1		5 . 6		4 . 5			
F A N $\Delta$ P				0 . 3 1				$\phi$ B				4 . 7		4 . 1		4 . 8			
H X O U T T				6 5				$\phi$ C				3 . 9		4 . 2		4 . 2			
O 2 F L O W				0 . 0		0 . 0		F U E L C E L L P H				- -		- -		- -			
N 2 F L O W				0 . 0		0 . 0		A M P S				2 0 5		2 1 0		2 1 0			
I M U F A N $\Delta$ P						4 . 3		R E A C V L V O P				O P		O P		O P			
$\Delta$ V				F C 1		F C 2		F C 3		S T A C K T				+ 1 9 1		+ 2 0 2		+ 2 0 1	
S S 1				2 2		2 1		2 2		E X I T T				1 5 0		1 5 1		1 5 0	
S S 2				2		2		2		C O O L P				6 0		6 1		6 1	
S S 3				2 3		2 1		2 1		P U M P									
T O T A L A M P S				4 1 5															
K W				1 2															

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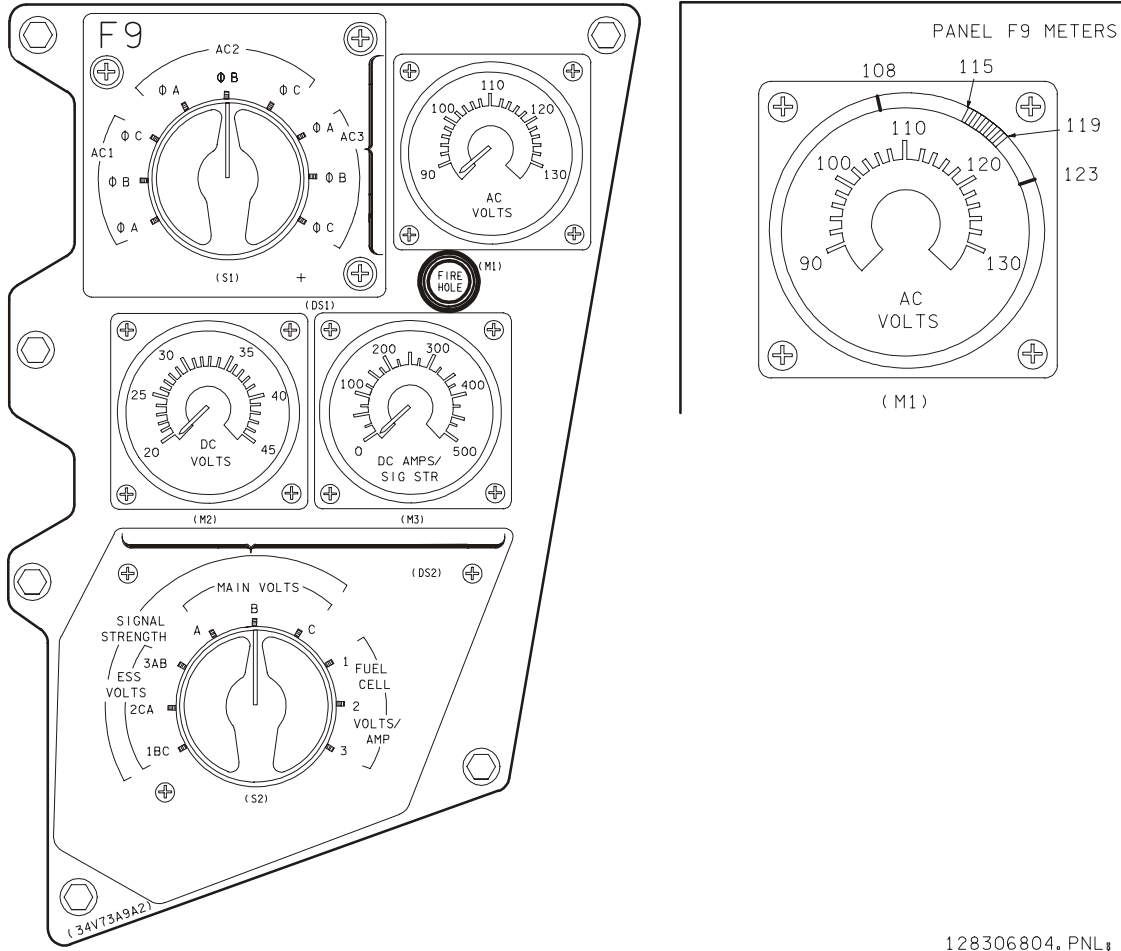
**Figure 4.2.1-11. The SM SYS SUMM 1 onboard CRT display AC bus parameters**

2011/		/067			ELECTRIC			2 224/ 15: 20: 01 000/ 01: 30: 00		
DC		1/A	2/B	3/C	AC	1	2	3		
VOLT	FC	30.2	30.2	30.3	V	Φ A	118	117	117	
	MN	30.1	30.1	30.2		Φ B	117	117	118	
PCA	FWD	29.8	29.8	29.9		Φ C	117	117	116	
	AFT	30.0	30.0	30.2	AMP	Φ A	4.5	2.2	4.0	
CNTL	AB	28.9	28.9	28.9		Φ B	4.1	4.6	4.5	
	BC	29.0	29.0	29.0		Φ C	2.4	2.0	4.7	
	CA	29.0	29.0	29.0	OVLD					
ESS		29.2	29.2	29.1	O/U	V				
AMPS	FC	190	190	180	PAYLOAD	DC	AMPS			
	FWD	116	122	134	AFT	B				
	MID	37	33	31		C				
	AFT	37	35	6						
TOTAL	AMPS		561							
	KW		17.0							

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**Figure 4.2.1-12. The SPEC 67 electric onboard CRT display AC bus parameters**





128306804, PNL 1

Figure 4.2.1-13. Panel F9 meter (AC volts)

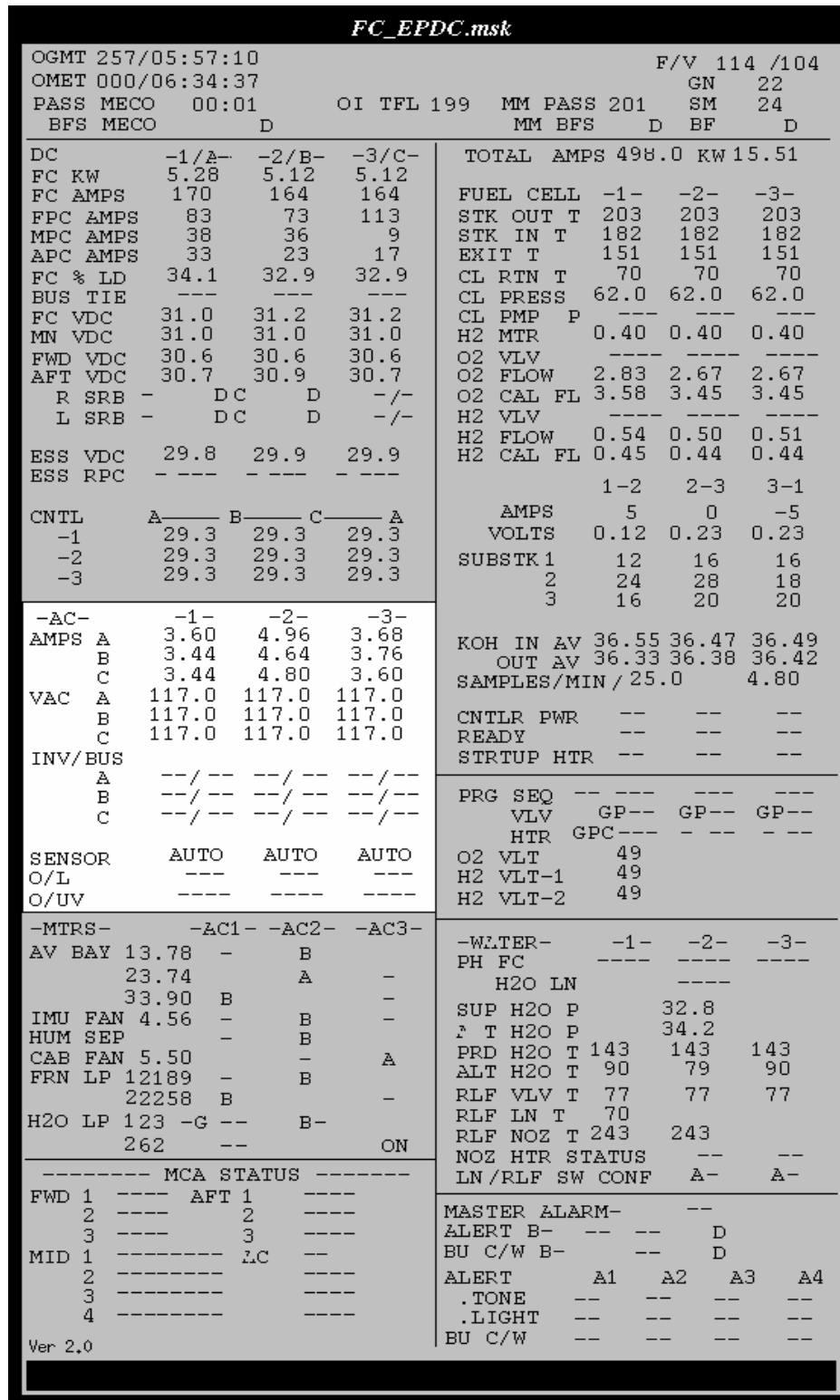


Figure 4.2.1-14. EPS ground display

The AC current data shown on the ground and onboard displays is for the AC bus current, not the inverter output current. To improve the overall power factor and to lessen the inverter workload, a 10-microfarad shunt capacitor was added to the inverter output, upstream of the AC bus current sensors (see SSSH drawing 2.3-1, zone P, 6). Inverter load differs from AC bus current as a function of the load power factor (pF). The bus current telemetry reads higher than the actual inverter output current. The following equations show the relationship between the two.

$$I_{BUS} = 2.95 + \sqrt{1 - (pF)^2} + \sqrt{(I_{INV})^2 - 8.7(pF)^2}$$
$$(I_{INV})^2 = 8.7 + (I_{BUS})^2 + 5.9(I_{BUS}) \left( \frac{pF}{|pF|} \right) \sqrt{1 - (pF)^2}$$

Reference EGIL Flight Rule A9.1.4-5 for more information.

Real-time graphical plots of the AC voltages and currents are available using the EGIL workstation applications RTPlot and PIRT. These plots make it possible for the EGIL/EPS flight controllers to monitor for shorts, equipment power on/power off, and off-nominal conditions and trends.

**TITLE**

AC LOADS – EEL

**Table 4.2.2-1. Baseline AC loads - electronic equipment list  
April 1991**

**Ascent:**

	EEL loc	Item	AC1									Item	AC2									Item	AC3								
			ΦA			ΦB			ΦC				ΦA			ΦB			ΦC				ΦA			ΦB			ΦC		
			Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps
+ TACAN (GPC MODE) T/R, SEARCH T/R, TRACK	0208	#1							163 147	-0.85 -0.85	1.67 1.50	#2							163 147	-0.85 -0.85	1.67 1.50	#3							163 147	-0.85 -0.85	1.67 1.50
NUMERIC LTG *	0333	FWD				17.0	-0.90	0.16				#2	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01	#3	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01
INV DIST CNTL ASSY LDG PROX SNSR ELECT PKG	0610 0620	#1	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01	#2	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01	#3	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01
MN ENG CNTR	2001	CTR 1A	108	+0.94	1.0	108	+0.94	1.0	108	+0.94	1.0	LFT 2A	108	+0.94	1.0	108	+0.94	1.0	108	+0.94	1.0	RT 3A	108	+0.94	1.0	108	+0.94	1.0	108	+0.94	1.0
FCP PMPS & H <sub>2</sub> O SNSR	2001	RT 3B	95.3	+0.93	0.89	95.3	+0.93	0.89	95.3	+0.93	0.89	CTR 1B	95.3	+0.93	0.89	95.3	+0.93	0.89	95.3	+0.93	0.89	LFT 2B	95.3	+0.93	0.89	95.3	+0.93	0.89	95.3	+0.93	0.89
CABIN FAN CABIN AIR TEMP CNTL ELEC CABIN AIR SIG COND	4001 4003 4004	SEC	3.75	-0.84	0.04	1.40	-0.84	0.01				B	161.0	-0.83	1.69	161.0	-0.83	1.69	161.0	-0.83	1.69	PRI	3.75	-0.84	0.04						
HUM SEP	4005											B	10.7	-0.33	0.28	10.7	-0.33	0.28	10.7	-0.33	0.28										
AV BAY FAN	4008											2A	58.0	-0.71	0.71	58.0	-0.71	0.71	58.0	-0.71	0.71										
AV BAY SIG CNDR	4009	BAY 2	58.0	-0.68	0.74	58.0	-0.68	0.74	58.0	-0.68	0.74	1B	58.0	-0.72	0.70	58.0	-0.72	0.70	58.0	-0.72	0.70	BAY 1				2.00	-0.84	0.02			
IMU FAN	4011											B	15.97	-0.78	0.18	15.97	-0.78	0.18	15.97	-0.78	0.18										
H <sub>2</sub> O LOOP PMP H <sub>2</sub> O BYPASS CNTLR SIG COND	4013 4015	SEC(2)	5.90	-0.85	0.06							LOO	66.0	-0.55	1.04	66.0	-0.55	1.04	66.0	-0.55	1.04	PRI(1)	5.90	-0.85	0.06				66.0	-0.55	1.04
FREON LOOP PUMP	4029	1A	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69	2A	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69	2B				5.0	-0.9	0.05			
FREON LOOP INSTR	4036											1A				5.0	-0.9	0.05				2B				5.0	-0.9	0.05			
HYD QTY SNSR	5008	#1				1.40	-0.80	0.02				#2				1.40	-0.80	0.02				#3				1.40	-0.80	0.02			
HYD H <sub>2</sub> O BLR CNTLR LOGIC /SNSRS HYD ACTUATORS	5037 5018 5020	3A							5.70 5.0	-0.70 -0.70	0.07 0.06	1A	5.50	-0.70	0.07				11.0	-0.70	0.14	2A	5.60	-0.70	0.07						
CREW SEAT ASSY	6007											CDR	111.55	-0.97	1.0	111.55	-0.97	1.0	111.55	-0.97	1.0	PLT	111.55	-0.97	1.0	111.55	-0.97	1.0	111.55	-0.97	1.0

Note: Calculations assume 115V ac.  
\*Wattages indicate full bright.  
+TACAN may be powered by dc bus.

Verify that this is the correct version before use

4.2.2-2

Table 4.2.2-1. Baseline AC loads - electronic equipment list  
 April 1991 (continued)

Orbit:

	EEL loc	Item	AC1									Item	AC2									Item	AC3																				
			ΦA			ΦB			ΦC				ΦA			ΦB			ΦC				ΦA			ΦB			ΦC														
			Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps									
PANEL LIGHTS *	0331	L/CTR	298.0	-0.90	2.88							RT				163.2	-0.90	1.58							MS				29.5	-0.90	0.29												
	0331	L/OVHD				202.4	-0.90	1.96				R/OVHD	140.1	-0.90	1.35													OS/PS				277.4	-0.90	2.68									
INSTR LIGHTS *	0332	RT	48.5	-0.90	0.47							D				27.5	-0.90	0.27										L/CTR				55.0	-0.90	0.53									
	0332	OS							14.0	-0.90	0.14	OVHD										21.0	-0.90	0.20																			
NUMERIC LIGHTS *	0333	FWD				17.0	-0.90	0.16																																			
INV DIST CNTL ASSY	0610	#1	.70	-0.90	0.01	.70	-0.90	0.01	.70	-0.90	0.01	#2	.70	-0.90	0.01	.70	-0.90	0.01	.70	-0.90	0.01	#3	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01									
LG PROX SNSR																																											
ELEC PKG	0620											#2	8.00	-0.99	0.07										#1	8.00	-0.99	0.07															
FCP PUMPS & H <sub>2</sub> O																																											
SNSR	3005	#1	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82	#2	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82	#3	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82						
CABIN FAN	4001											B	161.0	-0.83	1.69	161.0	-0.83	1.69	161.0	-0.83	1.69																						
CABIN AIR T ELEC	4003	SEC	3.75	-0.84	0.04							PRI	3.75	-0.84	0.04																												
CABIN AIR SIG COND	4004					1.40	-0.84	0.04																																			
HUM SEP SIG COND	4006																				1.90	-0.84	0.02																				
HUM SEPARATOR	4005											B	10.7	-0.33	0.28	10.7	-0.33	0.28	10.7	-0.33	0.28																						
AV BAY FAN	4008	3B	58.0	-0.68	0.74	58.0	-0.68	0.74	58.0	-0.68	0.74	1B	58.0	-0.72	0.70	58.0	-0.72	0.70	58.0	-0.72	0.70																						
	4008											2A	58.0	-0.71	0.71	58.0	-0.71	0.71	58.0	-0.71	0.71																						
AV BAY SIG CONDR	4009	BAY 2				2.00	-0.84	0.02				BAY 3				2.00	-0.84	0.02							BAY 1				2.00	-0.84	0.02												
IMU FAN	4011											B	15.97	-0.78	0.18	15.97	-0.78	0.18	15.97	-0.78	0.18																						
IMU FAN SIG CONDR	4012																													1.75	-0.84	0.02											
H <sub>2</sub> O PUMP	4013																							LOOP 2	66.0	-0.55	1.04	66.0	-0.55	1.04	66.0	-0.55	1.04										
H <sub>2</sub> O BYPASS CNTLR																																											
SIG CONDR	4015	SEC(2)	5.90	-0.85	0.06																			PRI(1)	5.9	-0.85	0.06																
FREON LOOP PMP	4029	1A	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69													2A	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69							
FREON LOOP INSTR	4036																																										
HYD QTY SNSR	5008	#1				1.40	-0.80	0.02				LP1(A)				5.00	-0.90	0.05																									
HYD H <sub>2</sub> O BLR CNTL												#2				1.40	-0.80	0.02																									
LOGIC/SNSRS	5037	3A							5.70	-0.70	0.07	1A	5.50	-0.70	0.07																												
HYD ACTUATORS	5018-								5.0	-0.70	0.06																																
	5020																																										

Note: Calculations assume 115V ac.

\*Wattages indicate full bright.

Verify that this is the correct version before use

4.2.2-3

**Table 4.2.2-1. Baseline AC loads - electronic equipment list  
April 1991 (continued)**

Entry:

	EEL loc	Item	AC1									Item	AC2									Item	AC3											
			ΦA			ΦB			ΦC				ΦA			ΦB			ΦC				ΦA			ΦB			ΦC					
			Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps			
TACAN (GPC MODE) T/R, SEARCH T/R, TRACK	208	#1							163	-0.85	1.67	#2							163	-0.85	1.67	#3							163	-0.85	1.67			
									147	-0.85	1.5								147	-0.85	1.5								147	-0.85	1.5			
PANEL LIGHTS *	0331	L-CTR	298.0	-0.90	2.88							RT				163.2	-0.90	1.58																
		L-OVHD				202.35	-0.90	1.96				R-OVH	140.1	-0.90	1.3							L-CTR				55.0	-0.90	0.53						
INSTR LIGHTS *	0332	RT	48.5	-0.90	0.47							OVHD				27.5	-0.90	0.27																
NUMERIC LTS *	0333	FWD				17.0	-0.90	0.16																										
INV DIST CNTL ASSY	0610	#1	.70	-0.90	0.01	.70	-0.90	0.01	.70	-0.90	0.01	#2	.70	-0.90	0.01	.70	-0.90	0.01	.70	-0.90	0.01	#3	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01	0.70	-0.90	0.01
LG PROX SNSR ELEC PKG	0620											#2	8.00	-0.99	0.07							#1	8.00	-0.99	0.07									
FCP PMP & H <sub>2</sub> O SNSR	3005	#1	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82	#2	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82	#3	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82	58.6	-0.62	0.82
CABIN FAN	4001											B	161.0	-0.83	1.69	161.0	-0.83	1.69	161.0	-0.83	1.69													
CABIN AIR TEMP ELEC	4003	SEC	3.75	-0.84	0.04							PRI	3.75	-0.84	0.04																			
CABIN AIR SIG COND	4004					1.40	-0.84	0.04																										
HUM SEP SIG COND	4006																																	
HUM SEP	4005											B	10.7	-0.33	0.28	10.7	-0.33	0.28	10.7	-0.33	0.28													
AV BAY FAN	4008	3B	58.0	-0.68	0.74	58.0	-0.68	0.74	58.0	-0.68	0.74	1B	58.0	-0.72	0.70	58.0	-0.72	0.70	58.0	-0.72	0.70													
	4008											2A	58.0	-0.71	0.71	58.0	-0.71	0.71	58.0	-0.71	0.71													
AV BAY SIG CONDR	4009	BAY 2				2.00	-0.84	0.02				BAY 3				2.00	-0.84	0.02				BAY 1				2.00	-0.84	0.02						
IMU FAN	4011											B	15.97	-0.78	0.18	15.97	-0.78	0.18	15.97	-0.78	0.18													
IMU FAN SIG CONDR	4012																																	
H <sub>2</sub> O PUMP	4013																				LOOP 2	66.0	-0.55	1.04	66.0	-0.55	1.04	66.0	-0.55	1.04				
H <sub>2</sub> O BYPASS CNTL SIG CNDR	4015	SEC(2)	5.90	-0.85	0.06																PRI(1)	5.90	-0.85	0.06										
FREON PUMP	4029	1A	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69										2A	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69	124.7	-0.64	1.69	
FREON LOOP INST	4036											#1				5.00	-0.90	0.05				#2				5.00	-0.90	0.05						
HYD QTY SNSR	5008	#1				1.4	-0.80	0.02				#2				1.4	-0.80	0.02				#3				1.4	-0.80	0.02						
HYD H <sub>2</sub> O BLR CNTLR LOGIC/SNSRS	5037	3A							5.70	-0.70	0.07	1A	5.50	-0.70	0.07							2A	5.60	-0.70	0.07									
HYD ACTUATORS									5.0	-0.70	0.06																							
CREW SEAT ASSY	6007											CDR	111.55	-0.97	1.0	111.55	-0.97	1.0	111.55	-0.97	1.0	PLT	111.55	-0.97	1.0	111.55	-0.97	1.0	111.55	-0.97	1.0	111.55	-0.97	1.0

Note: Calculations assume 115V ac.

\*Wattages indicate full bright.

Verify that this is the correct version before use

4.2.2-4





**Table 4.2.2-1. Baseline AC loads - electronic equipment list  
April 1991 (continued)**

**Other ac equipment (continued):**

MANIFOLD 3 ISO VLV	EEL loc	Item	AC1									Item	AC2									Item	AC3																																	
			φA			φB			φC				φA			φB			φC				φA			φB			φC																											
			Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps																									
	2212																																																							
MANIFOLD 4 ISO VLV	2212																																																							
VACUUM CLEANER	4001	(AC1)	150	-0.90	1.45	150	-0.90	1.45	150	-0.90	1.45																																													
H <sub>2</sub> O BYP VALVE	4014	SEC	16.00	-0.98	0.14																																																			
H <sub>2</sub> O SEP WASTE	4017	SYS 1	66.3	-0.67	0.86	66.3	-0.67	0.86	66.3	-0.67	0.86	SYS 2	66.3	-0.67	0.86	66.3	-0.67	0.86	66.3	-0.67	0.86																																			
FOOD WARMER	4023		203.00	-0.87	2.03				203.00	+0.87	0.80																																													
RAD BYP VLV	4033	MTR 1										MTR 2																																												
		LP 1	14.0	-0.70	0.17							LOOP 1				14.0	-0.70	0.17																																						
		MTR 1																																																						
		LP 2				14.00	-0.70	0.17																																																
FREON FLOW PROPER VLV	4035											LP 1	34.5	-0.98	0.30																																									
RUD/SPDBRK SW	5018	#1							1.00	-0.70	0.01																																													
ME 1 SW V ACTV	5019											PITCH																																												
	5019											YAW																																												
ME 2 SW V ACTV	5019											P/Y																																												
ME 3 SW V ACTV	5019											P/Y																																												
ELEVON ACT SW VLV	5020	ACT LO.										PS2 LO.																																												
		L1, RI, RO							1.00	-0.70	0.01	LI, RI, RO																																												
WSB HYD BYP	5036	#1B	23.83	-0.98	0.21							#2B																																												
		CNTL VLV							24.12	-0.98	0.21	#1A	25.02	-0.98	0.22																																									
RMS D&C PNL	5103	#3A	92.1	-0.85	0.94							B/U	6.84	-0.85	0.07																																									
LH RMS SHLDR																																																								
		BRACE ACTR																																																						
LH MANIP DEPLMT	5103																																																							
		ACTR										#2	23.3	-0.70	0.29	23.3	-0.70	0.29	23.3	-0.70	0.29	23.3	-0.70	0.29																																
L MAN RET	5104											FWD																																												
		MID																																																						
LCH ACTR	5106	#1	20.0	-0.70	0.25	20.0	-0.70	0.25	20.0	-0.70	0.25	#1	20.0	-0.70	0.25	20.0	-0.70	0.25	20.0	-0.70	0.25	20.0	-0.70	0.25																																
												#2																																												

Note: Calculations assume 115V ac.

Verify that this is the correct version before use

4.2.2-6



Table 4.2.2-1. Baseline AC loads - electronic equipment list  
April 1991 (continued)

Other ac equipment (continued)

	EEL loc	Item	AC1									Item	AC2									Item	AC3																															
			ΦA			ΦB			ΦC				ΦA			ΦB			ΦC				ΦA			ΦB			ΦC																									
			Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps		Watts	PF	Amps	Watts	PF	Amps	Watts	PF	Amps																							
VENT DR-LFT (cont)												8/9 CLO MTR 2	20.0	-0.45	0.38	20.0	-0.45	0.38	20.0	-0.45	0.38																																	
VENT DR-RT	5228	1/2 OPN MTR 1	15.0	-0.45	0.29	15.0	-0.45	0.29	15.0	-0.45	0.29		1/2 OPN MTR 2	14.7	-0.45	0.28	14.7	-0.45	0.28	14.7	-0.45	0.29	3 OPN MTR 2	34.0	-0.45	0.65	3 CLO MTR 2	17.0	-0.45	0.33	5 OPN MTR 2	34.0	-0.45	0.65	5 CLO MTR 2	17.0	-0.45	0.33	4/7 OPN MTR 1	38.0	-0.45	0.73	4/7 CLO MTR 1	14.5	-0.45	0.28	8 OPN MTR 1	35.5	-0.45	0.68	8 CLO MTR 1	18.0	-0.45	0.34
PLBD BULKHEAD LCH MTR	5236	LH FD MTR 1	56.3	-0.56	0.87	56.3	-0.56	0.87	56.3	-0.56	0.87		LH FD MTR 2	56.3	-0.56	0.87	56.3	-0.56	0.87	56.3	-0.56	0.87	LH AFT MTR 2	56.3	-0.56	0.87	RH FD MTR 1	56.3	-0.56	0.87	56.3	-0.56	0.87	56.3	-0.56	0.87	56.3	-0.56	0.87	56.3	-0.56	0.87												
PLBD CTRL LINE LCH MTR	5237	5-8 MTR 1	50.0	-0.60	0.72	50.0	-0.60	0.72	50.0	-0.60	0.72		3-16 MTR 2	50.0	-0.60	0.72	50.0	-0.60	0.72	50.0	-0.60	0.72	1-4 MTR 2	50.0	-0.60	0.72	5-8 MTR 2	50.0	-0.60	0.72	9-12 MTR 2	50.0	-0.60	0.72	3-16 MTR 1	50.0	-0.60	0.72	50.0	-0.60	0.72													
RAD RET LCH MTR	5238	LH 1-6 MTR 1	20.7	-0.69	0.26	20.7	-0.69	0.26	20.7	-0.69	0.26		LH 1-6 MTR 2	20.7	-0.69	0.26	20.7	-0.69	0.26	20.7	-0.69	0.26	LH 7-12 MTR 2	20.7	-0.69	0.26	RH 7-12 MTR 1	20.7	-0.69	0.26	20.7	-0.69	0.26	20.7	-0.69	0.26	20.7	-0.69	0.26															

Note: Calculations assume 115V ac.

Verify that this is the correct version before use

4.2.2-8

Table 4.2.2-1. Baseline AC loads - electronic equipment list  
April 1991 (concluded)

Other ac equipment (concluded)

	EEL loc	Item	AC1									Item	AC2									Item	AC3										
			ΦA			ΦB			ΦC				ΦA			ΦB			ΦC				ΦA			ΦB			ΦC				
			Watts	PF	Armps	Watts	PF	Armps	Watts	PF	Armps		Watts	PF	Armps	Watts	PF	Armps	Watts	PF	Armps		Watts	PF	Armps	Watts	PF	Armps	Watts	PF	Armps		
RAD RET LCH MTR (cont)		RH17-12 MTR1	20.7	-0.69	0.26	20.7	-0.69	0.26	20.7	-0.69	0.26																						
RAD DEPLOY DRV MTR	5239	LH MTR1 RH MTR1	20.7	-0.69	0.26	20.7	-0.69	0.26	20.7	-0.69	0.26																						
CREW OPTICAL ALIGN SIGHT	6001																																
EDO RCRS	4015	COMPRESS MTR1  FAN MTR1  VCV ACT1  CNTLR1	100	-0.42	2.07	100	-0.42	2.07	100	-0.42	2.07																						
			16	-0.70	0.2	16	-0.70	0.2	16	-0.70	0.2																						
			50	-0.8	0.54																												
			20	TBD	TBD																												

Note: Calculations assume 115V ac.

Verify that this is the correct version before use

4.2.2-9

## TITLE

AC POWER TRANSFER CABLE

## BACKGROUND

The AC Power Transfer Cable procedure was developed to regain power to an unshorted AC bus. The procedure, MAL EPS SSR-200, was designed to be a standalone procedure with all the necessary bus loss actions included. However, SSR-200 can also be entered from the main bus loss and FPC bus loss actions in the MAL or Entry Pocket Checklist and is performed in the contingency deorbit loss of two fuel cells. MAL EPS SSR-200 is the calling procedure to the IFM Checklist, AC POWER TRANSFER CABLE INSTALLATION, page A-5, which contains the actual procedure for installing the cable.

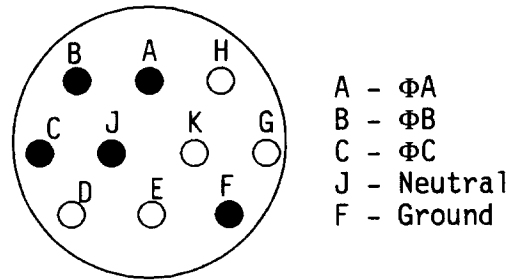
The AC Power Transfer Cable procedure is performed only for a nonshorted AC bus. The procedure is typically used under the following conditions:

- A. The DC power to the inverters is lost (MN or FPC bus lost).
- B. Two or three of the inverters to a three-phase AC bus are lost.
- C. Failure occurs in another system, requiring power to a single phase for vehicle safety.

The AC Power Transfer Cable connects two AC buses via orbiter utility outlets. The AC power provided by one set of inverters is used to power the other AC bus. For example, AC1 inverters supply three-phase current to the AC1 bus. The AC1 bus supplies three-phase current to the AC1 utility outlet on panel F1 or MO52J. One end of the cable is plugged into either the panel F1 or MO52J outlet, and the other end of the cable is plugged into panel A15 or MO13Q AC3 utility outlet. AC1 inverters are now powering both the AC1 and AC3 buses.

## CABLE DESCRIPTION

The AC Power Transfer Cable is 15 feet long and contains two Teflon-coated, 22-gauge twisted wire pairs. Phases A and B are twisted together, and phases C and neutral are twisted together. The plug at each end of the cable is a 10-pin male connector, part number NB6GE12-10PNT, which meets Marshall specification 40M39569. The plug is compatible with the orbiter AC utility outlet sockets for AC1 (F1 or MO52J), AC3 (A15 or MO13Q), and AC2 (Mission Station Patch Panel J37 and Mission Station Patch Panel J36). The four wires of the AC Power Transfer Cable are connected to plug pin A (A), pin B (B), pin C (C), and pin J (AC neutral). (Reference Figure 4.2.3-1, utility outlet connector.) The cable is stored in the In-Flight Maintenance (IFM) contingency hose and cable kit.



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**Figure 4.2.3-1. Utility outlet connector**

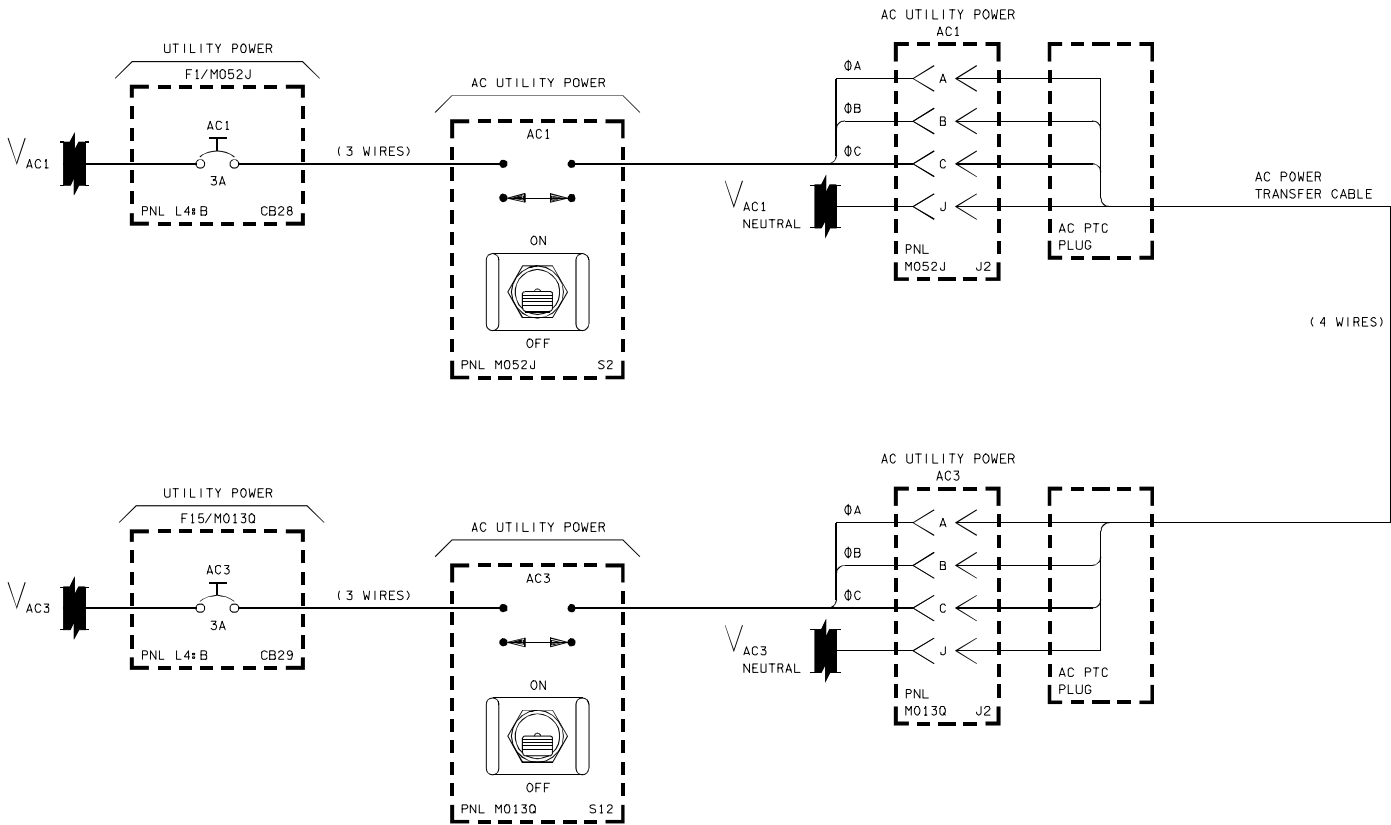
## PROCEDURE

The AC Power Transfer Cable procedure takes 25 minutes for an AC1-to-AC3 installation and 40 minutes for either an AC1-to-AC2 or AC3-to-AC2 installation. Less time is required to connect the AC Power Transfer Cable from AC1 to AC3, because it is connected only to the AC utility outlets. However, to connect one end to AC2, the panel L17 cover at the payload station must be removed to access the AC2 outlet. An alternative would be to connect AC2 to AC3 via the mission station panel. This panel must also be removed to access the panels. It is more desirable to use the AC1-to-AC3 connection, because the commander can easily reset the circuit breakers located on panel L4 from his seat. The circuit breakers for the AC2 connection are on the middeck panel MA73C. Reference Figure 4.2.3-2 for AC1-to-AC3 Power Transfer Cable connection, Figure 4.2.3-3 for AC1-to-AC2 Power Transfer Cable connection, Figure 4.2.3-4 for AC2-to-AC3 Power Transfer Cable connection, and Figure 4.2.3-5 for payload and mission station patch panels.

MAL EPS SSR-200, blocks 2, 3, and 4 perform the bus loss actions for the three-phase AC bus. The fuel cell is shut down, and Environmental Control and Life Support System (ECLSS) three-phase rotating equipment is unpowered and swapped to another AC bus. Blocks 5, 6, and 7 unpower all single-phase loads on the failed AC bus.

Blocks 8, 10, and 11 disconnect and unpower the failed AC bus inverters. The AC bus sensor is taken off, the inverters are disconnected from their AC buses, and the inverter power is then turned off. The inverters are disconnected from their associated buses prior to connecting the Power Transfer Cable because of possible differences in phase relationship between the two different three-phase AC buses. The inverters are unpowered; because an inverter that remains powered but is not connected to its associated bus will still draw current, creating an unnecessary load on the orbiter.

Blocks 11, 13, and 14 perform the IFM and take the failed AC bus sensor to monitor. The IFM procedure can be found in the IFM Checklist, page A-5. The IFM procedure connects one end of the AC Power Transfer Cable to the AC bus utility outlet associated with the unpowered AC bus and the other end to the AC bus utility outlet with good power.

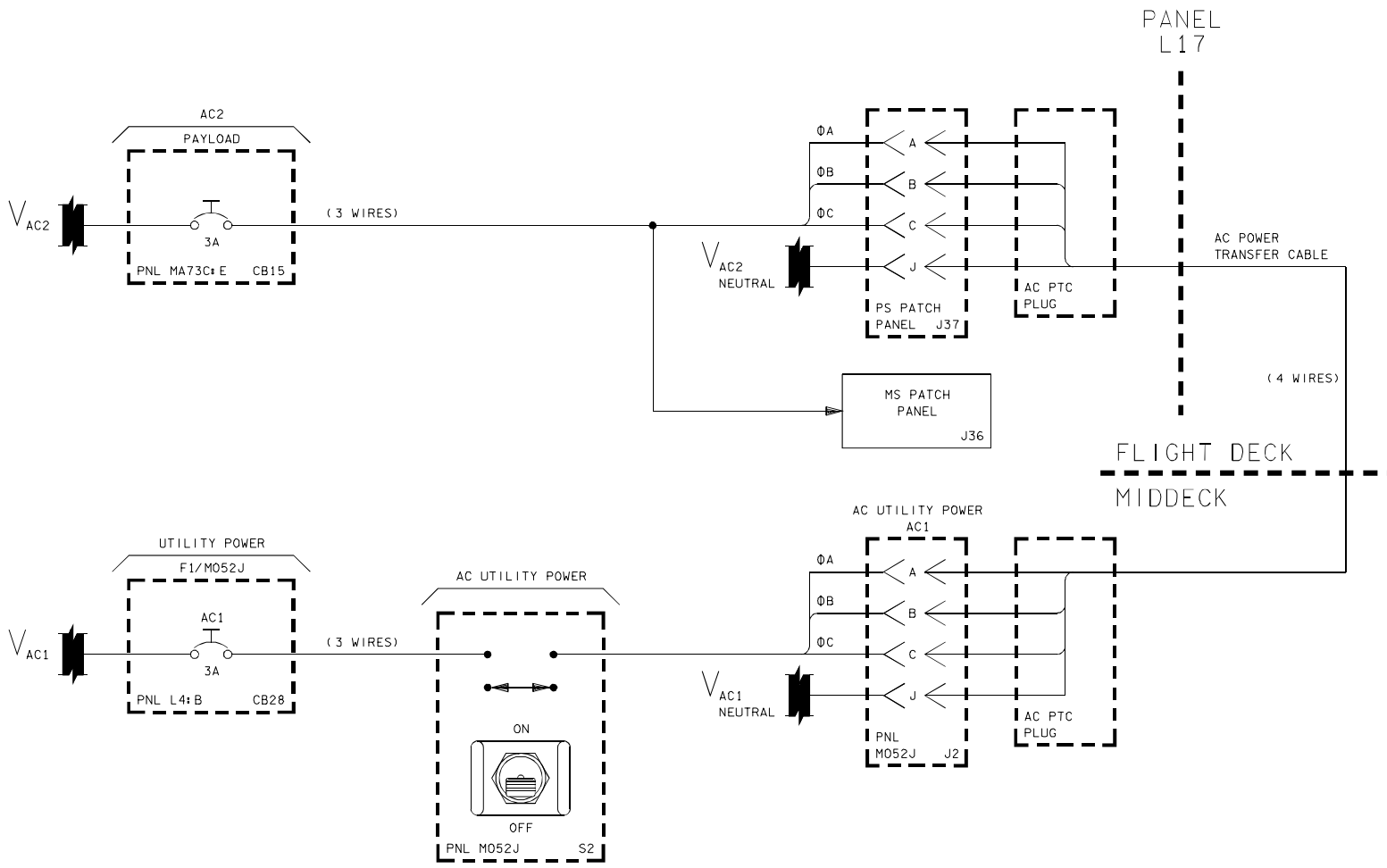


128302244, SCH 2

Figure 4.2.3-2. AC1-to-AC3 Power Transfer Cable connection

4.2.3-3

Verify that this is the correct version before use



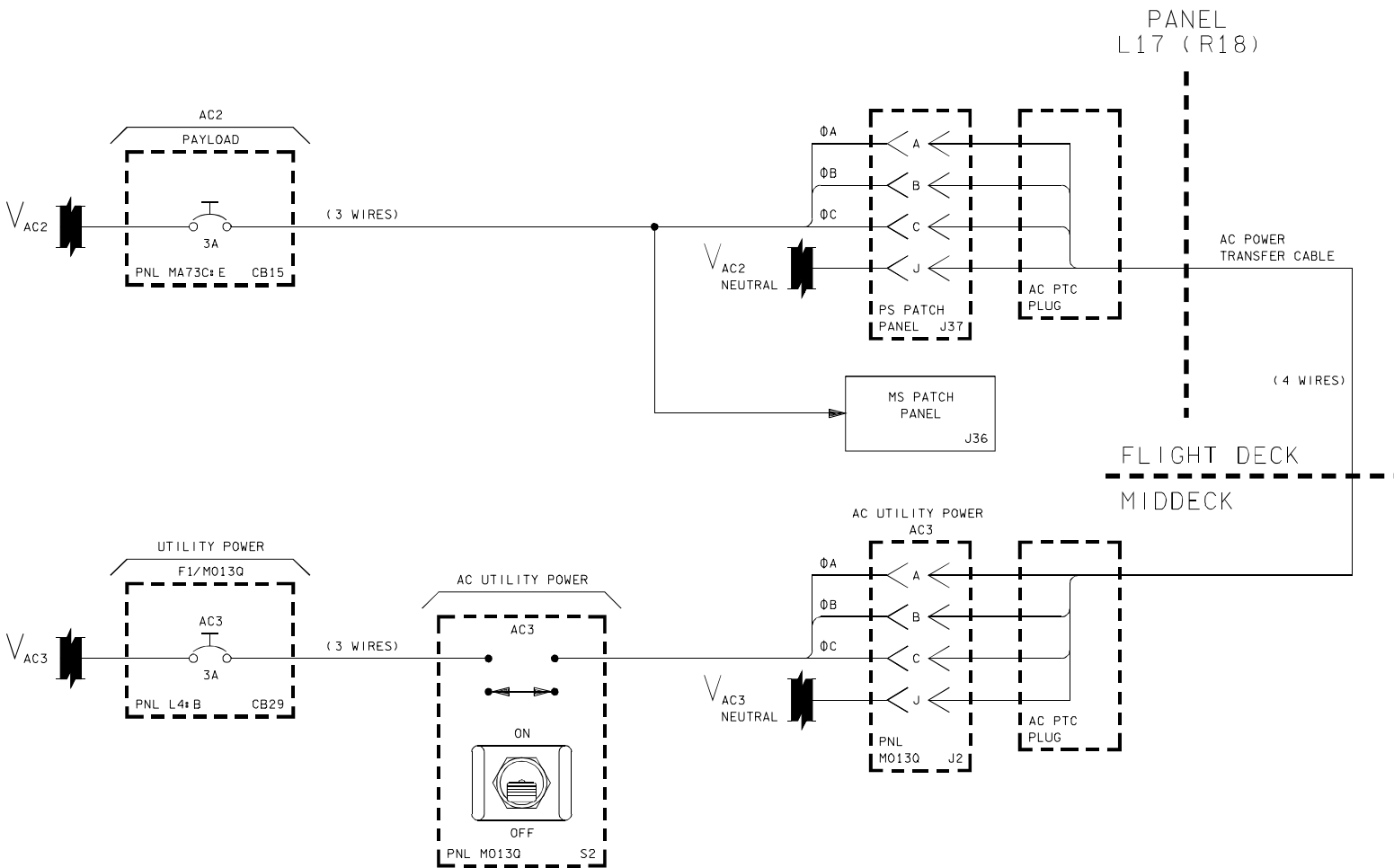
128302243. SCH 3

Figure 4.2.3-3. AC1-to-AC2 Power Transfer Cable connection

4.2.3-4

Verify that this is the correct version before use



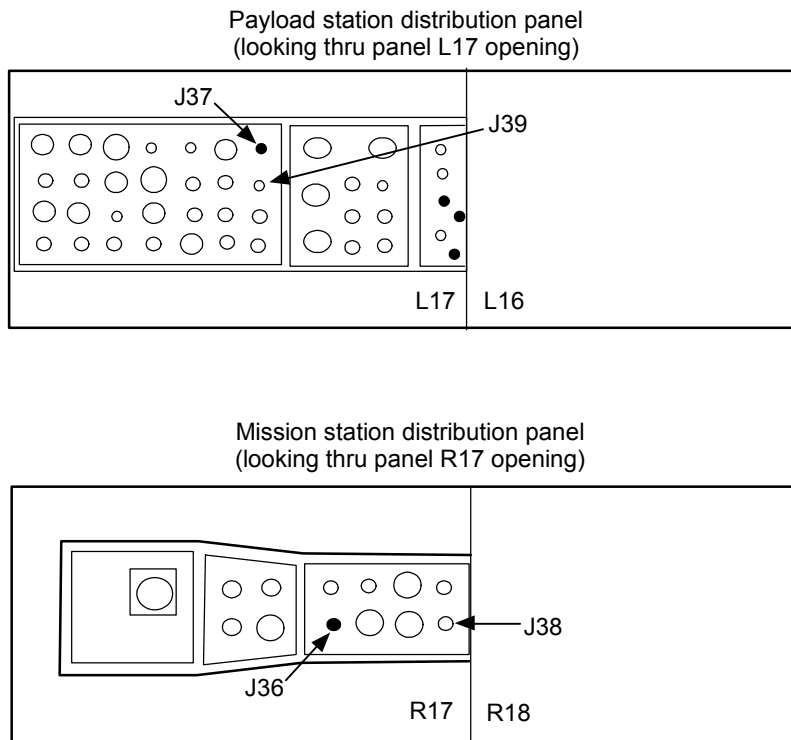


128302245. SCH# 2

Figure 4.2.3-4. AC3-to-AC2 Power Transfer Cable connection

4.2.3-5

Verify that this is the correct version before use



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**Figure 4.2.3-5. Connector locations on payload and mission station panels**

The IFM procedure connects and properly secures the Power Transfer Cable. It is written in two parts: the first section is for an AC1-to-AC3 connection, and the second section is for an AC2-to-AC1 (AC3) connection. The procedure verifies that the utility outlet power is off and the associated circuit breakers are open. The cable is then connected between the two outlets and secured. The circuit breakers are closed, and with an MCC GO, the utility power is turned on. An AC2-to-AC1 (AC3) connection requires additional steps to remove the panel to access the AC2 outlet. These additional steps are found in the procedure.

When the cable is installed and the utility power is turned on, the voltage of the unpowered AC bus is recovered, indicating a good AC Power Transfer Cable installation. This voltage is actually the voltage of the AC bus providing power (they should be equivalent). The AC amps of the unpowered bus will remain zero; any loads that are turned on to the unpowered AC bus will be reflected in the AC bus providing power. For example, for an AC1 (unpowered bus) –to–AC3 (good bus) connection, when FC1 is restarted, the FC1 pumps startup will be on the AC3 amps.

When the AC Power Transfer Cable has been successfully installed, the procedure determines if the upgraded av bay fan or cabin fan operation is required on the bus regained by the transfer cable. These large three-phase motors will be operated only if the redundant fan is lost. Due to the limitations on the 3-amp circuit breaker at the utility

outlet, the loads must be kept under 3 amps per phase. If they are required, other loads on the transfer cable will have to be unpowered. In this case, the only two continuous loads allowed will be the fuel cell pumps and the required fan. Blocks 12, 15, and 16 open the AC three-phase MCA power circuit breakers to prevent any of the loads powered through them from being powered (vent doors, payload bay doors, Payload Retention Latch Assemblies (PRLAs), Manipulator Retention Latches (MRLs), etc.).

Blocks 17 and 19 ask if MNA or MNB (respectively) are shorted. If the main bus is shorted, blocks 22 and 23 are used to determine which equipment can be operated via the transfer cable. They list all the single and three-phase continuous, intermittent, and contingency equipment loads. If the main bus is not shorted, FC1 or FC2 will be started by performing EPS SSR-6 FC POWERUP. When the fuel cell is started, blocks 22 and 23 are used to determine which equipment can be operated via the transfer cable, in addition to the fuel cell pumps.

In the case of FC/MNC/AC3, there is not a block to identify if the MNC is shorted. This is because the capability exists to connect FC3 directly to the primary payload bus. Block 21 performs EPS SSR-6 FC POWERUP to regain FC3 (SSR-6 will tie FC3 to MNB via the primary payload for a shorted MNC). When the fuel cell is restarted, block 24 can be used to determine which equipment can be operated via the transfer cable, in addition to the fuel cell pumps.

### **AC POWER TRANSFER CABLE LOAD MANAGEMENT**

The total load capability of the AC bus powered via the transfer cable is 3 amps per phase because of the 3-amp circuit breaker protection on the utility outlets. The loading must be minimized to avoid exceeding the 3 amps per phase limitation. The bus-loading table is provided in the SSR to assist in determining which equipment is to be repowered in order to prevent tripping of the AC utility outlet circuit breakers.

It is acceptable to operate the vent doors during entry on the bus regained by the transfer cable if only the fuel cell pumps and single-phase signal conditioners are running on that AC bus. The AC amps may peak as high as 5.1 amps per phase for 1 second (dual motor ops). That amount of current versus the run time does not exceed the circuit breaker thermal trip limitations, and the circuit breakers should not open. However, if another failure dictates running another piece of equipment on the AC bus recovered via the transfer cable, certain vent door circuit breakers should be opened (reference blocks 12, 15, and 16 of SSR-200).

The AC bus that repowers a failed AC bus via the transfer cable must supply current to its own load plus up to 3 amps per phase to the repowered AC bus. Flight Rule A9.1.4-5 states that the inverter output power capability is 7.7 (6.76) amps continuous. The inverter amps have to be managed to stay below the 6.76 amps per phase.

## **HIP POCKET IFM**

The AC3 Payload 3 $\phi$  power, pin J38 on the Mission Station Patch Panel and pin J39 on the Payload Station Patch Panel, are keyed differently than the transfer cable. Therefore, the AC Power Transfer Cable cannot be used for those connectors. A hip pocket IFM exists that uses four pin-to-pin 22-gauge jumper wires in lieu of the transfer cable. This is an alternate method to connect AC2 (J37) to AC3 (J39) on the Payload Station Distribution Panel or to connect AC2 (J36) to AC3 (J38) on the Mission Station Distribution Panel. A ganged 3 amps per phase circuit breaker on panel MA73C:E provides AC2 power to the Mission Station and Payload Station panels. A ganged 3 amps per phase circuit breaker on panel MA73C:E provides AC3 power to the mission station and payload station panels. If any payload equipment is using the payload three-phase power, they must be disconnected to perform the IFM. The total load on the four pin-to-pin connections is still limited to 3 amps per phase because of circuit breaker restrictions.

## **REFERENCES**

Flight Rules A9.1.4-5B, AC Inverter Thermal Life.

Flight Rules A9.1.4-8, AC Power Transfer Cable.

MAL EPS SSR-200.

IFM Checklist, AC Power Transfer Cable Installation.

SSSH, Section 2.

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-2	OV-102	11/12/1981	11/14/1981	AC	OSTA	OSTA pallet Freon Pump delta P	During the STS-2 mission, the Office of Space and Terrestrial Applications (OSTA) pallet Freon pump delta pressure measurement was observed to be degraded. Review of the associated current measurements indicated that the pallet Freon pump was operating on only two of three phases, phases B and C. This was caused by a resistance condition within the three-phase circuit breaker BV16 on panel MA73C (an abnormal amount of residue on the contact surfaces). The crew was adviced to cycle the suspect circuit breaker should some equipment fail to activate when powered up in flight. Experience shows that high contact resistance conditions can be cleared by cycling the circuit breaker.
STS-3	OV-102	03/22/1982	03/30/1982	AC	OP-Stat	MMC3 Op-Stat 4 fail	During OV-102 STS-3 flight, the midmotor control assembly 3 ops status bit 4 was off when it should have been on. The possibility of a self-healing internal short in the hybrid relay could account for the condition experienced. This anomaly seems to be an isolated instance.

4.2.4-1

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-5	OV-102	11/11/1982	11/16/1982	AC	Inverter	AC1 phase B Inverter trip	During the STS-5 mission, the AC bus 1 array phase B power static inverter tripped offline with an overload indication via the AC sensor. Available bus voltage and current measurements showed no abnormal conditions at the time of disconnect. Subsequently, the AC1 sensor was placed in the monitor mode for the entry phase, and another fault indication was experienced. The failure was attributed to a stainless steel particle that created a short across the terminals of the OVERLOAD TEST pushbutton switch. Better process and inspection controls have been requested of the limit switch manufacturer.
STS-6	OV-99	04/04/1983	04/09/1983	AC	Hum Sep	Hum Sep B Fan cb	During the STS-6 mission, the humidity asparator B fan motor circuit breakers (3) and the humidity separator assembly S-C circuit breaker (1) opened. This was caused by a four-phase short on AC buses 2 and 3 (18-amp current spikes on AC2, all three phases, and AC3 phase A). Postflight inspection revealed severe wire damage to the bundle near the separator package in the ECLSS bay. The wire harness had shorted to the structure. The damage was probably due to a hard metal object striking the wire bundle, forcing it against the frame. An aware bulletin to Palmdale personnel for proper movement in the ECLSS bay was initiated. Rubber

4.2.4-2

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							strips, Teflon wraps, and other efforts will continue to minimize wire damage. Note: Two loads that are sensitive to multiple bus transients are the Space Shuttle Main Engines (SSME) controller and the landing proximity sensor electronics assembly.
STS-41C	OV-99	04/06/1984	04/13/1984	AC	OP-Stat	AMC1 Op-Stat 1 fail	Approximately 19 hours into the OV-99 41-C mission, the aft motor control assembly 2 operational status bit 1 measurement (V76X2261E) failed to return to its no op state after reconfiguring some OMS valves. This indicates that one of the 15 relays did not release or return to the nonenergized position. Other available data reflects that all associated valves controlled by these relays were in the proper position. On the following day, the OMS crossfeed valve B did not respond to a close command. This data indicates that the relay (K51) within the aft motor control assembly 2 was hung up between relay positions. During postflight tests, the relay was actuated to the energized position and everything

4.2.4-3

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							operated properly. The aft motor control assembly was removed to allow replacement of hte suspect relay.
STS-41B	OV-99	02/03/1984	02/11/1984	AC	RCS	RCS thrusters failed off	During the OV-99 STS 41-B mission, the RCS thrusters (R5D and R5R) failed off. The problem was traced to the power source of the aft load controller 2. Postflight analysis found a breakdown of the output transistor in the hybrid driver. This failure is considered to be an isolated instance.
STS-51B	OV-99	04/29/1985	05/06/1985	AC	OP-Stat	MMC2 Op-Stat 5 fail	During orbiter OV-99 51-B mission, it was noted that the midmotor control assembly 2 status bit measurement 5 (V76X2225E) was off when it should have been on. Available flight and postflight test data indicated that the hybrid relay (K7), left aft bulhead latch control, was always in the energized position. The hybrid relay was analyzed, and the fault was isolated to an internal failure of the hybrid driver. In most instances, power can be

4.2.4-4

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							removed from the load by the redundant relay or by pulling the associated circuit breaker.
STS-51B	OV-99	04/29/1985	05/06/1985	AC	ET Door	ET Door motor B2 inopropriate drive	On the OV-99 STS 51-B mission, when the right ET umbilical door was closed on orbit, motor B2 in the door drive actuator was inoperative. In postflight inspection, the problem was isolated to a loose/separated electrical connector. Most probable cause was failure to fully engage the pin/ramp locking feature when remating the connector. Difficult access and limited visibilitiy due to connector location could have contributed to this condition. New standards of conformation of the connection have been initiated.

4.2.4-5

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-57	OV-105	06/21/1993	07/01/1993	AC	Vent Door	AC3 Phase-to-Phase Short	Right Vent Door #5 motor 2 experienced an AC3 phase B to phase C short when commands to simultaneously open and close the vent door were present. MA73C:C MCA logic MCA power AC3 MID 4 circuit breaker opened due to high current. The dual commands were removed from the vent door motor, the AC3 MID 4 circuit breaker was reset, and the right vent door #5 motor 2 was successfully used to reopen the door. Since the same motor windings are used to drive open and close the vent doors, and no problem was experienced using the motor after the short, no problems were expected during entry and postlanding operations with the affected motor.
STS-57	OV-105	06/21/1993	07/01/1993	AC	Spacehab PDU	Spacehab PDU Fuse Failure Due to Orbiter AC3 Short	Troubleshooting an Orbiter AC3 bus problem resulted in an undervoltage of the PL AC3 Bus. The low bus voltage caused the SH ARS and HAB fans to draw high AC current. The high current draw caused fuses in the SH PDU to blow, removing Orbiter AC power from the fans. SH ARS and HAB fans could not operate on the Orbiter bus. An IFM was performed to changeout the PDU fuses (three) to regain Orbiter AC power. The Orbiter AC power was successfully recovered and the ARS and HAB fans were reconfigured to the Orbiter power source (nominal configuration).

4.2.4-6

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-36	OV-104	02/28/1990	03/04/1990	AC	Inverter	AC2 phase A Inverter voltage spikes	During STS-36 prelaunch ground ops, AC2 phase A inverter had numerous voltage spikes nad current fluctuations in a 2-minute period. The inverter was removed and replaced. Retest was nominal. Failed unit was sent to vendor for failure analysis. Problem isolated to loose connection caused by four loose screws (improperly torqued). Other suspected units were inspected and found to have loose screws also. These other units were removed and replaced.
STS-65	OV-102	07/08/1994	07/23/1994	AC	Spacelab	Spacelab lost AC bus power	During the STS-65 mission (OV-102), the Spacelab experiment AC BUS lost power when it was switched from the SS inverter to the unpowered experiment inverter. The EXP AC BUS was regained 3 minutes later by reconnecting it back to the SS inverter. There was no impact to the mission; the EXP AC BUS was recovered. The crew may have inadvertently bumped the EXP AC BUS switch on panel R7 to the EXP INV position.

4.2.4-7

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-73	OV-102	10/20/1995	11/05/1995	AC	AC MCA	AC1 MCA 2 phase ops	During the OV-102 STS-73 flight, the left vent door 8/9 motor was driven. During prelaunch, no currents were observed an AC1 phase B. Post MECO, no AC1 phase B currents were observed during ET door closure for centerline latch motor 1, centerline latch 2 motor 1, or left latch motor 1. The currents for each of these events indicated two-phase operation of motors. These motors are fed from MCA logic MCA power AC1 three-phase circuit breaker. Had two-phase operation of vent door 8/9 motor 1 during entry. ET doors and vent door 8/9 motor 1 are the only equipment affected by this circuit breaker. This signature is most probably due to oxidation on the circuit breaker contacts. Postlanding, the circuit breaker was cycled, and AC1 phase B was recovered.
STS-75	OV-102	02/22/1996	03/09/1996	AC	TIPS	AC1 phase B short	During orbiter OV-102 STS-75 mission, a short was observed on AC1 phase B. Reading of approximates 20 amps (OSH) and 13.4 volts were observed on AC1 phase B. This occurred right after TIPS deactivation. Crew reported that the MA73C:F MAR three-phase circuit breaker was out and that all other MA73C and L4 AC1 circuit breakers were in proper configuration. The AC utility outlets J31 and J7 were available for the remainder of the flight. The MAR three-phase circuit

4.2.4-8

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							breaker was not reset. When required, the alternate TIPS and a different power outlet were used.
STS-78	OV-102	06/20/1996	07/07/1996	AC	BDPU	EPDB 2AC bus transducer failure	During STS-78 mission, OV-102, when the bubble Drop and Particle Unit (BDPU) "Saville" went to run, EPDB 2 AC phase A amps (L01C0436A) increased by approximately 0.2 amps, while phase B and phase C increased approximately 0.8 amps. Current increase on the subsystem inverter was approximately 0.8 amps on all three phases. A similar phenomenon was seen on STS-66 (EPDB 1 AC amps, L01C0416A). Spacelab EPDB 2 AC bus amps transducer was considered failed. Subsystem inverter phase A amps was used for insights into EPDB 2 AC phase A bus amps. EPDB 2 AC phases B and C amps measurements also remain good.

4.2.4-9

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
STS-78	OV-102	06/20/1996	07/07/1996	AC	Spacelab	EPDB 3 AC phase C amps ducer	During the STS-78 mission, OV-102, at GMT 186/23:45:00, the Spacelab EPDB 3 AC phase C amps transducer (L01C0458A) began to malfunction by displaying curenent while the EPDB 2 AC bus was not powered. The measurement increased from 0 amps to about 0.9 amps and then decreased to about 0.5 amps until 187/00:31:00, when it returned to 0 amps. Data review showed this was not reflected in subsystem inverter phase C amps readings. Data for the spacelab essential bus, which powers the malfunctioning transducer, was also examined and showed no changes. EPDB 3 AC bus was not used for this flight. The transducer was changed out postflight.
STS-92	OV- 103	10/11/2000	10/24/2000	AC	Air Lock Fan	AC Circuit Breaker Not Conducting	Data review revealed that when the Airlock Fan A was turned on at GMT 289/21:11, it started and ran on lny phaes A and C. At GMT 290/13:20 the crew confirmed that all 3 circuit breakers for Airlock Fan A on panel MA73C:G were closed. At GMT 290/13:31:21, the crew was instructed to cycle the AC phase B circuit breaker once with a "mark". No change in AC1 bus current was observed. The crew was instructed to cycle the circuit breaker 5 more times and leave it in the closed position. The 5 circuit breaker cycles performed at GMT 290/13:31:21 each resulted in good conduction

4.2.4-10

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Brief Discription
							current through the breaker. Circuit breaker functionality was recovered. Nominal Airlock Fan operations were resumed.
STS-93	OV-102	07/22/1999	07/27/1999	AC	MEC	AC1 phase A short	Right after liftoff, there was a 13.3 amp short on AC1 phase A. The voltage on AC1 phase A dropped to 21.4 volts. There was some sharing on the other 2 phases. The voltage sag caused the main engine controllers to drop (center A, right B), FC pH to annunciate, and the H2O Loop F7 light to come on. All breakers were as expected on MA73C and L4. Working with Booster the data clearly showed the main engine controllers dropped offline after the voltage drop. The short lasted for 0.5 seconds, which was not long enough to open a circuit breaker. Postmission inspection found a damaged wire in one of hte payload bay wire trays. The failure analysis revelealed that the conductor was exposed because of mechanical impact, something striking the wire harness against a screw that had raised burrs on the head.

4.2.4-11

Verify that this is the correct version before use

**TITLE**

CIRCUIT PROTECTION DEVICES

**PURPOSE**

To provide a general description and a comparison of characteristics of the various types of circuit protective devices used in the orbiter vehicle. These include circuit breakers (cb's), fuses, Remote Power Controllers (RPCs), and hybrid drivers.

A listing of devices used on the orbiter with some pertinent characteristics (i.e., voltage drop and minimum wire size for the circuit being protected) is shown in Figure 4.3.1-1.

**REFERENCES**

- Rockwell Spec. MC454-0031, Circuit Breaker, Thermal.
- Rockwell Spec. MC451-0010, Fuse, Electrical.
- Rockwell Spec. MC450-0017, Remote Power Controller.
- R.I. Spec. Control Dwg. ME451-0009, Fuse, Miniature, Cartridge.
- R.I. Spec. Control Dwg. ME451-0010, Fuse, Microminiature, Axial Lead.
- R.I. Spec. Control Dwg. ME451-0016, Fuse, High Current.
- R.I. Spec. Control Dwg. ME451-0018, Fuse, Subminiature.
- R.I. Doc. 03953, Space Shuttle Electrical Power Distribution Avionics Equipment Manual.
- SODB Section 4.5.6.2, Control.
- SODB Section 4.5.6.4, Protective Devices.
- MIL-C-05809, Circuit Breaker, Aircraft.
- MIL-F-5372, Fuse, Electrical.
- In-Flight Maintenance Tool Catalog, JSC 23446.



CIRCUIT BREAKER (MC454-0026)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
2010	1.0	95	0.95	110	1.10	145	1.45	1.100	26
2020	2.0	95	1.90	110	2.20	145	2.90	0.750	26
2030	3.0	95	2.85	110	3.30	145	4.35	0.550	26
2050	5.0	95	4.75	110	5.50	145	7.25	0.265	24
2075	7.5	95	7.125	110	8.25	145	10.875	0.250	22
2100	10.0	95	9.50	110	11.00	145	14.50	0.280	20
2150	15.0	95	14.25	110	16.50	145	21.75	0.020	14
2200	20.0	95	19.00	110	22.00	145	29.00	0.180	12

CIRCUIT BREAKER - 3ph AC (MC454-0032)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
3030	3.0	95	2.85	110	3.3	145	4.35	0.550	26

REMOTE POWER CONTROLLER (MC450-0017)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
1030	3.0	100	3.0	125	3.75	150	4.50	0.500	26
1050	5.0	100	5.0	125	6.25	150	7.50	0.500	24
1075	7.5	100	7.5	125	9.375	150	11.25	0.500	22
1100	10.0	100	10.0	125	12.50	150	15.00	0.500	20
1150	15.0	100	15.0	125	18.75	150	22.50	0.500	14
1200	20.0	100	20.0	125	25.00	150	30.00	0.500	12

FUSE - LARGE (MB451-0016)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
2035	35.0	100	35.0	110	38.5	170	59.5	0.222	8
2050	50.0	100	50.0	110	55.0	170	85.0	0.227	8
2080	80.0	100	80.0	110	88.0	235	188.0	0.059	4
2100	100.0	100	100.0	110	110.0	235	235.0	0.066	0
2125	125.0	100	125.0	110	137.5	200	250.0	0.072	0
2150	150.0	100	150.0	110	165.0	200	300.0	0.079	0
2200	200.0	100	200.0	110	220.0	200	400.0	0.091	0

FUSE - SLOWBLOW (MB451-0016)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
3035	35.0	100	35.0	110	38.5	240	84.0	0.056	8
3050	50.0	100	50.0	110	55.0	240	120.0	0.056	6
3150	150.0	100	150.0	110	165.0	240	360.0	0.106	0
3200	200.0	100	200.0	110	220.0	240	480.0	0.125	0

HYBRID DRIVER-CURRENT CAPACITY

TYPE	PART NUMBER	MAX LOAD AMPS	VLT DRP	MAX ULTIMATE FAULT CURRENT	MIN. WIRE SIZE
I	MC477-0261-0002	0.15	2.0	5.2	26
II	MC477-0262-0002	0.05	2.0	5.2	26
III	MC477-0263-0002	5.00	1.3	14.5	20
IV	MC477-0264-0002	5.00	1.3	5.2	26
V	MC477-0265-0002	0.05	2.0	5.2	26

MB0150-046 KAPTON WIRE - CURRENT CAPACITY

WIRE GAGE	MAXIMUM CURRENT	OHMS/FT. AT 200 ° F	WIRE GAGE	MAXIMUM CURRENT	OHMS/FT. AT 200 ° F
0	240.0	0.000146	14	24.5	0.003873
2	220.0	0.000229	16	20.0	0.006146
4	160.0	0.000335	18	17.0	0.007876
6	115.0	0.000563	20	14.0	0.012614
8	83.0	0.000896	22	11.0	0.020658
10	49.0	0.001601	24	8.6	0.037339
12	33.0	0.002556	26	5.2	0.061281

OTHER COMPONENT - VOLTAGE DROP

COMPONENT - DESCRIPTION	VOLT. DROP
DIODE - BLOCKING OR ZENER (FWD. DIRECTION)	0.800
* RELAY-LATCHING	0.175
* RELAY GEN. PURPOSE 12 AMP	0.175
* RELAY GEN. PURPOSE 25 AMP (MAIN CONTACTS)	0.175
* RELAY GEN. PURPOSE 25 AMP (AUX. CONTACTS)	0.120
* RELAY-HYBRID	0.175
* CONTACTOR-GEN. PURPOSE	0.200

FUSE-CARTRIDGE (MB451-0009)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
1032	0.5	50	0.25	100	0.5	150	0.75	0.500	26
1001	1.0	50	0.50	100	1.0	150	1.50	0.680	26
1002	2.0	50	1.00	100	2.0	150	3.00	0.320	26
1003	3.0	50	1.50	100	3.0	150	4.50	0.200	26
1021	5.0	50	2.50	100	5.0	135	6.75	0.338	24
1019	7.5	50	3.75	100	7.5	135	10.13	0.200	22
1005	10.0	50	5.00	100	10.0	135	13.50	0.250	20
1006	15.0	50	7.50	100	15.0	135	20.25	0.135	16
1007	20.0	50	10.00	100	20.0	135	27.00	0.165	12
1008	25.0	50	12.50	100	25.0	135	33.75	0.479	10
1009	30.0	50	15.00	100	30.0	135	40.50	0.125	10

FUSE-SMALL WITH AXIAL LEADS (MB451-0010)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
1001	0.125	50	0.063	100	0.13	150	0.19	2.676	26
1002	0.25	50	0.125	100	0.25	150	0.38	0.455	26
1005	0.50	50	0.250	100	0.50	150	0.75	0.290	26
1007	0.75	50	0.375	100	0.75	150	1.13	0.330	26
1010	1.00	50	0.500	100	1.00	150	1.50	0.200	26
1015	1.50	50	0.750	100	1.50	150	2.25	0.216	26
1020	2.00	50	1.00	100	2.00	150	3.00	0.235	26
1030	3.00	50	1.50	100	3.00	150	4.50	0.210	26
1040	4.00	50	2.00	100	4.00	150	6.00	0.235	24
1050	5.00	50	2.50	100	5.00	150	7.50	0.221	24
1070	7.00	50	3.50	100	7.00	150	10.50	0.210	22
1100	10.00	50	5.00	100	10.00	150	15.00	0.190	18

FUSE-SUBMINATURE PLUG IN (MB451-0018)

DASH NO.	AMPERE RATING	MAXIMUM LOAD		ULTIMATE TRIP			* VOLT DROP	MIN. WIRE SIZE	
				MINIMUM	MAXIMUM				
		%	AMPS	%	AMPS	%			AMPS
0012	0.125	50	0.063	100	0.125	150	0.188	2.676	26
0025	0.25	50	0.125	100	0.25	150	0.38	0.455	26
0050	0.50	50	0.250	100	0.50	150	0.75	0.290	26
0075	0.75	50	0.375	100	0.75	150	1.13	0.330	26
0100	1.00	50	0.500	100	1.00	150	1.50	0.200	26
0150	1.50	50	0.750	100	1.50	150	2.25	0.216	26
0200	2.00	50	1.00	100	2.00	150	3.00	0.235	26
0300	3.00	50	1.50	100	3.00	150	4.50	0.210	26
0400	4.00	50	2.00	100	4.00	150	6.00	0.235	24
0500	5.00	50	2.50	100	5.00	150	7.50	0.221	24
0750	7.00	50	3.50	100	7.00	150	10.50	0.210	22
1000	10.00	50	5.00	100	10.00	150	15.00	0.190	18

BUS SYSTEM VOLTAGES

ORBITER BUS	MIN. VOLTAGE
AC CIRCUIT BREAKER PANELS	114.8
DC CIRCUIT BREAKER PANELS	25.6
FWD. BAY DC DISTRIBUTION	26.2
MID BODY DC DISTRIBUTION	27.0
AFT BODY DC DISTRIBUTION	26.1

NOTES:

\* MAXIMUM VOLTAGE DROP AT RATED CURRENT. ADJUST FOR ACTUAL CIRCUIT CURRENT.

1 BASED ON MAXIMUM LOAD CONDITIONS DURING ANY MISSION PHASE WITH MINIMUM FUEL CELL VOLTAGE OUTPUT OF 27.5 VOLTS. THIS CONDITION MAY LAST FOR 15 MINUTES, MAXIMUM. HEATERS AND OTHER LOADS INSENSITIVE TO THIS TRANSIENT CONDITION MAY USE DC BUS VOLTAGES 1.5 VOLTS GREATER THAN THOSE SPECIFIED.

2 27.5 VOLTS MINIMUM DURING ASCENT PHASE.

3 SEE IL 392-610-77-018 FOR WIRE SIZE RATIONALE

4 1.15 VOLTS DROP AT 3.0 AMPS

5 BASED ON 200 ° F AND 1 x10<sup>-6</sup> TORR,

THE CONTENTS OF THIS PAGE SUPERSEDES REFERENCE DATA ON THE ORBITER WIRE CALCULATOR FOR OV-102

THESE TABLES ARE A REPRODUCTION OF THE ORIGINAL TABLES PRODUCED BY J.R. FUHRMANN. ORIGINAL TABLES WERE USED AS A GUIDE DURING THE DESIGN OF THE EPDC SUBSYSTEM

J.R FUHRMANN 5-20-77

Figure 4.3.1-1. Orbiter circuit protection device characteristics

## BACKGROUND

### A. Circuit breakers

The cb's used on the orbiter are standard aircraft-type breakers meeting MIL-C-05809 specifications. Single-phase cb's are used in standard ratings from 1 to 20 amperes, and three-phase cb's rated at 3 amperes per phase are used on panel MA73C.

The majority of cb's are mounted on the overhead cockpit panels O13, O14, O15, O16, and on the left and right side panels L4 and R4. The middeck panels MA73C and ML86B also contain a significant number of cb's.

The trip characteristics of this type of cb are shown in Figure 4.3.1-2. The 200-percent overload trip at 10 seconds is a specification requirement and is verified by acceptance tests. All cb's are "trip free" (i.e., they cannot be closed and forced to maintain circuit continuity in the face of an overload condition, even when the actuator is mechanically held in the ON position unless there is a mechanical failure). For three-phase cb's, any single pole sensing an overload will trip all three poles, and if the overload is sustained, will cause the cb to be "trip free."

A cross-sectional view of a typical single-pole circuit breaker is shown in Figure 4.3.1-3.

### B. Fuses

Fuses are used extensively in the power and control circuits of the orbiter in a wide variety of sizes and configurations to suit particular applications. They range from 125-milliampere subminiature fuses to 200-ampere slow-blow fuses. Fuses generally meet the requirements of MIL-F-5372. The subminiature fuses conform to MIL-F-23419.

The characteristics of fuses rated from 1 to 60 amperes are shown in Figures 4.3.1-7 and 4.3.1-8. The characteristics of the high-current fuses are shown in Figures 4.3.1-9 and 4.3.1-10. The subminiature fuse ratings are given in Table 4.3.1-1.

A number of fuses used in various control and signal circuits could be replaced in flight, if required (ref. Memo CF7-80-33 prepared by R. T. Brown). Spare fuses are carried in the IFM pin kit.

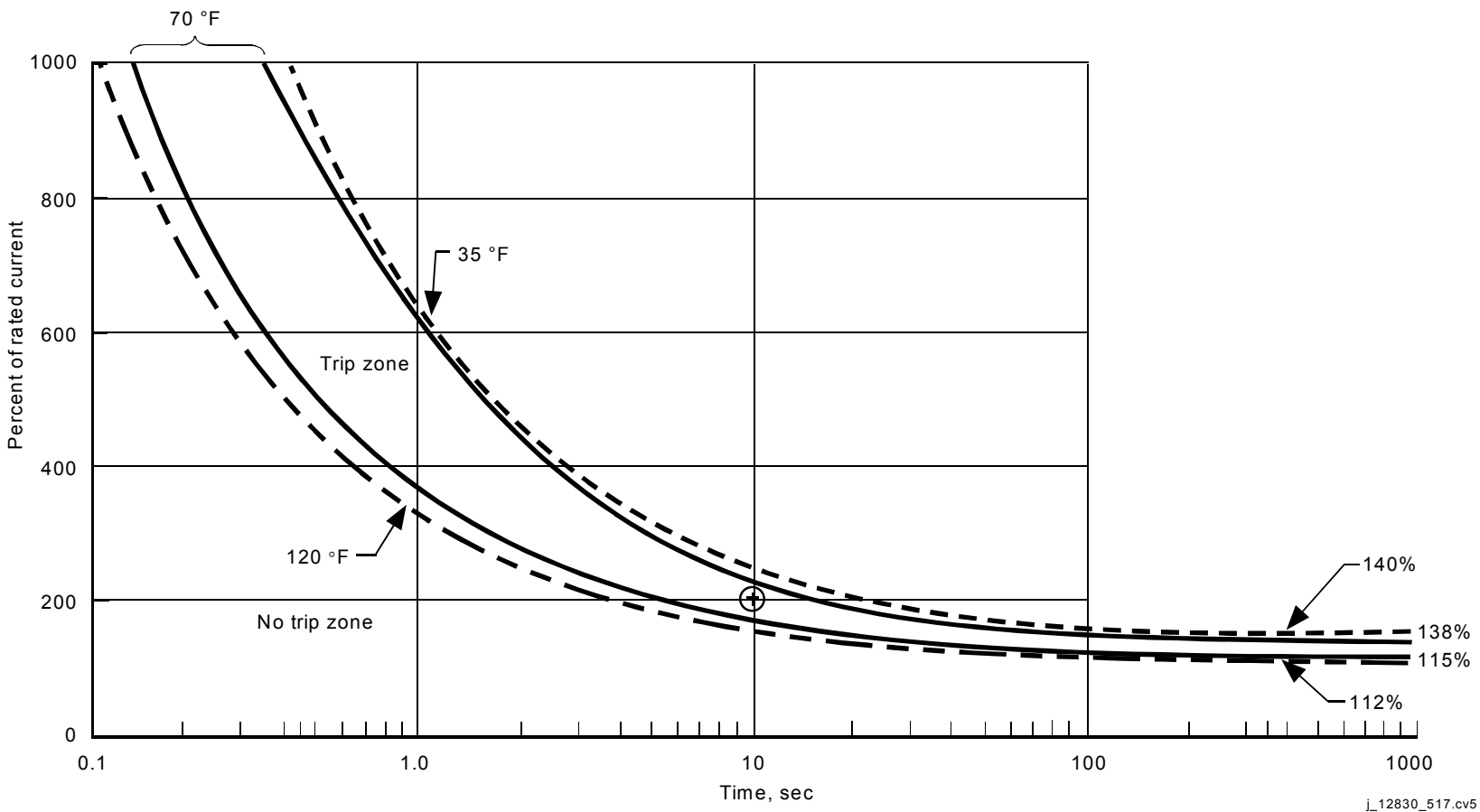
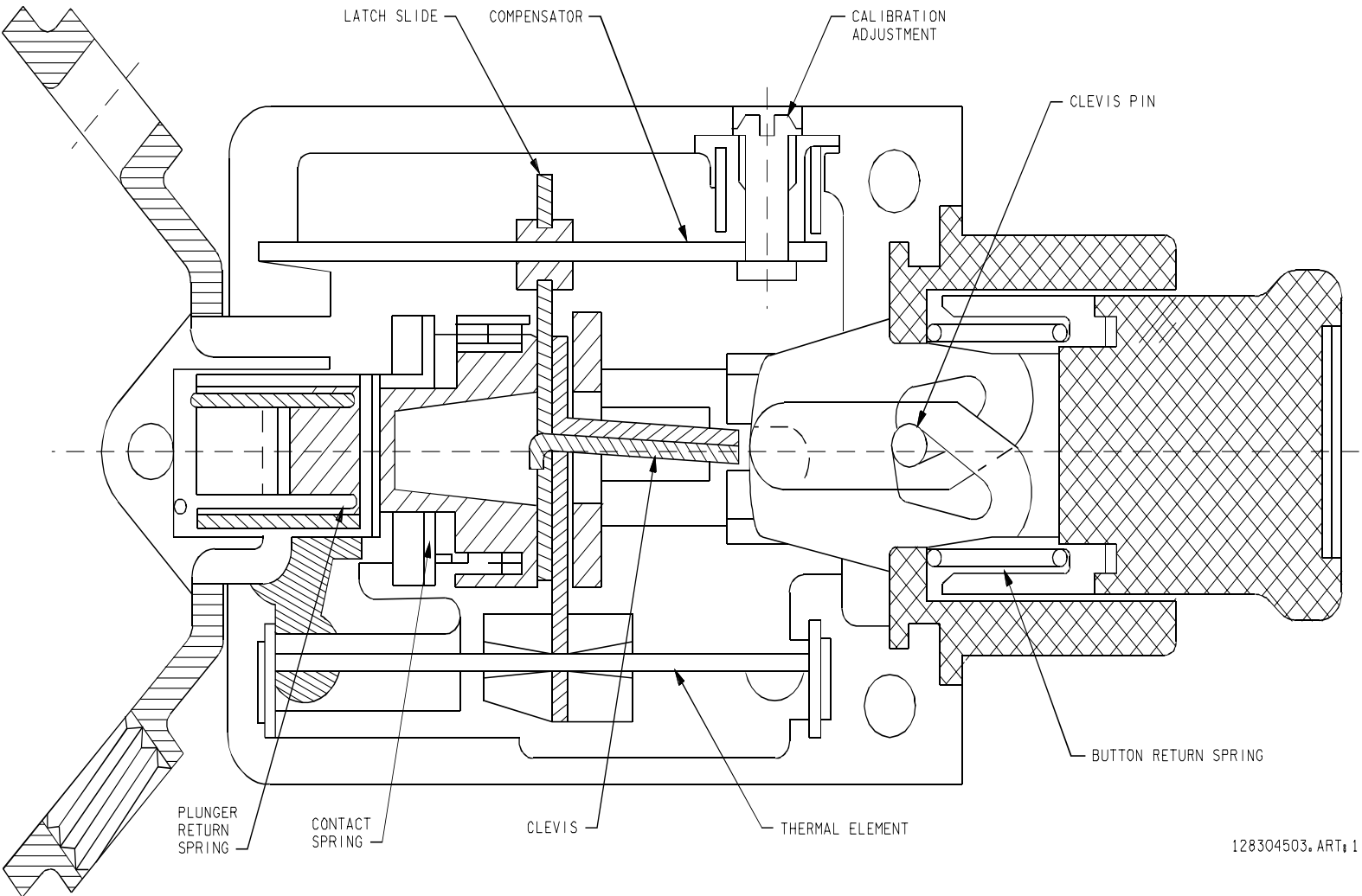


Figure 4.3.1-2. Thermal cb trip curve at 14.7 psia

4.3.1-4

Verify that this is the correct version before use

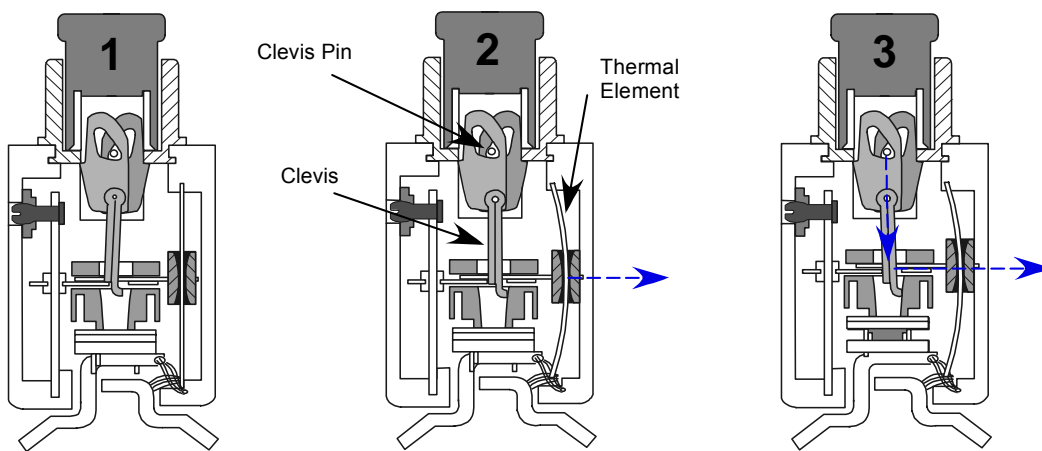


128304503, ART. 1

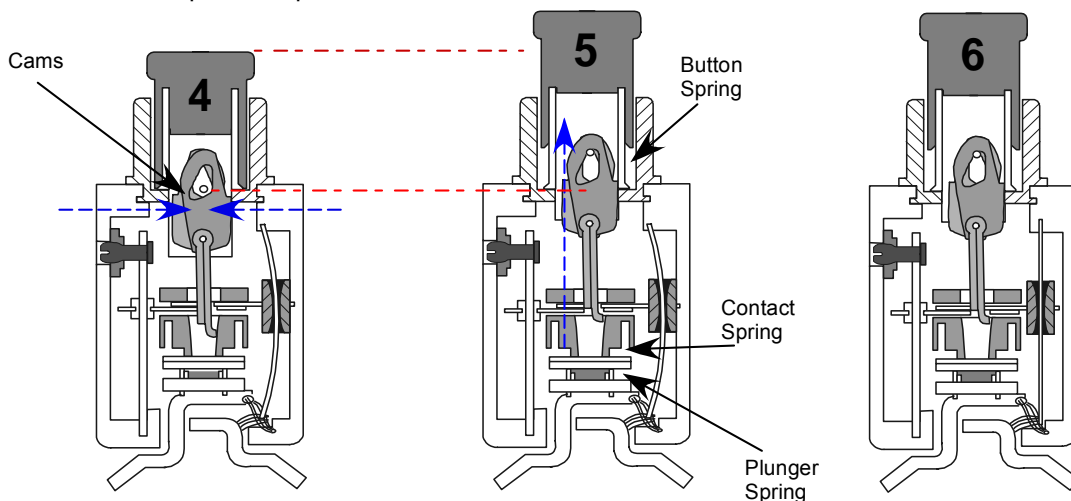
**Figure 4.3.1-3. Circuit breaker (closed position)**

4.3.1-5

**Verify that this is the correct version before use**



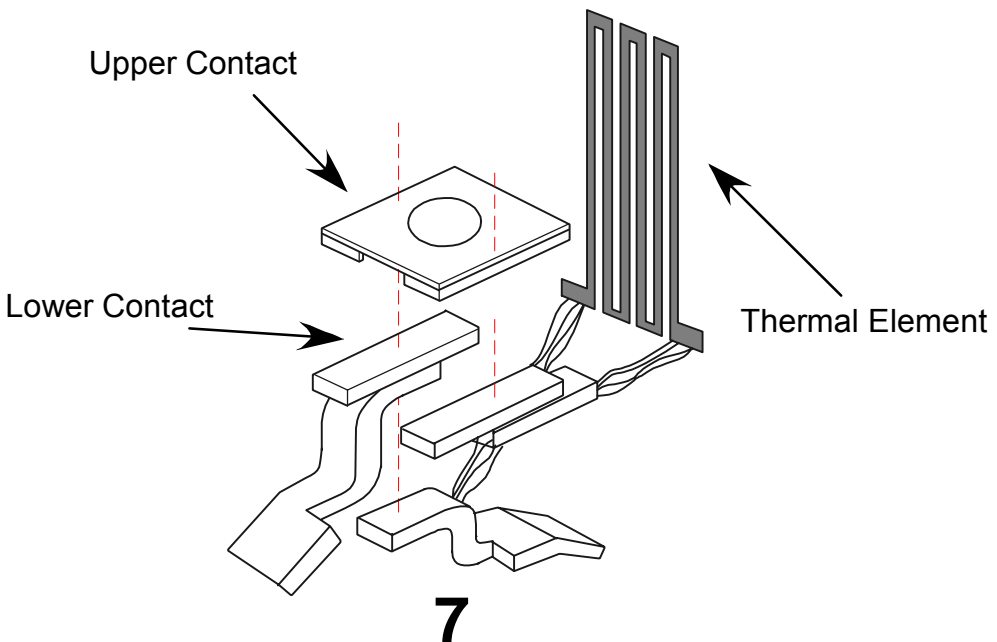
1. Nominal cb configuration - no short.
2. cb bi-metal thermal element experiencing excess current causing distortion.
3. Clevis shifts to right, causing Cams to rotate.
4. Cams pulled in off of latch and released by clevis motion.
5. Spring force causes clevis pin upward motion, contacts to open and cb button to pop out.
6. Final unpowered position of cb.



**Fig 4.3.1-4. Circuit breaker operation during trip scenario**

4.3.1-6

Verify that this is the correct version before use



**7**  
*Fig 4.3.1-5. Internal circuit breaker elements*

4.3.1-7

**Verify that this is the correct version before use**

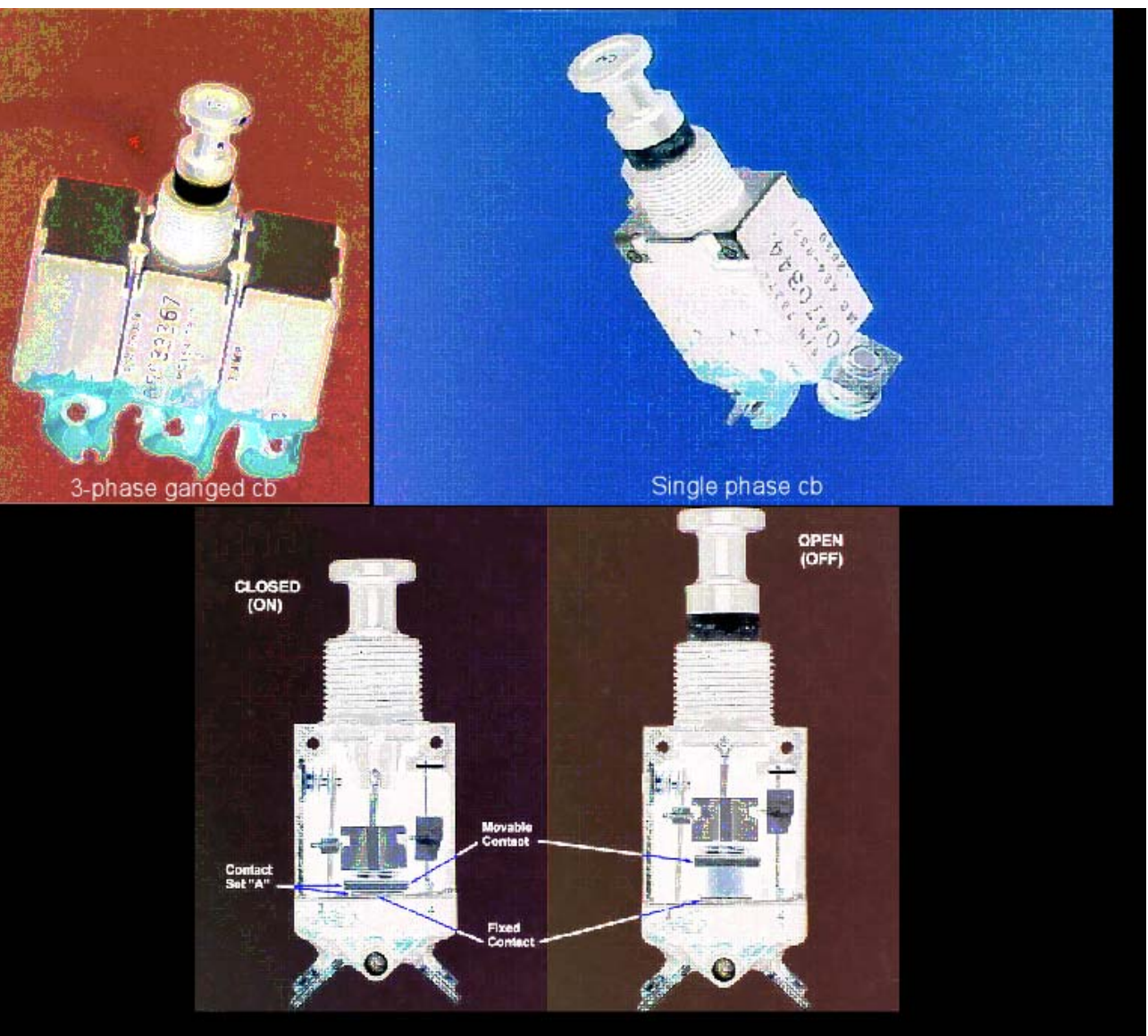
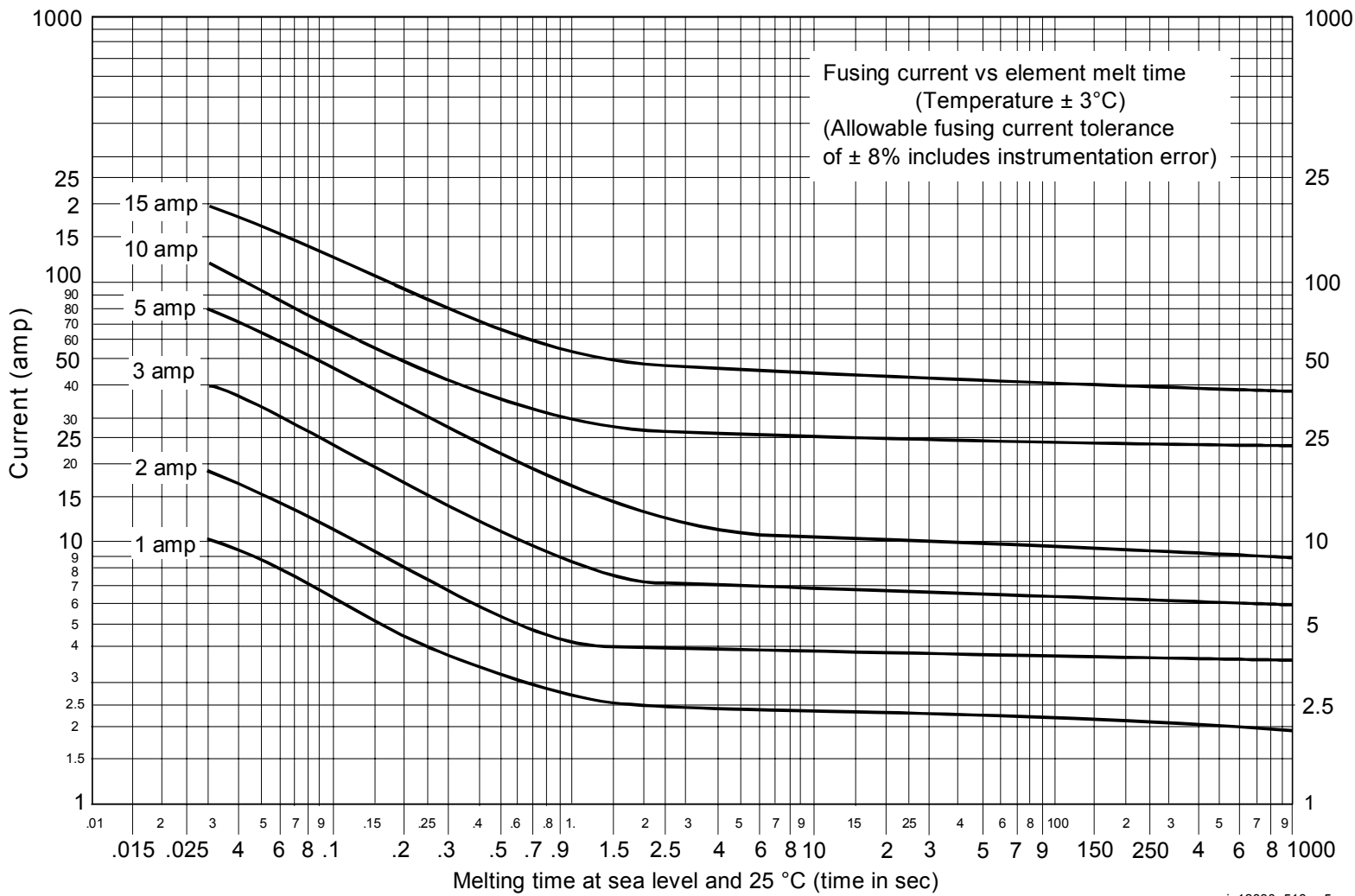


Fig 4.3.1-6. Actual vehicle circuit breaker photos

4.3.1-8

Verify that this is the correct version before use



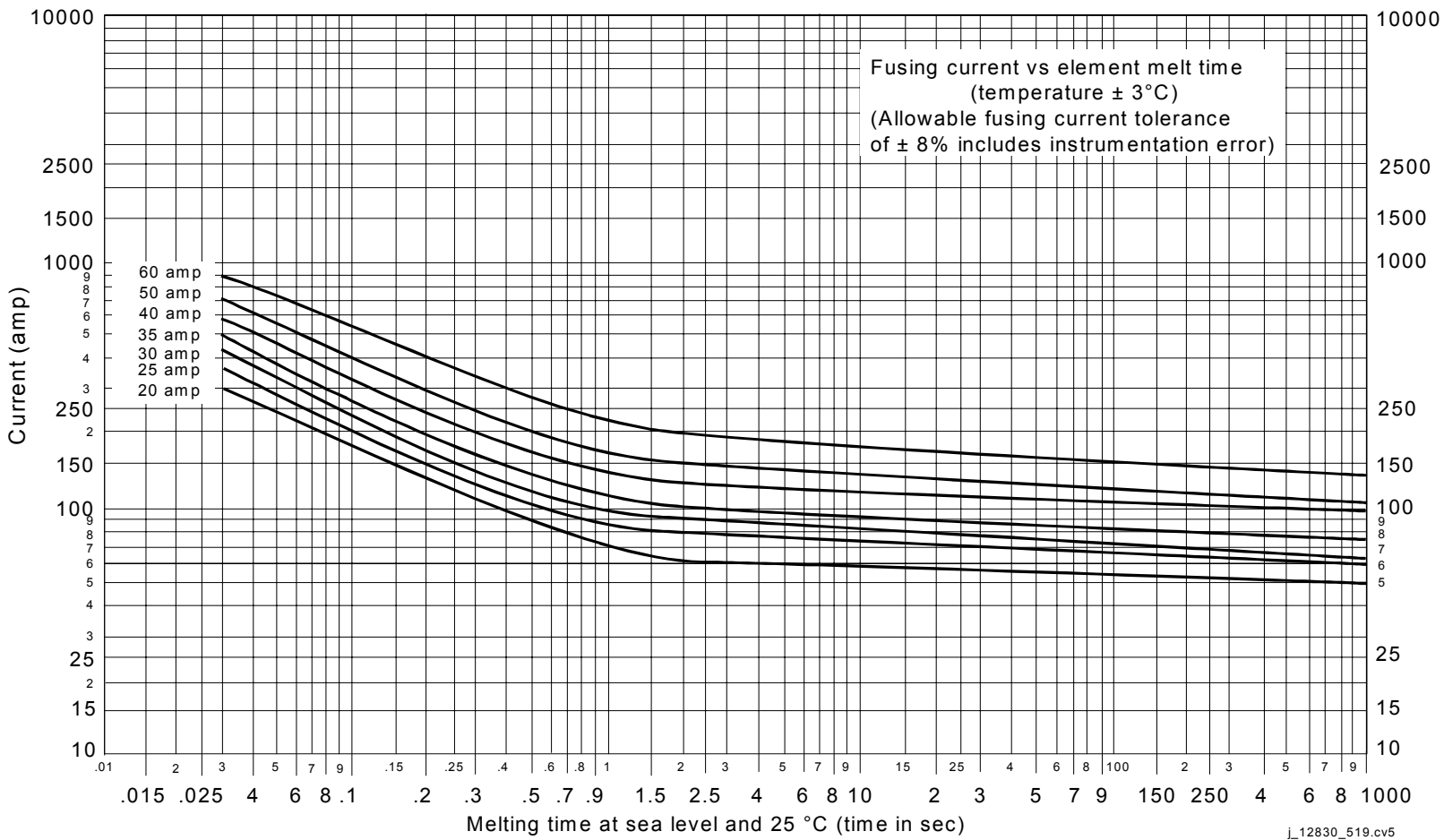
i\_12830\_518.cv5

**Figure 4.3.1-7. Fusing current vs. element melt time  
(fuses from 1 to 15 amps)**

4.3.1-9

Verify that this is the correct version before use





**Figure 4.3.1-8. Fusing current vs. element melt time  
(fuses from 20 to 60 amps)**

4.3.1-10

Verify that this is the correct version before use

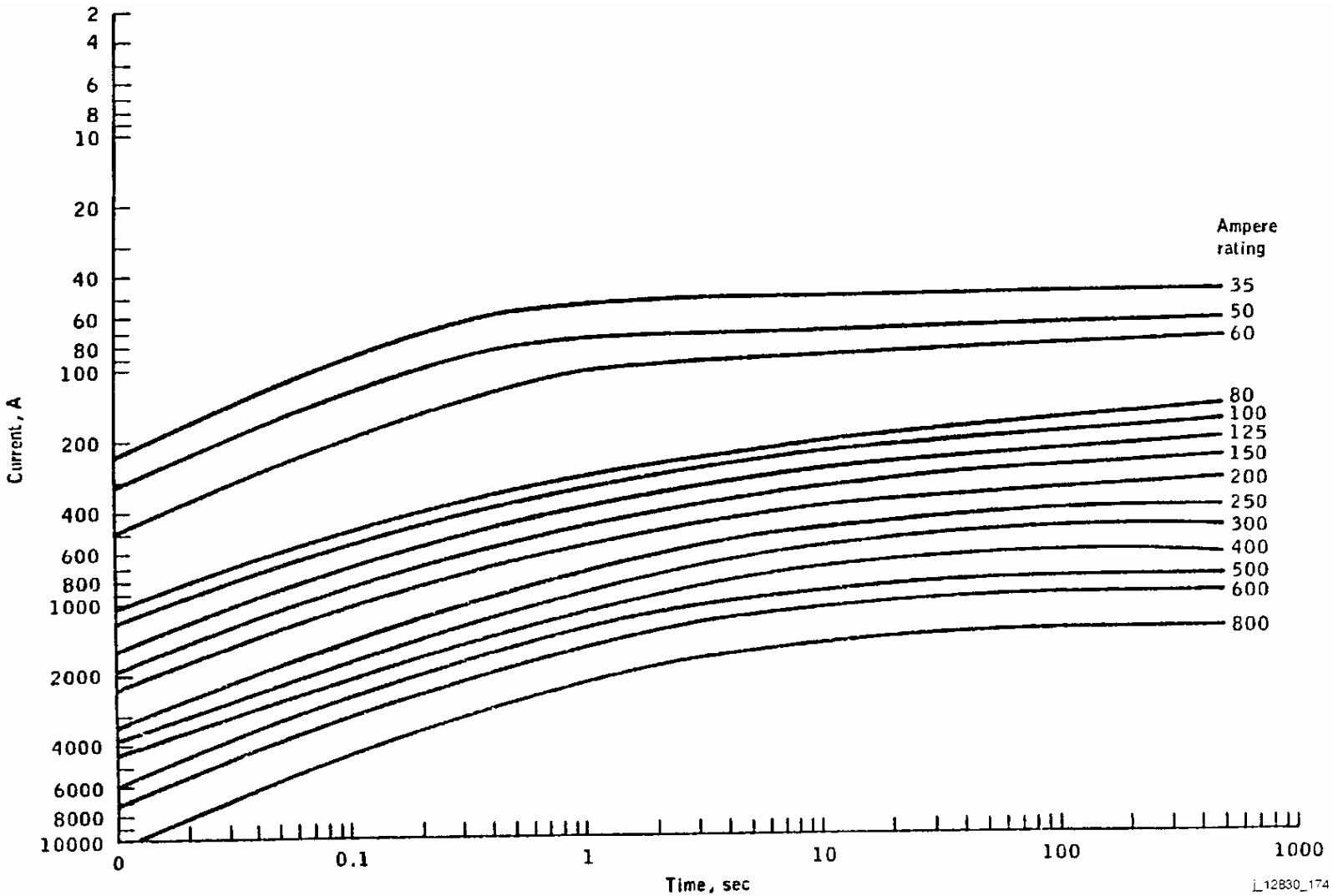
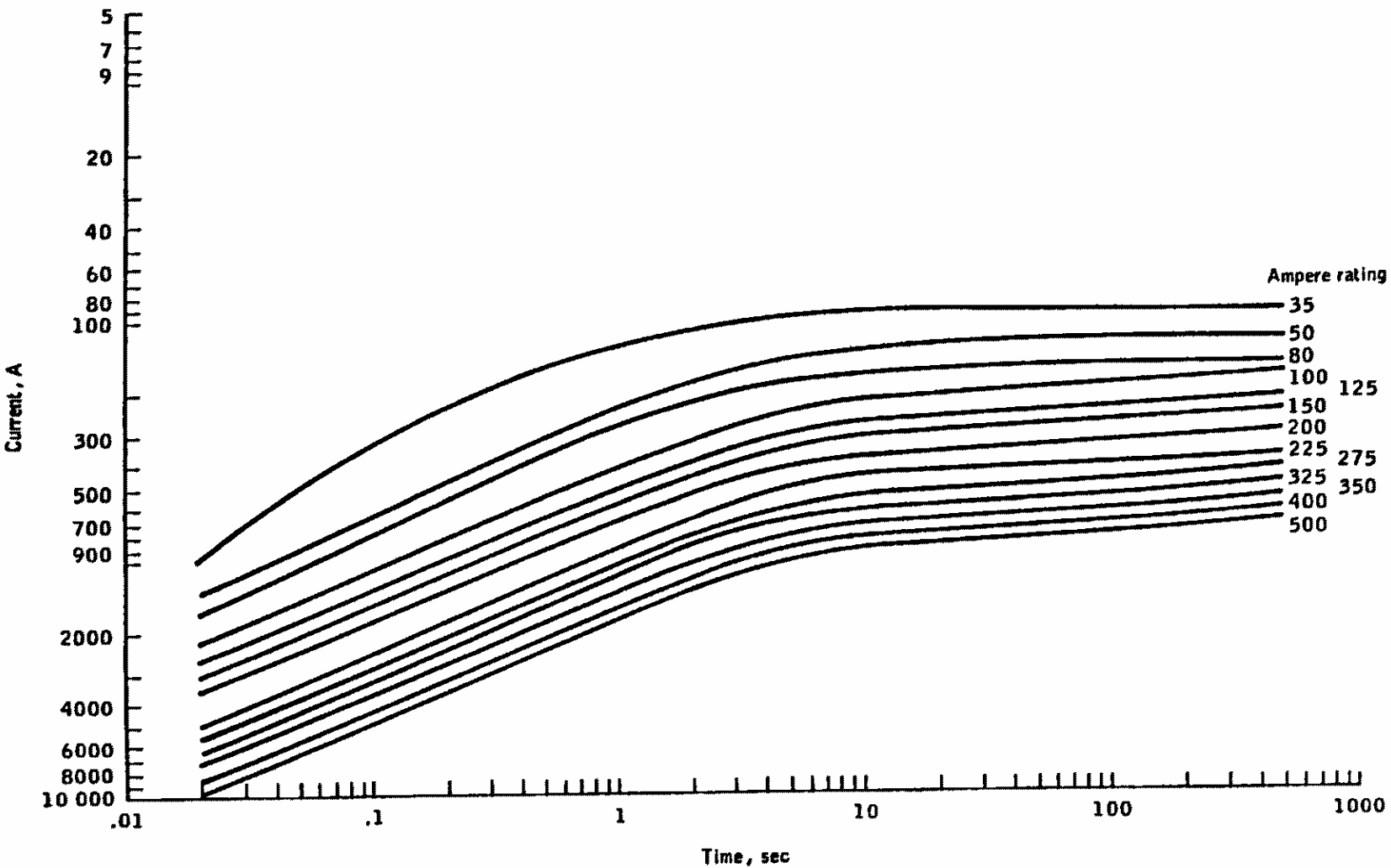


Figure 4.3.1-9. Average opening time for fuse dash numbers 0035 to 0500 and 2035 to 2500 (fast blow)

4.3.1-11

Verify that this is the correct version before use



I\_12830\_175

Figure 4.3.1-10. Average opening time for fuse dash numbers 1035 to 1500 and 3035 to 3500 (slow blow)

4.3.1-12

Verify that this is the correct version before use

**Table 4.3.1-1. Fuse, subminiature - voltage drop, interrupt time**

Dash No.	Current rating, A	Voltage drop, V		Overload interrupt time, sec	
		50 percent nominal rating	100 percent nominal rating	200 percent nominal rating	300 percent nominal rating
0012	0.125	0.07 - 0.12 5	0.45 - 0.58	0.01 - 0.05	0.00 - 0.012 4
0025	.25	.06 - .1	.14 - .225	.014 - .04	.005 - .012
0050	.5	.055 - .08	.175 - .21	.015 - .035	.005 - .015
0075	.75	.055 - .08	.135 - .185	.02 - .09	.008 - .018
0100	1	.055 - .075	.135 - .18	.018 - .05	.008 - .018
0150	1.5	.05 - .075	.135 - .18	.02 - .05	.008 - .02
0200	2	.055 - .09	.15 - .215	.02 - .06	.01 - .02
0300	3	.045 - .08	.135 - .185	.025 - .11	.01 - .023
0400	4	.045 - .075	.125 - .155	.04 - .3	.015 - .033
0500	5	.045 - .075	.14 - .19	.04 - .3	.015 - .033
0750	7.5	.04 - .065	.1 - .13	.107 - .131	.011 - .014
1000	10	.045 - .065	.115 - .16	.05 - .2	.005 - .035

C. RPCs

The RPC is a solid-state device manufactured by Westinghouse that gives circuit protection and, in addition, controls the application of power to a circuit in response to a low-level control signal. The RPC has a current-limiting characteristic that differentiates it from cb's and fuses. When a fault on a circuit occurs, the RPC does not immediately trip; instead, the device operates to limit the current flow to 125 to 150 percent of the rated value (for the first 50  $\mu$  sec there is no current limiting). If the fault persists for a period of 2 to 3 seconds, the RPC will trip, shutting off power completely, and must then be reset in order to restore the output power. Following an overload trip, if the RPC is reset in less than 20 to 30 seconds, the current-limiting time will be reduced from the nominal 2 to 3 seconds. If it is immediately reset into a fault, it will immediately trip again.

A functional diagram of the RPC is shown in Figure 4.3.1-11. When a control signal of more than  $10.5 \pm 1.5$  V DC is applied to the control terminal of the RPC, the control circuitry turns on the output transistors, and the line-to-load circuit is completed. The control input requires 10 ma maximum at 28 V DC; the nominal value is 7 ma. The voltage drop across the RPC is about 0.5 V DC. It should be noted that the output transistors (2N6331) are installed in parallel, with one transistor for each ampere of RPC rating (i.e., a 5-ampere RPC has five output transistors). When an overcurrent condition of more than 125 to 150 percent of the RPC rated value is detected, the circuit acts to limit the conductance of the output transistors and, at the same time, triggers the time-delay circuit.

When the time-delay circuit times out, it triggers the flip-flop and interrupts the circuit. The flip-flop may be reset by either of two methods: taking the control signal to zero and then back on, or taking the line voltage to off and then back on. Either action will then restore power to the branch circuit but, as noted above, will not maintain power on the circuit if the fault still exists.

When the control signal voltage falls below  $6 \pm 1$  V DC, the RPC will switch off its output power. The power consumption in the Off or Tripped state is 0.5 W typical, 0.7 W maximum.

**D. In-flight maintenance - spare fuses**

The OV-102 flight deck and middeck panels, along with the forward power control, load control, and motor control assemblies, were checked for possible in-flight fuse replacement. The following fuse usage data were compiled.

<b>Fuse part no.</b>	<b>Rating</b>	<b>Quantit y</b>	<b>Fuse type</b>	<b>Circuit use</b>
ME451-0009-1001	1 ampere	8	Cartridge	Control signals
ME451-0009-1003	3 amperes	2	Cartridge	Control signals
ME451-0009-1021	5 amperes	15	Cartridge	Control signals and power
ME451-0009-1006	15 amperes	2	Cartridge	Lights
ME451-0009-1007	20 amperes	8	Cartridge	Fwd RCS heaters
ME451-0018-0100	1 ampere	421	Plug-in	Control signals
ME451-0018-0200	2 amperes	14	Plug-in	Control signals
ME451-0018-0300	3 amperes	105	Plug-in	Control signals and lights
ME451-0018-0500	5 amperes	49	Plug-in	Control signals and lights
ME451-0018-0750	7.5 amperes	22	Plug-in	Lights
ME451-0018-1000	10 amperes	15	Plug-in	Lights

The 1-ampere cartridge fuses provide signal power automatically to cut off motor drive to the air data probe and star tracker doors. Each system can be manually controlled if the fuse fails; therefore, no spares are recommended for the 1-ampere cartridge fuse.

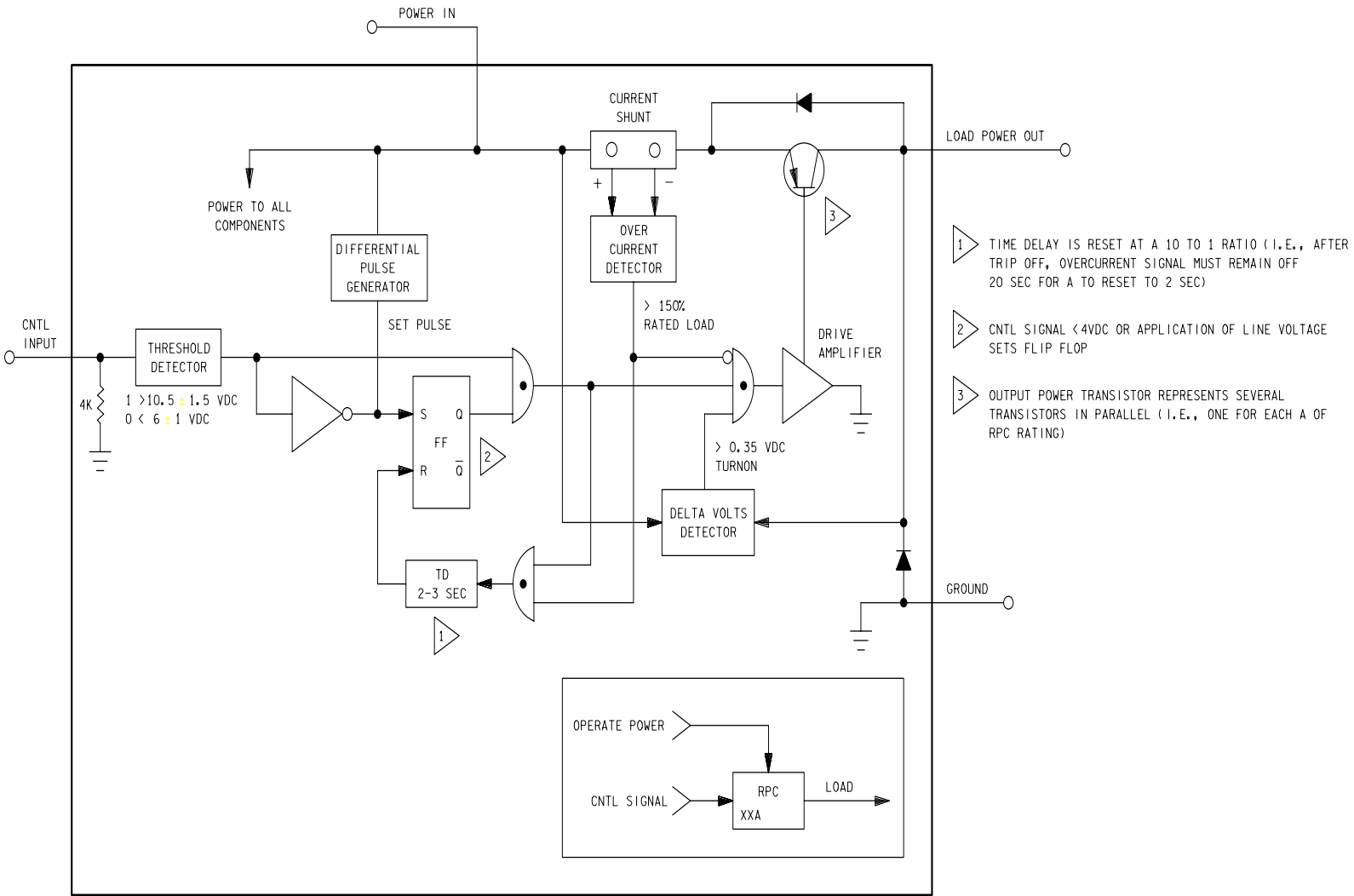
The 3-ampere cartridge fuses are used for one of four air data probe heater current sensors and for the S-band power amplifier no. 2 normal commands. If their respective redundant system also fails, a 5-ampere cartridge fuse could be used as an emergency spare.

The 5-ampere cartridge fuses provide control signal power for GPC backup flight control engage, for providing redundant power to nine Electrical Power System

(EPS) control buses, for commands to landing gear system-1 pyros, for landing gear dump and control valves, and for forward motor control assembly preflight test bus power. Fuse swapping with the preflight test bus fuses provides one spare in avionics bay 1 and one spare in avionics bay 3. To allow several attempts at removing shorts, it is recommended that three additional spare fuses be carried.

The 15-ampere cartridge, along with the 7.5- and 10-ampere plug-in fuses, power lights whose loss would not be serious enough to require in-flight panel removal for fuse replacement.

The 20-ampere cartridge fuses are used for forward RCS heaters: four in avionics bay 1 for system A and four in avionics bay 2 for system B. The redundant system fuses can be interchanged for emergency spares.



128304508. SCH 2

Figure 4.3.1-11. Remote power controller functional diagram

4.3.1-16

Verify that this is the correct version before use

The 1-, 3-, and 5-ampere plug-in fuses are used in quantities for control signal fusing. Some fuse swapping can be done; however, in many cases, this would require the removal of an additional control panel to get the replacement fuse. It is recommended that five spares be carried for each of the 1-, 3-, and 5-ampere plug-in fuses.

The 2-ampere fuses are used for control signal power to forward reaction jet driver control relays and to antiskid brake control circuits. A 3-ampere fuse can be used as a spare, if required.

The following spare fuses are carried on the orbiter in the In-Flight Maintenance (IFM) pin kit.

<b>Fuse part no.</b>	<b>Rating (amperes)</b>	<b>Quantity</b>	<b>Fuse type</b>
ME451-0009-1022	0.25	2	Cartridge
ME451-0009-1023	0.5	2	Cartridge
ME451-0009-1001	1.0	2	Cartridge
ME451-0009-1002	2.0	2	Cartridge
ME451-0009-1003	3.0	2	Cartridge
ME451-0009-1021	5.0	5	Cartridge
ME451-0009-1019	7.5	2	Cartridge
ME451-0009-1005	10.0	2	Cartridge
ME451-0018-0050	0.5	2	Plug-in
ME451-0018-0100	1.0	5	Plug-in
ME451-0018-0200	2.0	2	Plug-in
ME451-0018-0300	3.0	5	Plug-in
ME451-0018-0500	5.0	5	Plug-in
ME451-0018-0750	7.5	2	Plug-in
ME451-0018-1000	10.0	2	Plug-in

In addition to being used as orbiter replacement spares, the plug-in fuses listed above are used with the IFM breakout box (12, 16, 20, and 22 gauge carried). The IFM fuse cap test lead utilizes the cartridge fuses.



**TITLE**

BUS LOSS VS EGIL FUNCTION LOST

		MAIN A	5/12/2000
Bus lost		Equipment and functions lost	Instrumentation lost
DA1	O14	O2 TK 1 HTR CUR SNSR 1 MNC CONTR pwr redund to FC/MN C, MN C Bus Tie, PL PRI MN C, PRI FC3, AFT MN C ACA1 FWD MNA PWR; dc TACAN 1 Av Bay 3 Fire Suppression Overhead CDR Left Console flood light DC UTIL PWR (019 & MO52J)	FWD, MID, AFT CURR SNSRS Cabin Press PPO2 Sensor A L/R FLT DK and AV BAY 2A/3B Smoke Detn DSC OF 1/4 A and OM 1/2 A redundancy MDM OF 1/2 A and OF 3/4 A redundancy
	CRYO1	O2/H2 TK 1 HTR A; O2 TK1 HTR 1A, 2A TRIP capability	
	CRYO3	O2/H2 TK 3 HTR A; O2 TK3 HTR 1A, 2A TRIP capability	
	CRYO5	O2/H2 TK 5 HTR A ; O2 TK5 HTR 1A, 2A TRIP capability	
	R1A1	MN A pwr to CNTL AB1,2,3 & CA1,2,3; ESS2CA/ESS3AB RPC	CNTL AB1,2,3/CA1,2,3 & ESS2CA/ESS3AB RPC A ON
M A I N  A	ML86B	FC PCM power (FCMS) Middeck Floodlights 1/8, & 9; WMC/MO13Q and Airlock 1 Tunnel Adapter floodlight #2 O2 TK 3 HTR CURR SNSR 1 O2 TK 5 HTR CURR SNSR 1	
	R14	MNA pwr (center feed) to CNTL BC1,2,3 ADC 1A/2A, MDU MFD2, MDU PLT 1 GCILC MNA PWR; Payload Station Floodlight, CCTV MON 1	
	A6/A14	ODS Forward Truss Docking light (A6)	PRLA Sys 1 Logic
	O14/A8	NONE	
	FPC1	MNA PWR to CNTL AB1,2,3 and CA1,2,3 RPC A AC1 (DC Inverter input power) MDU CRT 1; IDP 1	FPC1 VOLTS CNTL AB1,2,3/CA1,2,3 RPC A ON
	FLC1	AV Bay 3 agent discharge capability	
	FMC1	NONE	FWD MCA 1 OP ST 1,2,3,4
	AC1 multi	FC1 COOL PUMP/H2 PUMP AC1 Middeck UTIL Panel (MUP) AC1 UTIL (F1, MO52J) AC1 INVERTERS	
	φA	FC1 PH Sensor Right Panel INSTR lights (C2, F8, F9) PNL Left/Center lights (L1, L2, L4, C2, C3, F2, F6, F7) CABIN T CNTLR 2	
	φB	Left Panel Overhead Light (O5, O6, O7, O13, O14, O15) Panel Numeric Forward Light (O3, O7)	AV BAY 2 S/C CABIN AIR S/C
φC	Instrumentation Orbit Station Light (A1, A2)		
	FMC1	NONE	
	MMC1	NONE	
	MMC3	NONE	
	AMC1	NONE	
	MPC1	FC1 CPM; FC PCM pwr (FCMS) PCS O2 Supply Valve 1 FC1 PURGE VLV'S FC H2O LINE & RELIEF HTR A FC1 STARTUP HTR INHIBIT FC3 REAC VLV CNTLR ON C3 MNA Pwr to CAB PL1,2,3 PL AUX A BUS pwr MNA Pwr to ESS2CA and ESS3AB PLB Floods 1,6,8 (FWD PORT, AFT STBD, DOCK) Port Vestibule Docking Lights	FC1 O2/H2 FLOW DUCER FC1 SS 1,2,3 DV (CPM) O2 Sys 1 Supply tb FC PURGE HTR RPC A ON PL AUX MNA RPC  MNA ESS2CA/3AB RPC ON
	A7	External Airlock lights 1 & 4	
	MMC1	NONE	MID MCA 1 OP ST 1,2,3,4,5,6 AC1 PBM/PBD ENABL 1 & 2
	MMC3	NONE	MID MCA 3 OP ST 1,2,3,4,5,6 AC1 PBM/PBD ENABL 1 & 2
	APC4		Aft Amps & Volts
	ALC1	NONE	APC4 Volts
	APC1	NONE	
	AMC1	Landing Gear Extend Isol Valve	AFT MCA 1 OP ST 1,2,3,4; ISOL VLV tb

		MAIN B	5/12/2000
Bus lost	Equipment and functions lost		Instrumentation lost
DA2		MUP (ML85E & MAR PUMPS) PRI PL MNB pwr	FWD, MID, AFT CURR SNSRS
	O15	O2 TK 2 HTR CUR SNSR 2 MNA CONTR pwr redundancy to FC/MN A; MN A Bus Tie; ODS SYS 1 pwr and Vent Valves DC TACAN 2; ACA1, 2/3, 4/5 MNB pwr MNB DC UTIL pwr (F1 & MO13Q) Left Seat, CTR Console, & RT Console OVHD lights AV Bay 1 Agent Discharge Drag Chute - SYS2(PLT ARM)	Smoke Detn Bay 1B/3A DSC OM3, OF1/4 B, OF2/3 A, and OM1/2 B; MDM OF1/2 B redundancy
	CRYO2	O2/H2 TK 2 HTR B; O2 TK2 1B, 2B Htr Trip capability O2/H2 TK 2 HTR A AUTO	
	CRYO3	O2/H2 TK 3 HTR B; O2 Tk3 1B, 2B Htr Trip capability O2/H2 TK 3 HTR A AUTO	
	CRYO4	O2/H2 TK 4 HTR B & O2/H2 TK 4 A AUTO	
	R1A1	MNB pwr to CNTL AB1,2,3/BC1,2,3 & ESS 1BC/3AB RPC B	CNTL AB1,2,3/BC1,2,3 & ESS 3AB/1BC RPC B ON
	ML86B	O2 TK 3 HTR CURR SNSR 2  O2 TK4 HTR CURR SNSR 1 Bunk 2, 4 lights; Middeck Floodlights 2, 6, & 10(PHS) Tunnel Adapter #3 & Airlock #3, lights CDR & PLT Seat adjust via AC2 MAR 1 and MAR 2	
	R14	MDU CDR2 & MFD1, ADC 1B/2B MNB pwr (center feed) to CNTL CA1,2,3 Orbit Station Floodlight	IDP3, IDP4 ADC data lost CCTV MON 2
	A6&A14	ODS Truss Aft Dock Light (A6); MAD5	PRLA Sys 2 Logic
	O15&A7&A8	NONE	
	FPC2	MNB PWR to CNTL AB1,2,3 and BC1,2,3 AC2 (DC inverter pwr) MDU CRT 2; IDP2 NSP 1/COMSEC 1	FPC2 VOLTS; CRT 2 blanks Cntl AB1,2,3/BC1,2,3 RPC ON
	FLC2	PSP 1, NSP1, S-BD FM Sys 1	
	FMC2	NONE	FWD MCA 2 OP ST 1,2,3,4
	AC2 multi	FC2 COOL PUMP/H2 PUMP AC2 UTIL (MS & PL Patch panels) AC2 INVERTERS	
	φA	FC2 PH; PROX BOX 2 Panel Right Overhead Light CABIN T CNTLR 1	
	φB	COMMON PH; Panel RT & Instrumentation OVHD Lights	AV BAY 3 S/C
	φC	Orbit Station Numeric Lights; MS & PS Patch PNL	
	FMC2	NONE	
	MMC1	NONE	
	MMC2	NONE	
	MMC3	NONE	
	MMC4	NONE	
	AMC2	NONE	
	MPC2	FC2 CPM FC2 PURGE VLV'S FC2 STARTUP HTR INHIBIT PCS O2 Supply Valve 2 FC1 REAC VLV CNTLR ON C3 MNB Pwr to CAB PL1,2,3 PL AUX B BUS pwr MNB Pwr to ESS1BC and ESS3AB PLBFL 2,3,7 (FWD STBD, MID PORT FWD BHD)	FC2 SS 1,2,3 DV (CPM) O2/H2 Flow Transducers FC PURGE HTR RPC B ON O2 Sys 2 Supply tb  PL AUX B RPC MNB ESS1BC/3AB RPC ON
	A7	EXT A/L LTS 2,3	
	MMC1	NONE	MID MCA 1 OP ST 7, 8
	MMC2	NONE	MID MCA 2 OP ST 1, 2 AC2 PBM/PBD ENABL 1& 2
	MMC3	NONE	MID MCA 3 OP ST 7,8 AC2 PBM/PBD ENABL 1& 2
	MMC4	NONE	MID MCA 4 OP ST 1,2,3,4 AC2 PBM/PBD ENABL 1& 2
	APC5		AFT Volts & Amps
	ALC2	NONE	APC5 Volts
	APC2	AFT PL MN B	PL AFT MNB Amps
	AMC2	NONE	AFT MCA 2 OP ST 1,2,3,4

		MAIN C	5/12/2000
		Equipment and functions lost	Instrumentation lost
M A I N  C	DA3	PRI PL MNC pwr MO63P DC util pwr (104)	FWD, MID, AFT CURR SNSRS
	O16	O2 TK 1 HTR CUR SNSR 2 O2 TK 2 HTR CUR SNSR 1  MNB CONTR pwr redundancy to FC/MN B; MN B Bus Tie; PL PRI MN B, ODS Sys 2 pwr and Vent Valves DC TACAN 3; ACA, 2/3, 4/5 MNC PWR DC UTIL PWR (A11, A15 & MO30F) RT Seat, Center Console Floodlights DRAG Chute(CDR Arm)	DSC OM3 B and OF2/3 B; MDM OF3/4 B redundancy Cabin & Av Bay 1A/2B Smoke Detn
	CRYO1	O2/H2 TK 1 HTR B; O2 TK 1 2A, 2B HTR Trip capability O2/H2 TK 1 HTR A AUTO	
	CRYO2	O2/H2 TK 2 HTR A; O2 TK 2 1A, 2A HTR Trip capability	
	CRYO4	O2/H2 TK 4 HTR A	
	CRYO5	O2/H2 TK 5 HTR B O2/H2 TK 5 A AUTO O2 TK5 HTR 1B, 2B Trip capability	
	R1A1	MNC pwr to CNTL BC1,2,3/CA1,2,3 & ESS 1BC/2CA RPC	CNTL BC1,2,3/CA1,2,3 & ESS 1BC/2CA RPC C ON
	ML86B	Middeck floodlights 3,4,5,7; MO13Q panel light 1 BUNK 1 & 3, Tunnel Adapter #4, Airlock #4 lights O2 TK 4 HTR CURR SNSR 2 O2 TK 5 HTR CURR SNSR 2  CDR, PLT Seat adjust via AC3	
	R14	MDU CDR 1, MDU PLT 2, MDU AFD 1, AUD CTR 2, P/S AIRLOCK AUDIO, Mission Station floodlight GCILC MNC pwr (center feed) to CNTL AB1,2,3	
	A14	NONE	
	O16RJD	NONE	
	O14&A8	NONE	
	FPC3	MNC PWR toCNTL BC1,2,3 and CA1,2,3 AC3 (DC Inverter input pwr) IDP/CRT 3, 4	FPC3 VOLTS CNTL BC1,2,3/CA1,2,3 RPC ON
	FLC3	NSP2, S-BD FM Sys 2, PSP 2	
	FMC3	NONE	FWD MCA 3 OP ST 1,2,3,4
	AC3 multi	FC3 COOL PUMP/H2 PUMP AC3 UTIL (A15, MO13Q, MS & PL patch panels) AC3 INVERTERS	
	φA	FC3 PH; Prox Box 1 COAS	H2O CNTLR 1
	φB	Instrumentation Left/Center light (C2, F6, F7) Mission Station Panel light (R10, R12)	Av Bay 1 S/C
	φC	Orbit Station panel light (A1,A2,A6,A7,A8,A13,L9)	
	FMC3	NONE	
MMC2	NONE		
MMC4	NONE		
AMC3	NONE		
MPC3	FC3 CPM FC3 PURGE VLV'S FC3 STARTUP HTR INHIBIT FC2 REAC VLV CNTLR ON C3 MNC Pwr to ESS1BC and ESS2CA FC H2O Line & Relief HTR B, Nozzle HTR PLBFL 4,5 (MID STBD, AFT PORT)	FC3 SS1,2,3 DV(CPM) FC3 O2/H2 FLOW DUCER FC PURGE HTR RPC C-1 & C2 ON MNC ESS 1BC/2CA RPC ON	
MMC2	NONE	MID MCA 2 OP ST 3, 4, 5, 6, 7, 8 AC3 PBM/PBD ENABL 1&2	
MMC4	NONE	MID MCA 4 OP ST 5, 6, 7, 8 AC3 PBM/PBD ENABL 1&2	
APC6		AFT AMPS & VOLTS PL MNC Current Signal Conditioner	
ALC3	NONE	APC6 VOLTS	
APC3	AFT PL MN C	PL AFT MNC Amps	
AMC3	NONE	AFT MCA 3 OP ST 1,2,3,4	

ESS 1BC			
Bus lost		Equipment and functions lost	Instrumentation lost
1BC			FC1 to ESS On ESS 1BC VOLTS FC/MN BUS A tb MN Bus TIE A tb
	MPC1	FC1 ECU FC1 REAC VLVS (R1) O2/H2 MANF VLV 1	COOL PUMP ΔP (tb bp) FC1 REAC VLVS ind CL (tb - CL) O2/H2 MANF 1 VLVS ind CL (tb - CL) FC1 READY (tb bp)
	FP & LC1	AC1 INV PWR control (cannot disconnect AC INV PWR)	AC1 INV PWR (3φ's) ind OFF (tb - OFF)
	FD	FC1 ECU AC1 INV & BUS CONTROL (cb & switches) - cannot disconnect INV or AC BUS FC1 AUTO PURGE (VLV GPC disc ↓) O2 TK 2, 4, 6 & 7 HTR CURR SNSR TEST  O2/H2 TK 6&7 CPC MN A PWR to CAB PL1,2,3 PL AUX A	FC1 CNTLR PWR INV PWR tb STAYS on FC1 PURGE VLV (GPC & MNL) ind O2/H2 TK2,6,7 HTR A, B switch posn O2/H2 TK4 HTR A,B switch posn 1BC VOLTS on F9 meter  O2/H2 TK 6&7 QTY (spec) PL CAB MNA ON PL AUX ON ind PL AUX A RPC ind
	013 & R14	O13 MNA CONTR pwr redundancy to FC/MN A; MN A Bus Tie; ODS SYS 1 pwr and Vent Valves AC1 BUS SNSR C&W A O2/H2 TK 2 CPC PNL F7 LIGHTSL	INV/AC1 BUS (3φ's) ON (tb OFF) AC1 BUS SNSR OFF O2/H2 TK 2 CNTLR P O2/H2 TK 2 QTY (meter & spec)
		R14 LDG GEAR ARM/DN RESET AUDIO LEFT LEFT GLARESHIELD FLOOD pwr via O6	
	ML86B	O2/H2 TK 4 CPC Airlock FLOOD 2 TNL ADP FLOOD 1	O2/H2 TK 4 CNTLR P O2/H2 TK 4 QTY (meter & spec)
	APC4		
	ALC1		

ESS 2CA		
Bus lost	Equipment and functions lost	Instrumentation lost
2CA		FC to ESS On ESS 2CA VOLTS FC/MN BUS B tb MN BUS TIE B tb PL PRI MNB tb
MPC2	FC2 ECU FC2 REAC VLVS (R1) O2/H2 MANF VLV 2	COOL PUMP ΔP FC2 REAC VLVS ind CL (tb - CL) O2/H2 MANF 2 VLVS ind CL (tb - CL) FC2 READY (tb bp)
FP & LC2	AC2 INV PWR Control (cannot disconnect INV PWR)	AC2 INV PWR (3φ's) ind OFF (tb - OFF)
FD	FC2 ECU AC2 INV BUS CONTROL (cb & switches) - cannot disconnect INV or AC BUS ALL FC AUTO PURGE (HTR & FC2 Purge VLV GPC disc ↓) O2 TK1, 8, 9 HTR CURR SNSR TEST O2 TK5 HTR CURR SNSR TEST O2/H2 TK 8 & 9 CPC MN B PWR TO CAB PL1,2,3 PL AUX B	FC2 CNTRL PWR INV PWR tb STAYS ON GPC PURGE HTR FC2 PURGE VLV (GPC & MNL) O2/H2 TK 1, 8, 9 HTR A,B switch posn O2/H2 TK 5 HTR A,B switch posn O2/H2 TK 8&9 CNTRL P O2/H2 TK 8&9 QTY AUX MNB RPC ind PL CAB MNB ind ESS2CA VOLTS ON F9 METER
013 & R14	O13 COMM via AUD CTR 1 MNB CONTR pwr redundancy to FC/MN B; MN B Bus Tie; PL PRI MN B, ODS Sys 2 pwr and Vent Valves AC2 BUS SNSR C&W B O2/H2 TK 1 CPC	AC2 BUS SNSR AC2 INV/AC BUS (tb OFF) PRI & B/U C&W LIGHT fails ON O2/H2 TK 1 CNTRL P O2/H2 TK 1 QTY (spec & meter)
	R14 RIGHT AUDIO & AUD CTR 1 RIGHT GLARESHIELD pwr via pnl O8	
ML86B	O2/H2 TK 5 CPC	O2/H2 TK 5 QTY (spec & meter)
APC5		
AP & LC2		AFT PL MN B ON

ESS 3AB		
Bus lost	Equipment and functions lost	Instrumentation lost
3AB		FC to ESS ON ESS 3AB VOLTS FC/MN BUS C tb MN BUS TIE C tb PL PRI MNC tb PL PRI FC3 tb
MPC3	FC3 ECU FC3 REAC VLVS (R1)	COOL PUMP ΔP FC3 REAC VLVS ind CL (tb - CL) FC3 READY (tb bp)
FP & LC3	AC3 INV PWR Control - cannot disconnect INV PWR EMERGENCY LIGHTING	AC3 INV PWR (3ø's) ind OFF (tb - OFF)
FD	FC3 ECU AC3 INV BUS CONTROL (cb & switches) - cannot disconnect INV or AC BUS BFS Engage to all GPCs ALL FC AUTO PURGE via switch FC3 AUTO PURGE (VLV GPC disc ↓) O2 TK3 HTR CURR SNSR TEST EMERGENCY LIGHTING via switch (C3&ML18F)	FC3 CNTLR PWR INV PWR tb STAYS ON FC3 PURGE VLV (GPC & MNL) O2/H2 TK 3 HTR A,B switch posn ESS3AB VOLTS ON F9 METER
013	MNC CONTR pwr redundancy to FC/MN C, MN C Bus Tie, PL PRI MN C, PL PRI FC3, and AFT MN C AC3 BUS SNSR GPC STATUS cb (O13) ADU (O1) (Annunciator Display Unit - aka Computer Status matrix)	INV/AC BUS 3 ON (tb OFF) AC3 BUS SENSOR
ML86B	O2/H2 TK 3 CPC	O2/H2 TK 3 CNTLR P O2/H2 TK 3 QTY (meter & spec)
APC6		
AP & LC3		PL AFT MN C ON

**CONTROL BUS LOSS**

<b>CNTL bus</b>	<b>Equipment and functions lost</b>	<b>Instrumentation lost</b>
AB1	O2/H2 MANF VLV 1 & O2 PCS Sys 1 VLV control FC1 REAC VLVs (R1) FC3 redundant REAC VLVs (C3 cb) FC1 STOP SWITCH & Manual Purge VLV control FC H2O Line HTRS & RLF VLV, Vent line, Barrel Htrs A MDU CRT; IDP 1 O2/H2 TK 1 HTR B (UNLESS PAIRED W/ TK 2 or HTR A AUTO) O2/H2 TK 3 HTR A (UNLESS PAIRED W/ TK 4 or HTR B AUTO) PLB FLOODS (1,6,7 FWD PORT, AFT STBD, FWD BLKHD)	FC H2O RLF HTRS A – AUTO FC H2O Line HTRS A – AUTO
AB2	FC1 REAC VLVs (R1) O2, H2 MANF VLV 1 & O2 PCS Sys 1 Vlv control FC1 STOP SWITCH FC1 MAN PURGE VLV control FC3 redundant REAC VLVs (C3) O2/H2 TK1 HTR B & TK3 HTR A	
AB3	MNA FMC1 MNA AMC1 MNA MMC1 MNA MMC3	FWD 1 OPS STATS 1-4 AFT 1 OPS STATS 1-4 MID 1 OPS STATS 1-6 MID 3 OPS STATS 1-6
BC1	FC2 REAC VLVs (R1) O2, H2 MANF VLV 2 and O2 PCS Sys 2 VLV control FC H2O Line & RLF Vent, Barrel, Nozzle HTRS B AC2 PBM MMC2 AC2 PBM MMC3 AC2 PBM MMC4 FC2 STOP switch FC2 MAN PURGE VLV control FC1 redundant REAC VLVs (C3 cb) PLB FLOODS (2,3 FWD STBD & MID PORT) O2/H2 TK 2 & 4 HTR A (UNLESS PAIRED W/ TK 1 & 3 or HTR B AUTO) O2/H2 TK 5 HTR B (UNLESS HTR A AUTO)	FC PURGE HTR RPC C-1 ON  AC2 PBM/PBD MMC2 Bus Enable 1 (V76X2172E) AC2 PBM/PBD MMC3 Bus Enable 1 (V76X2183E) AC2 PBM/PBD MMC4 Bus Enable 2 (V76X2192E)  FC H2O RLF HTRS B AUTO ind FC H2/O2 Purge HTR RPC C-1 ON ind FC H2O Line HTRS B Auto ind
BC2	FC2 REAC VLVs (R1) O2/H2 MANF VLV 2 & O2 PCS SYS 2 VLV control MDU CRT2, IDP2 FC2 STOP switch FC2 MAN PURGE VLV control FC1 redundant REAC VLVs (C3) AC2PBM MMC2 AC2PBM MMC3 AC2PBM MMC4 O2/H2 TK 2 and TK4 HTR A	AFT PL MN B CURRENT  AC2PBM MMC2 Bus Enable 2 (V76X2171E) AC2PBM MMC3 Bus Enable 2 (V76X2184E) AC2PBM MMC4 Bus Enable 1 (V76X2191E)
BC3	MNB FMC2 MNB AMC2 MNB MMC1 MNB MMC3 MNB MMC2 MNB MMC 4 Smoke Detn Test Capability (all detectors) O2/H2 TK 2 & 4 HTR B (UNLESS PAIRED W/TK 1 & 3 OR HTR A AUTO) O2, H2 TK5 HTR B	FWD 2 OPS STATS 1-4 AFT 2 OPS STATS 1-4 MID 1 OPS STATS 7-8 MID 3 OPS STATS 7-8 MID 2 OPS STATS 1-2 MID 4 OPS STATS 1-4
CA1	FC3 REAC VLV (R1) FC3 STOP SWITCH FC3 MAN PURGE VLV control FC2 redundant REAC (C3 cb) MDU CRT3; IDP 3 GPC 3, 5 engage capability PLT BFS engage capability O2/H2 TK 1 HTR A (UNLESS PAIRED WITH TK2 OR HTR B AUTO) O2/H2 TK 3 HTR B (UNLESS PAIRED WITH TK4 OR HTR A AUTO) O2/H2 TK 5 HTR A (UNLESS HTR B AUTO) PLB FLOODS (4,5,8 MID STBD, AFT PORT, DOCKING)	AFT PL MN C CURRENT  FC O2/H2 Purge HTR Manual A ON ind FC H2/O2 Purge HTR RPC A ON ind
CA2	FC3 REAC VLVs (R1) FC2 redundant REAC (C3) FC3 STOP Switch FC3 MAN PURGE VLV control IDP4, MDU CRT4 O2/H2 TK 1 & TK 5 HTR A & TK3 HTR B	
CA3	MNC FMC3 MNC AMC3 MNC MMC2 MNC MMC4 O2/H2 TK 2 & 4 HTR B	FWD 3 OPS STATS 1-4 AFT 3 OPS STATS 1-4 MID 2 OPS STATS 3-8 MID 4 OPS STATS 5-8

**MDM COMMANDS**

<b>MDM</b>	<b>GPC output</b>	<b>MDM</b>	<b>GPC output</b>
PL1	FC1 AUTO PURGE VLV FC2 AUTO PURGE VLV APCU1 DATA	PL2	FC1,2,3 AUTO HTRS / CAPABILITY FC3 AUTO PURGE VLV APCU2 DATA

**Verify that this is the correct version before use**



**TITLE**

WIRING OVERVIEW WITH WIRE HARNESS/LIST PROCEDURES

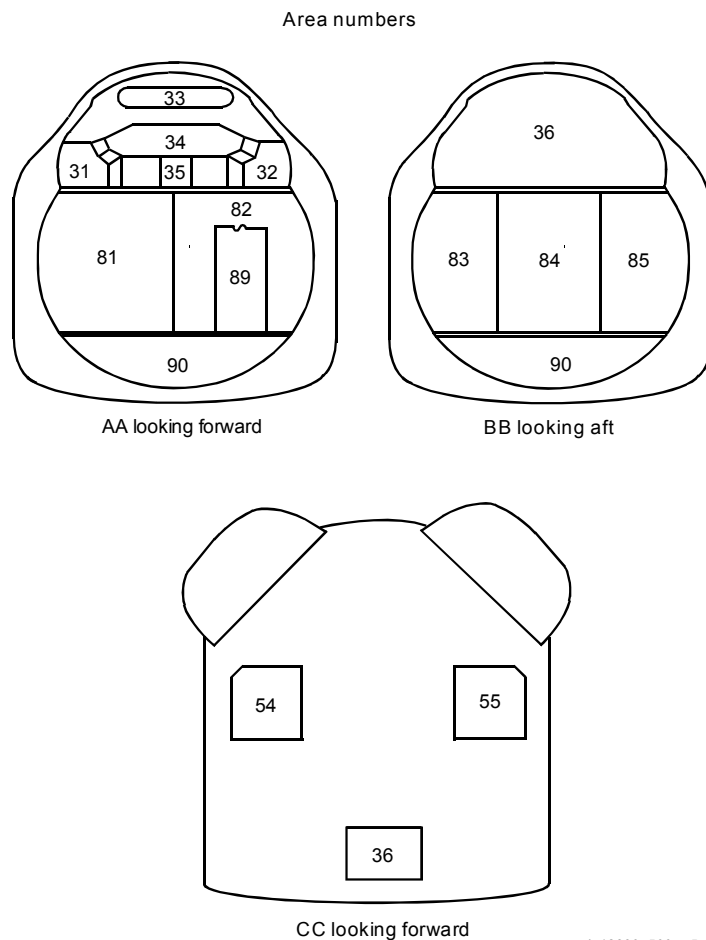
**PURPOSE**

This SB defines the harness layout and wire segment identification, and will aid in finding information about a subsystems segment of wire by using the automated wire list (AWL).

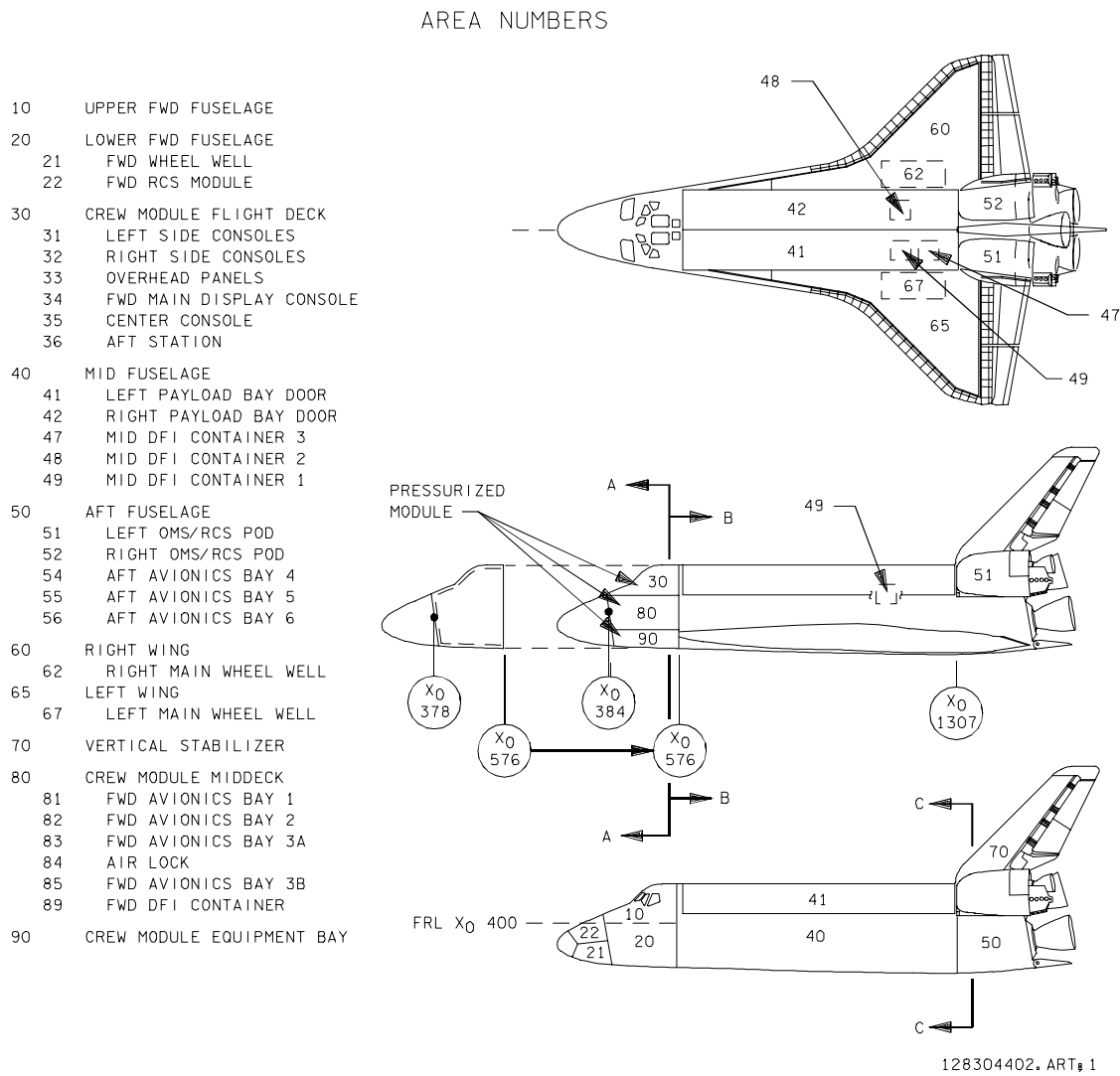
**ORBITER WIRING**

A wire harness is a set of wires and/or cables that interconnects subsystems through connectors, splices, and terminal boards. There are several hundred wire harnesses on the shuttle. The AWL contains all the information needed to fabricate a wire harness.

Orbiter wiring is divided into three major sections: FWD, MID, and AFT (see figure 4.3.3-1). Each section is divided into subsections. The subsections are given an identifying number. This area is a two-digit code that identifies a specific orbiter area. For example, 81 = Av Bay 1 (see figure 4.3.3-2 area numbers - general overview for a full listing of area codes).

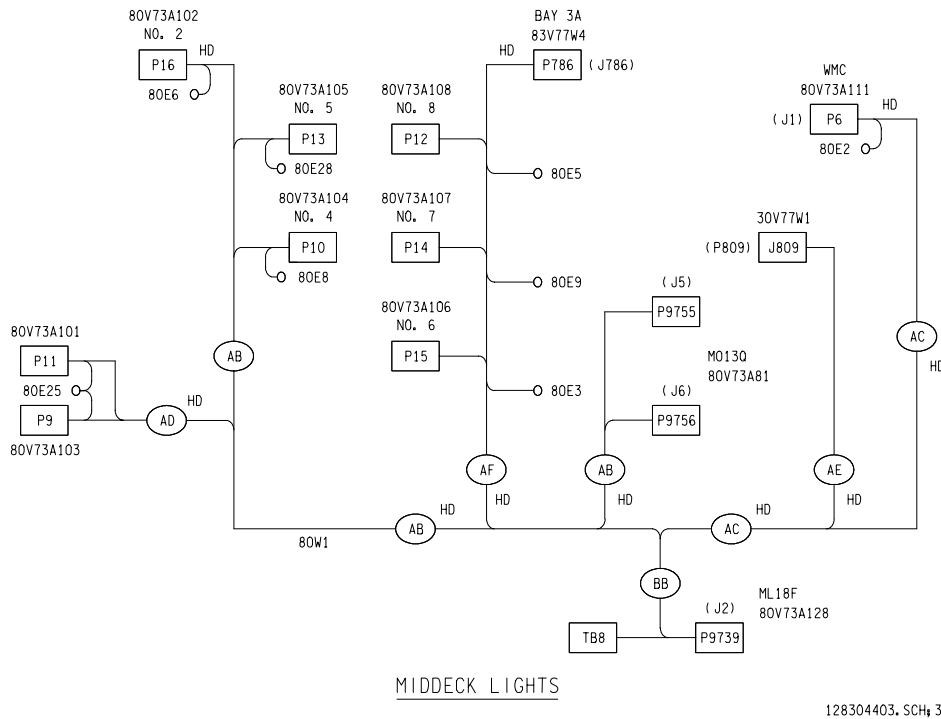


**Figure 4.3.3-1. Area numbers – looking forward and aft**



**Figure 4.3.3-2. Area numbers – general overview**

The orbiter wiring is installed in designated routes that are coded on the orbiter structure. The MID fuselage has two wiring trays, one on the starboard and one on the port sides. These trays are used to route wire harnesses that are connecting the AFT, MID, and FWD systems. Figure 4.3.3-3 is an example of a harness routing diagram and a harness layout.



**Figure 4.3.3-3. 80W1 harness**

Each harness has a specific drawing and reference designator (example: drawings number V070-778901, reference designator 80W01). The drawing number is the integrated schematic drawing number. The reference designator can also be obtained from the integrated schematic. Each reference designator is coded as follows:

- Area - two digit area code identifying the area of the orbiter (81 = AV Bay 1)
- Production ID - letter designator (V = Orbiter, T = ET)
- Subsystem number - two digit code (77 = interconnecting wire, 71 = GNC)
- Assembly or component designator - letter (W = wire bundle, A = LRU)
- Assembly number - sequential by subsystem
- Item class designator (if required) - letter (J = receptacle, P = plug, S = splice)
- Item class number - sequential by assembly

For example, reference designator = 81V77W8P58: Area 81 = Av Bay 1, production ID V = orbiter, subsystem number 77 = interconnecting wire, assembly designator W = wire, assembly number 8 = wire bundle number 8, item class designator P = plug, and item class number 58 = plug number 58.

**PROCEDURE**

A link to the AWL can be found on the DF73 home page. The path is as follows:

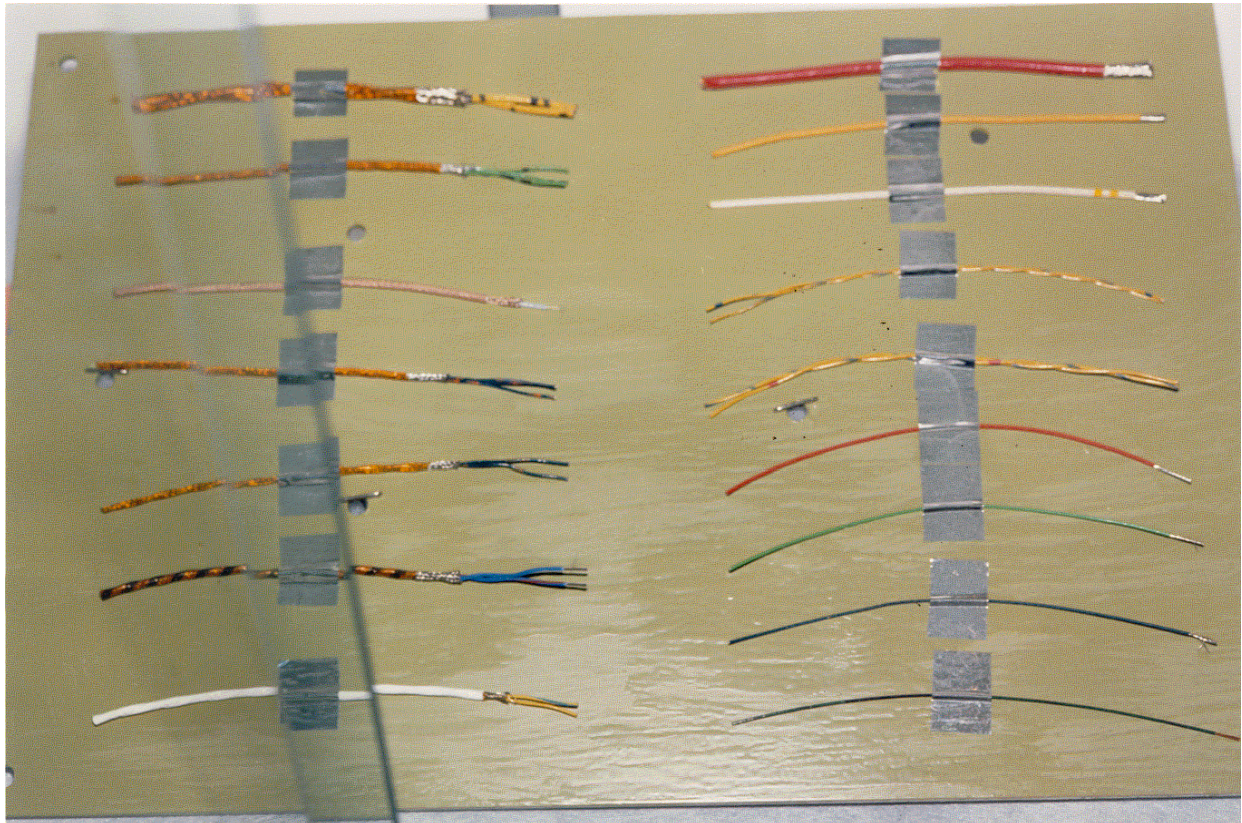
**DF73/SYSTEM Links/KSC WIRE LIST/Connector Search**

When the connector search page is reached you can select a specific vehicle or miscellaneous. Enter the reference designator number you would like to search for. Once the reference designator number is entered it will bring up a screen like the one in figure 4.3.3-4. For information on the abbreviations and nomenclature click on the title of the column and the corresponding information will appear. (Note: In the Circ Seg ID Routing the last digits are the wire gage. In figure 4.3.3-4, the Circ Seg Id Routing shows an 8-gauge wire.)

Thank you 139.169.83.213 for using the BNA Electronic Wire List. The following was extracted from OV-105s Flight 13 wire list which was created 03/09/98. Changes to the wire list after this date have not been incorporated.

Comp Info					
From Ref Des	Nomenclature	Part Number Adapter Cable 1 Adapter Cable 2	No of Term	Mate Ref Des	Callout Doc No
81P20	PLUG, GPC 4 PWR	ME414-0235-5250	4	81V72A1917	1499
81P20	BACKSHELL, STRAIN RELIEF	ME414-0610-2022			7058
Wire Info					
From Ref Des	From End Shld Cable Term Fit Code Desc	Circ Seg Id Routing	Color or Size	Function Remark Signal Code	To Ref Des
81P20	A 2T1	4K560A8 4G	1	GPC 4 PWR	81P13
81P20	B 2T1	4K560A8 4G	2	GPC 4 RTN	81P13
81P20	C				
81P20	D 1F 1S1	4K561A8 4G		SIGNAL GROUND	81E12
81P20	1F 1F 1S1	4K561A8SH 4G		SHIELD	81E12
81P20	1F	JR24		SHIELD TERMINATE	81P20
81P20	1T L006 +	JR24		SHIELD TERMINATE	81P20
Dwg Code Info					
Dwg Code	Harness Number	Harness Name	Harness Revision Letter	Ref Des	Last Revised
81A	V070-778910	WIRE HARN BAY 1 POWER	A	81V77W10	04 MARCH 1993
General Notes					
Gen Note	General Note Description				
EG	SHIELDED WIRE AT CONNECTOR SHALL HAVE THE SHIELD CUT BACK NO MORE THAN 2.5 IN. FROM REAR FACE OF CONNECTOR				

Figure 4.3.3-4. Automated wire list (example GPC 4 power connector)



*Figure 4.3.3-5. Wire Samples*

## TITLE

LIGHTING AND UTILITY POWER

## PURPOSE

This SB describes the orbiter lighting and utility power layout.

## ORBITER LIGHTING

The orbiter lighting subsystem provides illumination to the flight deck and middeck interiors, panels, instruments, airlock, and to the payload bay.

### A. Interior lighting

Orbiter interior lighting uses DC power. There are 11 interior lights on the flight deck, 7 fluorescent (16.5 W) and 4 incandescent (22 W). All flight deck interior lights have 3-amp circuit breakers, and are controlled by switches and potentiometers. The four incandescent lights are controlled by two switches, two lights per switch. The switch allows the CDR or PLT to select either the lights to center console, seat, or off. Switches for the right and left glareshield fluorescent lights allow two modes of operation, potentiometer control and full bright.

All middeck interior lights are 16.5-W fluorescent lights powered via ON/OFF switches and through 3-amp circuit breakers. There are eight middeck floodlights, three of which are redundantly powered for emergency situations (middeck 6, 7, 8). The airlock has four module floodlights. Module light 2 is powered by ESS1BC through a 3-amp circuit breaker and two ON/OFF switches. There are four mission-dependent 16.5-W fluorescent lights on the middeck. They are located at the head of each bunk of the sleep station. Each of these is powered through a 3-amp circuit breaker and controlled via a potentiometer. The Waste Management Compartment (WMC) also has a 16.5-W floodlight. Panel MO13Q has two 6.6-W fluorescent lights, all of which are powered through the main buses. The tunnel adapter kit contains four 16.5-W fluorescent floodlights. Three are controlled through main bus circuit breakers, and one is connected through ESS1BC circuit breakers with two ON/OFF switches. The emergency lighting is powered by ESS3AB through two switches, one switch on each deck. To activate the emergency lights, the switches must be in the same position. The switches activate a 7.5-amp RPC that powers three fluorescent lights on the flight deck (orbiter station floodlight, left and right glareshield floodlight) and three on the middeck (middeck floodlights 6, 7, 8). Details of the interior lighting system can be found in drawing 4.1 of the Space Shuttle Systems Handbook (SSSH).

If the internal airlock has been removed, two middeck floodlights (9 and 10) have been installed in the corners of the aft bulkhead and the Av Bay 3A and Av Bay 3B. Middeck floodlight 9 is located on the port side (corner of aft bulkhead and Av Bay 3B), powered by MNA ML86B, protected by a 3-amp circuit breaker located on ML86B:F, and controlled via a switch on panel MO13Q. Middeck floodlight 10 is

located on the starboard side (corner of aft bulkhead and Av Bay 3A), powered by MNB ML86B, protected by a 3-amp circuit breaker located on ML86B:F, and controlled via a switch on panel MO13Q.

B. Panel lighting

Panel lights on the flight deck are powered through 3-amp circuit breakers by single-phase AC power, controlled via potentiometers, and stepped down to 5 V AC max. The panel lighting is transmitted through small holes, allowing the light to propagate through the coating and illuminate the panels. The light source is a lamp assembly made up of incandescent bulbs. The number and type of bulbs vary per edge panel assembly. Panel lighting details can be found in SSSH drawing 4.2.

On the middeck, only panel MO13Q is illuminated. This panel is lighted by two 6.6-W fluorescent lights receiving DC power from the middeck floodlight 3/4 and the WMC flood circuit breakers via an MO13Q LTG ON/OFF switch. Details for MO13Q lighting are in SSSH drawing 4.1.

C. Instrumentation lighting

Instrument lighting on the flight deck is powered by single-phase AC through 3-amp circuit breakers, and lighting is controlled using potentiometers. Instruments are illuminated by integral incandescent lamps behind the instrument face. Prisms are used to distribute the light evenly over the instrument face. Details of instrument lighting are shown in SSSH drawing 4.2-2.

Multifunction Electronic Display System (MEDS), will be replacing most instruments. The MEDS will use the existing instrument lights power circuits for the edge key and edge panel lights.

D. Digital readout lighting

Numeric lighting has six digital readouts on the flight deck. Illumination is provided by a single incandescent lamp in each segment of a digit. Seven segments are required to generate the numbers zero through nine. A red light on each readout will illuminate any time a segment lamp fails. The following readouts use numeric lighting: forward and aft event and mission timers, Reaction Control System/Orbital Maneuvering System (RCS/OMS) propellant quantity, and rendezvous radar Digital (DIGI). Numeric lighting is powered by single-phase AC power through 3-amp circuit breaker and controlled via potentiometers. Numeric lighting details can be found in SSSH drawing 4.2-2.

E. Annunciation control assembly lighting

Annunciation lighting provides visual indications of mission events and vehicle status. Annunciation is controlled by five Annunciation Control Assemblies (ACAS). The ACAs are passively cooled and are located in the forward left flight deck (ACAs 1 and 2), the forward right flight deck (ACA 3), and the aft right flight

deck (ACAs 4 and 5). The DC power to the ACAs is through 5-amp circuit breakers (two for each ACA), a bus select switch allowing selection of one of two main buses for power, and a switch allowing potentiometer control or full brightness. Each ACA can have 40 annunciator channels, driving one indicator per channel. Two small incandescent lamps are in each indicator. Indicators come in five colors: red for emergency and warning, yellow for caution and alternate configurations, white for status, green for normal configuration, and blue for special applications. The Caution and Warning (C&W) matrix on panel F7 and the General Purpose Computer (GPC) status matrix on panel O1 are driven through special ACAs dedicated to them. The C&W ACA is powered by ESS1BC, and the GPC matrix is powered by ESS3AB. Annunciator lamps may be tested by lamp test switches above the seats (tests forward ACAs) and on the aft station (tests aft ACAs). Details of annunciation lighting can be found in SSSH Table 4.1 and drawing 4.3.

#### F. External lighting

External lighting consists of seven 200-W metal halide lamps in the payload bay and a 175-W incandescent overhead docking light. The external lights are controlled by eight switches on panel A7U. These switches provide control power to 10-amp RPCs located in the midpower controller. The RPCs provide mid-main DC power to the floodlight electronics assemblies and the lights. The payload bay floodlights have an initial startup time of approximately 2 to 3 minutes for full brightness. However, the restart of the payload bay floodlights has the following constraints:

1. Unblocked radiation configuration: A minimum of 10 minutes is required before attempting to restart the lights.
2. Blocked radiation configuration: For payload configurations that block radiation exchange between the payload bay floodlights and space, the following should be considered:
  - a. The nominal minimum off time before restarting should be extended to 12 minutes for all payloads, including cylindrical payloads of 160-inch diameter or less.
  - b. The minimum off time should be extended to 16 minutes for cylindrical payloads with a diameter greater than 160 inch.

There are no hazard conditions if the restart constraints have not been met; however, the restart will be delayed. The longer restart time is because the cathode in the light must be cooled before it can arc the plasma that provides illumination. When the payload bay floodlight is started, it should remain on for 10 minutes\* before unpowering to allow for thermal/chemical stabilization. All payload bay floodlights are passively cooled except the forward bulkhead light, which is water cooled. A detailed schematic of the exterior lighting is shown in SSSH drawing 4.4. For flight-specific floodlight constraints, reference the Flight Rules Annex for that flight.

4.4.1-3



*\*Note: Prior to May of 2003, the Payload Bay Floodlight minimum "ON" time requirement was 25 minutes. However, bench testing performed in May of 2003 revealed that the Payload Bay Floodlights sufficiently reach thermal/chemical stabilization after only 10 minutes.*

For more information on the ODS floodlights, reference the ODS SCP.

## UTILITY POWER

There are 11 utility power outlets in the crew compartment used with various electrical accessories. On the flight deck, there are four DC outlets and two AC outlets. The middeck has three DC and two AC outlets. The DC outlets operate at 28 V DC and are powered through 10-amp circuit breakers via ON/OFF switches. Details of the DC utility outlet are shown in Figure 4.4.1-1 and can also be found in SSSH drawing 2.2-3. The AC utility outlets operate at 115 V AC, are powered through 3-amp three-phase circuit breakers, and controlled by ON/OFF switches. Details of the AC utility outlets are shown in Figure 4.4.1-2 and can also be found in SSSH drawing 2.2-3.

There are two AC powered outlets located on the mission station distribution panel and two more at the payload station distribution panel. Their designation is mission specific. To gain use of these connections, an IFM must be performed.

On the middeck, panel ML85E, is a Middeck Utility Panel (MUP). The MUP is powered by MNB DA2 through two 35 amp fuses that distributes the power to two 20-amp circuit breakers (MAR1, MAR2) and by AC1 through a 3-amp/phase circuit breaker. The MUP DC power is distributed to four 10-amp circuit breakers, and two 3-amp circuit breakers. Each of the 10-amp circuit breakers feeds a DC utility outlet that is controlled via ON/OFF switches. Each of these connectors is 16-gauge pin/sockets. The two 3-amp DC circuit breakers feed one outlet and are controlled by the same ON/OFF switch. The connector is a 20-gauge pin/socket. The AC power on the MUP is controlled via an ON/OFF switch that provides AC power to J31 utility outlet connector and to a 1-amp/phase circuit breaker (J7 utility outlet connector). All the AC utility outlet connectors are 20-gauge pin/sockets. For more information on the MUP, reference Figure 4.4.1-3 and SSSH drawing 2.2-3.

In addition to the pnl ML85E MUP an utility outlet panel has been added to the middeck on panel MO63P for the capability to power additional middeck payloads during missions. The pnl MO63P utility outlet panel is powered by MNC DA3 through a 35-amp fuse and distributed to six circuit breakers on the panel. The panel has the capability to be configured to a 10-amp or a 15-amp utility outlet configuration. There are two POWER switches that allow the associated outlets to be configured to the 10-amp or 15-amp configuration. In the 10-amp configuration S1 POWER switch has the ability to power two utility outlets (J3 & J4), and the S7 POWER switch has the ability to power only one utility outlet (J6). All 10-amp DC Utility Outlet connectors are 16-gauge pin/socket. When in the 15-amp configuration each switch can power one utility outlet (S1 can power J2, and S7 can power J5), and all 15-amp DC Utility Outlet connectors are 12-gauge pin/socket. When in the 15-amp configuration a 3-amp circuit breaker is

used to provide switch power to the 15-amp utility outlets. One 3-amp circuit breaker provides power to both the POWER Switches (S1 & S7) and both of the Utility Outlet power ON/OFF switches (S2, &S5). The On/OFF switches control a relay so that when the Utility Power switches are ON the relay is energized thus allowing power to the 15-amp utility outlet. (Reference Figure 4.4.1-4 and SSSH 2.2-3)

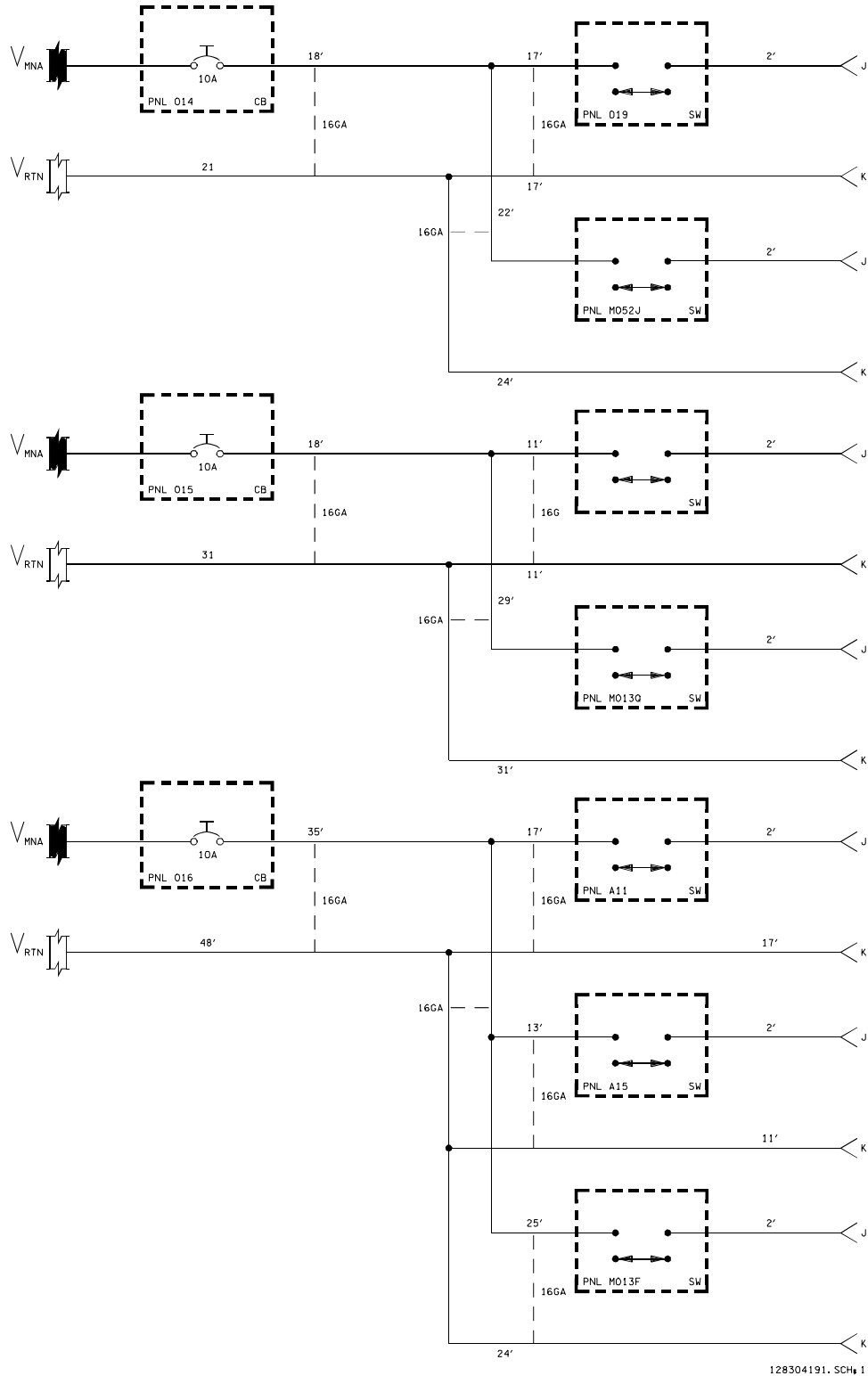
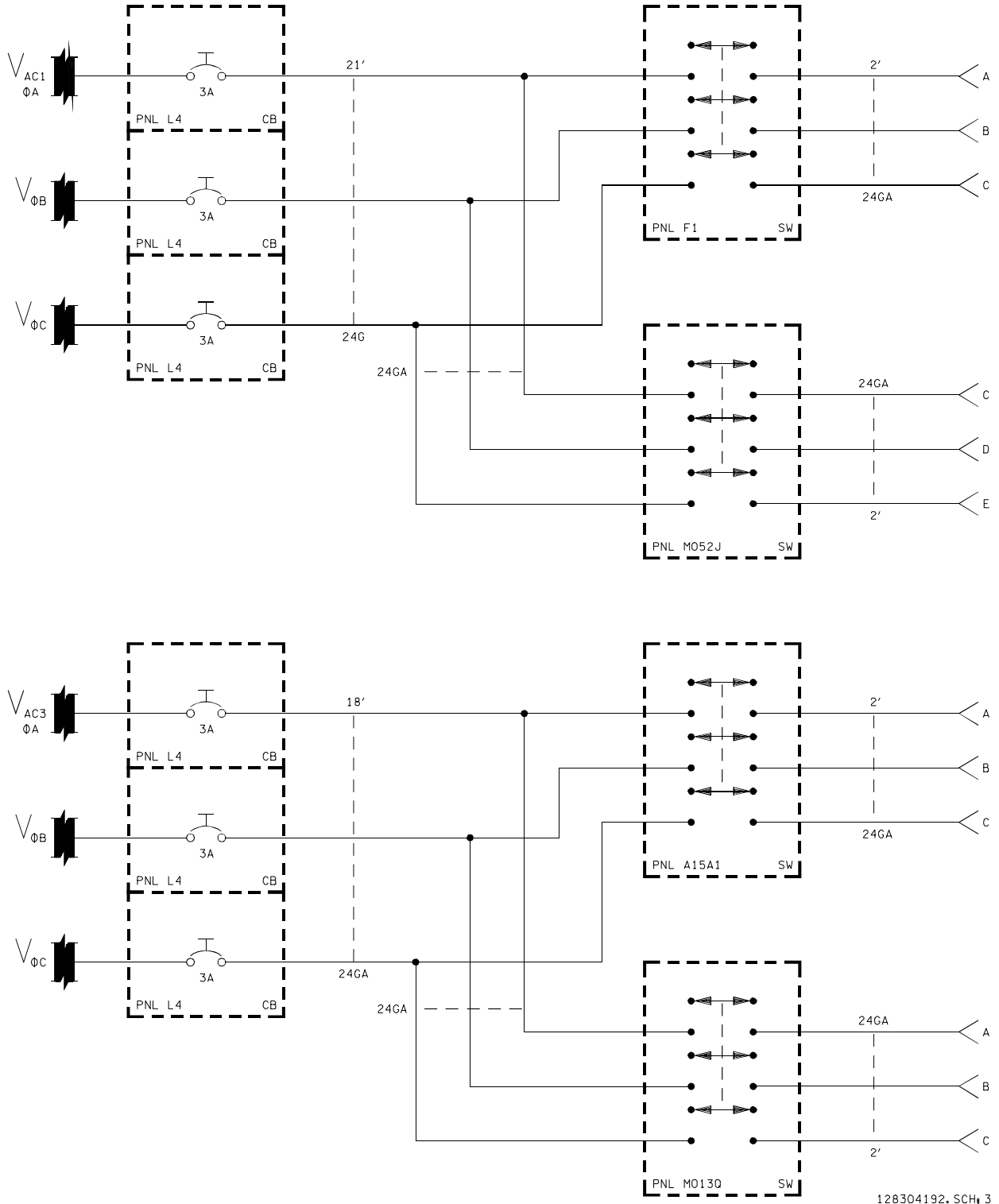


Figure 4.4.1-1. DC utility distribution

4.4.1-6

Verify that this is the correct version before use

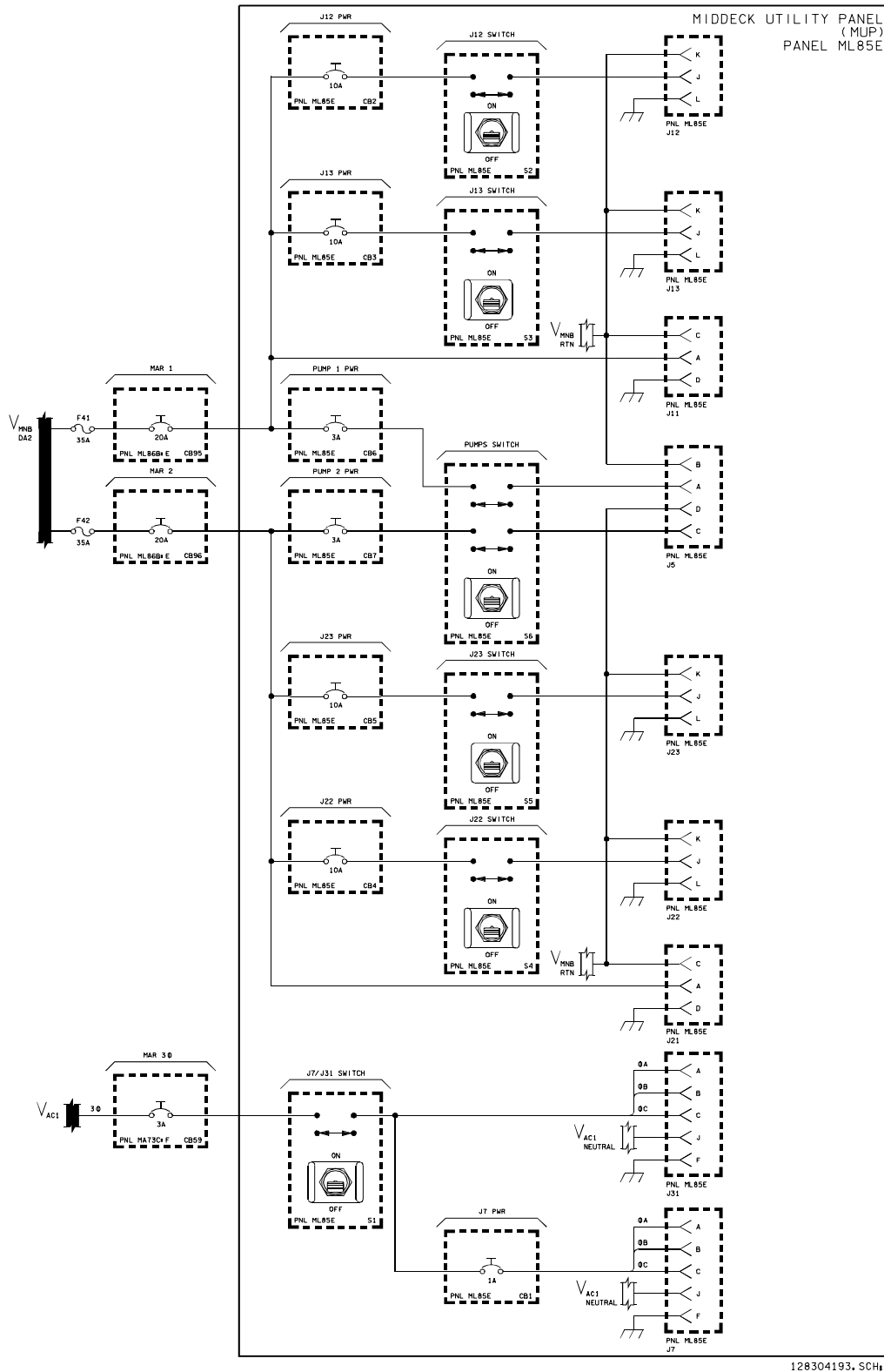


128304192.SCH# 3

Figure 4.4.1-2. AC utility distribution

4.4.1-7

Verify that this is the correct version before use



128304193, SCH 1

Figure 4.4.1-3. Middeck utility panel

4.4.1-8

Verify that this is the correct version before use

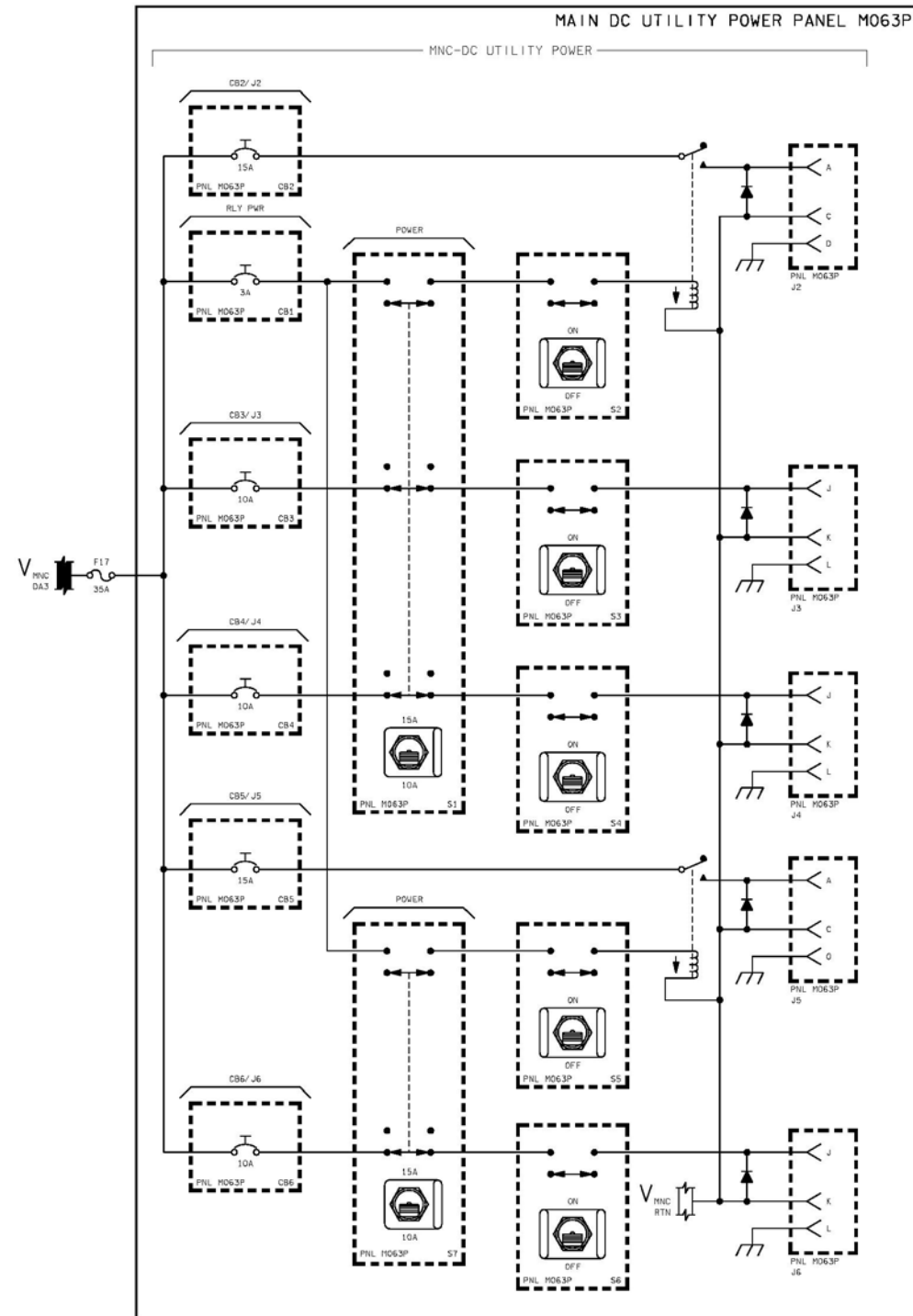


Figure 4.4.1-4. M063P Middeck Expansion Panel

## TITLE

MIDDECK ACCOMMODATIONS RACK AND MIDDECK UTILITY PANEL

## PURPOSE

To familiarize the console operator with the Middeck Accommodations Rack (MAR) and the MUP.

## DESCRIPTION

The MAR and the MUP are located on the port side of the orbiter, the MAR being immediately forward of the entry hatch on the lower deck (see Figure 4.4.2-1). The MAR uses the old galley fittings for installation, provides additional stowage space of about 15 cubic feet, and accommodates up to 340 lb of payload.

The MAR has two configurations considered to be standard. One is the use of the hardware for stowage, where there will be three standard middeck locker volumes and loose stowage space above and below the locker areas. The locker volumes are sized for standard locker trays. The second configuration is for the MAR to be dedicated to a single large payload. In the dedicated mode, the entire MAR and its subsystems will be integrated by a single user and will be treated by the SSP as a single entity.

The MUP, an electrical power distribution system, is designed to distribute AC and DC power when orbiter power is required to be supplied to a payload or experiment that is integrated into or near the MAR. The system provides additional AC and DC general utility outlets for the middeck area and is permanently installed below orbiter panel ML86B (Figure 4.4.2-2).

The DC portion of the MUP has two fused direct feeders to the main DA2. These feeders also have two 20-amp circuit breakers located on panel ML86B (see Figure 4.4.2-1). Instead of drawing power from the panel ML86B sub-bus (like the rest of the circuit breakers on the panel), the MUP circuit breakers are directly connected to the MNB DA2 via 35-amp fuses.

The AC portion of the MUP is connected to AC1 by a 3-amp circuit breaker on panel MA73C. Although most AC circuit breakers on the orbiter are 3 amp, the J7 outlet has an additional 1-amp circuit breaker. This lessens its variety of uses.

## SAFETY-CRITICAL FUNCTION INTERFACES

The use of any of the orbiter/payload interfaces to control safety-critical payload operations will be identified by the Standard Switch Panel (SSP) user during the orbiter/payload Interface Control Document (ICD) development phase.

The SSP user will also provide payload design features that permit test verification of critical electrical/fluid interfaces postmate, including all redundancy.

These critical interface and design features will be identified in the orbiter/payload ICD and SSP user payload hazard report.

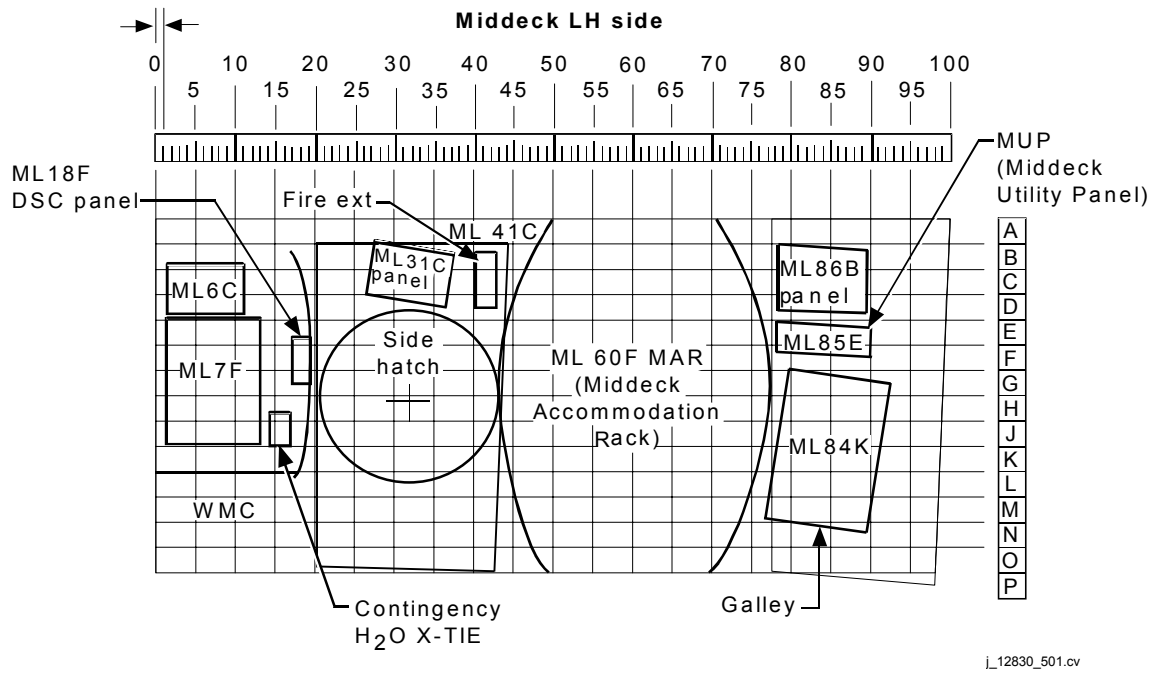


Figure 4.4.2-1. Location of MAR and MUP

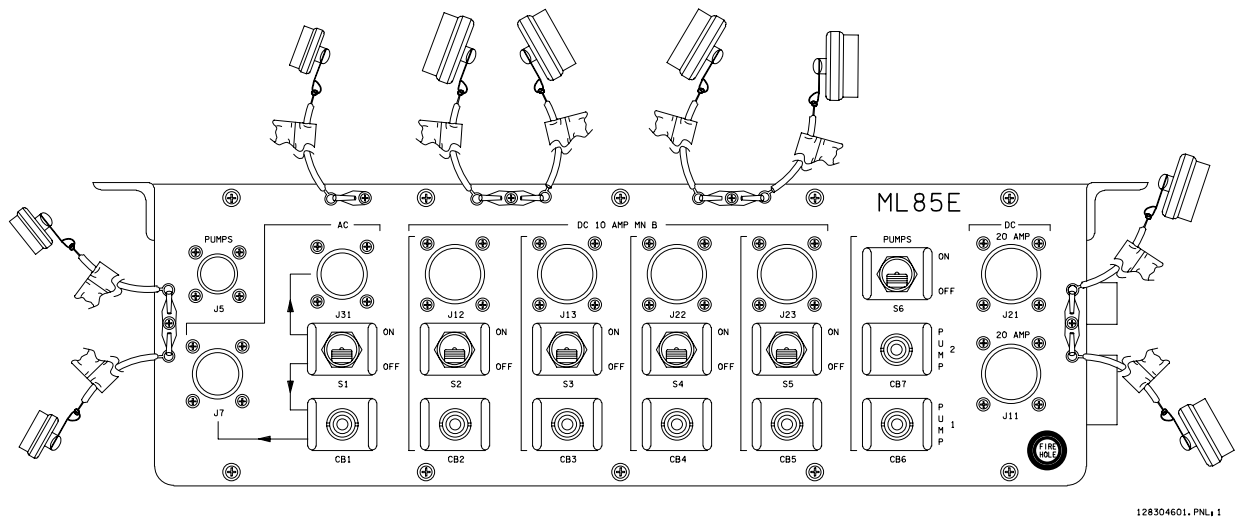


Figure 4.4.2-2. MUP panel layout

4.4.2-2

Verify that this is the correct version before use



Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-4	OV-102	06/27/1982	07/04/1982	EPDC	PLB Floodlight	PLB Floodlight Fail	The crew reported that the PLB lights did not illuminate (AFT Starboard, Forward Port, and Forward Bulkhead). It was believed that one or two RPCs tripped - those controlling AFT Starboard and Forward Port lights. EECOM suggested that they be capped and no attempts were made to reset those RPCs. It turns out that the bulbs failed to illuminate due to cracked bulbs.
STS-5	OV-102	11/11/1982	11/16/1982	EPDC	PLB Floodlight	PLB FWD Port & STBD Floodlights Failed	At GMT 320/08:07 (MET 4/19:48) the crew reported that the Payload Bay FWD Port and Starboard Floodlights were inoperative, but they did not indicate when they had failed. There was no impact to the mission. It turns out the lights failed to illuminate due to cracked bulbs.
STS-5	OV-102	11/11/1982	11/16/1982	EPDC	Interior Lights	Pnl O6 Inst Lighting	Mechanical failure of the dimmer switch
STS-5	OV-102	11/11/1982	11/16/1982	EPDC	Lighting	AFT Mission and Event Timers	AT MET 03/19:45 the crew reported that the AFT Mission and Event timers were inoperative since early in the flight. The crew verified that all the associated switches and circuit breakers had been checked. Numeric Lighting for the AFT timers share a common transformer and fuse. There was no mission impact.
STS-31	OV-103	04/24/1990	04/29/1990	EPDC	PLB Floodlight	Mid Starboard Payload Bay Floodlight	Mid Starboard PLB Floodlight failed to come to full brightness. 7 amps spikes were seen on Mid MN C. There was no impact to the mission. The Floodlights were left off for the remaining duration of the flight.
STS-37	OV-104	04/24/1990	04/29/1990	EPDC	PLB Floodlight	Forward Bulkhead Floodlight	The EVA crewmen reported that the Forward Bulkhead Floodlight was not working. The switch was cycled OFF for 10 minutes, the back ON, and the light did not come ON. There was no mission impact. The Forward Bulkhead Floodlight may require replacement during turnaround of

4.4.3-1

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
							OV-104.
STS-37	OV-104	04/24/1990	04/29/1990	EPDC	PLB Floodlight	Mid Port Floodlight	When the crew powered the PLB Floodlights, the Mid Port Floodlight flickered and did not come up to full brightness. There was no mission impact. The Mid Port Floodlight may require replacement during turnaround of OV-104.
STS-51A	OV-103	11/08/1984	11/16/1984	EPDC	PLB Floodlight	Aft Port	Failed to illuminate due to cracked bulb
STS-51A	OV-103	11/08/1984	11/16/1984	EPDC	PLB Floodlight	Aft Starboard	Failed to illuminate due to cracked bulb
STS-51G	OV-103	06/17/1985	06/24/1985	EPDC	PLB Floodlight	Forward Starboard	PLB Floodlight electronics shorted
STS-31	OV-103	04/24/1990	04/29/1990	EPDC	PLB Floodlight	Mid Starboard	Failed, observed arcing
STS-32	OV-102	01/09/1990	01/20/1990	EPDC	PLB Floodlight	Forward Bulkhead	RPC trip due to shorted transistor in electronics assembly 1
STS-36	OV-104	02/28/1990	03/04/1990	EPDC	PLB Floodlight	Aft Starboard	Observed flickering
STS-36	OV-104	02/28/1990	03/04/1990	EPDC	PLB Floodlight	Mid Port	Failed to illuminate
STS-37	OV-104	04/05/1991	04/11/1991	EPDC	PLB Floodlight	Aft Port	Failed to illuminate
STS-37	OV-104	04/05/1991	04/11/1991	EPDC	PLB Floodlight	Mid Port	Failed to illuminate
STS-43	OV-103	08/02/1991	08/11/1991	EPDC	PLB Floodlight	Payload Bay Floodlight Failure	When Payload Bay Floodlight were powered, Mid MNC amps increased 15 amps for 3-4 seconds. This signature indicated an RPC trip for the Mid STBD Floodlight. Subsequent testing at GMT 222/06:566 confirmed the Mid STBD Flood failed and also that the FWD Port and Mid Port lightw were degraded. There was degraded illumination for Payload Bay viewing due to loss of MID STBD, FWD PORT, and MID PORT Payload Bay Floodlights, but the Floodlights were not a requirement for duration of STS-43. Postflight testing was required.

4.4.3-2

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-44	OV-104	11/24/1991	12/01/1991	EPDC	PLB Floodlight	Aft Starboard	Failed to achieve full brightness
STS-44	OV-104	11/24/1991	12/01/1991	EPDC	PLB Floodlight	Mid Port	Observed flickering during startup
STS-44	OV-104	11/24/1991	12/01/1991	EPDC	PLB Floodlight	Mid Starboard	Failed to illuminate
STS-49	OV-105	05/07/1992	05/16/1992	EPDC	PLB Floodlight	FWD PORT Payload Bay Floodlight Problem	At GMT 132/21:12 the crew reported that FWD PORT PLB Floodlight did not work, so they turned it OFF. At GMT 132/22:01 the crew repowered the FWD PORT PLB Floodlight and a 1.5 amp spike was noticed, but no additional electrical signatures of a nominal PLB Floodlight startup were observed. Due to this there is less illumination in the Payload Bay. The FWD Port PLB Floodlight remained OFF for the duration of the mission.
STS-49	OV-105	05/07/1992	05/16/1992	EPDC	PLB Floodlight	Forward Starboard	Failed to illuminate
STS-49	OV-105	05/07/1992	05/16/1992	EPDC	PLB Floodlight	Forward Bulkhead	Failed to illuminate
STS-49	OV-105	05/07/1992	05/16/1992	EPDC	PLB Floodlight	Aft Starboard	Failed to illuminate
STS-50	OV-102	06/25/1992	07/09/1992	EPDC	PLB Floodlight	FWD STBD Floodlight	After PLB Door closing, the crew reported that the FWD STBD Floodlight flickered, but did not come ON. There was no impact to the mission. The light was required. Testing of the FWD STBD Floodlight is required during turnaround ground ops.
STS-51	OV-103	09/12/1993	09/22/1993	EPDC	PLB Floodlight	Mid Starboard Payload Bay Floodlight	The crew reported that the MID Starboard Payload Bay Floodlight was flickering and did not come up to full bright. Therefore, they turned it OFF. On the Mid MNC amps, small spikes were seen which would relate to arcing or flickering. There was no impact to the mission. The Mid Starboard Payload Bay Floodlight was not used for the remaining duration of the flight.

4.4.3-3

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-52	OV-102	10/22/1992	11/01/1992	EPDC	Interior Lights	Middeck Floodlight #6 and #8 Failure	Prelaunch, Middeck Floodlight #6 and #8 were reported to be flickering and then failed OFF. Other lights from the same power source confirmed to be functional. There was no impact to the mission. There were other available Middeck lights for the crew's use.
STS-54	OV-105	01/13/1993	01/19/1993	EPDC	PLB Floodlight	P/L Bay Floodlight Problem	During P/L Bay Floodlight power up, the crew reported that the FWD STBD and both MID Floodlights were not working. The MID STBD light current was flickering for approximately 13 minutes, then the current increased approximately 6 amps for 12 seconds followed by an approximate 13 amp decrease. This signature indicated the MID STBD RPC tripped. Also the crew reported that approximately one hour later, the MID PORT light came ON. There was no impact to the mission. The crew used the remaining PLB Floodlights as required. The MID STBD Floodlight was not used for the remaining duration of the flight, due to the RPC trip.
STS-57	OV-105	06/21/1993	07/01/1993	EPDC	PLB Floodlight	Payload Bay Floodlight Failures	During Payload Bay Floodlight operations (EURECA Retrieval), Mid MNC amps reflected current indicative of a 10 RPC tripping (increase of 15 amps for 2.5 seconds). At the point, it was uncertain which MID MNC Floodlight (AFT PORT or MID STBD) had failed. During the EVA, an RPC trip signature was again observed on MID MNC, and the MID STBD Floodlight was the only light powered by MID MNC. EVA crewman verified MID STBD light OFF. At GMT 182/09:07, during Payload Bay Door Closing config, MID MNA currents showed another RPC trip when Floodlights were turned ON and the crew confirmed that the AFT STBD Floodlight did not illuminate. The crew also reported that the MID

4.4.3-4

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
							PORT Floodlight did not illuminate. There was no impact to the mission. The affected floodlights were not used for the remaining of the mission.
STS-58	OV-102	10/18/1993	11/01/1993	EPDC	PLB Floodlight	Payload Bay Floodlight Funny	When the Payload Bay Floodlights were turned ON for Payload Bay Door closing, spikes were seen on the MID MNA and MID MNC amps. Two lights were turned on MID MNA, one signature was nominal and the other had spikes. Two lights were turned on MID MNB with nominal signatures. One light was turned on MID MNC and had spikes in the signature. It appeared that the two lights with spikes in the signature did not come up to full bright. These types of spikes/signatures have been related to arcing and flickering. The crew was asked to verify that hte lights came up to full bright. The crew reported that all the lights were full bright. For MID MNA a possible failure of either the FWD PORT or AFT STBD Floodlight or Floodlight electronics assembly (FEA). For MID MNC a possible failure of either the FWD STBD or AFT PORT Floodlight or FEA. The MID STBD usage was restricted on this flight. Postlanding testing of hte PLB Floodlights was requested.
STS-59	OV-105	04/09/1994	04/20/1994	EPDC	PLB Floodlight	Forward Starboard	Showed signs of arcing during startup

4.4.3-5

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-59	OV-105	04/09/1994	04/20/1994	EPDC	PLB Floodlight	FWD PORT Payload Bay Floodlight Failed	During SIR-C/X-SAR stow, the crew turned on the FWD PORT, FWD STBD, and FWD BULKHEAD Payload Bay Floodlights. Current signatures for the FWD PORT Floodlight (MID MNA) did not confirm full brightness. The crew was asked the status of the FWD PORT LIGHT and reported that the light was not illuminated. There was no impact to the mission. The crew turned the Payload Bay Flood FWD PORT Light OFF and installed a yellow booty on the switch. This light was not used for the remainder of the flight.
STS-59	OV-105	04/09/1994	04/20/1994	EPDC	PLB Floodlight	AFT PORT Floodlight Fail	During the second deorbit prep attempt, the FWD BLKHD and AFT PORT Floodlights were turned ON for PLBD closing. Current signatures for the AFT PORT Floodlight (MID MNC) did not confirm full brightness, along with crew confirmation. There was no impact to the mission. Alternate lights were used.
STS-61	OV-105	12/02/1993	12/13/1993	EPDC	PLB Floodlight	AFT STBD Floodlight Fail	During Payload Bay Door closure, nominal signatures were seen for the FWD BULKHEAD and AFT PORT Floodlights, but not the AFT STBD (All FWD and MID Floodlights have constraints against usage). After the doors were closed the crew confirmed the AFT STBD light was not illuminated nad the switch was in the ON position. Data review also showed Floodlight may not have illuminated at GMT 344/11:38 when the other lights illuminated. There was no impact to the mission. AFT STBD Floodlight will remain OFF for the duration of the flight.

4.4.3-6

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-62	OV-102	03/04/1994	03/18/1994	EPDC	PLB Floodlight	MID-PORT Payload Bay Floodlight Failure	When the Payload Bay Floodlights were turned ON for the Educational TV Downlink, spikes (which indicate arcing and/or flickering) were seen on the MID MNB Amps. When questioning the crew on the status of the lights, they reported that MID-PORT PLB Floodlight was flickering. The only mission impact was loss of MID-PORT Payload Bay Floodlight. The Floodlight was turned OFF and a switch guard was installed over the switch for the duration of the mission.
STS-62	OV-102	03/04/1994	03/18/1994	EPDC	PLB Floodlight	MID-STARBOARD PLB Floodlight Failure	When the Payload Bay Starboard Floodlight was turned ON, abnormal currents were observed. Data indicates that the RPC current limited and then tripped. Crew reported that light did not illuminate when the switch was placed in the ON position. Mission impact was loss of MID-Starboard Payload Bay Floodlight. The Floodlight was turned OFF and a switch guard was installed over the switch.
STS-65	OV-102	07/08/1994	07/23/1994	EPDC	PLB Floodlight	AFT PORT Payload Floodlight Failed	AT GMT 203:06:55, The Payload Bay Floodlights were switched ON to support Payload Bay Door closing. Signatures on the MNC MPC3 indicated that the AFT PORT Floodlight was not operating properly. The crew was asked and confirmed the AFT PORT Floodlight was not illuminated. There was no mission impact. The AFT PORT Floodlight was switched to OFF. Troubleshoot of this failure was requested for Post-Mission.
STS-66	OV-104	11/03/1994	11/14/1994	EPDC	PLB Floodlight	Payload Bay Floodlight Failures	During CRISTA/SPAS Retrieval, the crew reported that multiple Payload Bay Floods had not illuminated. Telemetry showed that MID MNA and MID MNB had signatures that showed Floodlight arcing and possible Floodlight RPC's tripping. The Payload Bay Floods confirmed failed were FWD Bulkhead, FWD STBD, and AFT

4.4.3-7

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
							STBD. There was no impact to the mission. The remaining Floodlights (FWD PORT, AFT PORT) could be used as required. The Floodlights were requested to be checked out Post-Flight.
STS-68	OV-105	09/30/1994	10/01/1994	EPDC	PLB Floodlight	Forward PORT PLB Floodlight Failure	When the crew turned on the FWD PORT Payload Bay Floodlight, arcing was observed on the MID MNA bus current. The crew was unable to discern if the light was ON, OFF, or flickering. The FWD PORT Payload Bay Floodlight was considered failed for the remainder of the mission. The crew was instructed to turn the Floodlight OFF and place a yellow bootie over the FWD PORT Floodlight switch and not use that Floodlight.
STS-69	OV-105	09/07/1994	09/18/1994	EPDC	PLB Floodlight	Payload Bay Floodlight Failures	AT GMT 258:11:35, during payload bay floodlight operation, currents on the MID MNB bus showed evidence of arcing and an RPC trip. When asked by the ground, the crew reported that they hadn't noticed any failed floodlights. The mid port, forward starboard, and forward bulkhead lights are powered by MID MNB. At GMT 259:08:01 the crew powered on all the lights. There was no evidence of the mid port floodlight coming on. Thirty minutes later the crew turned on the forward starboard floodlight, currents showed a start up but no indication of the light coming up to full illumination. Finally, the forward bulkhead light was turned on and operated nominally. The crew reported that the forward starboard and forward port floodlights were dimly flickering and purple in color, but did not report the Mid Port light status. An hour after initial floodlight activation the crew reported that both

4.4.3-8

Verify that this is the correct version before use



Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
							forward floodlights were still not working, they were given a go to shut these off. The forward port, forward starboard, and mid port floodlight were unavailable for the remainder of the flight. The forward Port, FWD Starboard and MID Port PLB Floodlights were considered failed and the crew did not use them for the remainder of the flight. The crew used the other payload bay floodlights as required.
STS-69	OV-105	09/07/1994	09/18/1994	EPDC	PLB Floodlight	Mid Starboard	Failed to illuminate (possible arcing and RPC trip)
STS-69	OV-105	09/07/1994	09/18/1994	EPDC	PLB Floodlight	Aft Port	Failed to illuminate
STS-72	OV-105	01/11/1996	01/20/1996	EPDC	PLB Floodlight	Forward Port Payload Bay Floodlight Failed	During EVA 2, evidence of arcing was seen on MNA MPC1 when the Payload Bay Floodlights were powered. During the EVA, downlink video revealed the Forward Payload Bay Floodlight was failed, which the crew verified. No mission impact other than the loss of Forward Payload Bay Floodlight; all the other floodlights remained operational.
STS-72	OV-105	01/11/1996	01/20/1996	EPDC	PLB Floodlight	Forward Bulkhead	Failed, tripped RPC
STS-74	OV-104	11/12/1995	11/20/1995	EPDC	PLB Floodlight	Payload Bay Floodlight Failure	During Payload bay floodlight activation, a bus current signature was seen on MID MNC AMP (V76C3087A) indicative of a payload bay floodlight RPC current limiting and tripping. The flight crew reported that both AFT PORT and AFT STBD lights appeared to be out. The AFT PORT light is powered from MID MNC. The only impact to the mission was loss of both AFT PORT and AFT STBD lights. Both lights were switched OFF

4.4.3-9

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
							by the crew, and were not used for the remainder of the flight.
STS-75	OV-105	02/22/1996	03/09/1996	EPDC	PLB Floodlight	FWD PLB Floodlight Failures	When the crew switched ON the FWD PLB Floodlights, neither light came on (FWD PORT or FWD STBD). The current traces indicated a short in the FWD STBD light (RPC trip signature on MID MNB). It also indicated current spiking (arcing on MID MNA), and no normal startup current ramping for the FWD PORT light. The lights were switched OFF after three minutes. Per EGIL troubleshooting plan, FWD PORT Floodlight power was cycled a few times while the payload bay was in sunlight. There was no arcing, and the light powered up to full brightness. The light was turned off until shortly before TSS OPS, when it was repowered successfully. The FWD STBD PLB Floodlight was unavailable for the rest of the flight.
STS-77	OV-105	05/19/1996	05/29/1996	EPDC	PLB Floodlight	Mid Starboard Payload Bay Floodlight Fail	When the Payload Bay Floodlights were turned ON for Payload Bay Door closure, there was evidence of arcing on MID MNC. The crew reported no visible signs of any lights flickering. However, the crew reported that they observed no change in the illumination when shutting off the MID STBD Payload Bay Floodlight. It is believed that the MID STBD floodlight did not fully illuminate when it was turned on. There was no impact to the mission. The MID STBD Payload Bay Floodlight was not used for the remainder of the flight. The crew used the other Payload Bay Floodlights as required.

4.4.3-10

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-81	OV-104	01/12/1997	01/22/1997	EPDC	PLB Floodlight	Forward Port	Observed arcing and failed to illuminate
STS-82	OV-103	02/11/1997	02/21/1997	EPDC	PLB Floodlight	Aft Starboard Payload Bay Floodlight Failed	At GMT 049/03:37 EGIL observed a signature on MNA MPC1 current (V76C3085A) consistent with a Payload Bay Floodlight shorting and tripping off its 10 amp RPC. Subsequent inspection by the crew revealed that the AFT Starboard Payload Bay Floodlight was burned out. The switch was then taken to the OFF position. The Aft Starboard Payload Bay Floodlight was lost for the remainder of the mission. The Aft Port Payload Bay Floodlight remained operational for Aft Bulkhead Latch verification.
STS-84	OV-104	05/15/1997	05/24/1997	EPDC	PLB Floodlight	Mid Port	Observed arcing during PLBD closure
STS-86	OV-104	09/25/1997	10/06/1997	EPDC	PLB Floodlight	Forward Starboard Payload Bay Floodlight Failed	At GMT 271/20:27:55 the crew turned on the starboard forward payload bay floodlight. There was an increase of approximately 1.5 amps on MID MNB, but no indication fo the light coming up to full illumination (current should continue to ramp up as light reaches full illumination). When asked, the crew reported that the light was not illuminated. The crew cycled the switch off then back on at GMT 271/20:36, there was a current drop off of aproximately 1.5 amps followed by a subsequent increase of approximately 1.5 amps. The light still did not illuminate. The crew turned the switch OFF at GMT 271/20:54 and there was a corresponding drop in current of approximately 1.5 amps. There was no impact to the mission, the other PLB floodlights were used as required. The crew was instructed to place a yellow bootie over the forward starboard floodlight switch on panel A7U and instructed to leave the light off for the remainder of the flight.

4.4.3-11

Verify that this is the correct version before use

Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-88	OV-105	12/04/1998	12/15/1998	EPDC	PLB Floodlight	FWD PORT PLB Floodlight Failure	At MET 9/13:07, ground data (MID MNA amps) indicated a nominal start for the FWD PORT PLB floodlight. At MET 9/13:30, the crew reported that the floodlight was flashing (recorded on downlink video). This flashing (or arcing) was also reflected in the MID MNA currents. At PLBD closing, a light test was performed and the FWD PORT light came on with a nominal signature. No further arcing was seen. The crew was initially instructed to turn OFF the failed floodlight and FWD PORT considered unusable, however after the PLBD closing light test, the light worked fine and was then considered to be usable again.
STS-88	OV-105	12/04/1998	12/15/1998	EPDC	PLB Floodlight	AFT PORT PLB Floodlight Failure	At approximately MET 08/20:20 data on the MID MNC bus showed a possible floodlight failure. There was a drop in bus current followed by what appeared to be arcing. At MET 9/10:07 the crew turned ON the AFT PORT & MID STBD PLB floodlights, and at MET 9/10:18 they confirmed that the AFT PORT PLB Floodlight was failed. The crew was instructed to turn OFF the failed floodlight. The remaining PLB floodlights were used for subsequent PLB operations. The AFT PORT PLB floodlight was considered unusable.
STS-88	OV-105	12/04/1998	12/15/1998	EPDC	PLB Floodlight	AFT STBD, FWD STBD, & MID PORT PLB Floodlights failed	At approximately 3/13:51 MET, during the EVA activity, the crew reported that the AFT STBD and FWD STBD Payload Bay Floodlights were not illuminated. The crew confirmed that the switches on panel A7U were in the ON position. The crew was instructed to turn those two lights OFF. At MET 003/17:22, the CDR reported the MID PORT Payload Bay floodlight was not illuminated. MCC instructed the crew to turn that light OFF as well. Ground telemetry for MID MNA and MID MNB amps showed no obvious

4.4.3-12

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
							signs of arcing of RPC trips. The AFT STBD, FWD STBD, and MID PORT PLB floodlights were considered unusable. The failed floodlights were turned OFF and the remaining floodlights were used for subsequent PLB operations.
STS-89	OV-105	01/22/1998	01/31/1998	EPDC	PLB Floodlight	Payload Bay Floodlight RPCs Trip	When the Forward Bulkhead, the Mid Port, and the Forward Starboard Payload Bay floodlights were turned ON in preparation for Payload Bay door close, the currents on MNB MPC2 indicated that two RPCs tripped and only one of there three floodlights illuminated. The crew confirmed that the Forward Starboard and the Mid Port Floodlight did not illuminate. The Forward Startboard and Mid Port Payload Bay floodlight switches were taken to OFF and were not used for the remainder of the flight. The Forward Starboard and Mid Port Payload bay floodlights were considered failed. If required, the crew could use the remaining operational Payload Bay floodlights.
STS-103	OV-103	12/19/1999	12/27/1999	EPDC	Middeck Floodlight	Middeck Floodlight No. 4	Prelaunch the floodlight flickered, used no.1 for ascent

4.4.3-13

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Mission	Vehicle	Launch	Landing	Sub-System	Equipment	Title	Description
STS-100	OV-105	04/19/2001	05/01/2001	EPDC	PLB Floodlight & FEA #1	PLB Floodlight MID PORT Failed	When the crew turned on the PLB Floodlights for MPLM Berthing OPS at GMT 117:14:31, a 13.5 amp spike was seen on MNB MPC2 (V76C3086A) for 2.5 seconds, which tripped its associated RPC. The crew confirmed that the MID PORT PLB Floodlight was not illuminated. MCC instructed the crew to take the MID PORT floodlight switch to OFF and mark it with a yellow booty. The MID PORT PLB Floodlight switch was taken OFF and a yellow Booty was placed on the switch to remind the crew not to take the switch to ON for subsequent PLB floodlight operations. The MID PORT PLB Floodlight was considered unusable for the remainder of the flight.
STS-110	OV-104	04/08/2002	04/19/2002	EPDC	PLB Floodlight	Payload Bay Flood Light	At GMT 2002/109:12:20:57 prior to payload bay door closing when the payload bay floodlights were taken ON, a 14 amp spike was seen on MN MPC1 that lasted for ~2.5 seconds. This signature could have been indicative of payload bay floodlight FWD PORT 1 or AFT STBD 6 RPC trip. There was no impact to the mission. The Payload bay floodlights were not required for the remainder of the flight.

4.4.3-14

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## TITLE

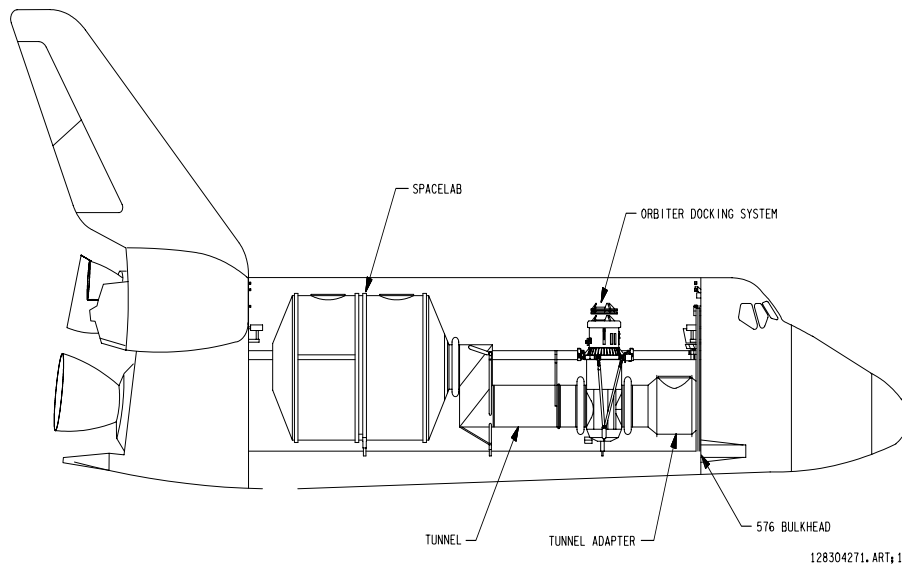
ORBITER DOCKING SYSTEM

## PURPOSE

This SB gives a brief overview of the orbiter docking system (ODS), its operation, ODS power, and the ODS lights.

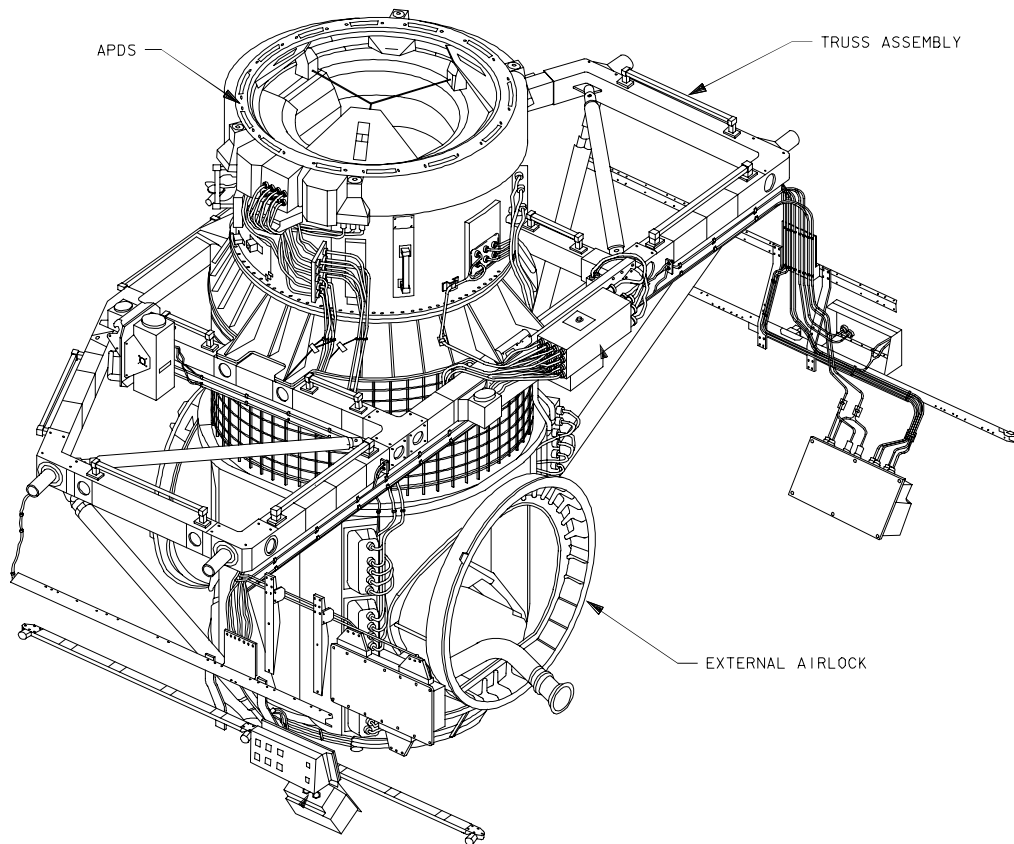
## OVERVIEW

The ODS is installed aft of the 576 bulkhead in bay 2 of the payload bay (figure 4.5-1). It can be installed on all vehicles. The ODS was installed for STS-71, the first mission to dock with the Russian Space Station Mir. It will also be used for docking with the future International Space Station (ISS). Below is the basic view of the ODS in the shuttle payload bay (exact configuration is mission dependent).



**Figure 4.5-1. View of ODS in shuttle payload bay**

There are three major ODS components: (1) external airlock, (2) androgynous peripheral docking system (APDS), and (3) truss assembly (figure 4.5-2). The APDS effects a mechanical connection between the orbiter and Mir/ISS. The external airlock provides an airtight tunnel between the two orbiting spacecraft, post docking. The truss assembly provides a sound structural base on which the external airlock, APDS, and rendezvous/docking aids cameras, lights, and trajectory control system reside. The truss assembly is attached to the payload bay.



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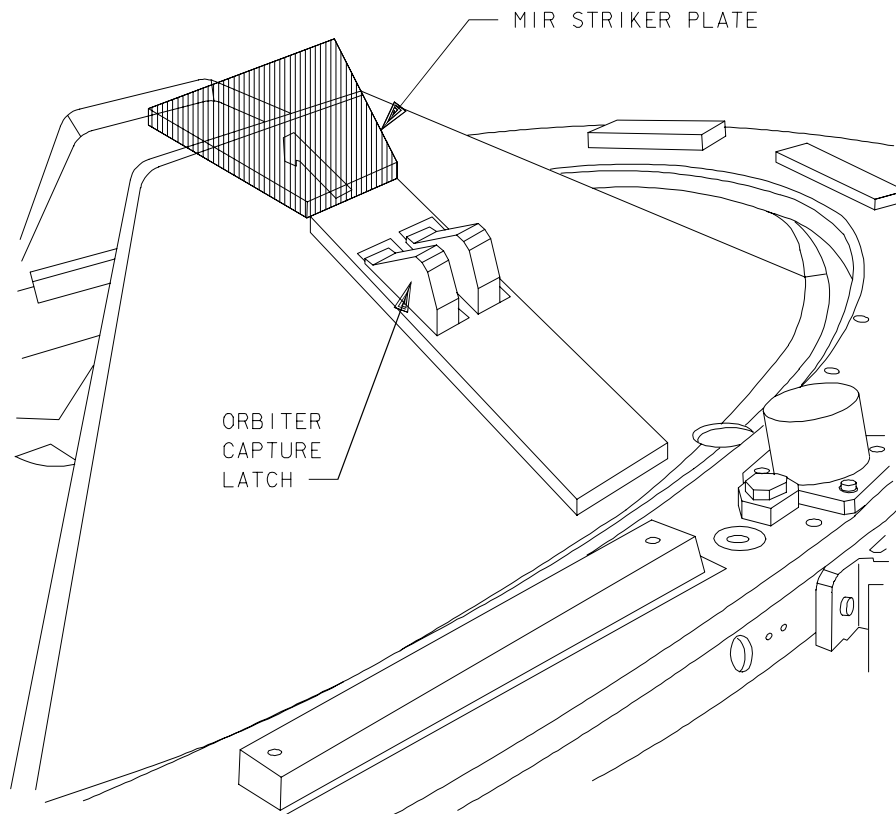
**Figure 4.5-2. ODS assembly**

APDS is the component which enables the mechanical docking between the orbiter and Mir/ISS. Once docking is complete, an airtight tunnel is created. The APDS on both vehicles are basically identical. APDS has two rings: the active docking ring, and the structural ring. Also located on the APDS are numerous sensors which provide insight into the system.

The active docking ring, or inner ring, is the movable portion of the APDS. The active docking ring has three operational positions: (1) final-ring is fully retracted inside the structural ring, (2) initial-ring is extended upward 13 inches, and (3) forward-ring is fully extended about 18 inches. The active docking ring has six major components: guides, capture latches, ball screw/nut, dampers, fixers, and the ring drive system.

The guidelines are used to direct the mating between systems (figure 4.5-3). There are three identical guides found on both the orbiter and Mir/ISS active docking ring. The guides are juxtaposed such that the orbiter guides fit into the spaces of the station, and vice versa.



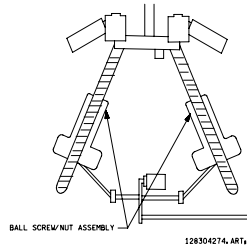


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**Figure 4.5-3. Glides and capture latches**

The capture latches provide initial, but temporary connection. There are three latches, one in the center of each guide, and each latch is made up of 2 latches driven by one motor. As contact is made striker plates on the Mir/ISS slide over the guides, collapsing the capture latches. Once the striker plates pass beyond the capture latches, the latches return to their initial position trapping the striker plates and providing temporary connection. The capture latches have two positions: open, and closed. Changing the position of an internal cam lever moves the force vector required to collapse the latch. Once the two vehicles are mated and the hooks are in place, the capture latches are opened and the striker plates released.

There are three ballscrew/nut assemblies on the active docking ring (figure 4.5-4). Each assembly contains two ballscrews and two ballnuts which position the active docking ring through movements of the ballscrews into and out of the ballnuts. When used in conjunction with the right drive system it gives six degrees of freedom during docking.



**Figure 4.5-4. Ball screw/nut assembly**

There are three active dampers at the base of the ring and three passive dampers under each guide. The dampers absorb some of the energy induced upon initial contact and act to slow the relative motion of the two vehicles.

There are five fixers on the active docking ring, one for each ball screw/nut assembly, and two on the mechanical system linkage. The fixers provide the mechanical connection between the two ball screws in a pair so they move as one unit. The fixers on the ring move in a pure axial motion.

The ring drive system is made of redundant dc motors, power drive unit (PDU), and a gear drive train. The PDU output drives the gear train through several layers of gear reduction. The end result is the three pair of ball screw/nut assemblies drive at the same rate and the docking ring extends or retracts as commanded by the automatic docking sequence or manually by the crew.

The structural ring of the APDS is the outer, fixed ring. The orbiter and Mir/ISS structural rings work together to provide an airtight seal and create a vestibule between the two vehicles. The components of the structural ring are: (1) undocking springs, (2) pressure seals, (3) alignment pins, and (4) active/passive hooks.

There are two undocking springs on each structural ring, one adjacent to each alignment pin. These springs provide the force necessary to initiate separation of the two vehicles during undocking. The pressure seals consist of two concentric seals on the innermost edge of the orbiter structural ring. When compressed they provide the airtight seal between the two vehicles. There are two alignment pins on each structural ring, which provide precise alignment of the rings. There are twelve pairs of active/passive hooks on the structural ring. The active hooks move during the docking sequence to engage Mir/ISSs passive hooks, and vice versa. These hooks create the structural rigidity and provides the airtight interface by compressing the concentric seals on the ring.

## ODS OPERATIONS

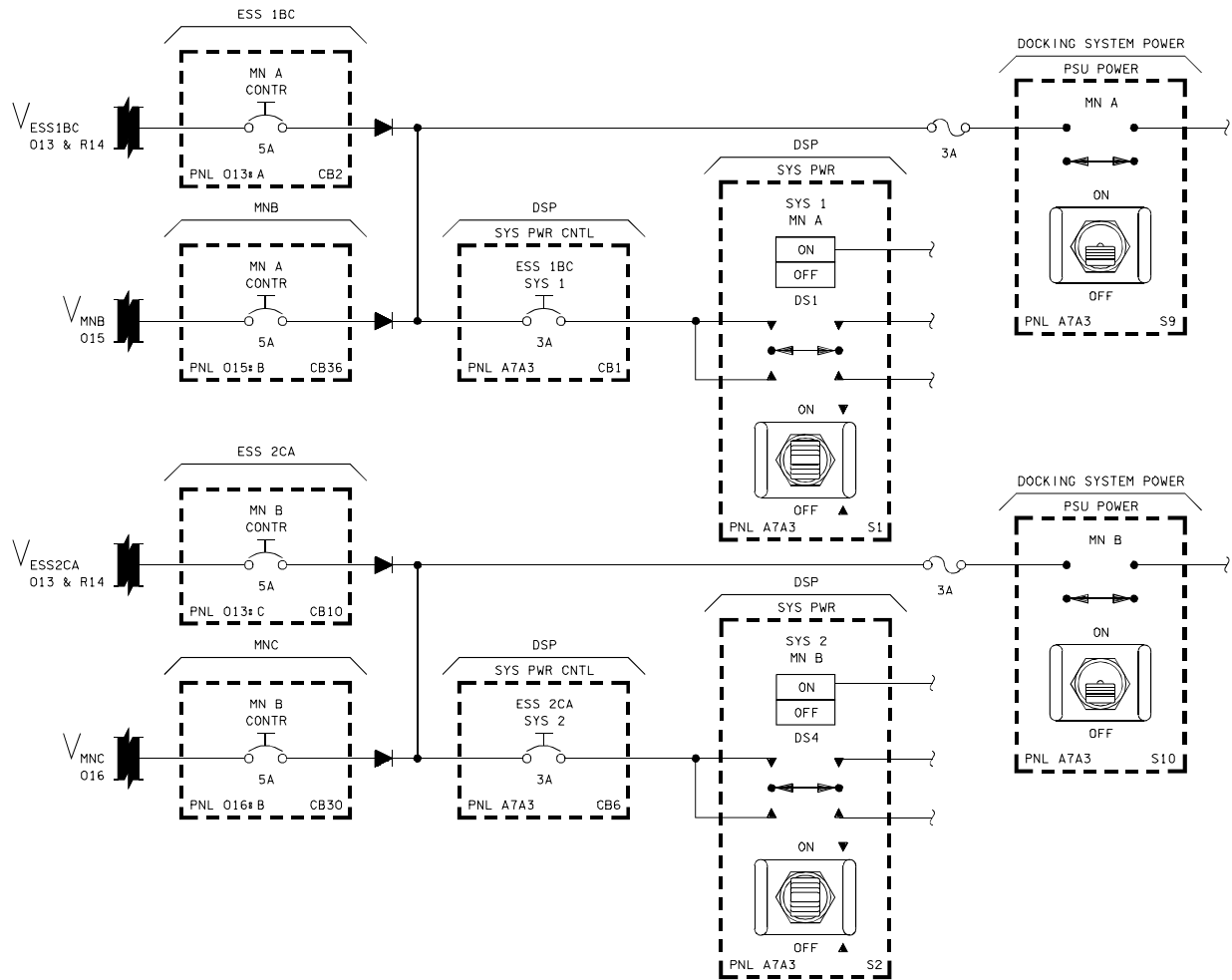
A checkout of the ODS is performed on FD2 after the installation of the centerline camera. The checkout includes powering up ODS, extending the ring, and powering down ODS. On the day of docking the ODS is powered up 35 minutes prior to contact in the rendezvous timeline. The ODS is constrained to be powered for a maximum of 2 hours. This 2 hour constraint is to avoid excessive heat buildup because the avionics boxes are covered with a foam with bad heat dissipation. The foam was installed over the avionics boxes to protect from shorts. Once the avionics have been powered the boxes must be powered down for a minimum of 30 minutes to allow for adequate heat dissipation. The DCU boxes do not have a power time constraint (reference Flight Rules Annex, APDS Power on Time Constraint).

After an unsuccessful capture, the docking ring will be extended and realigned, fully retracted, and then reextended to the initial position prior to attempting another docking. The avionics will also be reinitialized by means of a power cycle. This power cycle ensures that its logic is in the proper state for another docking attempt (reference Flight Rules Annex, APDS Reconfiguration After Failed Docking). For the loss of two or more APDS logic buses, prior to docking, the docking will be aborted, because loss of two APDS logic buses results in inability to perform any APDS motor functions necessary for docking. If two or more APDS logic buses are lost after docking continue nominal mission (reference Flight Rules Annex, APDS Rules Reference Matrix).

An airlock tunnel fan (aka booster fan) is flown to provide air circulation from shuttle to Mir/station. The orbiter shall provide conditioned air to support Mir/station environmental control systems by installing an air duct assembly across the shuttle ODS and DM hatches. Prior to docking the air duct assembly is installed. At this time the booster fan is temporarily turned off, the assembly installed, and the fan is turned back on. During undocking the assembly is removed, again the fan is turned off, assembly removed, and the fan is turned back on. These procedures are found in the Flight Supplement, Orbit OPS Checklist, Airlock Ingress, Airlock Egress. The EGIL operator should watch for a 3 phase ~0.8 amp/phase dropoff on AC1 (fan 1), or AC2 (fan 2). The EGIL operator should also give a heads up to the EECOM operator that the airlock tunnel fan steps are being performed.

#### **ODS POWER**

Power is provided to the ODS from MNA MPC1, MNB MPC2, and MNC MPC3 (figure 4.5-5). The control power to the APDS switches is provided from MNA CONTROL POWER, and MNB CONTROL POWER (the same two circuit breakers that power the FC/MN, BUS TIE switches). For more information about the ODS Power see SSSH Drawing 2.6 Orbiter Docking System.



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**Figure 4.5-5. ODS control power**

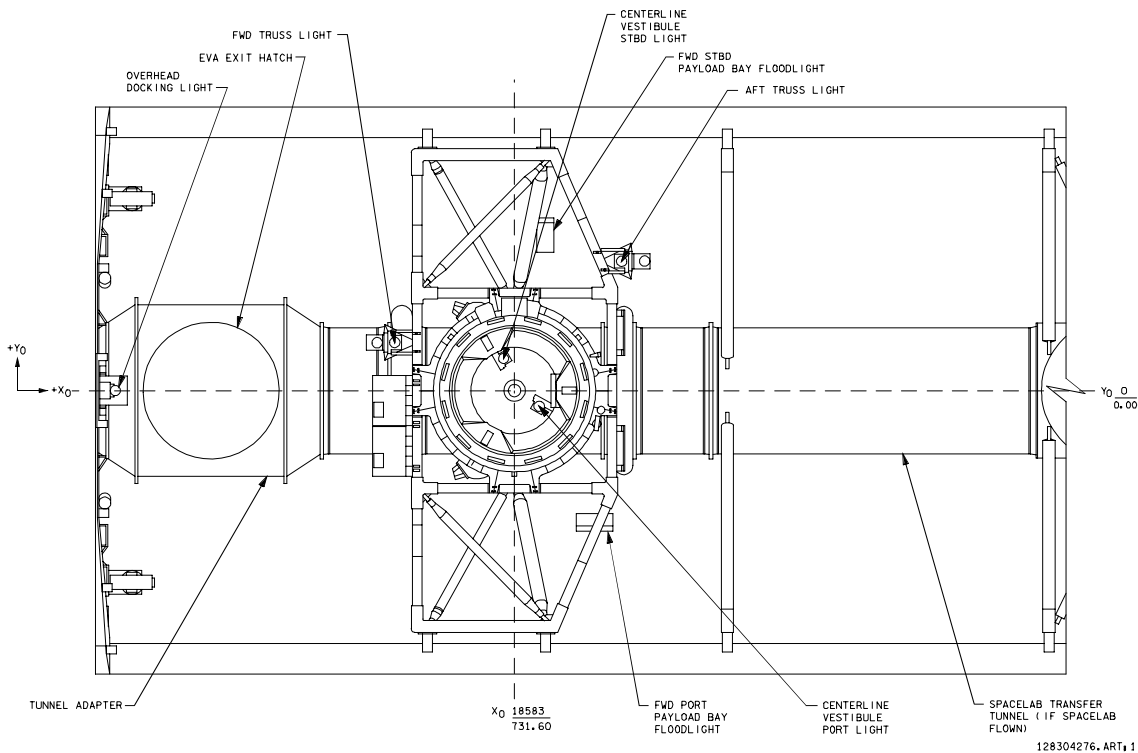
There are six circuit breaker switches on the APDS CONTROL PANEL (see table 4.5-1). The APDS POWER circuit breaker switches are the 5-amp circuit breakers with a trip current of 8.5 amps and trip time of 5 minutes; at 600% overload trip time is 0.1 seconds. The CONTROL PANEL POWER circuit breaker switches are 3-amp circuit breakers with a 5.1 amp trip, trip time of 5 minutes, and at 600% an overload trip time of 0.1 seconds. Reference the below table for more information.

**Table 4.5-1. ODS circuit breaker switches tripping information**

Type of circuit breaker	Nominal current	Tripping current	Tripping time at rated overload	Tripping time at 600% overload
As2-1	1.0A	2.5A	10 min	0.1 sec
As2-2	2.0A	4.2A	10 min	0.1 sec
As2-3	3.0A	5.1A	5 min	0.1 sec
As2-5	5.0A	6.5A	5 min	0.1 sec

**ODS LIGHTING**

The ODS has four external light assemblies (figure 4.5-6 and table 4.5-2). Each light is a 135-watt spotlight, and is of the same design as the RMS spotlight assemblies. There is one light located on the forward truss, one on the aft truss, one on the port centerline vestibule, and one on the starboard centerline vestibule.



**Figure 4.5-6. ODS lighting location**

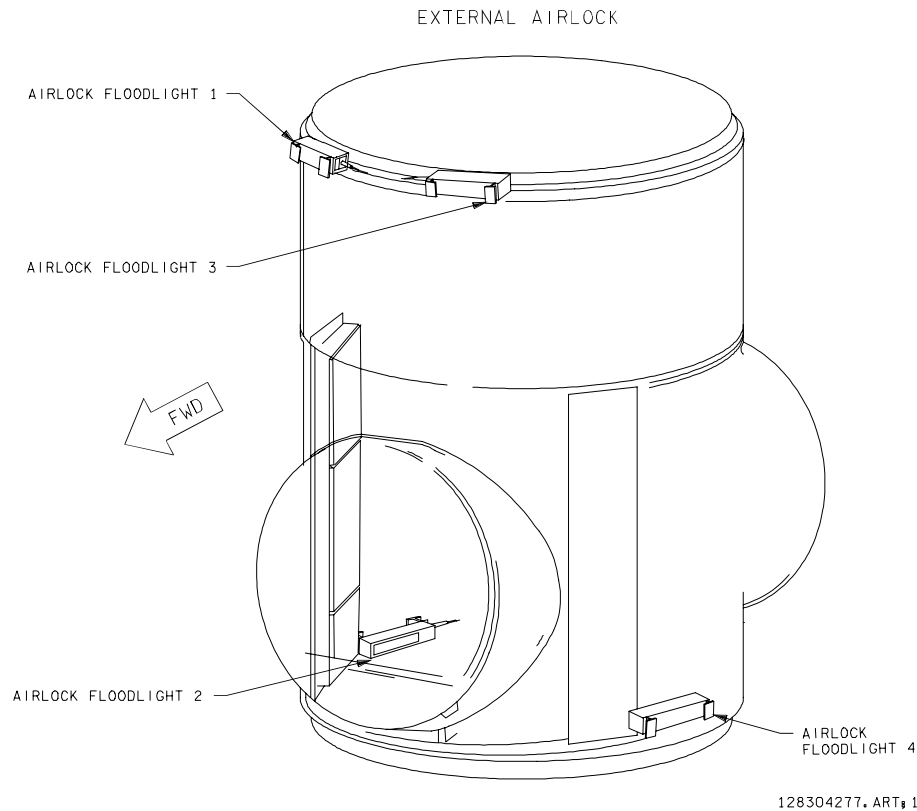
**Table 4.5-2. ODS lighting location**

ODS lights	X <sub>0</sub>		Y <sub>0</sub>		Z <sub>0</sub>	
	IN	MM	IN	MM	IN	MM
C/L Stbd	728.34	18500	11.4	290	441.71	11219
C/L Port	740.94	18820	-7.3	-185	441.71	11219
Truss fwd	687.96	17474	17.82	453	419.21	10648
Truss aft	770.47	19570	47.43	1205	419.21	10648

The forward truss light receives power from MNA A7 through a 10-amp circuit breaker, and is controlled via an ON/OFF switch. The aft truss light receives power from MNB A7 through a 10-amp circuit breaker, and is controlled via an ON/OFF switch. The centerline vestibule port light receives power from MNA MPC1 through a power contractor, a 10-amp fuse, a 10-amp circuit breaker, and is controlled via an ON/OFF switch. To operate the centerline vestibule port light the DSP SYS 1 power must be on so that MNA MPC1 power can proceed through the fuse and circuit breaker. The centerline vestibule starboard light receives power from MNB MPC2 through a power contractor, a 10-amp fuse, a 10-amp circuit breaker, and is controlled via an

ON/OFF switch. To operate the centerline vestibule starboard light the DSP SYS 2 power must be on so that MNB MPC2 power can proceed through the fuse and circuit breaker (reference SSSH drawing 4.5 ODS AL LGHTS).

There are four internal ODS lights located in the external airlock (figure 4.5-7). Two are located in the upper forward portion of the airlock and two are located on the lower starboard and port portion of the airlock. The airlock lights on 16.5-watt fluorescent flood lights. The upper right (airlock flood 1) and lower left (airlock flood 4) are powered by MNA A7, each going through their own 3-amp fuse, and controller by the same switch light airlock 1/4 MNA. The lower right (airlock flood 2) and upper left (airlock flood 3) are powered by MNB A7, each through their own 3-amp fuse, and controlled by the same switch lights airlock 2/3 MNB.



**Figure 4.5-7. External airlock flood lights**

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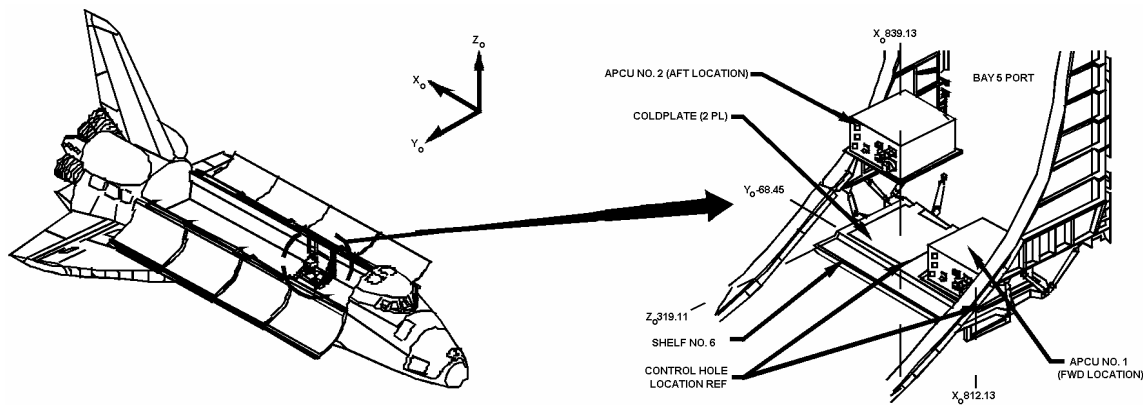
APCU

**PURPOSE**

Provide a general overview of the APCU.

**GENERAL**

The Assembly Power Converter Unit (APCU) is a DC-DC converter intended for the support of ISS assembly, initialization, and resupply missions by the shuttle. The APCU can also be used to power ISS-compatible payloads. It is an orbiter Line Replaceable Unit (LRU) mounted in the Payload Bay (PLB) below the liner (see Figure 4.6-1). It functions by taking orbiter 28-V input and converting it to either 140 or 124 V DC output. Nominally, the APCUs are flown in pairs and have a variety of output configurations that are hardwired for each specific flight.



**Figure 4.6-1. APCU locations**

**A. Control/power**

The APCU is controlled by the crew via a flight-specific Standard Switch Panel (SSP). No commands (GPC or ground-initiated) are available. APCU power comes directly from the primary payload PRI PL bus. Control power for the SSP switches can vary from mission to mission. The switches can be powered either by the CAB PL bus or by one of the PL AUX buses.

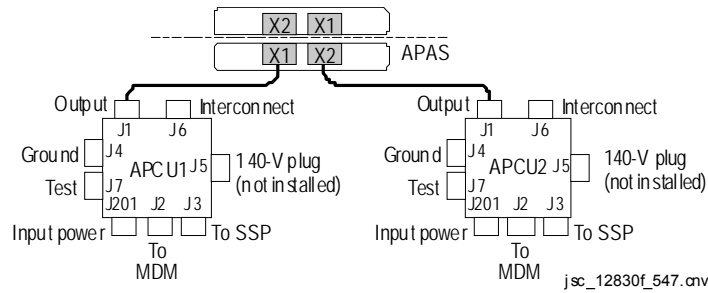
**B. APCU operations**

The APCU output voltage level is selected preflight. The voltage can be changed between 140 and 124 V DC by installing or removing a shorting plug. When the shorting plug is not installed, the APCU converter operates at 124 V DC. When the shorting plug is installed, the APCU converter operates at 140 V DC. The APCU output voltage cannot be changed in flight. Current plans require that both

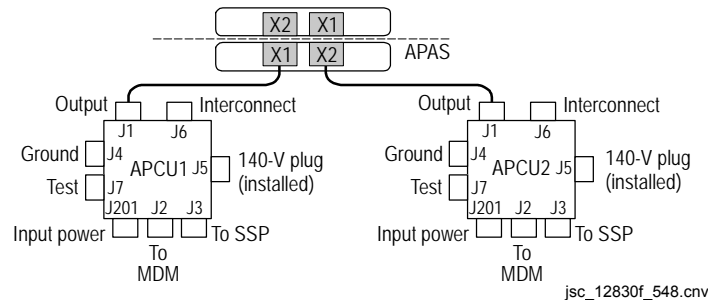
APCUs be configured for the same output voltage for each mission. The voltage will be set to 124 or 140 V DC, depending on flight requirements.

The output configuration is also configured preflight and cannot be changed on orbit. Each APCU can be configured to operate (1) independently with separate output feeds, (2) independently with dioded output feeds, (3) connected in parallel with a single output feed, or (4) connected in parallel with dual output feeds. See Figure 4.6-2 for examples of each configuration.

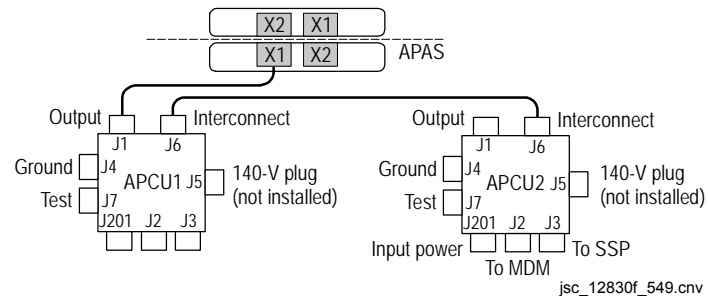
**Configuration A** - Isolated APCUs, both connected to the Orbiter Docking System (ODS), 124 V DC output



**Configuration B** - Isolated APCUs, both connected to the ODS, 140 V DC output



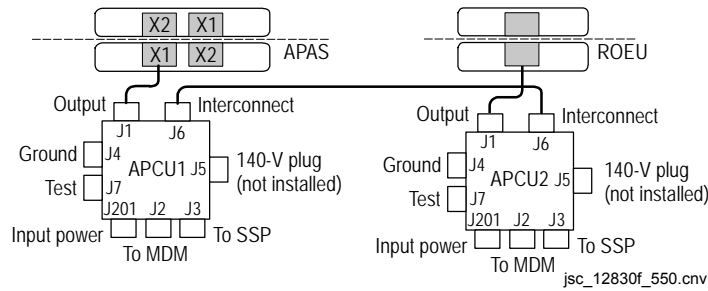
**Configuration C** - Paralleled APCUs, one output connected to the ODS, one output connected to the Remotely Operated Electrical Umbilical (ROEU), 124 V DC output



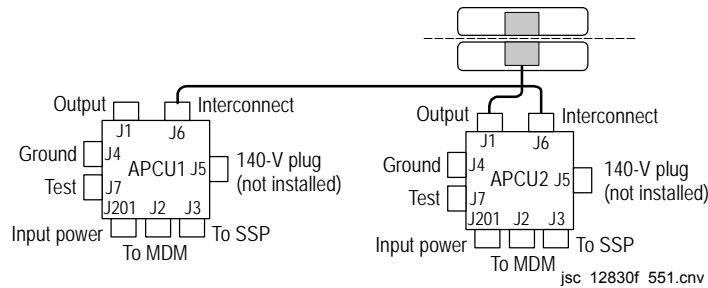
**Figure 4.6-2. APCU configurations**



Configuration D - Paralleled APCUs, one output connected to the ODS, one output connected to the ROEU, 124 V DC output



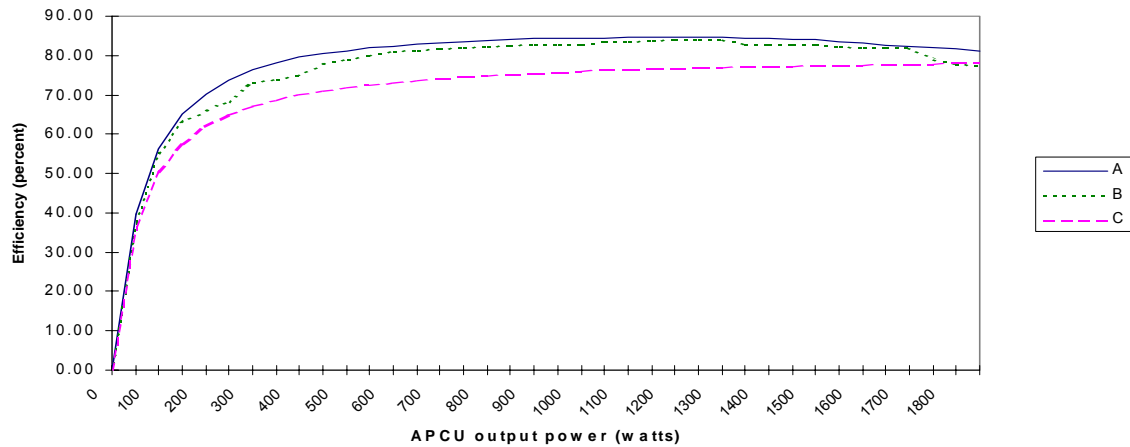
Configuration E - Paralleled APCUs, one output connected to the ROEU, 124 V DC output



**Figure 4.6-2. Concluded**

Each APCU is rated to have an output power of 2000 W at 140 V, or 1800 W at 124 V. The output power is based on keeping the total output amps below 14.7 amps for each APCU. The 14.7 amps equate to 2058 W and 1823 W for 140 V and 124 V, respectively, but to be conservative and to include measurement error, this was rounded down. The APCU can operate slightly above the rated output; however, for mission planning and design, the output power should be kept below the rated values of 2000 W and 1800 W.

In Figure 4.6-3 curve A represents efficiency derived from test data. Curve B is based on test data plus a small “worst case” pad. Curve C represents theoretical worst case. All APCUs have performed much better than the worst-case curves (B and C), and the A curve is used for all EGIL analysis work.



**Figure 4.6-3. APCU efficiency**

The internal electronics of the APCU are not isolated from the PRI PL bus; therefore, the APCU draws some power whenever PRI PL is powered, regardless of whether the converters are ON or OFF. When no loads are connected to the APCU, it draws about 10 W. When the converters are ON with no loads connected, the APCU draws about 100 W.

Each APCU is controlled by a pair of switches on an orbiter SSP. Exact switch nomenclature can vary from mission to mission based on the mission kit used for installation. The converters are powered by PRI PL bus, but the SSP switch control power can also vary from mission to mission. The switches may be powered either by the CAB PL bus or by one of the PL AUX buses. The APCU power switch controls the converter operation. The APCU output switch controls the operation of the output relay. The output relay isolates the APCU circuitry from the load it powers. APCU power will always be OFF before opening or closing the output relay. The output relay was never tested or certified to open under load. Originally, it was thought that this would cause arcing that would fail the relay. It was later learned that the arcing would merely shorten the expected lifetime of the relay. Therefore, it is okay to open the relay under load, but nominal operation procedures are written to preclude doing so. Note that when the APCUs are connected in parallel, no switch isolates them from one another.

Operationally, the APCU either works properly or shuts itself off for any off-nominal conditions. APCU mal procedures primarily focus on shutting down an APCU that has a malfunction that should have caused the APCU to trip. The procedures also help the crew identify transducer failures and continue APCU operations.

C. Circuit operation

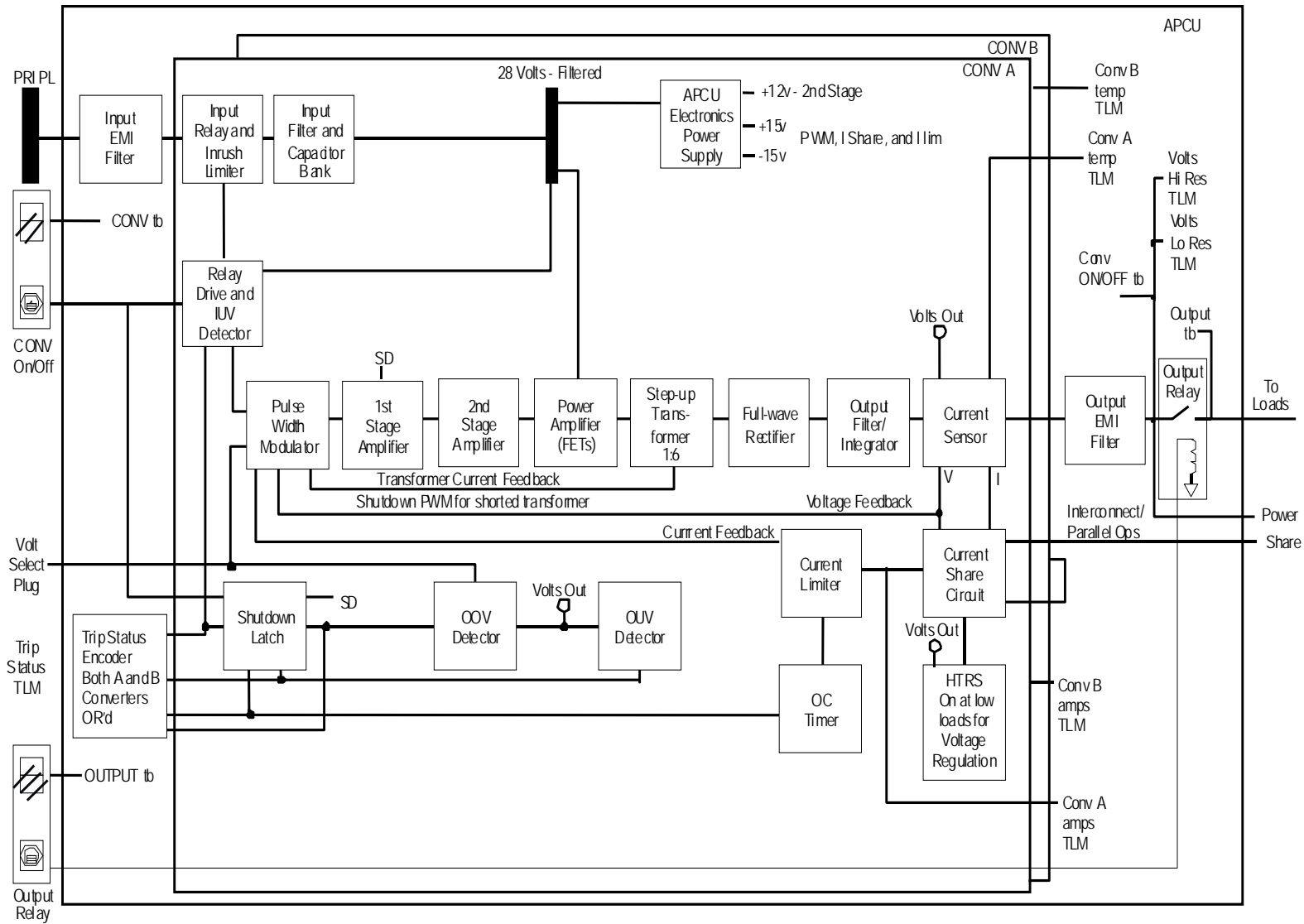
The APCU basic circuit is a switching-type DC-DC converter. A pulse-width modulated signal is amplified and fed into a step-up transformer. The transformer output is rectified and integrated. Output voltage feedback is used to control the width of the input stage. If the voltage is below the desired value (124 or 140 V), the pulse width widens, which results in higher volts when rectified and integrated. Conversely, when the output voltage is higher than desired, a narrower pulse width lowers the output voltage. Output loads also affect the pulse width. To maintain output voltage, the pulse width increases as loads increase, and vice versa.

Each APCU contains two DC-DC converters in parallel, converter A and converter B (see Figure 4.6-4). Each converter has its own separate feedback, failure detection, and shutdown trip circuitry. A failure and subsequent trip-off of one converter does not necessarily mean that both converters have tripped.

Current feedback is also employed. A current-share circuit equally distributes the load between the A and B converters within a single APCU. If two APCUs are connected in parallel (configurations C, D, and E, Figure 4.6-2), all four converters will current share. In current sharing, the converter that has the highest output volts will take control, and the other converters will increase their output volts until the load is shared equally (usually within 1 amp of each other).

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Figure 4.6-4. Circuit block diagram

D. Circuit details

1. **Input Electromagnetic Interference (EMI) filter** - Prevents high frequency signals or noise on the orbiter PRI PL bus from interfering with internal APCU electronics. Also prevents any signals or noise generated by the APCU from affecting the orbiter buses.
2. **Input relay and inrush limiter** - Separates the EMI filter from the input capacitor bank. It consists of a relay in parallel with a resistive load. When power is initially applied to the PRI PL bus, there is no energy stored in the input capacitor bank, and the bank will begin to rapidly charge. To prevent this inrush current from being excessive, the resistive load limits the current level. After the initial inrush is complete, the relay may be closed, and input current is no longer limited by the resistive load.
3. **Input filter and capacitor bank** - Provides energy storage for the APCU. A large capacitor bank stores charge, so it is available to supply transient loads through the APCU without putting large transients back on the PRI PL bus. It also lessens the effect that any voltage fluctuations on the PRI PL bus have on the APCU.
4. **Input relay drive and input undervolt detector** - Controls the input relay and monitors the PRI PL bus for undervoltage condition. When the CONV ON/OFF switch is taken to ON, the relay is driven closed after a 1-second delay (this allows for any inrush current to be limited and damp out). Once the drive detects good (>24.5) input volts, the Pulse Width Modulator (PWM) is powered on. The Input Undervolt (IUV) detector issues a shutdown discrete if the input volts drop below 24.5 V.
5. **28 V filtered bus** - Provides 28 V to the power stage and the APCU electronics power supply.
6. **APCU electronics power** - Converts 28 V to +12 V for the second-stage amplifier and  $\pm 15$  V for the PWM, I-share, and I-lim circuits.
7. **PWM** - Is a square wave generator. Width of pulse varies based on voltage select setting, voltage feedback, and current feedback. To produce a larger output voltage, a wider pulse width is generated and vice versa.
8. **First-stage amplifier** - Couples the PWM output transformer to a pair of drivers to control the positive and negative pulse. The shutdown latch removes power from this stage if the trip detection circuits "trip."
9. **Second-stage amplifier** - Uses differential op amps to cascade the PWM signal to the power stage.

10. **Power amplifier** - Contains a Field Effect Transistor (FET) driver that provides  $\pm 28$  V to the step-up transformer. Circuitry also contains a snubber to reduce "ringing."
11. **Step-up transformer** - Operates as 1:8 step-up transformer and raises PWM signal to output voltage level. It also contains feedback that will shut down the PWM if a short circuit occurs in the transformer circuits. A short circuit results in an Output Undervolt (OUV) trip.
12. **Full wave rectifier** - Rectifies the negative pulses to create a stream of positive pulses.
13. **Output filter/integrator** - Puts the output signal through an integrator/filter. Final voltage is proportional to the pulse width. This filter also acts as an energy storage device so that, as power is used, the pulse width also increases to maintain a constant output voltage.
14. **Current sensor** - Uses a small precision resistor in the return path to measure the current. Current and voltage are passed on to the share circuits, the current limiter circuits, and the output overvolt and undervolt detector circuits. The temp sensor is also located here.
15. **Output EMI filter** - Combines A and B converter outputs and passes the outputs through a noise filter. Just past the filter is where the CONV ON/OFF talkback is powered and where the volts telemetry is picked off.
16. **Output relay** - Connects the APCU to the loads. The output relay was never certified to open or close under load. If this occurs, arcing within the relay box may occur, thus reducing the total lifetime of the relay. As a result, all procedures have instructions to turn off APCU power before opening or closing the output relay.
17. **Current share circuit** - Compares the output voltage of the A and B converters and attempts to increase the output volts of the lower converter, so that both converters A and B carry roughly the same current. If two APCUs are connected in parallel, all four converters attempt to current share.

E. Shutdown/protection

Each converter (A and B) has built-in protection circuitry that will shut down the converter to prevent circuit damage. A shutdown can occur for IUUV, Output Overvolts (OOVs), OUVs, and Overcurrent (OC). In addition, a short circuit in the primary transformer circuit shuts down the PWM, which results in an OUV shutdown.

The IUUV circuit causes a shutdown when input voltage is  $< 20$  V.

The 140- to 124-V shorting plug circuitry interfaces with the OOV trip circuit. OOV shuts down within 10 ms when the output voltage is  $>165 \pm 2$  ( $130.5 \pm 2.3$ ) for 140-V (124-V) operation.

The OUV circuit causes a shutdown when the output voltage is  $<115 \pm 2.5$  V regardless of 124-V or 140-V operation.

There are two types of OC protection. When output current exceeds 14.7 amps/converter (this is approximately 200 percent rated load), current limiting begins. The feedback from the output amps will cause output voltage to sag in an attempt to limit output current. If the output draws too much current, it will current limit, thus causing an OUV shutdown. There is also a hard current limiter that starts when current limiting begins an overcurrent condition that remains for 30 to 60 ms, causing an OC trip, and the converter shuts down. Thus, current limiting will allow transients that last less than the overcurrent timer and will attempt to reduce the magnitude of transients above 14.7 amps. In the case of a sustained overcurrent, the circuitry will shut down the converter with an OUV for overloads and an OC for short-circuited output. In addition, the primary side of the transformer has current sensors that will shut down the converter if a short occurs. The short results in an OUV trip.

The shutdown latch receives a discrete input from the trip detection circuits and removes power from the first amplifier stage when a trip occurs. The trip circuit "remembers" the trip condition(s) that caused the shutdown and latches the appropriate trip signal. The APCU must be power cycled OFF, then ON, to reset the trip.

#### F. Feedback/telemetry

The crew receives feedback via talkbacks (tb's) on the SSP. There are two tb's per APCU (converter on/off and output relay status.) Feedback that is more complete is also available on a flight-specific SPEC (2XX). The following telemetry is available on the SPEC: APCU volts high and low res, trip status volts, converter amps, and temp. The trip indication is generated by four discrete signals within each APCU. Since four bilevel TLM channels were not available, a single analog channel is utilized. Therefore, each APCU has a digital-to-analog converter that converts the four discrete inputs into a 16-level analog output (range = -5 to +5 V). The crew must use a chart to interpret the trip output. On the ground, tb position is not available, but all the SPEC data are available. For the trip status volts, a computation converts the 16-level signal back into the four discrete inputs. Note that each converter (A and B) within an APCU has its own protection circuitry, and the trip discrettes are OR'd together. Therefore, a single converter within the APCU can trip, and the remaining converter may continue to operate. It may not always be obvious which converter has failed.

SM FDA class 3 limits are based on test data with development units. When PRI PL is not powered, all feedback TLM goes to midrange values (all output -5 to +5 V DC goes to 0 V).

See Table 4.6-1 for trip voltage values and Table 4.6-2 for APCU telemetry.

**Table 4.6-1. Trip voltage values**

Output voltage	Trip type			
	Output overvoltage	Output undervoltage	Output overcurrent	Input undervoltage
+4.88	X	X	X	X
+4.23	X	X	X	
+3.59	X	X		X
+2.95	X	X		
+2.27	X		X	X
+1.62	X		X	
+0.98	X			X
+0.34	X			
-0.30		X	X	X
-0.95		X	X	
-1.59		X		X
-2.23		X		
-2.91			X	X
-3.56			X	
-4.20				X
-4.86 (no trip)				



**Table 4.6-2. APCU telemetry**

Parameter	MSID	Range	Unit	FDA limits		
				Low	High	Filter
APCU 1 conv A output current	P50C9003V	0 to12	Amp	OSL	8.5	5
APCU 1 conv B output current	P50C9004V	0 to12	Amp	OSL	8.5	5
APCU 2 conv A output current	P50C9009V	0 to12	Amp	OSL	8.5	5
APCU 2 conv B output current	P50C9011V	0 to12	Amp	OSL	8.5	5
APCU 1 conv A temperature	P50T9002V	0 to 212	°F	20	130° F	15
APCU 1 conv B temperature	P50T9005V	0 to 212	°F	20	130° F	15
APCU 2 conv A temperature	P50T9010V	0 to 212	°F	20	130° F	15
APCU 2 conv B temperature	P50T9012V	0 to 212	°F	20	130° F	15
APCU 1 output volts (high res)	P50V9000V	110 to 160	Volt	122	126.5	5
APCU 1 output volts (low res)	P50V9001V	0 to 180	Volt	None	None	NA
APCU 1 trip status	P50V9006V	See table		OSL	-4.40	5
APCU 2 output volts (low res)	P50V9007V	0 to 180	Volt	None	None	NA
APCU 2 output volts (high res)	P50V9008V	110 to 160	Volt	122	126.5	5
APCU 2 trip status	P50V9013V	See table		OSL	-4.40	5

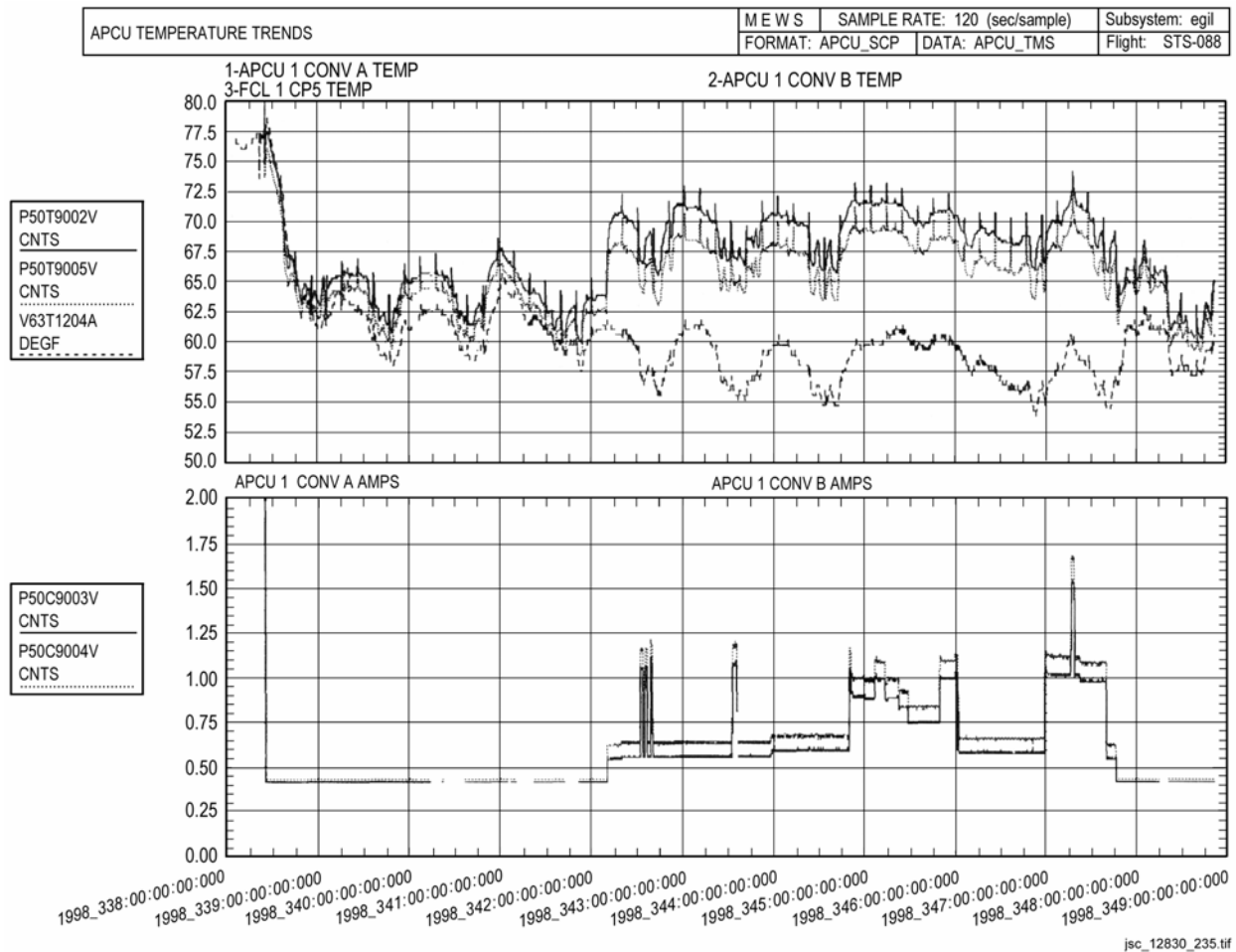
G. Flight operations

The PHALCON ISS Flight Control position is responsible for all nominal APCU operations before and during ISS missions. This includes developing a power profile for use in EGIL consumables analysis.

The EGIL Flight Control position is responsible for all off-nominal APCU operations, including malfunction procedure development. APCU consumables analysis is part of normal EPS Flight Design.

The converter temperatures reflect a combination of the orbiter Freon temperature and the APCU load. When the converters are off, the temperature measurements are within a few degrees of the Freon Coolant Line (FCL) midbody CP5 out temperature (V63T1204A, V63T1404A). As the FCL temperatures change, the converter temperatures also change. When the APCU converters are ON, the

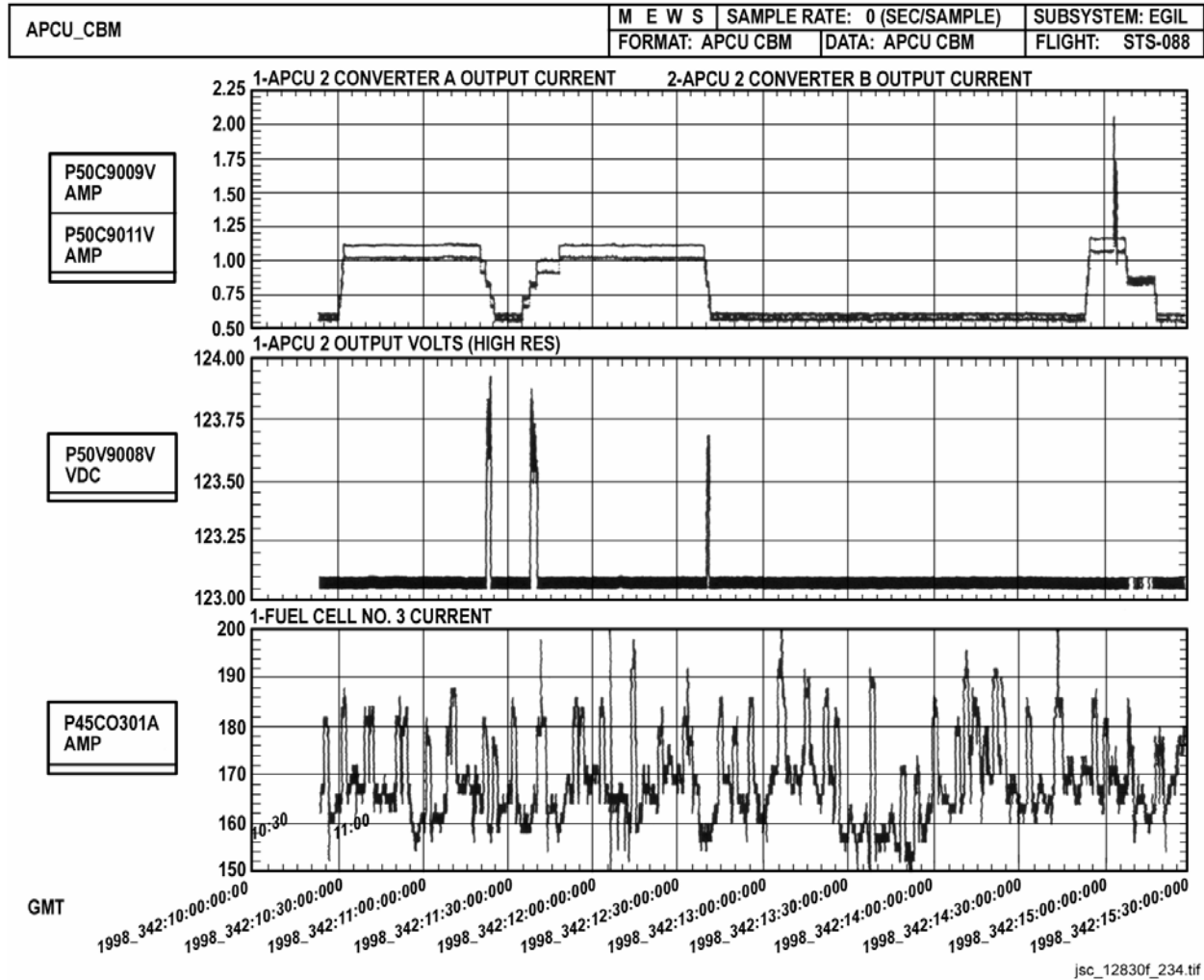
converter temperatures rise above the CP5 temperature by an amount that is proportional to waste heat generated by the APCU. It will still track the CP5 temperatures, but will be biased above them (see Figure 4.6-5).



**Figure 4.6-5. Plot A**

APCU voltage regulation is designed to be fairly tight. It is important to note that output over- and undervolt trips occur well outside the regulation range. It is, therefore, possible to have an APCU with shifted voltage regulation that does not autotrip to OFF. For these cases, the voltage limits on individual pieces of equipment must be used to see whether APCU ops can continue. It is possible that regulation can be recovered by a power cycle or by leaving it OFF for an extended period.

Flight experience has shown voltage regulation to be quite good. Only small transients in the voltage occur when output loads are varied (see Figure 4.6-6).



**Figure 4.6-6. Plot B**

Special operational consideration must be given when working with inductive loads. Large motors such as that on the node cabin fan can have large startup transients. To keep the transient from causing an output overcurrent trip, loads must be managed to limit the total current during fan start or when increasing fan speed. These management plans are documented in the flight rules.

The opposite is true when turning the fan OFF or when lowering fan speed. Stored energy in the magnetic field of the fan is reduced when the fan speed is lowered or turned off. If no other loads are present, the energy produces what is known as back Electromagnetic Field (EMF) voltage. The voltage feeds back into the APCU, which can cause an OUV trip. Placing additional loads on the APCU creates a place for this energy to dissipate. The flight rules document explains exactly how to manage this condition.

H. Summary

The following procedures apply to operation of the APCU:

1. Minimize or decrease APCU loads before turning on a large motor or increasing its speed.
2. Increase APCU loads before turning off a large motor or decreasing its speed.

Use the flight rules for exact management procedures.

**TITLE**

SPACEHAB OVERVIEW - TBD

## 4.8.1 STATION TO SHUTTLE POWER TRANSFER SYSTEM (SSPTS)

### OVERVIEW

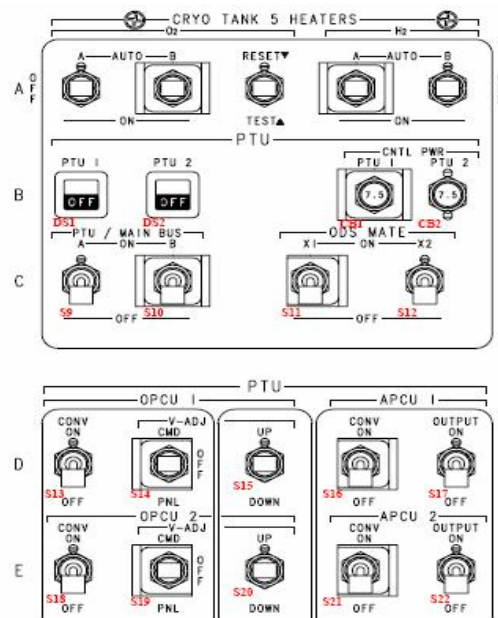
The Station to Shuttle Power Transfer System (SSPTS) was developed in order to increase the docked duration from ~ 6-8 docked days to ~ 9-12 docked days. The upper limit of 12 docked days (16+2 day mission) is due to orbiter certification limits (in order to surpass a 16+2 day mission items such as MMOD, S-Band Quad Switch, OMS/RCS Thermal Constraints, Tire Pressure Maintenance, etc. would need to be evaluated).

When the Orbiter is docked to the International Space Station (ISS), the SSPTS converts ISS 120 Volts, Direct Current (Vdc), power to 28 Vdc Orbiter power to supplement power from the fuel cells. The maximum transfer capability is ~ 8 kW. Load sharing with the fuel cells reduces the use of O<sub>2</sub> and H<sub>2</sub> cryogenic reactants, thereby providing increased on-orbit docked mission duration. The SSPTS also incorporates converters for converting 28 Vdc Orbiter power to 120 Vdc to provide power for payloads.

These two functions are incorporated in a Power Transfer Unit (PTU) (see Figure 4.8.1-2). The 120 Vdc to 28 Vdc converter functions are known as Orbiter Power Conversion Unit (OPCU), and the 28 Vdc to 120 Vdc converter functions are known as Assembly Power Conversion Unit (APCU). Two identical PTUs replace the standalone APCUs. The PTUs are Line Replaceable Units (LRU) mounted in the Payload Bay below the liner.

### A. PTU Control

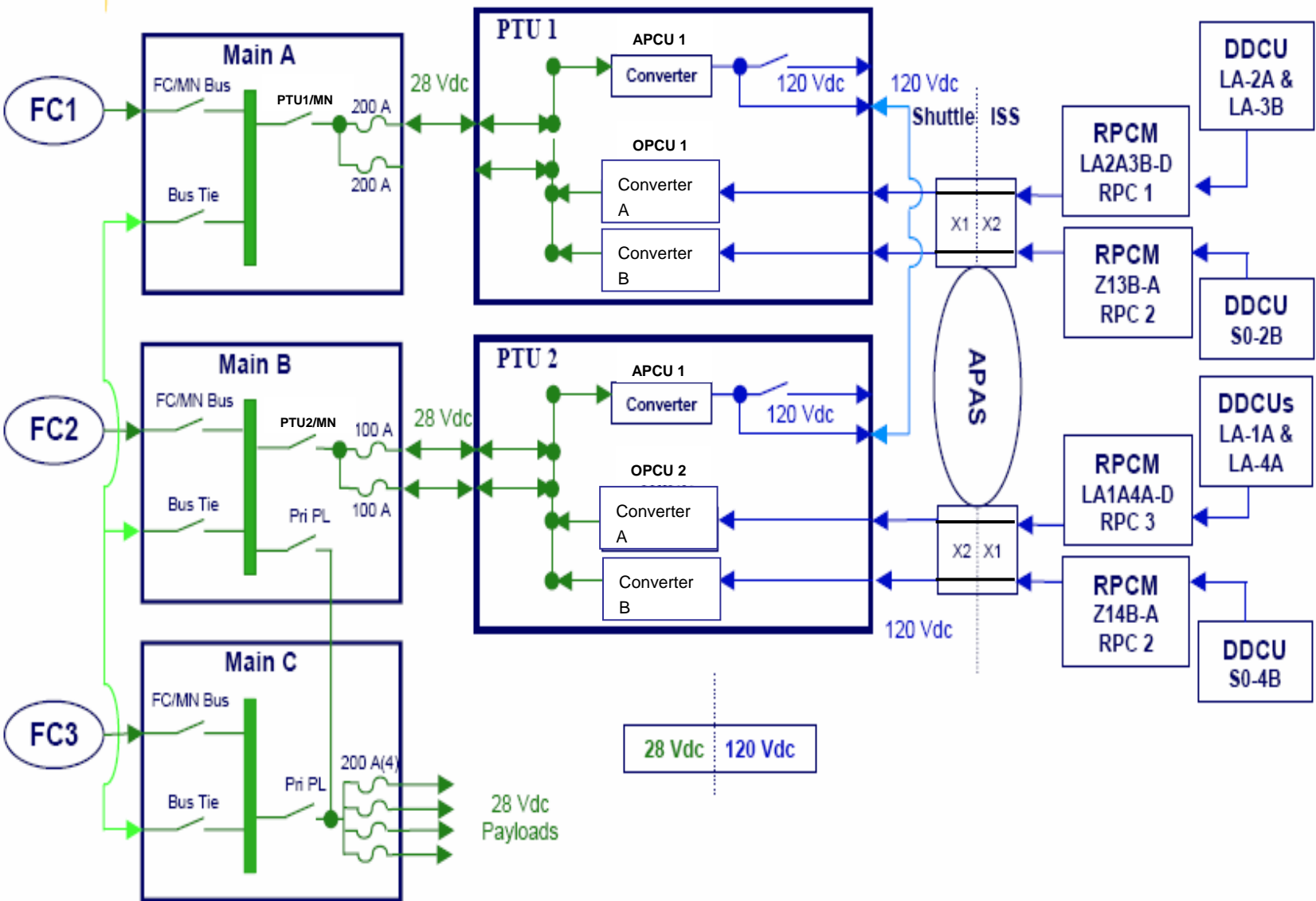
All the switches for the PTU are on panel A15 (see Figure 4.8.1-1.) where the Extended Duration Orbiter (EDO) switches were (EDO switches were on OV104 and 105 only). The APCU switches were moved off the Standard Switch Panel (SSP) since the PTU will be an orbiter LRU (the stand alone APCU was a payload piece of equipment). This also freed up the space on the SSP for payloads. In addition the X1, X2 Orbiter Docking System connector mate switches were moved from the SSP to Panel A15. NOTE: OV-104 will not be updated with SSPTS and will fly the standalone APCU with the switches on the SSP.



**Figure 4.8.1-1. A15 Panel - SSPTS Switches**

4.8.1-1

**Verify that this is the correct version before use**



4.8.1-2

Verify that this is the correct version before use

Figure 4.8.1-2. SSPTS Architecture

## OPCU DESCRIPTION

### A. Input/Output Power Paths

Each PTU has two OPCU converters, designated OPCU Channel A and OPCU Channel B. Each receive a 120 Vdc feed from a Type VI RPCM output, via ISS to the Androgynous Peripheral Attachment System (APAS also know as APDS - Androgynous Peripheral Docking System) connector then to the PTU through Orbiter cabling. The OPCU channels are physically partitioned into two modules within the PTU chassis, and are functionally independent. The two modules are rated at 2 kW each, and operate in a parallel output configuration to provide 4 kW at ~ 28 VDC to an Orbiter main bus.

PTU1 (2) connects to MNA (MNB) through the EDO power contactor switch in MDCA1 (2): PTU/MN Bus Contact. The PTU/MN Bus Contactor is capable of 4500 A for 0.1 seconds or 6000 A for 0.01 seconds. PTU1 will interface with MNA through a single 200A fuse, and PTU2 will interface with MNB through two 100A fuses (see Figure 4.8.1-2). The integration of the PTU in the pair of 100A fuses in MDCA2 allows parallel feeders to be run the long distance from PTU2 to MDCA2, whereas the 200A fuses in MDCA1 allow a single feeder to be used to connect PTU1 to MDCA1, a much shorter distance, thereby balancing out the upstream resistance.

### B. Operational Modes

The OPCU operates by sensing the voltage near its regulation point (which is very close to the associated main bus), and then tries to control the voltage at this regulation point to a preset level. The OPCU will maintain the voltage at the main bus at the specified set point voltage (**Voltage Regulation Mode**) until the maximum output power for the converter is reached (~2kW for each converter for a total of 4kW per PTU). At that time, the converter goes into (input) **Current Limiting Mode** by dropping its output voltage and becomes a constant output power source. So to summarize, the OPCU will maintain its output voltage picking up additional loads as they turn on until it reaches its maximum output power; at that point the OPCU will drop its output voltage allowing the fuel cell to pick up the additional load.

The OPCU shares the orbiter loads with the fuel cells. The amount of power being provided by the fuel cell depends on the output voltage of the OPCU and the performance curve of the fuel cell. For example an OPCU at a preset voltage of 31 Vdc will allow a curve 6 fuel cell to output ~4.65 kW while a curve 12 fuel cell will output 2.3 kW. When the orbiter is at a group B powerdown power level, the OPCUs will most likely not be outputting their maximum power due to the individual main bus loads being less than 6 kW (2 kW min power output from the fuel cell required due to certification limitations, then the OPCU will provide the rest of the power up to 4 kW). Therefore in order to maximize power transfer, a bus tie could be preformed connecting MNC to either MNA or MNB enabling one of the PTU OPCUs to provided power to two main buses. This should in turn cause that OPCU to go into constant power mode thereby dropping its output voltage some. This allows the OPCU only connected to one main bus to pick up additional dioded loads thereby increasing the overall power transfer capability.



The OPCU is not required to power a main bus without a fuel cell connected to it (either directly or through a bus tie). If the OPCU were to try to power a main bus without a fuel cell connected to it and the power draw on the OPCU was greater than 4 kW, the OPCU will drop its output voltage until it reaches its Output Under Volt trip off point (discussed later), Output Current Limit (discussed later) or until the power required by the bus is ~ 4kW.

**Output Current Limit Mode** is another mode of operation; though this mode should not normally be seen. To get into this mode many conditions have to occur: 1) there has to be a high input voltage to the OPCU, 2) the OPCU has to have a higher Input Current Limit point than the typical point for most of the converters, 3) the OPCU also has to have a high efficiency, and 4) the output voltage of the OPCU has to be low. When in Output Current Limit Mode the output current takes over feedback control; making the converter work as a constant current source. Output current limit mode appears when the output current reaches 82A +/-2 Amps.

### C. Output Voltage Set point

The OPCU channels begin power conversion when 120 VDC power is applied from the ISS, and the Orbiter Panel A15 switch: OPCU1(2) CONVERTER is taken ON. Each OPCU channel will default to an initial output voltage setting of 31.12 ±0.1 Vdc. The maximum voltage set point is 31.8 Vdc to match the Flight Rule instrumentation limit on the main bus. The default setting of 31.12 was chosen in order to minimize the amount of voltage adjustment required to increase the voltage up to 31.8 Vdc while ensuring a power level above 2 kW\*\* for all 20 representative fuel cell curves (\*\* 2 kW was originally the minimum certified fuel cell power level; however, this limit was deleted and the constraint became the voltage had to be less than 32 volts.) Since there is not a minimum fuel cell power level requirement the voltage of the OPCU can be set at the upper limit of 31.8 in order to decrease the load on the fuel cell as much as possible.

#### Output Voltage Feedback

Feedback to control the output voltage to the set point is provided in one of two ways. 1) If the PTU receives a signal from the Orbiter that the PTU/MN Bus Contactor is open, then the OPCU will use local sensing to control its output voltage (PTU will sense the voltage at its output terminals). 2) If the PTU receives a signal that the PTU/MN Bus Contactor is closed, then the OPCU will use a remote sense line to measure the voltage at the main bus and adjust its voltage accordingly to obtain the set point voltage at the main bus (see Figure 4.8.1-3). If the PTU/MN Bus Contactor status signal line breaks causing the PTU to always be in local sense mode, the effect will be that the voltage will be controlled to the set point voltage at the output terminals of the box vs. at the main bus. Therefore the voltage at the main bus will be lower than the set point voltage due to the line losses - degrading the power transfer capability.

#### Voltage Set point Control

The OPCU voltage set point can be changed from the default value by the crew or by the MCC. Adjustment by the crew is performed on Panel A15 by first placing the 'OPCU Volt Adj' switch in PNL; then to adjust the output set point in 40 mV increments the "OPCU Volt Adj" momentary switch is repeatedly toggled Up or Down. Adjustment

by the MCC is enabled when the "OPCU Volt Adj" switch is in CMD, and the voltage set point is adjusted in 40 mV (+/- 10mV) increments by the "OPCU Volt Adj Up Cmd" and "OPCU Volt Adj Dn Cmd" commands sent via the FA MDMs. The voltage adjustment range is 29.28 +0.0/-0.15 to 31.80 +/-0.04 Vdc. When the "OPCU Volt Adj" switch is in the OFF position neither the crew nor the MCC can adjust the output voltage set point.

#### **Voltage Set point Reset**

The voltage set point will be maintained as long as the minimum house keeping voltage (80 Vdc) is maintained (for example: if the OPCU converters are turned off via the Orbiter cockpit switch, but the ISS RPCs are left on, when the OPCU converters are turned back on the voltage set point will reinitialize to the point it was before the converters were turned off). Therefore after the OPCU output voltage has been adjusted, if only OPCU channel A's input power is removed and then repowered (i.e. the RPC is turned off then back on), the OPCU channels will not have the same output set point. Channel A will have the initialization set point of 31.12 and Channel B will have the set point in which it was adjusted to. Also the OPCU converters are not expected to equally share the output power. Even if both Channels have the same set point, it is expected that one channel will provide all the power until it reaches its max output (~2kW) and then the other channel will start providing power.

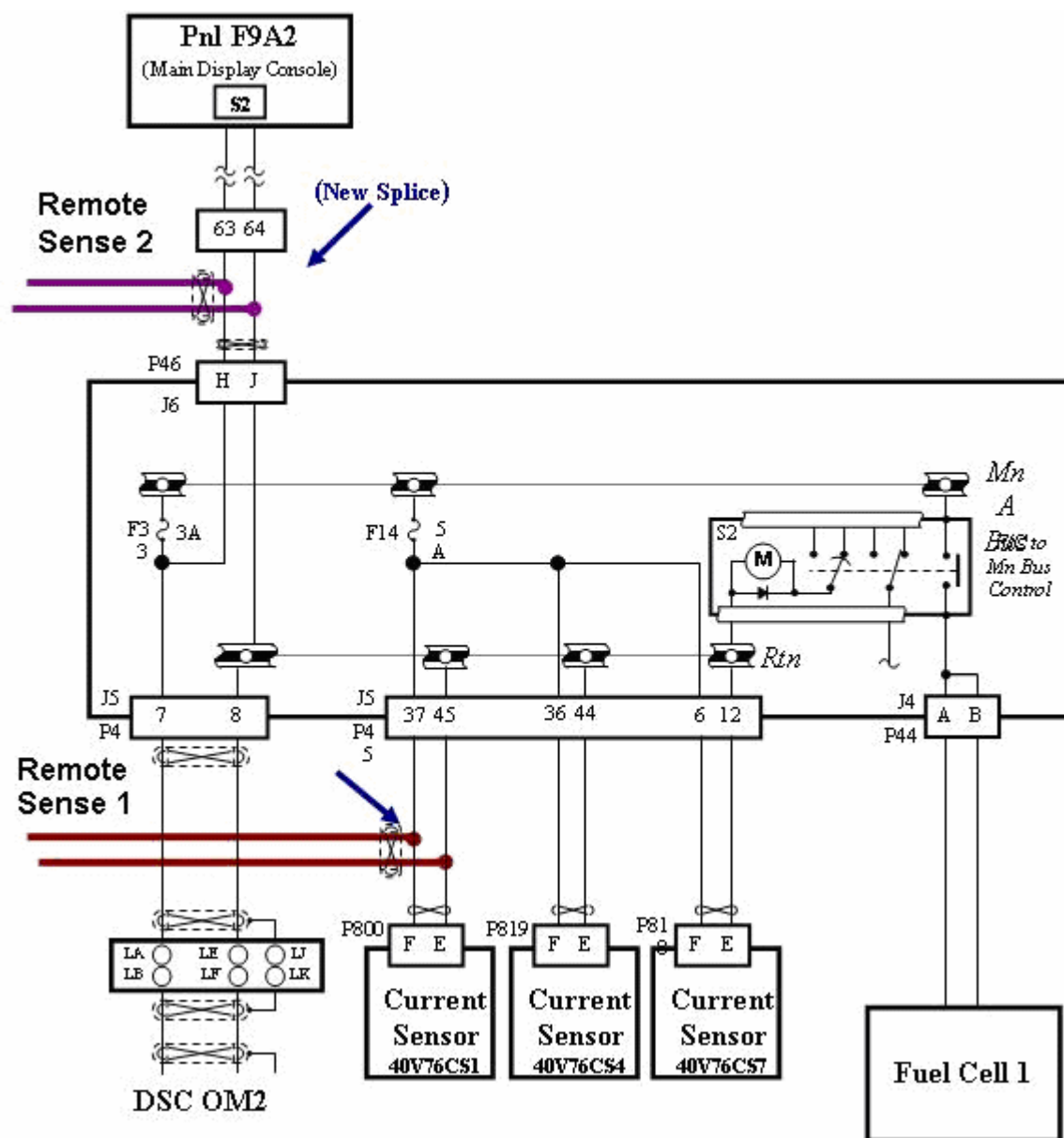


Figure 4.8.1-3. OPCU Remote Sense MN Bus Connections (only PTU1 shown)

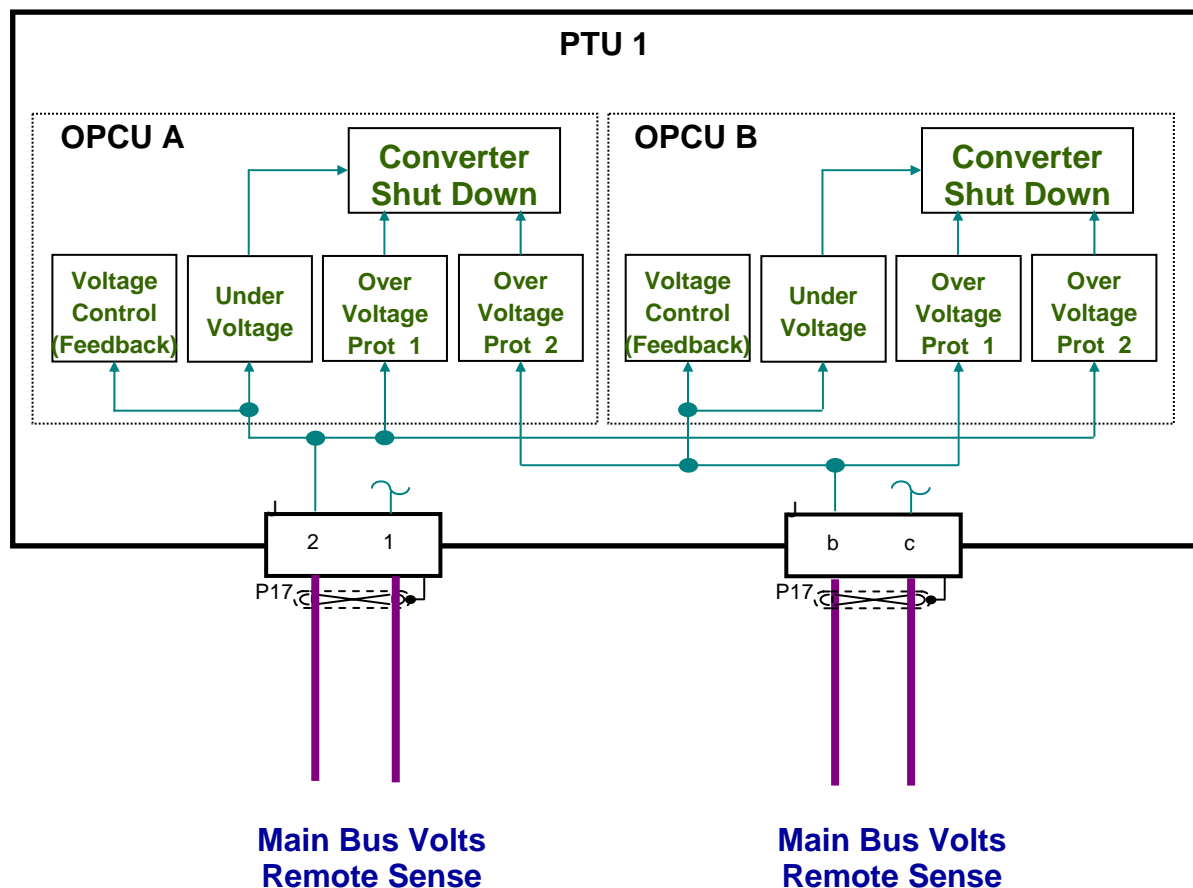
#### D. Fault Protection

The following paragraphs describe the conditions in which the OPCU converter will trip itself - disabling power conversion.

##### 1. Output Over Voltage (OOV)

An OPCU output over voltage event that back feeds the Orbiter fuel cells or propagates to equipment on the main bus is considered a catastrophic hazard. To prevent this hazard, overvoltage protection is part of the PTU design. Each OPCU channel has an overvoltage protection circuit. Two remote sense lines

trigger the overvoltage protection circuit of each OPCU channel (see Figure 4.8.1-4). One sense line taps into the main bus via the circuitry for the forward, mid, and aft current sensors; the other sense line taps in via the circuitry for the main bus F9 Voltage meter (see Figure 4.8.1-3). Each remote sense line can trigger the overvoltage protection stage 1 of its own OPCU channel (this sense line also provides the feedback for that channel's voltage control circuit), and trigger the overvoltage protection stage 2 of its opposite OPCU channel. In addition, loss of a remote sense line (i.e. break in the line) will trip the Under Voltage stage of its OPCU channel. This cross-strapping of remote sense lines provides two-fault tolerance against a failure of the overvoltage protection stages or remote sense lines. The Over Voltage protection circuitry is checked out on the ground between every flight to ensure its functionality.



**Figure 4.8.1-4. OPCU Over Voltage and Voltage Control Circuitry**

Each of the overvoltage protection stages within an OPCU channel has two trip levels. The fast trip level will cause the channel to cease power conversion within 35 microseconds if either remote sense line exceeds  $37 +0.0/-0.2$  Vdc. The slow trip level will cause the channel to cease power conversion if

either remote sense line exceeds  $32 +0.0/-0.12$  Vdc (maximum of 31.999978 Vdc) for 149 +/- 50 ms. In addition the voltage control circuit will only adjust the voltage up to  $31.8 +/- 0.04$  Vdc (maximum of 31.84296 Vdc).

So in summary SSPTS is two fault tolerant to failures which would cause an output over voltage at the main bus. There are three circuits in each OPCU converter which will not allow the main bus voltage to be greater than 32 volts: 1) the voltage control circuit will only adjust the voltage up to  $31.8 +/- 0.04$  Vdc (maximum of 31.84296 Vdc), 2) an over voltage protection circuit will stop OPCU power conversion if the voltage on the main bus is  $> 32 +0/-0.12$  Vdc (maximum of 31.999978 Vdc), and 3) a second over voltage protection circuit which will also stop power conversion if the voltage on the main bus is  $> 32 +0/-0.12$  Vdc (maximum of 31.999978 Vdc). The OOV will trip the converters off regardless of whether or not the OPCU sees the PTU/MN Bus Contactor status CLOSED (i.e. the PTU is connected to the MN Bus). The circuit can be reset by either removing the input power to the channel for more than 10 seconds before re-applying it or taking the OPCU CONV switch to OFF and then back to ON (the OOV trip status clears once the switch is taken ON - all other OPCU trip status clear within ~ 1 sec after the switch is taken OFF and the capacitors discharge).

#### Operational Troubleshooting:

If an OPCU converter causes an over voltage, both OPCU converters will trip off. In order to determine which converter caused the problem, the input power to each converter will need to be cycled separately. In order to accomplish this, the OPCU is first isolated by turning off the converter and disconnecting the PTU from the MN Bus, followed by turning the converter back on. Note that when the converter switch is taken back to ON, the OPCU converter producing the high voltage will do so without being tripped off (see section F: OPCU Behavior When not Connected to Main Bus). Then the ISS RPC for the A converter will need to be commanded OFF. If the voltage goes to the expected set point ( $< 32$  volts), then converter A is the culprit and that RPC shall be left OFF. However, if the voltage stays high ( $> 32$  volts) then converter B is the culprit; therefore, convert B's RPC should be commanded OFF and converter A's RPC should be commanded back ON (check the output voltage of A for good measure). The OPCU can then be reconnected to the main bus.

#### **2. Output Under Voltage (Broken Remote Sense Line)**

The concern associated with a broken sense line is that the affected OPCU channel voltage control circuit will think there is a low voltage on the bus and therefore will try to adjust its voltage up in order to obtain the correct set point voltage. If this is allowed to happen, the affected OPCU channel would eventually increase the voltage on the bus until the Output Over Voltage trip occurred - tripping off both OPCU converters (assumes both converters were on). However, for the loss of a remote sense line, (the OPCU channel sees a voltage less than  $10 +0/-1$  volts) that OPCU channel will trip off within 10.3 ms.

Therefore the affected OPCU channel converter will trip off due to the under voltage condition (removing its high voltage on the bus) before the unaffected OPCU channel converter trips off due to high voltage sensed on the bus. The OUV will only trip the converters off if the OPCU sees the PTU/MN Bus Contactor status CLOSED (i.e. the PTU is connected to the MN Bus) - this is different from what the OOV circuit does. The circuit can be reset by either removing the input power to the channel then re-applying it or taking the OPCU CONV switch to OFF then back to ON.

The Output Under Voltage trip was purposely designed to not trip the converter off if it's output voltage fell below the rated voltage for the MN Bus (27 V) in order to allow the possibility to connect the OPCU to a dead bus for contingency reasons.

### 3. Input Undervoltage

Each OPCU channel is equipped with an input undervoltage trip function. If the channel's input voltage drops below 110 Vdc for 119 +40/-41 ms, the channel will cease power conversion. The circuit can be reset by either removing the input power to the channel then re-applying it or taking the OPCU CONV switch to OFF then back to ON.

The ISS DDCU's output of 124.5 V is very reliably. The maximum voltage expected at the OPCU input is ~118 Vdc due to long cable losses on the ISS + losses in the APAS + losses in the Orbiter wiring between the APAS and the PTU.

### 4. Input Overcurrent

Each OPCU channel is designed to limit the input current draw to no more than 20 +0.0/-1.0 amps. The current limitation is for APAS pins. In addition to input current limiting, each channel has input overcurrent protection; the channel will cease power conversion when the input current exceeds 22 +/-1 A for 190 +/-70 ms. The circuit can be reset by either removing the input power to the channel and then re-applying it or taking the OPCU CONV switch to OFF and then back to ON.

The overcurrent trip provides extra protection to the ISS-Orbiter APAS connector pins in addition to the upstream protection given by the ISS RPC.

### 5. Fault Isolator - Transformer short

The OPCU design has a possible failure mode that may result in an output **over voltage condition** that would bypass the over voltage protection circuits. An electrical short between the 120 Vdc OPCU input power and the OPCU output power terminals (primary to secondary winding short) within the OPCU (extremely unlikely due to the design of the transformer) would apply the 120 Vdc power from ISS to the OPCU output without interruption from either over voltage protection stage circuit. An additional PTU design feature, the Fault Isolator, protects against this failure mode. The Fault Isolator, using a current sensor at the PTU input, will detect the sudden current surge that would accompany a

primary-to-secondary short. When the Fault Isolator detects the current surge, a fast-trip circuit interrupts the 120 Vdc input to the OPCU converter. If the Fault Isolator were to fail, the current surge from a primary-to-secondary transformer short would trip the upstream ISS RPC before the overvoltage hazard to the Orbiter would result. The action of the Fault Isolator together with the trip action of the upstream RPC, will give two-failure tolerance against this hazard. The Fault Isolator trip level is 33.4 +/- 4 amps for 10 microseconds. When the Fault Isolator trips it removes input power to the house keeping power supply; therefore all telemetry associated with that converter will be lost. The signature of this failures looks the same as the loss of an ISS RPC except that the ISS RPC will still indicate ON for the Fault Isolator trip. The Fault Isolator circuitry can only be reset if the associated ISS RPC cycled OFF for 10 seconds.

The Fault Isolator protection circuitry is checked out on the ground between every flight to ensure its functionality.

## 6. ISS RPCM

All the ISS SSPTS feeds are from Type VI RPCMs. The RPCM (Remote Power Controller Module) acts as a multi-channel, high power circuit breaker. RPCMs are used to control power distribution and provide electrical protection and isolation. These functions are accomplished through one or more electrical switches termed RPCs, which are located within each RPCM. The **Remote Power Controller (RPC)** is a switching device that supports on/off control of loads or other RPCMs. A single RPCM may contain up to 18 RPCs. These RPCs are either solid-state switches (Field Effect Transistors - FETs) or non-latching relays that provide power outputs and circuit protection for individual electrical loads. The Type VI RPCM contains solid-state RPCs which are rated to 25 amps each and trip off for a current of 27.5 - 30.0 amps in 40 - 48 ms, or after 1 - 2 ms at 47.5 - 52.2 amps, or after 0.01 ms at 125 - 150 amps. Theses RPCs are not current limiting so if a fault occurs the RPC will let an unlimited amount of current through until it trips.

## E. Telemetry

The OPCU has 4 discrete instrumentation trip signals for each converter (Output Over volt, Output Under Volt, Input Under Volt and Input Over Current) and 3 instrumentation analog signals for each converter (Output Voltage, Output Current, and Temperature). The OPCU telemetry is active whenever input power is applied (the ISS RPC is ON). For example, if the PTU is connected to the main bus and the ISS RPC is ON, but the OPCU CONV is OFF, the OPCU voltage will read that of the main bus.

## F. OPCU Behavior When not Connected to Main Bus

When the OPCU is not connected to the Main Bus (or the PTU/MN Bus Contactor status shows OPEN), the OPCU will still trip off if high voltage is sensed on the Main Bus. However, if the OPCU produces a high voltage at its output terminals the OPCU will not trip itself off since the Main Bus is not seeing the over voltage (remember the OPCU is not connected to the Main Bus). If one of the remote sense lines breaks

an *input under voltage trip status* will appear, but the OPCU converter will not trip itself off, unless it is reconnected to the Main Bus.

## APCU DESCRIPTION

The SSPTS APCU is similar to the standalone APCU which it is replacing. It converts 28 Vdc power to 120 Vdc power for use in the payload bay. However, the APCU does not have the capability to provide 140V power. This decision was made in order to optimize the design and maximize the efficiency. There is no longer a requirement for 140V power. Each PTU has one APCU conversion module; the module is rated at 1800 watts. The two APCUs (one in PTU1 and one in PUT2) can have their outputs tied together in parallel, upstream of their output relays, allowing them to power large loads.

When the OPCU is not operating, the APCU receives its input power from the main bus through the same feed(s) that connects the OPCU to the main bus through the PTU/MN Bus Contactor in the MDCA (the SSPTS APCU does not receive its power from the Primary Payload Bus as did the standalone APCU - allowing those feeds to be available for payloads). When the OPCU is operating, the APCU receives its input power from the OPCU and the main bus (see Figure 4.8.1-2). In theory the OPCU is able to solely power the APCU when the PTU/MN Bus Contactor is open. However, there is no requirement to do so. Since the OPCU might be supplying power to the APCU and to the main bus at the same time, the input voltage range of the APCU is from 0 to 36 Vdc to allow for the higher output voltage at the terminals of the OPCU.

There is a feedback signal between the two APCUs that will dictate that the APCUs output the same amount of power to within ~ 1A of each other if they are connected in parallel. If they are not connected in parallel the feedback signal will have no affect.

### A. APCU Function

The APCU starts converting power once: first, input power is applied and then the APCU Converter switch transitions from OFF to ON. If the input power is cycled while the APCU Converter switch is ON all the status signals will show tripped until the Converter is cycled OFF and then back ON. The APCU is capable of providing a minimum of 14.7 A continuous output current for input voltages greater than 27.0 Vdc. When the voltage is between 24.0 and 27.0 Vdc, the APCU is capable of providing a minimum of 8.5 A continuous output current. Upon application of power, the maximum input current should not exceed 600 A nor be more than 84 A after 5 msec. When the converter(s) are turned off, the APCU output voltage will drop below 10 Vdc within 10 seconds.

The APCU output relay was not certified to open or close under load. Therefore the output relay should be connected/disconnected when the APCU converter is off or when the load is less than 1 amp. However, if required it can be switched under load.

### B. Fault Protection



The APCU has two trip levels for output over voltage protection. The fast trip level will cause the APCU to cease power conversion if the output voltage is greater than 153 +/- 2 Vdc for over 50 microseconds. The slow trip level will cause the APCU to cease power conversion if the output voltage exceeds 130 +/- 2.3 Vdc for 2.5 +/- 0.5 ms. The APCU will trip off due to an output under voltage condition if the voltage is less than 115 +/- 2.5 Vdc for 55.5 +/- 5 ms. The APCU is equipped with an input undervoltage trip function. If the APCU's input voltage drops below 23 +/- 0.5 Vdc for 250 +/- 50 ms, the APCU will cease power conversion for an input under voltage condition. Each channel also has output over current protection; the APCU will cease power conversion when the output current exceeds 14.8 A for 200 +/- 100 microseconds. The APCU will current limit to between 14.7 and 22 A when an overload condition is present. All trip signals can be reset by taking the APCU Converter to OFF and then back to ON (trips will clear in ~ 1 sec).

### C. Telemetry

The APCU has 4 discrete instrumentation trip signals (Output Overvolt, Output Under Volt, Input Under Volt, and Output Over Current) and 5 other instrumentation signals for each converter (Output Voltage, Output Current, Input Voltage, Temperature, and Output Relay Status). The APCU telemetry is active whenever the associated Input power is applied. The Output Relay Status will show closed (high) if either the switch is ON or the voltage downstream of the output relay is high. However, if there is no input power the Output Relay status will always show Open (low).

### PTU House Keeping Power

The OPCUs house keeping power is required to be less than 180 watts (from ISS) in order to meet the requirement to safely mate or de-mate the APAS - the requirements states that one verifiable upstream electrical inhibit must be in place (the ISS RPC) and a downstream load reduction to less than 180W must be in place. Testing on the engineering unit showed that the actual housekeeping power was less than 5 watts per channel.

The APCU house keeping power was shown to be ~ 3 watts during Qual testing. House keeping power is drawn anytime input power is available - either when the PTU is connected to the main bus or when the OPCU is activated.

**CREW DISPLAYS**

Onboard CRT display for monitoring the SSPTS is SM OPS 2 S179 POWER TRANSFER (see Figure 4.8.1-5).

XXXXX/XXX/179	POWER TRANSFER				XX X	DDD/HH/MM/SS
	1/A-TIE		2/B-TIE		3/C-TIE	
FC POWER (KW)	XX.X		XX.X		XX.X	
MAIN VOLTS	XX.XXS		XX.XXS		XX.XXS	
PTU/MAIN BUS	XXX		XXX			
	PTU 1		PTU 2			
OPCU	A	B	A	B		
OUT VOLTS	XX.XXS	XX.XXS	XX.XXS	XX.XXS		
AMPS	XX.XS	XX.XS	XX.XS	XX.XS		
TEMP	XXXS	XXXS	XXXS	XXXS		
TRIP	IN OC	IN OC	IN OC	IN OC		
	IN UV	IN UV	IN UV	IN UV		
	OUT UV	OUT UV	OUT UV	OUT UV		
	OUT OV	OUT OV	OUT OV	OUT OV		
APCU						
Out Volts	XXX.XS		XXX.XS			
Amps	XX.XS		XX.XS			
In Amps	XX.XS		XX.XS			
Temp	XXXS		XXXS			
Relay	XX		XX			
Trip	IN UV	OUT UV	IN UV	OUT UV		
	OUT OV	OUT OC	OUT OV	OUT OC		

**Figure 4.8.1-5. SPEC 179 POWER TRANSFER (For Reference only)**

## 4.8.2 SSPTS REAL-TIME COMMANDING (GCS)

### REFERENCES

1. SS-P-0002-140, Space Shuttle Computer Program development Specifications (CPDS), Space Shuttle Downlink/Uplink Software Requirements, section 5.
2. Generic Command Server (GCS) Command Inventory.

### DESCRIPTION

The SSPTS Command Library contains a complete listing of all the Station-Shuttle Power Transfer System (SSPTS) flight-critical MDM set and reset real-time commands currently verified and available for uplink in GNC OPS 2 and OPS 9. A complete understanding of the function of each set and reset command is very important. The complete command library is stored in the GCS in the RTC inventory (reference Command Inventory Display). These commands are safed in the GCS because they are potentially hazardous if they are executed in an uncontrolled manner. Therefore these commands must be unsafed prior to being uplinked.

### OVERVIEW

The SSPTS PTU voltage setpoints can be adjusted by crew switch actions or by real-time commands. There are three possible command actions available for each PTU: adjust voltage up, adjust voltage down, and reset commands. Each SSPTS voltage adjust RTC executes **both a reset and a set** action of a desired FA MDM. The MDM address to be set or reset can be determined simply by decoding the hexadecimal set and reset words.

The architecture of the SSPTS RTCs is such that, with each executed command, two primary events occur. First, the desired SSPTS command MDM address is set to "0", or reset. This function ensures that the desired MDM bit is cleared prior to commanding. Secondly, the same SSPTS command MDM address is set to "1". Until a reset command is subsequently issued to this MDM address, it will remain set indefinitely. For this reason, a separate SSPTS reset command is available.

When first powered, the SSPTS OPCU voltage setpoint initializes to 31.12V. In order to increase the share of orbiter main bus load that the ISS powers, the voltage may be adjusted up in increments of 0.04V up to 31.8V. In order to decrease the share of orbiter main bus load that the ISS powers, the voltage may be adjusted down, also in increments of 0.04V, as low as 29.28V. It is important to understand that a single command will affect both converters A and B in an OPCU; reference SSPTS Systems Brief (SCP 4.8.1). When the desired voltage setpoint is reach, the appropriate reset command should be sent to set the associated MDM output to "0".

## Detailed Discussion

At this point in the discussion, analyzing a specific RTC would help to enforce the elements identified so far. DSM 5600, for the OPCU (PTU 1) VOLTS UP function, represents a typical example of the stored RTCs. This RTC resets and sets MDM FA1 bits. The hexadecimal reset words, C1050C00 and C9050800, can be coded by the following format:

C	1			0		5		0		C	0		0		
1 1 0 0	0	0 0	1 0	0 0 0 0 0 1 0 1		0 0 0 0		1 1 0 0		0 0 0 0		0 0 0 0			
CD	Set/ Rst	Spare	CH	MDM		Bit 0,1,2,3...		4,5,6,7		...		...14,15			
C	9			0		5		0		8		0		0	
1 1 0 0	1	0 0	1 0	0 0 0 0 0 1 0 1		0 0 0 0		1 0 0 0		0 0 0 0		0 0 0 0			
CD	Set/ Rst	Spare	CH	MDM		Bit 0,1,2,3...		4,5,6,7		...		...14,15			

Or, MDM FA1 CD12 CH2 Bits 4 and 5, the SSPTS OPCU (PTU1) VOLTS UP and DN command addresses will both be reset to "0" (the reset function controlled by the Set/Rst bit, where Set=1 and Rst=0) and then MDM FA1 CD12 CH2 Bit 4 will be set to "1".

**Table 4.8.2-1 SSPTS Command Library**

DSM			RESET			SET		
#	TITLE	MSID	CMD	Address	HEX	CMD	Address	HEX
5600	OPCU (PTU1) Volts UP	V76K2432U		FA1 CD12 CH2 Bit 4 & 5	C1050C00	V76K2432X	FA1 CD12 CH2 Bit 4	C9050800
5601	OPCU (PTU1) Volts DN	V76K2433U		FA1 CD12 CH2 Bit 4 & 5	C1050C00	V76K2433X	FA1 CD12 CH2 Bit 5	C9050400
5604	OPCU (PTU1) RESET	V76K2439U		FA1 CD12 CH2 Bit 4 & 5	C1050C00		FA1 CD12 CH2 Bit 0	C9050000
5602	OPCU (PTU2) Volts UP	V76K2532U		FA2 CD12 CH2 Bit 4 & 5	C1060C00	V76K2532X	FA2 CD12 CH2 Bit 4	C9060800
5603	OPCU (PTU2) Volts DN	V76K2533U		FA2 CD12 CH2 Bit 4 & 5	C1060C00	V76K2533X	FA2 CD12 CH2 Bit 5	C9060400
5605	OPCU (PTU2) RESET	V76K2539U		FA2 CD12 CH2 Bit 4 & 5	C1060C00		FA2 CD12 CH2 Bit 0	C9060000

## Detailed Procedure

## REFERENCES

### CAUTION

This procedure is governed by FCOH SOP 3.1 and is not to be changed in real time without review and approval of the Flight Director or changed pre-mission without review and approval at the FOIG.

1. INCO, Master Data Format Processor System Orbiter RTC/MRTC list.

4.8.2-2

**Verify that this is the correct version before use**

2. Space Shuttle Systems Handbook schematics drawing 2.6, SSPTS OPCU

## PURPOSE

This section provides the procedures for performing SSPTS voltage adjustment by Real-Time Commands (RTC's).

## GENERAL

CMD CR# \_\_\_\_\_ DATE:

Hazard/Safety Implication: (Should Be/Are Safed?) The Commands are Safed in the GCS

Valid Software Major Modes: GNC OPS 2, OPS 9

Valid OI Loads: All

Vehicle, LRU/Hardware Version Constraints: OV-103 and OV-105

Time Constraints, Crew Coordination Requirements: Onboard PTU OPCU 1(2) V-ADJ panel switches must be in the CMD position and OPCUs must have input power present (ISS RPC's ON).

1. Safety Critical steps are surrounded by a double lined box.
--

2. RTCs will only be useful on orbit when input power (from ISS) is applied to OPCUs.
3. The EGIL will direct INCO which PTU will be commanded and the particular command DSM's to be sent. Since voltage adjustment increments are small, commands may need to be sent multiple times in order to increment to the desired output voltage setpoint. EGIL will direct INCO how many adjustments in a given direction are required and INCO may use a batch commanding tool or manual single stage commands to achieve the desired result. After OPCU voltage adjustment is complete, EGIL will direct INCO to send the appropriate OPCU reset command(s). A reset command can be sent at any point during the OPCU commanding with no adverse impacts.
4. The commands used for the SSPTS OPCU are listed in table 4.8.2-1.
5. EGIL/EPS will establish communications with INCO on the INCO Loop and with COMMAND on the COMMAND Loop. The EGIL/EPS will read out the DSM

numbers of the RTCs for the SSPTS OPCU commands and MDM resets per the attached flight note. Communications between above disciplines should be maintained throughout the command sequence. EGIL/EPS should determine that the correct commands were uplinked by reviewing the command track display, and that proper OPCU voltage adjustment occurred to the extent possible. Problems will be reported to the flight director. The SSPTS OPCU commands are all safed, and must be unsafed by COMMAND prior to uplink. When commanding is complete, the commands should be safed again.

#### 6. **MCC Operations**

While executing the SCP the safed status of commands can be observed via the following DNAV menu:

MASTER DNAV / Other Apps / Command Server / TELCOM displays / SSP / Safed Command Groups.

Presence of the RTC DSM number on this list indicates it is a safed command. Absence of the DSM number means it is unsafed.

While uplinking and executing the commands the Command System Monitor display can be observed via the following DNAV menu:

MASTER DNAV / Other Apps / Command Server / TELCOM displays / SSP / Command Track

An additional display can be used to see the MRTC or RTC designation:

MASTER DNAV / Other Apps / Command Server / TELCOM displays / SSP / Command Inventory

**FLIGHT NOTE**

TO: FLIGHT/CAPCOM/INCO/COMMAND  
FROM: EGIL/EPS

GMT: 

/	:	:
---	---	---

SUBJECT: Real-Time Commands for SSPTS

**WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations).**

**NOTE:** If subsequent SSPTS OPCU voltage adjustments are desired, a separate procedure will be required, one for each command sequence. To track the number and order of SSTS OPCU operations, the command sequence boxes at the beginning of the procedure must be completed (e.g. Command 1 of 1).

The Command Sequences listed contain the RTC's required to adjust OPCU voltage in the indicated direction. Once sent, the commands will remain until reset.

MDM and electrical failures may affect command capability. Commands are only to be sent during GNC OPS 2 and 9.

**RATIONALE** (for performing procedure):

---

Step 1. The following Real Time Command(s) are Requested (choose desired commands):

<input type="checkbox"/> OPCU (PTU1) VOLTS UP	<input type="checkbox"/> OPCU (PTU2) VOLTS UP
<input type="checkbox"/> OPCU (PTU1) VOLTS DN	<input type="checkbox"/> OPCU (PTU2) VOLTS DN
<input type="checkbox"/> OPCU (PTU1) RESET	<input type="checkbox"/> OPCU (PTU2) RESET

Step 2. EGIL/EPS attaches a copy of the correct Command Sequence to this flight note.

Step 3. EGIL/EPS sends copies of this form and the Command Sequence to the EPS/EGIL for verification. EGIL will distribute the note to the FLIGHT, CAPCOM, INCO, and COMMAND consoles. EGIL/EPS will contact INCO on the INCO loop and COMMAND on the COMMAND loop to inform them of the impending commands and to coordinate future actions.

Step 4. EGIL will verify the following configuration:

Desired OPCU INPUT POWER ON (OPCU Temp not OSL)  
A15      ✓PTU OPCU 1(2) V-ADJ - CMD

### Adjust SSPTS OPCU Voltage

Step 5. EPS choose **DSM number** from this table corresponding to the voltage adjustment desired, **DSM number** for the corresponding reset, and fills in the Desired DSM Boxes in Step 7.

<u>OPCU PTU</u>	<u>Direction</u>	<u>DSM</u>
PTU 1	Up	<input type="checkbox"/> 5600
	Down	<input type="checkbox"/> 5601
	Reset	<input type="checkbox"/> 5604
PTU 2	Up	<input type="checkbox"/> 5602
	Down	<input type="checkbox"/> 5603
	Reset	<input type="checkbox"/> 5605

Step 6. Upon approval by FLIGHT, EGIL/EPS will ask:

- a. COMMAND (on COMMAND loop) to unsafe the desired RTCs.
- b. INCO (on INCO loop) to configure DSM panel for GNC GPC DESTINATION and SINGLE-STAGE AUTO EXECUTE

Step 7. EGIL/EPS will request INCO/COMMAND to perform the following:

*Note: EGIL/EPS will verify command uplinks verbally and via the Command Tracking display.*

Send DSM's in this order, with EGIL/EPS calling out the DSM numbers and the number of instances for the adjustment command in each step to

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- a.  (DSM commands to adjust voltage for PTU 1)
- b.  (Number of times to execute adjustment commands)
- c.  (DSM commands to adjust voltage for PTU 2)
- d.  (Number of times to execute adjustment commands)
- e. **ON EGIL GO**, (when adjustment complete or after adjustment commanding)  
 and/or  (RTC's to Reset all SSPTS OPCU commands)

Step 8. EGIL/EPS will verify the adjustment was performed properly to the extent possible.

Step 9. EGIL/EPS will verify final configuration.

Step 10. EGIL/EPS will ask COMMAND to save the SSPTS commands which were unsaved in step 6a. COMMAND will report to EGIL/EPS when saved.

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EGIL Officer

**SECTION 5  
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## TITLE

CAUTION AND WARNING SYSTEM

## PURPOSE

The purpose of this brief is to provide an introduction to orbiter Caution and Warning (C&W), a description of systems components and their functions, and also to provide some insight into system failure recognition.

## REFERENCES

C&W T2102 Training Manual.

Space Shuttle Systems Handbook (SSSH), dwg. 5.2.

In-Flight Maintenance Checklist.

## ALARM CLASSES

- A. Class 1, Emergency - This alarm class has two different types of aural alarms; the Klaxon generated for a rapid cabin depressurization indication and a siren generated for a fire from smoke concentration indications.
- B. Class 2, C&W - This alarm class consists of two subclasses, the primary and the Backup (B/U). The primary C&W is a hardware system, and the B/U C&W is a software system. A Master Alarm (MA) is annunciated if a parameter exceeds a predetermined value.
- C. Class 3, Alert - This alarm class also utilizes a software system. A Systems Management (SM) alert is annunciated if a parameter exceeds a predetermined value.
- D. Class 0, Limit Sensing - This software system consists of displaying an up or down arrow (↑, ↓) on the Cathode-Ray Tube (CRT) or Multifunction Display Unit (MDU) next to the parameter that exceeds a predetermined value. No alarms are annunciated for this alarm class.

## SYSTEM DESCRIPTIONS

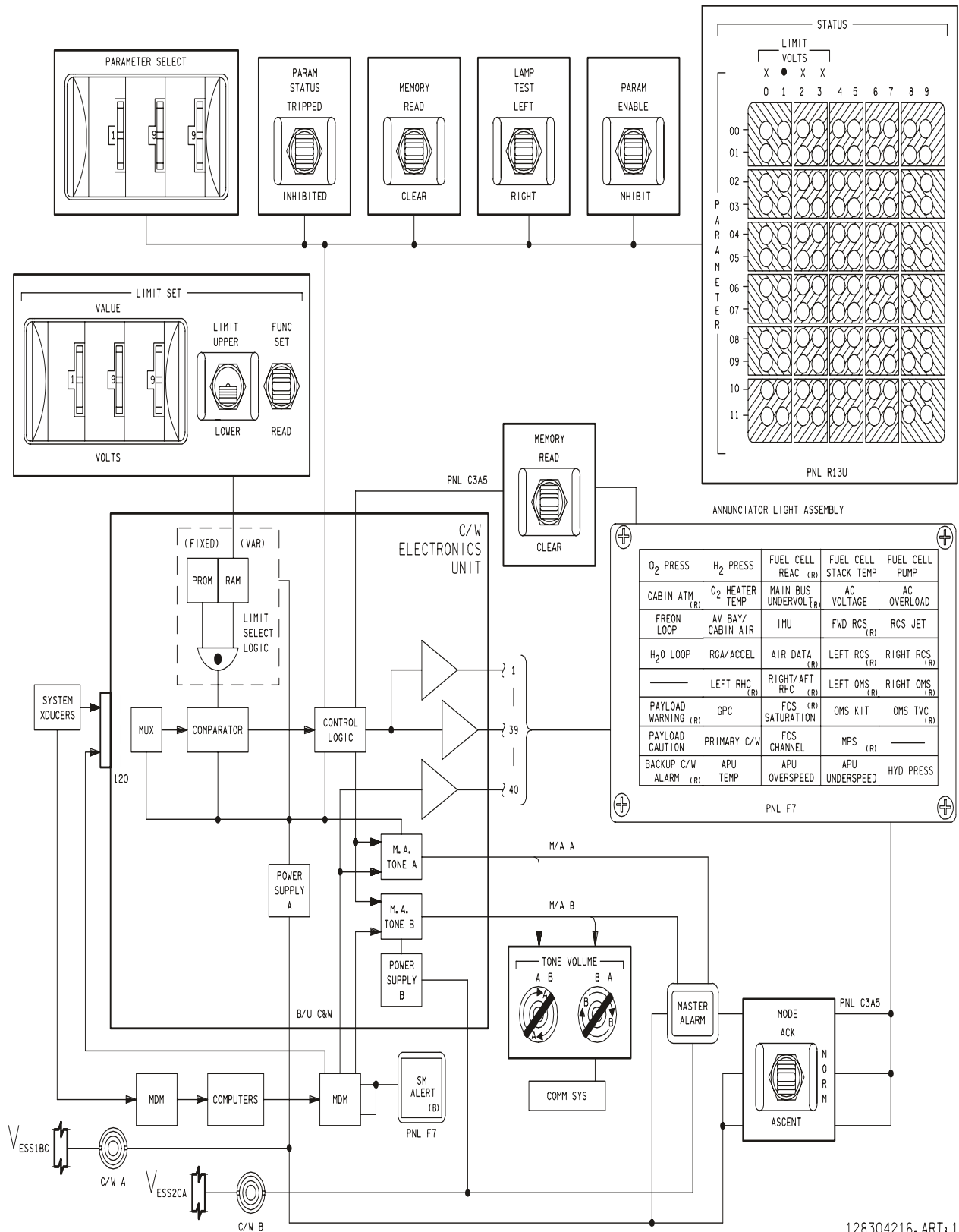
- A. The C&W subsystem is designed to alert the crew to the existence of a malfunctioning orbiter or payload system. Both aural and visual cues are used to alert the crew to potential problems. Redundant C&W systems are used to ensure that any single system failure will not leave the crew without a warning for a critical orbiter or payload system failure.
  - 1. Primary C&W (class 2) - Also is referred to as the hardware C&W system. The system comprises the C&W Electronics Unit (CWEU), crew interface switches, status and annunciator lights, MA pushbutton indicators (pbi's), and aural annunciation equipment (siren, Klaxon, C&W, and alert tone

generators). The system has the capability of monitoring 120 different parameters. The CWEU is located in the forward avionics bay-3 (AV Bay 3A) and includes one front plug-in C&W limit module. The Programmable Read-Only Memory (PROM) limit module is programmed to include the limits for all the 120 possible inputs coming into the electronics unit. At powerup, the CWEU is initially configured as follows:

- Inhibit logic cleared
- Alarm limit Random Access Memory (RAM) cleared
- C&W tone outputs activated
- Limits reset at default PROM values
- Tripped memory cleared
- MA outputs activated
- C&W fail output activated

The unit is placed in the normal operational configuration by actuating an MA reset command (depressing an MA pbi). Each of the 120 monitored parameters is hardwired directly into the CWEU from either a transducer through a signal conditioner or from one of the forward Multiplexer-Demultiplexers (MDMs) and distributed to 1 of 16 multiplexers. Of these 120 inputs, 98 come from transducers, 5 are from input/output processors, 15 are from MDMs, and 2 are spares. The inputs can be either bilevel or analog; analog inputs are 0 to 5 volts, and discretes are 0, 5, or 28 volts DC. Through the use of a binary counter, an oscillator-generated timing signal, and four additional multiplexers, each parameter is individually sampled at 80 Hz. A comparator is used to compare the sampled parameter with a preset value stored in the limit value RAM; both an upper and lower limit are stored for each parameter. The control logic uses a D-type flip-flop counter and an N count-over flow memory to count the number of sequential samples the parameter is out of limits. If the parameter is out of limits for eight consecutive samples, a flip-flop and a driver circuit trigger an MA sequence for the parameter. A simplified flow diagram is shown in Figure 5.1-1. For a more detailed diagram, refer to SSSH, drawing 5.2.

The out-of-limits parameter is annunciated by a C&W tone generated by the primary CWEU tone logic circuitry. Other cues of annunciation are illumination of the parameter-associated lamp on the F7 panel Caution and Warning Annunciator (CWA) matrix; these lights will remain illuminated until the out-of-limits condition is corrected or the parameter is inhibited by the crew. The out-of-limit signals are transmitted from the CWEU to the CWA matrix. The CWA matrix has 40 Annunciator modules, with each module having 2 incandescent bulbs. The caution Annunciator modules are yellow, and the warning modules are red. The four red MA pbi's on panels F4, F2, A7, and M052J are illuminated for all class II alarms. Each MA pbi light illumination is driven by one of the six Annunciator Control Assemblies (ACAs). The primary C&W electronics will also provide a signal to illuminate



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Figure 5.1-1. Hardware caution and warning overview

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an MA indicator in any habitable payload, such as the Spacehab. The MA can be extinguished by the depression of one of the MA pbi's.

The hardware C&W system has three modes of operation: normal, ascent and acknowledge, selected by mode switch on panel C3. In the normal mode of operation, an out-of-limits parameter will generate all the annunciation indications as stated above. The ascent mode is operated in the same way as the normal mode, except that the commander's MA light is deactivated. This allows the commander the option of not being distracted by MA lights during ascent. The only other red lights on the commander's side are the range safe arm and the abort lights. The ascent mode is not usually used. In the acknowledge mode, the status annunciation on the CWA matrix for an out-of-limits parameter is illuminated only when either the F2(CDR) or F7(PLT) MA pbi is depressed.

Any parameter that has gone out of limits will have its C&W channel number stored in a memory for later recall by the crew using the C&W status display on the R13 panel or on the CWA matrix using the C3 panel memory read switch. Changes can be made to the hardware C&W through the use of the hardware system switches located on the R13 panel. The lower and upper limit values at which a parameter is considered tripped can be changed. Each individual channel can be inhibited so that an alarm will not be annunciated for that channel. The stored memory of all the previously tripped channels may also be cleared.

## 2. C&W hardware interfaces

The three C&W parameter select thumbwheels on panel R13 provide signals to the CWEU to determine the specific parameter for enabling or inhibiting the parameter and for setting and reading the parameter's limits.

The C&W limit set switch grouping on panel R13 is used to change limits or to read a parameter's limits.

The three value thumbwheels provide the signals to the C&W unit, defining the voltage value setting of a parameter's upper or lower limit, X.XX.

The C&W limit set upper switch on panel R13 provides a signal to the CWEU, which modes the electronics to set or read the upper limit of a parameter specified by the settings on the value thumbwheels for that parameter and the C&W limit function switch is cycled to set or read the upper limit of that parameter.

The C&W limit lower switch on panel R13 functions in the same manner as the limit upper switch, except for the lower limit for a parameter.

The C&W limit set function set switch position on panel R13 provides a signal to the CWEU, which sets the value specified by the limit set value

thumbwheels into the parameter as specified by the parameter select thumbwheels and the limit set limit switch.

The limit set function read switch position on panel R13 provides a signal to the CWEU, which illuminates the lights under the status limit volts X.XX columns on panel R13 that correspond to the voltage parameter limit specified by the parameter select thumbwheels and the limit set limit switch. The value read corresponds to the parameter's full-scale range on a scale of 0 to 5 V DC. The limit set function switch center position disables the set and read functions.

The C&W parameter enable switch position on panel R13 provides a signal to the CWEU to enable the parameter indicated on the parameter select thumbwheels, which allows the parameter to trigger the primary C&W alarm when out of limits. The inhibited position operates the same as enable, except that it inhibits the parameter from triggering the primary C&W alarm. The center position of the switch disables the enable and inhibit functions.

The C&W parameter status tripped switch position on panel R13 provides a signal to the CWEU, which illuminates the C&W status lights on panel R13 that correspond to the parameters that are presently out of limits, including those that are inhibited. The inhibited position illuminates those C&W lights on panel R13 that have been inhibited. The center position disables the tripped and inhibited functions.

The C&W memory read switch position on panel R13 provides a signal to the CWEU, which illuminates the C&W status lights on panel R13 that correspond to the parameters that have been out of limits since the last memory clear was performed. The clear position on panel R13 or C3 provides a signal to the CWEU that clears from the memory any parameters that are presently within limits. Any parameters that are out of limits during this action remain in memory. The center position of the switch on panel R13 or panel C3 disables the clear and read functions.

The C&W tone volume A switch on panel R13, when adjusted clockwise, increases the system A siren, Klaxon, C&W, and SM tone generator output signals to the audio central control unit. The B switch functions the same as the A switch for system B tone generators.

The C&W lamp test switch on panel R13, when positioned to the left, provides a signal to the CWEU, which illuminates the left five columns of the C&W status matrix lights on panel R13. The right position functions the same as the left, except for the right five columns of lights.

- B. B/U C&W (class 2) - Also referred to as the software C&W system. B/U C&W alarms are annunciated when monitoring software called Fault Detection and Annunciation (FDA), contained in the General Purpose Computers (GPCs), detects an out-of-limits condition for a parameter. During ascent, System Management

(SM) FDA is performed by the Backup Flight System (BFS) GPC. On orbit, SM FDA is performed by the SM GPC. The parameters that are being monitored and their limit values in the SM and BFS FDA software are not identical. The parameters are compared to both an upper and lower limit value for an out-of-limits condition. A filter value is also set that requires the parameter to be out of limits for a preset number of samples. The rate at which each parameter is sampled is not the same. This is part of the software load. Typical SM GPC data acquisition rates for FDA are 1.04 Hz (approximately once per second), or 0.52 Hz (approximately once every other second).

The out-of-limits parameters are annunciated with an MA. The SM GPC sends a signal through several of the forward MDMs to the CWEU, and an audible C&W tone is generated by the CWEU. Other annunciation cues are the illumination of the B/U C&W light on the F7 panel and the four red MA pbi's on panels F4, F2, A7, and M052J. A software fault message indicating the type of failure is also generated on the fault summary line of the CRT/MDU, as well as on the fault summary page. Primary C&W electronics will also provide a signal to illuminate an MA indicator in any habitable payload, such as the Spacehab.

Changes can be made to the B/U C&W system parameter default limit set through the use of the SM TABLE MAINT display (Spec 60) or through a Table Maintenance Block Update (TMBU). Details on how these changes are done are not covered in this system brief. Changes that can be made include both the upper and lower limit values and the filter value. Each parameter can also be inhibited so that it will not annunciate an alarm when it is out of limits.

- C. SM alert (class 3) - A software C&W system designed to alert the crew to situations that may lead to a class 2 C&W. SM alerts are annunciated when monitoring software contained in the GPCs detects an out-of-limits condition for a parameter. The parameter is compared to both an upper and lower limit value for an out-of-limits condition. A filter value is also set that requires the parameter to be out of limits for a preset number of samples. Unlike the B/U C&W, there are up to three possible limit sets for each parameter. The limit set used by the software to actively monitor the parameter depends on preset condition (i.e., the value of a different parameter).

When a parameter's limits are violated, an SM alert is annunciated. A signal is sent from the SM GPC through several of the forward MDMs to the CWEU, and an audible SM tone is generated by the CWEU. Other annunciation cues are a blue SM alert light on the F7 panel and a software fault message displayed at the bottom of the CRT/MDU fault message line, as well as on the fault summary page.

Changes can be made to the SM alert software default limit set through the use of the SM TABLE MAINT display (Spec 60) or through a TMBU. Details on how these changes are made are not covered in this system brief. Changes that can be made include the upper and lower limit values and the filter value. The parameter can also be inhibited so that it will not enunciate an alarm when it is out of limits.



## SYSTEM FAILURES

A. C&W power supply A/system timing - A failure of power supply A or loss of the system timing will illuminate all lights on the CWA matrix on the F7 panel (except the B/U C&W alarm light), enunciate a C&W tone, and illuminate two of the four bulbs in each MA pbi. The A power supply receives power through the Essential (ESS) 1BC C&W A circuit breaker on the O13 panel. With the loss of this power supply, the O13 circuit breaker should be opened to extinguish the CWA lights. Functions that are lost with this failure are

1. All F7 panel C&W annunciation lights
2. The C&W status panel lights and all functions on R13U
3. Two of four bulbs in each MA light
4. Emergency tones to dedicated speaker coils
5. Bypass tones to flight deck Speaker Unit (SU)
6. Primary C&W limit sensing
7. Smoke detection A-tone generation (L1 lights still function.)
8. Operational Instrumentation (OI) telemetry of MAs

The next-worst failure is an ESS 2CA bus loss, which results in a time-critical fuel cell failure. This failure is not annunciated because the C&W B is also being unpowered. A crewmember is required to continually monitor the fault summary messages on the CRT until the "Caution and Warning Electronics Unit Contingency Power" In-Flight Maintenance (IFM) is performed.

**Note: If the ESS 1BC C&W A circuit breaker on O13 is cycled and the power supply A is regained, memory for the hardware C&W has been cleared. Parameter inhibits and limit values that differ from the default values must be reset.**

The loss of the ESS 1BC O13 bus, which supplies power to C&W A, will illuminate the MA lights (only two of four bulbs) and enunciate an MA tone; however, no lights will be illuminated on the C&W matrix on the F7 panel.

B. C&W power supply B - A failure of power supply B will illuminate both the primary and B/U C&W lights on the CWA matrix on F7, enunciate a C&W tone, and illuminate two of the four bulbs in the MA pbi's.

The B power supply receives power through the ESS 2CA C&W B circuit breaker on panel O13. Functions that are lost with this failure are

1. Two of four bulbs in each MA light.

2. Emergency tones to dedicated speaker coils.
3. Bypass tones to middeck SU.
4. Smoke detection B-tone generation (L1 lights still work.)
5. B/U C&W light on F7 cannot be reset.

The next-worst failure is an ESS 1BC bus loss, which results in a time-critical fuel cell failure. This failure is not annunciated because the C&W A is also being unpowered. A crewmember is required to continually monitor the fault summary messages on the CRT until the "Caution and Warning Electronics Unit Contingency Power" IFM is performed.

Failure of the ESS 2CA O13 bus, which supplies power to the C&W B system, will have the same indications as power supply B, with the exception of additional bus loss indications, such as loss of pilot Audio Terminal Unit (ATU) talk capability (R - audio power) and AC2 bus sensor.

#### C. C&W IFM

If a failure occurs that affects the ability of C&W system A or B to generate tones (power supply or essential bus power), the loss of the essential bus power to the remaining C&W system will not be annunciated. Because a time-critical shutdown of the fuel cell associated with this essential bus loss would be required to prevent a catastrophic failure, the fault summary messages must be continually monitored. An IFM procedure has been developed that redundantly powers the remaining C&W system or restores power to the C&W system with the bus failure. This procedure will provide C&W tone generation redundancy to alert the crew to an essential bus failure.

If C&W power supply B (A) fails, the IFM will use a breakout box and the Caution and Warning System (CWS) contingency power cable to redundantly power C&W power supply A (B). The remaining power supply will now be redundantly powered from the ESS 1BC (2CA) bus and through the breakout box, which is receiving power through a utility outlet. The CWS cable is equipped with in-line diodes to isolate the two power sources from each other. The essential bus circuit breaker is closed to supply the redundant essential bus power.

If the ESS 1BC (2CA) bus is lost, the IFM will use a breakout box and the CWS contingency power cable to power the associated C&W power supply A (B). This procedure reestablishes power to the C&W power supply through the breakout box. For this procedure, a 5-amp fuse is installed in the breakout box that will reestablish the power to the associated MA lamps and amplifiers. The essential bus circuit breaker is left open to isolate the lost bus from the power source.

## TITLE

BFS SM/SP

## PURPOSE

The purpose of the Backup Flight System (BFS) Systems Management/Special Processes (SM/SP) system brief is to familiarize the reader with the BFS as it relates to the Electrical Power System (EPS) operator. Because the BFS is an extremely complex system, no attempt will be made to thoroughly explain it here. Only the relationship between the BFS and the electrical system will be covered, plus some unique characteristics of the BFS that affect the EPS operator. If more information is required, the reader is encouraged to complete the training workbooks on the BFS.

For detailed information regarding any of the software/hardware tasks, interfaces, etc., the following references may be used:

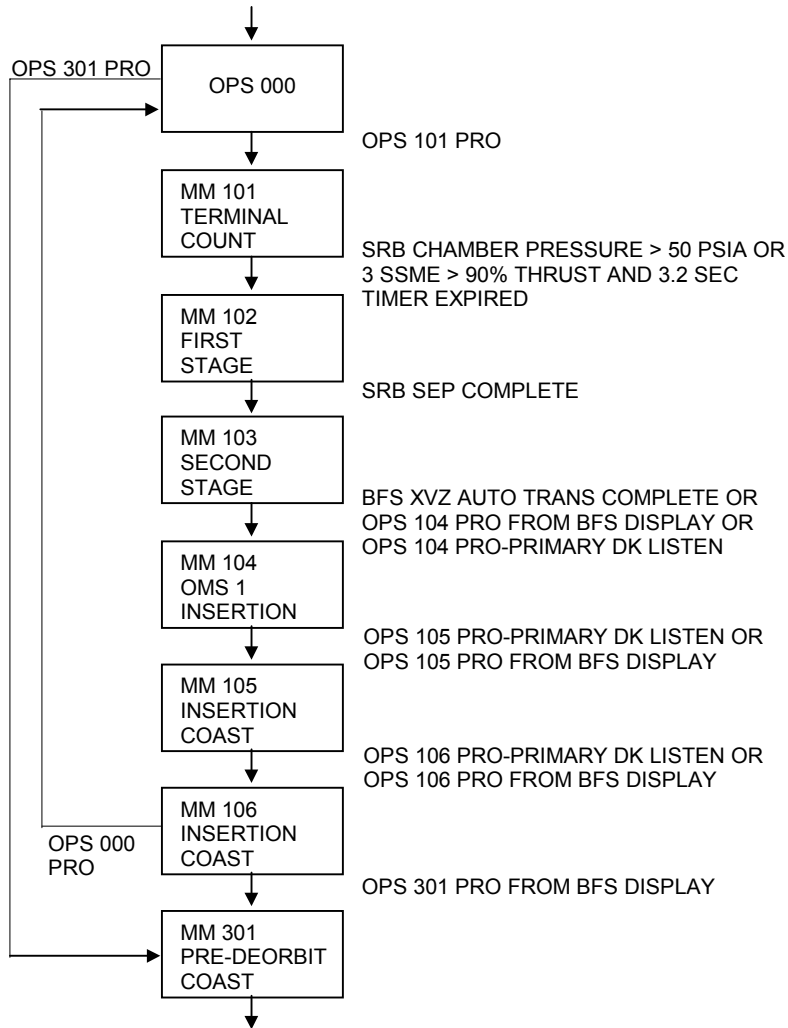
BFS PRD OVERVIEW	MG038100
BFS BOS PRD	MG038101
BFS SM/SP&S PRD	MG038119

## GENERAL

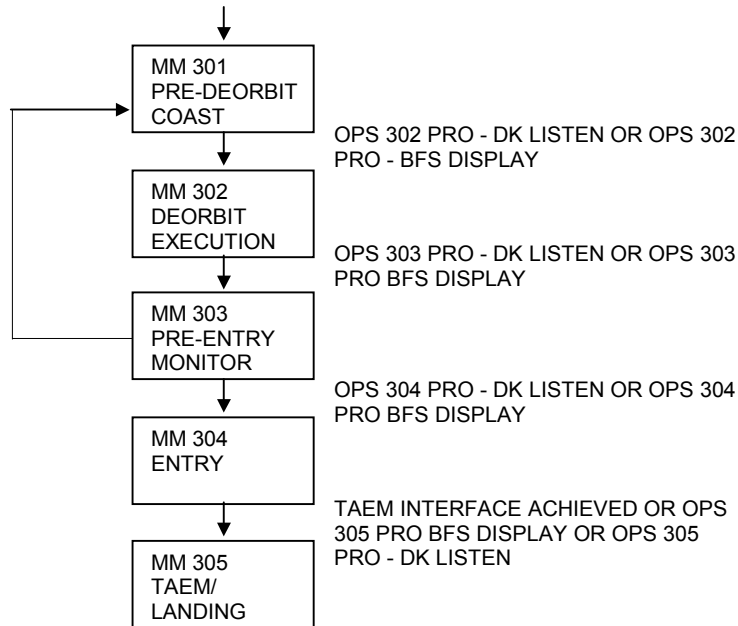
The BFS is a standalone software system that is designed to serve as a backup to the Primary Avionics Software System (PASS) during critical flight phases. The BFS is resident within a single computer and is designed to perform both Guidance, Navigation, and Control (GNC) functions and SM functions. The BFS SM/SP application programs are primarily concerned with the ascent and entry operational missions. The ascent timeline (Figure 5.2-1) begins at T-10 hours (OPS 000) and continues through MM 106 on orbit. The entry timeline (Figure 5.2-2) begins at transition to MM 301 on orbit and continues through Ground Support Equipment (GSE) connect on the ground. During ascent and entry (OPS 1 and OPS 3), the BFS performs all the nonflight control SM functions, whether the BFS is engaged or disengaged. The SM function scaling/display includes FDA. The FDA function includes both the Class 2 (backup C&W) and Class 3 (SM alert) FDAs. The BFS SP computer application program contains and provides computation and control processes for the following BFS functions:

- A. Fuel cell total current and power calculations
- B. Fuel cell end cell heater monitoring - Resident in BFS, but heaters are no longer on the fuel cell

These functions are executed whenever the BFS GPC mode switch is in either the STDBY or RUN mode and are executed once per major cycle, which occurs every 960 milliseconds.



**Figure 5.2-1. Ascent major mode transitions**



**Figure 5.2-2. Entry major mode transitions**

Figure 5.2-3 shows the invocation tree for SM and SP. It also indicates the control structure and software elements contained in SM and SP. The blocks in this figure represent tasks (where the module is attached or detached), procedures or functions (where the module is called), or inline code blocks. The implementation of any particular module as a task procedure, function, or inline code block depends upon such factors as space and time efficiency, Input/Output (I/O) requirements, and BFS Operating System (BOS) interface and synchronization requirements. A description of each of these elements follows.

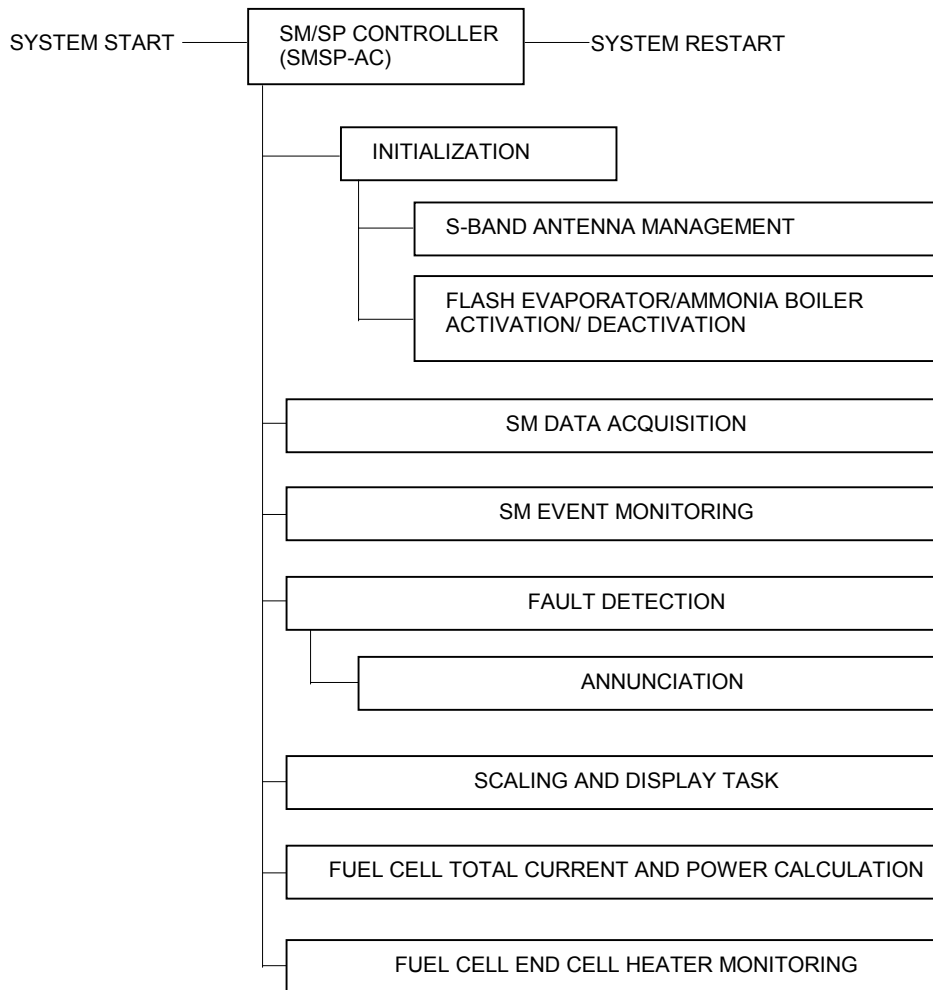
## PROCEDURE

### 1. SM/SP controller

The SM/SP application controller is activated by the BOS at BFS start or restart time. It performs four functions.

- a. Initialization - Executed when the SM/SP application controller is first entered at a BFS start or restart. It initializes the COMPOOL data and attaching of all SM/SP tasks to be executed cyclically whenever the BFS is active and where outputs are not dependent upon Pulse Code Modulation Master Unit (PCMMU) or payload data acquisition. These tasks include S-band antenna management and flash evaporator/ammonia boiler activation and deactivation.
- b. SM data acquisition - Accomplished by the SM/SP application controller, who determines whether the I/O transactions performed by the BOS to acquire data from the PCMMU and the payload Multiplexer/Demultiplexers (MDMs) have been successful. If the transactions have been successfully completed, the SM controller attaches the required tasks.

- c. SM event monitoring - Runs cyclically after initialization and responds to any of the time- or mission-dependent events by attaching or detaching the appropriate module.
- d. Restart recovery - Also performed by the SM/SP application controller whenever the BOS indicates that a restart has been initiated because of a power transient or other condition. When a restart occurs, the BOS will attach the SM/SP application controller. The restart has no effect, other than the loss of an indeterminate amount of time (GPC memory is not destroyed). All SM modules are restarted as if it was their first invocation.



**Figure 5.2-3. SM/SP invocation tree**

2. Fault detection and annunciation

The FDA system in the BFS is very similar to the FDA in the PASS software. There are some exceptions, including the following:

- a. No variable filter count for annunciation
- b. Different fault messages
- c. Fewer limit-sensed parameters

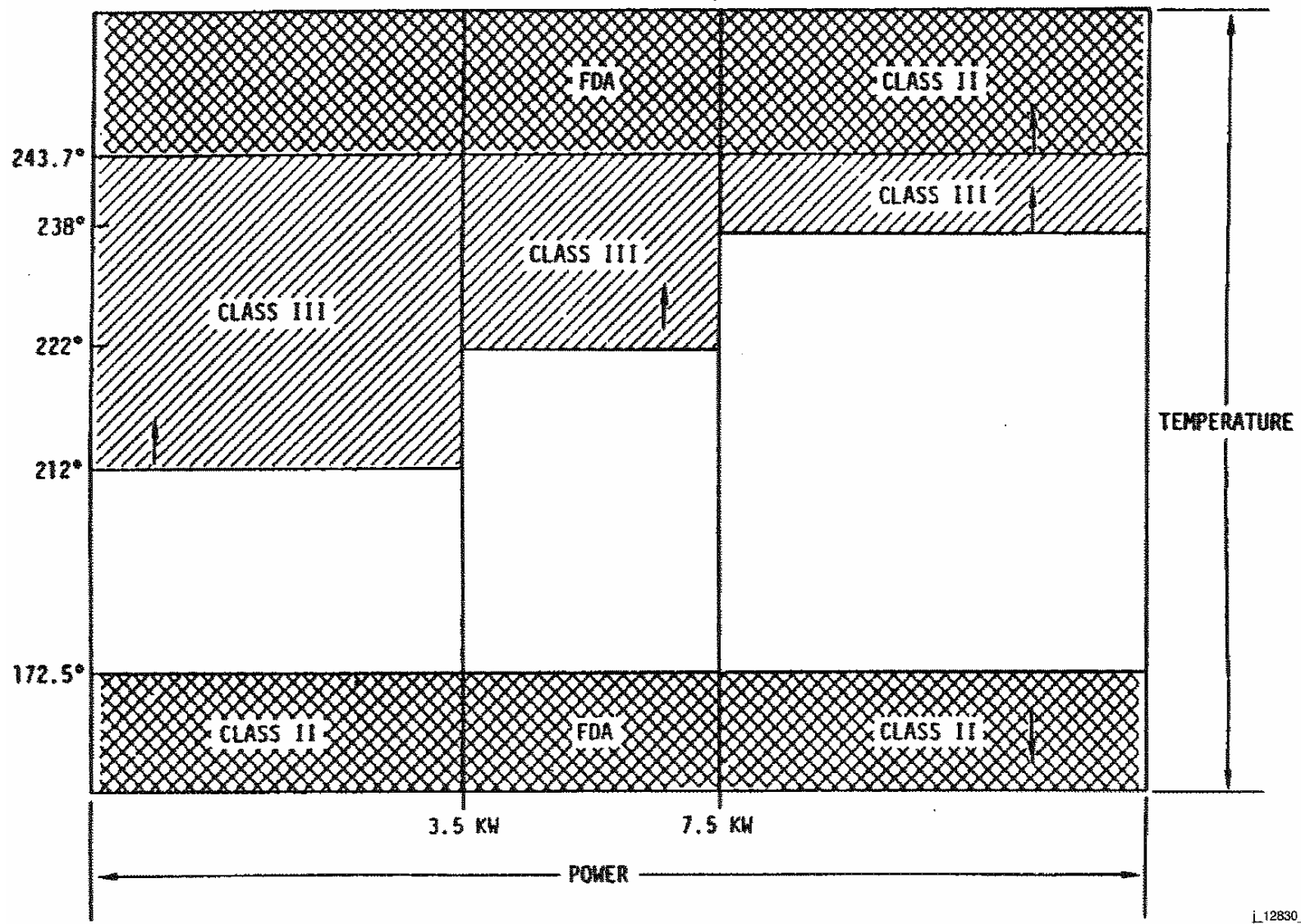
The lack of the variable filter count for annunciation means that a parameter must be out of limits for two, and only two, cycles of the FDA software before it is annunciated. In the PASS SM, the n-count filter is variable; i.e., the software can be set such that it will not annunciate until the parameter has been out of limits for a variable number (up to 15) of cycles. In the BFS, it will always annunciate after two successive out-of-limit cycles. In addition, the parameter must return within limits for the same number of cycles in order to be considered within limits by the FDA software, thereby stopping annunciation. This is true in both BFS and PASS.

The fault messages generated by the BFS FDA software are, in many cases, different from the messages generated by the PASS FDA, even for the same parameter being out of limits. For example, an out-of-limits O<sub>2</sub> manifold pressure in the PASS will generate an S68 O<sub>2</sub> MANF PRESS message, but the BFS message will be SM2 CRYO O<sub>2</sub> MANF. In almost all cases, the BFS messages are more specific. For a complete list of the FDA messages in the BFS and PASS, consult the Reference Data book in the Flight Data File or the Flight Software Requirements.

3. Fuel cell stack cool-out temperature (Stack Out T)

Fault detection on the fuel cell stack coolant outlet temperature is performed in basically the same manner in the BFS as in the PASS, with one difference. The Class 2 alarm in the PASS and BFS is generated whenever the fuel cell stack temperature is less than 172.5° F or greater than 243.7° F. Generation of the Class 3 alarms, however, is different in the PASS and BFS. In the PASS, both upper and lower limits exist and are conditional on the fuel cell power being produced by that fuel cell. The higher the power level is, the higher the limits are. In BFS, the Class 3 upper limits are conditional on power, but there are no lower limits. The only low-limit protection is the Class 2 alarm.

The three fuel cell stack cool-out temperature parameters have multiple limits. These limits are divided into two groups. Group 1 consists of the maximum and minimum temperatures allowable. Class 2 alarms are issued when these limits are exceeded. Group 2 consists of variable upper limits that depend on the fuel cell power outputs. Class 3 alarms are issued when these limits are exceeded. Figure 5.2-4 depicts the relationship between power outputs and stack cool-out temperature.



5.2-6

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Figure 5.2-4. Fuel cell current and power computation/stack coolant and outlet temperature alarms

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The following list evaluates the relationship between fuel cell output and associated stack temperature needed to satisfy the multilimit sets for fuel cell cool-out temperature. If, for any cell, the stack cool-out temperature is under 172.5° F or above 243.7° F, a Class 2 alarm is issued.

- a. FUEL CELL NO. 1 CURRENT V45C0101A(I1)
- b. FUEL CELL NO. 2 CURRENT V45C0201A(I2)
- c. FUEL CELL NO. 3 CURRENT V45C0301A(I3)
- d. FUEL CELL NO. 1 VOLTAGE V45V0100A(E1)
- e. FUEL CELL NO. 2 VOLTAGE V45V0200A(E2)
- f. FUEL CELL NO. 3 VOLTAGE V45V0300A(E3)
- g. FUEL CELL NO. 1 STACK COOL OUT TEMP V45T0120A
- h. FUEL CELL NO. 2 STACK COOL OUT TEMP V45T0220A
- i. FUEL CELL NO. 3 STACK COOL OUT TEMP V45T0320A

Comparing the magnitude of the power level output of each fuel cell (E111, E212, and E313 in kW) against the following signals:

- (1) FC POWER LEVEL 1 (3.5 KW) V92E0630C
- (2) FC POWER LEVEL 2 (7.5 KW) V92E0631C

If the magnitude of the power level of any fuel cell is equal to or less than 3.5 and its respective stack cool-out temperature (7), (8), (9) above, is greater than 212° F, a Class 3 alarm is issued.

If the magnitude of the power level of any fuel cell is between 3.5 and 7.5 and its respective stack cool-out temperature (7), (8), (9) above, is greater than 222° F, a Class 3 alarm is issued.

If the magnitude of the power level of any fuel cell is equal to or greater than 7.5 and its respective stack cool-out temperature (7), (8), (9) above, is greater than 238° F, a Class 3 alarm is issued.

#### 4. H<sub>2</sub> and O<sub>2</sub> reactant valves

Each fuel cell has its H<sub>2</sub> and O<sub>2</sub> reactant valve positions combined into one display. If both valves are open, an OP will be displayed. If either the H<sub>2</sub> or O<sub>2</sub> valve is closed, a CL will be displayed.

5. SP computer application programs

- a. There are two SP application programs having output that is not dependent upon PCMMU or payload data acquisition. These tasks are S-band antenna management and flash evaporator/ammonia boiler activation and deactivation.
- b. The remaining SP application programs require PCMMU or payload data. These tasks include the fuel cell total current and power computation and the fuel cell end cell heater monitor.

(1) Fuel cell total current and power computation

This sequence computes the total current and power of the three fuel cells. The total current and power computation of the fuel cells are active for both ascent and entry to provide a status of the EPS. The backup flight computer is used to perform this special processing requirement during ascent and entry. The total current and power generated by the three fuel cells are computed by summing (in kW) the current and power, respectively, generated by the individual fuel cells.

The measured values of current and voltage for each fuel cell are obtained from the orbiter instrumentation data. The results of the computations of total current and power are available on the CRT display. The sequence monitors the input parameters and processes the computed outputs at a rate of once every two major cycles.

Step 1 - The following signals are monitored to perform the current and power computations:

- |    |                         |               |
|----|-------------------------|---------------|
| 1. | FUEL CELL NO. 1 CURRENT | V45C0101A(I1) |
| 2. | FUEL CELL NO. 2 CURRENT | V45C0201A(I2) |
| 3. | FUEL CELL NO. 3 CURRENT | V45C0301A(I3) |
| 4. | FUEL CELL NO. 1 VOLTAGE | V45V0101A(E1) |
| 5. | FUEL CELL NO. 2 VOLTAGE | V45V0201A(E2) |
| 6. | FUEL CELL NO. 3 VOLTAGE | V45V0301A(E3) |

Step 2 - The total current and total power of the fuel cells are computed by the following equations:

$$I_T = I_1 + I_2 + I_3 \quad V92C0311C$$

and

$$P_T = (E1 \cdot I1 + E2 \cdot I2 + E3 \cdot I3) / 1000$$

V92C0310C

where

$I_T$  = Total current in amperes

$P_T$  = Total power in kilowatts

$I1$  = Current fuel cell No. 1

$I2$  = Current fuel cell No. 2

$I3$  = Current fuel cell No. 3

$E1$  = Voltage fuel cell No. 1

$E2$  = Voltage fuel cell No. 2

$E3$  = Voltage fuel cell No. 3

If  $I_T > 1500$ , the value of  $I_T$  is set equal to 1500 with a status indicator of "H." If  $I_T < 0$ , the value of  $I_T$  is equal to 0 with a status indicator of "L."

If  $P_T > 60$ , the value of  $P_T$  is set equal to 60 with a status indicator of "H." If  $P_T < 0$ , the value of  $P_T$  is set equal to 0 with a status indicator of "L."

Step 3 - The following outputs from the computations, along with any associated status indicators, are made available for CRT display:

1. TOTAL FUEL CELL CURRENT ( $I_T$ ) V92C0311C
2. TOTAL FUEL CELL KILOWATTS ( $P_T$ ) V92E0310C

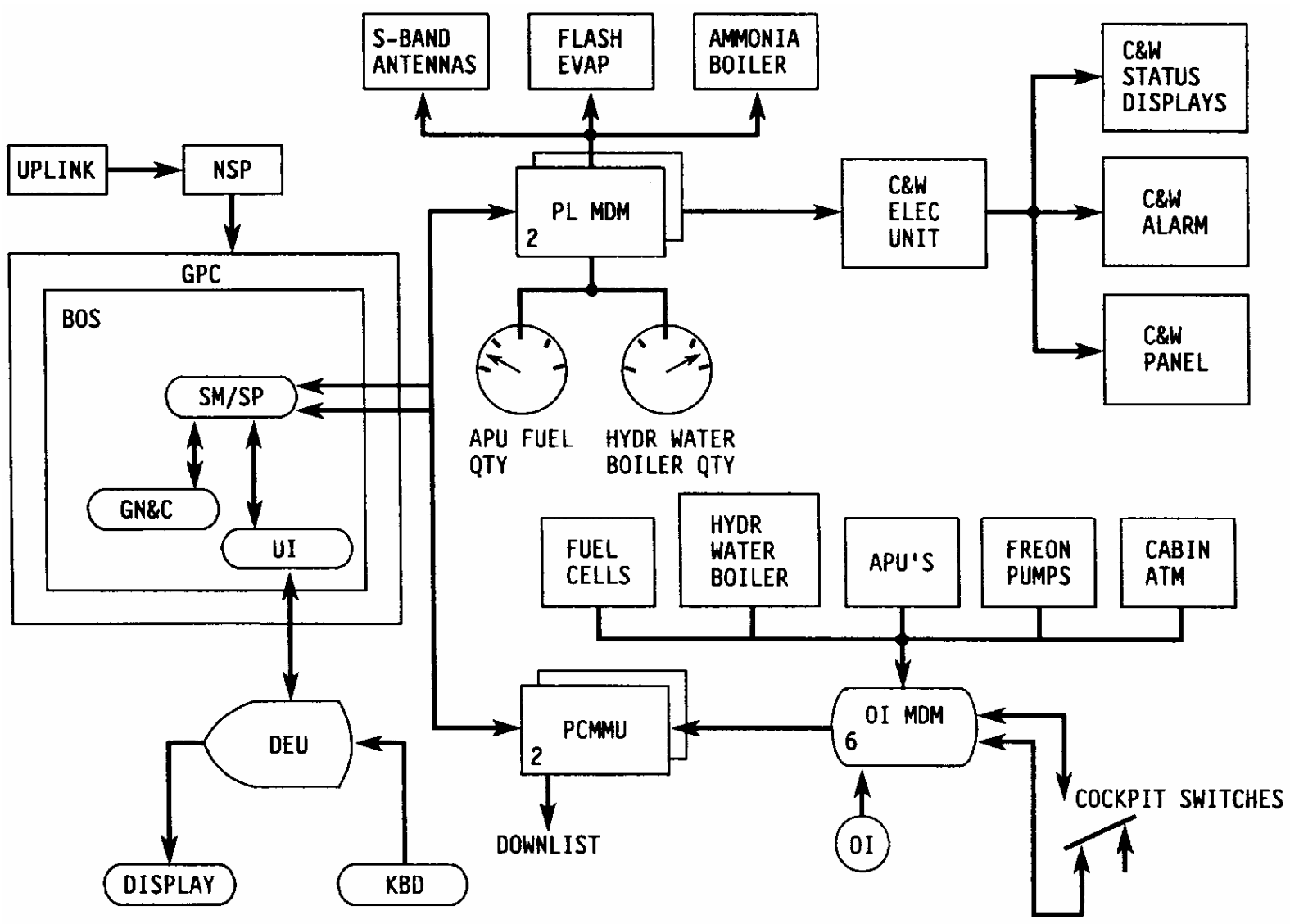
**Note: If a parameter value required by this computation has a missing or invalid status indicator enabled, the respective computation is suspended and displays the most recently calculated value, along with a status indication of "M."**

(2) Fuel cell end cell heater monitor

Because the end cell heaters do not exist on the current fuel cells, no FDA should be received for this. For information on how this SP works, refer to the BFS PRD MG038119.

6. SM/SP hardware interface

An overview of the hardware interfaces with the SM/SP software is shown in Figure 5.2-5.



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Figure 5.2-5. SM/SP hardware interfaces

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5.2-11

**TITLE**

CAUTION AND WARNING ELECTRONICS UNIT CONTINGENCY POWER (CIL)

**PROCEDURES**

In-Flight Maintenance (IFM) procedure regains fail-safe operation of the C&W Electronics Unit (EU) by either bypassing a failed essential bus or redundantly powering a C&W EU power supply. This procedure is used to eliminate a time-critical unannounced fuel cell failure due to the loss of an essential bus following a previous loss of one-half of the C&W EU (system A or B). This procedure requires the use of premanufactured Caution and Warning System (CWS) contingency power cables, of which there are two, cable A and cable B. Cable A mates with the connector for the C&W EU A power supply, and cable B mates with the connector for the B power supply.

1. Access C&W EU in Av bay 3A.
2. Power down EU.
3. Install C&W system contingency power cable (A or B).
4. Repower EU.
5. Perform C&W system checkout.
6. Close out Av bay 3A.

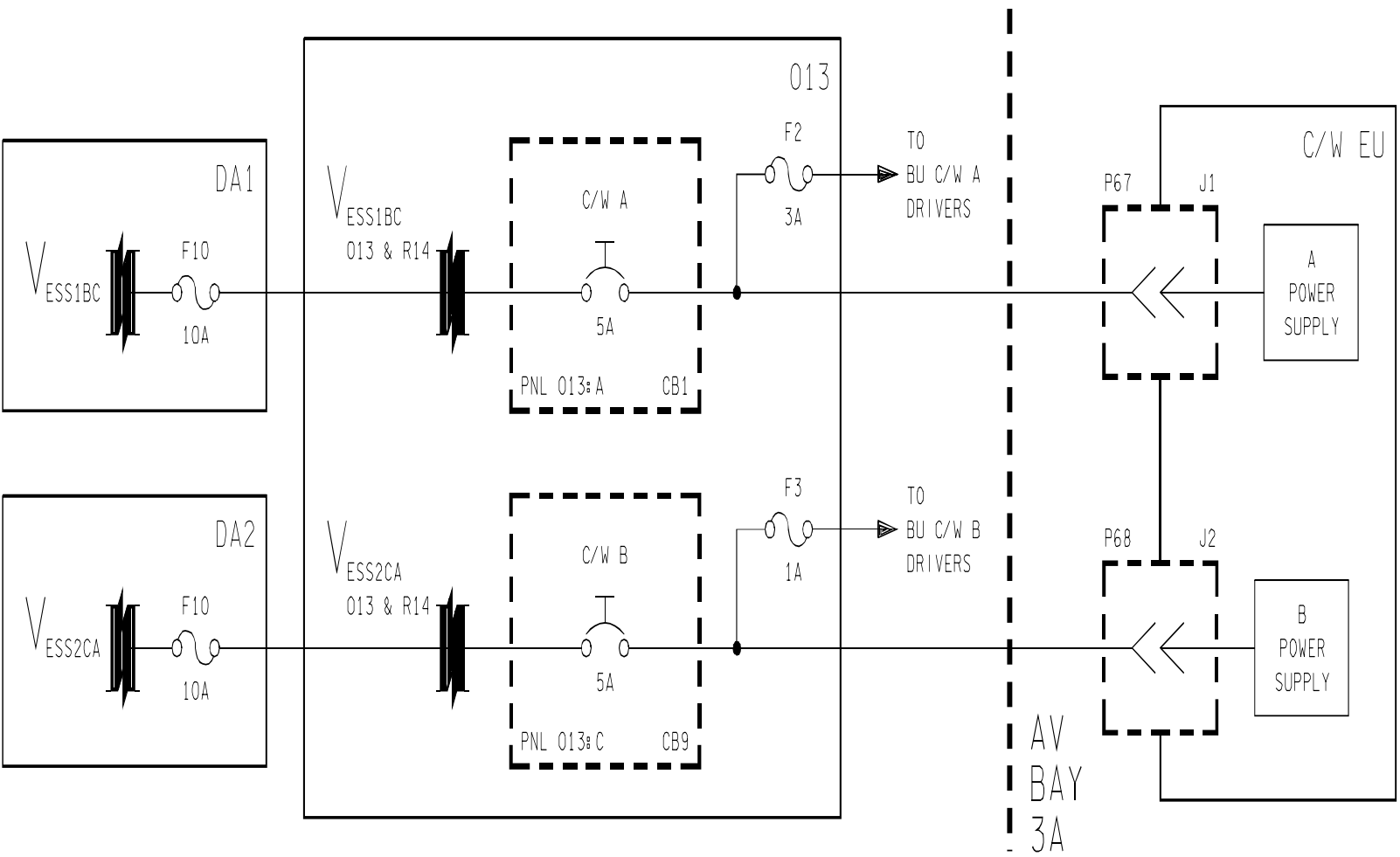
**FAILURES**

A single loss of any one of the following:

- A. C&W power supply A
- B. C&W power supply B
- C. Essential bus 1BC DA1
- D. Essential bus 1BC O13/R14
- E. Essential bus 2CA DA2
- F. Essential bus 2CA O13/R14

**BACKGROUND**

Essential bus 1BC and 2CA supply power to the C&W A and B power supplies, respectively (Figure 5.3-1).



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Figure 5.3-1. Orbiter C&W connections

5.3-2

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Loss of an essential bus will cause the loss of a fuel cell coolant pump. The fuel cell must be shut down within 9 minutes to avoid a possible loss of crew/vehicle due to fuel cell overheating and crossover. An essential bus loss following a previous loss of redundant C&W capability (loss of system A or B) will result in the time-critical coolant pump loss situation with no aural warning to the crew.

Possible solutions following the loss of one-half of C&W:

1. Shut down the fuel cell associated with the essential bus powering the remaining C&W system.
2. Have the crew continuously monitor CRTs and talkbacks for failure indications of the bus in question.
3. Implement the IFM.

There are two failure modes that cause loss of one-half of C&W:

- A. Essential bus loss 1BC DA1, 1BC O13/R14, 2CA DA2, or 2CA O13/R14
- B. C&W power supply A (or B) failure

The CWS contingency power cables can be used to alleviate both of these failure modes. The cables are installed in-line with the existing C&W EU power harnesses. By inserting a fuse into the contingency power cable, the cable can be used to send power both into the EU and back to the O13 panel to power the backup C&W annunciators (see Figures 5.3-2 and 5.3-4). With the fuse removed, the cable can be used to diode two power sources together and thus redundantly power the EU power supply (see Figures 5.3-3 and 5.3-5). The malfunctions procedures book directs the crew to perform this IFM following a loss of one-half of C&W. The cable is designed to remain installed for the remainder of the mission and for entry.



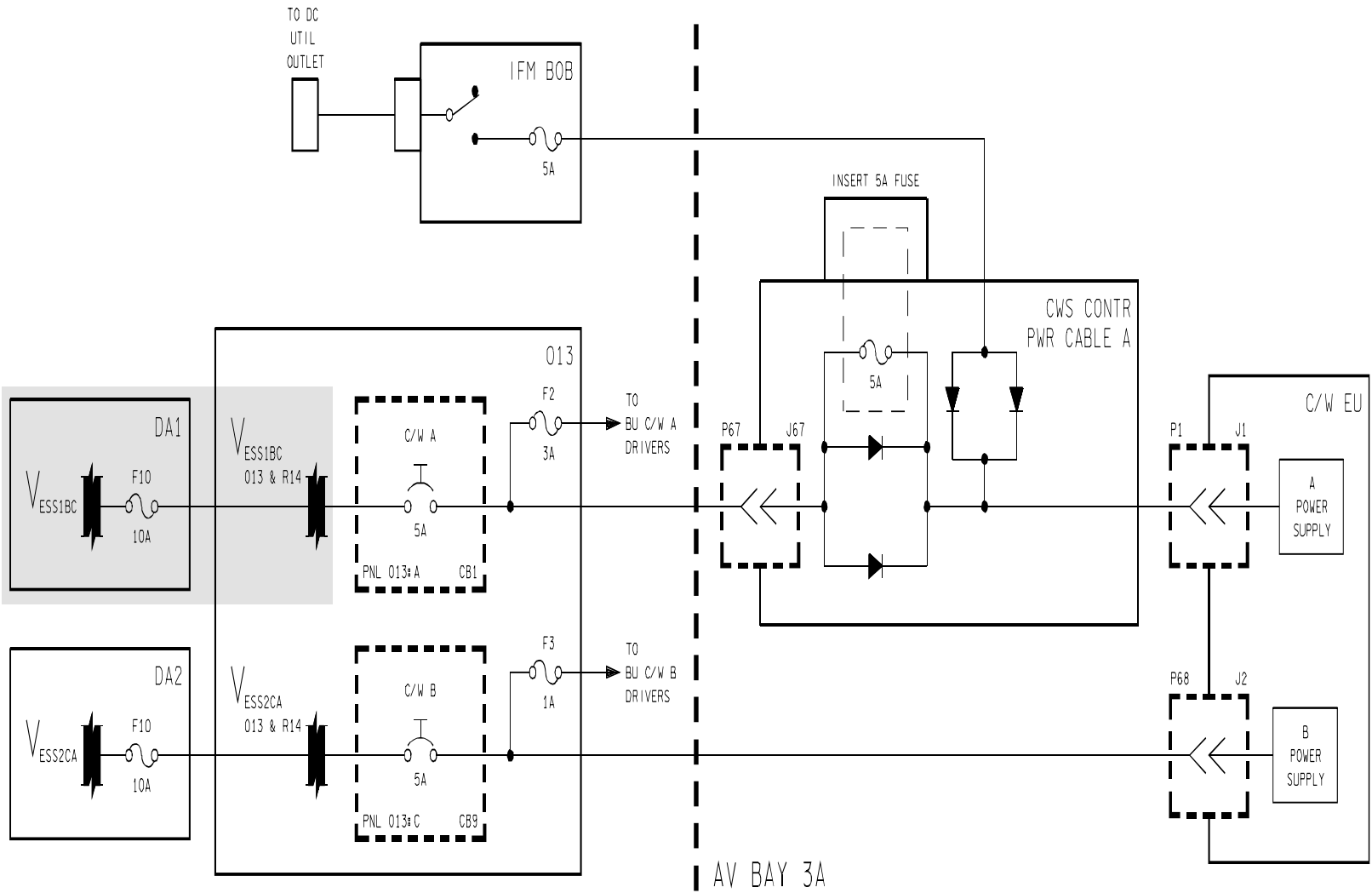


Figure 5.3-2. C&W contingency power cables/orbiter C&W connection - case I

5.3-4

Verify that this is the correct version before use.

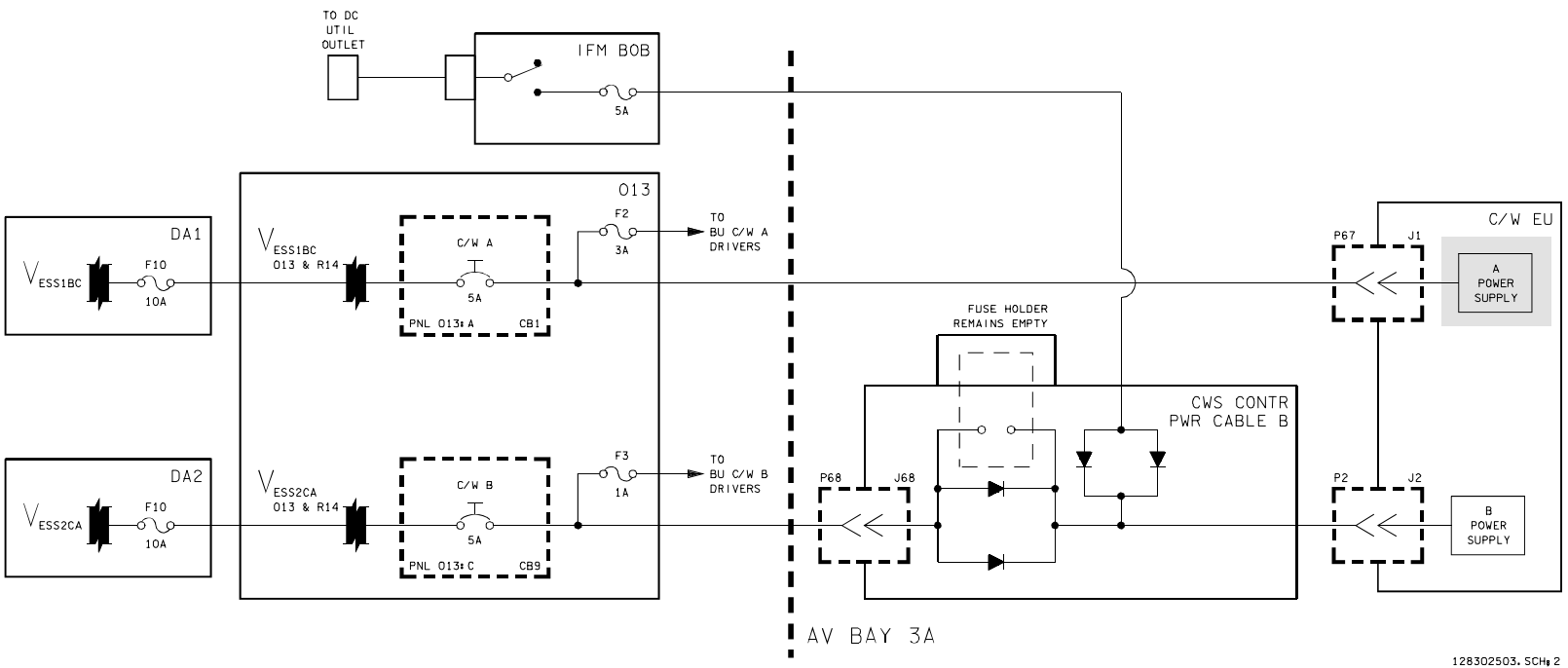
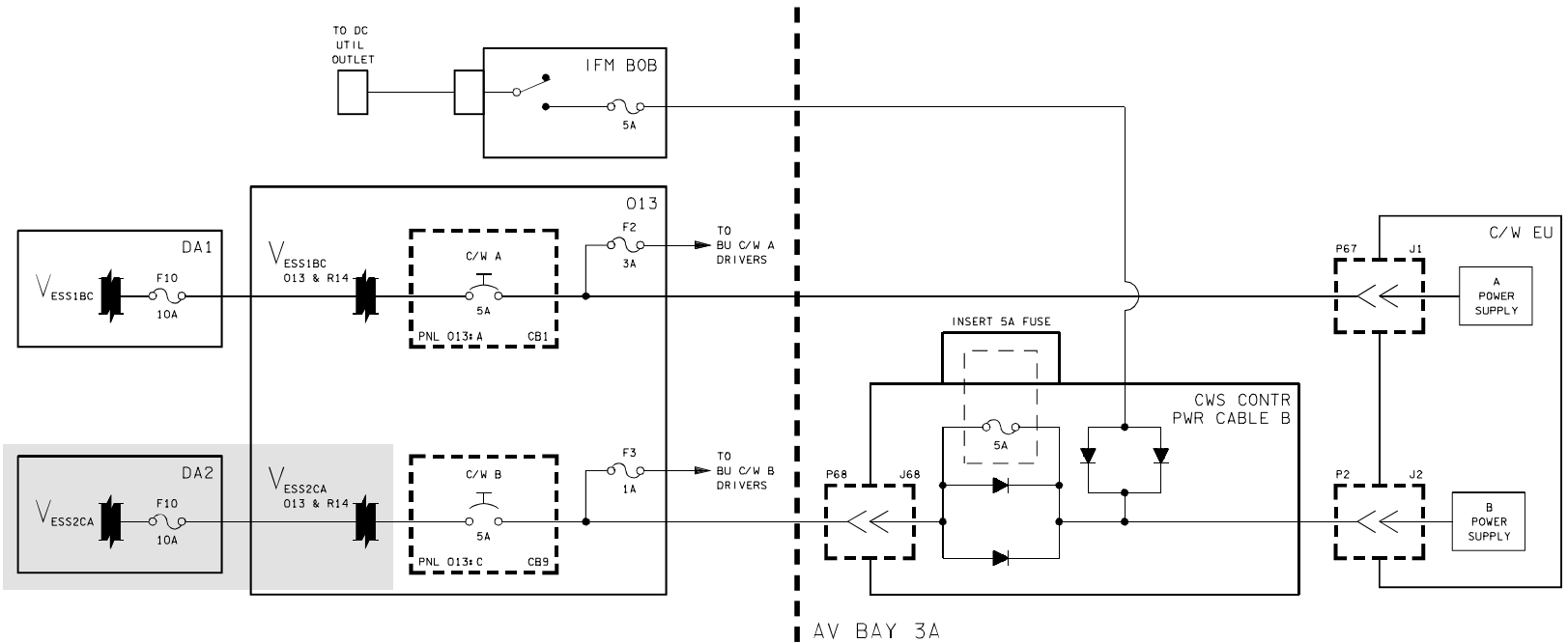


Figure 5.3-3. C&W contingency power cables/orbiter C&W connection - case II

5.3-5

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128302504, SCH 2

Figure 5.3-4. C&W contingency power cables/orbiter C&W connection - case III

5.3-6

Verify that this is the correct version before use.

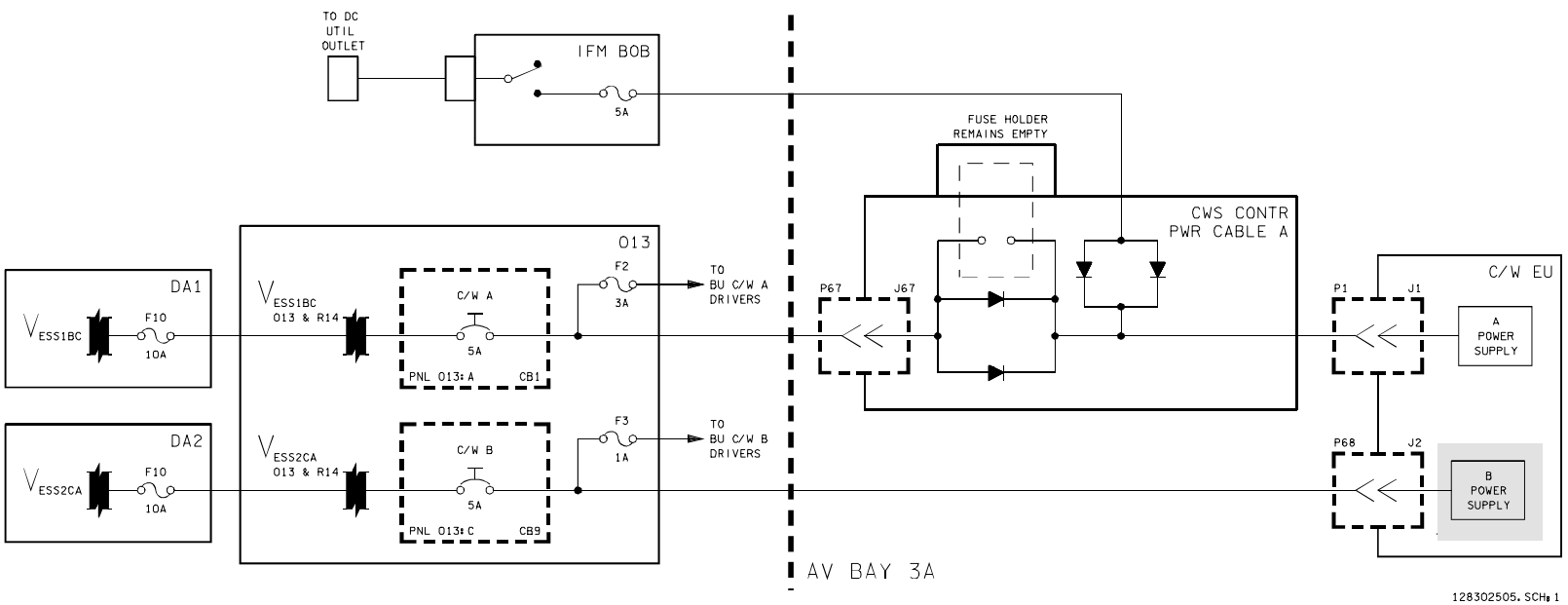


Figure 5.3-5. C&W contingency power cables/orbiter C&W connection - case IV

5.3-7

Verify that this is the correct version before use.

**Notes for cases I and III (Figures 5.3-2 and 5.3-4)**

1. Regains full C&W.
2. Contingency power cable is used to bypass the failed bus. Cable A is shown in Figure 5.3-2; cable B is shown in Figure 5.3-4.
3. In this configuration, the diodes serve no electrical purpose and are unnecessary.
4. A 5-amp fuse is inserted to act as a “copper penny,” which bypasses the diodes and powers the backup C&W annunciators.

**Notes for cases II and IV (Figures 5.3-3 and 5.3-5)**

1. The C&W system remains single string, but the remaining power supply is now redundantly powered. In the event of an essential bus loss, the C&W unit remains powered and the crew will get an alarm signal.
2. The diodes in the cable are used to isolate the essential bus power source from the DC utility power supply. This redundantly powers the remaining C&W power supply. Cable A is shown in Figure 5.3-3; cable B is shown in Figure 5.3-5.
3. Pairs of diodes installed in parallel are used for circuit isolation because the most common failure mode for a diode is for it to fail to conduct in the forward direction. Thus, a single diode can fail and the cable still performs its function.
4. Cable is to remain unfused.
5. Circuit protection is from the circuit breaker in panel O13 and from the 5-amp fuse in the IFM breakout box.

**REFERENCES**

CWS contingency power cables:

- A. Flight Support Equipment Configuration Control Board (FSE CCB) Change Request (CR) #G1981.
- B. Boeing drawing number 528-20216.

C&W EU:

- A. Rockwell Integrated Schematic VS70-730129.
- B. FMEA/CIL 05-3-12309-09.

## TITLE

CAUTION AND WARNING MODE SWITCH

## PURPOSE

This SCP describes the function of the Caution and Warning (C/W) Mode switch.

## DISCUSSION

The purpose of the C/W Mode switch is to allow the crew the ability to select various modes of annunciation for the C/W system. The switch has three positions: ACK (acknowledge), NORM (normal), and ASCENT (see Figure 5.4-1). The position of this switch affects the annunciation of the Master Alarm (MA) pushbutton indicator (pbi) lights and the C/W matrix on panel F7. The C/W mode switch is located on the flight deck on panel C3. Figure 5.4-2 provides a simplified schematic of the circuitry for the C/W mode switch. SSSH drawing 5.2 sheet 2 provides a more detailed schematic.



**Figure 5.4 - 1. Caution / Warning Mode Switch**

When the switch is in NORM mode, all four MA pbi lights and the corresponding F7 C/W matrix light(s) will illuminate when the C/W system sends a MA signal. During prelaunch operations the C/W Mode switch is taken to the NORM position and typically remains there through out the entire flight because it provides the most annunciation and insight into a failure.

When the switch is in ACK mode, all four MA pbi lights will illuminate when a C/W MA signal is sent; however, the associated F7 C/W matrix light(s) will not illuminate. The F7 lights can be illuminated by pressing and holding the MA pbi on either panel F2 (commander) or panel F4 (pilot). This applies power to the F7 C/W matrix by way of the MA pbi. This position is used when the crew does not want the F7 C/W matrix annunciator lights to distract them or cause excessive glare. This position could be used for night landings.

When the switch is in ASCENT mode, the MA pbi lights on panel F2 will not illuminate when a C/W MA signal is sent. The other three MA pbi lights and the associated F7 C/W matrix light(s) will illuminate. The ascent position was intended to keep the commander from confusing the MA light with the abort light when the abort light was located next to the MA pbi light on panel F2. The abort light is now located on panel F6 so this is no longer a concern, and the ASCENT position is not ordinarily used.

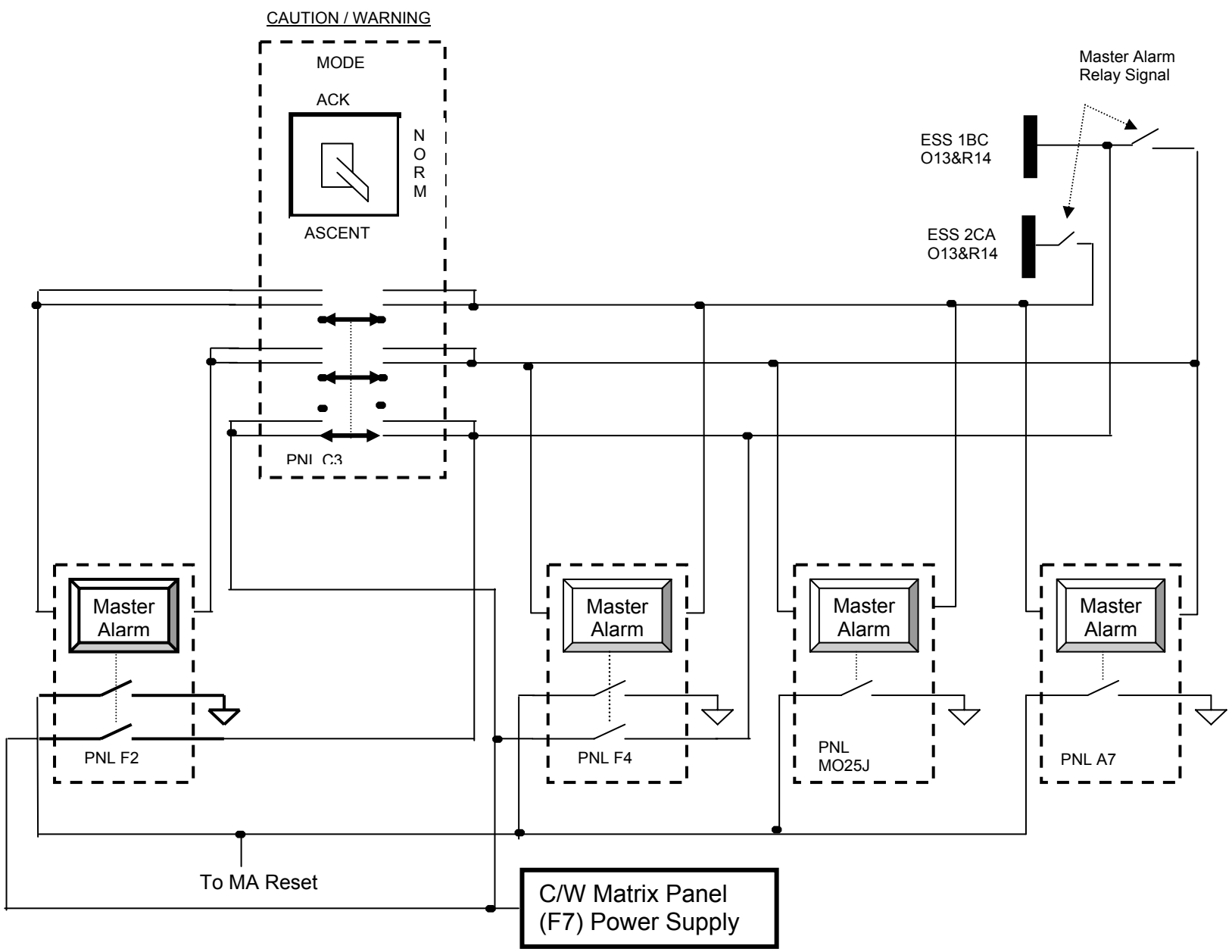


Figure 5.4 - 2. Caution / Warning Mode Switch Schematic

5.4-2

Verify that this is the correct version before use

## TITLE

RANGE SAFETY SYSTEM

## SUMMARY

The shuttle Range Safety System (RSS) is an airborne command destruct system for each Solid Rocket Booster (SRB) and the External Tank (ET) of the shuttle vehicle. This destruct system allows the Range Safety Officer (RSO) at the Eastern Space and Missile Center (ESMC) or the Western Space and Missile Center (WSMC) to intentionally destroy the above elements of the shuttle vehicle in the event of a trajectory deviation or inadvertent separation.

### A. Solid rocket booster

Each SRB RSS consists of the following:

Redundant command antennas (for location, see Figures 5.5-1 and 5.5-2)

Directional coupler

Hybrid coupler

Redundant Integrated Receiver Decoders (IRDs)

Distributor assembly (redundant and isolated control circuits, hereafter referred to as systems A and B)

Redundant NASA Standard Detonators (NSDs)

Safe and Arm (S&A) device

Seven Confined Detonating Fuse (CDF) assemblies

Redundant CDF manifolds

Linear-Shaped Charges (LSC) (see Figures 5.5-3)

Redundant battery power (RSS BATT 1, BATT 2, which is also the recovery system battery)

Interconnecting cables

The functional block diagram is depicted in Figure 5.5-4. The component specifications are listed in Table 5.5-1.

### B. External tank

The ET RSS consists of the following:

Redundant command antennas (for location, see Figures 5.5-1 and 5.5-2)

Directional coupler

Hybrid coupler

IRD

Distributor assembly (simplex input from decoder, but redundant thereafter)

Redundant NSDs

S&A device

Seven CDF assemblies

Two LSCs (Figure 5.5-5)



Redundant range safety batteries  
Interconnecting cables

The functional block diagram is depicted in Figure 5.5-6. The component specifications are listed in Table 5.5-1.

C. Cross-strapping SRB and ET

The SRB and ET are electrically cross-strapped for the ARM and FIRE commands (Figure 5.5-7) to provide access from any of the SRB antennas before SRB SEP.

## **RSS OPERATION**

The shuttle RSS is an airborne command destruct system for the SRBs and the ET of the shuttle vehicle.

When flight termination (destruct) is required, the RSO will transmit the appropriate commands to whichever ground station is active at that time. The selected ground station will transmit the RF command signals to the shuttle.

On the shuttle, each SRB and ET has two antennas (Figures 5.5-1 and 5.5-2). These antennas are updated versions of the Saturn 1B instrument unit command system equipment. They are located to minimize cable losses and to provide 95 percent spherical coverage.

In order to provide the required 95 percent spherical coverage and the required 12 dB threshold sensitivity at any point in the mission trajectory, the RSS was designed to cross-strap signals bidirectionally at a DC pulse level. This DC design was selected over the RF cross-strapping because the RF cross-strapping resulted in high signal loss due to cable attenuation. The DC pulse design reduces complexity and improves the effective antenna coverage (Figure 5.5-7).

The IRD receives the frequency modulated range command message at 416.5 megahertz (MHz) and demodulates the audio message format. The decoder section uses high-speed microprocessing techniques to determine that the received audio message has the same tone pair format as the flight code loaded into memory prior to launch. When the received message contains a tone pair sequence identical to the ARM or FIRE preloaded code, a corresponding output command of 28 volts is issued to the distributor for processing.

A nonvolatile, solid state memory device is designed within the IRD that will store two-tone, 11-character codes.

The ARM and FIRE outputs of the RSS IRD are connected directly to the distributor. The distributor provides isolation and routing for the cross-strapped ARM and FIRE signals to/from each SRB and to the ET from each SRB (Figure 5.5-7). Each section (A and B) of the distributor contains two electronic-type latching switches (as differentiated from electromechanical relays). One of these latching switches receives the ARM command pulses from the IRD (or cross-strapping), while the other receives the FIRE

command pulses. When the ARM switch is actuated, the following functions are performed:

- Provides an ARM signal to the orbiter interface to illuminate the RSS ARM light (panel F6). This light has two vertical halves to provide a fail-safe indication of ARM to the crew personnel. A light on each side of the ARM indicator is a valid ARM command indication, which could require crew action to eject.
- Provides a connection between battery power and the PIC for logic and capacitor bank charging.
- Provides a power supply to the FIRE latching switch. This function makes sure that the RSS is operational even if the ARM and FIRE commands are received in reverse order.

The FIRE latching switch receives a FIRE pulse from the RSS IRD or from cross-strapping, and, provided the ARM latching switch has previously been actuated, performs the following:

- Initiates a  $30 \pm 10$  ms time delay circuitry (this allows time for the cross-strapped FIRE signal to reach the other SRB and ET before the local system destructs).
- Upon completion of the time delay, the PIC output is switched on and the capacitor bank is discharged into the NASA NSD.

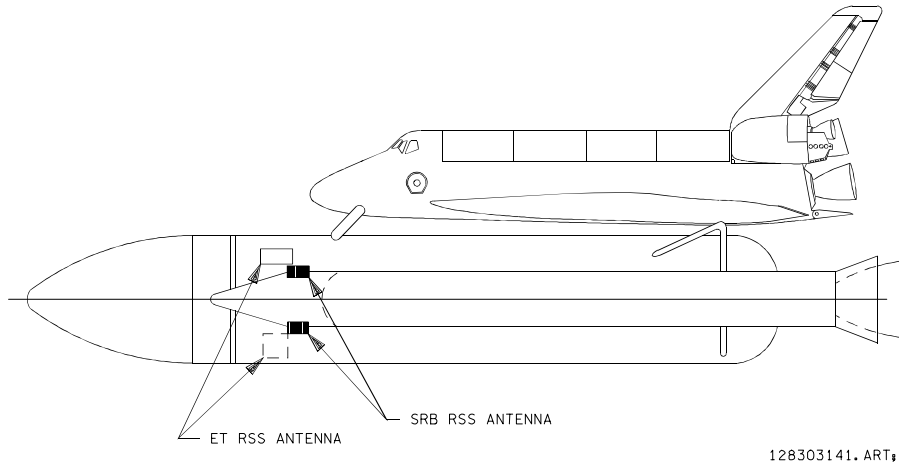
The control distributor further provides the following:

- Controls INHIBIT/RESET for the ARM latching switch.
- Controls RSS power OFF/ON.
- Distributes power to IRDs.
- Routes commands from the orbiter and GSE to ARM or SAFE the S&A device.
- Routes RSS measurements through the SRB MDM to the orbiter downlist transmission system (the ET RSS flight measurements are routed directly to the orbiter OI system).
- Contains the PIC subassemblies.

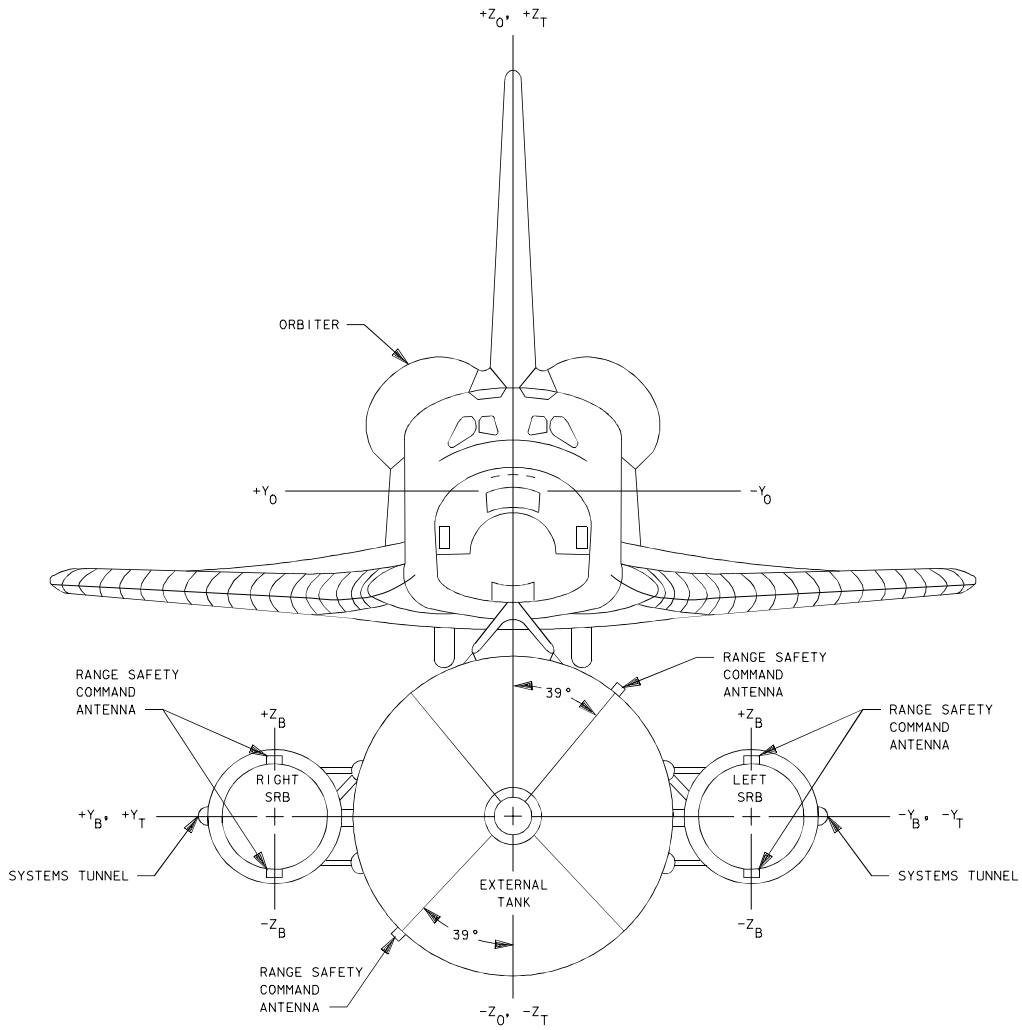
The S&A device consists of a Ledex 95° rotary solenoid assembly, a metal rotor shaft with two PETN explosive inserts, and position sensing and command switches actuated by the rotor shaft cam. An S&A device ARM command, from the LPS, causes the solenoid assembly to rotate the shaft (containing the two explosive inserts) 90°. This action aligns the inserts between the NSDs and the CDF adapters to form the initial part of the explosive train. An S&A device SAFE command causes the solenoid to advance the shaft 90°, resulting in the explosive inserts being out of alignment with the explosive train.

After live ordnance is installed on the launch vehicle, the S&A is maintained in the SAFE position to guard against inadvertent destruct. The range requirements dictate the ordnance be armed at lift-off. The ARM command is sent by ground equipment at T-5 minutes in the countdown.

During the mission and prior to the SRB separation from the orbiter and the ET, the onboard SRB separation sequence SAFES the S&A device. This is required to protect the SRB recovery personnel.

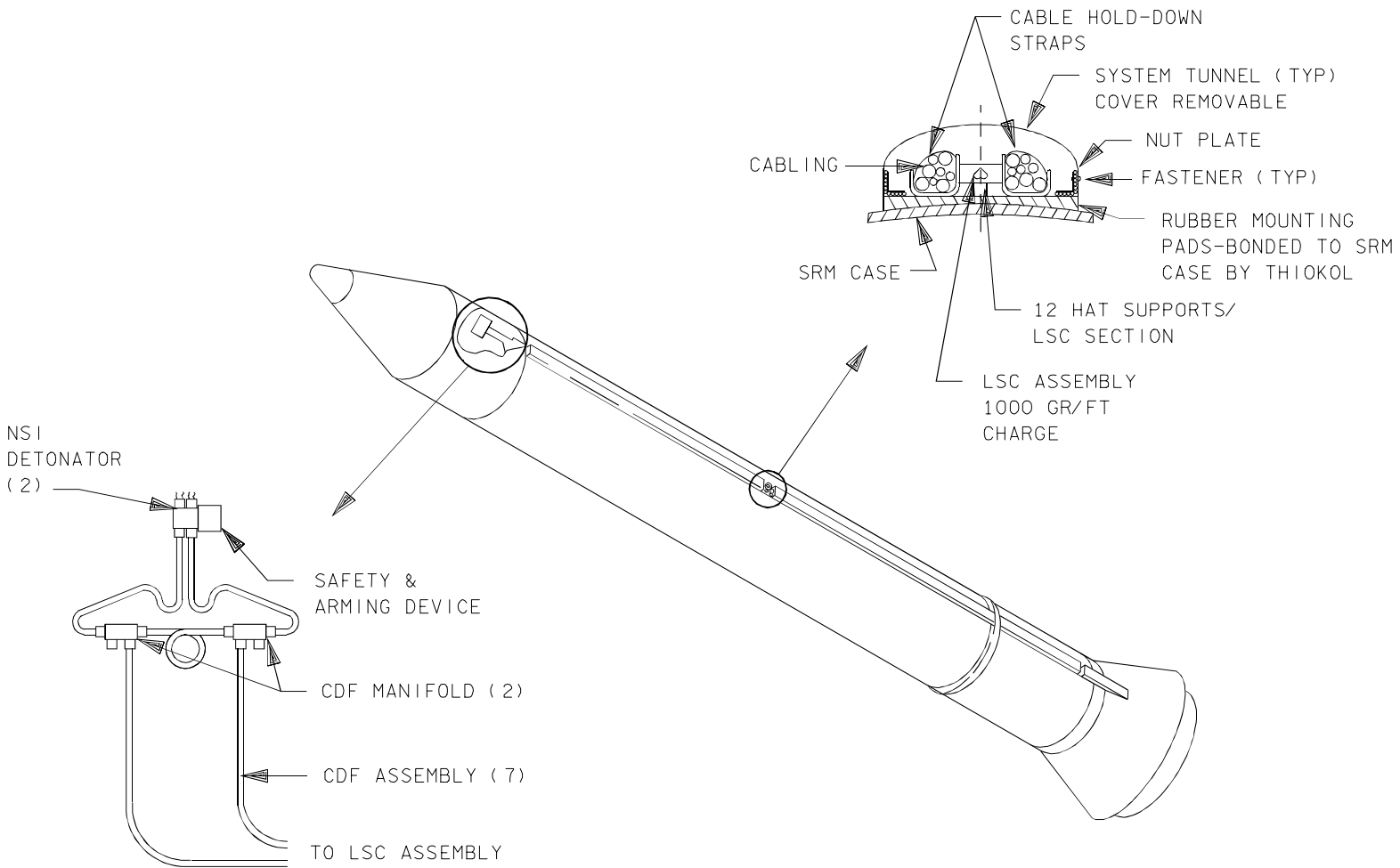


**Figure 5.5-1. Antenna locations**



128303142, ART 1

**Figure 5.5-2. Antenna locations (looking aft)**



128303143. ART# 3

Figure 5.5-3. Range safety command destruct system

5.5-6

Verify that this is the correct version before use.

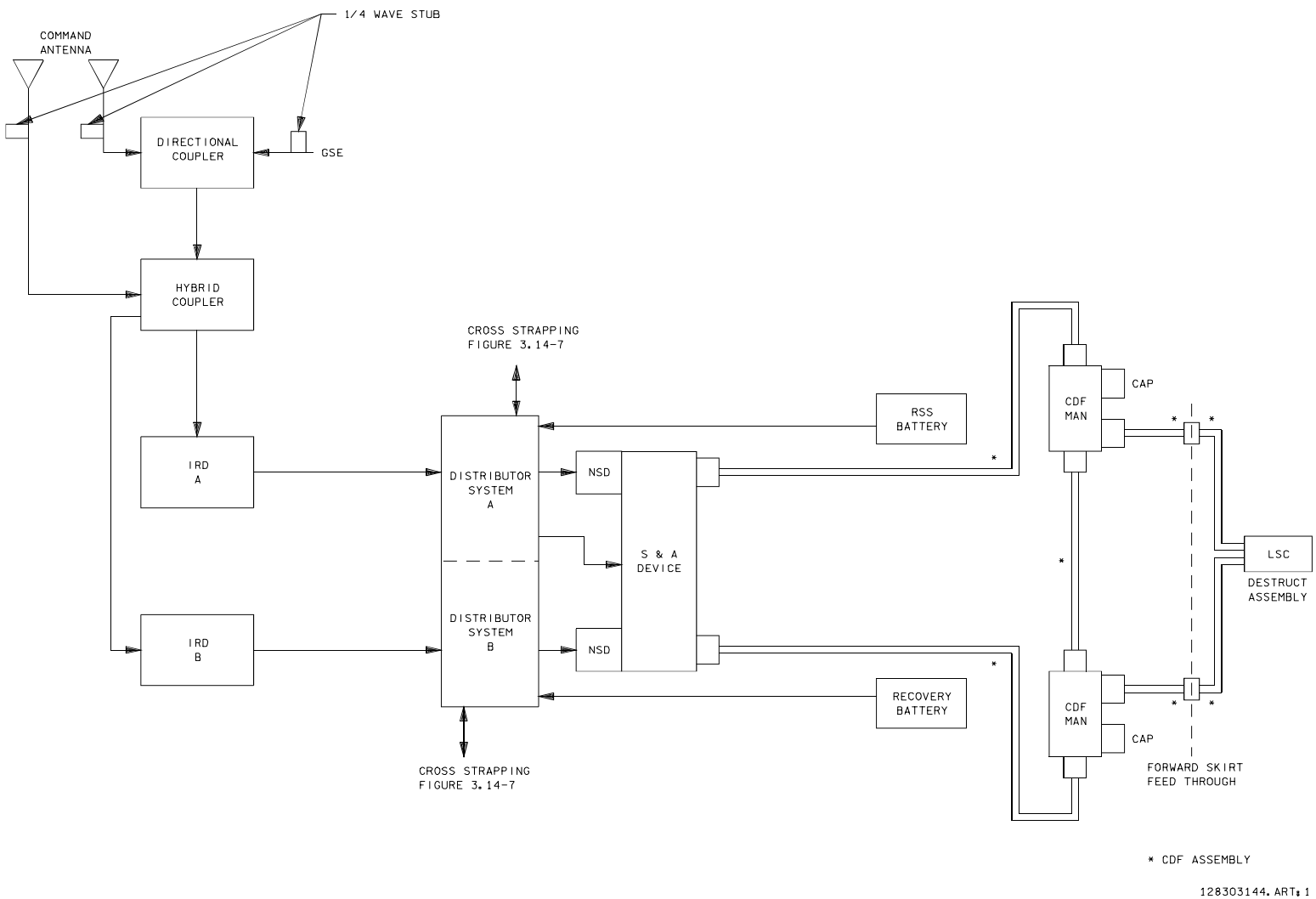
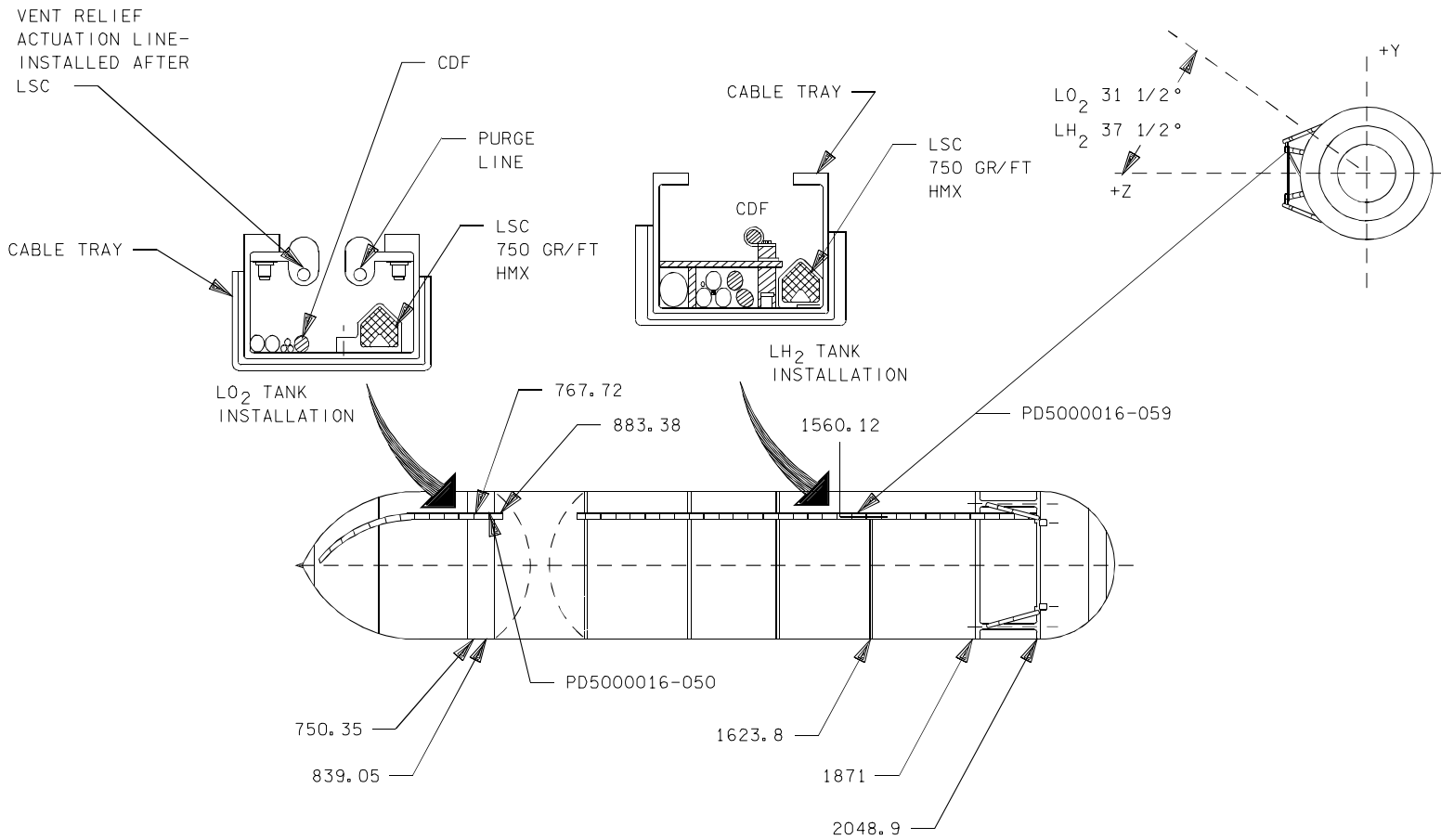


Figure 5.5-4. SRB RSS block diagram

5.5-7

Verify that this is the correct version before use.



128303145. ART# 1

Figure 5.5-5. ET RSS linear-shaped charge

5.5-8

Verify that this is the correct version before use.

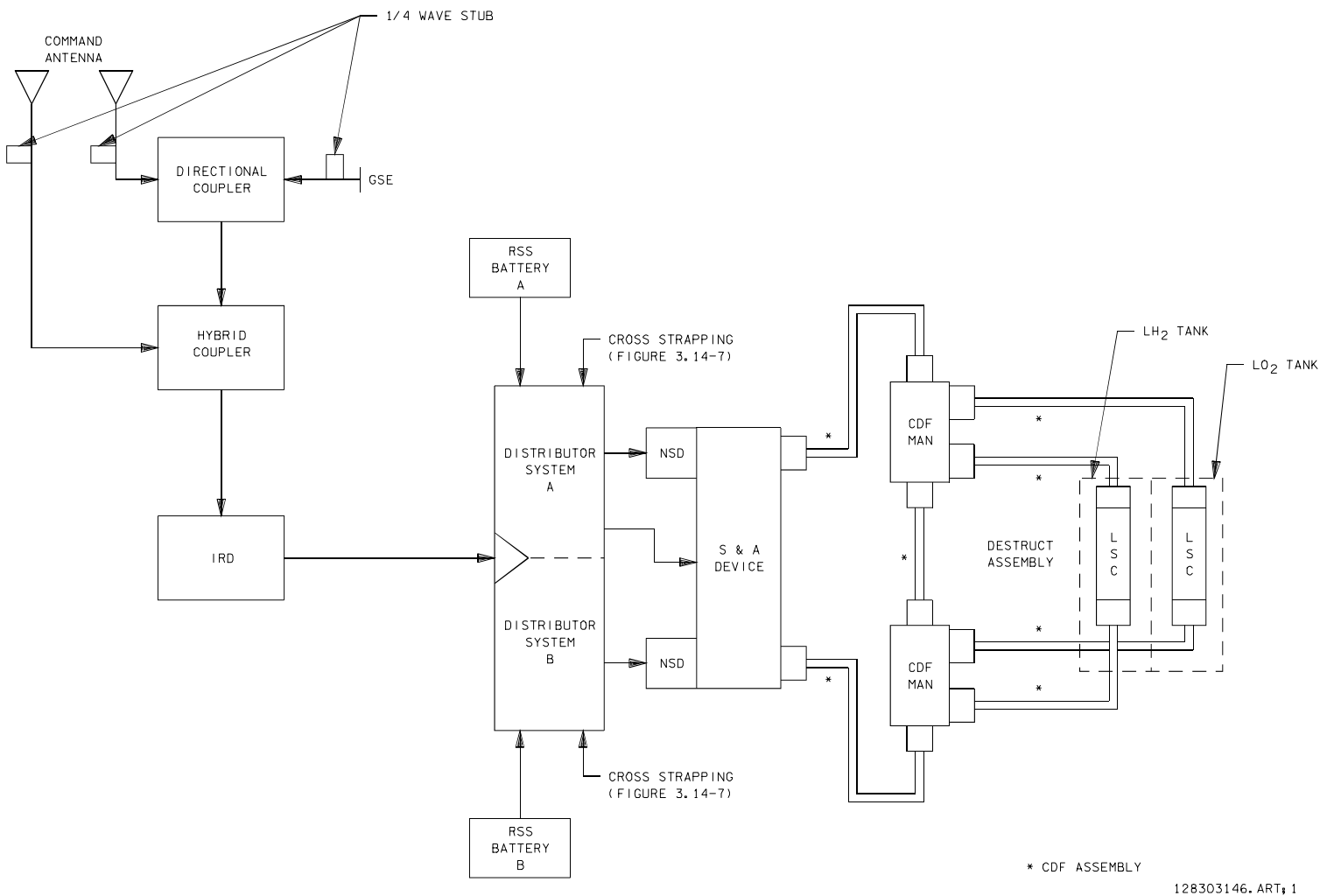
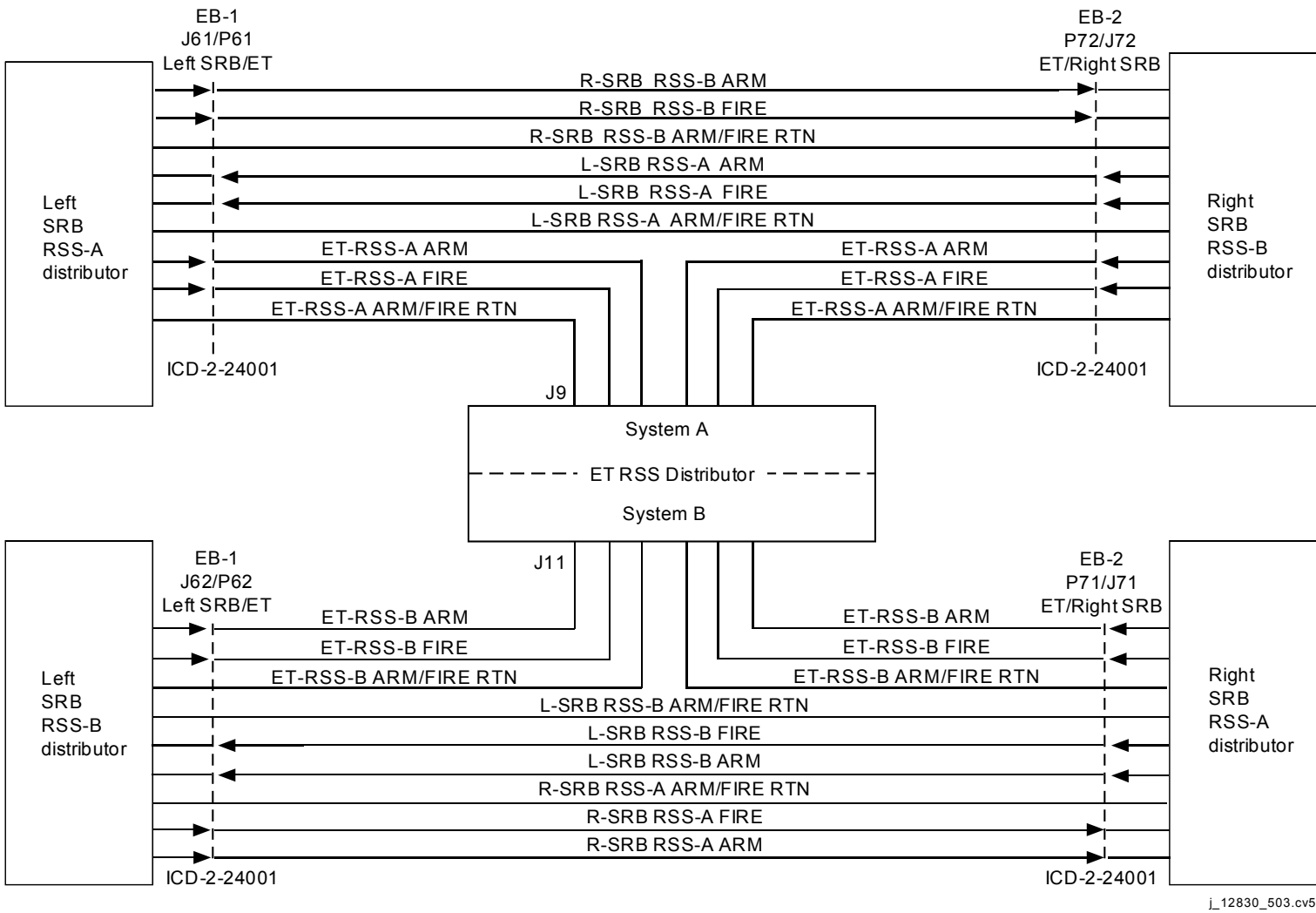


Figure 5.5-6. ET RSS block diagram

5.5-9

Verify that this is the correct version before use.





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Figure 5.5-7. SRB and ET RSS cross-strap diagram

5.5-10

Verify that this is the correct version before use.

**Table 5.5-1. RSS component characteristics**

ET and SRB command antenna characteristics (model 320)

VSWR	1.5 (maximum) at 416.5 MHz
Frequency range	406 to 420 MHz
Polarization	Left-hand circular
Operating life	1000 hr (minimum)
Useful life	20 flights (minimum)
Storage life	5 yr (sheltered)
Weight	7.68 lb
Outline dimensions	H: 3.66 in. W: 8.00 in. D: 15.93 in.

ET and SRB directional coupler characteristics (model 318)

VSWR	1.25:1 (max)
Frequency range	406 to 420 MHz
Input impedance	50 ohms
Insertion loss	0.30 dB (max)
Coupling	16 ± 3 dB
Directivity	24 dB (min)
Operating life	1000 hr (min)
Useful life	20 flights (min)
Storage life	5 yr (sheltered)
Weight	1.28 lb
Outline dimensions	H: 2.30 in. W: 9.50 in. D: 2.88 in.

**Table 5.5-1. RSS component characteristics (continued)**

ET and SRB hybrid coupler characteristics (model 319)

VSWR	1.25:1 (max)
Frequency range	406 to 420 MHz
Input impedance	50 ohms
Power division and insertion loss	3.1 ± 0.3 dB (max)
Isolation	24 dB (min)
Operating life	1000 hr (min)
Useful life	20 flights (min)
Storage life	5 yr (sheltered)
Weight	2.0 lb
Outline dimensions	H: 1.30 in. W: 11.00 in. D: 6.50 in.

IRD characteristics

Input power	<ul style="list-style-type: none"> <li>• 24 V DC to 36 V DC, 40 V DC for 4 minutes</li> <li>• 50 V DC reverse polarity (no damage)</li> <li>• Standby power 12 watts max</li> <li>• Incremental or step changes in supply voltage (0 to 40 V DC) will not cause command outputs transients greater than 2 V peak and 0.1 msec in duration</li> </ul>
Isolation	<p>10 MΩ minimum between primary power and:</p> <ul style="list-style-type: none"> <li>• Case</li> <li>• Secondary power and signal return</li> </ul> <p>1 MΩ minimum between case and command output lines</p> <p>Customer option: Command output return may be connected internally to 28V return line</p>
Weight	5.5 lb max
Size	100 in. <sup>3</sup>

**Table 5.5-1. RSS component characteristics (continued)**

<u>IRD characteristics (continued)</u>	
Outline dimensions	H: 4.52 in. (max) W: 7.41 in. (max) D: 4.00 in. (max)
<u>Receiver section</u>	
Fixed tuned	416.5 MHz specified
VSWR -20 to 50 °C	1.5:1 max
-40 to -20 °C and 50 to 80 °C	2.0:1 max
RF sensitivity (message)	-97 dBm
Capture	≤ 3 dB audio output reduction with interfering 416.5 MHz unmodulated carrier 2 dB below desired
Deviation	± 20 kHz to ± 35 kHz per tone (will not operate ≤ ± 4 kHz per tone)
(A) Operational bandwidth	± 45 kHz min from 416.5 MHz (-97 dBm, ± 30 kHz per tone)
(B) If passband ripple	3 dB max within ± 45 kHz of 416.5 MHz
(C) 60 dB bandwidth	± 180 kHz max from 416.5 MHz
Response > ± 10 MHz from 416.4 MHz	JSC-SL-E-0002 (80 dB image rejection required)
Signal strength telemetry	No input signal: 0.1 to 0.5 V DC  -97 dBm: 0.25 to 0.75 V DC increase above no signal level  -53 dBm: 4.5 V DC min (not saturated)  ≤ +13 dBm: ≤ 5.25 V DC (monotonic increase required)  Load: 100 kΩ
Audio bandwidth (-97 dBm to +13 dBm and ± 60 kHz deviation)	7 to 14 kHz: 1 dB max peak-to-valley

**Table 5.5-1. RSS component characteristics (continued)**

IRD characteristics (continued)

	15.45 kHz:	3 dB (max) attenuation
Audio distortion (-47 dBm, ±60 kHz deviation, 7 and 14 kHz)		10 percent max
<u>Decoder section</u>		
Radar jamming		Reliable operation with 2-msec blanking pulse in each command message character
Auxiliary decoder input		6V P-P nominal level
Address code insertion, verification, and storage		Store, verify, and retain for 3 months minimum five independent 11-character command codes (or null codes where desired). Field programmable with KYK-13 electronic transfer device.
		Readout of stored codes is inhibited
Logic requirements		Decode, verify, and output commands for any chosen address code when it matches a stored code.
		Inhibit command outputs under the following conditions:
		<ul style="list-style-type: none"><li>• Invalid transmitted code</li><li>• Improper message timing</li><li>• Missing characters</li><li>• Improper code order</li><li>• Character detection errors</li><li>• Other than two tones per character</li></ul>
Decoder software requirements		The decoder recovers for the following momentary interruptions:
		<ul style="list-style-type: none"><li>• Noise and power transients</li><li>• Invalid data parameters</li><li>• Input noise</li><li>• Invalid input signals</li></ul>

**Table 5.5-1. RSS component characteristics (continued)**

IRD characteristics (concluded)

Single-point failure	No single-point failure (hardware or software) causes generation of a signal on a command output line
Commands	<p>Number of commands: 5 (one at a time)</p> <p>Output level: 28 ± 2 V DC (ON) 0V DC + 0.8, -0.5 V DC (OFF)</p> <p>Load: 175 Ω to 65 kΩ</p> <p>Duration: 45 ± 5 msec</p> <p>Transients: ≤ 2 volts peak and ≤ 0.1 msec max</p> <p>Rate: ≤ 5.7 commands/sec</p> <p>Leakage: 5 microamperes max</p> <p>Response time: 104.7 ± 3 msec</p>
Pilot tone	<p>Frequency: 15,450 Hz</p> <p>Modulation: ± 20 kHz to ± 35 kHz RF carrier deviation (will not operate ± 4 kHz deviation or less)</p> <p>Load: 375 kΩ nominal</p> <p>Output level: On = &lt;3 V DC OFF = &gt;15 V DC</p> <p>Response time: &lt;100 msec (ON or OFF)</p> <p>Ground isolation: Pilot tone signal return to case ground, 10 MΩ min (connected to 28 V DC return)</p>

Recovery battery characteristics (SRB no. 2 only)

Type	Silver zinc
Pressure relief valve	Open at 8 psig Close at 3 psig
Voltage:	
Underload	28 + 4, - 2 V
Open circuit	35.5 V (max)
During all discharge	26 V (min)

***Table 5.5-1. RSS component characteristics (continued)***

Recovery battery characteristics (SRB no. 2 only) (concluded)

Operating life	1 mission
Useful life	1 flight
Storage life	2 yr
Weight	45 lb (max)
Outline dimensions	H: 6.88 in. W: 9.73 in. D: 12.48 in.
Stand time	90 days
Capacity	50 A-hr

RSS battery characteristics, SRB 1 and ET

Type	Lithium monofluorographite
Pressure relief valve	Open at 8 psig Close at 3 psig
Voltage:	28 + 5, -2 V
Underload	45.0 V (max)
Open circuit	26.0 V (min)
During all discharge	
Operating life	1 mission
Useful life	1 flight
Storage life	2 yr
Weight	9.6 lb (max)
Outline Dimensions	H: 5.48 in. W: 6.72 in. D: 8.00 in.
Stand time	90 days
Capacity	18 A-hr

ET and SRB safety and arming device characteristics

Auto ignition and melting points	275 °F (min)
Insulation resistance	100 MΩ (min) at 500 V DC

**Table 5.5-1. RSS component characteristics (concluded)**ET and SRB safety and arming device characteristics (concluded)

## Solenoid or motor performance:

Net starting torque	0.75 ± 0.05 in.-lb at 30 V DC and 0.25 ± 0.05 in.-lb at 21 V DC
Operating voltage	28 ± 4 V DC
Operating current	3 A (max)
Rotation	90° to 95° under no load in 50 msec (max)

## S&amp;A performance:

Safe position power on	
Voltage input	28 ± 4 V DC
Elapsed time	90° rotation in 250 msec (max)

Armed position power on	
Voltage input	28 ± 4 V DC
Elapsed time	90° rotation in 250 msec (max)

Operating life	Electric: 10 missions Ordnance: 1 cycle
----------------	--

Storage life	10 yr (max)
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Weight	3.0 lb (max)
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Outline dimensions	H: 3.84 in. W: 3.62 in. D: 5.76 in.
--------------------	---

ET and SRB confined detonating fuse assembly characteristics

Auto ignition and melting points	275 °F (min) SRB 400 °F (min) ET
Components	Mild Detonating Fuse (MDF) and a confining cover
MDF breaking strength	3.6 lb
Detonating rate	6,500 m/sec (min) SRB 7,000 m/sec (min) ET
Operating life	1 cycle
Fuse core	PETN - SRB HNS - ET
Useful life	1 flight
Storage life	10 yr
Weight	0.06 lb/ft
Outside diameter	0.310 to 0.325 in.



## TITLE

RANGE SAFETY SYSTEM STATUS MONITORING

## PURPOSE

To define how the EPS console operators monitor the status of the Range Safety System (RSS).

## BACKGROUND

The shuttle RSS is an airborne command destruct system for the SRB and the ET of the shuttle vehicle. This system enables the RSO at ESMC to intentionally destroy the above elements of the shuttle vehicle in the event of flight path deviation or inadvertent separation.

## REFERENCES

- A. Display MSK Pyro.
- B. SSSH drawing 5.5 (SRB/ET Range Safety System), sheets 1 and 2.
- C. SD75-SH-0246 D Launch Sequencing and Interlocks Document (LSID).
- E. Launch countdown Test and Checkout Procedure (TCP).

## PROCEDURE

It should be noted that the RSS is under command control by the Eastern Test Range Safety Officer (ETRSO). The EPS and INST console operators monitor the RSS status of the SRBs and ET for FCR information only. These console positions have no interacting dynamic control.

In maintaining status of the RSS, MSK display Pyro is used. The following parameters are monitored on the Pyro display: SRB and ET battery voltages, receiver signal strengths, decoder power status, RSS arm status, RSS fire status, and S&A device status. The Pyro display also has SRB/ET inhibit status, as well as the status of the ET tumble arm command.

- A. At approximately T-50 minutes, a final closed-loop test is performed on the RSS using the Launch Processing System (LPS). After this test, the range transmitter is on and maintains capture of the IRD throughout the flight. The progress of the test can be monitored by verifying the events as listed in the countdown TCP (ref. Launch Sequencing and Interlocks Document (LSID) SD75-SH-0246).
- B. Upon completion of the LSID tests, verify that the SRB RSS A and B IRDs and the ET RSS IRDs are powered.
- C. At T-5 minutes, verify that the LH and RH SRB plus ET S&A devices are ARMED when commanded by the LPS.

- D. During prelaunch, all SRB/ET batteries are monitored to verify adequate voltage and energy for operations as specified in the Launch Commit Criteria (LCC).
- E. The following SRB-separation sequence is for system knowledge only since EPS does not normally monitor the range safety and recovery system after launch. At approximately 5 seconds before SRB separation, the orbiter computer will sense SRB motor pressure decay and will begin the SRB separation sequence. As a part of this sequence, both SRB S&A devices will be commanded (through the Master Events Controller (MEC)) to the SAFED position, and SRB RSS power will be commanded off. The ET RSS will not be commanded off, but will remain active until it reenters the atmosphere.
- F. In the event that the RSO has to destruct the vehicle, an ARM command will be issued. This ARM command can be verified using the MSK display Pyro. When the ARM command is issued by the RSO, the EPS operator will take a snapshot of history tab and notify EGIL, who in turn will notify the flight director if the RSO has not already done so. After an elapsed time of TBD seconds, the RSO will issue the FIRE command. This command will probably not be visible on the displays because it results in vehicle destruction.

## TITLE

PYROTECHNIC INITIATOR CONTROLLER

## INTRODUCTION

The Pyrotechnic Initiator Controller (PIC) provides the energy impulse necessary to discharge a NASA Standard Initiator (NSI), type 1 (NSI-1). The PIC supplies 100 millijoules minimum to the initiator for 5 ms from electrical energy stored in an internal capacitor bank.

PIC circuits include both operational and test circuits as follows.

### Operational

- ARM
- FIRE 1
- FIRE 2
- Capacitor bank voltage analog

### Test

- Resistance test
- Load test

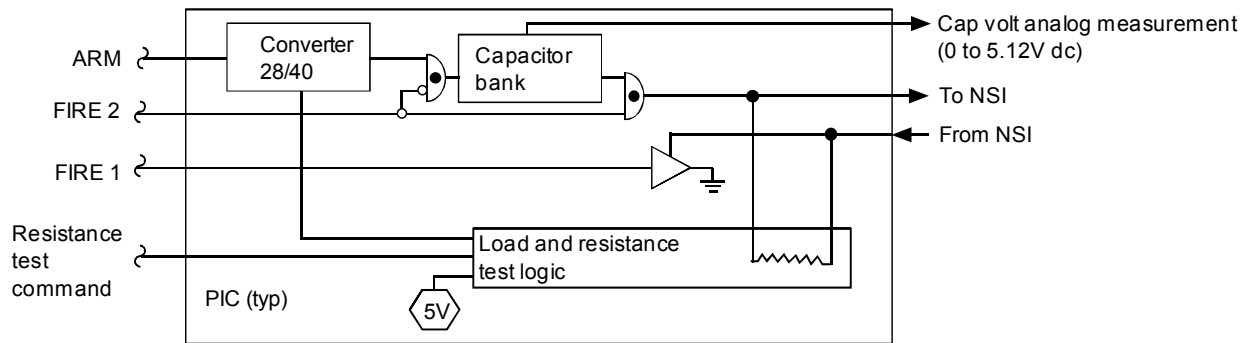
## OVERVIEW

The PIC requires three input commands to provide the pyro output energy pulse to the NSI-1. These are the ARM, FIRE 1, and FIRE 2 commands. The PIC will not fire if the ARM and FIRE commands are applied out of sequence. No two failures can cause a PIC to fire prematurely. The ARM command provides voltage to the energy storage capacitor bank. The FIRE 1 command provides a switch closure in the negative return output leg, and the FIRE 2 command provides a switch closure in the positive output leg of the NSI-1 firing circuit.

In addition to these inputs, there are the two pyro circuit status checking test circuits, the resistance test circuit and the load test circuit. The resistance test provides prefiring circuit continuity and resistance verification, resulting in a GO/NO-GO resistance test discrete signal output. The load test circuit provides postfiring verification of the PIC output energy level, generating a GO signal if the energy level is within designated limits.

## OPERATION

Figure 5.7-1 illustrates the PIC operations that follow.



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**Figure 5.7-1. Pyrotechnic initiator controller circuit functional diagram**

**A. ARM command**

The ARM power supply circuit generates three separate DC power levels when positive voltage and return is applied to its input. The ARM command input voltage is 28 V DC nominal, with a minimum of 20 V DC and a maximum of 32 V DC. Rise time under these conditions is less than 10 milliseconds.\* The ARM signal must be applied to the PIC for a minimum of 0.25 second before the FIRE signals. The ARM command has a duration of 1 second minimum and must be maintained for at least 5 milliseconds after the issuance of both FIRE commands. The ARM current has a 0.5-ampere maximum value decaying to 0.2 ampere in 1 second. Filter inrush is 30 millijoules maximum within 10 milliseconds. Following the issuance of the ARM command or the FIRE 2 command, a 300-milliampere transient of 10 milliseconds maximum duration may occur over and above the 0.5-ampere maximum.

The DC power levels generated as a result of the ARM command are 5 V ( $\pm 10$  percent) and 12.5 V ( $\pm 10$  percent) for the power input of the load test circuit, and 41.1 V DC ( $\pm 10$  percent) as the charging voltage for the capacitor bank.

The response time for supplying these voltages is within 30 milliseconds after the ARM command is received. Should it be desirable to remove the ARM command with no FIRE command present, the capacitor bank voltage will discharge to a maximum of 1.5 V DC in less than 30 seconds as indicated by the capacitor voltage analog signal. The maximum voltage level of the ARM command in the OFF state is 1.7 V DC.

**B. FIRE 1 and FIRE 2 commands**

The FIRE 1 command must precede or be concurrent with the FIRE 2 command in order to cause the PIC capacitor bank to discharge through the pyrotechnic initiator. The FIRE 2 command must not be initiated less than 1 second after the

\* Preliminary testing indicates that the PIC capacitor bank will continue to charge with an input voltage less than 20 V DC. Approximate values show that for a low input voltage of  $\sim 13$  V DC, the capacitor bank will still charge up to  $\sim 37$  V DC. Rise time is  $\sim 10^+$  milliseconds.

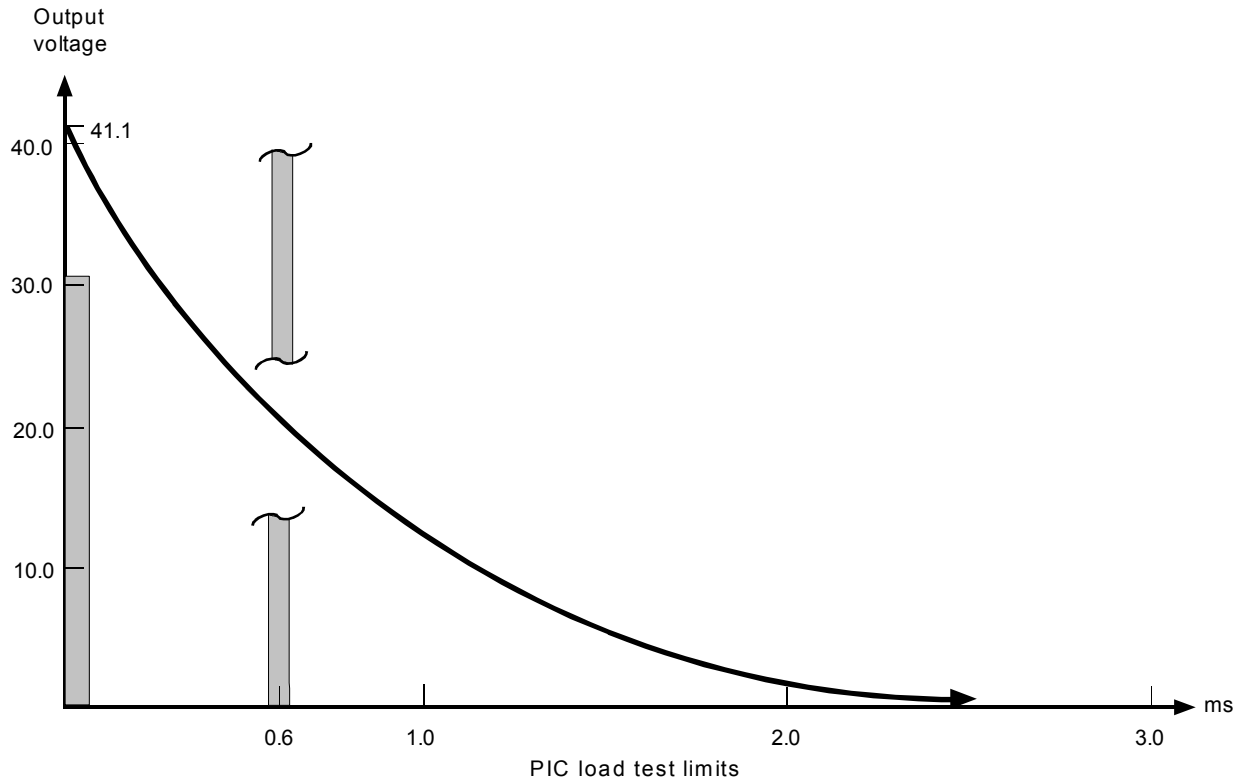
ARM command. The voltage requirements for the FIRE 1 and FIRE 2 commands are the same as those for the ARM command. The FIRE 1 and FIRE 2 currents have a maximum of 10 milliamperes (each). Both commands must be provided simultaneously for a minimum of 10 milliseconds to effect a discharge of the PIC capacitor bank through the pyrotechnic initiator. The voltage applied to the FIRE command circuits in the OFF condition has a value of 1.7 V DC maximum.

C. System test circuits

System test circuits are provided to ensure that the live pyro resistance after NSI-1 installation is within allowable limits (resistance test) and that the PIC output energy level is sufficient to discharge the pyro (load test).

The load test circuit is triggered each time a PIC is discharged. This test is performed during ground test operations. For purposes of this test, a dummy load is inserted instead of the NSI-1. This dummy load consists of a 0.931-ohm ( $\pm 1$  percent) wire-wound resistor in series with two diodes. The load test is performed by generating an ARM command followed by both FIRE commands not less than 1 second later. If the PIC pulse generating circuitry is operating normally, a GO signal is generated within 10 milliseconds from the second FIRE command.

A graph of the voltage decay versus the time curve of the capacitor bank is provided in Figure 5.7-2. The load test circuit voltage must decay at a specific rate in order to satisfy the requirements for a GO condition. As indicated by the graph, the output voltage starts out at X40 V; at 0.6 milliseconds the level must pass through the "window" as shown. If these requirements are met, the load test circuit will provide a GO.

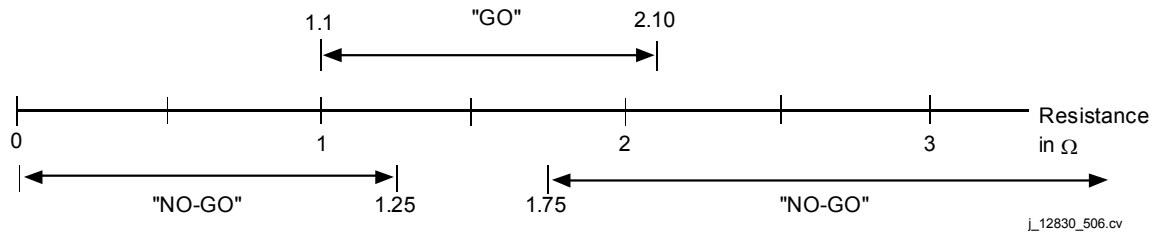


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**Figure 5.7-2. Load test PIC circuit voltage decay**

The resistance command voltage has the same requirements as the ARM command voltage. The resistance command current to the PIC has a maximum value of 70 milliamperes. Upon receipt of the resistance test command, the PIC performs a resistance test of the circuit connected to the PIC pyro output terminals. This PIC resistance test is performed to provide instantaneous verification before flight that the dummy load has been removed and the NSI installed with all the interface connections between the PIC and the NSI properly mated. This test also performs a check of wire/cable integrity and NSI electrical integrity.

Receipt of the resistance test command (28 V DC nominal) energizes the PIC circuit, providing a maximum of 1 V DC and a maximum current of 20 milliamperes at the pyro output terminals. The external resistance of the circuit must be greater than 1 to 1.25 ohms and less than 1.75 to 2.1 ohms to generate a GO signal. If the dummy load has not been removed before this test, the two diodes in the load will guarantee a NO-GO response. The resistance test discrete initializes a NO-GO state. Removal of the resistance test command will also result in a NO-GO signal (Figure 5.7-3).



**Figure 5.7-3. Resistance test command**

#### D. PIC outputs

The PIC outputs include two discrete signal outputs: the resistance test discrete signal and the load test discrete signal. Each of these discrete outputs consists of an isolated switch closure, with a closed switch corresponding to a GO state and an open switch corresponding to a NO-GO state. The positive side of a 5 V dc or a 12 V DC ( $\pm 10$  percent) power supply is provided continuously to the PIC for connection only to each of these two switches. The maximum current through each of these switches during the closed (GO) state is 0.5 milliamperes. A 1200-ohm resistor is located in series with each of these switches. The maximum voltage drop through a closed switch is 0.5 V. Maximum leakage through an open switch is 50 amperes.

The load test discrete signal output provides an indication that the energy level available from the PIC during ground test operations is within the range limits for detonation of the NSI. This test is conducted as described above. The FIRE circuit can be expected to deliver 75 millijoules\* of energy to an NSI-1 of 0.95 to 1.15 ohms; however, the test will not reject a PIC operating within the entire PIC operational temperature range. An open circuit condition in the PIC or in the circuit containing the NSI-1 will result in a NO-GO output within 20 milliseconds after the ARM command has been generated. Removal of the ARM command will result in a reset of the load test discrete signal to a NO-GO state.

The resistance test discrete signal output (generated as a result of the resistance test) is present within 10 milliseconds of the issuance of a resistance test command. The resistance test discrete signal output results in a GO/NO-GO based on the criteria listed in Tables 5.7-1 and 5.7-2.

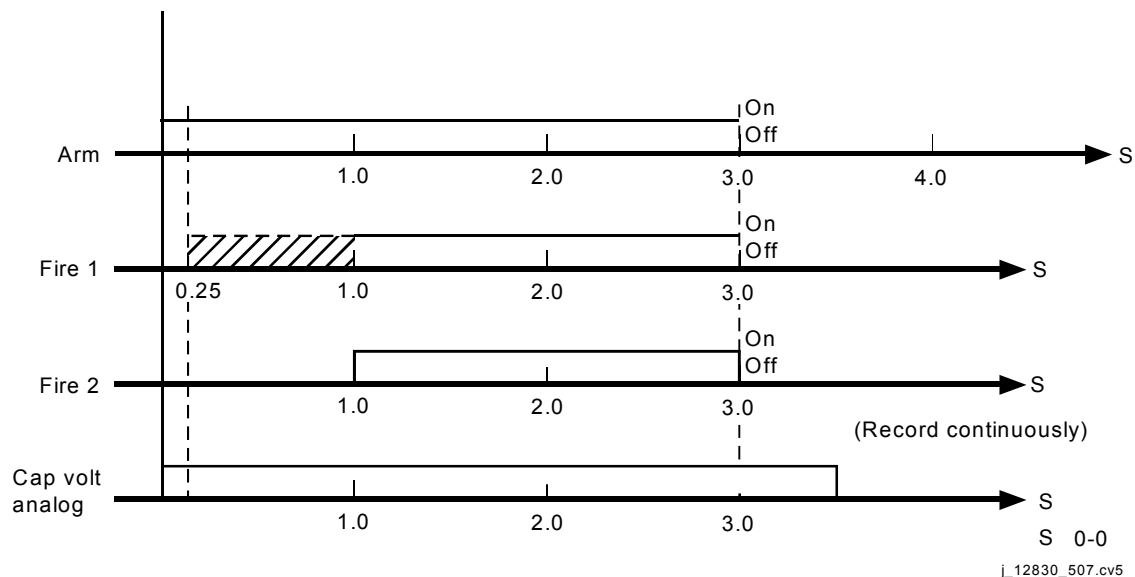
Initialization of the circuit results in a NO-GO. Removal of the resistance test command causes the resistance test discrete signal output to be reset to a NO-GO state.

\* The 75-millijoule energy level is the known minimum requirement for proper NSI-1 firing. One hundred millijoules for 5 milliseconds is set as the minimum energy level required, allowing for a 25-millijoule safety margin. Analytically, however, the worst case minimum output from the capacitor band is 106.9 millijoules, which again exceeds the 100-millijoule requirement. In practice, output levels are typically around 200 millijoules in the ambient environment, allowing for a significant system operating margin.

The initiator firing pulse will be generated in response to the ARM command followed by both FIRE commands. It provides a capacitive discharge pulse, the energy of which at the NSI-1 interface has a minimum value of 40 amperes. In the armed state, without both FIRE commands, the leakage to the NSI has a maximum value of 10 milliamperes.

The capacitive voltage analog signal provides a continuous measurement of the voltage on the PIC capacitor bank. The output range of the capacitor voltage analog signal is 0 to 5.12 V DC nominal, which correlates to 0 to maximum (40.75 V) capacitor bank voltage.

The application of the command and test signals required for PIC operation is represented in the timeline of the PIC ON/OFF cycle (Figure 5.7-4).



**Figure 5.7-4. The PIC command/test signals**



**Table 5.7-1. Pyrotechnic initiator controller inputs**

	<b>Purpose</b>	<b>Voltage</b>	<b>Current</b>	<b>Duration/sequencing</b>
ARM CMD	Provides arming for capacitor bank	28 V DC (nom) 20 V DC (min) to 32 V DC (max) 1.7 V DC (max) in OFF state	0.5A (max) decaying to 0.2A in 1 sec	1 sec (min) duration applied at least 0.25 sec before FIRE 1 and maintained at least 5 msec after issuance of both FIRE CMDs
FIRE 1 CMD	Reqd. coincident with FIRE 2 CMD to cause PIC capacitor bank to discharge through NSI	28 V DC (nom) 20 V DC (min) to 32 V DC (max) 1.7 V DC (max) in OFF state	10 mA (max)	Issued not <0.25 sec following ARM CMD Issued before or concurrent with FIRE 2 CMD FIRE 1 and FIRE 2 CMDs must overlap for at least 10 msec to effect firing of NSI
FIRE 2 CMD	Reqd. coincident with FIRE 1 CMD to cause PIC capacitor bank to discharge through NSI	28 V DC (nom) 20 V DC (min) to 32 V DC (max) 1.7 V DC (max) in OFF state	10 mA (max)	Issued not <1 sec after ARM CMD Issued concurrent with or following FIRE 1 CMD FIRE 1 and FIRE 2 CMDs must overlap for at least 10 msec to effect firing of NSI
Resistance test	Reqd. to perform resistance test of the ckt. connected to PIC pyro output terminals (i.e., verification before flight that dummy load has been removed and NSI installed and properly mated)	28 V DC (nom) 20 V DC (min.) to 32 V DC (max) 1.7 V DC (max) in OFF state	70 mA (max.)	Duration 1.1 sec (min) CMD shall <u>not</u> be issued simultaneously with ARM or FIRE CMDs

5.7-7

Verify that this is the correct version before use.

**Table 5.7-1. Pyrotechnic initiator controller inputs (concluded)**

	Purpose	Characteristics
Capacitor voltage analog signal	Provides a continuous measurement of the PIC capacitor bank voltage	Output range is 0 to 5.12 V DC (nom) corresponding to 0 to 40.75 V DC (max) capacitor bank voltage
Resistance test discrete signal	Provides GO or NO-GO indication for the resistance test performed on external ckt. connected to PIC initiator firing pulse terminals	Resistance test discrete signal output shall be present in <10 msec after issuance of resistance test command External resistance ranges: <1.25 Ω = NO-GO >1.25 Ω and <1.75 Ω = GO >1.75 Ω = NO-GO
Load test discrete signal output	Provides indication that the energy for a detonation of NSI is available	Performed during ground test operations with dummy load inserted Load test is performed by generating the ARM CMD followed by both FIRE CMDs not <1 sec later; a GO condition shall be generated within 10 msec from FIRE 2 CMD 100 mJ for 5 msec is set as the minimum energy level required A NO-GO condition will be indicated within 20 msec after the ARM CMD has been generated; removal of ARM CMD will reset load test discrete signal to NO-GO state

5.7-8

Verify that this is the correct version before use.

## PIC LOCATIONS AND MONITORING

A compilation of the PIC locations in the orbiter, the ET, and the SRBs is included in Table 5.7-2. This table indicates PIC location, safing, and the Space Shuttle Systems Handbook (SSSH) drawing number in which the PIC appears.

The PICs are monitored by EGIL on MSK Pyro. The PIC capacitor voltage is the parameter most frequently monitored, although some MSKs are used to indicate whether ARM and FIRE commands have been sent. MSK Pyro displays the capacitor voltage for the fire suppression bottles in avionics bays 1, 2, and 3. They also display the capacitor voltages on the PICs in the landing gear pyros, RMS jettison pyros, Ku-band antenna jettison pyros, SRB ignition pyros, SRB separation pyros, SRB recovery pyros, and range safety pyros. Parameter numbers, limits, and corresponding DDD format numbers for the PICs monitored by EGIL are included in Table 5.7-3. This table shows the limits for PIC capacitor V to be set at -0.1 to +0.2. These limits are kept low so that an event light will light at the first sign of capacitor charging. The low limit of -0.1 V is chosen as a means of preventing an event light from coming on for a capacitive charge of zero.

**Table 5.7-2. PIC locations**

PIC	Location		How safed		HB dwg no.
	Sys A	Sys B	Sys A	Sys B	
<u>FLC PIC functions</u>					
Orb/ET fwd sep	FLC1 <sup>a</sup>	FLC2 <sup>b</sup>	MEC	MEC	N/A
Av bay fire extinguisher					
Av bay 1	FLC2	--	015:C fire suppr bay 1 - open	--	5.1
Av bay 2	FLC3	--	016:C fire suppr bay 2 - open	--	5.1
Av bay 3A	FLC1	--	014:C fire suppr bay 3 - open	--	5.1
RNDEZ RDR ANT PLB area	FLC1	FLC3	(c)	(c)	(c)
NLG backup uplink release Nose wheel well area 21	FLC3	FLC2	LG ARM/ON reset sw pnl A12	PIC logic	13.1-2
NLG strut thruster (ext power assist) Nose wheel well area 21	FLC3	FLC2	PIC logic	PIC logic	13.1-2
RMG backup uplink release R wheel well area 62	FLC3	FLC2	PIC logic	PIC logic	13.1-2
LMG backup uplink release L wheel well area 67	FLC3	FLC2	PIC logic	PIC logic	13.1-2
Ku-BD ANT guillotine	FLC1	FLC3	3A cb PNL ML86B:D	3A cb PNL ML86B:D	15.7-1
Ku-BD ANT jettison	FLC1	FLC3	3A cb PNL ML86B:D	3A cb PNL ML86B:D	15.7-1
Docking tunnel PLB area	FLC1	FLC3	(c)	(c)	(c)

<sup>a</sup> Drive output located MEC no. 1.

<sup>b</sup> Drive output located MEC no. 2.

<sup>c</sup> To be flown TBD.

5.7-10

Verify that this is the correct version before use.

**Table 5.7-2. PIC locations (continued)**

PIC	Location		How safed		HB dwg no.
	Sys A	Sys B	Sys A	Sys B	
<u>MEC orb PIC functions</u>					
Orb/ET L aft sep	MEC1	MEC2	MEC	MEC	
Orb/ET R umb disc Pyros 1A, 2A, 3A Pyros 1B, 2B, 3B	MEC1	MEC2	MEC MEC	MEC MEC	
Orb/ET R aft sep	MEC1	MEC2	MEC	MEC	
<u>Mid JTN cont assy PIC functions</u>					
RH MANIP arm shldr PLB area Pyros A (2)	Assy no. 1		5A cb PNL ML86B:D		14.6-3
Pyros B (2)		Assy no. 1		5A cb PNL ML86B:D	14.6-3
RH MANIP arm fwd latch PLB area Pyros A (2)	Assy no. 1		5A cb PNL ML86B:D		14.6-3
Pyros B (2)		Assy no. 1		5A cb PNL ML86B:D	14.6-3
RH MANIP arm mid latch PLB area Pyros A (2)	Assy no. 1		5A cb PNL ML86B:D		14.6-3
Pyros B (2)		Assy no. 1		5A cb PNL ML86B:D	14.6-3
RH MANIP arm aft latch PLB area Pyros A (2)	Assy no. 1		5A cb PNL ML86B:D		14.6-3
Pyros B (2)		Assy no. 1		5A cb PNL ML86B:D	14.6-3

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5.7-11

SHUTTLE OPS  
EGL/JSC-12830

ORIG: R. C. SMITH  
01/31/02: BASIC, REV. F

PIC  
SCP 5.7

**Table 5.7-2. PIC locations (continued)**

PIC	Location		How safed		HB dwg no.
	Sys A	Sys B	Sys A	Sys B	
LH MANIP arm shldr PLB area Pyros A (2)	Assy no. 2	Assy no. 2	5A cb PNL ML86B:D	5A cb PNL ML86B:D	14.6-3
Pyros B (2)					14.6-3
LH MANIP arm fwd latch PLB area Pyros A (2)	Assy no. 2	Assy no. 2	5A cb PNL ML86B:D	5A cb PNL ML86B:D	14.6-3
Pyros B (2)					14.6-3
LH MANIP arm mid latch PLB area Pyros A (2)	Assy no. 2	Assy no. 2	5A cb PNL ML86B:D	5A cb PNL ML86B:D	14.6-3
Pyros B (2)					14.6-3
LH MANIP arm fwd latch PLB area Pyros A (2)	Assy no. 2	Assy no. 2	5A cb PNL ML86B:D	5A cb PNL ML86B:D	14.6-3
Pyros B (2)					14.6-3
<u>MED to GSE PIC functions</u>					
R (LOX) T-0 umb rel Pyro A (1) Pyro B (1)	GSE pyro control rack 9A MLP	GSE pyro control rack 9A MLP			
L (LH <sub>2</sub> ) T-0 umb rel Pyro A (1) Pyro B (1)	GSE pyro control rack 9A MLP	GSE pyro control rack 9A MLP			

5.7-12

Verify that this is the correct version before use.

**Table 5.7-2. PIC locations (concluded)**

PIC	Location		How safed		HB dwg no.
	Sys A	Sys B	Sys A	Sys B	
R SRB holddown Pyros A (4) Pyros B (4)	GSE pyro control rack 9A MLP	GSE pyro control rack 9A MLP			
L SRB holddown Pyros A (4) Pyros B (4)	GSE pyro control rack 9A MLP	GSE pyro control rack 9A MLP			
L SRB sep	L SRB <sup>a</sup> (6)	L SRB <sup>b</sup> (6)			
R SRB sep	R SRB <sup>a</sup> (6)	R SRB <sup>b</sup> (6)			
L SRB ign	L SRB <sup>a</sup> (1)	L SRB <sup>b</sup> (1)	Launch processor sys		
R SRB ign	R SRB <sup>a</sup> (1)	R SRB <sup>b</sup> (1)	Launch processor sys		
ET vent umb ret	ET vent arm panel	ET vent arm panel			
ET RSS	ET RSS distributor	ET RSS distributor	Manual safing and locking pin		5.5
Tumble sys					
Recovery sys					
Nozzle ext JTN	L SRB (1) R SRB (1)	--		None	5.4
Nose cap sep	L SRB (1) R SRB (1)	--		None	5.4
Frustrum sep	L SRB (1) R SRB (1)	--		None	5.4
Main parachute disc	L SRB (1) R SRB (1)	--		None	5.4
RSS	RSS distributor(2)	RSS distributor(2)	Manual safing and locking pin		5.5

<sup>a</sup> Drive output located MEC no. 1.

<sup>b</sup> Drive output located MEC no. 2.

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5.7-13

The Landing Gear (LG) pyros, all except those for the NLG extend actuator assist, are armed when the LG ARM pushbutton indicator (pbi) is pushed. The NLG extend actuator assist pyro is armed 2 seconds after the LG DOWN pbi is pushed. Only the extend actuator NLG PICs, however, will discharge through an NSI during normal LG deployment. The extend actuator NLG capacitor volts will drop back to zero instantaneously as the PIC discharges. The emergency extend NLG, LMG, and RMG capacitor volts in this case will bleed back down to zero in 2 to 3 seconds. Should it be necessary to fire the emergency extend PICs, the emergency extend capacitor volts will drop back to zero instantaneously. A summary of the fire suppression bottle, landing gear, RSS, and ET/SRB separation system parameters is kept on the appropriate history tab MSKs (Table 5.7-3).

A new function installed during vehicle major mods, which utilize the PICs, are the dragchute deploy and jettison functions. The PIC volts can be found in the MMACS MSK 3108 display, and can be referenced in SSSH drawing 13.4 sheet 2.

**Table 5.7-3. The PIC history tab/DDD displays**

- Smoke detection/fire suppression - 0633/0634 = History tabs

	<b>Low</b>	<b>High</b>	<b>DDD format</b>
V76V4736A BAY 1 PIC CAP V	-0.1	+0.2	30
V76V4716A BAY 2 PIC CAP V	-0.1	+0.2	30
V76V4700A BAY 3A PIC CAP V	-0.1	+0.2	30

- LG - 0619/0620 = History tabs

V76V4820A EXT ACTR 1 NLG	-0.1	+0.2	30
V76V4821A EXT ACTR 2 NLG	-0.1	+0.2	30
V76V4830A EMER EXT A NLG	-0.1	+0.2	30
V76V4832A EMER EXT B NLG	-0.1	+0.2	30
V76V4900A EMER EXT A LMG	-0.1	+0.2	30
V76V4902A EMER EXT B LMG	-0.1	+0.2	30
V76V4950A EMER EXT A RMG	-0.1	+0.2	30
V76V4952A EMER EXT B RMG	-0.1	+0.2	30

- SRB/ET sep seq. - 0663/0664 = History tabs

V98X0744X BFS-SRB SEP ARM CMD	-	ARM	60
V98X0752X BFS-ET SEP ARM CMD	-	ARM	60

- RSS - 0647/0648 = History tabs

B55V1623C LH PIC CAP A V	35.7	40.75	-
B55V1624C LH PIC CAP B V	35.7	40.75	-
B55V2623C RH PIC CAP A V	35.7	40.75	-
B55V2624C RH PIC CAP B V	35.7	40.75	-



*Table 5.7-3. The PIC history tab/DDD displays (concluded)*

T55V1730A ET PIC CAP A V	35.7	40.75	-
T55V1731A ET PIC CAP B V	35.7	40.75	-
B55X1877X LH RSS A ARM	-	ARM	60
B55X1878X LH RSS B ARM	-	ARM	60
B55X2877X RH RSS A ARM	-	ARM	60
B55X2878X RH RSS B ARM	-	ARM	60
T55X1931E ET RSS ARM	-	ARM	60
B55X1879X LH RSS A FIRE	-	FIRE	-
B55X1880X LH RSS B FIRE	-	FIRE	-
B55X2879X RH RSS A FIRE	-	FIRE	-
B55X2880X RH RSS B FIRE	-	FIRE	-
T55X1933E ET RSS FIRE	-	FIRE	-
B55X1870X LH RSS S&A ARM	-	ARM	-
B55X2870X RH RSS S&A ARM	-	ARM	-
T55X1870X ET RSS S&A ARM	-	ARM	-

## TITLE

PYROTECHNIC COMPONENT FAILURES

## DISCUSSION

A. NSI Unfired on the ET                      STS-1, FLT-1, OV-102, LD4-12-81.  
Umbilical:                                      STS-4, FLT-04, OV-102, LD 6-27-82.

### 1. Anomaly

Three NSI failures have occurred in the shuttle program, one on STS-1 and two on STS-4. In each case, the NSI was intended to separate an ET umbilical which was accomplished by the redundant NSI. All three anomalies were discovered in postflight inspection. Microscopic inspection and X-ray diffraction analysis confirmed that the NSI bridgewire had melted but a gap between the propellant and bridgewire prevented the propellant from igniting. Therefore, the PIC worked properly by providing sufficient current to melt the bridgewire and the NSIs had failed.

### 2. Resolution

The two problem reports concluded that the firing of the redundant detonator caused a shock which displaced the initiation propellant in the second detonator from the bridgewire, which prevented the second detonator from firing. It should be noted, however, that the temperature of the ET umbilical NSIs, at time of operation, could be as low as -250° F (the coldest NSIs in the shuttle system), which could be a contributing factor in the failures.

Because of this cold environment, each ET umbilical frangible nut has one NSI from two vendors, SOS and Hi-Shear, to minimize the risk of a generic manufacturing weakness. It should be noted that all three failed NSIs were manufactured by SOS. Subsequently, excessive lot test failures of NSIs at low temperatures forced the NSTS Program Office to investigate methods of improving NSI reliability. Several manufacturing techniques were experimented with and the best results were obtained when using a new "slurry" feature in the NSIs. The slurry feature is a special bonding between the propellant and bridgewire. The NSTS Program Office decided to incorporate the slurry feature into all NSIs and replace the existing shuttle hardware prior to STS-26.

B. Landing gear pyros fired postlanding: STS-7, FLT-2, OV-099, LD 6-18-83.

1. Anomaly

During postlanding operations, a bus tie DTO was performed to measure the electrical transients during a bus tie to a dead main bus and the subsequent reconnect of the AC bus to the inverter.

The problem occurred when FC2 was shut down and MNB was regained via bus tie (the AC2 system power was to be regained a short time later). With the LG ARM and LG DOWN PBIs enabled from landing, regaining MNB caused the pyro capacitors to recharge. Since the AC2 phase A bus was unpowered, the LG proximity sensor electronic box 2 indicated the RMG door was unlocked. This caused the RMG backup release 1 pyro to fire after the DC bus was powered.

2. Impact

Possible injury to ground personnel in the vicinity of the landing gear if a pyro is fired.

3. Resolution

Nominal postlanding procedures were changed to ensure that the LG safing procedure is performed prior to powering down any main buses. This procedure will be performed either by the crew or, in the event of an extended power up, by the convoy. In the event that MNB(C) is dropped in flight, the MMACS and EGIL console operators must not allow MNB(C) to be repowered before the LG safing procedure is performed.

Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Description
STS-29	OV-103	03/13/1989	03/18/1989	C/W	Power Supply B	Power Supply B fail	A couple of C/W system failures have occurred on flight units. In 1983, C/W Electronics (CWE) unit B power supply S/N 6 failed an internal self-test, generating a master alarm. The problem was isolated to a zener diode used to protect the power supply regulator. The diode was replaced, and the CWE unit was returned for flight use. During STS-29 postflight checkout, similar failure indications occurred on the same CWE unit. The problem could not be duplicated, and the CWE unit was moved to SAIL for confidence testing.
STS-88	OV-105	12/04/1998	12/15/1998	C/W	R13 Param Select	Sticky C&W Parameter Select and Limit Select Thumb Wheels	During the MOD Post-Flight Debrief, the crew reported that both the parameter select and limit value select mechanisms on the Hardware Caution and Warning panel R13 were sticky. The sticky mechanisms made changing hardware Caution and Warning more difficult than usual. This presented the risk of setting incorrect limits or inadvertently changing Hardware Caution and Warning limits. Troubleshooting was recommended during OV-105 turnaround activities.

5.9-1

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Description
STS-102	OV-103	03/08/2001	03/21/2001	C/W	Pushbutton	Shuttle Caution & Warning Pushbutton Failure	At GMT 069/12:27:13, the crew reported that while attempting to change hardware caution and warning for the 10.2 depress, the tenths place on the Limit Set value down pushbutton (pnl R13U) did not work. The crew reported they obtained the proper values by using the up pushbutton. There was no impact to the mission. Because the Limit Set Value function can be operated with either the up or down pushbutton, the crew can use the up position to set the tenths place on the Limit Set Value function. Several instances of problems with the pushbutton rotary switches have been detected. The switches are used for the C/W parameter select and limit set value functions on panel R13. Failures have varied from buttons hard-to-push to inoperable swithces. Causes are varied, including physical abuse, sticky plunger, bent plunger, loose wickets, and failed continuity. Operator error may account for many of these failures.
STS-112	OV-104	10/07/2002	10/16/2002	C/W	F7 SM Alert Light	Panel F7 SM Alert Light	After the Lamp Test on FD1, the crew reported that the SM Alery light on panel F7 did not illuminate. After further clarification, the crew reported that the Lamp Test was performed during a day pass and the SM Alert Light was functioning but dim. Post Sleep on FD2, the crew reported that with the Annunciator Intensity in full bright, the SM Alert Light was usable but still dim.

5.9-2

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Mission	Vehicle	Launch	Landing	Subsystem	Equipment	Title	Description
							There was no impact to the mission. The SM light was still functional and was used as is.
STS-113	OV-105	11/23/2002	12/07/2002	C/W	Pushbutton	Hardware C/W Pushbutton Failures	At GMT 335/04:05, the crew reported that while attempting to change Hardware Caution and Warning the "tens" place on the panel R13U C/W PARAMETER SELECT down pushbutton did not work. The crew then reported they were able to use the up pushbutton to obtain the correct parameters. The crew also reported that while attempting to change the C/W LIMIT SET VALUE, the "ones" place up pushbutton initially did not work. After several attempts, the crew was able to get the up pushbutton to work, however the crew felt the up bushbutton was "sticky". There was no impact to the mission.

5.9-3

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**TITLE**

EGIL FLIP BOOK

**PURPOSE**

This SCP provides a list of curves, charts, tables, and information to make an EGIL flip book.

**PROCEDURE**

To make an EGIL flip book, make copies of the following information available in other SCPs or other Flight Data File documents, or use the attached documents. These attached documents contain information from various resources. Copies can be made and added to your EGIL flip book.

Title	Source
O <sub>2</sub> K curve	EGIL CHB, Rev. F, Figure 3.2-8b
H <sub>2</sub> K curve	EGIL CHB, Rev. F, Figure 3.2-8a
O <sub>2</sub> flow capacity	EGIL CHB, Rev. F, Figure 3.7-12
H <sub>2</sub> flow capacity	EGIL CHB, Rev. F, Figure 3.7-13
SM FDA EGIL messages	EGIL CHB, Rev. F, SCP 6.1.2
BFS EGIL messages	EGIL CHB, Rev. F, SCP 6.1.3
Bus Loss vs. EGIL Function Lost	EGIL CHB, Rev. F, SCP 4.3.2
Control Bus - Panel Wiring Matrix	MAL EPS SSR-109, Control Bus - Panel Wiring Matrix
ac run/startup currents	EGIL CHB, Rev. F, Table 6.1.1-1
Baseline ac loads (amps)	EGIL CHB, Rev. F, Table 6.1.1-2
Baseline ac loads (watts pF)	EGIL CHB, Rev. F, Table 6.1.1-3
KOH nomengraph	SODB, Figure 4.4.1-34, FC Electrolyte Concentration
Orbiter panels	SSSH drawing, Section 20
FC purge commands	EGIL CHB, Rev. F, Figure 6.1.1-1
FC/PRSD layout	EGIL CHB, Rev. F, Figure 6.1.1-2
Flight phase vs. book	EGIL CHB, Rev. F, Figure 6.1.1-3
MCA sheet	EGIL CHB, Rev. F, Figure 6.1.1-4
LCC sheet	EGIL CHB, Rev. F, Table 6.1.1-4
CRYO/MDM/MISC information	EGIL CHB, Rev. F, Figure 6.1.1-5
O <sub>2</sub> critical pressure plot	SODB, Figure 4.4.2-14
H <sub>2</sub> critical pressure plot	SODB, Figure 4.4.2-6
MDM loss/DSC loss	EGIL CHB, Rev. F, Figures 6.1.4-1 through 6.1.4-8
Circuit protection device characteristics	EGIL CHB, Rev. F, Figure 4.3.1-1
Circuit breaker trip curve	EGIL CHB, Rev. F, Figure 4.3.1-2
Fuse (1 to 15 amps) melt time	EGIL CHB, Rev. F, Figure 4.3.1-4
Fuse (20 to 60 amps) melt time	EGIL CHB, Rev. F, Figure 4.3.1-5
Fuse fast blow	EGIL CHB, Rev. F, Figure 4.3.1-6
Fuse slow blow	EGIL CHB, Rev. F, Figure 4.3.1-7
Caution and warning sheet	EGIL CHB, Rev. F, Figure 6.1.1-6



**Table 6.1.1-1. AC run/startup currents**

Equipment	Phase current - amps					
	Φ A		Φ B		Φ C	
	3 Φ	2 Φ	3 Φ	2 Φ	3 Φ	2 Φ
Cabin fan <sup>2</sup>	1.84 (7)	2.95	1.84	2.95	1.84	2.95
H <sub>2</sub> O pump <sup>1</sup>	1.1 (1.71)	1.51	1.1 (1.71)	1.51	1.1 (1.71)	1.51
WCS fan sep (High torque)	0.8 (3.52)		0.8 (3.52)		0.8 (3.52)	
Booster fan <sup>1</sup>	0.8 (1.4)		0.8 (1.4)		0.8 (1.4)	
Galley fan <sup>1</sup>	0.32 (0.48)		0.32 (.48)		0.32 (.48)	
Vacuum cleaner	0.7 (5.0)		0.7 (5.0)		0.7 (5.0)	
H <sub>2</sub> motor <sup>1</sup>	0.2 (1.3)	0.45	0.2 (1.3)	0.45	0.2 (1.3)	0.45
Cool pump <sup>1</sup>	0.5 (1.05)	0.62	0.5 (1.05)	0.62	0.5 (1.05)	0.62
IMU fan <sup>1</sup>	0.155 (0.5)	.33	0.155 (0.5)	.33	0.155 (0.5)	.33
Avionics bay fan <sup>1</sup>	0.768 (2.33)	1.44	0.768 (2.33)	1.44	0.768 (2.33)	1.44
Humidity sep <sup>1</sup>	0.434 (0.7)	0.566	0.434 (0.7)	0.566	0.434 (0.7)	0.566
Freon pump <sup>1</sup>	1.83 (3.75)	2.67	1.83 (3.75)	2.67	1.83 (3.75)	2.67

<sup>1</sup>Capable of starting on two phases.

<sup>2</sup>Will start on two-phase, providing that failed-phase circuit breaker is closed and all three-phase equipment on bus is activated.

<sup>3</sup>( ) = Locked rotor; i.e., startup.

**Table 6.1.1-2. Baseline ac loads (amps)**

EQUIPMENT	EEL LOC	ITEM	AC1			ITEM	AC2			ITEM	AC3		
			A	B	C		A	B	C		A	B	C
			Amps	Amps	Amps		Amps	Amps	Amps		Amps	Amps	Amps
TACAN Gould	0217	#1			1.61	#2			1.61	#3			1.61
Panel Lights	0331	L/CTR	2.83			RIGHT		1.55		MS		0.28	
	0331	L/OVHD	3.80	1.92		R/OVHD	1.33	2.06		OS/PS			2.63
Instr Lights	0332	RIGHT	0.46	2.56		OVHD	1.77	0.26		L/CTR		0.52	
	0332	OS			0.13							0.50	
Numeric Lights	0333	FWD		0.16		OS			0.20				
DFI Freon Pump	0524	1 or 2	1.31	1.31	1.31								
DFI Sig Cond	0522					ARS		0.07		ATCS	0.02		
Inv Dist Cntl Assy	0610	#1	0.01	0.01	0.01	#2	0.01	0.01	0.01	#3	0.01	0.01	0.01
Lg Prox Snsr II Prg	0620					#2	0.07			#1	0.07		
MN Eng Cntr	2001	CTR 1A	0.97	0.97	0.97	LFT 2A	0.97	0.97	0.97	TR 3A	0.97	0.97	0.97
	2001	RT 3B	0.88	0.88	0.88	CTR 1B	0.88	0.88	0.88	LFT 2B	0.88	0.88	0.88
FCP Pump & H2O Snsr	3005	#1	0.79	0.79	0.79	#2	0.80	0.80	0.80	#3	0.77	0.77	0.77
Cabin Fan	4001					B	1.66	1.66	1.66	A	1.70	1.70	1.70
Cabin Air Temp Cntl	4002	SEC	0.15			PRI	0.15						
Cabin Air Elec Cntl	4003	SEC	0.04			PRI	0.04						
ECLSS Sig Cond	4004	CAB AIR S/C		0.04						HUM SEP S/C	0.02		
Humidity Sep	4005	A	0.27	0.27	0.27	B	0.27	0.27	0.27				
Avionics Bay Fan	4008	1A	0.72	0.72	0.72	2A	0.71	0.71	0.71	3A	0.73	0.73	0.73
	4008	3B	0.73	0.73	0.73	1B	0.73	0.73	0.73	2B	0.73	0.73	0.73
AV Bay Sig Cond	4009	BAY 2		0.02		BAY 3		0.03		BAY1		0.02	
IMU Fan	4011	A	0.18	0.18	0.18	B	0.18	0.18	0.18	C	0.18	0.18	0.18
IMU Fan Sig Cond	4012											0.02	
H2O Pump	4013	1A	0.96	0.96	0.96	1B	0.98	0.98	0.98	2	1.03	1.03	1.03
H2O Bypass Cntl S/C	4015	SEC (2)	0.06							PRI (1)	0.06		
Freon Pump	4029	1A	1.67	1.67	1.67	1B	1.67	1.67	1.67	2A	1.67	1.67	1.67
	4029	2B	1.67	1.67	1.67								
Freon Loop Instr	4036					LOOP 1 (A)		0.05		LOOP 2 (B)		0.05	
HYD Qty Snsr	5008	#1		0.01		#2		0.01		#3		0.01	
HYD H2O BLR Cntr Lau	5037	3A			0.04	1A	0.04			2A	0.04		
	5037	1B	0.05			2B			0.05	3B			0.05
HYD ACTR Instr	5019				0.06				0.13				
INV Input DC Watts Total Bus/Inv		Total kW Watts Pf Amps				Total kW Watts Pf Amps				Total kW Watts Pf Amps			

Table 6.1.1-3. Baseline ac loads (watts pF)

EQUIPMENT	EEL LOC	ITEM	AC1			AC2			AC3							
			A Watts	B Watts	C Watts	A Watts	B Watts	C Watts	A Watts	B Watts	C Watts					
TACAH Gould Panel Lights	0217	#1			160.00					160.00						
	0331	L/CTR	298.00	0.90						163.20	0.90			29.50	0.90	
	0331	L/OVHD	400.00	0.90	202.40	0.90				140.10	0.90					
Instr Lights	0332	RIGHT	48.50	0.90	270.00	0.90				186.00	0.90					
	0332	OS			14.00	0.90										
Numeric Lights	0333	FWD			17.00	0.90										
DFI Freon Pump	0524	1 or 2	78.00	0.51	78.00	0.51										
DFI Sig Cond	0522															
Inv Dist Cntrl	0610	#1	0.70	0.90	0.70	0.90				0.70	0.90			0.70	0.90	
Lg Prox Snsr II Prg	0620															
MHI Eng Cntrl	2001	CTR 1A	108.00	0.95	108.00	0.95				108.00	0.95			108.00	0.95	
	2001	RT 3B	95.30	0.93	95.30	0.93				95.30	0.93			95.30	0.93	
FCP Pump & H2O Snsr	3005	#1	59.50	0.64	59.50	0.64				58.80	0.63			57.70	0.64	
Cabin Fan	4001									159.30	0.82			164.70	0.83	
Cabin Air Temp Cntrl	4002	SEC	16.90	0.98						16.90	0.98					
Cabin Air Elec Cntrl	4003	SEC	4.10	0.84						4.00	0.84					
ECLSS Sig Cond	4004	CAB AIR S/C			3.70	0.84										
Humidity Sep	4005	A	9.60	0.30	9.60	0.30				9.50	0.30			9.50	0.30	
Avionics Bay Fan	4008	1A	55.30	0.66	55.30	0.66				54.30	0.65			57.00	0.67	
	4008	3B	56.00	0.66	56.00	0.66				56.00	0.66			56.20	0.66	
AV Bay Sig Cond	4009	BAY 2			1.80	0.84								2.40	0.84	
IMU Fan	4011	A	16.10	0.78	16.10	0.78				16.20	0.78			16.30	0.77	
IMU Fan Sig Cond	4012															
H2O Pump	4013	1A	65.00	0.58	65.00	0.58				65.40	0.57			63.90	0.53	
H2O Bypass Cntrl S/C	4015	SEC (2)	5.90	0.85										5.90	0.85	
Freon Pump	4029	1A	124.70	0.64	124.70	0.64				124.70	0.64			124.70	0.64	
	4029	2B	124.70	0.64	124.70	0.64				124.70	0.64			124.70	0.64	
Freon Loop Instr	4036															
HYD Qty Snsr	5008	#1			1.40	0.80				5.00	0.90			5.00	0.90	
HYD H2O BLR Cntrl Lau	5037	3A								2.90	0.70			3.60	0.70	
	5037	1B	3.90	0.70												
HYD ACTR Instr	5019				5.00	0.70										

**BFS**

Procedure:

1. Get INCO to UNSAFE Group 1
2. Send Commands

**Safed Command Groups**

EDTE Page MSK 2666

Group	Commands	Enable/Disable	DSM #	Command
1	8	Disable	5400	FC3 Purge Vlv A/B Open
			5401	FC3 Purge Vlv A/B Closed
			5402	FC2 Purge Vlv A/B Open
			5403	FC2 Purge Vlv A/B Closed
			5404	FC1 Purge Vlv A/B Open
			5405	FC1 Purge Vlv A/B Closed
			5406	FC Purge Heaters ON
			5407	FC Purge Heater OFF

**RTC Inventory:**

EDTE Page MSK 0919

DSM	MSID	Command	MDM1/2	RST	MDM1/2	Set
5400	V45K0837U	FC3 Purge Vlv A/B Open	708A	0000	788A	C000
5401	V45K0838U	FC3 Purge Vlv A/B Closed	708A	C000	788A	0000
5402	V45K0839U	FC2 Purge Vlv A/B Open	E089	0000	E889	C000
5403	V45K0840U	FC2 Purge Vlv A/B Closed	E089	C000	E889	0000
5404	V45K0841U	FC1 Purge Vlv A/B Open	7089	0000	7889	C000
5405	V45K0842U	FC1 Purge Vlv A/B Closed	7089	C000	7889	0000
5406	V45K0843U	FC Purge Heaters On	E08A	0000	E88A	C000
5407	V45K0844U	FC Purge Heaters Off	E08A	C000	E88A	0000

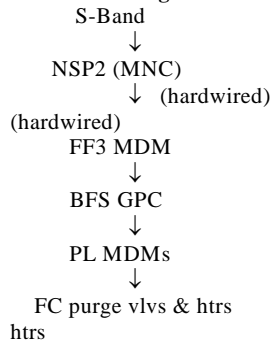
EDTE Page MSK 0918

**MRTC Inventory**

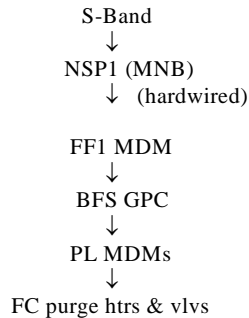
5410	FC 1/2/3 Purge Start <i>(Heaters on, valves open)</i>	5406, 5400, 5402, 5404
------	---	------------------------

**Ascent/Entry FC Purge Commanding**

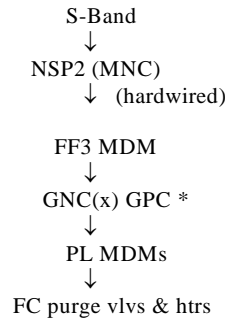
**Nominal Config with NSP2**



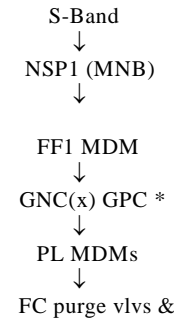
**If on NSP1**



**If on NSP 2 with BFS down**



**If on NSP1 w/ BFS dov**



\* Which GNC GPC commands PL MDMs depends on the restrig assignments.

**PASS/SM (TMBU)**

Sequence Start	V92X0634X	(set to 1)
Set Time in Minutes	FC1 Time	V92W0636C
	FC2 Time	V92W0637C
	FC3 Time	V92W0638C

FC Auto Purge Line Temps: O2= 69° H2-Temp1=79°, H2-Temp2=40°
--

**Figure 6.1.1-1. FC purge commands**

Verify that this is the correct version before use

6.1.1-6

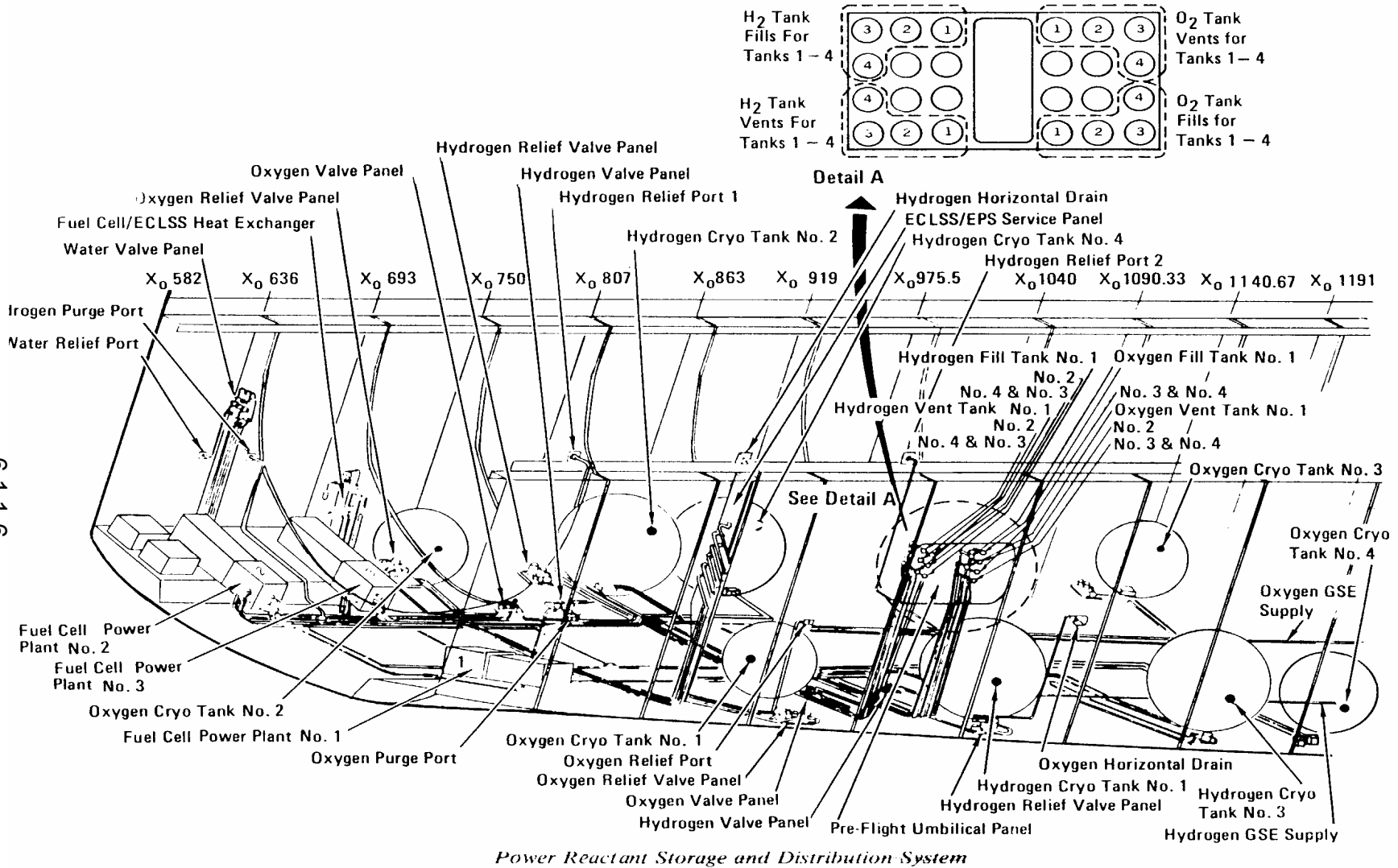


Figure 6.1.1-2. FC/PRSD layout

**Nominal Sequence of Major Modes**

			Off Nominal	Nominal
MM	101	Prelaunch	AESP (white)	Ascent Checklist
	102	Liftoff		
	103	SRB Sep		
	104	MECO	APCL	
	105	Post Oms 1		
	106	Post Oms 2	OPCL	Post Insertion
MM	201	Orbit	OPCL/MAL	Flight Plan
	202	mnvr/door ops		
MM	301	D/O Prep (Pre-TIG, ~TIG-2:15)	EPCL	Entry Checklist
	302	Pre-TIG (~TIG -20min)		
	303	Post D/O TIG burn		
	304	EI -5min (~TD-35min)	AESP (blue)	
	305	TAEM Interface (~TD -6.5 min) through landing		
MM	901	Postlanding		

**RTLS Sequence**

			Off-Nominal	Nominal
MM	101	Prelaunch	AESP (white)	Ascent Checklist
	102	Liftoff		
	103	SRB Sep		
MM	601	RTLS Select Onboard		
	602	MECO	AESP (blue)	
	603	TAEM Interface (~TD -7.5 min) through landing		
MM	901	Postlanding		Entry Checklist

**TAL Sequence**

			Off-Nominal	Nominal
MM	101	Prelaunch	AESP (white)	Ascent Checklist
	102	Liftoff		
	103	SRB Sep		
	104	MECO		
MM	301 (304)	Post MECO	AESP (blue)	
	305	TAEM Interface thru landing		
MM	901	Postlanding		Entry Checklist

**AOA Sequence**

			Off-Nominal	Nominal
MM	101	Prelaunch	AESP (white)	Ascent Checklist
	102	Liftoff		
	103	SRB Sep		
	104	MECO	APCL	
	105	Post Oms 1		
MM	301/302	Pre-TIG (~TIG -10min)	EPCL	
	303	Post D/O TIG burn		
	304	EI -5min (~TD -35min)	AESP (blue)	Entry Checklist
	305	TAEM Interface (~TD -6.5 min) through landing		
MM	901	Postlanding		

**Figure 6.1.1-3. Flight phase vs. book**

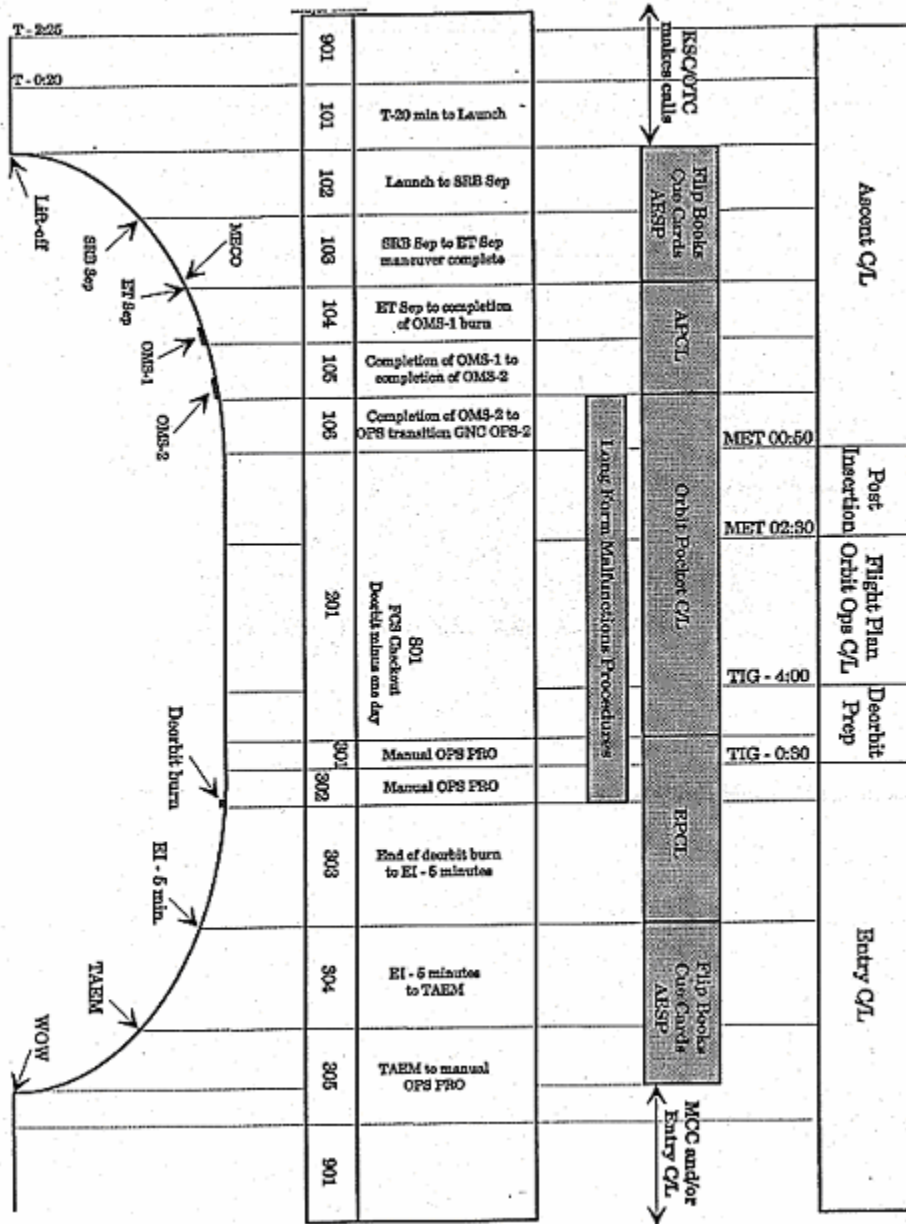


Figure 6.1.1-7 Timeline from Pre-launch thru Landing

PLB Door Motor	Open	Close	AC Power	Current (amps)	time sec dual/single	PLBD sys	PL MDM	CNTL Bus	MMC Bus (MID)
CL 1-4 mtr1	mid 3 stat 4	mid 3 stat 3	AC1 MMC3	~0.55	20/40	2	1	AB2/AB3	MNA MMC3
CL 1-4 mtr2	mid 2 stat 4	mid 2 stat 3	AC3 MMC2	~0.55	20/40	1	2	CA1/CA3	MNC MMC2
CL 5-8 mtr1	mid 3 stat 6	mid 3 stat 5	AC1 MMC3	~0.55	20/40	2	1	AB2/AB3	MNA MMC3
CL 5-8 mtr2	mid 2 stat 8	mid 2 stat 7	AC3 MMC2	~0.55	20/40	1	2	CA1/CA3	MNC MMC2
CL 9-12 mtr1	mid 1 stat 3	mid 1 stat 4	AC1 MMC1	~0.55	20/40	1	1	AB1/AB3	MNA MMC1
CL 9-12 mtr2	mid 4 stat 8	mid 4 stat 5	AC3 MMC4	~0.55	20/40	2	2	CA2/CA3	MNC MMC4
CL 13-16 mtr1	mid 4 stat 6	mid 4 stat 7	AC3 MMC4	~0.55	20/40	2	2	CA2/CA3	MNC MMC4
CL 13-16 mtr2	mid 2 stat 1	mid 2 stat 2	AC2 MMC2	~0.55	20/40	1	1	BC1/BC3	MNB MMC2
Port fwd mtr1	mid 1 stat 4	mid 1 stat 3	AC1 MMC1	~0.55	30/60	1	1	AB1/AB3	MNA MMC1
Port fwd mtr2	mid 4 stat 3	mid 4 stat 2	AC2 MMC4	~0.55	30/60	2	2	BC2/BC3	MNB MMC4
Port aft mtr1	mid 3 stat 2	mid 3 stat 1	AC1 MMC3	~0.55	30/60	2	1	AB2/AB3	MNA MMC3
Port aft mtr2	mid 2 stat 6	mid 2 stat 5	AC3 MMC2	~0.55	30/60	1	2	CA1/CA3	MNC MMC2
Port door mtr1	mid 4 stat 5	mid 4 stat 8	AC3 MMC4	~1.35	63/126	2	2	CA2/CA3	MNC MMC4
Port door mtr2	mid 2 stat 1	mid 2 stat 2	AC2 MMC2	~1.35	63/126	1	1	BC1/BC3	MNB MMC2
STBD fwd mtr1	mid 1 stat 1	mid 1 stat 2	AC1 MMC1	~0.55	30/60	1	1	AB1/AB3	MNA MMC1
STBD fwd mtr2	mid 4 stat 4	mid 4 stat 1	AC2 MMC4	~0.55	30/60	2	2	BC2/BC3	MNB MMC4
STBD aft mtr1	mid 4 stat 7	mid 4 stat 6	AC3 MMC4	~0.55	30/60	2	2	CA2/CA3	MNC MMC4
STBD aft mtr2	mid 2 stat 2	mid 2 stat 1	AC2 MMC2	~0.55	30/60	1	1	BC1/BC3	MNB MMC2
STBD door mtr1	mid 1 stat 5	mid 1 stat 6	AC1 MMC1	~1.10	63/126	1	1	AB1/AB3	MNA MMC1
STBD door mtr2	mid 4 stat 1	mid 4 stat 4	AC2 MMC4	~1.10	63/126	2	2	BC2/BC3	MNB MMC4

ET Doors	Open	Close	AC Bus	current	drive time
CL Lat1 mtr1	aft 1 stat 3&4	aft 1 stat 1&2	AC1	~0.5	6 sec
CL Lat1 mtr2	aft 2 stat 1&2	aft 2 stat 3&4	AC2	~0.5	6 sec
CL Lat2 mtr1	aft 1 stat 1&2	aft 1 stat 3&4	AC1	~0.5	6 sec
CL Lat2 mtr2	aft 3 stat 1&2	aft 3 stat 3&4	AC3	~0.5	6 sec
Left Latch mtr1	aft 1 stat 1&2	aft 1 stat 3&4	AC1	~0.5	6 sec
Left Latch mtr2	aft 2 stat 1&3	aft 2 stat 2&4	AC2	~0.5	6 sec
Left door mtr1	aft 1 stat 3	aft 1 stat 1	AC1	~0.5	24 sec
Left door mtr2	aft3 stat 4	aft 3 stat 2	AC3	~0.5	24 sec
Right Latch mtr1	aft 3 stat 1&2	aft 3 stat 3&4	AC3	~0.5	6 sec
Right Latch mtr2	aft 2 stat 3&4	aft 2 stat 1&2	AC2	~0.5	6 sec
Right door mtr1	aft 3 stat 3	aft 3 stat 1	AC3	~0.5	24 sec
Right door mtr2	aft 2 stat 1	aft 2 stat 3	AC2	~0.5	24 sec

Ku Band Ant:	MCA'sv- DPLY	MCA's - STOW	AC Bus	current	time
Mtr1	mid 2 stat 4 mid 2 stat 5	mid 2 stat 3 mid 2 stat 6	AC3	~0.8	20 sec
Mtr2	mid 4 stat 2 mid 4 stat 3	mid 4 stat 1 mid 4 stat 4	AC2	~0.8	20 sec

**Circuit Breaker Nomenclature:**

<b>FMC1</b> pnl MA73C:C MCA LOGIC MCA POWER AC1 3p FWD 1 pnl MA73C:H AC1 FWD RCS VLV pA or B or C
<b>FMC2</b> pnl MA73C:C MCA LOGIC MCA POWER AC2 3p FWD 2 pnl MA73C:H AC2 FWD RCS VLV pA or B or C
<b>FMC3</b> pnl MA73C:C MCA LOGIC MCA POWER AC3 3p FWD 3 pnl MA73C:H AC3 FWD RCS VLV pA or B or C
<b>AMC1</b> pnl MA73C:D MCA LOGIC MCA POWER AC1 3p AFT 1 pnl MA73C:I AC1 AFT POD VLV GP 1 pA or B or C
<b>AMC2</b> pnl MA73C:D MCA LOGIC MCA POWER AC2 3p AFT 2 pnl MA73C:I AC2 AFT POD VLV GP 2 pA or B or C
<b>AMC3</b> pnl MA73C:D MCA LOGIC MCA POWER AC3 3p AFT 3 pnl MA73C:I AC3 AFT POD VLV GP 3 pA or B or C

<b>MMC1</b> pnl MA73C:C MCA LOGIC MCA POWER AC2 3p MID1 pnl MA73C:C MCA POWER AC1 3p MID1
<b>MMC2</b> pnl MA73C:C MCA LOGIC MCA POWER AC2 3p MID2 pnl MA73C:C MCA POWER AC3 3p MID2
<b>MMC3</b> pnl MA73C:D MCA LOGIC MCA POWER AC2 3p MID3 pnl MA73C:D MCA POWER AC1 3p MID3
<b>MMC4</b> pnl MA73C:D MCA LOGIC MCA POWER AC2 3p MID4 pnl MA73C:D MCA POWER AC3 3p MID4

**Figure 6.1.1-4. MCA sheet**



Table 6.1.1-4. LCC violations

Parameter	LCC	page	T-time	min	max	ppc	GO/NO-GO
AC Bus Amps	EPDC-04	26-04	T-6h to T-31s	0.16	9.6	*	instrumentation failure = GO if 2 of 3 Good & the volts available (F9 Meter)
AC Bus Volts	EPDC-03	26-03	T-6h to T-31s	115	120	*	instrumentation failure = GO if 0 of 3 Good & the amps available (F9 Meter)
Caution & Warning	INS-06	33-06	T-6h to T-31s			*	Unexplained Master Alarm = NO GO F7 Light failed on = GO (NO Tone)
CNTL Bus RPC	EPDC-02	26-02	T-6h to T-10s	ON		*	instrumentation failure = GO if 8 of 9 Good & 2 of 3 pwr sources Good loss of 2 RPC's or an RPC & cb = NO GO
ESS to FC Bus	EPDC-07	26-07	T-6h to T-31s			*	Mandatory unless verified as instrumentation failure
ESS Bus RPC	EPDC-06	26-06	T-6h to T-31s	ON		*	GO if 5 of 6 RPC sources Good Before APU start: for RPC-OFF do PPC. Inst. Fail = GO if 5 of 6 sources Good After APU start: NO prior RPC failure, 1 failure indication = GO. If prior RPC failure: 2nd RPC on same ESS bus, verify 1 of 2 mn bus sources Good per PPC. 2nc RPC on diff bus, perform PPC, if RPC fail = NO GO, if inst = GO.
FC Amps	FCP-01	25-01	FC Cal to T-5m		450	*	max value 450 amps = NO GO (F9 Meter)
FC Cool P	FCP-02	25-02	FC Cal to T-10s	55	75	*	instrumentation failure = GO if FC Stack Out T, Stack In T, Exit T Good (3 of 4)
FC Coolant Pmp	FCP-04	25-04	FC cal to t-10s	ON		*	instrumentation failure = GO
FC Exit T	FCP-02	25-02	FC Cal to T-31s	140	160	*	instrumentation failure = GO if FC Stack out T, Stack In T, Cool P Good (3 of 4) instrumentation failure = GO if 2 of 3 Exit T Good GO if KOH btw 24-48%
FC H2 Mtr	FCP-04	25-04	FC Cal to T-10s	0.28	1	*	instrumentation failure = GO value >1.0 = GO if due to AC phase imbalances (lighting adjust)
			FC Cal to T-9m	0.28	0.8	*	value >0.75 = NO GO
FC H2O Rlf Noz T	FCP-06	25-06	T-6h to T-9m	157	235	*	instrumentation failure = GO for 1 of 2 Good NOz temp sensor cntl function loss = GO if htr controls btw 157-317 F. ** temporary temp excursions are acceptable during periods of rain
FC H2O Rlf Vlv T	FCP-06	25-06	T-6h to T-9m	60			2 of 3 measurements req'd = GO, 1 of 2 heaters req'd. (A or B)
FC H2O Rlf Line T	FCP-06	25-06	T-6h to T-9m	60			confirmed instrumentation failure = GO 1 of 2 heaters req'd = GO
FC Alt H2O line T	FCP-06	25-06	T-6h to T-9m	60			instrumentation failure = GO if 2 of 3 are Good FC1 A & B hrs req'd, FC 2 & FC3 1 of 2 hrs (A or B) req'd
FC/MN Bus Volts	FCP-01	25-01	FC Cal to T-5m	28.3	32	*	instrumentation failure 1 of 2 measurements = GO (F9 Meter)
FC/MN Bus Volts	EPDC-01	26-01	T-6h to T-31s	28.3	32	*	GO if assoc. MN Bus Volts/FC Volts Ok (F9 Meter). Inst. Fail 1 of 2 meas = GO
FC pH / H2O pH	FCP-05	25-05	FC Cal to T-31s	OFF		*	instrumentation failure = GO if 3 of 4 are Good violations of 5 min or less = continue violations of 5 min or more = hold & evaluate
FC SS DV	FCP-03	25-03	T-6h to T-31s		150	*	instrumentation failure = hold & evaluate (NO GO if confirmed instrumentation)
			T-6h to T-9m				fixed value at self test 50mv = hold & evaluate (NO change with load change)
			T-6h to T-9m				fixed value at 0mv = hold & evaluate (NO change with load change)
			T-6h to T-9m				(contingency - S0007 V5)
			T-6h to T-9m				SS DV change >18mv = hold & evaluate (at steady state load)
			T-6h to T-9m				SS DV change >28mv = hold & evaluate (during load change)
FC Stack In T	FCP-02	25-02	FC Cal to T-31s	176	191	*	inst fail = GO if FC Stack out T, Exit T, Cool P Good (3 of 4); KOH btw 24-48%
FC Stack Out T	FCP-02	25-02	FC Cal to T-31s			*	instrumentation failure = GO if FC STK In T, Exit T, Cool P ok (3 of 4) (O2 Meter)
FC REAC VLV	PRSD-03	24-03	T-6h to T-10s	ON		*	instrumentation failure or tb failure = GO
H2 Manf Vlv	PRSD-02	24-02	T-6h to T-31s	ON		*	instrumentation failure = GO (S0007 V5)
H2 TK/Cntrl Press	PRSD-06	24-06	T-6h to T-31s			*	instrumentation failure 1 of 2 measurements per tank = GO
				196	298		Control P failed High = NO-GO
				(213)			paired tank both CPC failed low = NO-GO
				192	294		TK Press high NOT cracking ob-relief & press control re-established = GO
				(209)			ovbd-relief crack pressure = hold/evaluate (S0007 V5)
H2 TK Quantity	PRSD-08	24-08	T-6h to T-9m	0		*	2 quantity measurement req'd, (1 of which must be tk 1 or 2) = GO (meter)
GSE O2/H2 Vlv	PRSD-05	24-05	T-2.5m to T-31s	ON		*	confirmed instrumentation = GO
MCA Stat - FVVD	AFM-16	29-16	T-6h to T-31s	ON		*	MCA Stat indication - Hold & evaluate
MCA Stat - MID	AFM-17	29-17	T-6h to T-31s	ON		*	MCA Stat indication - Hold & evaluate
MCA Stat - AFT	AFM-18	29-18	T-6h to T-31s	ON		*	MCA Stat indication - Hold & evaluate
O2 Manf Vlv	PRSD-02	24-02	T-6h to T-31s	ON		*	instrumentation failure = GO
O2 TK htr SNSR	PRSD-04	24-04	T-6h to T-31s	OFF		*	1 set of current snrs req'd = GO 2 tk's with NO htr current snsr tripped = GO (1 of those tks can have cb)
O2 Tk/Cntrl Press	PRSD-01	24-01	T-6h to T-31s			*	instrumentation failure 1 of 2 measurements per tank = GO
				791	993		Control P failed High = NO-GO
				(820)			paired tank both CPC failed low = NO-GO
				779	981		TK Press high NOT cracking ob-relief & press control re-established = GO
				(808)			ovbd-relief crack pressure = hold/evaluate (S0007 V5)
O2 TK Quantity	PRSD-07	24-07	T-6h to T-9mm	30		*	2 quantity measurement req'd, (1 of which must be tk 1 or 2) = GO (meter)

<p><b>FC/MN Control Circuit Breakers</b></p> <p>FC1/MNA pdl 013:A ESS1BC MNA CONTR pdl 015:B MNE MNA CONTR</p> <p>FC2/MNB pdl 013:C ESS2CA MNB CONTR pdl 016:B MNC MNB CONT</p> <p>FC3/MNC pdl 013:E ESS3AB MNC CONTR pdl 014:B MNA MNC CONTR</p>	<p><b>FC Control Switch</b></p> <p>FC1 pdl 014:A FC1 CNTLR</p> <p>FC2 pdl 015:A FC2 CNTLR</p> <p>FC3 pdl 016:A FC3 CNTLR</p> <p><b>FC PUMPS Circuit Breakers</b></p> <p>FC_ pdl 14:C AC_ FC_ PUMP φA, B, C</p>	<p><b>Control Bus Circuit Breakers</b></p> <p>pdl R14:B MNC CNTRL BUS AB 1/2/3</p> <p>pdl R14:B MNA CNTRL BUS BC 1/2/3</p> <p>pdl R14:B MNB CNTRL BUS CA 1/2/3</p>
<p><b>FC PURGE Switches</b></p> <p>pdl R11U FC Purge Heater GPC/OFF/ON</p> <p>pdl R11U FC Purge Valves _ OPEN/GPC/CLOSE</p>	<p><b>Caution &amp; Warning Circuit Breakers</b></p> <p>CWA pdl 013:A ESS1BC C/W A</p> <p>CWB pdl 013:C ESS2CA C/W B</p>	

MEC:

ACV>130 - MEC should not be functional

ACV< 95 - MEC should not be functional

OR

AC1 = Center - A, Right - B

AC2 = Left - A, Center - B

AC3 = Right - A, Left - B

Entry:

AC2 φA = Prox Box 2

AC3 φA = Prox Box 1

Tacans:

Collins = DC (FPC)

Gould = AC (phase C ~1.1a/p)

ME Power ~ 1 amp/phase

~0.5 per controller

**MDM Power**

MDM	MNA	MNB	MNC	RPC/CB	MDM	MNA	MNB	MNC	RPC/CB
FF1	FPC1	FPC2		5A RPC	PF1	FPC1	FPC2		5A RPC
FF2		FPC2	FPC3	5A RPC	PF2		FPC2	FPC3	5A RPC
FF3	FPC1		FPC3	5A RPC					
FF4		FPC2	FPC3	5A RPC	OF1/2	O14	O15		7.5A cb
					OF 3/4	O14		O16	7.5A cb
FA1	APC4	APC5		5A RPC					
FA2		APC5	APC6	5A RPC	OA1	APC4	APC5		5A RPC
FA3	APC4		APC6	5A RPC	OA2		APC5	APC6	5A RPC
FA4	APC4		APC6	5A RPC	OA3	APC4		APC6	5A RPC

**CRYO**

O2	H2
Tank @ 100% = 781 lb	Tank @ 100% = 92 lb
Heater element = 250 Watts	Heater element = 100 Watts
Usage Factor (U.F.) = 0.695 lb/kWh	Usage Factor (U.F.) = 0.087 lb/kWh
FC Consumption = 47.5 amp-h/lb	FC Consumption = 377 amp-h/lb
Crew Usage = 0.073 lb/hr per crewman	
Vent Usage OV-102 = 1.69 lb/day	
OV-103 = 1.20 lb/day	
OV-104 = 1.20 lb/day	
OV-105 = 1.50 lb/day	

**Calculating K for multiple feeding Tanks:**

Multiple Tks @ same quantity:

$$K_{total} = \frac{1}{1/K1 + 1/K2 + \dots + 1/Kn}$$

**Decay:**  $psl/min = Pwr (kW) * U.F. (\frac{lb}{hr}) * K (psl/min)$       **Rise:**  $psl/min = [Flow Capacity (\frac{lb}{hr}) * Hr (W) - Pwr (kW) * U.F. (\frac{lb}{hr})] * K (psl/min)$

**Redline Determination:** = Measurement Uncertainty + Residuals

**Residuals:**

O2	H2
A. Any tanks >6.5% = $(781 lbm * .065)^2$ (# of tanks)	A. Tanks 1 & 2 = $(92 lbm * .04)^2$ (tanks)
B. Any tanks <6.5% = $(781 lbm * Q\%)$	B. Tanks 3-9, Any tank >2.5% = $(92 lbm * .025)^2$ (# of tanks)
Total O2 Residual = Sum of all O2 tanks	C. Tanks 3-9, Any tank <2.5% = $(92 lbm * Q\%)$
	Total H2 Residual = Sum of all H2 tanks

**Measurement Uncertainty:**  $M.U. = [100\% tank Quantity * 0.026 * (\# of tanks)^{1/2}]$   
*Once a tank is depleted it can be removed from the M.U. calculation*

**Figure 6.1.1-5. CRYO/MDM/MISC information**

O2 PRESS (Y)	H2 PRESS (Y)	FUEL CELL REAC (R)	FUEL CELL STACK TEMP (Y)	FUEL CELL PUMP (Y)
0 O2 TK1 Press 10 O2 TK2 Press 20 O2 TK3 Press 30 O2 TK4 Press 40 O2 TK5 Press	50 H2 TK1 Press 60 H2 TK2 Press 70 H2 TK3 Press 80 H2 TK4 Press 90 H2 TK5 Press	2 FC1 O2 VLV CL 12 FC1 H2 VLV CL 22 FC2 O2 VLV CL 32 FC2 H2 VLV CL 42 FC3 O2 VLV CL 52 FC3 H2 VLV CL	62 FC1 Stack Temp 72 FC2 Stack Temp 82 FC3 Stack Temp	92 FC1 PMP DP Low 102 FC2 PMP DP Low 112 FC3 PMP DP Low
CABIN ATM (R)	O2 HEATR TEMP (Y)	MAIN BUS UNDERVOLT (R)	AC VOLTAGE (Y)	AC OVERLOAD (Y)
4 Cabin Press 14 SYS1 O2 Flow 24 SYS2 O2 Flow 34 O2 PP A 44 O2 PP B 54 SYS1 GN2 Flow 64 SYS2 GN2 Flow	1 O2 TK1 HTR 1 T 11 O2 TK1 HTR 2 T 21 O2 TK2 HTR 1 T 31 O2 TK2 HTR 2 T 41 O2 TK3 HTR 1 T 51 O2 TK3 HTR 2 T 61 O2 TK4 HTR 1 T 71 O2 TK4 HTR 2 T 81 O2 TK5 HTR 1 T	3 MN BUS A U/V 13 MN BUS B U/V 23 MN BUS C U/V	33 AC1 Bus O/V-U/V 43 AC2 Bus O/V-U/V 53 AC3 Bus O/V-U/V	63 AC1 Bus Overload 73 AC2 Bus Overload 83 AC3 Bus Overload
FREON LOOP (Y)	AV BAY/ CABIN AIR (Y)	IMU (Y)	FWD RCS (R)	RCS JET (Y)
106 FCL1 Flow 107 FCL1 EVAP Out T 116 FCL2 Flow 117 FCL2 EVAP Out T	74 Cabin Fan Delta P 84 Av Bay 1 Out Air T 94 Av Bay 2 Out Air T 104 Av Bay 3 Out Air T 114 Cabin HX Air Out T	103 IMU Fail	6 RCS-F OX TK ULL P 16 RCS-F FU TK ULL P 26 RCS-F Leak/TK P	96 RCS JET Fail
H2O LOOP (Y)	RGA/ACCEL (Y)	AIR DATA (R)	LEFT RCS (R)	RIGHT RCS (R)
105 Loop1 H2O Pmp P 115 Loop2 H2O Pmp P	93 RGA/ACCEL Fail	91 NAV Sensor Fail	36 RCS-L OX TK ULL P 46 RCS-L FU TK ULL P 56 RCS-L Leak/TK P	66 RCS-R OX TK ULL P 76 RCS-R FU TK ULL P 86 RCS-R Leak/TK P
— (Y)	LEFT RHC (R)	RIGHT/AFT RHC (R)	LEFT OMS (R)	RIGHT OMS (R)
113 SPARE	100 Left RHC Fail	110 Right/AFT RHC Fail	7 OMS-L OX TK ULL P 17 OMS-L FU TK ULL P 27 OMS-L ENG Abnorm	37 OMS-R OX TK ULL P 47 OMS-R FU TK ULL P 57 OMS-R ENG Abnorm
PAYLOAD WARNING (R)	GPC (Y)	FCS SATURATION (R)	OMS KIT (Y)	OMS TVC (R)
55 P/L Warning 1 65 P/L Warning 2 75 P/L Warning 3 85 P/L Warning 4 95 P/L Warning 5	5 GPC1 Fail 15 GPC2 Fail 25 GPC3 Fail 35 GPC4 Fail 45 GPC5 Fail	101 FCS Saturation	77 OMS PBK OX TK ULL P 87 OMS PBK FU TK ULL P	67 OMS TVC Fail
PAYLOAD WARNING (Y)	PRIMARY C/W (Y)	FCS CHANNEL (Y)	MPS (R)	— (Y)
97 P/L Caution	CWE SELF TEST Fail	111 FCS Chan Bypass/Fail	9 MPS-C Eng He TK P 19 MPS-L Eng He TK P 29 MPS-R Eng He TK P 39 MPS-C Eng REG P 49 MPS-L Eng REG P 59 MPS-R Eng REG P 69 MPS-LO2 Eng Manf P 79 MPS-LH2 Eng Manf P	89 SPARE
BACKUP C/W ALARM (R)	APU TEMP (Y)	APU OVERSPEED (Y)	APU UNDERSPEED (Y)	HYD PRESS (Y)
BACKUP C/W A BACKUP C/W B	8 APU 1 EGT 18 APU 2 EGT 28 APU 3 EGT 38 APU1 Lube Oil T 48 APU2 Lube Oil T 58 APU3 Lube Oil T	68 APU1 Overspeed 78 APU2 Overspeed 88 APU3 Overspeed	98 APU1 Underspeed 108 APU2 Underspeed 118 APU3 Underspeed	99 HYD SYS1 P 109 HYD SYS2 P 119 HYD SYS3 P

**SYS A Power Supply Failure:**  
 (1) PRIMARY C/W light on  
 (2) All F7 lts ON except BACKUP C/W It

Loss of following equipment:

- R13U C/W status pnl lts and function
- Smoke detection siren test ckt A
- C/W Memory Read
- Lower Master Alarm bulbs (except during lamp test)

**SYS B Power Supply Failure:**  
 (3) PRIMARY C/W light on  
 (4) BACKUP C/W It ON (no reset)

Loss of following equipment:

- Smoke detection siren test ckt B
- Upper Master Alarm bulbs (except during lamp test)

**IFM INFO:**  
 IFM CHECKLIST P C-2,  
 CAUTION & WARNING  
 ELECTRONICS UNIT  
 CONTINGENCY POWER  
 Time: 1 hour 30 min

CASE I : ESS1BC Failure  
 CASE II : A PWR SUPPLY Failure  
 CASE III : ESS2CA Failure  
 CASE IV : B PWR SUPPLY Failure

CASE I & III bypass failed bus to provide power to caution and warning.  
 CASE II & IV provide redundant power to remaining power supply in

Parameter	Actual Value	Actual Value	Prom Value	Prom Value	Notes
	Low	High	Low (V)	High (V)	
AC Overload		1		5.00	(BL) > 14.5 for 10-20 sec
AC OV-UV		1		5	(BL) PRI C/W AC OV (>123--127 for 50-90ms) - UV (<102-108 for 6.5-8.5 sec)
AC Volt Backup C/W	108	123			rec'v Backup C/W It at these values
CRYO H2 CNTL P	153	293.8	0.25	4.65	
CRYO O2 CNTL P	540	985	0.25	4.7	
CRYO O2 HTR T		344		4.3	TK5 assembly 2 does not have HW C/W
DC VOLT MN	26.4		3.3		
FC PUMPS	0		4.8		(BL) Pump OFF or delta P <2 psi
FC REAC VLV	0		4.8		(BL) vavle closed
FC STACK T	170.7	241.9	3.3	4.25	

Figure 6.1.1-6. Caution and warning sheet

**TITLE**

EGIL SM FDA

SM message	Parameter	LL	UL	Filter	Alarm class	TLM range	Notes
S67 AC AMPS 1(2,3)	V76C1540A (1541,1542) AC1 phA (phB,phC) Amps	OSL	10	4	3	0/20	
	V76C1640A (1641,1642) AC2 phA (phB,phC) Amps	OSL	10	4	3	0/20	
	V76C1740A (1741,1742) AC3 phA (phB,phC) Amps	OSL	10	4	3	0/20	
S67 AC OVLD 1(2,3)	V76X1506E (1606,1706) AC1(2,3) Overload	1*	-	2	2	BL	*O/L on display
S67 AC VOLTS 1(2,3)	V76V1500A (1501,1502) AC1 phA (phB,phC) Volts	108	123	2	2	0/140	V76X1505E = O/UV PRI C&W V76X1605E = O/UV PRI C&W V76X1705E = O/UV PRI C&W
	V76V1600A (1601,1602) AC2 phA (phB,phC) Volts	108	123	2	2	0/140	
	V76V1700A (1701,1702) AC3 phA (phB,phC) Volts	108	123	2	2	0/140	
S67 APC/ALC A(B,C)	V76V3091A (3092,3093) Aft PCA 4(5,6) Volts	26.2	OSH	2	3	0/40	
S67 CNTL BUS V	V76V0120A (220,320) CNTL AB1 (BC1,CA1) Volts	24.5	OSH	2	3	0/40	
	V76V0121A (221,321) CNTL AB2 (BC2,CA2) Volts	24.5	OSH	2	3	0/40	
	V76V0122A (222,322) CNTL AB3 (BC3,CA3) Volts	24.5	OSH	2	3	0/40	
S67 CNTL RPC	V76X0124E (125,126) Control Bus AB1/CA1 RPC (AB2/CA2,AB3/CA3)	0	-	2	3	BL	
	V76X0224E (225,226) Control Bus AB1/BC1 RPC (AB2/BC2,AB3/BC3)	0	-	2	3	BL	
	V76X0324E (325,326) Control Bus BC1/CA1 RPC (BC2/CA2,BC3/CA3)	0	-	2	3	BL	
S67 ESS BUS V 1BC (2CA,3AB)	V76V0130A (230,330) ESS 1BC (2CA,3AB) Volts	25	OSH	2	3	0/40	
S67 FPC/FLC 1(2,3)	V76V3071A (3072,3073) Fwd PCA 1(2,3) Volts	26.2	OSH	2	3	0/40	
S67 MPC 1(2,3)	V76C3085A (3086,3087) Mid PCA 1(2,3) Amps	1 OSL	OSH OSH	2 2	3 3	0/100	V76X2211E (2221, 2223) = 0 MMC1 ST1 (MMC2 ST1, MMC2 ST3) = 1
S67 MAIN BUX V A(B,C)	V76V0100A (200,300) MNA (B,C) Volts	27 26.4	32 OSH	2 2	3 2	0/40	BU C&W limit
S168 PALLET T	V45T0902A(903) Pallet Temp Stbd A(B) V45T0904A(905) Pallet Temp Port A(B)	-45 -45	130 130	15 15	3 3	-75/ +175 -75/ +175	
S168 PALLET V A(B)	V76V4452A (4453) Pallet PCA 1(2) Bus Volts	26	OSH	2	3	0/40	
S78 H2 CNTL P 1(2,3,4,5)	V45P2110A (2210,2310,2410,2510) H2 TK 1(2,3,4/5,5) Control Press	153	293.8	2	2	145/305	
S168 H2 CNTL P 6(7,8,9)	V45P4110A (4210,4310,4410) H2 TK 6(7,8,9) Contr P	153	293.8	2	2	145/305	
S68 H2 HTR T 1(2,3,4,5)	V45T2107A (2207,2307,2407,2507) H2 TK1(2,3,4,5) Heater Temp	OSL	210	15	3	-425/ +475	
S168 H2 HTR T 6(7,8,9)	V45T4107A (4207,4307,4407) H2 TK6(7,8,9) Htr T	OSL	210	15	3	-425/ +475	

6.1.2-2

Verify that this is the correct version before use

SM message	Parameter	LL	UL	Filter	Alarm class	TLM range	Notes
S68 H2 MANF PRESS	V45P2140A (2145) H2 Manf 1(2) Pressure	150	OSH	15	3	0/400	
S68 H2 MANF VALV	V45X2141E (2146) H2 Manf Valv TK1(2)	0*	-	15	3	BL	*0 = Closed
S68 H2 TK P 1(2,3,4,5)	V45P2100A(2200,2300,2400,2500) H2 Tk1(2,3,4,5) P	165 189.8	283 283	15	3	0/400	Heaters A and B not in AUTO Heaters A or B in AUTO
S168 H2 TK P 6(7,8,9)	V45P4100A(4200,4300,4400) H2 TK6(7,8,9) P	165 189.8	283 283	15	3	0/400	Heaters A and B not in AUTO Heaters A or B in AUTO
S68 O2 CNTL P 1(2,3,4,5)	V45P1110A (1210,1310,1410,1510) O2 TK 1(2,3,4/5,5) Control Press	540	985	2	2	515/1015	
S168 O2 CNTL P 6(7,8,9)	V45P3110A (3210,3310,3410) O2 TK 6(7,8,9) Contr P	540	985	2	3	515/1015	
S68 O2 HTR T 1(2,3,4,5)	V45T1107A (1207,1307,1407,1507) O2 TK1(2,3,4,5) Heater Assm 1 Temp	OSL	349	2	2	-425/ +475	
	V45T1109A (1209,1309,1409,1509) O2 TK1(2,3,4,5) Heater Assm 2 Temp	OSL	349	2	2*	-425/ +475	*No H/W channel for tank 9, class 3 only
S168 O2 HTR T 6(7,8,9)	V45T3107A (3207,3307,3407) O2 TK6(7,8,9) Heater Assm 1 Temp	OSL	349	2	3	-425/ +475	
S68 O2 HTR TRP 1	V45X1185(86,87,88) O2 TK1 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	#1 = TRIP
TRP 2	V45X1285(86,87,88) O2 TK2 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	
TRP 3	V45X1385(86,87,88) O2 TK3 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	
TRP 4 (4/5)	V45X1485(86,[87,88]) O2 TK4[4/5] Htr Snsr 1A(2A,1B[1B/1A],2B[2B/2A])*	1#	-	2	3	BL	* 87(88) = TK4/5 snsr 1B/1A(2B/2A) OV-102
TRP 5	V45X1585(86,87,88) O2 TK5 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	
S168 O2 HTR TRP 6	V45X3185(86,87,88) O2 TK6 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	#1 = TRIP
TRP 7	V45X3285(86,87,88) O2 TK7 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	
TRP 8	V45X3385(86,87,88) O2 TK8 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	
TRP 9	V45X3485(86,87,88) O2 TK9 Htr Snsr 1A(2A,1B,2B)	1#	-	2	3	BL	
S68 O2 MANF PRESS	V45P1140A (1145) O2 Manf 1(2) Pressure	200	OSH	15	3	0/1200	
S68 O2 MANF VALV	V45X1141E (1146) O2 Manf Valve TK1(2)	0*	-	15	3	BL	*0 = Closed
S68 O2 TK P 1(2,3,4,5)	V45P1100A(1200,1300,1400,1500) O2 Tk1(2,3,4,5) P	575 740	960 960	15	3	0/1200	Heaters A and B not in AUTO Heaters A or B in AUTO

6.1.2-3

Verify that this is the correct version before use

SM message	Parameter	LL	UL	Filter	Alarm class	TLM range	Notes
S168 O2 TK P 6(7,8,9)	V45P3100A(3200,3300,3400) O2 TK6(7,8,9) P	575 740	960 960	15	3	0/1200	Heaters A and B not in AUTO Heaters A or B in AUTO
	V45T3109A(3209,3309,3409) O2 TK6(7,8,9) Heater Assm 2 Temp	OSL	349	2	2	-425/ +475	
S69 DELTA AMPS 1(2,3)	V92C2142C (2143,2144) FC 1/2(2/3,3/1) Delta Amps	OSL	OSH	15	3	-500/ +500	
S69 FC AMPS 1(2,3)	V45C0101A (201,301) FC1(2,3) Amps	54	360	2	3	0/500	
S69 FC COOL P 1(2,3)	V45P0147A (247,347) Coolant Pressure	50	75	2	3	0/100	
S69 FC DELTA V1 V2 V3	V45V0102A (103,104) FC1 SS1(2,3) Delta Volts	OSL	150	15	3	0/500	
	V45V0202A (203,204) FC2 SS1(2,3) Delta Volts	OSL	150	15	3	0/500	
	V45V0302A (303,304) FC3 SS1(2,3) Delta Volts	OSL	150	15	3	0/500	
S69 FC EXIT T 1(2,3)	V45T0130A (230,330) FC1(2,3) Condenser Exit T	131	164	7	3	0/250	
S69 FC H2 FLOW 1(2,3)	V45R0170A (270,370) FC1(2,3) H2 Flow	OSL	1.6	7	3	0/2.5	
S69 FC H2 PUMP 1(2,3)	V45V0114A (214,314) FC1(2,3) H2 Pump Status	0.2	0.8	7	3		
S69 FC H2O ALT 1(2,3)	V45T0182A (282,382) FC1(2,3) Alt H2O Line T	60	185	7	3	0/250	
S69 FC H2O PRI 1(2,3)	V45T0181A (281,381) FC1(2,3) Product H2O Line T	60	185	7	3	0/250	
S69 FC H2O RLF 1(2,3)	V45T0412A (422,432) FC1(2,3) H2O Relief Vlv T	60	185	7	3	0/250	
S69 FC H2O RLF LINE	V45T0450A H2O Relief Line T	60	185	7	3	0/250	
S69 FC H2O RLF HTR	V45S0445E (446) FC H2O Relief Htr Status - A,B	0*	-	7	3	BL	* Alarm if both A&B heaters OFF
		1#	-	7	3	BL	# Alarm if both A&B heaters AUTO
S69 FC H2O RLF NOZ	V45T0455A (456) FC H2O Relief Nozzle A(B) T	150	425	7	3	0/450	
S69 FC O2 FLOW 1(2,3)	V45R0160A (260,360) FC1(2,3) O2 Flow	OSL	11.1	7	3	0/15	
S69 FC PH 1(2,3)	V45X0410E (420,430) FC1(2,3) pH High	1*	-	7	3	BL	* 1 = high, crew display shows down arrow

6.1.2-4

Verify that this is the correct version before use

SM message	Parameter	LL	UL	Filter	Alarm class	TLM range	Notes
S69 FC PRG LN H2	V45T0699A (700) FC H2 VENT LINE T 1(2)	OSL	380	7	3	0/400	
S69 FC PRG LN O2	V45T0600A FC O2 VENT LINE T	OSL	380	7	3	0/400	
S69 FC PUMP 1(2,3)	V45X0143E (243,343) FC1(2,3) Coolant Pump Status	0*	-	2	2	BL	* 0 = low delta P
S69 FC REAC 1(2,3)	V45X1150E (1155,1160) FC1(2,3) O2 Reac Valve	0#	-	2	2	BL	# 0 = Reactant valve closed
	V45X2150E (2155,2160) FC1(2,3) H2 Reac Valve	0#	-	2	2	BL	# 0 = Reactant valve closed
S69 FC READY 1(2,3)	V45X0105E (205,305) FC1(2,3) Ready for Load	0*	-	7	3	BL	* 0 = barber pole (not ready)
S69 FC STACK T 1(2,3)	V45T0120A (220,320) FC1(2,3) Stack Out T	180	212	7	3	-75/ +300	For kW ≤ 3.5
		190	222	7	3		For kW > 3.5 and < 7.5
		198	238	7	3		For kW ≥ 7.5
		172.5	243.7	2	2		BU C&W limit
S69 FC VOLTS 1(2,3)	V45V0100A (200,300) FC1(2,3) Volts	27.5	32.5	2	3	0/40	
S69 H2O LN PH	V45X0462E FC Common H2O Line pH High	1*	-	7	3	BL	* 1 = high, crew display shows down arrow
FC PURGE SEQ	V45X0804E FC AUTO Purge Talkback	0#	-		3	BL	# If auto purge switch not held for 3 sec
flag = (V92X2106X)	V45K0604Y (605) FC Purge Heater GPC A(B) cmd	0*	-		3	BL	* Neither htr cmd present after auto prg start
	V45S0604E FC Purge Htr - GPC	0#	-		3	BL	# If sw taken out of GPC after auto prg start
FC PURGE TEMP*	V45T0699A (700) FC Purge Line H2 T1(2)						* Flag set if 30 min timer expires before H2
flag = TBD	V45T0600A FC Purge Line O2 Temp						T1&2 > 79&40, and O2 T > 69
FC PURGE 1(2,3)#	V45R0160A (260,360) FC1(2,3) O2 Flow						# Checks if valves closed by comparing cal flow to flow ducers. Flow ducers not accurate so this is inhibited in the software
flag = TBD	V45R0170A (270,370) FC1(2,3) H2 Flow						
	V45C0101A (201,301) FC1(2,3) Amps						
S2XX APCU 1(2) AMPS	P50C9003V (9004) APCU 1A(1B) Amps	OSL	8.5	5	3	0/12	* Spec # is flight specific
HIGH*	P50C9009V (9011) APCU 2A(2B) Amps	OSL	8.5	5	3	0/12	
S2XX APCU 1(2) TEMP	P50T9002V (9005) APCU 1A(1B) Temperature	20	130	15	3	0/212	* Spec # is flight specific
LMT*	P50T9010V (9012) APCU 2A(2B) Temperature	20	130	15	3	0/212	
S2XX APCU 1(2) TRIP*	P50V9006V (9013) APCU 1(2) Tripped Off	OSL	-4.4	5	3	-5/ +5	* Spec # is flight specific
S2XX APCU 1(2) VOLTS	P50V9000V (9008) APCU 1(2) Hi Res Volts High/Low	121	127	5	3	110/160	* Spec # is flight specific
LMT*							

6.1.2-5

Verify that this is the correct version before use



SM message	Parameter	LL	UL	Filter	Alarm class	TLM range	Notes
S179 OPCU1(2) CH A(B) AMPS	V76C2405A (2406) OPCU 1 CH A(B) Out Amps	OSL	75	5	3	0/90	
	V76C2505A (2506) OPCU 2 CH A(B) Out Amps	OSL	75	5	3	0/90	
S179 OPCU1(2) CH A(B) VOLT	V76V2407A (2408) OPCU 1 CH A(B) Out Volts	27*	OSH	5	3	25/35	*Alarm if OPCU CONV sw - ON (V76S2424E)
	V76V2507A (2508) OPCU 2 CH A(B) Out Volts	27*	OSH	5	3	25/35	*Alarm if OPCU CONV sw - ON (V76S2524E)
S179 OPCU1(2) CH A(B) TEMP	V76T2409A (2410) OPCU 1 CH A(B) Temp	OSL	187	15	3	0/225	
	V76T2509A (2510) OPCU 2 CH A(B) Temp	OSL	187	15	3	0/225	
S179 OPCU1(2) CH A(B) I OC	V76X2416E (2420) OPCU 1 CH A(B) Input Over Current Trip	1#	-	5	3	BL	#1 = TRIP
	V76X2516E (2520) OPCU 2 CH A(B) Input Over Current Trip	1#	-	5	3	BL	#1 = TRIP
S179 OPCU1(2) CH A(B) I UV	V76X2417E (2421) OPCU 1 CH A(B) Input Under Volt Trip	1#	-	5	3	BL	#1 = TRIP
	V76X2517E (2521) OPCU 2 CH A(B) Input Under Volt Trip	1#	-	5	3	BL	#1 = TRIP
S179 OPCU1(2) CH A(B) O UV	V76X2418E (2422) OPCU 1 CH A(B) Out Under Volt Trip	1#	-	5	3	BL	#1 = TRIP
	V76X2518E (2522) OPCU 2 CH A(B) Out Under Volt Trip	1#	-	5	3	BL	#1 = TRIP
S179 OPCU1(2) CH A(B) O OV	V76X2419E (2423) OPCU 1 CH A(B) Out Over Volt Trip	1#	-	5	3	BL	#1 = TRIP
	V76X2519E (2523) OPCU 2 CH A(B) Out Over Volt Trip	1#	-	5	3	BL	#1 = TRIP
S179 APCU1(2) IN AMPS	V76C2401A (2501) APCU 1(2) In Amps	OSL	85	5	3	0/90	
S179 APCU1(2) OUT AMPS	V76C2402A (2502) APCU 1(2) Out Amps	OSL	14.7	5	3	0/20	
S179 APCU1(2) OUT VOLT	V76V2403A (2503) APCU 1(2) Out Volts	122*	127	5	3	0/150	*Alarm if OPCU CONV sw - ON (V76S2428E (2528))
S179 APCU1(2) TEMP	V76T2404A (2504) APCU 1(2) Temp	OSL	169	15	3	0/225	
S179 APCU1(2) IN UV	V76X2411E (2511) APCU 1(2) Input Under Volt Trip	1#	-	5	3	BL	#1 = TRIP
S179 APCU1(2) OUT OC	V76X2413E (2513) APCU 1(2) Out Over Current Trip	1#	-	5	3	BL	#1 = TRIP
S179 APCU1(2) OUT UV	V76X2414E (2514) APCU 1(2) Out Under Volt Trip	1#	-	5	3	BL	#1 = TRIP
S179 APCU1(2) OUT OV	V76X2415E (2515) APCU 1(2) Out Over Volt Trip	1#	-	5	3	BL	#1 = TRIP

6.1.2-6

Verify that this is the correct version before use

**TITLE**

EGIL BFS FDA

BFS message	Parameter	LL	UL	Alarm class	TLM range	Notes
SM1 AC OVLD 1(2,3)	V76X1506E (1606,1706) AC1 (2,3) O/L	1*	-	2	BL	*1 = O/L
SM1 AC VOLTS 1(2,3)	V76V1500A (1501,1502) AC1 phA (phB,phC) Volts	108	123	2	0/140	V76X1505E = O/UV C/W
	V76V1600A (1601,1602) AC2 phA (phB,phC) Volts	108	123	2	0/140	V76X1605E = O/UV C/W
	V76V1700A (1701,1702) AC3 phA (phB,phC) Volts	108	123	2	0/140	V76X1705E = O/UV C/W
SM1 CNTL/ESS V	V76V0120A (220,320) CNTL AB1(BC1,CA1) V	24.5	OSH	3	0/40	
	V76V0121A (221,321) CNTL AB2(BC2,CA2) V	24.5	OSH	3	0/40	
	V76V0122A (222,322) CNTL AB3(BC3,CA3) V	24.5	OSH	3	0/40	
	V76V0130A (230,330) ESS 1BC (2CA,3AB) Volts	25	OSH	3	0/40	
SM1 CNTL RPC	V76X0124E (125,126) Control Bus AB1/CA1 RPC (AB2/CA2, AB3/CA3)	0	-	3	BL	OI-29 and subs
	V76X0224E (225,226) Control Bus AB1/BC1 RPC (AB2/BC2, AB3/BC3)	0	-	3	BL	OI-29 and subs
	V76X0324E (325,326) Control Bus BC1/CA1 RPC (BC2/CA2, BC3/CA3)	0	-	3	BL	OI-29 and subs
SM1 MAIN BUS V A(B,C)	V76V0100A (200,300) MNA (B,C)	27 26.4	32 OSH	3 2	0/40	B/U C/W alarm
SM2 CRYO H2 MANF	V45P2140A (2145) H2 MANF 1(2) PRESS	189.8	OSH	3	0/400	
SM2 CRYO H2 PRES	V45P2110A (2210,2310,2410,2510) H2 TK1(2,3,4,5) Heater Control Press	153	293. 8	2	145/305	
SM2 CRYO O2 HTR	V45T1107A (1207,1307,1407,1507) O2 TK1(2,3,4,5) Heater Assy 1 Temp	OSL	349	2	-425/ +475	
	V45T1109A (1209,1309,1409,1509) O2 TK1(2,3,4,5) Heater Assy 2 Temp	OSL	349	2	-425/ +475	
SM2 CRYO O2 MANF	V45P1140A (1145) O2 MANF 1(2) PRESS	740	OSH	3	0/1200	
SM2 CRYO O2 PRES	V45P1110A (1210,1310,1410,1510) O2 TK1(2,3,4,5) Heater Control Press	540	985	2	515/1015	
SM1 DC VOLT FC1(2,3)	V45V0100A (200,300) FC1(2,3) Volts	27.5	32.5	3	0/40	
SM1 FC AMPS 1(2,3)	V45C0101A (201,301) FC1(2,3) Amps	54	410	3	0/500	
SM1 FC COOL P 1(2,3)	V45P0147A (247,347) FC1(2,3) Coolant Press	50	75	3	0/100	
SM1 FC DELTA V 1(2,3)	V45V0102A (103,104) FC1 SS 1(2,3) Delta Volts	OSL	150	3	0/500	
	V45V0202A (203,204) FC2 SS 1(2,3) Delta Volts	OSL	150	3	0/500	
	V45V0302A (303,304) FC3 SS 1(2,3) Delta Volts	OSL	150	3	0/500	

6.1.3-2

Verify that this is the correct version before use

BFS message	Parameter	LL	UL	Alarm class	TLM range	Notes
SM1 FC EXIT T 1(2,3)	V45T0130A (230,330) FC1(2,3) Condenser Exit T	131	164	3	0/250	
SM1 FC PH 1(2,3)	V45X0410E (420,430) FC1(2,3) pH High	1*	-	3	BL	*down arrow on crew display
SM1 FC PUMP 1(2,3)	V45X0143E (243,343) FC1(2,3) Pump Delta-P Low	0#	-	2	BL	#0 = low delta P
SM1 FC REAC 1(2,3)	V45X1150E (1155,1160) FC1(2,3) O2 Reac Valve	0*	-	2	BL	0* = closed
	V45X2150E (2155,2160) FC1(2,3) H2 Reac Valve	0*	-	2	BL	0* = closed
SM1 FC STACK T 1(2,3)	V45T0120A (220,320) FC1(2,3) Stack Out Temp	OSL	212	3	-75/ +300	for kW ≤ 3.5
		OSL	222	3	-75/ +300	for kW ≥3.5 and ≤7.5
		OSL	238	3	-75/ +300	for kW ≥7.5
		172.5	243.7	2	-75/ +300	B/U C/W limit
168 PALLET H2 PRES*	V45P4110A (4210,4310,4410) H2 TK6(7,8,9) Control Pressure	153	OSH	2	145/305	*BFS OPS 3 & 6 only
168 PALLET H2 TK P*	V45P4100A (4200,4300,4400) H2 TK6(7,8,9) Press	165.8	OSH	3	0/400	*BFS OPS 3 & 6 only
168 PALLET O2 HTR*	V45T3107A (3207,3307,3407,3507) O2 TK6(7,8,9) Heater Assy 1 Temp	OSL	OSH	2	-425/ +475	*BFS OPS 3 & 6 only
		V45T3109A (3209,3309,3409,3509) O2 TK6(7,8,9) Heater Assy 2 Temp	OSL	OSH	2	-425/ +475
168 PALLET O2 PRES*	V45P3110A (3210,3310,3410) O2 TK6(7,8,9) Control Pressure	OSL	OSH	2	515/1015	*BFS OPS 3 & 6 only
168 PALLET O2 TK P*	V45P3100A (3200,3300,3400) O2 TK6(7,8,9) Press	OSL	OSH	3	0/1200	*BFS OPS 3 & 6 only

6.1.3-3

Verify that this is the correct version before use

## TITLE

MDM/DSC DISPLAYS

## PURPOSE

The purpose of these displays is to provide the EGIL/EPS console operator with a list of Multiplexer Demultiplexer (MDM) and Dedicated Signal Conditioners (DSCs) that are used to provide the data displayed on the EGIL ground displays. If an MDM or DSC failure occurs, the console operator can use these displays to determine which ground parameters are affected by this failure.

## DESCRIPTION

This section consists of EGIL ground displays with the parameter location replaced by the corresponding MDM/DSC used to provide that parameter (Figures 6.1.4-1 through 6.1.4-8). Some of the parameters do not show a DSC. This is because some parameters require both an MDM and a DSC to provide the data while other parameters require only an MDM.

The MDMs and DSCs for the displayed parameters are taken from the Space Shuttle Systems Handbook (SSSH) Rev. F, DCN-1, released on September 1, 1997, and were verified using ISP channel (shuttle data tape).

FC_EPDC.msk									
OGMT 257/05:57:10					F/V 114 /104				
OMET 000/06:34:37					GN 22				
PASS MECO 00:01		OI TFL 199		MM PASS 201		SM 24			
BFS MECO D				MM BFS D		BF D			
DC -1/A- -2/B- -3/C-					TOTAL AMPS 498.0 KW 15.51				
FC KW 5.28		5.12		5.12		FUEL CELL -1- -2- -3-			
FC AMPS 170		164		164		STK OUT T 203 203 203			
FPC AMPS 83		73		113		STK IN T 182 182 182			
MPC AMPS 38		36		9		EXIT T 151 151 151			
APC AMPS 33		23		17		CL RTN T 70 70 70			
FC % LD 34.1		32.9		32.9		CL PRESS 62.0 62.0 62.0			
BUS TIE						CL PMP P			
FC VDC 31.0		31.2		31.2		H2 MTR 0.40 0.40 0.40			
MN VDC 31.0		31.0		31.0		O2 VLV			
FWD VDC 30.6		30.6		30.6		O2 FLOW 2.83 2.67 2.67			
AFT VDC 30.7		30.9		30.7		O2 CAL FL 3.58 3.45 3.45			
R SRB - DC D -/-						H2 VLV			
L SRB - DC D -/-						H2 FLOW 0.54 0.50 0.51			
ESS VDC 29.8		29.9		29.9		H2 CAL FL 0.45 0.44 0.44			
ESS RPC						1-2 2-3 3-1			
CNTL A B C A						AMPS 5 0 -5			
-1 29.3 29.3 29.3						VOLTS 0.12 0.23 0.23			
-2 29.3 29.3 29.3						SUBSTK 1 12 16 16			
-3 29.3 29.3 29.3						2 24 28 18			
-AC- -1- -2- -3-						3 16 20 20			
AMPS A 3.60		4.96		3.68		KOH IN AV 36.55 36.47 36.49			
B 3.44		4.64		3.76		OUT AV 36.33 36.38 36.42			
C 3.44		4.80		3.60		SAMPLES/MIN /25.0 4.80			
VAC A 117.0		117.0		117.0		CNTLR PWR -- -- --			
B 117.0		117.0		117.0		READY -- -- --			
C 117.0		117.0		117.0		STRUP HTR -- -- --			
INV/BUS A --/-- --/-- --/--						PRG SEQ -- -- -- --			
B --/-- --/-- --/--						VLV GP-- GP-- GP--			
C --/-- --/-- --/--						HTR GPC-- -- -- --			
SENSOR AUTO AUTO AUTO						O2 VLT 49			
O/L ---- ---- ----						H2 VLT-1 49			
O/UV ---- ---- ----						H2 VLT-2 49			
-MTRS- -AC1- -AC2- -AC3-						-WATER- -1- -2- -3-			
AV BAY 13.78 - B						PH FC ---- ---- ----			
23.74 A -						H2O LN ----			
33.90 B -						SUP H2O P 32.8			
IMU FAN 4.56 - B						ALT H2O P 34.2			
HUM SEP - B						PRD H2O T 143 143 143			
CAB FAN 5.50 - A						ALT H2O T 90 79 90			
FRN LP 12189 - B						RLF VLV T 77 77 77			
22258 B -						RLF LN T 70			
H2O LP 123 -G -- B-						RLF NOZ T 243 243			
262 -- ON						NOZ HTR STATUS -- --			
----- MCA STATUS -----						LN /RLF SW CONF A- A-			
FWD 1 ---- AFT 1 ----						MASTER ALARM- --			
2 ---- 2 ----						ALERT B- -- -- D			
3 ---- 3 ----						BU C/W B- -- -- D			
MID 1 ---- AC --						ALERT A1 A2 A3 A4			
2 ----						.TONE -- -- --			
3 ----						.LIGHT -- -- --			
4 ----						BU C/W -- -- --			
Ver 2.0									

Figure 6.1.4-1. EGIL ground display FC\_EPDC

<i>CRYO_ASCENT.msk</i>					
<b>F/V 114 / 104</b>		ABORT SELECT - - - -			
OGMT 256/23:21:38	PRED MECO 00:00		00:00		
OMET 256/23:21:38	V-REL 0		H/ALT 600000		
			0		
CRYO O2	1	3	4	5	2
TANK P	940	945	945	940	940
CNTL P	943	943	943	943	943
MANF P-VLV	940 - OP				OP - 940
PCS VLV/P	OP / 864				OP / 864
Q(%)	99.6	99.6	99.6	99.6	99.6
FLUID T	-250	-250	-250	-250	-250
HTR 1 T	-250	-250	-250	-250	-250
HTR 2 T	-250	-250	-250	-250	-250
HTR A1/B1	-- / --	-- / --	-- / --	-- / --	-- / --
HTR A2/B2	-- / --	-- / --	-- / --	-- / --	-- / --
SNSR 1 A/B	- / -	- / -	- / -	- / -	- / -
SNSR 2 A/B	- / -	- / -	- / -	- / -	- / -
HTR SW A	-- AUTO	-- ----	-- ----	-- ----	-- AUTO
HTR SW B	-- ----	-- ----	-- ----	-- ----	-- ----
CRYO H2	1	3	4	5	2
TANK P	248	249	249	249	248
CNTL P	248	249	249	249	248
MANF P-VLV	248 - OP				OP - 248
Q(%)	99.3	99.3	99.3	99.3	99.3
FLUID T	-416	-416	-416	-416	-416
HTR T	-416	-416	-416	-416	-416
HTR A/B	-- / --	-- / --	-- / --	-- / --	-- / --
HTR SW A	-- AUTO	-- ----	-- ----	-- ----	-- AUTO
HTR SW B	-- ----	-- ----	-- ----	-- ----	-- ----
PAYLOAD POWER				TOTAL: O2 3890.21 KW-H 18.61	
FC3	MNA	MNB	MNC	H2 456.56 AMP-H 600.48	
PRI --	--	--	--	<b>Recycle</b>	
AUX --	--	--	--		
CABIN --	--	--	--		
AFT P/L				CRYO GSE O2/H2 CL / CL	
AFT AMPS	0.0	0.0		CABIN P 14.8	-1- -2-
AFT KWH	0.0	0.0		CABIN dp/dT 0.0	CAB O2 FLOW 0.00 0.00
PL/MNC GND		MNC		CABIN PP02 A 3.2	EVAP OUT T 42 42
Ver 2.0					

Figure 6.1.4-2. EGIL ground display CRYO\_ASCENT

<i>CRYO_ORBIT.msk</i>						
F/V 114 / 104		OGMT	256/23:20:25		OMET	256/23:20:25
CRYO O2		1	3	4	5	2
TANK P		950	950	950	950	950
CNTL P		949	951	951	951	949
MANF P-VLV		950 - OP				OP - 950
PCS VLV/P		OP / 948				OP / 948
Q(%)		99.6	99.6	99.6	99.6	99.6
FLUID T		-250	-250	-250	-250	-250
HTR 1 T		-250	-257	-257	-257	-250
HTR 2 T		-250	-257	-257	-257	-250
HTR A1/B1		-- / --	-- / --	-- / --	-- / --	-- / --
HTR A2/B2		-- / --	-- / --	-- / --	-- / --	-- / --
SNSR 1 A/B		- / -	- / -	- / -	- / -	- / -
SNSR 2 A/B		- / -	- / -	- / -	- / -	- / -
HTR SW A		-- AUTO	--	--	--	-- AUTO
HTR SW B		--	--	--	--	--
CRYO H2		1	3	4	5	2
TANK P		249	249	249	249	249
CNTL P		249	249	249	249	249
MANF P-VLV		248 - OP				OP - 248
Q(%)		99.3	99.3	99.3	99.3	99.3
FLUID T		-416	-416	-416	-416	-416
HTR T		-416	-416	-416	-416	-416
HTR A/B		-- / --	-- / --	-- / --	-- / --	-- / --
HTR SW A		-- AUTO	--	--	--	-- AUTO
HTR SW B		--	--	--	--	--
PAYLOAD POWER		TOTAL: O2 3890.21		KW-H 18.61		
FC3	MNA MNB MNC	H2 456.56		AMP-H 600.48		
PRI	--	--	--	CABIN P 14.7	-1-	-2-
AUX	--	--	--	AIRLOCK P 0.2	EMU VOLTS	0.0 0.0
CABIN	--	--	--	CABIN A/L dP 0.0	AMPS	-0.22 -0.22
AFT P/L	--	--	--	CABIN dP/dT 0.0		
AFT AMPS		0.0	0.0	PP02 A 3.2	EVAP OUT T	41 41
AFT KWH		0.00	0.00	B 3.2		
PL/MNC GND			MNC	C 3.2		
				EVLSS PRESS 948		
Ver 2.0						

Figure 6.1.4-3. EGIL ground display CRYO\_ORBIT



F/V	EDO_MEGA_ORB				
CRYO O2	1	3	4	5	2
TANK P	OF1/OF1	OF3/OF3	OF1/OF1	OF1/OF1	OF3/OF3
CNTL P	OF1/---	OF3/---	OF1/---	OF2/---	OF3/---
MANF P-VLV	OF1/OM1 -OF4	-----	-----	-----	OF4- OF3/OM2
PCS VLV/P	OF4/-/OF3/OF3	-----	-----	-----	OF4/-/OF2/OF2
Q(%)	OF1/OF1	OF3/OF3	OF3/OF3	OF2/OF2	OF2/OF2
FLUID T	OF2/OM2	OF3/OF3	OF3/OF3	OF3/OF3	OF3/OM1
HTR 1 T	OF1/OM1	OF1/OM1	OF3/OM2	OF2/OF2	OF3/OM1
HTR 2 T	OF3/OM2	OF3/OF3	OF3/OF3	OF3/OF3	OF2/OM2
HTR A1/B1	OF1/-/OF1/---	OA1/-/OA1/---	OA2/-/OA2/---	OA1/-/OA3/---	OF3/-/OF3/---
HTR A2/B2	OF1/-/OF1/---	OA1/-/OA1/---	OA2/-/OA2/---	OA1/-/OA3/---	OF3/-/OF3/---
SNSR 1 A/B	OF1/-/OF1/---	OA1/-/OA1/---	OA2/-/OA2/---	OA3/-/OA3/---	OF3/-/OF3/---
SNSR 2 A/B	OF1/-/OF1/---	OA1/-/OA1/---	OA2/-/OA2/---	OA1/-/OA3/---	OF3/-/OF3/---
HTR SW A	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---
HTR SW B	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---
CRYO H2	1	3	4	5	2
TANK P	OF1/OF1	OF1/OF1	OF3/OF3	OF1/OF1	OF3/OF3
CNTL P	OF2/---	OF1/---	OF2/---	OF1/---	OF3/---
MANF P-VLV	OF3/OM1 -OF4	-----	-----	-----	OF4- OF2/OM2
Q(%)	OF3/OF3	OF3/OF3	OF3/OF3	OF3/OF3	OF1/OF1
FLUID T	OF3/OM2	OF1/OM1	OF3/OM2	OF2/OF2	OF3/OM1
HTR T	OF1/OM1	OF3/OM1	OF2/OM2	OF3/OF3	OF2/OM2
HTR A/B	OF1/-/OF1/---	OA1/-/OA1/---	OA2/-/OA2/---	OA1/-/OA3/---	OF3/-/OF3/---
HTR SW A	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---
HTR SW B	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---	OF4/-/OF4/---
EDO CRYO PALLET	6				7
-EPDC-	MNA				MNB
PPC PWR	OF4/---				OF4/---
PPC V	OA1/OP1				OA3/OP2
PPC AMP	OF3/---				OA2/-/OA2/---
-HEATERS-	A				B
HTR SW	OA1/---				OA2/---
HTR T STBD	OF2/OP1				OF4/OP2
HTR T PORT	OF2/OP1				OF4/OP2
CABIN P	OF2/OF2				OF3/OF3
AIRLOCK P	OF3/OF3				OF1/OF1
CABIN A/L dP	OF1/OF1				OA2/OA2
EVAP OUT T	OA2/OA2				OA3/OA3
EMU VOLTS	OF1/OF1				OF1/OF1
AMPS	OF1/---				OF1/---
PAYLOAD POWER	6				7
FC3	OF2/OP1				OF4/OP2
MNA	OA1/---				OF3/---
MNB	OF2/OP1				OF4/OP2
MNC	OF4/OP2				OF2/OP1
PRI	OF3/---				OF3/---
AUX	OF1/---				OF2/---
CABIN	OF4/---				OF4/---
AFT P/L	OA2/---				OA3/---
AFT AMPS	OA2/---				OA3/---
AFT KWH	OF4/---				OF4/---
PL/MNC GND	OF3/---				OF3/---
MASTER ALARMS-					OF3/---
ALERT B-					
BU C/W B-					
ALERT					A1 A2 A3 A4
●TONE					FF1/- FF2/- FF3/- FF4/-
●LIGHT					FF1/- FF2/- FF3/- FF4/-
BU C/W B-					FF1/- FF2/- FF3/- FF4/-

128303115. CRT; 2

Figure 6.1.4-4. EGIL ground display 0609 EDO\_MEGA\_ORB

Verify that this is the correct version before use

F/V	EDO_MEGA_ORB					
MM PASS	MM BFS	ABORT SELECT				
		1	3	4	5	2
CRYO O2		OF1/OF1	OF3/OF3	OF1/OF1	OF1/OF1	OF3/OF3
TANK P		OF1/---	OF3/---	OF1/---	OF2/---	OF3/---
CNTL P		OF1/OM1	OF3/---	OF1/---	OF2/---	OF4/---/OF2/OF2
MANF P-VLV		OF4/---/OF3/OF3				
PCS VLV/P		OF1/OF1	OF3/OF3	OF3/OF3	OF2/OF2	OF2/OF2
Q(%)		OF2/OM2	OF3/OF3	OF3/OF3	OF3/OF3	OF3/OM1
FLUID T		OF1/OM1	OF1/OM1	OF3/OM2	OF2/OF2	OF3/OM1
HTR 1 T		OF3/OM2	OF3/OF3	OF3/OF3	OF3/OF3	OF2/OM2
HTR 2 T		OF1/---/OF1/---	OA1/---/OA1/---	OA2/---/OA2/---	OA1/---/OA3/---	OF3/---/OF3/---
HTR A1/B1		OF1/---/OF1/---	OA1/---/OA1/---	OA2/---/OA2/---	OA1/---/OA3/---	OF3/---/OF3/---
HTR A2/B2		OF1/---/OF1/---	OA1/---/OA1/---	OA2/---/OA2/---	OA3/---/OA3/---	OF3/---/OF3/---
SNSR 1 A/B		OF1/---/OF1/---	OA1/---/OA1/---	OA2/---/OA2/---	OA1/---/OA3/---	OF3/---/OF3/---
SNSR 2 A/B		OF1/---/OF1/---	OA1/---/OA1/---	OA2/---/OA2/---	OA1/---/OA3/---	OF3/---/OF3/---
HTR SW A		OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---
HTR SW B		OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---
CRYO H2		1	3	4	5	2
TANK P		OF1/OF1	OF1/OF1	OF3/OF3	OF1/OF1	OF3/OF3
CNTL P		OF2/---	OF1/---	OF2/---	OF1/---	OF3/---
MANF P-VLV		OF3/OM1	OF3/OF3	OF3/OF3	OF3/OF3	OF4/---/OF2/OM2
Q(%)		OF3/OF3	OF3/OF3	OF3/OF3	OF3/OF3	OF1/OF1
FLUID T		OF3/OM2	OF1/OM1	OF3/OM2	OF2/OF2	OF3/OM1
HTR T		OF1/OM1	OF3/OM1	OF2/OM2	OF3/OF3	OF2/OM2
HTR A/B		OF1/---/OF1/---	OA1/---/OA1/---	OA2/---/OA2/---	OA1/---/OA3/---	OF3/---/OF3/---
HTR SW A		OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---
HTR SW B		OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---
EDO CRYO PALLET			6	7	8	9
-EPDC-			OF2/OP1	OF4/OP2	OF2/OP1	OF4/OP2
	MNA	MNB	OF1/---	OF3/---	OA1/---	OA3/---
PPC PWR	OF4/---	OF4/---				
PPC V	OA1/OP1	OA3/OP2	OF2/OP1	OF4/OP2	OF2/OP1	OF4/OP2
PPC AMP	OF3/---	OA2/---/OA2/---	OF4/OP2	OF2/OP1	OF4/OP2	OF2/OP1
-HEATERS-	A	B	OF2/OP1	OF4/OP2	OF2/OP1	OF4/OP2
HTR SW	OA1/---	OA2/---	OF4/OP2	OF2/OP1	OF4/OP2	OF2/OP1
HTR T STBD	OF2/OP1	OF4/OP2	OA3/---/OA1/---	OA1/---/OA2/---	OA3/---/OA2/---	OA3/---/OA2/---
HTR T PORT	OF2/OP1	OF4/OP2	OA3/---/OA3/---	OA1/---/OA1/---	OA3/---/OA3/---	OA3/---/OA2/---
TOTAL: O2			OA1/---/OA1/---	OA2/---/OA2/---	OA2/---/OA2/---	OA2/---/OA3/---
H2			OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---
KWH			OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---
AMP-H			OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---	OF4/---/OF4/---
RECYCLE			6	7	8	9
			OF2/OP1	OF4/OP2	OF2/OP1	OF4/OP2
			OA1/---	OF3/---	OA1/---	OF3/---
CRYO GSE O2/H2		OF1/---	OF3/---			
CABIN P		OF2/OF2				
CABIN O2 FLOW		OF1/OF1	OF2/OF2			
EVAP OUT T		OA2/OA2	OA3/OA3			
PAYLOAD POWER						
FC3	MNA	MNB	MNC			
PR1	OF3/---	OF3/---	OF3/---			
AUX	OF1/---	OF2/---				
CABIN	OF4/---	OF4/---				
AFT P/L		OA2/---	OA3/---			
AFT AMPS		OA2/---	OA3/---			
AFT KWH						
PL/MNC GND		OF3/---				
			O1 TFL	OF3/---	ALERT	A1 A2 A3 A4
			MASTER ALARM-		•TONE	FF1/- FF2/- FF3/- FF4/-
			ALERT B-		•LIGHT	FF1/- FF2/- FF3/- FF4/-
			BU C/W B-		BU C/W B-	FF1/- FF2/- FF3/- FF4/-

128303116. CRT; 2

Figure 6.1.4-5. EGIL ground display 0610 EDO\_MEGA\_ASC

Verify that this is the correct version before use

SYSTEMS_CONFIG.msk																							
OGMT	256/23:18:49	MM PASS	101	SYSTEMS CONFIGURATION	SITE TDR	OI	129	SM	D														
OMET	256/23:18:49	MM BFS	101			GN	21	BF	12														
-GNC-					-INCO-			-MMACS-			-PDRS-												
TACAN	-1-	-2-	-3-	-4-	NSP	1	MN	A	B	C	BRAKES	A	B	C	RMS	PWR	PRI	---					
RA	ON	ON	ON		2					ON	PWR	ON	ON	ON			B/U	---					
MLS	-	-	-		PCMMU	1	ON	*		*	CA	RPC	ON	ON	MCIU	I/O		D					
IMU PWR SW	ON	ON	ON		2						BC	RPC	ON	ON	EE	MODE		D					
IMU A	ON	ON	ON		PWR AMP	1	-	-	-		ANTISKID	ON						D					
B	ON	ON	ON		2						CIRC PUMP	1	-	-	76	HTR	A	---					
C	ON	ON	ON		MSTR	MADS	PWR	-			2		-	-	76			D					
IMU OPER	OPER	OPER	OPER								3		-	-	76			D					
RGA PWR	ON	ON	ON								-APU-	-1-	-2-	-3-									
RPC A	ON	ON	ON		-DPS-					TK/FU	LN	-	-	-									
B	ON				GPC	1	RUN	ON	ON	ON	LUBE	OIL	-	-	-								
C	ON				2	RUN	ON	ON	ON	ON	GG/FU	PMP	-	-	-								
AA PWR SW	ON	ON	ON		3	RUN	ON	ON	ON	ON	MECH	PWR	1	---									
AA RPC A	ON	ON	ON		4	RUN	ON	ON	ON	ON	2	---											
B	ON				5	M	ON	ON	ON	ON	-EECOM-					-SMOKE ALM CONC-							
C	ON				BFC/CPU	1A	ON	ON	ON	ON	HI	LD	DT	A	-	-							
ASA PWR SW	ON	ON	ON		1B	ON	ON	ON	ON	ON	TOP	DUCT	A	-	-	BAY	1A	---	361.1	0.0	FUL		
RPC A	ON	ON	ON		2A	ON	ON	ON	ON	ON	TOP	NZ	L	A	-		B	---	293.7				
B	ON	ON	ON		2B	ON	ON	ON	ON	ON	R	A	-				2A	---	113.7	0.0	FUL		
C	ON	ON	ON		3A	ON	ON	ON	ON	ON	FDLN	PRI	A/B	-	-		B	---	401.6				
ATVC PWR	ON	ON	ON		FF	1	ON				SEC	A/B	-	-			3A	---	378.7	0.0	FUL		
RPC A	ON	ON	ON		2	ON					PRI	A	-	GPC			B	---	249.9				
B	ON	ON	ON		3	ON					B	-	-				B	---	113.7				
C	ON	ON	ON		4	ON					NH3	1	-	-	LFDK				---	394.3			
ADTA	ON	ON	ON		FA	1	ON				2	-	GPC		RFDK					---	351.5		
DDU	-A-	-B-	-C-		2	ON					GALLEY	OVEN	-		CABIN								
L *	ON	ON	ON		3	ON					H2O	HTR	-										
R *	ON	ON	ON		4	ON					GALLEY	SUP	V	CL									
A -	-	-	-		PL	1	ON				AV	BAY	1	AIR	T99.8								
STAR TKR	-Y	-	-		2	ON					2				95.8								
Z	-	-	-		MMU	1	ON				3				84.2								
COAS PWR	-	-	-		IDP/CRT	1	ON				CABIN	T			70.5								
					2	ON					-1-	-2-	-3-		-FC	H2O	PROD-						
					3	ON					6.51	6.36	6.70		15.1								
					4	ON		M			TOT	KW											
											19.57												
-PROP-					-BITE INDICATIONS-																		
RJDF-	-1A-	-1B-	-2A-	-2B-	DSC	OF	1	-	MDM	OF	1	-											
LGC	ON	ON	ON	ON	2	-			MDM	OF	2	-											
DRVVR	ON	ON	ON	ON	3	-			MDM	OF	3	-											
RJDA-					1	-			MDM	OF	4	-											
LGC A	ON	ON	ON		DSC	OM	1	-															
B	ON	ON	ON		2	-																	
C	ON	ON	ON		3	-																	
DRVVR A	ON	ON	ON		DSC	OA	1	-	MDM	OA	1	-											
B	ON	ON	ON		2	-			MDM	OA	2	-											
C	ON	ON	ON		3	-			MDM	OA	3	-											
OMS POD L	A/B	---	/	---																			
R	A/B	---	/	---																			
FWD RCS	A/B	---	/	---																			
XFD LINES	A/B	AUTO/		AUTO																			

Ver 2.0

Figure 6.1.4-6. SYSTEMS\_CONFIG

Verify that this is the correct version before use

6.1.4-7

Verify that this is the correct version before use

6.1.4-8

PYRO.msk													
F/V 114 / 104			SHUTTLE PYROTECHNIC										
OGMT 256/23:22:23			OMET 256/23:22:23			OI 129		GN 21		SM D			
-SRB PIC V-	L	R	-LANDG GEAR-	A	B	RANGE SAFETY			SRB/ET				
IGNITION A	37.7	37.7	NLG EXT	0.0	0.0	LH A LH B RH A RH B							
IGNITION B	37.7	37.7	NLG DPY	0.0	0.0	BAT V	0.0		0.0				
FWD SEP A	0.0	0.0	LMG DPY	0.0	0.0	BAT C	0.00		0.00				
FWD SEP B	0.0	0.0	RMG DPY	0.0	0.0	RCVR S	0.0	0.0	0.0	0.0			
AFT U SEP A	0.0	0.0		NLG tb	UP	DCDR P	OFF	OFF	OFF	OFF			
AFT U SEP B	0.0	0.0	ARM CMD	---	LMG tb	PIC V	0.0	0.0	0.0	0.0			
AFT M SEP A	0.0	0.0	DWN CMD	---	RMG tb	UP							
AFT M SEP B	0.0	0.0	PORT RMS JETT			A	B	INHIB					
AFT L SEP A	0.0	0.0	SHLDR GUILL	0.0	0.0	ARM							
AFT L SEP B	0.0	0.0	F LAT GUILL	0.0	0.0	FIRE							
F SEP MTR A	0.0	0.0	M LAT GUILL	0.0	0.0	S/A							
F SEP MTR B	0.0	0.0	A LAT GUILL	0.0	0.0	ET TUMBLE ARM CMD							
A SEP MTR A	0.0	0.0	SHLDR RETEN	0.0	0.0								
A SEP MTR B	0.0	0.0	F BLT RETEN	0.0	0.0								
SRB DISCRETES			L	R	M BLT RETEN	0.0	0.0						
IGN S&A ARMD	ARM	ARM	A BLT RETEN	0.0	0.0								
IGN S&A SAFE	---	---	P RMS-GLTN	---	JETT	---							
SRB RECOVERY			L	R	--KU JETT--			A	B				
NOSE CAP PIC	0.0	0.0				GLTN CAP V	0.0	0.0					
FRTM SEP PIC	0.0	0.0				BOLT CAP V	0.0	0.0					
NOZL SEV PIC	0.0	0.0				KU JETT ARM	---						
MN CHUTE PIC	0.0	0.0											
BATT CURRENT	H												
BATT TEMP	59	59											
BATT VOLTS	32.0	32.0											

Ver 2,0

Figure 6.1.4-7. Shuttle PYRO display

SHUTTLE OPS  
EGL/JSC-12830

ORIG: M. J. WELCH  
01/31/02: BASIC, REV. F

MDM/DSC DISP  
SCP 6.1.4

<i>APCU.msk</i>										
		APCU 1		APCU 2		<b>STS-114 / OV-104</b>				Ver 2.0
CONV A		<b>Ena</b>	<b>Dis</b>	<b>Ena</b>	<b>Dis</b>	OGMT: 256/23:23:08				
Out Amps	M	D	M	D	OMET: 000/00:00:35					
Out Temps		D		D						
CONV B		<b>Ena</b>	<b>Dis</b>	<b>Ena</b>	<b>Dis</b>	TRIP VDC				
Out Amps	M	D	M	D	APCU 1	D	M	M	M	M
Out Temps		D		D	APCU 2	D	M	M	M	M
OUT VOLTS					PWR Output		M		M	
Low (RES)		D		D	Total Amps		M		M	
High (RES)		D		D	KWH		M		M	
ODS Interface	X1-A/B	D/	D	X3 -	CP5 Temps					
(* = mated)	X2-A/B	D/	D	X4 -	FCL 1	82.8	FCL 2	82.8		

**Figure 6.1.4-8. EGIL ground display APCU**

**TITLE**

EGIL MDM AND DSC LOSS TABLE

Table 6.1.5-1 sorts MDM and DSC cards and channels by MSID.

This information is effective for STS-95 and subsequent flights using OI-26B flight software.

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID**

B76V1600C	LH VOLTAGE OPERATIONAL BUS A	MDM LL1	Card-03	Channel-05			
B76V1601C	LH VOLTAGE OPERATIONAL BUS B	MDM LL1	Card-07	Channel-08			
B76V2600C	RH VOLTAGE OPERATIONAL BUS A	MDM LR1	Card-03	Channel-05			
B76V2601C	RH VOLTAGE OPERATIONAL BUS B	MDM LR1	Card-07	Channel-08			
V45C0101A	FUEL CELL NO 1 CURRENT	MDM OF3	Card-15	Channel-00	DSC OM1	Card-09	Channel-A
V45C0201A	FUEL CELL NO 2 CURRENT	MDM OF3	Card-15	Channel-01	DSC OM1	Card-09	Channel-B
V45C0301A	FUEL CELL NO 3 CURRENT	MDM OF3	Card-15	Channel-02	DSC OM1	Card-09	Channel-C
V45K0604Y	FCP O2/H2 PURGE HTRS GPC-A ON	MDM PF2	Card-14	Channel-01			
V45K0605Y	FCP O2/H2 PURGE HTRS GPC-B ON	MDM PF2	Card-14	Channel-01			
V45K0815Y	FCP 1 PURGE VLVS GPC-A OPEN	MDM PF1	Card-07	Channel-01			
V45K0816Y	FCP 1 PURGE VLVS GPC-B OPEN	MDM PF1	Card-07	Channel-01			
V45K0825Y	FCP 2 PURGE VLVS GPC-A OPEN	MDM PF1	Card-14	Channel-01			
V45K0826Y	FCP 2 PURGE VLVS GPC-B OPEN	MDM PF1	Card-14	Channel-01			
V45K0835Y	FCP 3 PURGE VLVS GPC-A OPEN	MDM PF2	Card-07	Channel-01			
V45K0836Y	FCP 3 PURGE VLVS GPC-B OPEN	MDM PF2	Card-07	Channel-01			
V45P0147A	FUEL CELL 1 COOLANT PRESSURE	MDM OF1	Card-01	Channel-05	DSC OM1	Card-06	Channel-B
V45P0187A	FCP ALT PRODUCT H2O LINE PRESS	MDM OF3	Card-01	Channel-18	DSC OF3	Card-22	Channel-C
V45P0247A	FUEL CELL 2 COOLANT PRESSURE	MDM OF2	Card-03	Channel-02	DSC OM2	Card-14	Channel-C
V45P0347A	FUEL CELL 3 COOLANT PRESSURE	MDM OF3	Card-01	Channel-01	DSC OM2	Card-06	Channel-B
V45P1100A	PRSD O2 TK 1 PRESSURE	MDM OF1	Card-05	Channel-12	DSC OF1	Card-21	Channel-A
V45P1104A	PRSD O2 TK 1 ANNULUS VACUUM	MDM OF3	Card-05	Channel-08	DSC OM1	Card-15	Channel-A
V45P1110A	PRSD O2 TK 1 HTR CONTROL PRESS	MDM OF1	Card-05	Channel-07			
V45P1115A	PRSD O2 TK 1 HTR CTRL SNSR C/O	MDM OF1	Card-13	Channel-15	DSC OF1	Card-13	Channel-B
V45P1140A	PRSD O2 MANF 1 PRESSURE	MDM OF1	Card-03	Channel-04	DSC OM1	Card-06	Channel-C
V45P1145A	PRSD O2 MANF 2 PRESSURE	MDM OF3	Card-13	Channel-00	DSC OM2	Card-06	Channel-A
V45P1200A	PRSD O2 TK 2 PRESSURE	MDM OF3	Card-05	Channel-12	DSC OF3	Card-06	Channel-A
V45P1204A	PRSD O2 TK 2 ANNULUS VACUUM	MDM OF3	Card-05	Channel-20	DSC OF3	Card-28	Channel-A
V45P1210A	PRSD O2 TK 2 HTR CONTROL PRESS	MDM OF3	Card-05	Channel-26			
V45P1215A	PRSD O2 TK 2 HTR CTRL SNSR C/O	MDM OF3	Card-09	Channel-22	DSC OF3	Card-10	Channel-D
V45P1300A	PRSD O2 TK 3 PRESS (MID BODY KIT)	MDM OF3	Card-13	Channel-10	DSC OF3	Card-06	Channel-B

6.1.5-2

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45P1304A	PRSD O2 TK 3 ANNULUS VACUUM (MBK)	MDM OF3	Card-09	Channel-25	DSC OF3	Card-28	Channel-B
V45P1310A	PRSD O2 TK 3 HTR CONT PRESS (MBK)	MDM OF3	Card-03	Channel-24			
V45P1315A	PRSD O2 TK 3 HTR CONT SNSR C/O	MDM OF3	Card-01	Channel-22	DSC OF3	Card-24	Channel-C
V45P1400A	PRSD O2 TK 4 PRESS (MID BODY KIT)	MDM OF1	Card-09	Channel-26	DSC OF1	Card-21	Channel-C
V45P1404A	PRSD O2 TK 4 ANNULUS VACUUM (MBK)	MDM OF3	Card-09	Channel-09	DSC OM1	Card-15	Channel-B
V45P1410A	PRSD O2 TK 4(&5) HTR CONT PRESS	MDM OF1	Card-03	Channel-18			
V45P1465A	PRSD O2 TK 4(&5) HTR CONT SENSOR	MDM OF3	Card-03	Channel-21	DSC OF3	Card-25	Channel-C
V45P1500A	PRSD O2 TK 5 PRESS (MID BODY KIT)	MDM OF1	Card-03	Channel-20	DSC OF1	Card-29	Channel-A
V45P1504A	PRSD O2 TK 5 ANNULUS VACUUM (MBK)	MDM OF1	Card-03	Channel-22	DSC OF1	Card-30	Channel-A
V45P1510A	PRSD O2 TK 5 HTR CONT PRESS	MDM OF2	Card-09	Channel-01			
V45P1515A	PRSD O2 TK 5 HTR CONT SNSR C/O	MDM OF2	Card-09	Channel-11	DSC OF2	Card-10	Channel-C
V45P2100A	PRSD H2 TK1 PRESSURE	MDM OF1	Card-09	Channel-13	DSC OF1	Card-21	Channel-B
V45P2104A	PRSD H2 TK 1 ANNULUS VACUUM	MDM OF3	Card-13	Channel-06	DSC OM1	Card-15	Channel-C
V45P2110A	PRSD H2 TK 1 HTR CONTROL PRESS	MDM OF2	Card-03	Channel-07			
V45P2115A	PRSD H2 TK 1 HTR CTRL SNSR C/O	MDM OF2	Card-03	Channel-09	DSC OF2	Card-09	Channel-B
V45P2140A	PRSD H2 MANF 1 PRESSURE	MDM OF3	Card-01	Channel-09	DSC OM1	Card-14	Channel-B
V45P2145A	PRSD H2 MANF 2 PRESSURE	MDM OF2	Card-03	Channel-00	DSC OM2	Card-15	Channel-A
V45P2200A	PRSD H2 TK 2 PRESSURE	MDM OF3	Card-01	Channel-14	DSC OF3	Card-06	Channel-C
V45P2204A	PRSD H2 TK 2 ANNULUS VACUUM	MDM OF3	Card-13	Channel-22	DSC OF3	Card-28	Channel-C
V45P2210A	PRSD H2 TK 2 HTR CONTROL PRESS	MDM OF3	Card-09	Channel-19			
V45P2215A	PRSD H2 TK 2 HTR CTRL SNSR C/O	MDM OF3	Card-01	Channel-17	DSC OF3	Card-19	Channel-C
V45P2300A	PRSD H2 TK 3 PRESS (MID BODY KIT)	MDM OF1	Card-01	Channel-18	DSC OF1	Card-21	Channel-D
V45P2304A	PRSD H2 TK 3 ANNULUS VACUUM (MBK)	MDM OF3	Card-01	Channel-11	DSC OM1	Card-15	Channel-D
V45P2310A	PRSD H2 TK 3 HTR CONT PRESS (MBK)	MDM OF1	Card-13	Channel-09			
V45P2315A	PRSD H2 TK 3 HTR CONT SNSR C/O	MDM OF3	Card-05	Channel-22	DSC OF3	Card-25	Channel-D
V45P2400A	PRSD H2 TK 4 PRESS (MID BODY KIT)	MDM OF3	Card-03	Channel-11	DSC OF3	Card-06	Channel-D
V45P2404A	PRSD H2 TK 4 ANNULUS VACUUM (MBK)	MDM OF3	Card-01	Channel-23	DSC OF3	Card-28	Channel-D
V45P2410A	PRSD H2 TK 4(&5) HTR CONT PRESS	MDM OF2	Card-05	Channel-05			
V45P2465A	PRSD H2 TK 4(&5) HTR CONT SENSOR	MDM OF3	Card-03	Channel-22	DSC OF3	Card-24	Channel-D
V45P2500A	PRSD H2 TK 5 PRESS (MID BODY KIT)	MDM OF1	Card-03	Channel-21	DSC OF1	Card-29	Channel-B
V45P2504A	PRSD H2 TK 5 ANNULUS VACUUM (MBK)	MDM OF1	Card-03	Channel-23	DSC OF1	Card-30	Channel-B

6.1.5-3

Verify that this is the correct version before use



**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45P2510A	PRSD H2 TK 5 HTR CONT PRESS	MDM OF1	Card-09	Channel-01			
V45P2515A	PRSD H2 TK 5 HTR CONT SNSR C/O	MDM OF1	Card-05	Channel-06	DSC OF1	Card-10	Channel-B
V45P3100A	PRSD O2 TK 6 PRESS	MDM OF2	Card-01	Channel-20	DSC OP1	Card-02	Channel-A
V45P3110A	PRSD O2 TK 6 HTR CONT PRESS	MDM OF1	Card-05	Channel-28			
V45P3115A	PRSD O2 TK 6 HTR CONT SNSR C/O	MDM OF4	Card-14	Channel-08	DSC OP1	Card-10	Channel-A
V45P3200A	PRSD O2 TK 7 PRESS	MDM OF4	Card-11	Channel-00	DSC OP2	Card-02	Channel-A
V45P3210A	PRSD O2 TK 7 HTR CONT PRESS	MDM OF3	Card-05	Channel-28			
V45P3215A	PRSD O2 TK 7 HTR CONT SNSR C/O	MDM OF2	Card-03	Channel-24	DSC OP2	Card-10	Channel-A
V45P3300A	PRSD O2 TK 8 PRESS	MDM OF2	Card-01	Channel-21	DSC OP1	Card-02	Channel-B
V45P3310A	PRSD O2 TK 8 HTR CONT PRESS	MDM OA1	Card-09	Channel-05			
V45P3315A	PRSD O2 TK 8 HTR CONT SNSR C/O	MDM OF4	Card-14	Channel-09	DSC OP1	Card-10	Channel-B
V45P3400A	PRSD O2 TK 9 PRESS	MDM OF4	Card-11	Channel-01	DSC OP2	Card-02	Channel-B
V45P3410A	PRSD O2 TK 9 HTR CONT PRESS	MDM OA3	Card-00	Channel-25			
V45P3415A	PRSD O2 TK 9 HTR CONT SNSR C/O	MDM OF2	Card-03	Channel-25	DSC OP2	Card-10	Channel-B
V45P4100A	PRSD H2 TK 6 PRESS	MDM OF2	Card-01	Channel-22	DSC OP1	Card-02	Channel-C
V45P4110A	PRSD H2 TK 6 HTR CONT PRESS	MDM OF1	Card-05	Channel-29			
V45P4115A	PRSD H2 TK 6 HTR CONT SNSR C/O	MDM OF4	Card-14	Channel-10	DSC OP1	Card-10	Channel-C
V45P4200A	PRSD H2 TK 7 PRESS	MDM OF4	Card-11	Channel-02	DSC OP2	Card-02	Channel-C
V45P4210A	PRSD H2 TK 7 HTR CONT PRESS	MDM OF3	Card-05	Channel-29			
V45P4215A	PRSD H2 TK 7 HTR CONT SNSR C/O	MDM OF2	Card-03	Channel-26	DSC OP2	Card-10	Channel-C
V45P4300A	PRSD H2 TK 8 PRESS	MDM OF2	Card-01	Channel-23	DSC OP1	Card-02	Channel-D
V45P4310A	PRSD H2 TK 8 HTR CONT PRESS	MDM OA1	Card-09	Channel-21			
V45P4315A	PRSD H2 TK 8 HTR CONT SNSR C/O	MDM OF4	Card-14	Channel-11	DSC OP1	Card-10	Channel-D
V45P4400A	PRSD H2 TK 9 PRESS	MDM OF4	Card-11	Channel-03	DSC OP2	Card-02	Channel-D
V45P4410A	PRSD H2 TK 9 HTR CONT PRESS	MDM OA3	Card-00	Channel-29			
V45P4415A	PRSD H2 TK 9 HTR CONT SNSR C/O	MDM OF2	Card-03	Channel-27	DSC OP2	Card-10	Channel-D
V45Q1105A	PRSD O2 TK 1 QUANTITY	MDM OF1	Card-03	Channel-13	DSC OF1	Card-09	Channel-B
V45Q1205A	PRSD O2 TK 2 QUANTITY	MDM OF2	Card-13	Channel-08	DSC OF2	Card-15	Channel-A
V45Q1305A	PRSD O2 TK 3 QUANTITY (MBK)	MDM OF3	Card-13	Channel-20	DSC OF3	Card-25	Channel-A
V45Q1405A	PRSD O2 TK 4 QUANTITY (MBK)	MDM OF3	Card-09	Channel-26	DSC OF3	Card-24	Channel-A
V45Q1505A	PRSD O2 TK 5 QUANTITY (MBK)	MDM OF2	Card-05	Channel-04	DSC OF2	Card-11	Channel-B

6.1.5-4

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45Q2105A	PRSD H2 TK 1 QUANTITY	MDM OF3	Card-09	Channel-16	DSC OF3	Card-09	Channel-A
V45Q2205A	PRSD H2 TK 2 QUANTITY	MDM OF1	Card-01	Channel-15	DSC OF1	Card-14	Channel-D
V45Q2305A	PRSD H2 TK 3 QUANTITY (MBK)	MDM OF3	Card-01	Channel-21	DSC OF3	Card-25	Channel-B
V45Q2405A	PRSD H2 TK 4 QUANTITY (MBK)	MDM OF3	Card-13	Channel-21	DSC OF3	Card-24	Channel-B
V45Q2505A	PRSD H2 TK 5 QUANTITY (MBK)	MDM OF3	Card-03	Channel-03	DSC OF3	Card-11	Channel-B
V45Q3105A	PRSD O2 TK 6 QUANTITY	MDM OF2	Card-03	Channel-20	DSC OP1	Card-03	Channel-A
V45Q3205A	PRSD O2 TK 7 QUANTITY	MDM OF4	Card-14	Channel-00	DSC OP2	Card-03	Channel-A
V45Q3305A	PRSD O2 TK 8 QUANTITY	MDM OF2	Card-03	Channel-21	DSC OP1	Card-03	Channel-B
V45Q3405A	PRSD O2 TK 9 QUANTITY	MDM OF4	Card-14	Channel-01	DSC OP2	Card-03	Channel-B
V45Q4105A	PRSD H2 TK 6 QUANTITY	MDM OF2	Card-03	Channel-22	DSC OP1	Card-03	Channel-C
V45Q4205A	PRSD H2 TK 7 QUANTITY	MDM OF4	Card-14	Channel-02	DSC OP2	Card-03	Channel-C
V45Q4305A	PRSD H2 TK 8 QUANTITY	MDM OF2	Card-03	Channel-23	DSC OP1	Card-03	Channel-D
V45Q4405A	PRSD H2 TK 9 QUANTITY	MDM OF4	Card-14	Channel-03	DSC OP2	Card-03	Channel-D
V45R0160A	FUEL CELL NO 1 O2 FLOW	MDM OF1	Card-11	Channel-05			
V45R0170A	FUEL CELL NO 1 H2 FLOW	MDM OF1	Card-07	Channel-07			
V45R0260A	FUEL CELL NO 2 O2 FLOW	MDM OF2	Card-11	Channel-04			
V45R0270A	FUEL CELL NO 2 H2 FLOW	MDM OF2	Card-07	Channel-14			
V45R0360A	FUEL CELL NO 3 O2 FLOW	MDM OF3	Card-11	Channel-04			
V45R0370A	FUEL CELL NO 3 H2 FLOW	MDM OF3	Card-07	Channel-04			
V45S0180E	FCP NO 1 CONTROL POWER	MDM OF1	Card-14	Channel-02			
V45S0191E	FCP NO 1 STARTUP HEATER-INHIBIT	MDM OF4	Card-02	Channel-02			
V45S0280E	FCP NO 2 CONTROL POWER	MDM OA2	Card-05	Channel-01			
V45S0291E	FCP NO 2 STARTUP HEATER-INHIBIT	MDM OF4	Card-04	Channel-00			
V45S0380E	FCP NO 3 CONTROL POWER	MDM OF3	Card-14	Channel-01			
V45S0391E	FCP NO 3 STARTUP HEATER-INHIBIT	MDM OF4	Card-05	Channel-01			
V45S0441E	FCP H2O LINE HTRS A-AUTO	MDM OF4	Card-07	Channel-00			
V45S0442E	FCP H2O LINE HTRS B-AUTO	MDM OF4	Card-10	Channel-00			
V45S0445E	FCP H2O RELIEF HTRS A-AUTO	MDM OF4	Card-12	Channel-01			
V45S0446E	FCP H2O RELIEF HTRS B-AUTO	MDM OF4	Card-13	Channel-02			
V45S0601E	FCP O2/H2 PURGE HTRS MNL-A	MDM OF4	Card-02	Channel-01			
V45S0604E	FCP O2/H2 PURGE HTRS GPC-A ON	MDM OF4	Card-05	Channel-01			

6.1.5-5

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45S0811E	FCP 1 PURGE VLVS MNL OPEN-A	MDM OF4	Card-02	Channel-00			
V45S0815E	FCP 1 PURGE VLVS GPC-A OPEN	MDM OF4	Card-07	Channel-01			
V45S0821E	FCP 2 PURGE VLVS MNL OPEN-A	MDM OF4	Card-10	Channel-02			
V45S0825E	FCP 2 PURGE VLVS GPC-A OPEN	MDM OF4	Card-12	Channel-02			
V45S0831E	FCP 3 PURGE VLVS MNL OPEN-A	MDM OF4	Card-13	Channel-01			
V45S0835E	FCP 3 PURGE VLVS GPC-A OPEN	MDM OF4	Card-15	Channel-00			
V45S0900E	PRSD HEATER A 3A/4A ON	MDM OA1	Card-08	Channel-02			
V45S0901E	PRSD HEATER B 3B/4B ON	MDM OA2	Card-08	Channel-02			
V45S1131E	PRSD O2 TK 1 HTR A-ON A/B	MDM OF4	Card-02	Channel-00			
V45S1133E	PRSD O2 TK 1 HTR A-AUTO A/B	MDM OF4	Card-04	Channel-00			
V45S1136E	PRSD O2 TK 1 HTR B-ON A/B	MDM OF4	Card-05	Channel-00			
V45S1138E	PRSD O2 TK 1 HTR B-AUTO A/B	MDM OF4	Card-07	Channel-01			
V45S1231E	PRSD O2 TK 2 HTR A-ON A/B	MDM OF4	Card-10	Channel-00			
V45S1233E	PRSD O2 TK 2 HTR A-AUTO A/B	MDM OF4	Card-12	Channel-00			
V45S1236E	PRSD O2 TK 2 HTR B-ON A/B	MDM OF4	Card-13	Channel-00			
V45S1238E	PRSD O2 TK 2 HTR B-AUTO A/B	MDM OF4	Card-15	Channel-01			
V45S1331E	PRSD O2 TK 3 HTR A-ON A/B (MBK)	MDM OF4	Card-02	Channel-00			
V45S1333E	PRSD O2 TK 3 HTR A-AUTO A/B (MBK)	MDM OF4	Card-10	Channel-01			
V45S1336E	PRSD O2 TK 3 HTR B-ON A/B (MBK)	MDM OF4	Card-04	Channel-02			
V45S1338E	PRSD O2 TK 3 HTR B-AUTO A/B (MBK)	MDM OF4	Card-13	Channel-02			
V45S1431E	PRSD O2 TK 4 HTR A-ON A/B (MBK)	MDM OF4	Card-04	Channel-01			
V45S1433E	PRSD O2 TK 4 HTR A-AUTO A/B (MBK)	MDM OF4	Card-12	Channel-01			
V45S1436E	PRSD O2 TK 4/5 HTR B/A-ON A/B	MDM OF4	Card-07	Channel-02			
V45S1438E	PRSD O2 TK 4/5 HTR B/A-AUTO A/B	MDM OF4	Card-15	Channel-00			
V45S1531E	PRSD O2 TK 5 HTR A-ON A/B	MDM OF4	Card-00	Channel-01			
V45S1533E	PRSD O2 TK 5 HTR A-AUTO A/B	MDM OF4	Card-00	Channel-01			
V45S1536E	PRSD O2 TK 5 HTR B-ON A/B	MDM OF4	Card-03	Channel-01			
V45S1538E	PRSD O2 TK 5 HTR B-AUTO A/B	MDM OF4	Card-03	Channel-01			
V45S2131E	PRSD H2 TK 1 HTR A-ON A/B	MDM OF4	Card-02	Channel-02			
V45S2133E	PRSD H2 TK 1 HTR A-AUTO A/B	MDM OF4	Card-04	Channel-02			
V45S2136E	PRSD H2 TK 1 HTR B-ON A/B	MDM OF4	Card-05	Channel-02			

6.1.5-6

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45S2138E	PRSD H2 TK 1 HTR B-AUTO A/B	MDM	OF4	Card-07	Channel-02			
V45S2231E	PRSD H2 TK 2 HTR A-ON A/B	MDM	OF4	Card-10	Channel-02			
V45S2233E	PRSD H2 TK 2 HTR A-AUTO A/B	MDM	OF4	Card-12	Channel-02			
V45S2236E	PRSD H2 TK 2 HTR B-ON A/B	MDM	OF4	Card-13	Channel-02			
V45S2238E	PRSD H2 TK 2 HTR B-AUTO A/B	MDM	OF4	Card-15	Channel-02			
V45S2331E	PRSD H2 TK 3 HTR A-ON A/B (MBK)	MDM	OF4	Card-05	Channel-01			
V45S2333E	PRSD H2 TK 3 HTR A-AUTO A/B (MBK)	MDM	OF4	Card-13	Channel-01			
V45S2336E	PRSD H2 TK 3 HTR B-ON A/B (MBK)	MDM	OF4	Card-10	Channel-02			
V45S2338E	PRSD H2 TK 3 HTR B-AUTO A/B (MBK)	MDM	OF4	Card-02	Channel-02			
V45S2481E	PRSD H2 TK 4(&5) HTR A-ON A/B	MDM	OF4	Card-07	Channel-00			
V45S2483E	PRSD H2 TK 4(&5) HTR A-AUTO A/B	MDM	OF4	Card-15	Channel-01			
V45S2486E	PRSD H2 TK 4(&5) HTR B-ON A/B	MDM	OF4	Card-12	Channel-02			
V45S2488E	PRSD H2 TK 4(&5) HTR B-AUTO A/B	MDM	OF4	Card-04	Channel-00			
V45S2531E	PRSD H2 TK 5 HTR A-ON A/B	MDM	OF4	Card-00	Channel-01			
V45S2533E	PRSD H2 TK 5 HTR A-AUTO A/B	MDM	OF4	Card-00	Channel-01			
V45S2536E	PRSD H2 TK 5 HTR B-ON A/B	MDM	OF4	Card-03	Channel-01			
V45S2538E	PRSD H2 TK 5 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-01			
V45S3131E	PRSD O2 TK 6 HTR A-ON A/B	MDM	OF4	Card-03	Channel-00			
V45S3133E	PRSD O2 TK 6 HTR A-AUTO A/B	MDM	OF4	Card-03	Channel-00			
V45S3136E	PRSD O2 TK 6 HTR B-ON A/B	MDM	OF4	Card-08	Channel-02			
V45S3138E	PRSD O2 TK 6 HTR B-AUTO A/B	MDM	OF4	Card-08	Channel-02			
V45S3231E	PRSD O2 TK 7 HTR A-ON A/B	MDM	OF4	Card-03	Channel-00			
V45S3233E	PRSD O2 TK 7 HTR A-AUTO A/B	MDM	OF4	Card-03	Channel-00			
V45S3236E	PRSD O2 TK 7 HTR B-ON A/B	MDM	OF4	Card-08	Channel-02			
V45S3238E	PRSD O2 TK 7 HTR B-AUTO A/B	MDM	OF4	Card-08	Channel-02			
V45S3331E	PRSD O2 TK 8 HTR A-ON A/B	MDM	OF4	Card-08	Channel-02			
V45S3333E	PRSD O2 TK 8 HTR A-AUTO A/B	MDM	OF4	Card-08	Channel-02			
V45S3336E	PRSD O2 TK 8 HTR B-ON A/B	MDM	OF4	Card-03	Channel-00			
V45S3338E	PRSD O2 TK 8 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-00			
V45S3431E	PRSD O2 TK 9 HTR A-ON A/B	MDM	OF4	Card-08	Channel-02			
V45S3433E	PRSD O2 TK 9 HTR A-AUTO A/B	MDM	OF4	Card-08	Channel-02			

6.1.5-7

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45S3436E	PRSD O2 TK 9 HTR B-ON A/B	MDM OF4	Card-03	Channel-00				
V45S3438E	PRSD O2 TK 9 HTR B-AUTO A/B	MDM OF4	Card-03	Channel-00				
V45S4131E	PRSD H2 TK 6 HTR A-ON A/B	MDM OF4	Card-03	Channel-00				
V45S4133E	PRSD H2 TK 6 HTR A-AUTO A/B	MDM OF4	Card-03	Channel-00				
V45S4136E	PRSD H2 TK 6 HTR B-ON A/B	MDM OF4	Card-08	Channel-02				
V45S4138E	PRSD H2 TK 6 HTR B-AUTO A/B	MDM OF4	Card-08	Channel-02				
V45S4231E	PRSD H2 TK 7 HTR A-ON A/B	MDM OF4	Card-03	Channel-00				
V45S4233E	PRSD H2 TK 7 HTR A-AUTO A/B	MDM OF4	Card-03	Channel-00				
V45S4236E	PRSD H2 TK 7 HTR B-ON A/B	MDM OF4	Card-08	Channel-02				
V45S4238E	PRSD H2 TK 7 HTR B-AUTO A/B	MDM OF4	Card-08	Channel-02				
V45S4331E	PRSD H2 TK 8 HTR A-ON A/B	MDM OF4	Card-08	Channel-02				
V45S4333E	PRSD H2 TK 8 HTR A-AUTO A/B	MDM OF4	Card-08	Channel-02				
V45S4336E	PRSD H2 TK 8 HTR B-ON A/B	MDM OF4	Card-03	Channel-00				
V45S4338E	PRSD H2 TK 8 HTR B-AUTO A/B	MDM OF4	Card-03	Channel-00				
V45S4431E	PRSD H2 TK 9 HTR A-ON A/B	MDM OF4	Card-08	Channel-02				
V45S4433E	PRSD H2 TK 9 HTR A-AUTO A/B	MDM OF4	Card-08	Channel-02				
V45S4436E	PRSD H2 TK 9 HTR B-ON A/B	MDM OF4	Card-03	Channel-00				
V45S4438E	PRSD H2 TK 9 HTR B-AUTO A/B	MDM OF4	Card-03	Channel-00				
V45T0113A	FUEL CELL NO 1 STACK INLET TEMP	MDM OF2	Card-13	Channel-02	DSC OM3	Card-07	Channel-A	
V45T0120A	FUEL CELL NO 1 STACK COOL OUT TEMP	MDM OF1	Card-05	Channel-03	DSC OM1	Card-05	Channel-A	
V45T0130A	FUEL CELL NO 1 CONDENSER EXIT TEMP	MDM OF1	Card-01	Channel-04	DSC OM1	Card-04	Channel-A	
V45T0145A	FUEL CELL NO 1 COOLANT RETURN TEMP	MDM OF2	Card-01	Channel-00	DSC OM2	Card-12	Channel-A	
V45T0181A	FCP NO 1 PRODUCT H2O LINE TEMP	MDM OF1	Card-09	Channel-05	DSC OM1	Card-04	Channel-B	
V45T0182A	FCP NO 1 ALT PRODUCT H2O LINE TEMP	MDM OF3	Card-05	Channel-23	DSC OF3	Card-26	Channel-C	
V45T0213A	FUEL CELL NO 2 STACK INLET TEMP	MDM OF3	Card-03	Channel-23	DSC OF3	Card-26	Channel-B	
V45T0220A	FUEL CELL NO 2 STACK COOL OUT TEMP	MDM OF2	Card-05	Channel-00	DSC OM2	Card-13	Channel-A	
V45T0230A	FUEL CELL NO 2 CONDENSER EXIT TEMP	MDM OF2	Card-03	Channel-01	DSC OM2	Card-12	Channel-B	
V45T0245A	FUEL CELL NO 2 COOLANT RETURN TEMP	MDM OF3	Card-05	Channel-00	DSC OM2	Card-04	Channel-A	
V45T0281A	FCP NO 2 PRODUCT H2O LINE TEMP	MDM OF2	Card-09	Channel-02	DSC OM2	Card-12	Channel-C	
V45T0282A	FCP NO 2 ALT PRODUCT H2O LINE TEMP	MDM OA1	Card-13	Channel-27	DSC OM2	Card-28	Channel-D	
V45T0313A	FUEL CELL NO 3 STACK INLET TEMP	MDM OF1	Card-13	Channel-05	DSC OM2	Card-12	Channel-D	

6.1.5-8

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45T0320A	FUEL CELL NO 3 STACK COOL OUT TEMP	MDM OF3	Card-03	Channel-00	DSC OM2	Card-05	Channel-A
V45T0330A	FUEL CELL NO 3 CONDENSER EXIT TEMP	MDM OF3	Card-13	Channel-02	DSC OM2	Card-04	Channel-C
V45T0345A	FUEL CELL NO 3 COOLANT RETURN TEMP	MDM OF1	Card-05	Channel-05	DSC OM1	Card-04	Channel-C
V45T0381A	FCP NO 3 PRODUCT H2O LINE TEMP	MDM OF3	Card-09	Channel-05	DSC OM2	Card-04	Channel-B
V45T0382A	FCP NO 3 ALT PRODUCT H2O LINE TEMP	MDM OA2	Card-13	Channel-27	DSC OM3	Card-04	Channel-D
V45T0412A	FC NO 1 H2O RELIEF VALVE TEMP	MDM OF1	Card-13	Channel-08	DSC OM1	Card-04	Channel-D
V45T0422A	FC NO 2 H2O RELIEF VALVE TEMP	MDM OF2	Card-13	Channel-16	DSC OM3	Card-07	Channel-B
V45T0432A	FC NO 3 H2O RELIEF VALVE TEMP	MDM OF3	Card-01	Channel-03	DSC OM2	Card-04	Channel-D
V45T0450A	H2O RELIEF LINE TEMP	MDM OF3	Card-01	Channel-20	DSC OF3	Card-26	Channel-A
V45T0455A	FCP H2O RELIEF NOZZLE TEMP A	MDM OF2	Card-01	Channel-07	DSC OM2	Card-11	Channel-D
V45T0456A	FCP H2O RELIEF NOZZLE TEMP B	MDM OF3	Card-03	Channel-25	DSC OM3	Card-08	Channel-D
V45T0600A	FCP O2 VENT LINE TEMP	MDM OF3	Card-05	Channel-05	DSC OM1	Card-11	Channel-B
V45T0699A	FCP H2 VENT LINE TEMP 1	MDM OA2	Card-04	Channel-05	DSC OA2	Card-19	Channel-A
V45T0700A	FCP H2 VENT LINE TEMP 2	MDM OF3	Card-13	Channel-07	DSC OM1	Card-11	Channel-D
V45T0902A	PRSD CPC HEAT SINK TEMP 1	MDM OF2	Card-13	Channel-20	DSC OP1	Card-07	Channel-A
V45T0903A	PRSD CPC HEAT SINK TEMP 2	MDM OF4	Card-14	Channel-04	DSC OP2	Card-07	Channel-A
V45T0904A	PRSD CPC HEAT SINK TEMP 3	MDM OF2	Card-05	Channel-21	DSC OP1	Card-07	Channel-B
V45T0905A	PRSD CPC HEAT SINK TEMP 4	MDM OF4	Card-11	Channel-05	DSC OP2	Card-07	Channel-B
V45T1101A	PRSD O2 TK 1 FLUID TEMP	MDM OF2	Card-05	Channel-02	DSC OM2	Card-10	Channel-C
V45T1107A	PRSD O2 TK 1 HTR ASSY 1 TEMP	MDM OF1	Card-09	Channel-04	DSC OM1	Card-02	Channel-A
V45T1109A	PRSD O2 TK 1 HTR ASSY 2 TEMP	MDM OF3	Card-01	Channel-00	DSC OM2	Card-02	Channel-A
V45T1201A	PRSD O2 TK 2 FLUID TEMP	MDM OF3	Card-05	Channel-06	DSC OM1	Card-10	Channel-C
V45T1207A	PRSD O2 TK 2 HTR ASSY 1 TEMP	MDM OF3	Card-01	Channel-08	DSC OM1	Card-10	Channel-A
V45T1209A	PRSD O2 TK 2 HTR ASSY 2 TEMP	MDM OF2	Card-13	Channel-01	DSC OM2	Card-10	Channel-B
V45T1301A	PRSD O2 TK 3 FLUID TEMP (MBK)	MDM OF3	Card-09	Channel-24	DSC OF3	Card-27	Channel-C
V45T1307A	PRSD O2 TK 3 HTR ASSY 1 TEMP(MBK)	MDM OF1	Card-01	Channel-06	DSC OM1	Card-02	Channel-C
V45T1309A	PRSD O2 TK 3 HTR ASSY 2 TEMP(MBK)	MDM OF3	Card-03	Channel-20	DSC OF3	Card-27	Channel-A
V45T1401A	PRSD O2 TK 4 FLUID TEMP (MBK)	MDM OF3	Card-13	Channel-23	DSC OF3	Card-27	Channel-D
V45T1407A	PRSD O2 TK 4 HTR ASSY 1 TEMP(MBK)	MDM OF3	Card-05	Channel-02	DSC OM2	Card-02	Channel-C
V45T1409A	PRSD O2 TK 4 HTR ASSY 2 TEMP(MBK)	MDM OF3	Card-05	Channel-21	DSC OF3	Card-27	Channel-B
V45T1501A	PRSD O2 TK 5 FLUID TEMP (MBK)	MDM OF3	Card-03	Channel-28	DSC OF3	Card-29	Channel-B

6.1.5-9

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45T1507A	PRSD O2 TK 5 HTR ASSY 1 TEMP(MBK)	MDM OF2	Card-01	Channel-03	DSC OF2	Card-06	Channel-A
V45T1509A	PRSD O2 TK 5 HTR ASSY 2 TEMP(MBK)	MDM OF3	Card-03	Channel-29	DSC OF3	Card-29	Channel-A
V45T2101A	PRSD H2 TK 1 FLUID TEMP	MDM OF3	Card-03	Channel-01	DSC OM2	Card-02	Channel-B
V45T2107A	PRSD H2 TK 1 HTR ASSY TEMP	MDM OF1	Card-13	Channel-04	DSC OM1	Card-02	Channel-B
V45T2201A	PRSD H2 TK 2 FLUID TEMP	MDM OF3	Card-03	Channel-05	DSC OM1	Card-10	Channel-B
V45T2207A	PRSD H2 TK 2 HTR ASSY TEMP	MDM OF2	Card-09	Channel-00	DSC OM2	Card-10	Channel-A
V45T2301A	PRSD H2 TK 3 FLUID TEMP (MBK)	MDM OF1	Card-01	Channel-07	DSC OM1	Card-02	Channel-D
V45T2307A	PRSD H2 TK 3 HTR ASSY TEMP (MBK)	MDM OF3	Card-05	Channel-07	DSC OM1	Card-10	Channel-D
V45T2401A	PRSD H2 TK 4 FLUID TEMP (MBK)	MDM OF3	Card-09	Channel-07	DSC OM2	Card-02	Channel-D
V45T2407A	PRSD H2 TK 4 HTR ASSY TEMP (MBK)	MDM OF2	Card-13	Channel-07	DSC OM2	Card-10	Channel-D
V45T2501A	PRSD H2 TK 5 FLUID TEMP (MBK)	MDM OF2	Card-03	Channel-03	DSC OF2	Card-06	Channel-B
V45T2507A	PRSD H2 TK 5 HTR ASSY TEMP (MBK)	MDM OF3	Card-03	Channel-26	DSC OF3	Card-29	Channel-C
V45T3101A	PRSD O2 TK 6 FLUID TEMP	MDM OF4	Card-11	Channel-04	DSC OP2	Card-05	Channel-A
V45T3107A	PRSD O2 TK 6 HTR ASSY 1 TEMP	MDM OF2	Card-03	Channel-17	DSC OP1	Card-04	Channel-A
V45T3109A	PRSD O2 TK 6 HTR ASSY 2 TEMP	MDM OF4	Card-06	Channel-24	DSC OP2	Card-06	Channel-A
V45T3201A	PRSD O2 TK 7 FLUID TEMP	MDM OF2	Card-05	Channel-20	DSC OP1	Card-05	Channel-A
V45T3207A	PRSD O2 TK 7 HTR ASSY 1 TEMP	MDM OF4	Card-01	Channel-24	DSC OP2	Card-04	Channel-A
V45T3209A	PRSD O2 TK 7 HTR ASSY 2 TEMP	MDM OF2	Card-09	Channel-24	DSC OP1	Card-06	Channel-A
V45T3301A	PRSD O2 TK 8 FLUID TEMP	MDM OF4	Card-14	Channel-05	DSC OP2	Card-06	Channel-B
V45T3307A	PRSD O2 TK 8 HTR ASSY 1 TEMP	MDM OF2	Card-09	Channel-25	DSC OP1	Card-05	Channel-B
V45T3309A	PRSD O2 TK 8 HTR ASSY 2 TEMP	MDM OF4	Card-01	Channel-25	DSC OP2	Card-04	Channel-B
V45T3401A	PRSD O2 TK 9 FLUID TEMP	MDM OF2	Card-13	Channel-21	DSC OP1	Card-06	Channel-B
V45T3407A	PRSD O2 TK 9 HTR ASSY 1 TEMP	MDM OF4	Card-06	Channel-25	DSC OP2	Card-05	Channel-B
V45T3409A	PRSD O2 TK 9 HTR ASSY 2 TEMP	MDM OF2	Card-03	Channel-18	DSC OP1	Card-04	Channel-B
V45T4101A	PRSD H2 TK 6 FLUID TEMP	MDM OF4	Card-14	Channel-07	DSC OP2	Card-04	Channel-C
V45T4107A	PRSD H2 TK 6 HTR ASSY TEMP	MDM OF2	Card-05	Channel-22	DSC OP1	Card-05	Channel-C
V45T4201A	PRSD H2 TK 7 FLUID TEMP	MDM OF2	Card-13	Channel-23	DSC OP1	Card-04	Channel-C
V45T4207A	PRSD H2 TK 7 HTR ASSY TEMP	MDM OF4	Card-11	Channel-06	DSC OP2	Card-05	Channel-C
V45T4301A	PRSD H2 TK 8 FLUID TEMP	MDM OF4	Card-11	Channel-07	DSC OP2	Card-05	Channel-D
V45T4307A	PRSD H2 TK 8 HTR ASSY TEMP	MDM OF2	Card-13	Channel-22	DSC OP1	Card-06	Channel-C
V45T4401A	PRSD H2 TK 9 FLUID TEMP	MDM OF2	Card-05	Channel-23	DSC OP1	Card-05	Channel-D

6.1.5-10

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45T4407A	PRSD H2 TK 9 HTR ASSY TEMP	MDM OF4	Card-14	Channel-06	DSC OP2	Card-06	Channel-C
V45V0100A	FUEL CELL NO 1 VOLTAGE	MDM OF1	Card-07	Channel-05	DSC OM1	Card-01	Channel-A
V45V0102A	FCP NO 1 SUBSTACK 1 DELTA VOLTAGE	MDM OF4	Card-01	Channel-19			
V45V0103A	FCP NO 1 SUBSTACK 2 DELTA VOLTAGE	MDM OF4	Card-01	Channel-21			
V45V0104A	FCP NO 1 SUBSTACK 3 DELTA VOLTAGE	MDM OF4	Card-01	Channel-22			
V45V0114A	FCP NO 1 H2 PUMP MTR CONDITION	MDM OF2	Card-13	Channel-11			
V45V0200A	FUEL CELL NO 2 VOLTAGE	MDM OF2	Card-07	Channel-10	DSC OM2	Card-09	Channel-A
V45V0202A	FCP NO 2 SUBSTACK 1 DELTA VOLTAGE	MDM OF1	Card-01	Channel-24			
V45V0203A	FCP NO 2 SUBSTACK 2 DELTA VOLTAGE	MDM OF1	Card-01	Channel-27			
V45V0204A	FCP NO 2 SUBSTACK 3 DELTA VOLTAGE	MDM OF1	Card-01	Channel-29			
V45V0214A	FCP NO 2 H2 PUMP MTR CONDITION	MDM OF3	Card-13	Channel-15			
V45V0300A	FUEL CELL NO 3 VOLTAGE	MDM OF3	Card-07	Channel-07	DSC OM2	Card-01	Channel-A
V45V0302A	FCP NO 3 SUBSTACK 1 DELTA VOLTAGE	MDM OF2	Card-09	Channel-13			
V45V0303A	FCP NO 3 SUBSTACK 2 DELTA VOLTAGE	MDM OF2	Card-09	Channel-27			
V45V0304A	FCP NO 3 SUBSTACK 3 DELTA VOLTAGE	MDM OF2	Card-09	Channel-28			
V45V0314A	FCP NO 3 H2 PUMP MTR CONDITION	MDM OF1	Card-13	Channel-11			
V45X0105E	FUEL CELL NO 1 READY	MDM OF4	Card-02	Channel-01			
V45X0143E	FUEL CELL NO 1 COOLANT PUMP STATUS	MDM OF4	Card-04	Channel-01			
V45X0205E	FUEL CELL NO 2 READY	MDM OF4	Card-05	Channel-01			
V45X0243E	FUEL CELL NO 2 COOLANT PUMP STATUS	MDM OF4	Card-07	Channel-00			
V45X0305E	FUEL CELL NO 3 READY	MDM OF4	Card-10	Channel-01			
V45X0343E	FUEL CELL NO 3 COOLANT PUMP STATUS	MDM OF4	Card-12	Channel-01			
V45X0410E	FUEL CELL NO 1 H2O CONDITION	MDM OF1	Card-02	Channel-00			
V45X0420E	FUEL CELL NO 2 H2O CONDITION	MDM OF2	Card-02	Channel-00			
V45X0430E	FUEL CELL NO 3 H2O CONDITION	MDM OF3	Card-10	Channel-01			
V45X0460E	FCP H2O NOZZLE OVER TEMP	MDM OF2	Card-04	Channel-01			
V45X0461E	FCP H2O NOZZLE SECONDARY HTR ON	MDM OF2	Card-12	Channel-00			
V45X0462E	FUEL CELL H2O CONDUCTIVITY	MDM OA3	Card-14	Channel-01			
V45X0804E	FUEL CELL AUTO PURGE-ON	MDM OF4	Card-15	Channel-02			
V45X1080E	PRSD O2 ECS PRIM SUP VLV-OPEN	MDM OF4	Card-02	Channel-00			
V45X1083E	PRSD O2 ECS SEC SUP VLV-OPEN	MDM OF4	Card-04	Channel-01			

6.1.5-11

Verify that this is the correct version before use



**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45X1106E	PRSD O2 TK 1 HTR A1-ON	MDM OF1	Card-12	Channel-00			
V45X1108E	PRSD O2 TK 1 HTR B1-ON	MDM OF1	Card-04	Channel-02			
V45X1111E	PRSD O2 TK 1 HTR A2-ON	MDM OF1	Card-06	Channel-02			
V45X1113E	PRSD O2 TK 1 HTR B2-ON	MDM OF1	Card-06	Channel-01			
V45X1141E	PRSD O2 MANF 1 ISLN VLV-OPEN	MDM OF4	Card-10	Channel-00			
V45X1146E	PRSD O2 MANF 2 ISLN VLV-OPEN	MDM OF4	Card-12	Channel-00			
V45X1150E	PRSD FCP 1 O2 REAC VLV-OPEN	MDM OF4	Card-13	Channel-00			
V45X1155E	PRSD FCP 2 O2 REAC VLV-OPEN	MDM OF4	Card-15	Channel-01			
V45X1160E	PRSD FCP 3 O2 REAC VLV-OPEN	MDM OF4	Card-02	Channel-02			
V45X1185E	PRSD O2 TK 1 HTR CUR SNSR 1A-TRIP	MDM OF1	Card-12	Channel-00			
V45X1186E	PRSD O2 TK 1 HTR CUR SNSR 2A-TRIP	MDM OF1	Card-14	Channel-00			
V45X1187E	PRSD O2 TK 1 HTR CUR SNSR 1B-TRIP	MDM OF1	Card-12	Channel-02			
V45X1188E	PRSD O2 TK 1 HTR CUR SNSR 2B-TRIP	MDM OF1	Card-12	Channel-00			
V45X1195E	PRSD O2 GAS SPLY VLV-CLOSED	MDM OF1	Card-12	Channel-01			
V45X1206E	PRSD O2 TK 2 HTR A1-ON	MDM OF3	Card-04	Channel-01			
V45X1208E	PRSD O2 TK 2 HTR B1-ON	MDM OF3	Card-06	Channel-01			
V45X1211E	PRSD O2 TK 2 HTR A2-ON	MDM OF3	Card-12	Channel-02			
V45X1213E	PRSD O2 TK 2 HTR B2-ON	MDM OF3	Card-14	Channel-02			
V45X1285E	PRSD O2 TK 2 HTR CUR SNSR 1A-TRIP	MDM OF3	Card-06	Channel-00			
V45X1286E	PRSD O2 TK 2 HTR CUR SNSR 2A-TRIP	MDM OF3	Card-12	Channel-02			
V45X1287E	PRSD O2 TK 2 HTR CUR SNSR 1B-TRIP	MDM OF3	Card-14	Channel-01			
V45X1288E	PRSD O2 TK 2 HTR CUR SNSR 2B-TRIP	MDM OF3	Card-14	Channel-00			
V45X1306E	PRSD O2 TK 3 HTR A1-ON (MBK)	MDM OA1	Card-01	Channel-01			
V45X1308E	PRSD O2 TK 3 HTR B1-ON (MBK)	MDM OA1	Card-07	Channel-01			
V45X1311E	PRSD O2 TK 3 HTR A2-ON (MBK)	MDM OA1	Card-12	Channel-01			
V45X1313E	PRSD O2 TK 3 HTR B2-ON (MBK)	MDM OA1	Card-01	Channel-02			
V45X1385E	PRSD O2 TK 3 HTR CUR SNSR 1A-TRIP	MDM OA1	Card-05	Channel-00			
V45X1386E	PRSD O2 TK 3 HTR CUR SNSR 2A-TRIP	MDM OA1	Card-07	Channel-01			
V45X1387E	PRSD O2 TK 3 HTR CUR SNSR 1B-TRIP	MDM OA1	Card-10	Channel-02			
V45X1388E	PRSD O2 TK 3 HTR CUR SNSR 2B-TRIP	MDM OA1	Card-12	Channel-00			
V45X1393E	PRSD O2 TK 3 ISO VENT VALVE CLOSE	MDM OA3	Card-03	Channel-01			

6.1.5-12

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45X1394E	PRSD O2 TK 3 ISO FILL VALVE CLOSE	MDM OA3	Card-03	Channel-01			
V45X1406E	PRSD O2 TK 4 HTR A1-ON (MBK)	MDM OA2	Card-01	Channel-01			
V45X1408E	PRSD O2 TK 4/5 HTR B1/A1-ON	MDM OA2	Card-05	Channel-01			
V45X1411E	PRSD O2 TK 4 HTR A2-ON (MBK)	MDM OA2	Card-07	Channel-02			
V45X1413E	PRSD O2 TK 4/5 HTR B2/A2-ON	MDM OA2	Card-10	Channel-01			
V45X1485E	PRSD O2 TK 4 HTR CUR SNSR 1A-TRIP	MDM OA2	Card-12	Channel-02			
V45X1486E	PRSD O2 TK 4 HTR CUR SNSR 2A-TRIP	MDM OA2	Card-01	Channel-02			
V45X1487E	PRSD O2 TK 4/5 HTR CUR SNSR 1B/1A	MDM OA2	Card-05	Channel-00			
V45X1488E	PRSD O2 TK 4/5 HTR CUR SNSR 2B/2A	MDM OA2	Card-07	Channel-01			
V45X1506E	PRSD O2 TK 5 HTR A1-ON	MDM OA1	Card-08	Channel-02			
V45X1508E	PRSD O2 TK 5 HTR B1-ON	MDM OA3	Card-08	Channel-02			
V45X1511E	PRSD O2 TK 5 HTR A2-ON	MDM OA1	Card-08	Channel-02			
V45X1513E	PRSD O2 TK 5 HTR B2-ON	MDM OA3	Card-08	Channel-02			
V45X1585E	PRSD O2 TK 5 HTR CUR SNSR 1A-TRIP	MDM OA1	Card-08	Channel-02			
V45X1586E	PRSD O2 TK 5 HTR CUR SNSR 2A-TRIP	MDM OA3	Card-08	Channel-02			
V45X1587E	PRSD O2 TK 5 HTR CUR SNSR 1B-TRIP	MDM OA1	Card-08	Channel-02			
V45X1588E	PRSD O2 TK 5 HTR CUR SNSR 2B-TRIP	MDM OA3	Card-08	Channel-02			
V45X2106E	PRSD H2 TK 1 HEATER A-ON	MDM OF1	Card-14	Channel-02			
V45X2108E	PRSD H2 TK 1 HEATER B-ON	MDM OF1	Card-12	Channel-02			
V45X2141E	PRSD H2 MANF 1 ISLN VLV-OPEN	MDM OF4	Card-04	Channel-02			
V45X2146E	PRSD H2 MANF 2 ISLN VLV-OPEN	MDM OF4	Card-05	Channel-02			
V45X2150E	PRSD FCP 1 H2 REAC VLV-OPEN	MDM OF4	Card-07	Channel-02			
V45X2155E	PRSD FCP 2 H2 REAC VLV-OPEN	MDM OF4	Card-10	Channel-02			
V45X2160E	PRSD FCP 3 H2 REAC VLV-OPEN	MDM OF4	Card-12	Channel-02			
V45X2195E	PRSD H2 GAS SPLY VLV-CLOSED	MDM OF3	Card-12	Channel-01			
V45X2206E	PRSD H2 TK 2 HEATER A-ON	MDM OF3	Card-06	Channel-02			
V45X2208E	PRSD H2 TK 2 HEATER B-ON	MDM OF3	Card-12	Channel-00			
V45X2306E	PRSD H2 TK 3 HTR A-ON (MBK)	MDM OA1	Card-05	Channel-01			
V45X2308E	PRSD H2 TK 3 HTR B-ON (MBK)	MDM OA1	Card-10	Channel-01			
V45X2343E	PRSD H2 TK 3 ISO VENT VALVE CLOSE	MDM OA3	Card-14	Channel-00			
V45X2344E	PRSD H2 TK 3 ISO FILL VALVE CLOSE	MDM OA3	Card-14	Channel-00			

6.1.5-13

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45X2456E	PRSD H2 TK 4(&5) HTR A-ON	MDM OA2	Card-10	Channel-01			
V45X2458E	PRSD H2 TK 4(&5) HTR B-ON	MDM OA2	Card-12	Channel-00			
V45X2506E	PRSD H2 TK 5 HTR A-ON	MDM OA1	Card-08	Channel-02			
V45X2508E	PRSD H2 TK 5 HTR B-ON	MDM OA3	Card-08	Channel-02			
V45X3106E	PRSD O2 TK 6 HTR A1-ON	MDM OA3	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3108E	PRSD O2 TK 6 HTR B1-ON	MDM OA1	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3111E	PRSD O2 TK 6 HTR A2-ON	MDM OA3	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3113E	PRSD O2 TK 6 HTR B2-ON	MDM OA1	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3144E	PRSD O2 TK 6 VENT VALVE CLOSE	MDM OA1	Card-03	Channel-01			
V45X3145E	PRSD O2 TK 6 FILL VALVE CLOSE	MDM OA1	Card-03	Channel-01			
V45X3185E	PRSD O2 TK 6 HTR CUR SNSR 1A-TRIP	MDM OA3	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3186E	PRSD O2 TK 6 HTR CUR SNSR 2A-TRIP	MDM OA1	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3187E	PRSD O2 TK 6 HTR CUR SNSR 1B-TRIP	MDM OA3	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3188E	PRSD O2 TK 6 HTR CUR SNSR 2B-TRIP	MDM OA1	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X3206E	PRSD O2 TK 7 HTR A1-ON	MDM OA1	Card-08	Channel-02	DSC EC1	Card-02	Channel-A
V45X3208E	PRSD O2 TK 7 HTR B1-ON	MDM OA2	Card-03	Channel-02	DSC EC1	Card-02	Channel-A
V45X3211E	PRSD O2 TK 7 HTR A2-ON	MDM OA1	Card-08	Channel-02	DSC EC1	Card-02	Channel-A
V45X3213E	PRSD O2 TK 7 HTR B2-ON	MDM OA2	Card-03	Channel-02	DSC EC1	Card-02	Channel-A
V45X3244E	PRSD O2 TK 7 VENT VALVE CLOSE	MDM OA1	Card-03	Channel-01			
V45X3245E	PRSD O2 TK 7 FILL VALVE CLOSE	MDM OA1	Card-03	Channel-01			
V45X3285E	PRSD O2 TK 7 HTR CUR SNSR 1A-TRIP	MDM OA1	Card-08	Channel-02	DSC EC1	Card-02	Channel-A
V45X3286E	PRSD O2 TK 7 HTR CUR SNSR 2A-TRIP	MDM OA2	Card-03	Channel-02	DSC EC1	Card-02	Channel-A
V45X3287E	PRSD O2 TK 7 HTR CUR SNSR 1B-TRIP	MDM OA1	Card-08	Channel-02	DSC EC1	Card-02	Channel-A
V45X3288E	PRSD O2 TK 7 HTR CUR SNSR 2B-TRIP	MDM OA2	Card-03	Channel-02	DSC EC1	Card-02	Channel-A
V45X3306E	PRSD O2 TK 8 HTR A1-ON	MDM OA3	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X3308E	PRSD O2 TK 8 HTR B1-ON	MDM OA2	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X3311E	PRSD O2 TK 8 HTR A2-ON	MDM OA3	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X3313E	PRSD O2 TK 8 HTR B2-ON	MDM OA2	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X3344E	PRSD O2 TK 8 VENT VALVE CLOSE	MDM OA3	Card-03	Channel-01			
V45X3345E	PRSD O2 TK 8 FILL VALVE CLOSE	MDM OA3	Card-03	Channel-01			
V45X3385E	PRSD O2 TK 8 HTR CUR SNSR 1A-TRIP	MDM OA3	Card-03	Channel-02	DSC EC1	Card-03	Channel-A

6.1.5-14

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V45X3386E	PRSD O2 TK 8 HTR CUR SNSR 2A-TRIP	MDM OA2	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X3387E	PRSD O2 TK 8 HTR CUR SNSR 1B-TRIP	MDM OA3	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X3388E	PRSD O2 TK 8 HTR CUR SNSR 2B-TRIP	MDM OA2	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X3406E	PRSD O2 TK 9 HTR A1-ON	MDM OA3	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X3408E	PRSD O2 TK 9 HTR B1-ON	MDM OA2	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X3411E	PRSD O2 TK 9 HTR A2-ON	MDM OA3	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X3413E	PRSD O2 TK 9 HTR B2-ON	MDM OA2	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X3444E	PRSD O2 TK 9 VENT VALVE CLOSE	MDM OA3	Card-03	Channel-01			
V45X3445E	PRSD O2 TK 9 FILL VALVE CLOSE	MDM OA3	Card-03	Channel-01			
V45X3485E	PRSD O2 TK 9 HTR CUR SNSR 1A-TRIP	MDM OA3	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X3486E	PRSD O2 TK 9 HTR CUR SNSR 2A-TRIP	MDM OA2	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X3487E	PRSD O2 TK 9 HTR CUR SNSR 1B-TRIP	MDM OA3	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X3488E	PRSD O2 TK 9 HTR CUR SNSR 2B-TRIP	MDM OA2	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X4106E	PRSD H2 TK 6 HTR A-ON	MDM OA3	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X4108E	PRSD H2 TK 6 HTR B-ON	MDM OA1	Card-03	Channel-02	DSC EC1	Card-01	Channel-A
V45X4144E	PRSD H2 TK 6 VENT VALVE CLOSE	MDM OA1	Card-14	Channel-00			
V45X4145E	PRSD H2 TK 6 FILL VALVE CLOSE	MDM OA1	Card-14	Channel-00			
V45X4206E	PRSD H2 TK 7 HTR A-ON	MDM OA1	Card-08	Channel-02	DSC EC1	Card-02	Channel-A
V45X4208E	PRSD H2 TK 7 HTR B-ON	MDM OA2	Card-03	Channel-02	DSC EC1	Card-02	Channel-A
V45X4244E	PRSD H2 TK 7 VENT VALVE CLOSE	MDM OA1	Card-14	Channel-00			
V45X4245E	PRSD H2 TK 7 FILL VALVE CLOSE	MDM OA1	Card-14	Channel-00			
V45X4306E	PRSD H2 TK 8 HTR A-ON	MDM OA3	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X4308E	PRSD H2 TK 8 HTR B-ON	MDM OA2	Card-03	Channel-02	DSC EC1	Card-03	Channel-A
V45X4344E	PRSD H2 TK 8 VENT VALVE CLOSE	MDM OA3	Card-14	Channel-00			
V45X4345E	PRSD H2 TK 8 FILL VALVE CLOSE	MDM OA3	Card-14	Channel-00			
V45X4406E	PRSD H2 TK 9 HTR A-ON	MDM OA3	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X4408E	PRSD H2 TK 9 HTR B-ON	MDM OA2	Card-08	Channel-02	DSC EC1	Card-04	Channel-A
V45X4444E	PRSD H2 TK 9 VENT VALVE CLOSE	MDM OA3	Card-14	Channel-00			
V45X4445E	PRSD H2 TK 9 FILL VALVE CLOSE	MDM OA3	Card-14	Channel-00			
V62Q0590A	SMOKE DET CONC N LEFT-FLIGHT DECK	MDM OF3	Card-05	Channel-14	DSC OF3	Card-04	Channel-C
V62Q0591A	SMOKE DET CONC N RIGHT-FLIGHT DECK	MDM OF2	Card-01	Channel-04	DSC OF2	Card-04	Channel-A

6.1.5-15

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V62Q0595A	SMOKE DETR CONC N RTN AIR-CAB HX	MDM OF1	Card-03	Channel-08	DSC OF1	Card-04	Channel-A
V62Q0608A	SMOKE DETECTOR CONC N A-AV BAY 2	MDM OF1	Card-05	Channel-09	DSC OF1	Card-04	Channel-B
V62Q0609A	SMOKE DETECTOR CONC N B-AV BAY 2	MDM OF3	Card-01	Channel-12	DSC OF3	Card-04	Channel-A
V62Q0618A	SMOKE DETECTOR CONC N A-AV BAY 1	MDM OF2	Card-03	Channel-05	DSC OF2	Card-04	Channel-B
V62Q0619A	SMOKE DETECTOR CONC N B-AV BAY 1	MDM OF3	Card-03	Channel-09	DSC OF3	Card-04	Channel-B
V62Q0628A	SMOKE DETECTOR CONC N A-AV BAY 3	MDM OF1	Card-01	Channel-10	DSC OF1	Card-04	Channel-C
V62Q0629A	SMOKE DETECTOR CONC N B-AV BAY 3	MDM OF2	Card-09	Channel-07	DSC OF2	Card-04	Channel-C
V62S0810E	FIRE SUPPRESSION AV BAY 1 ARM	MDM OF2	Card-04	Channel-02			
V62S0811E	FIRE SUPPRESSION AV BAY 2 ARM	MDM OF3	Card-14	Channel-00			
V62S0812E	FIRE SUPPRESSION AV BAY 3 ARM	MDM OF1	Card-14	Channel-02			
V62X0596E	SMOKE DET-RTN AIR TO CAB HX	MDM OF4	Card-07	Channel-00			
V62X0606E	SMOKE DETECTOR-LEFT FLIGHT DECK	MDM OF4	Card-07	Channel-01			
V62X0607E	SMOKE DETECTOR-RIGHT FLIGHT DECK	MDM OF4	Card-10	Channel-01			
V62X0610E	SMOKE DETECTOR-A AV BAY-2	MDM OF4	Card-12	Channel-01			
V62X0611E	SMOKE DETECTOR-B AV BAY-2	MDM OF4	Card-13	Channel-01			
V62X0612E	FIRE BOTTLE AV BAY 1 FULL/EMPTY	MDM OF4	Card-15	Channel-00			
V62X0620E	SMOKE DETECTOR-A AV BAY-1	MDM OF4	Card-02	Channel-02			
V62X0621E	SMOKE DETECTOR-B AV BAY-1	MDM OF4	Card-04	Channel-02			
V62X0622E	FIRE BOTTLE AV BAY 2 FULL/EMPTY	MDM OF4	Card-05	Channel-02			
V62X0630E	SMOKE DETECTOR-A AV BAY 3	MDM OF4	Card-07	Channel-02			
V62X0631E	SMOKE DETECTOR-B AV BAY 3	MDM OF4	Card-10	Channel-02			
V62X0632E	FIRE BOTTLE AV BAY 3 FULL/EMPTY	MDM OF4	Card-12	Channel-02			
V64C0211A	EXTRA VEHICULAR LSS BAT CHG CUR 1	MDM OF1	Card-03	Channel-00			
V64C0214A	EXTRA VEHICULAR LSS BAT CHG CUR 2	MDM OF1	Card-03	Channel-01			
V64V0210A	EXTRA VEHICULAR LSS BAT CHG VOLT 1	MDM OF1	Card-09	Channel-12	DSC OF1	Card-22	Channel-A
V64V0213A	EXTRA VEHICULAR LSS BAT CHG VOLT 2	MDM OF1	Card-05	Channel-13	DSC OF1	Card-22	Channel-B
V73X1567E	C/W MASTER ALARM TLM OUTPUT	MDM OF3	Card-02	Channel-00			
V75X2185E	PALLET DSC 2 BITE	MDM OA3	Card-03	Channel-02	DSC OP2	Card-IT	Channel-B
V76C1540A	AC BUS 1 PHASE A CURRENT	MDM OF1	Card-07	Channel-09			
V76C1541A	AC BUS 1 PHASE B CURRENT	MDM OF1	Card-11	Channel-06			
V76C1542A	AC BUS 1 PHASE C CURRENT	MDM OF1	Card-07	Channel-08			

6.1.5-16

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V76C1640A	AC BUS 2 PHASE A CURRENT	MDM OF2	Card-07	Channel-16			
V76C1641A	AC BUS 2 PHASE B CURRENT	MDM OF2	Card-11	Channel-05			
V76C1642A	AC BUS 2 PHASE C CURRENT	MDM OF2	Card-07	Channel-17			
V76C1740A	AC BUS 3 PHASE A CURRENT	MDM OF3	Card-07	Channel-05			
V76C1741A	AC BUS 3 PHASE B CURRENT	MDM OF3	Card-11	Channel-05			
V76C1742A	AC BUS 3 PHASE C CURRENT	MDM OF3	Card-15	Channel-06			
V76C2811A	PAYLOAD AFT MAIN B CURRENT	MDM OA2	Card-02	Channel-17			
V76C2822A	PAYLOAD AFT MAIN C CURRENT	MDM OA3	Card-02	Channel-23			
V76C3075A	FWD PCA MAIN BUS A AMPS	MDM OF1	Card-07	Channel-04			
V76C3076A	FWD PCA MAIN BUS B AMPS	MDM OF2	Card-07	Channel-15			
V76C3077A	FWD PCA MAIN BUS C AMPS	MDM OF3	Card-07	Channel-06			
V76C3085A	MID PCA MAIN BUS A AMPS	MDM OF1	Card-11	Channel-01			
V76C3086A	MID PCA MAIN BUS B AMPS	MDM OF2	Card-11	Channel-03			
V76C3087A	MID PCA MAIN BUS C AMPS	MDM OF3	Card-11	Channel-06			
V76C3095A	AFT PCA MAIN BUS A AMPS	MDM OA1	Card-06	Channel-15			
V76C3096A	AFT PCA MAIN BUS B AMPS	MDM OA2	Card-06	Channel-15			
V76C3097A	AFT PCA MAIN BUS C AMPS	MDM OA3	Card-06	Channel-25			
V76C4450A	PALLET PCA 1 MN A CURRENT	MDM OF3	Card-11	Channel-02	DSC EC1	Card-01	Channel-A
V76K6941X	L SRB BUS C RPC A ON CMD	MDM FA4	Card-07	Channel-00			
V76K6942X	R SRB BUS C RPC A ON CMD	MDM FA4	Card-12	Channel-00			
V76S0134E	MAIN BUS C TO ESS BUS-1BC-ON	MDM OF4	Card-02	Channel-02			
V76S0163E	FUEL CELL 1 TO ESS BUS 1BC-ON	MDM OF4	Card-04	Channel-02			
V76S0234E	MAIN BUS A TO ESS BUS-2CA-ON	MDM OF4	Card-05	Channel-01			
V76S0263E	FUEL CELL 2 TO ESS BUS 2CA-ON	MDM OF4	Card-07	Channel-02			
V76S0334E	MAIN BUS B TO ESS BUS-3AB-ON	MDM OF4	Card-10	Channel-02			
V76S0363E	FUEL CELL 3 TO ESS BUS 3AB-ON	MDM OF4	Card-12	Channel-02			
V76S1503E	AC BUS 1 VOLTAGE SENSOR AUTO	MDM OF1	Card-12	Channel-00			
V76S1504E	AC BUS 1 VOLTAGE SENSOR MONITOR	MDM OF1	Card-14	Channel-01			
V76S1603E	AC BUS 2 VOLTAGE SENSOR AUTO	MDM OF2	Card-12	Channel-02			
V76S1604E	AC BUS 2 VOLTAGE SENSOR MONITOR	MDM OF2	Card-14	Channel-02			
V76S1703E	AC BUS 3 VOLTAGE SENSOR AUTO	MDM OF3	Card-04	Channel-02			

6.1.5-17

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V76S1704E	AC BUS 3 VOLTAGE SENSOR MONITOR	MDM OF3	Card-06	Channel-01			
V76S2851E	PAYLOAD CABIN-MAIN BUS A ON	MDM OF4	Card-10	Channel-00			
V76S2853E	PAYLOAD CABIN-MAIN BUS B ON	MDM OF4	Card-12	Channel-02			
V76S2861E	PAYLOAD AUXILIARY-MAIN BUS A ON	MDM OF4	Card-13	Channel-00			
V76V0100A	MAIN BUS A VOLTAGE	MDM OF2	Card-11	Channel-02	DSC OM2	Card-09	Channel-C
V76V0120A	CONTROL BUS AB1 VOLTAGE	MDM OF1	Card-01	Channel-08	DSC OF1	Card-05	Channel-A
V76V0121A	CONTROL BUS AB2 VOLTAGE	MDM OF1	Card-03	Channel-09	DSC OF1	Card-05	Channel-B
V76V0122A	CONTROL BUS AB3 VOLTAGE	MDM OF1	Card-05	Channel-10	DSC OF1	Card-05	Channel-C
V76V0130A	ESS BUS 1BC VOLTAGE	MDM OF2	Card-13	Channel-03	DSC OM2	Card-09	Channel-D
V76V0200A	MAIN BUS B VOLTAGE	MDM OF3	Card-11	Channel-00	DSC OM2	Card-01	Channel-C
V76V0220A	CONTROL BUS BC1 VOLTAGE	MDM OF2	Card-03	Channel-04	DSC OF2	Card-05	Channel-A
V76V0221A	CONTROL BUS BC2 VOLTAGE	MDM OF2	Card-09	Channel-05	DSC OF2	Card-05	Channel-B
V76V0222A	CONTROL BUS BC3 VOLTAGE	MDM OF2	Card-01	Channel-06	DSC OF2	Card-05	Channel-C
V76V0230A	ESS BUS 2CA VOLTAGE	MDM OF3	Card-01	Channel-07	DSC OM2	Card-01	Channel-D
V76V0300A	MAIN BUS C VOLTAGE	MDM OF1	Card-11	Channel-00	DSC OM1	Card-01	Channel-C
V76V0320A	CONTROL BUS CA1 VOLTAGE	MDM OF3	Card-03	Channel-08	DSC OF3	Card-05	Channel-A
V76V0321A	CONTROL BUS CA2 VOLTAGE	MDM OF3	Card-05	Channel-13	DSC OF3	Card-05	Channel-B
V76V0322A	CONTROL BUS CA3 VOLTAGE	MDM OF3	Card-13	Channel-11	DSC OF3	Card-05	Channel-C
V76V0330A	ESS BUS 3AB VOLTAGE	MDM OF1	Card-13	Channel-06	DSC OM1	Card-01	Channel-D
V76V1500A	AC BUS 1 PHASE A VOLT	MDM OF1	Card-07	Channel-01	DSC OF1	Card-01	Channel-A
V76V1501A	AC BUS 1 PHASE B VOLT	MDM OF1	Card-11	Channel-03	DSC OF1	Card-01	Channel-B
V76V1502A	AC BUS 1 PHASE C VOLT	MDM OF1	Card-11	Channel-04	DSC OF1	Card-01	Channel-C
V76V1600A	AC BUS 2 PHASE A VOLT	MDM OF2	Card-07	Channel-12	DSC OF2	Card-01	Channel-A
V76V1601A	AC BUS 2 PHASE B VOLT	MDM OF2	Card-11	Channel-01	DSC OF2	Card-01	Channel-B
V76V1602A	AC BUS 2 PHASE C VOLT	MDM OF2	Card-07	Channel-13	DSC OF2	Card-01	Channel-C
V76V1700A	AC BUS 3 PHASE A VOLT	MDM OF3	Card-07	Channel-09	DSC OF3	Card-01	Channel-A
V76V1701A	AC BUS 3 PHASE B VOLT	MDM OF3	Card-11	Channel-01	DSC OF3	Card-01	Channel-B
V76V1702A	AC BUS 3 PHASE C VOLT	MDM OF3	Card-07	Channel-10	DSC OF3	Card-01	Channel-C
V76V3071A	FWD PCA-1 VOLTAGE	MDM OF1	Card-11	Channel-20	DSC OF1	Card-05	Channel-D
V76V3072A	FWD PCA-2 VOLTAGE	MDM OF2	Card-11	Channel-24	DSC OF2	Card-05	Channel-D
V76V3073A	FWD PCA-3 VOLTAGE	MDM OF3	Card-11	Channel-23	DSC OF3	Card-05	Channel-D

6.1.5-18

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V76V3091A	AFT PCA-4 VOLTAGE	MDM OA1	Card-02	Channel-28	DSC OM1	Card-01	Channel-B
V76V3092A	AFT PCA-5 VOLTAGE	MDM OA2	Card-02	Channel-08	DSC OM2	Card-01	Channel-B
V76V3093A	AFT PCA-6 VOLTAGE	MDM OA3	Card-02	Channel-16	DSC OA3	Card-01	Channel-B
V76V4700A	AVN FEXT AV BAY 3A PYRO CAP VOLT	MDM OF1	Card-07	Channel-22	DSC OF1	Card-12	Channel-C
V76V4716A	AVN FEXT AV BAY 2 PYRO CAP VOLT	MDM OF3	Card-15	Channel-19	DSC OF3	Card-14	Channel-D
V76V4736A	AVN FEXT AV BAY 1 PYRO CAP VOLT	MDM OF2	Card-11	Channel-22	DSC OF2	Card-12	Channel-C
V76V4820A	NLG PYRO EXTEND ACTR-CAP VOLT-1	MDM OF3	Card-15	Channel-20	DSC OF3	Card-16	Channel-A
V76V4821A	NLG PYRO EXTEND ACTR-CAP VOLT-2	MDM OF2	Card-07	Channel-22	DSC OF2	Card-16	Channel-A
V76V4830A	NLG EMER EXT PYRO A CAP VOLT	MDM OF3	Card-07	Channel-23	DSC OF3	Card-16	Channel-D
V76V4832A	NLG EMER EXT PYRO B CAP VOLT	MDM OF2	Card-07	Channel-23	DSC OF2	Card-14	Channel-C
V76V4900A	LMG EMER EXT PYRO A CAP VOLT	MDM OF3	Card-11	Channel-16	DSC OF3	Card-12	Channel-A
V76V4902A	LMG EMER EXT PYRO B CAP VOLT	MDM OF2	Card-07	Channel-20	DSC OF2	Card-12	Channel-A
V76V4950A	RMG EMER EXT PYRO A CAP VOLT	MDM OF3	Card-07	Channel-20	DSC OF3	Card-14	Channel-A
V76V4952A	RMG EMER EXT PYRO B CAP VOLT	MDM OF2	Card-11	Channel-21	DSC OF2	Card-13	Channel-B
V76X0106E	MAIN BUS A TIE BUS-ON	MDM OF3	Card-04	Channel-01			
V76X0124E	MAIN BUS A CONT BUS AB1/CA1 RPC ON	MDM OF1	Card-04	Channel-01			
V76X0125E	MAIN BUS A CONT BUS AB2/CA2 RPC ON	MDM OF1	Card-06	Channel-01			
V76X0126E	MAIN BUS A CONT BUS AB3/CA3 RPC ON	MDM OF1	Card-12	Channel-02			
V76X0135E	MAIN BUS A ESS 3AB RPC ON	MDM OF1	Card-14	Channel-02			
V76X0136E	MAIN BUS A ESS 2CA RPC ON	MDM OF1	Card-04	Channel-02			
V76X0155E	FUEL CELL H2/O2 PGE HTR-RPC A ON	MDM OF1	Card-06	Channel-02			
V76X0156E	FUEL CELL H2/O2 PGE HTR-RPC B ON	MDM OF2	Card-04	Channel-02			
V76X0157E	FUEL CELL H2/O2 PGE HTR-RPC C-1 ON	MDM OF3	Card-04	Channel-00			
V76X0158E	FUEL CELL H2/O2 PGE HTR-RPC C-2 ON	MDM OF3	Card-12	Channel-00			
V76X0160E	FUEL CELL 1 TO MN BUS A-ON	MDM OF3	Card-06	Channel-00			
V76X0206E	MAIN BUS B TIE BUS-ON	MDM OF3	Card-12	Channel-02			
V76X0224E	MAIN BUS B CONT BUS AB1/BC1 RPC ON	MDM OF2	Card-04	Channel-02			
V76X0225E	MAIN BUS B CONT BUS AB2/BC2 RPC ON	MDM OF2	Card-06	Channel-02			
V76X0226E	MAIN BUS B CONT BUS AB3/BC3 RPC ON	MDM OF2	Card-12	Channel-01			
V76X0235E	MAIN BUS B ESS 3AB RPC ON	MDM OF2	Card-14	Channel-00			
V76X0236E	MAIN BUS B ESS 1BC RPC ON	MDM OF2	Card-04	Channel-01			

6.1.5-19

Verify that this is the correct version before use



**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V76X0260E	FUEL CELL 2 TO MN BUS B-ON	MDM OF3	Card-14	Channel-02			
V76X0306E	MAIN BUS C TIE BUS-ON	MDM OF3	Card-04	Channel-02			
V76X0324E	MAIN BUS C CONT BUS BC1/CA1 RPC ON	MDM OF3	Card-06	Channel-01			
V76X0325E	MAIN BUS C CONT BUS BC2/CA2 RPC ON	MDM OF3	Card-12	Channel-00			
V76X0326E	MAIN BUS C CONT BUS BC3/CA3 RPC ON	MDM OF3	Card-14	Channel-01			
V76X0335E	MAIN BUS C ESS 1BC RPC ON	MDM OF3	Card-04	Channel-01			
V76X0336E	MAIN BUS C ESS 2CA RPC ON	MDM OF3	Card-06	Channel-02			
V76X0360E	FUEL CELL 3 TO MN BUS C-ON	MDM OF3	Card-12	Channel-01			
V76X1505E	INVERTER BUS NO 1 O/V-U/V	MDM OF1	Card-04	Channel-01			
V76X1506E	AC BUS 1 OVERLOAD	MDM OF1	Card-06	Channel-02			
V76X1537E	AC BUS 1 PHASE A INPUT ON	MDM OF1	Card-04	Channel-02			
V76X1538E	AC BUS 1 PHASE B INPUT ON	MDM OF1	Card-06	Channel-01			
V76X1539E	AC BUS 1 PHASE C INPUT ON	MDM OF1	Card-12	Channel-02			
V76X1605E	INVERTER BUS NO 2 O/V-U/V	MDM OF2	Card-04	Channel-02			
V76X1606E	AC BUS 2 OVERLOAD	MDM OF2	Card-06	Channel-02			
V76X1637E	AC BUS 2 PHASE A INPUT ON	MDM OF2	Card-06	Channel-01			
V76X1638E	AC BUS 2 PHASE B INPUT ON	MDM OF2	Card-12	Channel-01			
V76X1639E	AC BUS 2 PHASE C INPUT ON	MDM OF2	Card-14	Channel-00			
V76X1705E	INVERTER BUS NO 3 O/V-U/V	MDM OF3	Card-12	Channel-02			
V76X1706E	AC BUS 3 OVERLOAD	MDM OF3	Card-14	Channel-02			
V76X1737E	AC BUS 3 PHASE A INPUT ON	MDM OF3	Card-14	Channel-01			
V76X1738E	AC BUS 3 PHASE B INPUT ON	MDM OF3	Card-04	Channel-02			
V76X1739E	AC BUS 3 PHASE C INPUT ON	MDM OF3	Card-06	Channel-00			
V76X1804E	ARRAY 1 MN BUS A PWR TO INV PH A	MDM OF1	Card-12	Channel-01			
V76X1808E	ARRAY 1 MN BUS A PWR TO INV PH B	MDM OF1	Card-14	Channel-00			
V76X1812E	ARRAY 1 MN BUS A PWR TO INV PH C	MDM OF1	Card-12	Channel-00			
V76X1824E	ARRAY 2 MN BUS B PWR TO INV PH A	MDM OF2	Card-12	Channel-01			
V76X1828E	ARRAY 2 MN BUS B PWR TO INV PH B	MDM OF2	Card-14	Channel-00			
V76X1832E	ARRAY 2 MN BUS B PWR TO INV PH C	MDM OF2	Card-12	Channel-02			
V76X1844E	ARRAY 3 MN BUS C PWR TO INV PH A	MDM OF3	Card-06	Channel-00			
V76X1848E	ARRAY 3 MN BUS C PWR TO INV PH B	MDM OF3	Card-12	Channel-02			

6.1.5-20

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V76X1852E	ARRAY 3 MN BUS C PWR TO INV PH C	MDM OF3	Card-14	Channel-02			
V76X2111E	FWD MCA 1 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00			
V76X2112E	FWD MCA 1 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00			
V76X2113E	FWD MCA 1 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00			
V76X2114E	FWD MCA 1 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00			
V76X2121E	FWD MCA 2 OPERATIONAL STATUS 1	MDM OF2	Card-04	Channel-00			
V76X2122E	FWD MCA 2 OPERATIONAL STATUS 2	MDM OF2	Card-04	Channel-00			
V76X2123E	FWD MCA 2 OPERATIONAL STATUS 3	MDM OF2	Card-06	Channel-00			
V76X2124E	FWD MCA 2 OPERATIONAL STATUS 4	MDM OF2	Card-06	Channel-00			
V76X2131E	FWD MCA 3 OPERATIONAL STATUS 1	MDM OF3	Card-04	Channel-00			
V76X2132E	FWD MCA 3 OPERATIONAL STATUS 2	MDM OF3	Card-04	Channel-00			
V76X2133E	FWD MCA 3 OPERATIONAL STATUS 3	MDM OF3	Card-04	Channel-00			
V76X2134E	FWD MCA 3 OPERATIONAL STATUS 4	MDM OF3	Card-04	Channel-00			
V76X2161E	MID MCA 1 OPERATIONAL STATUS 9	MDM OF1	Card-14	Channel-02			
V76X2162E	MID MCA 1 OPERATIONAL STATUS 10	MDM OF1	Card-12	Channel-01			
V76X2171E	MID MCA 2 OPERATIONAL STATUS 9	MDM OA2	Card-05	Channel-02			
V76X2172E	MID MCA 2 OPERATIONAL STATUS 10	MDM OA2	Card-05	Channel-02			
V76X2173E	MID MCA 2 OPERATIONAL STATUS 11	MDM OA2	Card-07	Channel-02			
V76X2174E	MID MCA 2 OPERATIONAL STATUS 12	MDM OA2	Card-07	Channel-02			
V76X2181E	MID MCA 3 OPERATIONAL STATUS 9	MDM OA1	Card-12	Channel-02			
V76X2182E	MID MCA 3 OPERATIONAL STATUS 10	MDM OA1	Card-12	Channel-00			
V76X2183E	MID MCA 3 OPERATIONAL STATUS 11	MDM OA1	Card-12	Channel-02			
V76X2184E	MID MCA 3 OPERATIONAL STATUS 12	MDM OA1	Card-12	Channel-02			
V76X2191E	MID MCA 4 OPERATIONAL STATUS 9	MDM OA1	Card-05	Channel-00			
V76X2192E	MID MCA 4 OPERATIONAL STATUS 10	MDM OA1	Card-05	Channel-02			
V76X2193E	MID MCA 4 OPERATIONAL STATUS 11	MDM OA1	Card-05	Channel-00			
V76X2194E	MID MCA 4 OPERATIONAL STATUS 12	MDM OA1	Card-05	Channel-02			
V76X2211E	MID MCA 1 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00			
V76X2212E	MID MCA 1 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00			
V76X2213E	MID MCA 1 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00			
V76X2214E	MID MCA 1 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00			

6.1.5-21

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V76X2215E	MID MCA 1 OPERATIONAL STATUS 5	MDM OF2	Card-04	Channel-00			
V76X2216E	MID MCA 1 OPERATIONAL STATUS 6	MDM OF2	Card-04	Channel-00			
V76X2217E	MID MCA 1 OPERATIONAL STATUS 7	MDM OF2	Card-06	Channel-00			
V76X2218E	MID MCA 1 OPERATIONAL STATUS 7	MDM OF1	Card-05	Channel-01			
V76X2221E	MID MCA 2 OPERATIONAL STATUS 1	MDM OF1	Card-06	Channel-00			
V76X2222E	MID MCA 2 OPERATIONAL STATUS 2	MDM OF1	Card-06	Channel-00			
V76X2223E	MID MCA 2 OPERATIONAL STATUS 3	MDM OF3	Card-04	Channel-00			
V76X2224E	MID MCA 2 OPERATIONAL STATUS 4	MDM OF3	Card-04	Channel-00			
V76X2225E	MID MCA 2 OPERATIONAL STATUS 5	MDM OF3	Card-04	Channel-00			
V76X2226E	MID MCA 2 OPERATIONAL STATUS 6	MDM OF3	Card-04	Channel-00			
V76X2227E	MID MCA 2 OPERATIONAL STATUS 7	MDM OF3	Card-04	Channel-00			
V76X2228E	MID MCA 2 OPERATIONAL STATUS 8	MDM OF3	Card-04	Channel-00			
V76X2231E	MID MCA 3 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00			
V76X2232E	MID MCA 3 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00			
V76X2233E	MID MCA 3 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00			
V76X2234E	MID MCA 3 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00			
V76X2235E	MID MCA 3 OPERATIONAL STATUS 5	MDM OF2	Card-04	Channel-00			
V76X2236E	MID MCA 3 OPERATIONAL STATUS 6	MDM OF2	Card-04	Channel-00			
V76X2237E	MID MCA 3 OPERATIONAL STATUS 7	MDM OF2	Card-06	Channel-00			
V76X2238E	MID MCA 3 OPERATIONAL STATUS 8	MDM OF2	Card-06	Channel-00			
V76X2241E	MID MCA 4 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00			
V76X2242E	MID MCA 4 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00			
V76X2243E	MID MCA 4 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00			
V76X2244E	MID MCA 4 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00			
V76X2245E	MID MCA 4 OPERATIONAL STATUS 5	MDM OA2	Card-01	Channel-01			
V76X2246E	MID MCA 4 OPERATIONAL STATUS 6	MDM OA2	Card-01	Channel-01			
V76X2247E	MID MCA 4 OPERATIONAL STATUS 7	MDM OA2	Card-01	Channel-01			
V76X2248E	MID MCA 4 OPERATIONAL STATUS 8	MDM OA2	Card-01	Channel-01			
V76X2251E	AFT MCA 1 OPERATIONAL STATUS 1	MDM OA1	Card-01	Channel-00			
V76X2252E	AFT MCA 1 OPERATIONAL STATUS 2	MDM OA1	Card-10	Channel-00			
V76X2253E	AFT MCA 1 OPERATIONAL STATUS 3	MDM OA1	Card-07	Channel-00			

6.1.5-22

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (continued)**

V76X2254E	AFT MCA 1 OPERATIONAL STATUS 4	MDM OA1	Card-07	Channel-00			
V76X2261E	AFT MCA 2 OPERATIONAL STATUS 1	MDM OA2	Card-07	Channel-00			
V76X2262E	AFT MCA 2 OPERATIONAL STATUS 2	MDM OA2	Card-01	Channel-00			
V76X2263E	AFT MCA 2 OPERATIONAL STATUS 3	MDM OA2	Card-10	Channel-00			
V76X2264E	AFT MCA 2 OPERATIONAL STATUS 4	MDM OA2	Card-10	Channel-00			
V76X2271E	AFT MCA 3 OPERATIONAL STATUS 1	MDM OA3	Card-01	Channel-00			
V76X2272E	AFT MCA 3 OPERATIONAL STATUS 2	MDM OA3	Card-10	Channel-00			
V76X2273E	AFT MCA 3 OPERATIONAL STATUS 3	MDM OA3	Card-10	Channel-00			
V76X2274E	AFT MCA 3 OPERATIONAL STATUS 4	MDM OA3	Card-07	Channel-00			
V76X2810E	PAYLOAD AFT MAIN B PWR-ON	MDM OA2	Card-05	Channel-00			
V76X2821E	PAYLOAD AFT MAIN C PWR-ON	MDM OA3	Card-01	Channel-01			
V76X2833E	PAYLOAD PRIMARY MAIN B PWR-ON	MDM OF3	Card-04	Channel-00			
V76X2838E	PAYLOAD PRIMARY MAIN C PWR-ON	MDM OF3	Card-04	Channel-02			
V76X2843E	PAYLOAD PRIMARY FC 3 PWR-ON	MDM OF3	Card-04	Channel-01			
V76X2845E	PAYLOAD PRI FC3 STRUCTURE GROUNDED	MDM OF3	Card-14	Channel-02			
V76X2868E	PAYLOAD AUX RPC A ON	MDM OF1	Card-14	Channel-02			
V76X2869E	PAYLOAD AUX RPC B ON	MDM OF2	Card-14	Channel-02			
V76X4390E	PCA R SRB BUS C RPC A ON	MDM OA1	Card-05	Channel-01			
V76X4393E	PCA L SRB BUS C RPC C ON	MDM OA3	Card-12	Channel-02			
V76X4394E	PCA R SRB BUS C RPC C ON	MDM OA3	Card-12	Channel-02			
V76X4399E	PCA L SRB BUS C RPC A ON	MDM OA1	Card-01	Channel-02			
V76X4454E	PALLET MDCA 1 MOTOR SW CLOSE	MDM OF4	Card-02	Channel-01			
V76X4455E	PALLET MDCA 2 MOTOR SW CLOSE	MDM OF4	Card-10	Channel-01			
V76X4705E	AVN FEXT AV BAY 3A PYRO L/T	MDM OF1	Card-10	Channel-01	DSC OF1	Card-09	Channel-A
V76X4710E	AVN FEXT AV BAY 3A PYRO RTST	MDM OF1	Card-10	Channel-01	DSC OF1	Card-09	Channel-A
V76X4720E	AVN FEXT AV BAY 2 PYRO L/T	MDM OF3	Card-02	Channel-02	DSC OF3	Card-09	Channel-A
V76X4730E	AVN FEXT AV BAY 2 PYRO RTST	MDM OF3	Card-02	Channel-02	DSC OF3	Card-09	Channel-A
V76X4740E	AVN FEXT AV BAY 1 PYRO L/T	MDM OF2	Card-02	Channel-01	DSC OF2	Card-09	Channel-A
V76X4750E	AVN FEXT AV BAY 1 PYRO RTST	MDM OF2	Card-02	Channel-01	DSC OF2	Card-09	Channel-A
V76X4823E	NLG PYRO EXTEND ACTR-L/T-1	MDM OF3	Card-10	Channel-00	DSC OF3	Card-09	Channel-A

6.1.5-23

Verify that this is the correct version before use

**Table 6.1.5-1. MDM and DSC listing for EGIL parameters sorted by MSID (concluded)**

V76X4824E	NLG PYRO EXTEND ACTR-L/T-2	MDM OF2	Card-02	Channel-00	DSC OF3	Card-09	Channel-A
V76X4826E	NLG PYRO EXTEND ACTR-RTST-1	MDM OF3	Card-10	Channel-00	DSC OF3	Card-09	Channel-A
V76X4827E	NLG PYRO EXTEND ACTR-RTST-2	MDM OF2	Card-02	Channel-00	DSC OF3	Card-09	Channel-A
V76X4835E	NLG EMER EXT PYRO L/T-A	MDM OF3	Card-10	Channel-02	DSC OF3	Card-09	Channel-A
V76X4836E	NLG EMER EXT PYRO L/T-B	MDM OF2	Card-10	Channel-01	DSC OF2	Card-09	Channel-A
V76X4838E	NLG EMER EXT PYRO RTST-A	MDM OF3	Card-10	Channel-02	DSC OF3	Card-09	Channel-A
V76X4839E	NLG EMER EXT PYRO RTST-B	MDM OF2	Card-10	Channel-01	DSC OF2	Card-09	Channel-A
V76X4905E	LMG EMER EXT PYRO L/T-A	MDM OF3	Card-10	Channel-00	DSC OF3	Card-09	Channel-A
V76X4906E	LMG EMER EXT PYRO L/T-B	MDM OF2	Card-10	Channel-00	DSC OF2	Card-09	Channel-A
V76X4908E	LMG EMER EXT PYRO RTST-A	MDM OF3	Card-10	Channel-00	DSC OF3	Card-09	Channel-A
V76X4909E	LMG EMER EXT PYRO RTST-B	MDM OF2	Card-10	Channel-00	DSC OF2	Card-09	Channel-A
V76X4955E	RMG EMER EXT PYRO L/T-A	MDM OF3	Card-10	Channel-00	DSC OF3	Card-09	Channel-A
V76X4956E	RMG EMER EXT PYRO L/T-B	MDM OF2	Card-10	Channel-00	DSC OF2	Card-09	Channel-A
V76X4958E	RMG EMER EXT PYRO RTST-A	MDM OF3	Card-10	Channel-00	DSC OF3	Card-09	Channel-A
V76X4959E	RMG EMER EXT PYRO RTST-B	MDM OF2	Card-10	Channel-00	DSC OF2	Card-09	Channel-A
V76X6775E	L SRB BUS A BU PWR ON	MDM OA1	Card-05	Channel-02			
V76X6776E	R SRB BUS A BU PWR ON	MDM OA1	Card-05	Channel-02			
V76X6777E	L SRB BUS B BU PWR ON	MDM OA2	Card-05	Channel-02			
V76X6778E	R SRB BUS B BU PWR ON	MDM OA2	Card-05	Channel-02			
V76X6930E	ORB/ET FWD SEP PYRO L/T A	MDM OF1	Card-10	Channel-01	DSC OF1	Card-09	Channel-A
V76X6931E	ORB/ET FWD SEP PYRO L/T B	MDM OF2	Card-02	Channel-01	DSC OF2	Card-09	Channel-A
V76X6932E	ORB/ET FWD SEP PYRO RTST A	MDM OF1	Card-10	Channel-01	DSC OF1	Card-09	Channel-A
V76X6933E	ORB/ET FWD SEP PYRO RTST B	MDM OF2	Card-02	Channel-01	DSC OF2	Card-09	Channel-A

6.1.5-24

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**TITLE**

EGIL MDM LOSS TABLE

Table 6.1.6-1 lists only MDM information and is sorted by MDM card and channel.

This information is effective for STS-95 and subsequent flights using OI-26B flight software.

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM**

V76K6941X	L SRB BUS C RPC A ON CMD	MDM FA4	Card-07	Channel-00
V76K6942X	R SRB BUS C RPC A ON CMD	MDM FA4	Card-12	Channel-00
B76V1600C	LH VOLTAGE OPERATIONAL BUS A	MDM LL1	Card-03	Channel-05
B76V1601C	LH VOLTAGE OPERATIONAL BUS B	MDM LL1	Card-07	Channel-08
B76V2600C	RH VOLTAGE OPERATIONAL BUS A	MDM LR1	Card-03	Channel-05
B76V2601C	RH VOLTAGE OPERATIONAL BUS B	MDM LR1	Card-07	Channel-08
V76X2251E	AFT MCA 1 OPERATIONAL STATUS 1	MDM OA1	Card-01	Channel-00
V45X1306E	PRSD O2 TK 3 HTR A1-ON (MBK)	MDM OA1	Card-01	Channel-01
V45X1313E	PRSD O2 TK 3 HTR B2-ON (MBK)	MDM OA1	Card-01	Channel-02
V76X4399E	PCA L SRB BUS C RPC A ON	MDM OA1	Card-01	Channel-02
V76V3091A	AFT PCA-4 VOLTAGE	MDM OA1	Card-02	Channel-28
V45X3144E	PRSD O2 TK 6 VENT VALVE CLOSE	MDM OA1	Card-03	Channel-01
V45X3145E	PRSD O2 TK 6 FILL VALVE CLOSE	MDM OA1	Card-03	Channel-01
V45X3244E	PRSD O2 TK 7 VENT VALVE CLOSE	MDM OA1	Card-03	Channel-01
V45X3245E	PRSD O2 TK 7 FILL VALVE CLOSE	MDM OA1	Card-03	Channel-01
V45X3108E	PRSD O2 TK 6 HTR B1-ON	MDM OA1	Card-03	Channel-02
V45X3113E	PRSD O2 TK 6 HTR B2-ON	MDM OA1	Card-03	Channel-02
V45X3186E	PRSD O2 TK 6 HTR CUR SNSR 2A-TRIP	MDM OA1	Card-03	Channel-02
V45X3188E	PRSD O2 TK 6 HTR CUR SNSR 2B-TRIP	MDM OA1	Card-03	Channel-02
V45X4108E	PRSD H2 TK 6 HTR B-ON	MDM OA1	Card-03	Channel-02
V45X1385E	PRSD O2 TK 3 HTR CUR SNSR 1A-TRIP	MDM OA1	Card-05	Channel-00
V76X2191E	MID MCA 4 OPERATIONAL STATUS 9	MDM OA1	Card-05	Channel-00
V76X2193E	MID MCA 4 OPERATIONAL STATUS 11	MDM OA1	Card-05	Channel-00
V45X2306E	PRSD H2 TK 3 HTR A-ON (MBK)	MDM OA1	Card-05	Channel-01
V76X4390E	PCA R SRB BUS C RPC A ON	MDM OA1	Card-05	Channel-01
V76X2192E	MID MCA 4 OPERATIONAL STATUS 10	MDM OA1	Card-05	Channel-02
V76X2194E	MID MCA 4 OPERATIONAL STATUS 12	MDM OA1	Card-05	Channel-02
V76X6775E	L SRB BUS A BU PWR ON	MDM OA1	Card-05	Channel-02
V76X6776E	R SRB BUS A BU PWR ON	MDM OA1	Card-05	Channel-02
V76C3095A	AFT PCA MAIN BUS A AMPS	MDM OA1	Card-06	Channel-15
V76X2253E	AFT MCA 1 OPERATIONAL STATUS 3	MDM OA1	Card-07	Channel-00
V76X2254E	AFT MCA 1 OPERATIONAL STATUS 4	MDM OA1	Card-07	Channel-00
V45X1308E	PRSD O2 TK 3 HTR B1-ON (MBK)	MDM OA1	Card-07	Channel-01
V45X1386E	PRSD O2 TK 3 HTR CUR SNSR 2A-TRIP	MDM OA1	Card-07	Channel-01
V45S0900E	PRSD HEATER A 3A/4A ON	MDM OA1	Card-08	Channel-02
V45X1506E	PRSD O2 TK 5 HTR A1-ON	MDM OA1	Card-08	Channel-02
V45X1511E	PRSD O2 TK 5 HTR A2-ON	MDM OA1	Card-08	Channel-02
V45X1585E	PRSD O2 TK 5 HTR CUR SNSR 1A-TRIP	MDM OA1	Card-08	Channel-02
V45X1587E	PRSD O2 TK 5 HTR CUR SNSR 1B-TRIP	MDM OA1	Card-08	Channel-02
V45X2506E	PRSD H2 TK 5 HTR A-ON	MDM OA1	Card-08	Channel-02
V45X3206E	PRSD O2 TK 7 HTR A1-ON	MDM OA1	Card-08	Channel-02
V45X3211E	PRSD O2 TK 7 HTR A2-ON	MDM OA1	Card-08	Channel-02

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45X3285E	PRSD O2 TK 7 HTR CUR SNSR 1A-TRIP	MDM	OA1	Card-08	Channel-02
V45X3287E	PRSD O2 TK 7 HTR CUR SNSR 1B-TRIP	MDM	OA1	Card-08	Channel-02
V45X4206E	PRSD H2 TK 7 HTR A-ON	MDM	OA1	Card-08	Channel-02
V45P3310A	PRSD O2 TK 8 HTR CONT PRESS	MDM	OA1	Card-09	Channel-05
V45P4310A	PRSD H2 TK 8 HTR CONT PRESS	MDM	OA1	Card-09	Channel-21
V76X2252E	AFT MCA 1 OPERATIONAL STATUS 2	MDM	OA1	Card-10	Channel-00
V45X2308E	PRSD H2 TK 3 HTR B-ON (MBK)	MDM	OA1	Card-10	Channel-01
V45X1387E	PRSD O2 TK 3 HTR CUR SNSR 1B-TRIP	MDM	OA1	Card-10	Channel-02
V45X1388E	PRSD O2 TK 3 HTR CUR SNSR 2B-TRIP	MDM	OA1	Card-12	Channel-00
V76X2182E	MID MCA 3 OPERATIONAL STATUS 10	MDM	OA1	Card-12	Channel-00
V45X1311E	PRSD O2 TK 3 HTR A2-ON (MBK)	MDM	OA1	Card-12	Channel-01
V76X2181E	MID MCA 3 OPERATIONAL STATUS 9	MDM	OA1	Card-12	Channel-02
V76X2183E	MID MCA 3 OPERATIONAL STATUS 11	MDM	OA1	Card-12	Channel-02
V76X2184E	MID MCA 3 OPERATIONAL STATUS 12	MDM	OA1	Card-12	Channel-02
V45T0282A	FCP NO 2 ALT PRODUCT H2O LINE TEMP	MDM	OA1	Card-13	Channel-27
V45X4144E	PRSD H2 TK 6 VENT VALVE CLOSE	MDM	OA1	Card-14	Channel-00
V45X4145E	PRSD H2 TK 6 FILL VALVE CLOSE	MDM	OA1	Card-14	Channel-00
V45X4244E	PRSD H2 TK 7 VENT VALVE CLOSE	MDM	OA1	Card-14	Channel-00
V45X4245E	PRSD H2 TK 7 FILL VALVE CLOSE	MDM	OA1	Card-14	Channel-00
V76X2262E	AFT MCA 2 OPERATIONAL STATUS 2	MDM	OA2	Card-01	Channel-00
V45X1406E	PRSD O2 TK 4 HTR A1-ON (MBK)	MDM	OA2	Card-01	Channel-01
V76X2245E	MID MCA 4 OPERATIONAL STATUS 5	MDM	OA2	Card-01	Channel-01
V76X2246E	MID MCA 4 OPERATIONAL STATUS 6	MDM	OA2	Card-01	Channel-01
V76X2247E	MID MCA 4 OPERATIONAL STATUS 7	MDM	OA2	Card-01	Channel-01
V76X2248E	MID MCA 4 OPERATIONAL STATUS 8	MDM	OA2	Card-01	Channel-01
V45X1486E	PRSD O2 TK 4 HTR CUR SNSR 2A-TRIP	MDM	OA2	Card-01	Channel-02
V76V3092A	AFT PCA-5 VOLTAGE	MDM	OA2	Card-02	Channel-08
V76C2811A	PAYLOAD AFT MAIN B CURRENT	MDM	OA2	Card-02	Channel-17
V45X3208E	PRSD O2 TK 7 HTR B1-ON	MDM	OA2	Card-03	Channel-02
V45X3213E	PRSD O2 TK 7 HTR B2-ON	MDM	OA2	Card-03	Channel-02
V45X3286E	PRSD O2 TK 7 HTR CUR SNSR 2A-TRIP	MDM	OA2	Card-03	Channel-02
V45X3288E	PRSD O2 TK 7 HTR CUR SNSR 2B-TRIP	MDM	OA2	Card-03	Channel-02
V45X3308E	PRSD O2 TK 8 HTR B1-ON	MDM	OA2	Card-03	Channel-02
V45X3313E	PRSD O2 TK 8 HTR B2-ON	MDM	OA2	Card-03	Channel-02
V45X3386E	PRSD O2 TK 8 HTR CUR SNSR 2A-TRIP	MDM	OA2	Card-03	Channel-02
V45X3388E	PRSD O2 TK 8 HTR CUR SNSR 2B-TRIP	MDM	OA2	Card-03	Channel-02
V45X4208E	PRSD H2 TK 7 HTR B-ON	MDM	OA2	Card-03	Channel-02
V45X4308E	PRSD H2 TK 8 HTR B-ON	MDM	OA2	Card-03	Channel-02
V45T0699A	FCP H2 VENT LINE TEMP 1	MDM	OA2	Card-04	Channel-05
V45X1487E	PRSD O2 TK 4/5 HTR CUR SNSR 1B/1A	MDM	OA2	Card-05	Channel-00
V76X2810E	PAYLOAD AFT MAIN B PWR-ON	MDM	OA2	Card-05	Channel-00
V45S0280E	FCP NO 2 CONTROL POWER	MDM	OA2	Card-05	Channel-01
V45X1408E	PRSD O2 TK 4/5 HTR B1/A1-ON	MDM	OA2	Card-05	Channel-01



**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V76X2171E	MID MCA 2 OPERATIONAL STATUS 9	MDM OA2	Card-05	Channel-02
V76X2172E	MID MCA 2 OPERATIONAL STATUS 10	MDM OA2	Card-05	Channel-02
V76X6777E	L SRB BUS B BU PWR ON	MDM OA2	Card-05	Channel-02
V76X6778E	R SRB BUS B BU PWR ON	MDM OA2	Card-05	Channel-02
V76C3096A	AFT PCA MAIN BUS B AMPS	MDM OA2	Card-06	Channel-15
V76X2261E	AFT MCA 2 OPERATIONAL STATUS 1	MDM OA2	Card-07	Channel-00
V45X1488E	PRSD O2 TK 4/5 HTR CUR SNSR 2B/2A	MDM OA2	Card-07	Channel-01
V45X1411E	PRSD O2 TK 4 HTR A2-ON (MBK)	MDM OA2	Card-07	Channel-02
V76X2173E	MID MCA 2 OPERATIONAL STATUS 11	MDM OA2	Card-07	Channel-02
V76X2174E	MID MCA 2 OPERATIONAL STATUS 12	MDM OA2	Card-07	Channel-02
V45S0901E	PRSD HEATER B 3B/4B ON	MDM OA2	Card-08	Channel-02
V45X3408E	PRSD O2 TK 9 HTR B1-ON	MDM OA2	Card-08	Channel-02
V45X3413E	PRSD O2 TK 9 HTR B2-ON	MDM OA2	Card-08	Channel-02
V45X3486E	PRSD O2 TK 9 HTR CUR SNSR 2A-TRIP	MDM OA2	Card-08	Channel-02
V45X3488E	PRSD O2 TK 9 HTR CUR SNSR 2B-TRIP	MDM OA2	Card-08	Channel-02
V45X4408E	PRSD H2 TK 9 HTR B-ON	MDM OA2	Card-08	Channel-02
V76X2263E	AFT MCA 2 OPERATIONAL STATUS 3	MDM OA2	Card-10	Channel-00
V76X2264E	AFT MCA 2 OPERATIONAL STATUS 4	MDM OA2	Card-10	Channel-00
V45X1413E	PRSD O2 TK 4/5 HTR B2/A2-ON	MDM OA2	Card-10	Channel-01
V45X2456E	PRSD H2 TK 4(&5) HTR A-ON	MDM OA2	Card-10	Channel-01
V45X2458E	PRSD H2 TK 4(&5) HTR B-ON	MDM OA2	Card-12	Channel-00
V45X1485E	PRSD O2 TK 4 HTR CUR SNSR 1A-TRIP	MDM OA2	Card-12	Channel-02
V45T0382A	FCP NO 3 ALT PRODUCT H2O LINE TEMP	MDM OA2	Card-13	Channel-27
V45P3410A	PRSD O2 TK 9 HTR CONT PRESS	MDM OA3	Card-00	Channel-25
V45P4410A	PRSD H2 TK 9 HTR CONT PRESS	MDM OA3	Card-00	Channel-29
V76X2271E	AFT MCA 3 OPERATIONAL STATUS 1	MDM OA3	Card-01	Channel-00
V76X2821E	PAYLOAD AFT MAIN C PWR-ON	MDM OA3	Card-01	Channel-01
V76V3093A	AFT PCA-6 VOLTAGE	MDM OA3	Card-02	Channel-16
V76C2822A	PAYLOAD AFT MAIN C CURRENT	MDM OA3	Card-02	Channel-23
V45X1393E	PRSD O2 TK 3 ISO VENT VALVE CLOSE	MDM OA3	Card-03	Channel-01
V45X1394E	PRSD O2 TK 3 ISO FILL VALVE CLOSE	MDM OA3	Card-03	Channel-01
V45X3344E	PRSD O2 TK 8 VENT VALVE CLOSE	MDM OA3	Card-03	Channel-01
V45X3345E	PRSD O2 TK 8 FILL VALVE CLOSE	MDM OA3	Card-03	Channel-01
V45X3444E	PRSD O2 TK 9 VENT VALVE CLOSE	MDM OA3	Card-03	Channel-01
V45X3445E	PRSD O2 TK 9 FILL VALVE CLOSE	MDM OA3	Card-03	Channel-01
V45X3106E	PRSD O2 TK 6 HTR A1-ON	MDM OA3	Card-03	Channel-02
V45X3111E	PRSD O2 TK 6 HTR A2-ON	MDM OA3	Card-03	Channel-02
V45X3185E	PRSD O2 TK 6 HTR CUR SNSR 1A-TRIP	MDM OA3	Card-03	Channel-02
V45X3187E	PRSD O2 TK 6 HTR CUR SNSR 1B-TRIP	MDM OA3	Card-03	Channel-02
V45X3306E	PRSD O2 TK 8 HTR A1-ON	MDM OA3	Card-03	Channel-02
V45X3311E	PRSD O2 TK 8 HTR A2-ON	MDM OA3	Card-03	Channel-02
V45X3385E	PRSD O2 TK 8 HTR CUR SNSR 1A-TRIP	MDM OA3	Card-03	Channel-02
V45X3387E	PRSD O2 TK 8 HTR CUR SNSR 1B-TRIP	MDM OA3	Card-03	Channel-02

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45X4106E	PRSD H2 TK 6 HTR A-ON	MDM OA3	Card-03	Channel-02
V45X4306E	PRSD H2 TK 8 HTR A-ON	MDM OA3	Card-03	Channel-02
V75X2185E	PALLET DSC 2 BITE	MDM OA3	Card-03	Channel-02
V76C3097A	AFT PCA MAIN BUS C AMPS	MDM OA3	Card-06	Channel-25
V76X2274E	AFT MCA 3 OPERATIONAL STATUS 4	MDM OA3	Card-07	Channel-00
V45X1508E	PRSD O2 TK 5 HTR B1-ON	MDM OA3	Card-08	Channel-02
V45X1513E	PRSD O2 TK 5 HTR B2-ON	MDM OA3	Card-08	Channel-02
V45X1586E	PRSD O2 TK 5 HTR CUR SNSR 2A -TRIP	MDM OA3	Card-08	Channel-02
V45X1588E	PRSD O2 TK 5 HTR CUR SNSR 2B -TRIP	MDM OA3	Card-08	Channel-02
V45X2508E	PRSD H2 TK 5 HTR B-ON	MDM OA3	Card-08	Channel-02
V45X3406E	PRSD O2 TK 9 HTR A1-ON	MDM OA3	Card-08	Channel-02
V45X3411E	PRSD O2 TK 9 HTR A2-ON	MDM OA3	Card-08	Channel-02
V45X3485E	PRSD O2 TK 9 HTR CUR SNSR 1A -TRIP	MDM OA3	Card-08	Channel-02
V45X3487E	PRSD O2 TK 9 HTR CUR SNSR 1B -TRIP	MDM OA3	Card-08	Channel-02
V45X4406E	PRSD H2 TK 9 HTR A-ON	MDM OA3	Card-08	Channel-02
V76X2272E	AFT MCA 3 OPERATIONAL STATUS 2	MDM OA3	Card-10	Channel-00
V76X2273E	AFT MCA 3 OPERATIONAL STATUS 3	MDM OA3	Card-10	Channel-00
V76X4393E	PCA L SRB BUS C RPC C ON	MDM OA3	Card-12	Channel-02
V76X4394E	PCA R SRB BUS C RPC C ON	MDM OA3	Card-12	Channel-02
V45X2343E	PRSD H2 TK 3 ISO VENT VALVE CLOSE	MDM OA3	Card-14	Channel-00
V45X2344E	PRSD H2 TK 3 ISO FILL VALVE CLOSE	MDM OA3	Card-14	Channel-00
V45X4344E	PRSD H2 TK 8 VENT VALVE CLOSE	MDM OA3	Card-14	Channel-00
V45X4345E	PRSD H2 TK 8 FILL VALVE CLOSE	MDM OA3	Card-14	Channel-00
V45X4444E	PRSD H2 TK 9 VENT VALVE CLOSE	MDM OA3	Card-14	Channel-00
V45X4445E	PRSD H2 TK 9 FILL VALVE CLOSE	MDM OA3	Card-14	Channel-00
V45X0462E	FUEL CELL H2O CONDUCTIVITY	MDM OA3	Card-14	Channel-01
V45T0130A	FUEL CELL NO 1 CONDENSER EXIT TEMP	MDM OF1	Card-01	Channel-04
V45P0147A	FUEL CELL 1 COOLANT PRESSURE	MDM OF1	Card-01	Channel-05
V45T1307A	PRSD O2 TK 3 HTR ASSY 1 TEMP(MBK)	MDM OF1	Card-01	Channel-06
V45T2301A	PRSD H2 TK 3 FLUID TEMP (MBK)	MDM OF1	Card-01	Channel-07
V76V0120A	CONTROL BUS AB1 VOLTAGE	MDM OF1	Card-01	Channel-08
V62Q0628A	SMOKE DETECTOR CONC N A -AV BAY 3	MDM OF1	Card-01	Channel-10
V45Q2205A	PRSD H2 TK 2 QUANTITY	MDM OF1	Card-01	Channel-15
V45P2300A	PRSD H2 TK 3 PRESS (MID BODY KIT)	MDM OF1	Card-01	Channel-18
V45V0202A	FCP NO 2 SUBSTACK 1 DELTA VOLTAGE	MDM OF1	Card-01	Channel-24
V45V0203A	FCP NO 2 SUBSTACK 2 DELTA VOLTAGE	MDM OF1	Card-01	Channel-27
V45V0204A	FCP NO 2 SUBSTACK 3 DELTA VOLTAGE	MDM OF1	Card-01	Channel-29
V45X0410E	FUEL CELL NO 1 H2O CONDITION	MDM OF1	Card-02	Channel-00
V64C0211A	EXTRA VEHICULAR LSS BAT CHG CUR 1	MDM OF1	Card-03	Channel-00
V64C0214A	EXTRA VEHICULAR LSS BAT CHG CUR 2	MDM OF1	Card-03	Channel-01
V45P1140A	PRSD O2 MANF 1 PRESSURE	MDM OF1	Card-03	Channel-04
V62Q0595A	SMOKE DETR CONC N RTN AIR -CAB HX	MDM OF1	Card-03	Channel-08
V76V0121A	CONTROL BUS AB2 VOLTAGE	MDM OF1	Card-03	Channel-09

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45Q1105A	PRSD O2 TK 1 QUANTITY	MDM OF1	Card-03	Channel-13
V45P1410A	PRSD O2 TK 4(&5) HTR CONT PRESS	MDM OF1	Card-03	Channel-18
V45P1500A	PRSD O2 TK 5 PRESS (MID BODY KIT)	MDM OF1	Card-03	Channel-20
V45P2500A	PRSD H2 TK 5 PRESS (MID BODY KIT)	MDM OF1	Card-03	Channel-21
V45P1504A	PRSD O2 TK 5 ANNULUS VACUUM (MBK)	MDM OF1	Card-03	Channel-22
V45P2504A	PRSD H2 TK 5 ANNULUS VACUUM (MBK)	MDM OF1	Card-03	Channel-23
V76X2111E	FWD MCA 1 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00
V76X2112E	FWD MCA 1 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00
V76X2211E	MID MCA 1 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00
V76X2212E	MID MCA 1 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00
V76X2231E	MID MCA 3 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00
V76X2232E	MID MCA 3 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00
V76X2241E	MID MCA 4 OPERATIONAL STATUS 1	MDM OF1	Card-04	Channel-00
V76X2242E	MID MCA 4 OPERATIONAL STATUS 2	MDM OF1	Card-04	Channel-00
V76X0124E	MAIN BUS A CONT BUS AB1/CA1 RPC ON	MDM OF1	Card-04	Channel-01
V76X1505E	INVERTER BUS NO 1 O/V-U/V	MDM OF1	Card-04	Channel-01
V45X1108E	PRSD O2 TK 1 HTR B1-ON	MDM OF1	Card-04	Channel-02
V76X0136E	MAIN BUS A ESS 2CA RPC ON	MDM OF1	Card-04	Channel-02
V76X1537E	AC BUS 1 PHASE A INPUT ON	MDM OF1	Card-04	Channel-02
V76X2218E	MID MCA 1 OPERATIONAL STATUS 7	MDM OF1	Card-05	Channel-01
V45T0120A	FUEL CELL NO 1 STACK COOL OUT TEMP	MDM OF1	Card-05	Channel-03
V45T0345A	FUEL CELL NO 3 COOLANT RETURN TEMP	MDM OF1	Card-05	Channel-05
V45P2515A	PRSD H2 TK 5 HTR CONT SNSR C/O	MDM OF1	Card-05	Channel-06
V45P1110A	PRSD O2 TK 1 HTR CONTROL PRESS	MDM OF1	Card-05	Channel-07
V62Q0608A	SMOKE DETECTOR CONC N A -AV BAY 2	MDM OF1	Card-05	Channel-09
V76V0122A	CONTROL BUS AB3 VOLTAGE	MDM OF1	Card-05	Channel-10
V45P1100A	PRSD O2 TK 1 PRESSURE	MDM OF1	Card-05	Channel-12
V64V0213A	EXTRA VEHICULAR LSS BAT CHG VOLT 2	MDM OF1	Card-05	Channel-13
V45P3110A	PRSD O2 TK 6 HTR CONT PRESS	MDM OF1	Card-05	Channel-28
V45P4110A	PRSD H2 TK 6 HTR CONT PRESS	MDM OF1	Card-05	Channel-29
V76X2113E	FWD MCA 1 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00
V76X2114E	FWD MCA 1 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00
V76X2213E	MID MCA 1 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00
V76X2214E	MID MCA 1 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00
V76X2221E	MID MCA 2 OPERATIONAL STATUS 1	MDM OF1	Card-06	Channel-00
V76X2222E	MID MCA 2 OPERATIONAL STATUS 2	MDM OF1	Card-06	Channel-00
V76X2233E	MID MCA 3 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00
V76X2234E	MID MCA 3 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00
V76X2243E	MID MCA 4 OPERATIONAL STATUS 3	MDM OF1	Card-06	Channel-00
V76X2244E	MID MCA 4 OPERATIONAL STATUS 4	MDM OF1	Card-06	Channel-00
V45X1113E	PRSD O2 TK 1 HTR B2-ON	MDM OF1	Card-06	Channel-01
V76X0125E	MAIN BUS A CONT BUS AB2/CA2 RPC ON	MDM OF1	Card-06	Channel-01
V76X1538E	AC BUS 1 PHASE B INPUT ON	MDM OF1	Card-06	Channel-01

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45X1111E	PRSD O2 TK 1 HTR A2-ON	MDM	OF1	Card-06	Channel-02
V76X0155E	FUEL CELL H2/O2 PGE HTR-RPC A ON	MDM	OF1	Card-06	Channel-02
V76X1506E	AC BUS 1 OVERLOAD	MDM	OF1	Card-06	Channel-02
V76V1500A	AC BUS 1 PHASE A VOLT	MDM	OF1	Card-07	Channel-01
V76C3075A	FWD PCA MAIN BUS A AMPS	MDM	OF1	Card-07	Channel-04
V45V0100A	FUEL CELL NO 1 VOLTAGE	MDM	OF1	Card-07	Channel-05
V45R0170A	FUEL CELL NO 1 H2 FLOW	MDM	OF1	Card-07	Channel-07
V76C1542A	AC BUS 1 PHASE C CURRENT	MDM	OF1	Card-07	Channel-08
V76C1540A	AC BUS 1 PHASE A CURRENT	MDM	OF1	Card-07	Channel-09
V76V4700A	AVN FEXT AV BAY 3A PYRO CAP VOLT	MDM	OF1	Card-07	Channel-22
V45P2510A	PRSD H2 TK 5 HTR CONT PRESS	MDM	OF1	Card-09	Channel-01
V45T1107A	PRSD O2 TK 1 HTR ASSY 1 TEMP	MDM	OF1	Card-09	Channel-04
V45T0181A	FCP NO 1 PRODUCT H2O LINE TEMP	MDM	OF1	Card-09	Channel-05
V64V0210A	EXTRA VEHICULAR LSS BAT CHG VOLT 1	MDM	OF1	Card-09	Channel-12
V45P2100A	PRSD H2 TK1 PRESSURE	MDM	OF1	Card-09	Channel-13
V45P1400A	PRSD O2 TK 4 PRESS (MID BODY KIT)	MDM	OF1	Card-09	Channel-26
V76X4705E	AVN FEXT AV BAY 3A PYRO L/T	MDM	OF1	Card-10	Channel-01
V76X4710E	AVN FEXT AV BAY 3A PYRO RTST	MDM	OF1	Card-10	Channel-01
V76X6930E	ORB/ET FWD SEP PYRO L/T A	MDM	OF1	Card-10	Channel-01
V76X6932E	ORB/ET FWD SEP PYRO RTST A	MDM	OF1	Card-10	Channel-01
V76V0300A	MAIN BUS C VOLTAGE	MDM	OF1	Card-11	Channel-00
V76C3085A	MID PCA MAIN BUS A AMPS	MDM	OF1	Card-11	Channel-01
V76V1501A	AC BUS 1 PHASE B VOLT	MDM	OF1	Card-11	Channel-03
V76V1502A	AC BUS 1 PHASE C VOLT	MDM	OF1	Card-11	Channel-04
V45R0160A	FUEL CELL NO 1 O2 FLOW	MDM	OF1	Card-11	Channel-05
V76C1541A	AC BUS 1 PHASE B CURRENT	MDM	OF1	Card-11	Channel-06
V76V3071A	FWD PCA-1 VOLTAGE	MDM	OF1	Card-11	Channel-20
V45X1106E	PRSD O2 TK 1 HTR A1-ON	MDM	OF1	Card-12	Channel-00
V45X1185E	PRSD O2 TK 1 HTR CUR SNSR 1A -TRIP	MDM	OF1	Card-12	Channel-00
V45X1188E	PRSD O2 TK 1 HTR CUR SNSR 2B -TRIP	MDM	OF1	Card-12	Channel-00
V76S1503E	AC BUS 1 VOLTAGE SENSOR AUTO	MDM	OF1	Card-12	Channel-00
V76X1812E	ARRAY 1 MN BUS A PWR TO INV PH C	MDM	OF1	Card-12	Channel-00
V45X1195E	PRSD O2 GAS SPLY VLV-CLOSED	MDM	OF1	Card-12	Channel-01
V76X1804E	ARRAY 1 MN BUS A PWR TO INV PH A	MDM	OF1	Card-12	Channel-01
V76X2162E	MID MCA 1 OPERATIONAL STATUS 10	MDM	OF1	Card-12	Channel-01
V45X1187E	PRSD O2 TK 1 HTR CUR SNSR 1B -TRIP	MDM	OF1	Card-12	Channel-02
V45X2108E	PRSD H2 TK 1 HEATER B-ON	MDM	OF1	Card-12	Channel-02
V76X0126E	MAIN BUS A CONT BUS AB3/CA3 RPC ON	MDM	OF1	Card-12	Channel-02
V76X1539E	AC BUS 1 PHASE C INPUT ON	MDM	OF1	Card-12	Channel-02
V45T2107A	PRSD H2 TK 1 HTR ASSY TEMP	MDM	OF1	Card-13	Channel-04
V45T0313A	FUEL CELL NO 3 STACK INLET TEMP	MDM	OF1	Card-13	Channel-05
V76V0330A	ESS BUS 3AB VOLTAGE	MDM	OF1	Card-13	Channel-06
V45T0412A	FC NO 1 H2O RELIEF VALVE TEMP	MDM	OF1	Card-13	Channel-08

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45P2310A	PRSD H2 TK 3 HTR CONT PRESS (MBK)	MDM	OF1	Card-13	Channel-09
V45V0314A	FCP NO 3 H2 PUMP MTR CONDITION	MDM	OF1	Card-13	Channel-11
V45P1115A	PRSD O2 TK 1 HTR CTRL SNSR C/O	MDM	OF1	Card-13	Channel-15
V45X1186E	PRSD O2 TK 1 HTR CUR SNSR 2A-TRIP	MDM	OF1	Card-14	Channel-00
V76X1808E	ARRAY 1 MN BUS A PWR TO INV PH B	MDM	OF1	Card-14	Channel-00
V76S1504E	AC BUS 1 VOLTAGE SENSOR MONITOR	MDM	OF1	Card-14	Channel-01
V45S0180E	FCP NO 1 CONTROL POWER	MDM	OF1	Card-14	Channel-02
V45X2106E	PRSD H2 TK 1 HEATER A-ON	MDM	OF1	Card-14	Channel-02
V62S0812E	FIRE SUPPRESSION AV BAY 3 ARM	MDM	OF1	Card-14	Channel-02
V76X0135E	MAIN BUS A ESS 3AB RPC ON	MDM	OF1	Card-14	Channel-02
V76X2161E	MID MCA 1 OPERATIONAL STATUS 9	MDM	OF1	Card-14	Channel-02
V76X2868E	PAYLOAD AUX RPC A ON	MDM	OF1	Card-14	Channel-02
V45T0145A	FUEL CELL NO 1 COOLANT RETURN TE MP	MDM	OF2	Card-01	Channel-00
V45T1507A	PRSD O2 TK 5 HTR ASSY 1 TEMP(MBK)	MDM	OF2	Card-01	Channel-03
V62Q0591A	SMOKE DET CONC N RIGHT -FLIGHT DECK	MDM	OF2	Card-01	Channel-04
V76V0222A	CONTROL BUS BC3 VOLTAGE	MDM	OF2	Card-01	Channel-06
V45T0455A	FCP H2O RELIEF NOZZLE TEMP A	MDM	OF2	Card-01	Channel-07
V45P3100A	PRSD O2 TK 6 PRESS	MDM	OF2	Card-01	Channel-20
V45P3300A	PRSD O2 TK 8 PRESS	MDM	OF2	Card-01	Channel-21
V45P4100A	PRSD H2 TK 6 PRESS	MDM	OF2	Card-01	Channel-22
V45P4300A	PRSD H2 TK 8 PRESS	MDM	OF2	Card-01	Channel-23
V45X0420E	FUEL CELL NO 2 H2O CONDITION	MDM	OF2	Card-02	Channel-00
V76X4824E	NLG PYRO EXTEND ACTR-L/T-2	MDM	OF2	Card-02	Channel-00
V76X4827E	NLG PYRO EXTEND ACTR-RTST-2	MDM	OF2	Card-02	Channel-00
V76X4740E	AVN FEXT AV BAY 1 PYRO L/T	MDM	OF2	Card-02	Channel-01
V76X4750E	AVN FEXT AV BAY 1 PYRO RTST	MDM	OF2	Card-02	Channel-01
V76X6931E	ORB/ET FWD SEP PYRO L/T B	MDM	OF2	Card-02	Channel-01
V76X6933E	ORB/ET FWD SEP PYRO RTST B	MDM	OF2	Card-02	Channel-01
V45P2145A	PRSD H2 MANF 2 PRESSURE	MDM	OF2	Card-03	Channel-00
V45T0230A	FUEL CELL NO 2 CONDENSER EXIT TEMP	MDM	OF2	Card-03	Channel-01
V45P0247A	FUEL CELL 2 COOLANT PRESSURE	MDM	OF2	Card-03	Channel-02
V45T2501A	PRSD H2 TK 5 FLUID TEMP (MBK)	MDM	OF2	Card-03	Channel-03
V76V0220A	CONTROL BUS BC1 VOLTAGE	MDM	OF2	Card-03	Channel-04
V62Q0618A	SMOKE DETECTOR CONC N A-AV BAY 1	MDM	OF2	Card-03	Channel-05
V45P2110A	PRSD H2 TK 1 HTR CONTROL PRESS	MDM	OF2	Card-03	Channel-07
V45P2115A	PRSD H2 TK 1 HTR CTRL SNSR C/O	MDM	OF2	Card-03	Channel-09
V45T3107A	PRSD O2 TK 6 HTR ASSY 1 TEMP	MDM	OF2	Card-03	Channel-17
V45T3409A	PRSD O2 TK 9 HTR ASSY 2 TEMP	MDM	OF2	Card-03	Channel-18
V45Q3105A	PRSD O2 TK 6 QUANTITY	MDM	OF2	Card-03	Channel-20
V45Q3305A	PRSD O2 TK 8 QUANTITY	MDM	OF2	Card-03	Channel-21
V45Q4105A	PRSD H2 TK 6 QUANTITY	MDM	OF2	Card-03	Channel-22
V45Q4305A	PRSD H2 TK 8 QUANTITY	MDM	OF2	Card-03	Channel-23
V45P3215A	PRSD O2 TK 7 HTR CONT SNSR C/O	MDM	OF2	Card-03	Channel-24

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45P3415A	PRSD O2 TK 9 HTR CONT SNSR C/O	MDM	OF2	Card-03	Channel-25
V45P4215A	PRSD H2 TK 7 HTR CONT SNSR C/O	MDM	OF2	Card-03	Channel-26
V45P4415A	PRSD H2 TK 9 HTR CONT SNSR C/O	MDM	OF2	Card-03	Channel-27
V76X2121E	FWD MCA 2 OPERATIONAL STATUS 1	MDM	OF2	Card-04	Channel-00
V76X2122E	FWD MCA 2 OPERATIONAL STATUS 2	MDM	OF2	Card-04	Channel-00
V76X2215E	MID MCA 1 OPERATIONAL STATUS 5	MDM	OF2	Card-04	Channel-00
V76X2216E	MID MCA 1 OPERATIONAL STATUS 6	MDM	OF2	Card-04	Channel-00
V76X2235E	MID MCA 3 OPERATIONAL STATUS 5	MDM	OF2	Card-04	Channel-00
V76X2236E	MID MCA 3 OPERATIONAL STA TUS 6	MDM	OF2	Card-04	Channel-00
V45X0460E	FCP H2O NOZZLE OVER TEMP	MDM	OF2	Card-04	Channel-01
V76X0236E	MAIN BUS B ESS 1BC RPC ON	MDM	OF2	Card-04	Channel-01
V62S0810E	FIRE SUPPRESSION AV BAY 1 ARM	MDM	OF2	Card-04	Channel-02
V76X0156E	FUEL CELL H2/O2 PGE HTR-RPC B ON	MDM	OF2	Card-04	Channel-02
V76X0224E	MAIN BUS B CONT BUS AB1/BC1 RPC ON	MDM	OF2	Card-04	Channel-02
V76X1605E	INVERTER BUS NO 2 O/V-U/V	MDM	OF2	Card-04	Channel-02
V45T0220A	FUEL CELL NO 2 STACK COOL OUT TEMP	MDM	OF2	Card-05	Channel-00
V45T1101A	PRSD O2 TK 1 FLUID TEMP	MDM	OF2	Card-05	Channel-02
V45Q1505A	PRSD O2 TK 5 QUANTITY (MBK)	MDM	OF2	Card-05	Channel-04
V45P2410A	PRSD H2 TK 4(&5) HTR CONT PRESS	MDM	OF2	Card-05	Channel-05
V45T3201A	PRSD O2 TK 7 FLUID TEMP	MDM	OF2	Card-05	Channel-20
V45T0904A	PRSD CPC HEAT SINK TEMP 3	MDM	OF2	Card-05	Channel-21
V45T4107A	PRSD H2 TK 6 HTR ASSY TEMP	MDM	OF2	Card-05	Channel-22
V45T4401A	PRSD H2 TK 9 FLUID TEMP	MDM	OF2	Card-05	Channel-23
V76X2123E	FWD MCA 2 OPERATIONAL STATUS 3	MDM	OF2	Card-06	Channel-00
V76X2124E	FWD MCA 2 OPERATIONAL STATUS 4	MDM	OF2	Card-06	Channel-00
V76X2217E	MID MCA 1 OPERATIONAL STATUS 7	MDM	OF2	Card-06	Channel-00
V76X2237E	MID MCA 3 OPERATIONAL STATUS 7	MDM	OF2	Card-06	Channel-00
V76X2238E	MID MCA 3 OPERATIONAL STATUS 8	MDM	OF2	Card-06	Channel-00
V76X1637E	AC BUS 2 PHASE A INPUT ON	MDM	OF2	Card-06	Channel-01
V76X0225E	MAIN BUS B CONT BUS AB2/BC2 RPC ON	MDM	OF2	Card-06	Channel-02
V76X1606E	AC BUS 2 OVERLOAD	MDM	OF2	Card-06	Channel-02
V45V0200A	FUEL CELL NO 2 VOLTAGE	MDM	OF2	Card-07	Channel-10
V76V1600A	AC BUS 2 PHASE A VOLT	MDM	OF2	Card-07	Channel-12
V76V1602A	AC BUS 2 PHASE C VOLT	MDM	OF2	Card-07	Channel-13
V45R0270A	FUEL CELL NO 2 H2 FLOW	MDM	OF2	Card-07	Channel-14
V76C3076A	FWD PCA MAIN BUS B AMPS	MDM	OF2	Card-07	Channel-15
V76C1640A	AC BUS 2 PHASE A CURRENT	MDM	OF2	Card-07	Channel-16
V76C1642A	AC BUS 2 PHASE C CURRENT	MDM	OF2	Card-07	Channel-17
V76V4902A	LMG EMER EXT PYRO B CAP VOLT	MDM	OF2	Card-07	Channel-20
V76V4821A	NLG PYRO EXTEND ACTR-CAP VOLT-2	MDM	OF2	Card-07	Channel-22
V76V4832A	NLG EMER EXT PYRO B CAP VOLT	MDM	OF2	Card-07	Channel-23
V45T2207A	PRSD H2 TK 2 HTR ASSY TEMP	MDM	OF2	Card-09	Channel-00
V45P1510A	PRSD O2 TK 5 HTR CONT PRESS	MDM	OF2	Card-09	Channel-01

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45T0281A	FCP NO 2 PRODUCT H2O LINE TEMP	MDM	OF2	Card-09	Channel-02
V76V0221A	CONTROL BUS BC2 VOLTAGE	MDM	OF2	Card-09	Channel-05
V62Q0629A	SMOKE DETECTOR CONC N B -AV BAY 3	MDM	OF2	Card-09	Channel-07
V45P1515A	PRSD O2 TK 5 HTR CONT SNSR C/O	MDM	OF2	Card-09	Channel-11
V45V0302A	FCP NO 3 SUBSTACK 1 DELTA VOLTAGE	MDM	OF2	Card-09	Channel-13
V45T3209A	PRSD O2 TK 7 HTR ASSY 2 TEMP	MDM	OF2	Card-09	Channel-24
V45T3307A	PRSD O2 TK 8 HTR ASSY 1 TEMP	MDM	OF2	Card-09	Channel-25
V45V0303A	FCP NO 3 SUBSTACK 2 DELTA VOLTAGE	MDM	OF2	Card-09	Channel-27
V45V0304A	FCP NO 3 SUBSTACK 3 DELTA VOLTAGE	MDM	OF2	Card-09	Channel-28
V76X4906E	LMG EMER EXT PYRO L/T-B	MDM	OF2	Card-10	Channel-00
V76X4909E	LMG EMER EXT PYRO RTST-B	MDM	OF2	Card-10	Channel-00
V76X4956E	RMG EMER EXT PYRO L/T-B	MDM	OF2	Card-10	Channel-00
V76X4959E	RMG EMER EXT PYRO RTST-B	MDM	OF2	Card-10	Channel-00
V76X4836E	NLG EMER EXT PYRO L/T-B	MDM	OF2	Card-10	Channel-01
V76X4839E	NLG EMER EXT PYRO RTST-B	MDM	OF2	Card-10	Channel-01
V76V1601A	AC BUS 2 PHASE B VOLT	MDM	OF2	Card-11	Channel-01
V76V0100A	MAIN BUS A VOLTAGE	MDM	OF2	Card-11	Channel-02
V76C3086A	MID PCA MAIN BUS B AMPS	MDM	OF2	Card-11	Channel-03
V45R0260A	FUEL CELL NO 2 O2 FLOW	MDM	OF2	Card-11	Channel-04
V76C1641A	AC BUS 2 PHASE B CURRENT	MDM	OF2	Card-11	Channel-05
V76V4952A	RMG EMER EXT PYRO B CAP VOLT	MDM	OF2	Card-11	Channel-21
V76V4736A	AVN FEXT AV BAY 1 PYRO CAP VOLT	MDM	OF2	Card-11	Channel-22
V76V3072A	FWD PCA-2 VOLTAGE	MDM	OF2	Card-11	Channel-24
V45X0461E	FCP H2O NOZZLE SECONDARY HTR ON	MDM	OF2	Card-12	Channel-00
V76X0226E	MAIN BUS B CONT BUS AB3/BC3 RPC ON	MDM	OF2	Card-12	Channel-01
V76X1638E	AC BUS 2 PHASE B INPUT ON	MDM	OF2	Card-12	Channel-01
V76X1824E	ARRAY 2 MN BUS B PWR TO INV PH A	MDM	OF2	Card-12	Channel-01
V76S1603E	AC BUS 2 VOLTAGE SENSOR AUTO	MDM	OF2	Card-12	Channel-02
V76X1832E	ARRAY 2 MN BUS B PWR TO INV PH C	MDM	OF2	Card-12	Channel-02
V45T1209A	PRSD O2 TK 2 HTR ASSY 2 TEMP	MDM	OF2	Card-13	Channel-01
V45T0113A	FUEL CELL NO 1 STACK INLET TEMP	MDM	OF2	Card-13	Channel-02
V76V0130A	ESS BUS 1BC VOLTAGE	MDM	OF2	Card-13	Channel-03
V45T2407A	PRSD H2 TK 4 HTR ASSY TEMP (MBK)	MDM	OF2	Card-13	Channel-07
V45Q1205A	PRSD O2 TK 2 QUANTITY	MDM	OF2	Card-13	Channel-08
V45V0114A	FCP NO 1 H2 PUMP MTR CONDITION	MDM	OF2	Card-13	Channel-11
V45T0422A	FC NO 2 H2O RELIEF VALVE TEMP	MDM	OF2	Card-13	Channel-16
V45T0902A	PRSD CPC HEAT SINK TEMP 1	MDM	OF2	Card-13	Channel-20
V45T3401A	PRSD O2 TK 9 FLUID TEMP	MDM	OF2	Card-13	Channel-21
V45T4307A	PRSD H2 TK 8 HTR ASSY TEMP	MDM	OF2	Card-13	Channel-22
V45T4201A	PRSD H2 TK 7 FLUID TEMP	MDM	OF2	Card-13	Channel-23
V76X0235E	MAIN BUS B ESS 3AB RPC ON	MDM	OF2	Card-14	Channel-00
V76X1639E	AC BUS 2 PHASE C INPUT ON	MDM	OF2	Card-14	Channel-00
V76X1828E	ARRAY 2 MN BUS B PWR TO INV PH B	MDM	OF2	Card-14	Channel-00

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V76S1604E	AC BUS 2 VOLTAGE SENSOR MONITOR	MDM OF2	Card-14	Channel-02
V76X2869E	PAYLOAD AUX RPC B ON	MDM OF2	Card-14	Channel-02
V45T1109A	PRSD O2 TK 1 HTR ASSY 2 TEMP	MDM OF3	Card-01	Channel-00
V45P0347A	FUEL CELL 3 COOLANT PRESSURE	MDM OF3	Card-01	Channel-01
V45T0432A	FC NO 3 H2O RELIEF VALVE TEMP	MDM OF3	Card-01	Channel-03
V76V0230A	ESS BUS 2CA VOLTAGE	MDM OF3	Card-01	Channel-07
V45T1207A	PRSD O2 TK 2 HTR ASSY 1 TEMP	MDM OF3	Card-01	Channel-08
V45P2140A	PRSD H2 MANF 1 PRESSURE	MDM OF3	Card-01	Channel-09
V45P2304A	PRSD H2 TK 3 ANNULUS VACUUM (MBK)	MDM OF3	Card-01	Channel-11
V62Q0609A	SMOKE DETECTOR CONC N B -AV BAY 2	MDM OF3	Card-01	Channel-12
V45P2200A	PRSD H2 TK 2 PRESSURE	MDM OF3	Card-01	Channel-14
V45P2215A	PRSD H2 TK 2 HTR CTRL SNSR C/O	MDM OF3	Card-01	Channel-17
V45P0187A	FCP ALT PRODUCT H2O LINE PRESS	MDM OF3	Card-01	Channel-18
V45T0450A	H2O RELIEF LINE TEMP	MDM OF3	Card-01	Channel-20
V45Q2305A	PRSD H2 TK 3 QUANTITY (MBK)	MDM OF3	Card-01	Channel-21
V45P1315A	PRSD O2 TK 3 HTR CONT SNSR C/O	MDM OF3	Card-01	Channel-22
V45P2404A	PRSD H2 TK 4 ANNULUS VACUUM (MBK)	MDM OF3	Card-01	Channel-23
V73X1567E	C/W MASTER ALARM TLM OUTPUT	MDM OF3	Card-02	Channel-00
V76X4720E	AVN FEXT AV BAY 2 PYRO L/T	MDM OF3	Card-02	Channel-02
V76X4730E	AVN FEXT AV BAY 2 PYRO RTST	MDM OF3	Card-02	Channel-02
V45T0320A	FUEL CELL NO 3 STACK COOL OUT TEMP	MDM OF3	Card-03	Channel-00
V45T2101A	PRSD H2 TK 1 FLUID TEMP	MDM OF3	Card-03	Channel-01
V45Q2505A	PRSD H2 TK 5 QUANTITY (MBK)	MDM OF3	Card-03	Channel-03
V45T2201A	PRSD H2 TK 2 FLUID TEMP	MDM OF3	Card-03	Channel-05
V76V0320A	CONTROL BUS CA1 VOLTAGE	MDM OF3	Card-03	Channel-08
V62Q0619A	SMOKE DETECTOR CONC N B -AV BAY 1	MDM OF3	Card-03	Channel-09
V45P2400A	PRSD H2 TK 4 PRESS (MID BODY KIT)	MDM OF3	Card-03	Channel-11
V45T1309A	PRSD O2 TK 3 HTR ASSY 2 TEMP (MBK)	MDM OF3	Card-03	Channel-20
V45P1465A	PRSD O2 TK 4(&5) HTR CONT SENSOR	MDM OF3	Card-03	Channel-21
V45P2465A	PRSD H2 TK 4(&5) HTR CONT SENSOR	MDM OF3	Card-03	Channel-22
V45T0213A	FUEL CELL NO 2 STACK INLET TEMP	MDM OF3	Card-03	Channel-23
V45P1310A	PRSD O2 TK 3 HTR CONT PRESS (MBK)	MDM OF3	Card-03	Channel-24
V45T0456A	FCP H2O RELIEF NOZZLE TEMP B	MDM OF3	Card-03	Channel-25
V45T2507A	PRSD H2 TK 5 HTR ASSY TEMP (MBK)	MDM OF3	Card-03	Channel-26
V45T1501A	PRSD O2 TK 5 FLUID TEMP (MBK)	MDM OF3	Card-03	Channel-28
V45T1509A	PRSD O2 TK 5 HTR ASSY 2 TEMP(MBK)	MDM OF3	Card-03	Channel-29
V76X0157E	FUEL CELL H2/O2 PGE HTR-RPC C-1 ON	MDM OF3	Card-04	Channel-00
V76X2131E	FWD MCA 3 OPERATIONAL STATUS 1	MDM OF3	Card-04	Channel-00
V76X2132E	FWD MCA 3 OPERATIONAL STATUS 2	MDM OF3	Card-04	Channel-00
V76X2133E	FWD MCA 3 OPERATIONAL STATUS 3	MDM OF3	Card-04	Channel-00
V76X2134E	FWD MCA 3 OPERATIONAL STATUS 4	MDM OF3	Card-04	Channel-00
V76X2223E	MID MCA 2 OPERATIONAL STATUS 3	MDM OF3	Card-04	Channel-00
V76X2224E	MID MCA 2 OPERATIONAL STATUS 4	MDM OF3	Card-04	Channel-00



**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V76X2225E	MID MCA 2 OPERATIONAL STATUS 5	MDM	OF3	Card-04	Channel-00
V76X2226E	MID MCA 2 OPERATIONAL STATUS 6	MDM	OF3	Card-04	Channel-00
V76X2227E	MID MCA 2 OPERATIONAL STATUS 7	MDM	OF3	Card-04	Channel-00
V76X2228E	MID MCA 2 OPERATIONAL STATUS 8	MDM	OF3	Card-04	Channel-00
V76X2833E	PAYLOAD PRIMARY MAIN B PWR-ON	MDM	OF3	Card-04	Channel-00
V45X1206E	PRSD O2 TK 2 HTR A1-ON	MDM	OF3	Card-04	Channel-01
V76X0106E	MAIN BUS A TIE BUS-ON	MDM	OF3	Card-04	Channel-01
V76X0335E	MAIN BUS C ESS 1BC RPC ON	MDM	OF3	Card-04	Channel-01
V76X2843E	PAYLOAD PRIMARY FC 3 PWR-ON	MDM	OF3	Card-04	Channel-01
V76S1703E	AC BUS 3 VOLTAGE SENSOR AUTO	MDM	OF3	Card-04	Channel-02
V76X0306E	MAIN BUS C TIE BUS-ON	MDM	OF3	Card-04	Channel-02
V76X1738E	AC BUS 3 PHASE B INPUT ON	MDM	OF3	Card-04	Channel-02
V76X2838E	PAYLOAD PRIMARY MAIN C PWR-ON	MDM	OF3	Card-04	Channel-02
V45T0245A	FUEL CELL NO 2 COOLANT RETURN TEMP	MDM	OF3	Card-05	Channel-00
V45T1407A	PRSD O2 TK 4 HTR ASSY 1 TEMP (MBK)	MDM	OF3	Card-05	Channel-02
V45T0600A	FCP O2 VENT LINE TEMP	MDM	OF3	Card-05	Channel-05
V45T1201A	PRSD O2 TK 2 FLUID TEMP	MDM	OF3	Card-05	Channel-06
V45T2307A	PRSD H2 TK 3 HTR ASSY TEMP (MBK)	MDM	OF3	Card-05	Channel-07
V45P1104A	PRSD O2 TK 1 ANNULUS VACUUM	MDM	OF3	Card-05	Channel-08
V45P1200A	PRSD O2 TK 2 PRESSURE	MDM	OF3	Card-05	Channel-12
V76V0321A	CONTROL BUS CA2 VOLTAGE	MDM	OF3	Card-05	Channel-13
V62Q0590A	SMOKE DET CONCEN LEFT -FLIGHT DECK	MDM	OF3	Card-05	Channel-14
V45P1204A	PRSD O2 TK 2 ANNULUS VACUUM	MDM	OF3	Card-05	Channel-20
V45T1409A	PRSD O2 TK 4 HTR ASSY 2 TEMP(MBK)	MDM	OF3	Card-05	Channel-21
V45P2315A	PRSD H2 TK 3 HTR CONT SNSR C/O	MDM	OF3	Card-05	Channel-22
V45T0182A	FCP NO 1 ALT PRODUCT H2O LINE TEMP	MDM	OF3	Card-05	Channel-23
V45P1210A	PRSD O2 TK 2 HTR CONTROL PRESS	MDM	OF3	Card-05	Channel-26
V45P3210A	PRSD O2 TK 7 HTR CONT PRESS	MDM	OF3	Card-05	Channel-28
V45P4210A	PRSD H2 TK 7 HTR CONT PRESS	MDM	OF3	Card-05	Channel-29
V45X1285E	PRSD O2 TK 2 HTR CUR SNSR 1A-TRIP	MDM	OF3	Card-06	Channel-00
V76X0160E	FUEL CELL 1 TO MN BUS A-ON	MDM	OF3	Card-06	Channel-00
V76X1739E	AC BUS 3 PHASE C INPUT ON	MDM	OF3	Card-06	Channel-00
V76X1844E	ARRAY 3 MN BUS C PWR TO INV PH A	MDM	OF3	Card-06	Channel-00
V45X1208E	PRSD O2 TK 2 HTR B1-ON	MDM	OF3	Card-06	Channel-01
V76S1704E	AC BUS 3 VOLTAGE SENSOR MONITOR	MDM	OF3	Card-06	Channel-01
V76X0324E	MAIN BUS C CONT BUS BC1/CA1 RPC ON	MDM	OF3	Card-06	Channel-01
V45X2206E	PRSD H2 TK 2 HEATER A-ON	MDM	OF3	Card-06	Channel-02
V76X0336E	MAIN BUS C ESS 2CA RPC ON	MDM	OF3	Card-06	Channel-02
V45R0370A	FUEL CELL NO 3 H2 FLOW	MDM	OF3	Card-07	Channel-04
V76C1740A	AC BUS 3 PHASE A CURRENT	MDM	OF3	Card-07	Channel-05
V76C3077A	FWD PCA MAIN BUS C AMPS	MDM	OF3	Card-07	Channel-06
V45V0300A	FUEL CELL NO 3 VOLTAGE	MDM	OF3	Card-07	Channel-07
V76V1700A	AC BUS 3 PHASE A VOLT	MDM	OF3	Card-07	Channel-09

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V76V1702A	AC BUS 3 PHASE C VOLT	MDM	OF3	Card-07	Channel-10
V76V4950A	RMG EMER EXT PYRO A CAP VOLT	MDM	OF3	Card-07	Channel-20
V76V4830A	NLG EMER EXT PYRO A CAP VOLT	MDM	OF3	Card-07	Channel-23
V45T0381A	FCP NO 3 PRODUCT H2O LINE TEMP	MDM	OF3	Card-09	Channel-05
V45T2401A	PRSD H2 TK 4 FLUID TEMP (MBK)	MDM	OF3	Card-09	Channel-07
V45P1404A	PRSD O2 TK 4 ANNULUS VACUUM (MBK)	MDM	OF3	Card-09	Channel-09
V45Q2105A	PRSD H2 TK 1 QUANTITY	MDM	OF3	Card-09	Channel-16
V45P2210A	PRSD H2 TK 2 HTR CONTROL PRESS	MDM	OF3	Card-09	Channel-19
V45P1215A	PRSD O2 TK 2 HTR CTRL SNSR C/O	MDM	OF3	Card-09	Channel-22
V45T1301A	PRSD O2 TK 3 FLUID TEMP (MBK)	MDM	OF3	Card-09	Channel-24
V45P1304A	PRSD O2 TK 3 ANNULUS VACUUM (MBK)	MDM	OF3	Card-09	Channel-25
V45Q1405A	PRSD O2 TK 4 QUANTITY (MBK)	MDM	OF3	Card-09	Channel-26
V76X4823E	NLG PYRO EXTEND ACTR-L/T-1	MDM	OF3	Card-10	Channel-00
V76X4826E	NLG PYRO EXTEND ACTR-RTST-1	MDM	OF3	Card-10	Channel-00
V76X4905E	LMG EMER EXT PYRO L/T -A	MDM	OF3	Card-10	Channel-00
V76X4908E	LMG EMER EXT PYRO RTST -A	MDM	OF3	Card-10	Channel-00
V76X4955E	RMG EMER EXT PYRO L/T -A	MDM	OF3	Card-10	Channel-00
V76X4958E	RMG EMER EXT PYRO RTST -A	MDM	OF3	Card-10	Channel-00
V45X0430E	FUEL CELL NO 3 H2O CONDITION	MDM	OF3	Card-10	Channel-01
V76X4835E	NLG EMER EXT PYRO L/T -A	MDM	OF3	Card-10	Channel-02
V76X4838E	NLG EMER EXT PYRO RTST -A	MDM	OF3	Card-10	Channel-02
V76V0200A	MAIN BUS B VOLTAGE	MDM	OF3	Card-11	Channel-00
V76V1701A	AC BUS 3 PHASE B VOLT	MDM	OF3	Card-11	Channel-01
V76C4450A	PALLET PCA 1 MN A CURRENT	MDM	OF3	Card-11	Channel-02
V45R0360A	FUEL CELL NO 3 O2 FLOW	MDM	OF3	Card-11	Channel-04
V76C1741A	AC BUS 3 PHASE B CURRENT	MDM	OF3	Card-11	Channel-05
V76C3087A	MID PCA MAIN BUS C AMPS	MDM	OF3	Card-11	Channel-06
V76V4900A	LMG EMER EXT PYRO A CAP VOLT	MDM	OF3	Card-11	Channel-16
V76V3073A	FWD PCA-3 VOLTAGE	MDM	OF3	Card-11	Channel-23
V45X2208E	PRSD H2 TK 2 HEATER B-ON	MDM	OF3	Card-12	Channel-00
V76X0158E	FUEL CELL H2/O2 PGE HTR-RPC C-2 ON	MDM	OF3	Card-12	Channel-00
V76X0325E	MAIN BUS C CONT BUS BC2/CA2 RPC ON	MDM	OF3	Card-12	Channel-00
V45X2195E	PRSD H2 GAS SPLY VLV-CLOSED	MDM	OF3	Card-12	Channel-01
V76X0360E	FUEL CELL 3 TO MN BUS C-ON	MDM	OF3	Card-12	Channel-01
V45X1211E	PRSD O2 TK 2 HTR A2-ON	MDM	OF3	Card-12	Channel-02
V45X1286E	PRSD O2 TK 2 HTR CUR SNSR 2A-TRIP	MDM	OF3	Card-12	Channel-02
V76X0206E	MAIN BUS B TIE BUS-ON	MDM	OF3	Card-12	Channel-02
V76X1705E	INVERTER BUS NO 3 O/V-U/V	MDM	OF3	Card-12	Channel-02
V76X1848E	ARRAY 3 MN BUS C PWR TO INV PH B	MDM	OF3	Card-12	Channel-02
V45P1145A	PRSD O2 MANF 2 PRESSURE	MDM	OF3	Card-13	Channel-00
V45T0330A	FUEL CELL NO 3 CONDENSER EXIT TEMP	MDM	OF3	Card-13	Channel-02
V45P2104A	PRSD H2 TK 1 ANNULUS VACUUM	MDM	OF3	Card-13	Channel-06
V45T0700A	FCP H2 VENT LINE TEMP 2	MDM	OF3	Card-13	Channel-07

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45P1300A	PRSD O2 TK 3 PRESS (MID BODY KIT)	MDM	OF3	Card-13	Channel-10
V76V0322A	CONTROL BUS CA3 VOLTAGE	MDM	OF3	Card-13	Channel-11
V45V0214A	FCP NO 2 H2 PUMP MTR CONDITION	MDM	OF3	Card-13	Channel-15
V45Q1305A	PRSD O2 TK 3 QUANTITY (MBK)	MDM	OF3	Card-13	Channel-20
V45Q2405A	PRSD H2 TK 4 QUANTITY (MBK)	MDM	OF3	Card-13	Channel-21
V45P2204A	PRSD H2 TK 2 ANNULUS VACUUM	MDM	OF3	Card-13	Channel-22
V45T1401A	PRSD O2 TK 4 FLUID TEMP (MBK)	MDM	OF3	Card-13	Channel-23
V45X1288E	PRSD O2 TK 2 HTR CUR SNSR 2B-TRIP	MDM	OF3	Card-14	Channel-00
V62S0811E	FIRE SUPPRESSION AV BAY 2 ARM	MDM	OF3	Card-14	Channel-00
V45S0380E	FCP NO 3 CONTROL POWER	MDM	OF3	Card-14	Channel-01
V45X1287E	PRSD O2 TK 2 HTR C UR SNSR 1B-TRIP	MDM	OF3	Card-14	Channel-01
V76X0326E	MAIN BUS C CONT BUS BC3/CA3 RPC ON	MDM	OF3	Card-14	Channel-01
V76X1737E	AC BUS 3 PHASE A INPUT ON	MDM	OF3	Card-14	Channel-01
V45X1213E	PRSD O2 TK 2 HTR B2-ON	MDM	OF3	Card-14	Channel-02
V76X0260E	FUEL CELL 2 TO MN BUS B-ON	MDM	OF3	Card-14	Channel-02
V76X1706E	AC BUS 3 OVERLOAD	MDM	OF3	Card-14	Channel-02
V76X1852E	ARRAY 3 MN BUS C PWR TO INV PH C	MDM	OF3	Card-14	Channel-02
V76X2845E	PAYLOAD PRI FC3 STRUCTURE GROUNDED	MDM	OF3	Card-14	Channel-02
V45C0101A	FUEL CELL NO 1 CURRENT	MDM	OF3	Card-15	Channel-00
V45C0201A	FUEL CELL NO 2 CURRENT	MDM	OF3	Card-15	Channel-01
V45C0301A	FUEL CELL NO 3 CURRENT	MDM	OF3	Card-15	Channel-02
V76C1742A	AC BUS 3 PHASE C CURRENT	MDM	OF3	Card-15	Channel-06
V76V4716A	AVN FEXT AV BAY 2 PYRO CAP VOLT	MDM	OF3	Card-15	Channel-19
V76V4820A	NLG PYRO EXTEND ACTR-CAP VOLT-1	MDM	OF3	Card-15	Channel-20
V45S1531E	PRSD O2 TK 5 HTR A-ON A/B	MDM	OF4	Card-00	Channel-01
V45S1533E	PRSD O2 TK 5 HTR A-AUTO A/B	MDM	OF4	Card-00	Channel-01
V45S2531E	PRSD H2 TK 5 HTR A-ON A/B	MDM	OF4	Card-00	Channel-01
V45S2533E	PRSD H2 TK 5 HTR A-AUTO A/B	MDM	OF4	Card-00	Channel-01
V45V0102A	FCP NO 1 SUBSTACK 1 DELTA VOLTAGE	MDM	OF4	Card-01	Channel-19
V45V0103A	FCP NO 1 SUBSTACK 2 DELTA VOLTAGE	MDM	OF4	Card-01	Channel-21
V45V0104A	FCP NO 1 SUBSTACK 3 DELTA VOLTAGE	MDM	OF4	Card-01	Channel-22
V45T3207A	PRSD O2 TK 7 HTR ASSY 1 TEMP	MDM	OF4	Card-01	Channel-24
V45T3309A	PRSD O2 TK 8 HTR ASSY 2 TEMP	MDM	OF4	Card-01	Channel-25
V45S0811E	FCP 1 PURGE VLVS MNL OPEN-A	MDM	OF4	Card-02	Channel-00
V45S1131E	PRSD O2 TK 1 HTR A-ON A/B	MDM	OF4	Card-02	Channel-00
V45S1331E	PRSD O2 TK 3 HTR A-ON A/B (MBK)	MDM	OF4	Card-02	Channel-00
V45X1080E	PRSD O2 ECS PRIM SUP VLV-OPEN	MDM	OF4	Card-02	Channel-00
V45S0601E	FCP O2/H2 PURGE HTRS MNL-A	MDM	OF4	Card-02	Channel-01
V45X0105E	FUEL CELL NO 1 READY	MDM	OF4	Card-02	Channel-01
V76X4454E	PALLET MDCA 1 MOTOR SW CLOSE	MDM	OF4	Card-02	Channel-01
V45S0191E	FCP NO 1 STARTUP HEATER-INHIBIT	MDM	OF4	Card-02	Channel-02
V45S2131E	PRSD H2 TK 1 HTR A-ON A/B	MDM	OF4	Card-02	Channel-02
V45S2338E	PRSD H2 TK 3 HTR B-AUTO A/B (MBK)	MDM	OF4	Card-02	Channel-02

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45X1160E	PRSD FCP 3 O2 REAC VLV-OPEN	MDM	OF4	Card-02	Channel-02
V62X0620E	SMOKE DETECTOR-A AV BAY-1	MDM	OF4	Card-02	Channel-02
V76S0134E	MAIN BUS C TO ESS BUS -1BC-ON	MDM	OF4	Card-02	Channel-02
V45S3131E	PRSD O2 TK 6 HTR A-ON A/B	MDM	OF4	Card-03	Channel-00
V45S3133E	PRSD O2 TK 6 HTR A-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S3231E	PRSD O2 TK 7 HTR A-ON A/B	MDM	OF4	Card-03	Channel-00
V45S3233E	PRSD O2 TK 7 HTR A-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S3336E	PRSD O2 TK 8 HTR B-ON A/B	MDM	OF4	Card-03	Channel-00
V45S3338E	PRSD O2 TK 8 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S3436E	PRSD O2 TK 9 HTR B-ON A/B	MDM	OF4	Card-03	Channel-00
V45S3438E	PRSD O2 TK 9 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S4131E	PRSD H2 TK 6 HTR A-ON A/B	MDM	OF4	Card-03	Channel-00
V45S4133E	PRSD H2 TK 6 HTR A-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S4231E	PRSD H2 TK 7 HTR A-ON A/B	MDM	OF4	Card-03	Channel-00
V45S4233E	PRSD H2 TK 7 HTR A-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S4336E	PRSD H2 TK 8 HTR B-ON A/B	MDM	OF4	Card-03	Channel-00
V45S4338E	PRSD H2 TK 8 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S4436E	PRSD H2 TK 9 HTR B-ON A/B	MDM	OF4	Card-03	Channel-00
V45S4438E	PRSD H2 TK 9 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-00
V45S1536E	PRSD O2 TK 5 HTR B-ON A/B	MDM	OF4	Card-03	Channel-01
V45S1538E	PRSD O2 TK 5 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-01
V45S2536E	PRSD H2 TK 5 HTR B-ON A/B	MDM	OF4	Card-03	Channel-01
V45S2538E	PRSD H2 TK 5 HTR B-AUTO A/B	MDM	OF4	Card-03	Channel-01
V45S0291E	FCP NO 2 STARTUP HEATER-INHIBIT	MDM	OF4	Card-04	Channel-00
V45S1133E	PRSD O2 TK 1 HTR A-AUTO A/B	MDM	OF4	Card-04	Channel-00
V45S2488E	PRSD H2 TK 4(&5) HTR B-AUTO A/B	MDM	OF4	Card-04	Channel-00
V45S1431E	PRSD O2 TK 4 HTR A-ON A/B (MBK)	MDM	OF4	Card-04	Channel-01
V45X0143E	FUEL CELL NO 1 COOLANT PUMP STATUS	MDM	OF4	Card-04	Channel-01
V45X1083E	PRSD O2 ECS SEC SUP VLV-OPEN	MDM	OF4	Card-04	Channel-01
V45S1336E	PRSD O2 TK 3 HTR B-ON A/B (MBK)	MDM	OF4	Card-04	Channel-02
V45S2133E	PRSD H2 TK 1 HTR A-AUTO A/B	MDM	OF4	Card-04	Channel-02
V45X2141E	PRSD H2 MANF 1 ISLN VLV-OPEN	MDM	OF4	Card-04	Channel-02
V62X0621E	SMOKE DETECTOR-B AV BAY-1	MDM	OF4	Card-04	Channel-02
V76S0163E	FUEL CELL 1 TO ESS BUS 1BC-ON	MDM	OF4	Card-04	Channel-02
V45S1136E	PRSD O2 TK 1 HTR B-ON A/B	MDM	OF4	Card-05	Channel-00
V45S0391E	FCP NO 3 STARTUP HEATER-INHIBIT	MDM	OF4	Card-05	Channel-01
V45S0604E	FCP O2/H2 PURGE HTRS GPC-A ON	MDM	OF4	Card-05	Channel-01
V45S2331E	PRSD H2 TK 3 HTR A-ON A/B (MBK)	MDM	OF4	Card-05	Channel-01
V45X0205E	FUEL CELL NO 2 READY	MDM	OF4	Card-05	Channel-01
V76S0234E	MAIN BUS A TO ESS BUS -2CA-ON	MDM	OF4	Card-05	Channel-01
V45S2136E	PRSD H2 TK 1 HTR B-ON A/B	MDM	OF4	Card-05	Channel-02
V45X2146E	PRSD H2 MANF 2 ISLN VLV-OPEN	MDM	OF4	Card-05	Channel-02
V62X0622E	FIRE BOTTLE AV BAY 2 FULL/EMPTY	MDM	OF4	Card-05	Channel-02

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V45T3109A	PRSD O2 TK 6 HTR ASSY 2 TEMP	MDM	OF4	Card-06	Channel-24
V45T3407A	PRSD O2 TK 9 HTR ASSY 1 TEMP	MDM	OF4	Card-06	Channel-25
V45S0441E	FCP H2O LINE HTRS A-AUTO	MDM	OF4	Card-07	Channel-00
V45S2481E	PRSD H2 TK 4(&5) HTR A-ON A/B	MDM	OF4	Card-07	Channel-00
V45X0243E	FUEL CELL NO 2 COOLANT PUMP STATUS	MDM	OF4	Card-07	Channel-00
V62X0596E	SMOKE DET-RTN AIR TO CAB HX	MDM	OF4	Card-07	Channel-00
V45S0815E	FCP 1 PURGE VLVS GPC-A OPEN	MDM	OF4	Card-07	Channel-01
V45S1138E	PRSD O2 TK 1 HTR B-AUTO A/B	MDM	OF4	Card-07	Channel-01
V62X0606E	SMOKE DETECTOR-LEFT FLIGHT DECK	MDM	OF4	Card-07	Channel-01
V45S1436E	PRSD O2 TK 4/5 HTR B/A-ON A/B	MDM	OF4	Card-07	Channel-02
V45S2138E	PRSD H2 TK 1 HTR B-AUTO A/B	MDM	OF4	Card-07	Channel-02
V45X2150E	PRSD FCP 1 H2 REAC VLV-OPEN	MDM	OF4	Card-07	Channel-02
V62X0630E	SMOKE DETECTOR-A AV BAY 3	MDM	OF4	Card-07	Channel-02
V76S0263E	FUEL CELL 2 TO ESS BUS 2CA-ON	MDM	OF4	Card-07	Channel-02
V45S3136E	PRSD O2 TK 6 HTR B-ON A/B	MDM	OF4	Card-08	Channel-02
V45S3138E	PRSD O2 TK 6 HTR B-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S3236E	PRSD O2 TK 7 HTR B-ON A/B	MDM	OF4	Card-08	Channel-02
V45S3238E	PRSD O2 TK 7 HTR B-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S3331E	PRSD O2 TK 8 HTR A-ON A/B	MDM	OF4	Card-08	Channel-02
V45S3333E	PRSD O2 TK 8 HTR A-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S3431E	PRSD O2 TK 9 HTR A-ON A/B	MDM	OF4	Card-08	Channel-02
V45S3433E	PRSD O2 TK 9 HTR A-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S4136E	PRSD H2 TK 6 HTR B-ON A/B	MDM	OF4	Card-08	Channel-02
V45S4138E	PRSD H2 TK 6 HTR B-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S4236E	PRSD H2 TK 7 HTR B-ON A/B	MDM	OF4	Card-08	Channel-02
V45S4238E	PRSD H2 TK 7 HTR B-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S4331E	PRSD H2 TK 8 HTR A-ON A/B	MDM	OF4	Card-08	Channel-02
V45S4333E	PRSD H2 TK 8 HTR A-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S4431E	PRSD H2 TK 9 HTR A-ON A/B	MDM	OF4	Card-08	Channel-02
V45S4433E	PRSD H2 TK 9 HTR A-AUTO A/B	MDM	OF4	Card-08	Channel-02
V45S0442E	FCP H2O LINE HTRS B-AUTO	MDM	OF4	Card-10	Channel-00
V45S1231E	PRSD O2 TK 2 HTR A-ON A/B	MDM	OF4	Card-10	Channel-00
V45X1141E	PRSD O2 MANF 1 ISLN VLV-OPEN	MDM	OF4	Card-10	Channel-00
V76S2851E	PAYLOAD CABIN-MAIN BUS A ON	MDM	OF4	Card-10	Channel-00
V45S1333E	PRSD O2 TK 3 HTR A-AUTO A/B (MBK)	MDM	OF4	Card-10	Channel-01
V45X0305E	FUEL CELL NO 3 READY	MDM	OF4	Card-10	Channel-01
V62X0607E	SMOKE DETECTOR-RIGHT FLIGHT DECK	MDM	OF4	Card-10	Channel-01
V76X4455E	PALLET MDCA 2 MOTOR SW CLOSE	MDM	OF4	Card-10	Channel-01
V45S0821E	FCP 2 PURGE VLVS MNL OPEN-A	MDM	OF4	Card-10	Channel-02
V45S2231E	PRSD H2 TK 2 HTR A-ON A/B	MDM	OF4	Card-10	Channel-02
V45S2336E	PRSD H2 TK 3 HTR B-ON A/B (MBK)	MDM	OF4	Card-10	Channel-02
V45X2155E	PRSD FCP 2 H2 REAC VLV-OPEN	MDM	OF4	Card-10	Channel-02
V62X0631E	SMOKE DETECTOR-B AV BAY 3	MDM	OF4	Card-10	Channel-02

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (continued)**

V76S0334E	MAIN BUS B TO ESS BUS -3AB-ON	MDM	OF4	Card-10	Channel-02
V45P3200A	PRSD O2 TK 7 PRESS	MDM	OF4	Card-11	Channel-00
V45P3400A	PRSD O2 TK 9 PRESS	MDM	OF4	Card-11	Channel-01
V45P4200A	PRSD H2 TK 7 PRESS	MDM	OF4	Card-11	Channel-02
V45P4400A	PRSD H2 TK 9 PRESS	MDM	OF4	Card-11	Channel-03
V45T3101A	PRSD O2 TK 6 FLUID TEMP	MDM	OF4	Card-11	Channel-04
V45T0905A	PRSD CPC HEAT SINK TEMP 4	MDM	OF4	Card-11	Channel-05
V45T4207A	PRSD H2 TK 7 HTR ASSY TEMP	MDM	OF4	Card-11	Channel-06
V45T4301A	PRSD H2 TK 8 FLUID TEMP	MDM	OF4	Card-11	Channel-07
V45S1233E	PRSD O2 TK 2 HTR A-AUTO A/B	MDM	OF4	Card-12	Channel-00
V45X1146E	PRSD O2 MANF 2 ISLN VLV-OPEN	MDM	OF4	Card-12	Channel-00
V45S0445E	FCP H2O RELIEF HTRS A-AUTO	MDM	OF4	Card-12	Channel-01
V45S1433E	PRSD O2 TK 4 HTR A-AUTO A/B (MBK)	MDM	OF4	Card-12	Channel-01
V45X0343E	FUEL CELL NO 3 COOLANT PUMP STATUS	MDM	OF4	Card-12	Channel-01
V62X0610E	SMOKE DETECTOR-A AV BAY-2	MDM	OF4	Card-12	Channel-01
V45S0825E	FCP 2 PURGE VLVS GPC-A OPEN	MDM	OF4	Card-12	Channel-02
V45S2233E	PRSD H2 TK 2 HTR A-AUTO A/B	MDM	OF4	Card-12	Channel-02
V45S2486E	PRSD H2 TK 4(&5) HTR B-ON A/B	MDM	OF4	Card-12	Channel-02
V45X2160E	PRSD FCP 3 H2 REAC VLV-OPEN	MDM	OF4	Card-12	Channel-02
V62X0632E	FIRE BOTTLE AV BAY 3 FULL/EMPTY	MDM	OF4	Card-12	Channel-02
V76S0363E	FUEL CELL 3 TO ESS BUS 3AB-ON	MDM	OF4	Card-12	Channel-02
V76S2853E	PAYLOAD CABIN-MAIN BUS B ON	MDM	OF4	Card-12	Channel-02
V45S1236E	PRSD O2 TK 2 HTR B-ON A/B	MDM	OF4	Card-13	Channel-00
V45X1150E	PRSD FCP 1 O2 REAC VLV-OPEN	MDM	OF4	Card-13	Channel-00
V76S2861E	PAYLOAD AUXILIARY-MAIN BUS A ON	MDM	OF4	Card-13	Channel-00
V45S0831E	FCP 3 PURGE VLVS MNL OPEN-A	MDM	OF4	Card-13	Channel-01
V45S2333E	PRSD H2 TK 3 HTR A-AUTO A/B (MBK)	MDM	OF4	Card-13	Channel-01
V62X0611E	SMOKE DETECTOR-B AV BAY-2	MDM	OF4	Card-13	Channel-01
V45S0446E	FCP H2O RELIEF HTRS B-AUTO	MDM	OF4	Card-13	Channel-02
V45S1338E	PRSD O2 TK 3 HTR B-AUTO A/B (MBK)	MDM	OF4	Card-13	Channel-02
V45S2236E	PRSD H2 TK 2 HTR B-ON A/B	MDM	OF4	Card-13	Channel-02
V45Q3205A	PRSD O2 TK 7 QUANTITY	MDM	OF4	Card-14	Channel-00
V45Q3405A	PRSD O2 TK 9 QUANTITY	MDM	OF4	Card-14	Channel-01
V45Q4205A	PRSD H2 TK 7 QUANTITY	MDM	OF4	Card-14	Channel-02
V45Q4405A	PRSD H2 TK 9 QUANTITY	MDM	OF4	Card-14	Channel-03
V45T0903A	PRSD CPC HEAT SINK TEMP 2	MDM	OF4	Card-14	Channel-04
V45T3301A	PRSD O2 TK 8 FLUID TEMP	MDM	OF4	Card-14	Channel-05
V45T4407A	PRSD H2 TK 9 HTR ASSY TEMP	MDM	OF4	Card-14	Channel-06
V45T4101A	PRSD H2 TK 6 FLUID TEMP	MDM	OF4	Card-14	Channel-07
V45P3115A	PRSD O2 TK 6 HTR CONT SNSR C/O	MDM	OF4	Card-14	Channel-08
V45P3315A	PRSD O2 TK 8 HTR CONT SNSR C/O	MDM	OF4	Card-14	Channel-09
V45P4115A	PRSD H2 TK 6 HTR CONT SNSR C/O	MDM	OF4	Card-14	Channel-10

**Table 6.1.6-1. MDM listing for EGIL parameters sorted by MDM (concluded)**

V45P4315A	PRSD H2 TK 8 HTR CONT SNSR C/O	MDM OF4	Card-14	Channel-11
V45S0835E	FCP 3 PURGE VLVS GPC-A OPEN	MDM OF4	Card-15	Channel-00
V45S1438E	PRSD O2 TK 4/5 HTR B/A-AUTO A/B	MDM OF4	Card-15	Channel-00
V62X0612E	FIRE BOTTLE AV BAY 1 FULL/EMPTY	MDM OF4	Card-15	Channel-00
V45S1238E	PRSD O2 TK 2 HTR B-AUTO A/B	MDM OF4	Card-15	Channel-01
V45S2483E	PRSD H2 TK 4(&5) HTR A-AUTO A/B	MDM OF4	Card-15	Channel-01
V45X1155E	PRSD FCP 2 O2 REAC VLV-OPEN	MDM OF4	Card-15	Channel-01
V45S2238E	PRSD H2 TK 2 HTR B-AUTO A/B	MDM OF4	Card-15	Channel-02
V45X0804E	FUEL CELL AUTO PURGE -ON	MDM OF4	Card-15	Channel-02
V45K0815Y	FCP 1 PURGE VLVS GPC-A OPEN	MDM PF1	Card-07	Channel-01
V45K0816Y	FCP 1 PURGE VLVS GPC-B OPEN	MDM PF1	Card-07	Channel-01
V45K0825Y	FCP 2 PURGE VLVS GPC-A OPEN	MDM PF1	Card-14	Channel-01
V45K0826Y	FCP 2 PURGE VLVS GPC-B OPEN	MDM PF1	Card-14	Channel-01
V45K0835Y	FCP 3 PURGE VLVS GPC-A OPEN	MDM PF2	Card-07	Channel-01
V45K0836Y	FCP 3 PURGE VLVS GPC-B OPEN	MDM PF2	Card-07	Channel-01
V45K0604Y	FCP O2/H2 PURGE HTRS GPC-A ON	MDM PF2	Card-14	Channel-01
V45K0605Y	FCP O2/H2 PURGE HTRS GPC-B ON	MDM PF2	Card-14	Channel-01

**TITLE**

EGIL DSC LOSS TABLE

Table 6.1.7-1 lists only DSC information and is sorted by DSC card and channel.

This information is effective for STS-95 and subsequent flights using OI-26B flight software.



**Table 6.1.7-1. DSC listing for EGIL parameters sorted by DSC**

V45X3106E	PRSD O2 TK 6 HTR A1-ON	DSC	EC1	Card-01	Channel-A
V45X3108E	PRSD O2 TK 6 HTR B1-ON	DSC	EC1	Card-01	Channel-A
V45X3111E	PRSD O2 TK 6 HTR A2-ON	DSC	EC1	Card-01	Channel-A
V45X3113E	PRSD O2 TK 6 HTR B2-ON	DSC	EC1	Card-01	Channel-A
V45X3185E	PRSD O2 TK 6 HTR CUR SNSR 1A-TRIP	DSC	EC1	Card-01	Channel-A
V45X3186E	PRSD O2 TK 6 HTR CUR SNSR 2A-TRIP	DSC	EC1	Card-01	Channel-A
V45X3187E	PRSD O2 TK 6 HTR CUR SNSR 1B-TRIP	DSC	EC1	Card-01	Channel-A
V45X3188E	PRSD O2 TK 6 HTR CUR SNSR 2B-TRIP	DSC	EC1	Card-01	Channel-A
V45X4106E	PRSD H2 TK 6 HTR A-ON	DSC	EC1	Card-01	Channel-A
V45X4108E	PRSD H2 TK 6 HTR B-ON	DSC	EC1	Card-01	Channel-A
V76C4450A	PALLET PCA 1 MN A CURRENT	DSC	EC1	Card-01	Channel-A
V45X3206E	PRSD O2 TK 7 HTR A1-ON	DSC	EC1	Card-02	Channel-A
V45X3208E	PRSD O2 TK 7 HTR B1-ON	DSC	EC1	Card-02	Channel-A
V45X3211E	PRSD O2 TK 7 HTR A2-ON	DSC	EC1	Card-02	Channel-A
V45X3213E	PRSD O2 TK 7 HTR B2-ON	DSC	EC1	Card-02	Channel-A
V45X3285E	PRSD O2 TK 7 HTR CUR SNSR 1A-TRIP	DSC	EC1	Card-02	Channel-A
V45X3286E	PRSD O2 TK 7 HTR CUR SNSR 2A-TRIP	DSC	EC1	Card-02	Channel-A
V45X3287E	PRSD O2 TK 7 HTR CUR SNSR 1B-TRIP	DSC	EC1	Card-02	Channel-A
V45X3288E	PRSD O2 TK 7 HTR CUR SNSR 2B-TRIP	DSC	EC1	Card-02	Channel-A
V45X4206E	PRSD H2 TK 7 HTR A-ON	DSC	EC1	Card-02	Channel-A
V45X4208E	PRSD H2 TK 7 HTR B-ON	DSC	EC1	Card-02	Channel-A
V45X3306E	PRSD O2 TK 8 HTR A1-ON	DSC	EC1	Card-03	Channel-A
V45X3308E	PRSD O2 TK 8 HTR B1-ON	DSC	EC1	Card-03	Channel-A
V45X3311E	PRSD O2 TK 8 HTR A2-ON	DSC	EC1	Card-03	Channel-A
V45X3313E	PRSD O2 TK 8 HTR B2-ON	DSC	EC1	Card-03	Channel-A
V45X3385E	PRSD O2 TK 8 HTR CUR SNSR 1A-TRIP	DSC	EC1	Card-03	Channel-A
V45X3386E	PRSD O2 TK 8 HTR CUR SNSR 2A-TRIP	DSC	EC1	Card-03	Channel-A
V45X3387E	PRSD O2 TK 8 HTR CUR SNSR 1B-TRIP	DSC	EC1	Card-03	Channel-A
V45X3388E	PRSD O2 TK 8 HTR CUR SNSR 2B-TRIP	DSC	EC1	Card-03	Channel-A
V45X4306E	PRSD H2 TK 8 HTR A-ON	DSC	EC1	Card-03	Channel-A
V45X4308E	PRSD H2 TK 8 HTR B-ON	DSC	EC1	Card-03	Channel-A
V45X3406E	PRSD O2 TK 9 HTR A1-ON	DSC	EC1	Card-04	Channel-A
V45X3408E	PRSD O2 TK 9 HTR B1-ON	DSC	EC1	Card-04	Channel-A
V45X3411E	PRSD O2 TK 9 HTR A2-ON	DSC	EC1	Card-04	Channel-A
V45X3413E	PRSD O2 TK 9 HTR B2-ON	DSC	EC1	Card-04	Channel-A
V45X3485E	PRSD O2 TK 9 HTR CUR SNSR 1A-TRIP	DSC	EC1	Card-04	Channel-A
V45X3486E	PRSD O2 TK 9 HTR CUR SNSR 2A-TRIP	DSC	EC1	Card-04	Channel-A
V45X3487E	PRSD O2 TK 9 HTR CUR SNSR 1B-TRIP	DSC	EC1	Card-04	Channel-A
V45X3488E	PRSD O2 TK 9 HTR CUR SNSR 2B-TRIP	DSC	EC1	Card-04	Channel-A
V45X4406E	PRSD H2 TK 9 HTR A-ON	DSC	EC1	Card-04	Channel-A
V45X4408E	PRSD H2 TK 9 HTR B-ON	DSC	EC1	Card-04	Channel-A
V45T0699A	FCP H2 VENT LINE TEMP 1	DSC	OA2	Card-19	Channel-A

**Table 6.1.7-1. DSC listing for EGIL parameters sorted by DSC (continued)**

V76V3093A	AFT PCA-6 VOLTAGE	DSC	OA3	Card-01	Channel-B
V76V1500A	AC BUS 1 PHASE A VOLT	DSC	OF1	Card-01	Channel-A
V76V1501A	AC BUS 1 PHASE B VOLT	DSC	OF1	Card-01	Channel-B
V76V1502A	AC BUS 1 PHASE C VOLT	DSC	OF1	Card-01	Channel-C
V62Q0595A	SMOKE DETR CONC N RTN AIR-CAB HX	DSC	OF1	Card-04	Channel-A
V62Q0608A	SMOKE DETECTOR CONC N A-AV BAY 2	DSC	OF1	Card-04	Channel-B
V62Q0628A	SMOKE DETECTOR CONC N A-AV BAY 3	DSC	OF1	Card-04	Channel-C
V76V0120A	CONTROL BUS AB1 VOLTAGE	DSC	OF1	Card-05	Channel-A
V76V0121A	CONTROL BUS AB2 VOLTAGE	DSC	OF1	Card-05	Channel-B
V76V0122A	CONTROL BUS AB3 VOLTAGE	DSC	OF1	Card-05	Channel-C
V76V3071A	FWD PCA-1 VOLTAGE	DSC	OF1	Card-05	Channel-D
V45Q1105A	PRSD O2 TK 1 QUANTITY	DSC	OF1	Card-09	Channel-B
V76X4705E	AVN FEXT AV BAY 3A PYRO L/T	DSC	OF1	Card-09	Channel-A
V76X4710E	AVN FEXT AV BAY 3A PYRO RTST	DSC	OF1	Card-09	Channel-A
V76X6930E	ORB/ET FWD SEP PYRO L/T A	DSC	OF1	Card-09	Channel-A
V76X6932E	ORB/ET FWD SEP PYRO RTST A	DSC	OF1	Card-09	Channel-A
V45P2515A	PRSD H2 TK 5 HTR CONT SNSR C/O	DSC	OF1	Card-10	Channel-B
V76V4700A	AVN FEXT AV BAY 3A PYRO CAP VOLT	DSC	OF1	Card-12	Channel-C
V45P1115A	PRSD O2 TK 1 HTR CTRL SNSR C/O	DSC	OF1	Card-13	Channel-B
V45Q2205A	PRSD H2 TK 2 QUANTITY	DSC	OF1	Card-14	Channel-D
V45P1100A	PRSD O2 TK 1 PRESSURE	DSC	OF1	Card-21	Channel-A
V45P2100A	PRSD H2 TK1 PRESSURE	DSC	OF1	Card-21	Channel-B
V45P1400A	PRSD O2 TK 4 PRESS (MID BODY KIT)	DSC	OF1	Card-21	Channel-C
V45P2300A	PRSD H2 TK 3 PRESS (MID BODY KIT)	DSC	OF1	Card-21	Channel-D
V64V0210A	EXTRA VEHICULAR LSS BAT CHG VOLT 1	DSC	OF1	Card-22	Channel-A
V64V0213A	EXTRA VEHICULAR LSS BAT CHG VOLT 2	DSC	OF1	Card-22	Channel-B
V45P1500A	PRSD O2 TK 5 PRESS (MID BODY KIT)	DSC	OF1	Card-29	Channel-A
V45P2500A	PRSD H2 TK 5 PRESS (MID BODY KIT)	DSC	OF1	Card-29	Channel-B
V45P1504A	PRSD O2 TK 5 ANNULUS VACUUM (MBK)	DSC	OF1	Card-30	Channel-A
V45P2504A	PRSD H2 TK 5 ANNULUS VACUUM (MBK)	DSC	OF1	Card-30	Channel-B
V76V1600A	AC BUS 2 PHASE A VOLT	DSC	OF2	Card-01	Channel-A
V76V1601A	AC BUS 2 PHASE B VOLT	DSC	OF2	Card-01	Channel-B
V76V1602A	AC BUS 2 PHASE C VOLT	DSC	OF2	Card-01	Channel-C
V62Q0591A	SMOKE DET CONC N RIGHT-FLIGHT DECK	DSC	OF2	Card-04	Channel-A
V62Q0618A	SMOKE DETECTOR CONC N A-AV BAY 1	DSC	OF2	Card-04	Channel-B
V62Q0629A	SMOKE DETECTOR CONC N B-AV BAY 3	DSC	OF2	Card-04	Channel-C
V76V0220A	CONTROL BUS BC1 VOLTAGE	DSC	OF2	Card-05	Channel-A
V76V0221A	CONTROL BUS BC2 VOLTAGE	DSC	OF2	Card-05	Channel-B
V76V0222A	CONTROL BUS BC3 VOLTAGE	DSC	OF2	Card-05	Channel-C
V76V3072A	FWD PCA-2 VOLTAGE	DSC	OF2	Card-05	Channel-D
V45T1507A	PRSD O2 TK 5 HTR ASSY 1 TEMP(MBK)	DSC	OF2	Card-06	Channel-A
V45T2501A	PRSD H2 TK 5 FLUID TEMP (MBK)	DSC	OF2	Card-06	Channel-B
V45P2115A	PRSD H2 TK 1 HTR CTRL SNSR C/O	DSC	OF2	Card-09	Channel-B

**Table 6.1.7-1. DSC listing for EGIL parameters sorted by DSC (continued)**

V76X4740E	AVN FEXT AV BAY 1 PYRO L/T	DSC	OF2	Card-09	Channel-A
V76X4750E	AVN FEXT AV BAY 1 PYRO RTST	DSC	OF2	Card-09	Channel-A
V76X4836E	NLG EMER EXT PYRO L/T-B	DSC	OF2	Card-09	Channel-A
V76X4839E	NLG EMER EXT PYRO RTST-B	DSC	OF2	Card-09	Channel-A
V76X4906E	LMG EMER EXT PYRO L/T-B	DSC	OF2	Card-09	Channel-A
V76X4909E	LMG EMER EXT PYRO RTST-B	DSC	OF2	Card-09	Channel-A
V76X4956E	RMG EMER EXT PYRO L/T-B	DSC	OF2	Card-09	Channel-A
V76X4959E	RMG EMER EXT PYRO RTST-B	DSC	OF2	Card-09	Channel-A
V76X6931E	ORB/ET FWD SEP PYRO L/T B	DSC	OF2	Card-09	Channel-A
V76X6933E	ORB/ET FWD SEP PYRO RTST B	DSC	OF2	Card-09	Channel-A
V45P1515A	PRSD O2 TK 5 HTR CONT SNSR C/O	DSC	OF2	Card-10	Channel-C
V45Q1505A	PRSD O2 TK 5 QUANTITY (MBK)	DSC	OF2	Card-11	Channel-B
V76V4902A	LMG EMER EXT PYRO B CAP VOLT	DSC	OF2	Card-12	Channel-A
V76V4736A	AVN FEXT AV BAY 1 PYRO CAP VOLT	DSC	OF2	Card-12	Channel-C
V76V4952A	RMG EMER EXT PYRO B CAP VOLT	DSC	OF2	Card-13	Channel-B
V76V4832A	NLG EMER EXT PYRO B CAP VOLT	DSC	OF2	Card-14	Channel-C
V45Q1205A	PRSD O2 TK 2 QUANTITY	DSC	OF2	Card-15	Channel-A
V76V4821A	NLG PYRO EXTEND ACTR-CAP VOLT-2	DSC	OF2	Card-16	Channel-A
V76V1700A	AC BUS 3 PHASE A VOLT	DSC	OF3	Card-01	Channel-A
V76V1701A	AC BUS 3 PHASE B VOLT	DSC	OF3	Card-01	Channel-B
V76V1702A	AC BUS 3 PHASE C VOLT	DSC	OF3	Card-01	Channel-C
V62Q0609A	SMOKE DETECTOR CONC N B-AV BAY 2	DSC	OF3	Card-04	Channel-A
V62Q0619A	SMOKE DETECTOR CONC N B-AV BAY 1	DSC	OF3	Card-04	Channel-B
V62Q0590A	SMOKE DET CONC N LEFT-FLIGHT DECK	DSC	OF3	Card-04	Channel-C
V76V0320A	CONTROL BUS CA1 VOLTAGE	DSC	OF3	Card-05	Channel-A
V76V0321A	CONTROL BUS CA2 VOLTAGE	DSC	OF3	Card-05	Channel-B
V76V0322A	CONTROL BUS CA3 VOLTAGE	DSC	OF3	Card-05	Channel-C
V76V3073A	FWD PCA-3 VOLTAGE	DSC	OF3	Card-05	Channel-D
V45P1200A	PRSD O2 TK 2 PRESSURE	DSC	OF3	Card-06	Channel-A
V45P1300A	PRSD O2 TK 3 PRESS (MID BODY KIT)	DSC	OF3	Card-06	Channel-B
V45P2200A	PRSD H2 TK 2 PRESSURE	DSC	OF3	Card-06	Channel-C
V45P2400A	PRSD H2 TK 4 PRESS (MID BODY KIT)	DSC	OF3	Card-06	Channel-D
V45Q2105A	PRSD H2 TK 1 QUANTITY	DSC	OF3	Card-09	Channel-A
V76X4720E	AVN FEXT AV BAY 2 PYRO L/T	DSC	OF3	Card-09	Channel-A
V76X4730E	AVN FEXT AV BAY 2 PYRO RTST	DSC	OF3	Card-09	Channel-A
V76X4823E	NLG PYRO EXTEND ACTR-L/T-1	DSC	OF3	Card-09	Channel-A
V76X4824E	NLG PYRO EXTEND ACTR-L/T-2	DSC	OF3	Card-09	Channel-A
V76X4826E	NLG PYRO EXTEND ACTR-RTST-1	DSC	OF3	Card-09	Channel-A
V76X4827E	NLG PYRO EXTEND ACTR-RTST-2	DSC	OF3	Card-09	Channel-A
V76X4835E	NLG EMER EXT PYRO L/T-A	DSC	OF3	Card-09	Channel-A
V76X4838E	NLG EMER EXT PYRO RTST-A	DSC	OF3	Card-09	Channel-A
V76X4905E	LMG EMER EXT PYRO L/T-A	DSC	OF3	Card-09	Channel-A
V76X4908E	LMG EMER EXT PYRO RTST-A	DSC	OF3	Card-09	Channel-A

**Table 6.1.7-1. DSC listing for EGIL parameters sorted by DSC (continued)**

V76X4955E	RMG EMER EXT PYRO L/T-A	DSC OF3	Card-09	Channel-A
V76X4958E	RMG EMER EXT PYRO RTST-A	DSC OF3	Card-09	Channel-A
V45P1215A	PRSD O2 TK 2 HTR CTRL SNSR C/O	DSC OF3	Card-10	Channel-D
V45Q2505A	PRSD H2 TK 5 QUANTITY (MBK)	DSC OF3	Card-11	Channel-B
V76V4900A	LMG EMER EXT PYRO A CAP VOLT	DSC OF3	Card-12	Channel-A
V76V4950A	RMG EMER EXT PYRO A CAP VOLT	DSC OF3	Card-14	Channel-A
V76V4716A	AVN FEXT AV BAY 2 PYRO CAP VOLT	DSC OF3	Card-14	Channel-D
V76V4820A	NLG PYRO EXTEND ACTR-CAP VOLT-1	DSC OF3	Card-16	Channel-A
V76V4830A	NLG EMER EXT PYRO A CAP VOLT	DSC OF3	Card-16	Channel-D
V45P2215A	PRSD H2 TK 2 HTR CTRL SNSR C/O	DSC OF3	Card-19	Channel-C
V45P0187A	FCP ALT PRODUCT H2O LINE PRESS	DSC OF3	Card-22	Channel-C
V45Q1405A	PRSD O2 TK 4 QUANTITY (MBK)	DSC OF3	Card-24	Channel-A
V45Q2405A	PRSD H2 TK 4 QUANTITY (MBK)	DSC OF3	Card-24	Channel-B
V45P1315A	PRSD O2 TK 3 HTR CONT SNSR C/O	DSC OF3	Card-24	Channel-C
V45P2465A	PRSD H2 TK 4(&5) HTR CONT SENSOR	DSC OF3	Card-24	Channel-D
V45Q1305A	PRSD O2 TK 3 QUANTITY (MBK)	DSC OF3	Card-25	Channel-A
V45Q2305A	PRSD H2 TK 3 QUANTITY (MBK)	DSC OF3	Card-25	Channel-B
V45P1465A	PRSD O2 TK 4(&5) HTR CONT SENSOR	DSC OF3	Card-25	Channel-C
V45P2315A	PRSD H2 TK 3 HTR CONT SNSR C/O	DSC OF3	Card-25	Channel-D
V45T0450A	H2O RELIEF LINE TEMP	DSC OF3	Card-26	Channel-A
V45T0213A	FUEL CELL NO 2 STACK INLET TEMP	DSC OF3	Card-26	Channel-B
V45T0182A	FCP NO 1 ALT PRODUCT H2O LINE TEMP	DSC OF3	Card-26	Channel-C
V45T1309A	PRSD O2 TK 3 HTR ASSY 2 TEMP(MBK)	DSC OF3	Card-27	Channel-A
V45T1409A	PRSD O2 TK 4 HTR ASSY 2 TEMP(MBK)	DSC OF3	Card-27	Channel-B
V45T1301A	PRSD O2 TK 3 FLUID TEMP (MBK)	DSC OF3	Card-27	Channel-C
V45T1401A	PRSD O2 TK 4 FLUID TEMP (MBK)	DSC OF3	Card-27	Channel-D
V45P1204A	PRSD O2 TK 2 ANNULUS VACUUM	DSC OF3	Card-28	Channel-A
V45P1304A	PRSD O2 TK 3 ANNULUS VACUUM (MBK)	DSC OF3	Card-28	Channel-B
V45P2204A	PRSD H2 TK 2 ANNULUS VACUUM	DSC OF3	Card-28	Channel-C
V45P2404A	PRSD H2 TK 4 ANNULUS VACUUM (MBK)	DSC OF3	Card-28	Channel-D
V45T1509A	PRSD O2 TK 5 HTR ASSY 2 TEMP(MBK)	DSC OF3	Card-29	Channel-A
V45T1501A	PRSD O2 TK 5 FLUID TEMP (MBK)	DSC OF3	Card-29	Channel-B
V45T2507A	PRSD H2 TK 5 HTR ASSY TEMP (MBK)	DSC OF3	Card-29	Channel-C
V45V0100A	FUEL CELL NO 1 VOLTAGE	DSC OM1	Card-01	Channel-A
V76V3091A	AFT PCA-4 VOLTAGE	DSC OM1	Card-01	Channel-B
V76V0300A	MAIN BUS C VOLTAGE	DSC OM1	Card-01	Channel-C
V76V0330A	ESS BUS 3AB VOLTAGE	DSC OM1	Card-01	Channel-D
V45T1107A	PRSD O2 TK 1 HTR ASSY 1 TEMP	DSC OM1	Card-02	Channel-A
V45T2107A	PRSD H2 TK 1 HTR ASSY TEMP	DSC OM1	Card-02	Channel-B
V45T1307A	PRSD O2 TK 3 HTR ASSY 1 TEMP(MBK)	DSC OM1	Card-02	Channel-C
V45T2301A	PRSD H2 TK 3 FLUID TEMP (MBK)	DSC OM1	Card-02	Channel-D
V45T0130A	FUEL CELL NO 1 CONDENSER EXIT TEMP	DSC OM1	Card-04	Channel-A
V45T0181A	FCP NO 1 PRODUCT H2O LINE TEMP	DSC OM1	Card-04	Channel-B

**Table 6.1.7-1. DSC listing for EGIL parameters sorted by DSC (continued)**

V45T0345A	FUEL CELL NO 3 COOLANT RETURN TEMP	DSC OM1	Card-04	Channel-C
V45T0412A	FC NO 1 H2O RELIEF VALVE TEMP	DSC OM1	Card-04	Channel-D
V45T0120A	FUEL CELL NO 1 STACK COOL OUT TEMP	DSC OM1	Card-05	Channel-A
V45P0147A	FUEL CELL 1 COOLANT PRESSURE	DSC OM1	Card-06	Channel-B
V45P1140A	PRSD O2 MANF 1 PRESSURE	DSC OM1	Card-06	Channel-C
V45C0101A	FUEL CELL NO 1 CURRENT	DSC OM1	Card-09	Channel-A
V45C0201A	FUEL CELL NO 2 CURRENT	DSC OM1	Card-09	Channel-B
V45C0301A	FUEL CELL NO 3 CURRENT	DSC OM1	Card-09	Channel-C
V45T1207A	PRSD O2 TK 2 HTR ASSY 1 TEMP	DSC OM1	Card-10	Channel-A
V45T2201A	PRSD H2 TK 2 FLUID TEMP	DSC OM1	Card-10	Channel-B
V45T1201A	PRSD O2 TK 2 FLUID TEMP	DSC OM1	Card-10	Channel-C
V45T2307A	PRSD H2 TK 3 HTR ASSY TEMP (MBK)	DSC OM1	Card-10	Channel-D
V45T0600A	FCP O2 VENT LINE TEMP	DSC OM1	Card-11	Channel-B
V45T0700A	FCP H2 VENT LINE TEMP 2	DSC OM1	Card-11	Channel-D
V45P2140A	PRSD H2 MANF 1 PRESSURE	DSC OM1	Card-14	Channel-B
V45P1104A	PRSD O2 TK 1 ANNULUS VACUUM	DSC OM1	Card-15	Channel-A
V45P1404A	PRSD O2 TK 4 ANNULUS VACUUM (MBK)	DSC OM1	Card-15	Channel-B
V45P2104A	PRSD H2 TK 1 ANNULUS VACUUM	DSC OM1	Card-15	Channel-C
V45P2304A	PRSD H2 TK 3 ANNULUS VACUUM (MBK)	DSC OM1	Card-15	Channel-D
V45V0300A	FUEL CELL NO 3 VOLTAGE	DSC OM2	Card-01	Channel-A
V76V3092A	AFT PCA-5 VOLTAGE	DSC OM2	Card-01	Channel-B
V76V0200A	MAIN BUS B VOLTAGE	DSC OM2	Card-01	Channel-C
V76V0230A	ESS BUS 2CA VOLTAGE	DSC OM2	Card-01	Channel-D
V45T1109A	PRSD O2 TK 1 HTR ASSY 2 TEMP	DSC OM2	Card-02	Channel-A
V45T2101A	PRSD H2 TK 1 FLUID TEMP	DSC OM2	Card-02	Channel-B
V45T1407A	PRSD O2 TK 4 HTR ASSY 1 TEMP(MBK)	DSC OM2	Card-02	Channel-C
V45T2401A	PRSD H2 TK 4 FLUID TEMP (MBK)	DSC OM2	Card-02	Channel-D
V45T0245A	FUEL CELL NO 2 COOLANT RETURN TEMP	DSC OM2	Card-04	Channel-A
V45T0381A	FCP NO 3 PRODUCT H2O LINE TEMP	DSC OM2	Card-04	Channel-B
V45T0330A	FUEL CELL NO 3 CONDENSER EXIT TEMP	DSC OM2	Card-04	Channel-C
V45T0432A	FC NO 3 H2O RELIEF VALVE TEMP	DSC OM2	Card-04	Channel-D
V45T0320A	FUEL CELL NO 3 STACK COOL OUT TEMP	DSC OM2	Card-05	Channel-A
V45P1145A	PRSD O2 MANF 2 PRESSURE	DSC OM2	Card-06	Channel-A
V45P0347A	FUEL CELL 3 COOLANT PRESSURE	DSC OM2	Card-06	Channel-B
V45V0200A	FUEL CELL NO 2 VOLTAGE	DSC OM2	Card-09	Channel-A
V76V0100A	MAIN BUS A VOLTAGE	DSC OM2	Card-09	Channel-C
V76V0130A	ESS BUS 1BC VOLTAGE	DSC OM2	Card-09	Channel-D
V45T2207A	PRSD H2 TK 2 HTR ASSY TEMP	DSC OM2	Card-10	Channel-A
V45T1209A	PRSD O2 TK 2 HTR ASSY 2 TEMP	DSC OM2	Card-10	Channel-B
V45T1101A	PRSD O2 TK 1 FLUID TEMP	DSC OM2	Card-10	Channel-C
V45T2407A	PRSD H2 TK 4 HTR ASSY TEMP (MBK)	DSC OM2	Card-10	Channel-D
V45T0455A	FCP H2O RELIEF NOZZLE TEMP A	DSC OM2	Card-11	Channel-D
V45T0145A	FUEL CELL NO 1 COOLANT RETURN TEMP	DSC OM2	Card-12	Channel-A

**Table 6.1.7-1. DSC listing for EGIL parameters sorted by DSC (continued)**

V45T0230A	FUEL CELL NO 2 CONDENSER EXIT TEMP	DSC OM2	Card-12	Channel-B
V45T0281A	FCP NO 2 PRODUCT H2O LINE TEMP	DSC OM2	Card-12	Channel-C
V45T0313A	FUEL CELL NO 3 STACK INLET TEMP	DSC OM2	Card-12	Channel-D
V45T0220A	FUEL CELL NO 2 STACK COOL OUT TEMP	DSC OM2	Card-13	Channel-A
V45P0247A	FUEL CELL 2 COOLANT PRESSURE	DSC OM2	Card-14	Channel-C
V45P2145A	PRSD H2 MANF 2 PRESSURE	DSC OM2	Card-15	Channel-A
V45T0282A	FCP NO 2 ALT PRODUCT H2O LINE TEMP	DSC OM2	Card-28	Channel-D
V45T0382A	FCP NO 3 ALT PRODUCT H2O LINE TEMP	DSC OM3	Card-04	Channel-D
V45T0113A	FUEL CELL NO 1 STACK INLET TEMP	DSC OM3	Card-07	Channel-A
V45T0422A	FC NO 2 H2O RELIEF VALVE TEMP	DSC OM3	Card-07	Channel-B
V45T0456A	FCP H2O RELIEF NOZZLE TEMP B	DSC OM3	Card-08	Channel-D
V45P3100A	PRSD O2 TK 6 PRESS	DSC OP1	Card-02	Channel-A
V45P3300A	PRSD O2 TK 8 PRESS	DSC OP1	Card-02	Channel-B
V45P4100A	PRSD H2 TK 6 PRESS	DSC OP1	Card-02	Channel-C
V45P4300A	PRSD H2 TK 8 PRESS	DSC OP1	Card-02	Channel-D
V45Q3105A	PRSD O2 TK 6 QUANTITY	DSC OP1	Card-03	Channel-A
V45Q3305A	PRSD O2 TK 8 QUANTITY	DSC OP1	Card-03	Channel-B
V45Q4105A	PRSD H2 TK 6 QUANTITY	DSC OP1	Card-03	Channel-C
V45Q4305A	PRSD H2 TK 8 QUANTITY	DSC OP1	Card-03	Channel-D
V45T3107A	PRSD O2 TK 6 HTR ASSY 1 TEMP	DSC OP1	Card-04	Channel-A
V45T3409A	PRSD O2 TK 9 HTR ASSY 2 TEMP	DSC OP1	Card-04	Channel-B
V45T4201A	PRSD H2 TK 7 FLUID TEMP	DSC OP1	Card-04	Channel-C
V45T3201A	PRSD O2 TK 7 FLUID TEMP	DSC OP1	Card-05	Channel-A
V45T3307A	PRSD O2 TK 8 HTR ASSY 1 TEMP	DSC OP1	Card-05	Channel-B
V45T4107A	PRSD H2 TK 6 HTR ASSY TEMP	DSC OP1	Card-05	Channel-C
V45T4401A	PRSD H2 TK 9 FLUID TEMP	DSC OP1	Card-05	Channel-D
V45T3209A	PRSD O2 TK 7 HTR ASSY 2 TEMP	DSC OP1	Card-06	Channel-A
V45T3401A	PRSD O2 TK 9 FLUID TEMP	DSC OP1	Card-06	Channel-B
V45T4307A	PRSD H2 TK 8 HTR ASSY TEMP	DSC OP1	Card-06	Channel-C
V45T0902A	PRSD CPC HEAT SINK TEMP 1	DSC OP1	Card-07	Channel-A
V45T0904A	PRSD CPC HEAT SINK TEMP 3	DSC OP1	Card-07	Channel-B
V45P3115A	PRSD O2 TK 6 HTR CONT SNSR C/O	DSC OP1	Card-10	Channel-A
V45P3315A	PRSD O2 TK 8 HTR CONT SNSR C/O	DSC OP1	Card-10	Channel-B
V45P4115A	PRSD H2 TK 6 HTR CONT SNSR C/O	DSC OP1	Card-10	Channel-C
V45P4315A	PRSD H2 TK 8 HTR CONT SNSR C/O	DSC OP1	Card-10	Channel-D
V45P3200A	PRSD O2 TK 7 PRESS	DSC OP2	Card-02	Channel-A
V45P3400A	PRSD O2 TK 9 PRESS	DSC OP2	Card-02	Channel-B
V45P4200A	PRSD H2 TK 7 PRESS	DSC OP2	Card-02	Channel-C
V45P4400A	PRSD H2 TK 9 PRESS	DSC OP2	Card-02	Channel-D
V45Q3205A	PRSD O2 TK 7 QUANTITY	DSC OP2	Card-03	Channel-A
V45Q3405A	PRSD O2 TK 9 QUANTITY	DSC OP2	Card-03	Channel-B
V45Q4205A	PRSD H2 TK 7 QUANTITY	DSC OP2	Card-03	Channel-C

**Table 6.1.7-1. DSC listing for EGIL parameters sorted by DSC (concluded)**

V45Q4405A	PRSD H2 TK 9 QUANTITY	DSC	OP2	Card-03	Channel-D
V45T3207A	PRSD O2 TK 7 HTR ASSY 1 TEMP	DSC	OP2	Card-04	Channel-A
V45T3309A	PRSD O2 TK 8 HTR ASSY 2 TEMP	DSC	OP2	Card-04	Channel-B
V45T4101A	PRSD H2 TK 6 FLUID TEMP	DSC	OP2	Card-04	Channel-C
V45T3101A	PRSD O2 TK 6 FLUID TEMP	DSC	OP2	Card-05	Channel-A
V45T3407A	PRSD O2 TK 9 HTR ASSY 1 TEMP	DSC	OP2	Card-05	Channel-B
V45T4207A	PRSD H2 TK 7 HTR ASSY TEMP	DSC	OP2	Card-05	Channel-C
V45T4301A	PRSD H2 TK 8 FLUID TEMP	DSC	OP2	Card-05	Channel-D
V45T3109A	PRSD O2 TK 6 HTR ASSY 2 TEMP	DSC	OP2	Card-06	Channel-A
V45T3301A	PRSD O2 TK 8 FLUID TEMP	DSC	OP2	Card-06	Channel-B
V45T4407A	PRSD H2 TK 9 HTR ASSY TEMP	DSC	OP2	Card-07	Channel-C
V45T0903A	PRSD CPC HEAT SINK TEMP 2	DSC	OP2	Card-07	Channel-A
V45T0905A	PRSD CPC HEAT SINK TEMP 4	DSC	OP2	Card-10	Channel-B
V45P3215A	PRSD O2 TK 7 HTR CONT SNSR C/O	DSC	OP2	Card-10	Channel-A
V45P3415A	PRSD O2 TK 9 HTR CONT SNSR C/O	DSC	OP2	Card-10	Channel-B
V45P4215A	PRSD H2 TK 7 HTR CONT SNSR C/O	DSC	OP2	Card-10	Channel-C
V45P4415A	PRSD H2 TK 9 HTR CONT SNSR C/O	DSC	OP2	Card-10	Channel-D
V75X2185E	PALLET DSC 2 BITE	DSC	OP2	Card-IT	Channel-B

**TITLE**

DELETED (MOVED TO SECTION 6.2.1)



TITLE

USEFUL FORMULAS

FUEL CELLS

32 cells per substack

96 cells per Fuel Cell (FC) (3 substacks make 1 FC stack)

H<sub>2</sub> consumption= 0.002653 lb/A-h or 376.9 A-h/lb

O<sub>2</sub> consumption= 0.02106 lb/A-h or 47.5 A-h/lb

H<sub>2</sub>O production = 0.02371 lb/A-h or 42.2 A-h/lb  
or 0.85 lb/hr of H<sub>2</sub>O per kW @ 27.9 V DC

O<sub>2</sub>: Inlet pressure limits = 100 to 1050 psia

Inlet temp limits = -260 to +170° F

Internal reg pressure = 55 to 65 psia (4.5 to 6 psi > H<sub>2</sub>)

Purge O<sub>2</sub> flow = 3.3 lb/hr max (2 min nominally) plus 0.7  
lb/hr/kW @ 30.1 V DC; quantity = 0.11 lb/purge max

Purge vent pressure = 30 psia max at 3.3 lb/hr flow

Purity = 99.989 mole percent min

Density = 0.08921 lb/ft<sup>3</sup> at 32° F, 1 atm

H<sub>2</sub>: Inlet pressure limits = 100 to 335 psia

Inlet temp limits = -402 to +170° F

Internal reg pressure = 55 to 65 psia (4.5 to 6.0 psi < O<sub>2</sub>)

Purge H<sub>2</sub> flow = 0.9 lb/hr maximum (2 min nominally) plus 0.09  
lb/hr/kW @ 29.5 V DC; quantity = 0.03 lb/purge max

**(Note: purge flows are max spec)**

Purge vent pressure = 30 psia max at 0.9 lb/hr flow

Purity = 99.99 mole percent min

Density = 0.005611 lb/ft<sup>3</sup> at 32° F, 1 atm

$$\text{O}_2 \text{ flow (lb / hr)} = \frac{\text{fuel cell amps}}{47.5}$$

$$\text{H}_2 \text{ flow (lb / hr)} = \frac{\text{fuel cell amps}}{377}$$

Trapped gas:

$$W = \frac{PVm}{RT}$$

where  $R = \frac{0.73 \text{ ft}^3 \text{ atm}}{\text{mole } ^\circ\text{R}}$

W = mass in lb

P = pressure in atm

V = volume in ft<sup>3</sup>

m = mole wt in lb/mole  
32 for O<sub>2</sub>; 2 for H<sub>2</sub>

T = temp in °R

or  $R = 18510 \text{ (in.}^3 \text{ psi)/(mole } ^\circ\text{R)}$  P = pressure in psia  
for

V = volume in in.<sup>3</sup>

°R = °F + 459.69° or 0° R = -459.69° F

**ELECTRIC**

$$\text{AC watts} = (0.765) \text{ DC W or DC } \frac{\text{ACW}}{0.765}$$

where 0.765 is inverter efficiency

$$\text{AC amperes/phase} \frac{\text{ACW/phase}}{\text{PF}(V_{\text{AC}})} = A/\Phi$$

where PF = power factor

V<sub>AC</sub> = volts AC

AC power in  
watts:

$$P = VI \cos \phi$$

where V = RMS AC volts

I = RMS AC current in amps

φ = phase angle between V and I

P = power in watts

VARS = volt amps reactive

PF = power factor

$$\text{PF} = \cos \phi$$

$$P = VI * \text{PF}$$

6.1.9-2

$$VI^2 = P^2 + VARS^2$$

$$VARS = VI * (1 - PF^2)^{0.5}$$

$$VI = (P^2 + VARS^2)^{0.5}$$

$$P = VI = RI^2$$

DC power in watts:

where V = volts DC  
I = amps DC  
R = ohms

$$FC \text{ amps} = (47.5)O_2 \text{ flow} = (377) H_2 \text{ flow}$$

HEAT

Direct BTU/hr = 3.414 \* watts  
conversion:

Estimate for converting fuel cell load (kW) to Freon (K BTU/hr) heat load.

$$\frac{K \text{ BTU}}{\text{hr}} = (4.5 \text{ to } 5) * \text{kW}$$

MISCELLANEOUS

$$1 \text{ joule} = 1 \text{ W-sec} = 2.778 \times 10^{-7} \text{ kW-hr or } 1 \text{ W} = 1 \text{ joule/sec}$$

$$1 \text{ W-hr} = 3600 \text{ joules}$$

$$1 \text{ psi} = 6.8046 \times 10^{-2} \text{ atm}$$

Speed of light:  $c = 2.99776 \times 10^{10} \text{ cm/sec or approx } 3 \times 10^8 \text{ m/sec}$

Gravity:  $g = 9.8066 \text{ m/s}^2 = 32.174 \text{ ft/s}^2 \text{ at mean sea level}$

Charge per electron:  $e^- = -1.602 \times 10^{-19} \text{ coulombs}$   
 $m_e = 9.109 \times 10^{-31} \text{ kg}$

Avogadro no.:  $N_A = 6.0228 \times 10^{23}/\text{mole}$

Total resistance in series:  $R_t = R_1 + R_2 + R_3 + \dots$

in parallel:  $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$

## TITLE

BOEING/NORTH AMERICAN (ROCKWELL) SCHEMATIC SYSTEM BRIEF

## PURPOSE

The purpose of this brief is to familiarize the flight controller with finding information about a component of a particular system in the Boeing/North American (B/NA) system schematics.


## BACKGROUND

In general, the orbiter consists of several subsystems, each represented by a system schematic. The system schematic is drawn on a large L-size drawing. A drawing number is associated with these schematics for each subsystem. The drawing numbers for the orbiter and related items consist of 11 characters and are typically defined as VS70-YYXXXZ, where V is for vehicle end item; S is for schematic; 70 is for the project number, in which 70 means orbiter; 72 is for shuttle, which includes the Solid Rocket Booster (SRB), External Tank (ET), and Main Propulsion System (MPS); YY is for system number (see Table 6.1.10-1 for a listing of all orbiter system numbers); XXXX is the sequence number; and Z is the vehicle ID. Therefore, VS70-760309 is an example of the electrical power distribution and control of the main DC power distribution subsystem schematic.

**Note:** *An integrated system schematic exists for each system that is different from subsystem schematics. The schematic numbers are defined as VS70-945099, where V, S, and 70 have the same meaning as defined above, 9 means integrated schematic, 45 is the system number, and 099 is the vehicle number. In addition, wiring drawings are defined as above for the subsystem drawings, except that the S is replaced by a zero (i.e., V070-YYXXXZ).*

## SYSTEM SCHEMATIC INFORMATION

- A. The general note section included at the beginning of the system schematic is a good source of information for that particular system regarding system effectivity, most common wire size, and other pertinent information. Figure 6.1.10-1 shows an example of the general notes for the cryo subsystem schematic diagram (VS70-450222).
- B. The major system functions that are covered in a particular schematic are listed on the first sheet of each page of the system schematic. This listing will assist the user in finding some of the functions more quickly, rather than looking through each page of the schematic sheet. The schematic sheet usually consists of several pieces of paper.

- C. The system schematic depicts an end-to-end circuitry of each electrical load, starting from the panel control located at the top of the page and ending at the interface of the load at the bottom of the page. The power control is located in the middle of the schematic page. On the system schematic layout, an area number shows the areas through which the circuit is routed, as well as all interfaces associated with the circuit. (Reference Section 4.3.1 for area number definition.)
- D. The connector number, pin number, wire size, area number, and a harness number for each segment of wire in a circuit are also noted on the schematic. Figure 6.1.10-2 gives the definition of all the parts involved with the circuit.
- E. All redundant circuits are routed through separate harnesses. Each redundant path is represented by a specific code on the schematic. For example, a DC harness HO classification would assign HO1 to the first redundant circuit, HO2 to the second redundant circuit in a different harness, and HO3 to the third redundant circuit in the third harness. Other harness classifications are routed in the same manner.
- F. The item list, which is generally found on the last page of the system schematic, provides component information regarding the reference designator, part number, component description, and component value. Figure 6.1.10-3 is an example of an item list.
- G. The symbol  means that the circuit is continued in a different place in the same schematic. The letter “a” represents the sheet number, and the letter “b” represents the zone location.

## SHUTTLE DRAWING SYSTEM

Many of the referenced drawings are now available electronically via the Shuttle Drawing System (SDS). The SDS is a web-based application hosted on United Space Alliance (USA) servers, requiring a login password and ID.

**Table 6.1.10-1. System numbers**

00	GENERAL
06	Orbiter TCS
07	Thermal/Aero Dynamics
08	Structural Dynamics
09	Orbiter TPS
10	Wing
11	Wing Leading Edge
12	Wing Box
13	Elevon
16	Wing TCS
19	Wing TPS
20	Vertical Stabilizer
21	Vertical Stabilizer Leading Edge
22	Vertical Fin
23	Rudder/Speed Brake
26	Vertical Stabilizer TCS
29	Vertical Stabilizer TPS
31	Fuselage, Upper Fwd
32	Fuselage, Lower Fwd
33	Crew Module
34	Fuselage Mid
35	Fuselage, Aft
36	Fuselage TCS
37	Payload Bay Doors
38	Purge, Vent and Drain
40	PROPULSION SYSTEMS
41	Main Propulsion
42	Reaction Control
43	Orbital Maneuvering
45	Electrical Power Generation
46	Auxiliary Power Unit

**Table 6.1.10-1. System numbers (concluded)**

50	MECHANICAL SYSTEMS
51	Landing Gear
52	Brake and Skid Control
53	Docking Mechanism
54	Payload Retention/Deployment
55	Accommodations
56	Ordnance/Pyrotechnics
57	Attachment/Separation
58	Aero Surface Flight Control
59	Hydraulic Miscellaneous
60	ENVIRONMENTAL CONTROL and LIFE SUPPORT SYSTEMS
61	Atmospheric Revitalization
62	Life Support
63	Thermal Control
64	Airlock Support
65	Crew Provisions and
66	Accommodations
67	Crew Equipment Biomedical
70	AVIONICS SYSTEMS
71	Guidance, and Navigation
72	Data Processing
73	Displays & Controls
74	Communications & Tracking
75	Instrumentation - Operational
76	Electrical Power Distribution & Control
77	Interconnecting Wiring
78	Instrumentation - Development
79	FLIGHT CONTROL SYSTEMS
80	STRUCTURE ACCESS/PENETRATION
99	Automatic Checkout Equipment

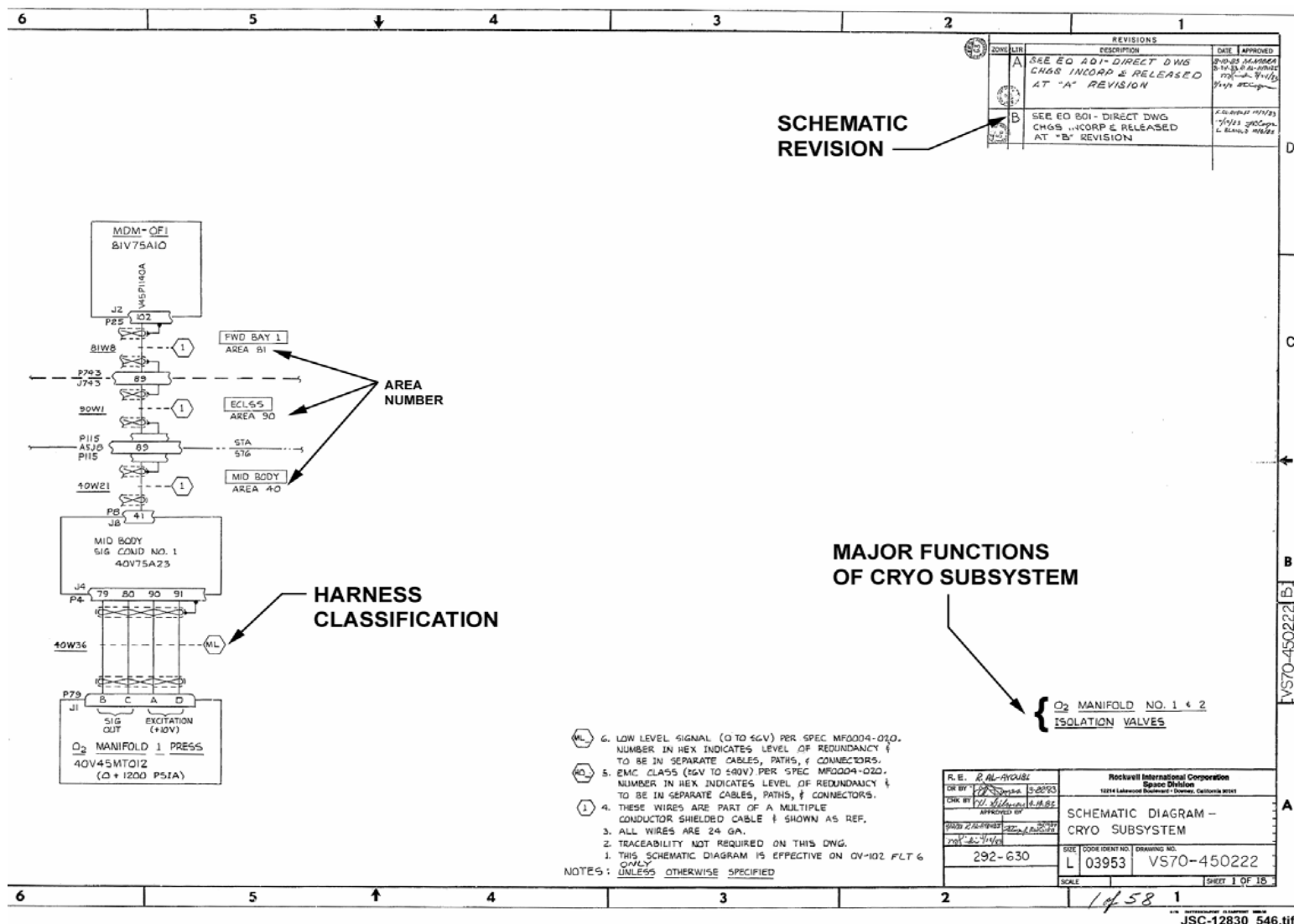
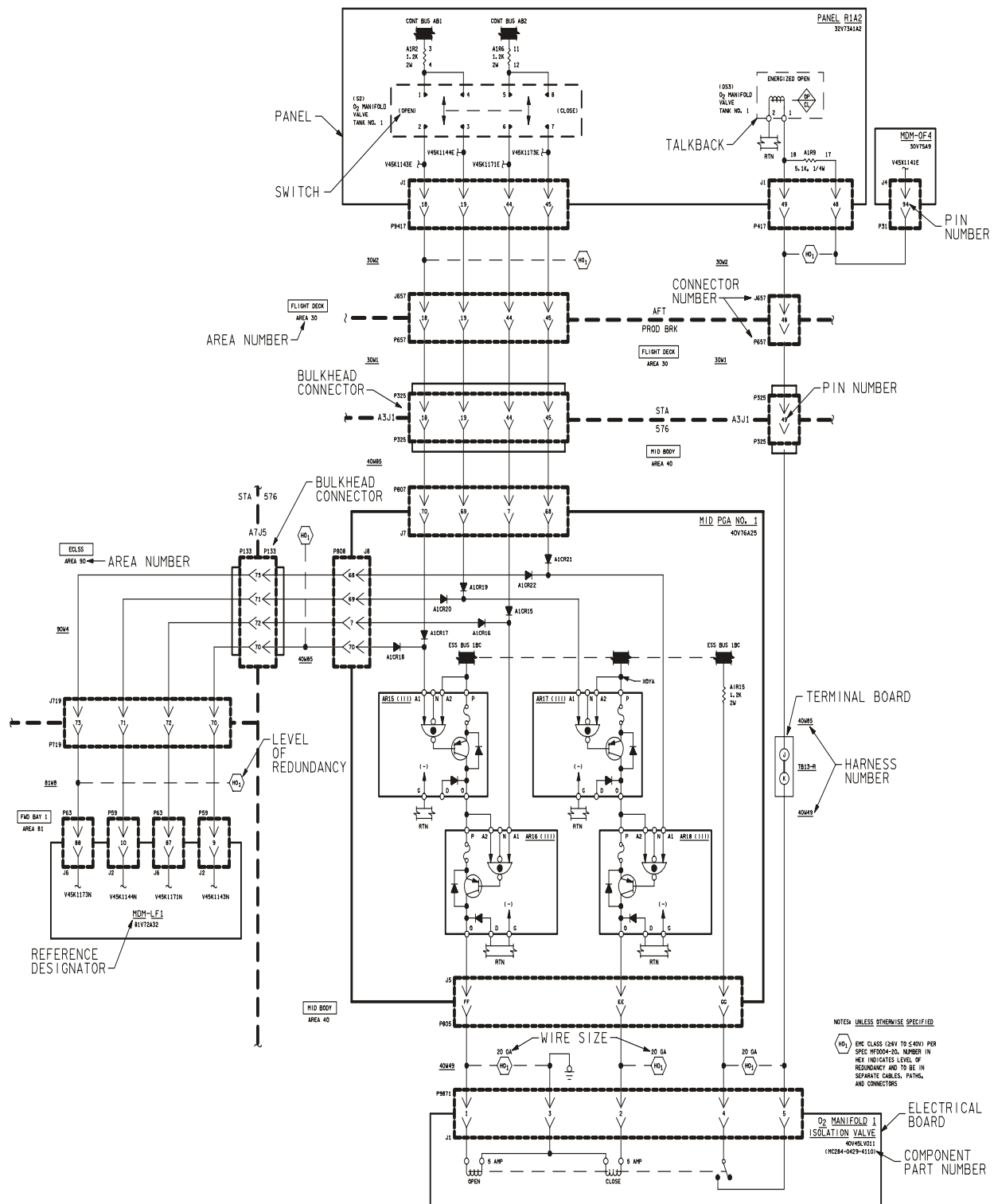


Figure 6.1.10-1. Example of typical schematic diagram

Verify that this is the correct version before use

6.1.10-5





128306806, ART. 4

Figure 6.1.10-2. Definition of all parts involved with a circuit

ITEM LIST				
REFERENCE DESIGNATION	PART OR IDENTIFICATION NO.	NOMENCLATURE OR DESCRIPTION	COMPONENT VALUE	ZONE
40V76A142		H <sub>2</sub> /O <sub>2</sub> CONT BOX 2		
F1	ME451-0009-1003	FUSE	3 AMP	132
F2	ME451-0009-1021	FUSE	5 AMP	132
F3	ME451-0009-1003	FUSE	3 AMP	140
F4	ME451-0009-1003	FUSE	3 AMP	283
F5	ME451-0009-1003	FUSE	3 AMP	127
F6	ME451-0009-1021	FUSE	5 AMP	127
F7	ME451-0009-1003	FUSE	3 AMP	251
F8	ME451-0009-1003	FUSE	3 AMP	251
F9	ME451-0009-1003	FUSE	3 AMP	266
F10	ME451-0009-1003	FUSE	3 AMP	266
F11	ME451-0009-1003	FUSE	3 AMP	141
F12	ME451-0009-1003	FUSE	3 AMP	284
R1	RE77G20R0	RESISTOR	20Ω, ±1%, 75W	252
RPC-1	MC450-0017-1050	REMOTE PWR CONT	5 AMP	132
RPC-2	MC450-0017-1050	REMOTE PWR CONT	5 AMP	132
RPC-3	MC450-0017-1050	REMOTE PWR CONT	5 AMP	127
RPC-4	MC450-0017-1050	REMOTE PWR CONT	5 AMP	127
RPC-5	MC450-0017-1100	REMOTE PWR CONT	10 AMP	266
RPC-6	MC450-0017-1100	REMOTE PWR CONT	10 AMP	265
RPC-7	MC450-0017-1100	REMOTE PWR CONT	10 AMP	264
RPC-8	MC450-0017-1100	REMOTE PWR CONT	10 AMP	264
RPC-9	MC450-0017-1100	REMOTE PWR CONT	10 AMP	254
RPC-10	MC450-0017-1100	REMOTE PWR CONT	10 AMP	253
RPC-11	MC450-0017-1100	REMOTE PWR CONT	10 AMP	251
RPC-12	MC450-0017-1100	REMOTE PWR CONT	10 AMP	252
RPC-13	MC450-0017-1030	REMOTE PWR CONT	3 AMP	265
J1	ME414-0234-5214	CONN		
J2	ME414-0234-5213	CONN		
J3	NBOE14-4SNT	CONN		
J4	NBOE14-4SWT	CONN		
J5	ME414-0234-5208	CONN		
J6	ME414-0234-5209	CONN		
J7	NLSOT22-355	CONN		
J8	NLSOT22-355A (CONT ZONE 436)	CONN		
54V75A13	MCG15-0004-4400	MDM-OA1		
J1	NLSOE24-35P	CONN		
J3	NLSOE24-35PB	CONN		
J5	NLSOE24-35SC	CONN		
J6	NLSOE24-35SB	CONN		
J7	NLSOE24-35SA	CONN		
J8	NLSOE24-35S	CONN		
55V75A14	MC615-0004-4400	MDM-OA2		
J1	NLSOE-24-35P	CONN		
J3	NLSOE-24-35PB	CONN		
J5	NLSOE-24-35SC	CONN		
J6	NLSOE-24-35SB	CONN		
J7	NLSOE-24-35SA	CONN		
J8	NLSOE-24-35S	CONN		

ITEM LIST				
REFERENCE DESIGNATION	PART OR IDENTIFICATION NO.	NOMENCLATURE OR DESCRIPTION	COMPONENT VALUE	ZONE
40V76A142	V070-T64470	H <sub>2</sub> /O <sub>2</sub> CONT BOX 2		
A1	MC449-0185-0010	SIG COND		129
A2	MC449-0185-0009	SIG COND		259
A3R1	RLR07C5101GR	RESISTOR	5.1K, ±2%, 1/4W	266
A3R2	RLR07C5101GR	RESISTOR	5.1K, ±2%, 1/4W	266
A3R3	RLR07C5101GR	RESISTOR	5.1K, ±2%, 1/4W	251
A3R4	RLR07C5101GR	RESISTOR	5.1K, ±2%, 1/4W	251
AR3	MC447-0261-0002	DRIVER MODULE ( I )		130
AR4	MC447-0261-0002	DRIVER MODULE ( I )		131
AR8	MC447-0263-0002	DRIVER MODULE ( III )		140
AR9	MC447-0261-0002	DRIVER MODULE ( I )		141
AR10	MC447-0263-0002	DRIVER MODULE ( III )		283
AR11	MC447-0261-0002	DRIVER MODULE ( I )		284
AR12	MC447-0261-0002	DRIVER MODULE ( I )		263
AR13	MC447-0261-0002	DRIVER MODULE ( I )		262
AR14	MC447-0261-0002	DRIVER MODULE ( I )		262
AR15	MC447-0261-0002	DRIVER MODULE ( I )		261
AR16	MC447-0261-0002	DRIVER MODULE ( I )		260
AR17	MC447-0261-0002	DRIVER MODULE ( I )		260
AR19	MC447-0261-0002	DRIVER MODULE ( I )		256
AR20	MC447-0261-0002	DRIVER MODULE ( I )		256
AR21	MC447-0261-0002	DRIVER MODULE ( I )		254
AR22	MC447-0261-0002	DRIVER MODULE ( I )		255
AR23	MC447-0261-0002	DRIVER MODULE ( I )		263
CLD-1	MC431-0137-0001	CURRENT LEVEL DET		264
CLD-2	MC431-0137-0001	CURRENT LEVEL DET		264
CLD-3	MC431-0137-0001	CURRENT LEVEL DET		253
CLD-4	MC431-0137-0001	CURRENT LEVEL DET		253
CR1	JANTXVIN4246	DIODE	1 AMP	132
CR2	JANTXVIN4246	DIODE	1 AMP	260
CR3	JANTXVIN4246	DIODE	1 AMP	132
CR4	JANTXVIN4246	DIODE	1 AMP	132
CR5	JANTXVIN4246	DIODE	1 AMP	132
CR7	JANTXVIN4246	DIODE	1 AMP	132
CR9	JANTXVIN4246	DIODE	1 AMP	132
CR10	JANTXVIN4246	DIODE	1 AMP	127
CR11	JANTXVIN4246	DIODE	1 AMP	127
CR13	JANTXVIN4246	DIODE	1 AMP	127
CR15	JANTXVIN4246	DIODE	1 AMP	126
CR17	JANTXVIN4246	DIODE	1 AMP	126
CR19	JANTXVIN4246	DIODE	1 AMP	266
CR21	JANTXVIN4246	DIODE	1 AMP	266
CR23	JANTXVIN4246	DIODE	1 AMP	266
CR25	JANTXVIN4246	DIODE	1 AMP	266
CR27	JANTXVIN4246	DIODE	1 AMP	262
CR28	JANTXVIN4246	DIODE	1 AMP	256
CR29	JANTXVIN4246	DIODE	1 AMP	251
CR31	JANTXVIN4246	DIODE	1 AMP	251
CR33	JANTXVIN4246	DIODE	1 AMP	251
CR35	JANTXVIN4246	DIODE	1 AMP	252
CR37	JANTXVIN4246	DIODE	1 AMP	265
CR38	JANTXVIN4246	DIODE	1 AMP	265
CR39	JANTXVIN4246	DIODE	1 AMP	265
CR40	JANTXVIN4246	DIODE	1 AMP	265

128306807. ART 1

Figure 6.1.10-3. Example of an item list

**TITLE**

IN-FLIGHT ANOMALIES

**PURPOSE**

Provide a brief summary of all EGIL-related In-Flight Anomalies (IFAs) generated from STS-1 through STS-105. This summary will be kept on the server and will be updated after each successive mission. Periodically, the CHB will be updated to include the most recent entries. Note that from STS-3 through STS-36, EGIL console responsibilities were part of the EECOM discipline, and appropriate IFAs are included here. Prelaunch anomalies and problem reports were also part of the IFA reporting system through STS-36 and are included, as well. IFAs from other disciplines that are electrical in nature also appear here.

STS-1	OV-102
EGIL-1	FC3 pH HIGH AT T-9 FOR 2 MINUTES
EGIL-1	OF1/OF4 CB POPPED, 50 AMP SHORT ON MNB O15, SHORTED DSC
EGIL-2	LOW FLOW ON AUTO PURGE. MANUAL PURGE REQUIRED
EGIL-3	PURGE LINE TEMP READING 330 DEGREES
EGIL-4	APC6 AMPS OSH
PROB-01	ALC2
PROB-10	O2 MANF 1,2 PRESSURE READING LOW
PROB-23	WATER RELIEF NOZZLE TEMP HIGH
PROB-30	LIQUID H2 T-0 UMB GROUND FILL DISCONNECT SEAL LOOSE
PROB-57	PAYLOAD BAY FLOODLIGHT FAILED
STS-2	OV-102
EGIL-1	FC2 VOLTS BIASED 0.7 VOLTS LOW
EGIL-2	FC2 O2 FLOW HIGH. MANUAL PURGE REQUIRED
EGIL-3	FC1 pH, FC FLOODING
EGIL-4	TWO 20 AMP SPIKES-SIR-A OPS
EGIL-5	UNEXPLAINED RESPONSE TO CIRC PUMP OPS
EGIL-6	AC3 PHASE A 1.5 AMP FOR 50 SECONDS-FOOD WARMER
EGIL-7	FC3 O2 FLOWMETER ERRATIC
EECOM-6	CB ON ML86B FOUND OPEN AND RESET
PROB-10	MA73C CB OPEN
PROB-18	FC1 H2 FLOW METER READS LOW
PROB-35	LIQUID H2 T-0 UMB GROUND FILL DISCONNECT SEAL LOOSE

STS-3	OV-102	
EECOM-01	CRYO H2 TK1 HTR B FAIL ON IN AUTO /	CL
EECOM-02	CRYO O2 TK FALSE AUTO TRIP /	CL
EECOM-07	PORT PLBD AFT BHD LATCH FAIL TO LATCH /	CL
EECOM-09	CRYO H2 TK 2 QTY OFFSCALE HIGH /	CL
EECOM-15	MCA PWR AC 3 FWD 3 CB WILL NOT CLOSE /	CL
EECOM-17	FC1 TCE VALVE CONTROLS LOW /	CL
EECOM-19	PYLD PRIM MNC TB FAIL OFF /	CL
EECOM-21	MMCA 3 OPS STAT 4 IND "0", S/B "1" /	CL
STS-4	OV-102	
EECOM-02	FC 1 EXIT TEMP NUISANCE ALARMS /	CL
EECOM-03	H2 TK 2 QTY XDCCR SHIFT /	CL
EECOM-04	H2 TK 4 HTR A FAIL /	CL
EECOM-05	PLB FLOODLIGHT FAIL /	CL
EECOM-07	H2 TK 2 HTR B FAIL /	CL
EECOM-08	FES HTR SHORT CIRCUIT /	CL
STS-5	OV-102	
EECOM-01	AFT MISSION & EVENT TIMERS INOPERATIVE / MINTER	CL
EECOM-04	PLB FWD PORT & STBD FLOOD LTS FAILED / MINTER	CL
EECOM-06	ACI PHASE B INVERTER TRIPOFF / MINTER	CL
STS-6	OV-99	
EECOM-01	AV BAY 1 FAN B STALL / MCLENDON	CL
EECOM-05	HUM SEP B SHORT / MCLENDON	CL
EECOM-09	FC2 H2 FLOW XDCCR FAILURE / CLARK	CL
STS-7	OV-99	
EECOM-04	UNKNOWN CB MNB SUPPLY H2O TK B INLET FOUND OPEN / HUMMELL	CL
STS-8	OV-99	

STS-9	OV-102	
EECOM-07	ORBITER CRYO O2 TANK 3 QTY XDUCER / HUMMELL	CL
EECOM-05A	H2O TK B QTY INCREASING AT GREATER RATE THAN H2O BEING PRODUCED BY FUEL CELLS / EVANS	CL
EECOM-10	PAYLOAD BAY FLOODLIGHT FAIL TO START SIGNATURE / BROWN	CL
STS-41B	OV-99	
PLD-01	AEM POWER CABLE NOT LOCKED / A. BURGE	OP
PROP-06A	RRCS MANF 5 DRIVER POWER FAILED / L. HAUTZINGER AFT LCA2 FAILURE	CL
STS-41C	OV-99	
CRSYS-01	LOW AIR FLOW ON BOTH FAN SEPS	
EECOM-01	FC3 O2 FLOW TRANSDUCER BIAS	
EECOM-02	AMCA 2 OP STAT 1 FAILED	
STS-41D	OV-103	
EECOM-01	FC1 SS DELTA VOLTS MEASUREMENT LOST	
STS-41G	OV-99	
DPS-01	DEU 2 FAIL (IFM: CABLE SWAP)	
PROB-20	PS FLOODLIGHT FAILED	
STS-51A	OV-103	
DPS-01	CRT 4 POWER SUPPLY FAIL	
EECOM-02	EMU 1 PWR SUPPLY / BATTERY CHARGER	
EECOM-03	WCS AC1 PHASE A CURRENT LOW	
EECOM-04	AFT PORT AND STBD PLB FLOODLIGHT FAIL	
EECOM-05	PCS SYS 2, O2 MANIF. LEAK / G. CONWAY	CL
STS-51-C	OV-103	
PROB-3C	FPC2 AMMETER NOISY	

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PROB-07	O2 TK2 HEATER CONTROL FAIL MOMENTARILY	
PROB-14	AC PHOTO FLOODLIGHT FAILED	
PROB-15	ACA 1 INTERMITTENT IN LIGHT CONTROL CIRCUIT	
STS-51D	OV-103	
EECOM-02	FWD MN B AMPS TRANSDUCER	
PROB-01	CRYO O2 TK 1 CONTROLLER AUTO MODE FAIL	
STS-51B	OV-99	
EECOM-01	MNC APC6 AMPS TRANSDUCER FAILURE / J. KOURI	CL
EECOM-02	ABORT ADVISORY LIGHT DID NOT GO DIM ON COMMAND / MURATORE	CL
EECOM-07A	SPACELAB TUNNEL BUS SPIKE / C. DINGELL	CL
EECOM-08A	MMC2 STATUS 5 FAILURE / J. CLARK	CL
EECOM-11	S/L SS INV OUTPUT AMPS XDCRS / C. DINGELL	OP
STS-51G	OV-103	
EECOM-01	ABNORMAL WCS FAN SEP 1 START-UP	
EECOM-02	FWD STBD PLB LIGHT FAIL TO START	
EECOM-03	A15 AC UTIL OUTLET, AC3 PHASE B SPIKE	
EECOM-04	FWD BLKHD PLB LIGHT	
STS-51F	OV-99	
EECOM-01	FC RELIEF LINE TEMP FALLING TO 57 DEGREES	
EECOM-02	BLKHD PLB LIGHT FAIL TO START	
STS-51I	OV-103	
EECOM-01	LOW FUEL CELL RELIEF LINE TEMPERATURE	
EECOM-05A	FC1 H2 FLOW TRANSDUCER ERRATIC / R. MIESSLER	CL
PROB-07	ANNUNCIATOR DISPLAY UNIT STATUS LIGHT INTERMITTENT	
STS-51J	OV-104	
EECOM-02	FAILURE OF FUEL CELL 3 O2 FLOW TRANSDUCER / R. FLOYD	CL

STS-61A	OV-99	
EECOM-02	FUEL CELL 1 EXIT TEMP OSCILLATIONS	
EECOM-03	SL SS/EXP INVERTER VOLTS HIGH	
EECOM-10	FC AC3C CB / R. MIESSLER	CL
EECOM-14	SPOC ANOMALOUS OPERATION IN SPACELAB / C. DINGELL	CL
STS-61B	OV-104	
EECOM-01B	CRYOGENIC O2 CONTAMINATION / C. DINGELL	CL
EECOM-02A	FUEL CELL FLOW DUCER FAILURES / R. ARMSTRONG	CL
EECOM-06	FC 2 SS3 D VOLTS / C. DINGELL	CL
EECOM-08	FUEL CELL 2 PERFORMANCE DEGRADATION / C. DINGELL	CL
STS-61C	OV-102	
PRLNCH	FUEL CELL 1 COOLANT LEAK	
EECOM-02	ESS1BC FUEL CELL 1 FEED / R. ARMSTRONG	CL
EECOM-04A	FC3 CURRENT SPIKE / R. ARMSTRONG	CL
STS-51L	OV-99	
STS-26	OV-103	
EECOM-01	FC2 PH HIGH / L. MINTER	CL
STS-27	OV-104	
EECOM-04	FUEL CELL 2 ALTERNATE WATER FLOW / R. BROWN	CL
STS-29	OV-103	
EECOM-01A	S68 CRYO H2 PRES MESSAGE ANOMALY / F. OUELLETTE	CL
EECOM-02B	UNEXPLAINED CRYO H2 PRESSURE SIGNATURES / F. OUELLETTE	CL
EECOM-03A	FUEL CELL 1 H2O RLF VLV TEMP OVERSHOOT / R. FLOYD	CL
STS-30	OV-104	
EECOM-02	FC STKT F7 BULB FAILURE / B. ANDERSON	CL

EECOM-03A	FC 2 H2 FLOW TRANSDUCER DRIFT / B. ANDERSON	CL
STS-28	OV-102	
EECOM-02	PANEL F6 ABORT LIGHT FAILURE / B. PAWLIK	CL
EECOM-03	FUEL CELL 1 H2 FLOW MEASUREMENT DRIFTING HIGH/ B. PAWLIK	CL
EECOM-09	MNC UTIL OUTLET/TELEPRINTER SHORT / B. ANDERSON	CL
STS-34	OV-104	
EECOM-02B	CRYO O2 MANIFOLD VLV TANK 2 FAILURE/R. BARCKHOLTZ/ L. PERRINE	CL
EECOM-03	FC2 H2 FLOW TRANSDUCER DRIFT / B. PAWLIK	CL
STS-33	OV-103	
EECOM-02B	CRYO O2 OVERPRESS DUE TO CABIN LEAK THROUGH WCS/P. CERNA	CL
PROB-08	CRYO TANK 1 CHECK VALVE STICKY	
STS-32	OV-102	
EECOM-03	FWD BLKHD FLOODLIGHT FAILURE / T. SCHAFER	CL
STS-36	OV-104	
PRELNCH	AC2 PHASE A INVERTER FAILURE	
EECOM-01	FC2 STARTUP / R. AL-AYOUBI	CL
EECOM-07	PLB FLOOD-LIGHTS / L. MINTER	CL
STS-31	OV-103	
EGIL-01	FC 2 PURGE ANOMALY / M. FUGITT	CL
EGIL-02	MID STARBOARD PAYLOAD BAY FLOODLIGHT/S. HIRSHORN	CL
STS-41	OV-103	
EGIL-01	FUEL CELL 1 H2 FLOWMETER FAIL / B. PAWLIK	CL



STS-38	OV-104	
EGIL-01	FC3 O2 FLOW XDCR ERRATIC / D. RANDALL	CL
EGIL-02A	H2 TANK 3 QUANTITY XDCR FAILURE / D. RANDALL	CL
EGIL-03	MNA MPC1 AMPS XDCR FAILURE / R. ARMSTRONG	CL
STS-35	OV-102	
EGIL-01A	H2 TANK 2 QUANTITY TRANSDUCER BIAS / B. ANDERSON	CL
STS-37	OV-104	
EGIL-01A	O2 MANIFOLD VALVE TK2 FAILED TO CLOSE / T. SCHAFER / D. RANDALL / L. MINTER	CL
EGIL-02	FORWARD BULKHEAD FLOODLIGHT / L. MINTER	CL
EGIL-03	MID PORT FLOODLIGHT / L. MINTER	CL
EGIL-04	FC 3 PH HIGH / L. MINTER	CL
STS-39	OV-103	
EGIL-01B	FC 1 H2O RLF VLV THERMOSTATS / D. RANDALL / B. PAWLIK	CL
EGIL-02A	FUEL CELL 3/MAIN C BUS CURRENT SPIKE / B. PAWLIK	CL
STS-40	OV-102	
EGIL-01B	H2 TK 3 A HTR FAIL / B. ANDERSON / B. PAWLIK	CL
STS-43	OV-104	
EGIL-01A	H2 TK 1 HTR B FAILURE / D. RANDALL	CL
EGIL-02	FC2 ALT H2O LINE FLOW / D. RANDALL	CL
EGIL-03B	PAYLOAD BAY FLOODLIGHT FAILURE/J. AZBELL/D. RANDALL	CL
EGIL-04A	CRYO H2 MANF VLV TK1 FAILED TO CLOSE / J. AZBELL	CL
STS-48	OV-103	
EGIL-01A	FC1 O2 REAC VLV INDICATION FAIL / D. RANDALL	CL
STS-44	OV-104	

STS-42	OV-103	
EGIL-01A	FUEL CELL 2 H2 MOTOR STATUS/L. MINTER/R. ARMSTRONG	CL
EGIL-02	SS INVERTER OVERVOLT SHUTDOWN / D. RANDALL	CL
STS-45	OV-104	
EGIL-01B	FUEL CELL 3 CELL PERFORMANCE MONITOR ANOMALY / S. HIRSHORN / T. SCHAFER	CL
EGIL-02B	CRYO O2 TANK 3 CONTROL PRESS BIAS / S. HIRSHORN	CL
STS-49	OV-105	
EGIL-01A	O2 MANF VLV 1 FAIL OPEN / D. RANDALL	CL
EGIL-02	FWD PORT PAYLOAD BAY FLOODLIGHT PROBLEM / R. AL-AYOUBI	CL
EGIL-03	FWD STBD PLB FLOODLT / L. MINTER	CL
EGIL-04	FWD BLKHD & AFT STBD PLB FLOODLTS / L. MINTER	CL
STS-50	OV-102	
EGIL-01B	CRYO O2 TANK 2 LEAK / S. HIRSHORN	CL
EGIL-02A	CRYO O2 TANK 2 HEATER A2 FAIL / S. HIRSHORN	CL
EGIL-03	FUEL CELL 3 O2 PURGE VLV ANOMALY / E. GODDARD	CL
EGIL-04A	LOSS OF ORBITER MASTER ALARM AUDIO ON SPACELAB SPEAKER / N. ROY	CL
EGIL-05	CRYO O2 TANK 7 CHECK VALVE / S. HIRSHORN	CL
EGIL-06	SPACELAB EPDB 2 AC PHASE A SENSOR / J. AZBELL	CL
EGIL-07	CRYO O2 TK 3 RAPID PRESSURE CYCLES / T.SCHAFFER	CL
EGIL-08	CRYO O2 TK 3 QTY XDCR / R. AL-AYOUBI	CL
EGIL-09	SS INVERTER OVERVOLT SHUTDOWN / J. AZBELL	CL
EGIL-10	FC1 ERRATIC VOLTAGE TRANSDUCER / T. SCHAFER	CL
EGIL-11	FWD STBD FLOODLIGHT / L. MINTER	CL
STS-46	OV-104	
STS-47	OV-105	
EGIL-01B	CRYO O2 TK 4 CNTLR PROBLEM / RAMI AL-AYOUBI / D. RANDALL	CL

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EGIL-02	H2O RELIEF LINE TEMP PROBLEM / R. AL-AYOUBI	CL
EGIL-03	FC2 O2 FLOW XDCR FAIL / D. RANDALL	CL
STS-52	OV-102	
EGIL-01	MIDDECK FLOODLIGHTS #6 AND #8 FAILURE / J. AZBELL	CL
EGIL-02	FUEL CELL 1 SUSPECT CELL PERFORMANCE MONITOR / S. HIRSHORN	CL
EGIL-03	CRYO O2 TK 2 HTR A2 INTERMITTENT / L. MINTER	CL
EGIL-04B	MNC A 11 DC UTILITY OUTLET FAILURE/L. FOX/S. HIRSHORN	CL
STS-53	OV-103	
STS-54	OV-105	
EGIL-01	P/L BAY FLOODLIGHTS PROBLEM / RAMI AL-AYOUBI	CL
EGIL-02	FUEL CELL 3 ALTERNATE WATER LINE TEMPERATURE INCREASE / B. PAWLIK	CL
STS-56	OV-103	
EGIL-01	FC1 O2 REAC VLV INDICATES CLOSED / Q. CARELOCK	CL
EGIL-02A	SPACELAB EPDB 1 AC PHASE A TRANSDUCER/C. GUDERIAN	CL
EGIL-03	FUEL CELL/SUBSTACK 3 DELTA VOLT INCREASE / S. HIRSHORN	CL
STS-55	OV-102	
EGIL-01	FC2 O2 FLOW TRANSDUCER / S. BRILLHART	CL
EGIL-02A	FUEL CELL 2 ALTERNATE LINE TEMP / S. BRILLHART	CL
STS-57	OV-105	
EGIL-01B	O2 MANF VLV TK 1 FAILED TO GO CLOSE / J. AZBELL	CL
EGIL-02A	PAYLOAD BAY FLOODLIGHT FAILURES / J. AZBELL	CL
EGIL-03A	FC3 H2 REACT VALVE FAILED TO GO CLOSED / A.J. CECCACCI	CL
EGIL-04A	C3 PHASE-TO-PHASE SHORT / R. ARMSTRONG	CL

EGIL-05	MCA LOGIC MCA POWER AC3 3-PHASE MID 4 CB STICKY / S. HIRSHORN	CL
STS-51	OV-103	
EGIL-01	MID STARBOARD PAYLOAD BAY FLOODLIGHT / L. FOX	CL
STS-58	OV-102	
EGIL-01	PAYLOAD BAY FLOODLIGHT FUNNY / L. FOX	CL
STS-61	OV-105	
EGIL-01	AFT STBD FLOODLIGHT FAIL / S. HIRSHORN	CL
STS-60	OV-103	
EGIL-01	O2 TK2 QTY XDGR ERRATIC / R. AL-AYOUBI	CL
STS-62	OV-102	
EGIL-01	Withdrawn	CL
EGIL-02A	CRYO H2 TK 6 "A" HTR FAIL / A. CECCACCI / L. FOX	CL
EGIL-03	MID-PORT PAYLOAD BAY FLOODLIGHT FAILURE / L. FOX	CL
EGIL-04	Withdrawn	CL
EGIL-05	MID-STARBOARD PLB FLOODLIGHT FAILURE / T. NORTH	CL
EGIL-06	O2 TK 7 QUANTITY MEASUREMENT FAILURE / L. FOX	CL
STS-59	OV-105	
EGIL-01E	H2 TANK 5 CHECK VALVE FAIL TO SEAT / A. CECCACCI	CL
EGIL-02	STICKY CRYO H2 TANK 2 CHECK VALVE / S. HIRSHORN	CL
EGIL-03	FWD PORT PAYLOAD BAY FLOODLIGHT FAILED / A.J. CECCACCI	CL
EGIL-04	AFT PORT FLOODLIGHT FAIL / R. MIESSLER	CL
STS-65	OV-102	
EGIL-01	SPACELAB EXP AC BUS POWER INTERRUPTION/M. STOKES	CL
EGIL-02	AFT PORT PAYLOAD FLOODLIGHT FAILED / A. CECCACCI	CL

STS-64	OV-103	
EGIL-01	AFT MCA 1 OP STAT 4 INDICATION / R. ARMSTRONG	CL
STS-68	OV-105	
EGIL-01	FORWARD PORT PLB FLOODLIGHT FAILURE / T. NORTH	CL
STS-66	OV-104	
EGIL-01	SPACELAB EPDB-1 AC PHASE A AMPS TRANSDUCER FAIL / N. ROY	CL
EGIL-02	FUEL CELL 2 H2O FLOW THROUGH ALTERNATE PATH / S. HIRSHORN	CL
EGIL-03	H2 TANK 4 QTY XDCR PROBLEM / R. AL-AYOUBI	CL
EGIL-04	FUEL CELL 2 H2 MOTOR STATUS ERRATIC / S. HIRSHORN	CL
EGIL-05	SPACELAB SS INVERTER SHUTDOWN / D. BUTLER	CL
EGIL-06	PAYLOAD BAY FLOODLIGHT FAILURES / A. J. CECCACCI	CL
STS-63	OV-103	
EGIL-01	FUEL CELL 2 H2 MOTOR STATUS / R. AL-AYOUBI / ARMSTRONG	CL
STS-67	OV-105	
STS-71	OV-104	
EGIL-01	H2 MANF VLV TK 1 FAILED OPEN / Rami Al-Ayoubi	CL
EGIL-02	CRYO O2 TK1 LEAK / RAMI AL-AYOUBI	CL
EGIL-03B	H2 Manifold Valve 1 Microswitch Failure / Ray O. Miessler	CL
EGIL-04	ERRATIC O2 TANK 5 HEATER TEMPERATURE / Benjamin Pawlik	CL
STS-70	OV-103	
STS-69	OV-105	

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EGIL-01A	FUEL CELL 2 CONDENSER EXIT TEMP HIGH-8/31/95 LAUNCH ATTEMPT / STEVEN HIRSHORN	CL
EGIL-02A	PAYLOAD BAY FLOODLIGHT FAILURES / Timothy R. North	CL
STS-73	OV-102	
EGIL-01	FC3 CELL PERFORMANCE MONITOR FAILURE / RAMI AL-AYOUBI	CL
EGIL-02A	No Drive current on AC 1 Phase B / Timothy R. North Explained Condition	CL
EGIL-03	H2 MANIFOLD VALVE TK1 FAILED OPEN / Jim Azbell	CL
STS-74	OV-104	
EGIL-01A	Fuel Cell 3 Cell Performance Monitor Funny / Steven Hirshhorn	CL
EGIL-02	Cryo O2 Manifold Tank 1 Valve Failed Open / Steven Hirshhorn	CL
EGIL-03	Payload Bay Floodlight Failure / B. Pawlik	CL
EGIL-04	H2 Manifold Valve 1 Microswitch Failure / Jim Azbell	CL
STS-72	OV-105	
EGIL-01	Forward Port Payload Bay Floodlight Failed / Steven Hirshhorn	CL
EGIL-02	RPC Trip on MID MN B / Timothy R. North	CL
STS-75	OV-102	
EGIL-01A	FWD PLB FLOODLIGHT FAILURES / Larry Minter	CL
EGIL-02	Fuel Cell 3 CPM not doing 'self tests' / D. Randall	CL
EGIL-03A	H2 TANK 4 HEATER A FAILURE / D. Randall	CL
EGIL-04	AC 1 phase B short / Tim North	CL
STS-76	OV-104	
STS-77	OV-105	
EGIL-01	Mid Starboard Payload Bay Floodlight Fail / Tim North	CL
STS-78	OV-102	
EGIL-01A	Cryo H2 Tank 4 B Heater Failure / David J. Fuesting	CL

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EGIL-02	Spacelab EPDB 2 AC Phase A Amps Transducer fail / Steven Hirshhorn	CL
EGIL-03	Spacelab EPDB 3 AC Phase C Amps Transducer Malfunction / Michael T. Maher	CL
STS-79	OV-104	
EGIL-01A	Fuel Cell 2 pH / Cindy Nobles / Ray Miessler EXPLAINED CONDITION	CL
EGIL-02	Fuel Cell 2 O2 Flow Transducer / Cindy Nobles	CL
EGIL-03A	H2 Manifold Valve 1 Microswitch Failure/ David L. Randall/ Ray Miessler	CL
EGIL-04A	Cryo H2 Tank 3 B Heater Failure / David J. Fuesting / Ray O. Miessler / Cindy A. Nobles/Jim A. Azbell/Steve R. Hirshorn	CL
STS-80	OV-102	
STS-81	OV-104	
EGIL-01	H2 Manifold Valve 1 Microswitch Failure / DF73/ Jim Azbell Known Condition	CL
EGIL-02	Fuel Cell 1 Voltage Erratic Behavior / EGIL / Steven Hirshhorn	CL
EGIL-03	Fuel Cell 2 Cell Performance Monitor Self-test Anomaly / Michael T. Maher	CL
EGIL-04	Forward Port Payload Bay Floodlight Failed / Tim North	CL
STS-82	OV-103	
EGIL-01D	FUEL CELL 3 H2O FLOW THROUGH ALTERNATE PATH / DAVID J. FUESTING/TIM NORTH/S.Hirshhorn Known Condition	CL
EGIL-02	Aft Starboard Payload Bay Floodlight Failed / Michael T. Maher	CL
STS-83	OV-102	
EGIL-01B	FC2 Substack 3 Deltavolts Anomaly/EGIL/Jim Azbell/Ray Miessler/ T. North	CL
EGIL-02	Fuel Cell 2 H2 Reactant Valve Failure / EPS / Steven Hirshhorn	CL
STS-84	OV-104	
EGIL-01	Fuel Cell 3 H2 Flow Transducer Erratic / Michael T Maher	CL

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EGIL-02	Aft PL MNC Amps Measurement Failed / Artimus D. Kinnon	CL
STS-94	OV-102	
EGIL-01	Fuel Cell 3 Cell Performance Monitor Suspect / Michael Maher / Cindy Sweitzer	CL
STS-85	OV-103	
STS-86	OV-104	
EGIL-01A	Fuel Cell 2 Substack 1 Delta Volts Transient / Ray Miessler / David J. Fuesting	CL
EGIL-02	Forward Starboard Payload Bay Floodlight Failed / Tim North	CL
STS-87	OV-102	
EGIL-01B	H2 Tank 4 Quantity Measurement Failure/Jim Azbell/Ray Miessler	CL
STS-89	OV-105	
EGIL-01	Payload Bay Floodlight RPCs Trip / Tim North IPR 88V-0011	CL
STS-90	OV-102	
EGIL-01	Spacelab Subsystem Inverter Voltage Oscillations / Jim Azbell	CL
STS-91	OV-104	
EGIL-01	Fuel Cell 3 Overboard Relief / Jim A. Azbell / Tim North IPR 91V-0149	CL
EGIL-02	Fuel Cell Monitoring System (FCMS) Data Recording / T. North, A.Ceccacci	CL
STS-95	OV-103	
None		
STS-88	OV-105	



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EGIL-001C	Aft Stbd, Fwd Stbd, and Mid Port PLB Floodlight failed/ K. Miller/ J. Spivey	CL
EGIL-002	Aft Port PLB Floodlight Failed/ M. Welch/ K. Miller	CL
EGIL-003B	Fwd Port PLB Floodlight Failed/ K. Miller	CL
EGIL-004	Sticky C/W Param Sel and Limit Select Thumbwheels/ T. North	CL
STS-96	OV-103	
EGIL-001	FC3 H2 Flow Transducer/ R. Smith	CL
STS-93	OV-102	
STS-103	OV-103	
STS-99	OV-105	
STS-101	OV-104	
EGIL-001A	F9 Meter Fluctuations/ R. Smith	CL
EGIL-002A	Cryo O2 Tk4 Htr A failed to come on/ M. Welch	CL
EGIL-003A	APCU1 Converter B/ K. Miller	CL
STS-106	OV-104	
EGIL-001A	MNB APC5 60 Amp Bus Transient/ R. Smith	CL
EGIL-002	FC1 H2 Flow Transducer Failed to OSL/ M. Fountaine	CL
STS-92	OV-103	
EGIL-001A	Cabin Payload 3 Bus Loss/ Mark Welch	CL
EGIL-002	AC Circuit Breaker Not Conducting/ Mark Welch	CL
STS-97	OV103	
EGIL-001A	Phase A of AC1 Aft1 Ganged Circuit Breaker Not Conducting/ R. Smith/ M. Fountaine	CL
EGIL-002	APCU1 Dropoff/ M. Welch	CL
EGIL-003	APCU2 Trip/ M. Welch	CL

STS-98	OV-104	
EGIL-001	Mid STBD PLB Floodlight Failed/ M. Maher	CL
STS-102	OV-103	
EGIL-001	C/W Pushbutton Failure/ R. Smith	CL
EGIL-002A	Airlock Fan Phase B Not Working/ A. Bauer	CL
STS-100	OV-105	
EGIL-001	PLB Floodlight Mid Port Failed/ G. Peck/ K. Miller	CL
STS-104	OV-104	
STS-105	OV-103	
EGIL-001A	Circuit Breaker AC2 3-phase Mid 2 Phase A Not Conducting/ K. Miller	CL

## EGIL/EPS PRE/POST FLIGHT RESPONSIBILITIES CHECKLIST

### PURPOSE

The purpose of this SCP is to define the console responsibilities of the EGIL/EPS operators within three weeks before the flight, up to the flight, and post-flight. The list is designed to be a checklist that the operators can reference prior to and during the mission. The EGIL FCR operator will be responsible for assuring his teams responsibilities are properly delegated and completed. *Each EGIL should e-mail the Lead EGIL upon completion of the actions that they are responsible for.*

### A. Ascent/Entry EGIL/EPS Pre/Post Flight Responsibilities

1. Verify copies of preflight consumables and EGIL pre-flight tagup packages are on EGIL and EPS consoles:
  - EGIL Final Analysis package (L-18 days)
  - EGIL Preflight Tagup Package (L-2 days).
2. Support L-1 Day Briefing
  - Log into console and pull up applications to assure all is OK.
  - Update Padhold numbers based on actual data; use SOCRATES and the Boiloff Spreadsheet. Put copies in the Console Log binder under "Consumables".
  - Verify directories on the PC are setup for the electronic logs and handovers (should have been performed by lead EGIL/EPS). Each console should start their electronic log with any notes from the L-1 day briefing.
  - Verify the Egil Work folder on the JSCMODM "U:" drive has been cleaned out (typically performed by MODM personnel).
  - Put L-1 day brief in the Console Log binder under "Preflight Items"
  - Verify OMI available electronically
  - Verify LCC book is up-to-date.
  - Check EGIL file allocation:
    - Bring up an x-term
    - type `"/usr/local/bin/qc"` and press return
    - Check that all server allocations are less than 80%, if not, inform the Group Lead

6.2.1-1

**Verify that this is the correct version before use**

- EPS creates a backup mission from the existing mission and names it xxx-backup.
  - Verify BFS SM TMBU's with DPS (if req'd)
3. Update Ascent/Entry limits as required (EPS).
  4. Recheck the VI coefficients, console books, and the FDF are correctly implemented and up to date.
  5. Re-verify TMBUs to be sent
  6. Coordinate and send the SM INIT TMBUs (if reqd.)
  7. Start RT-Manager at liftoff (can be started coming out of the T-9 minute hold). EGIL starts it on the current mission. EPS starts RT-Manager in the backup mission at liftoff (or after T-9 minutes).
  8. Recycle KWH/Amp-hr comps at liftoff (When Vent motion begins).
  
  9. After MECO when tank destrat is complete, update L/O quantities with those destratified quantities. Also verify L/O time is correct in the asflown and backup cases.
  10. Obtain TD+45 minute hardcopies for post mission consumables.
  11. Return all mission data and logs to the Lead EGIL's desk in the office, immediately after flight.

## **B. Orbit 2 EGIL/EPS Pre/Post Flight Responsibilities**

1. Set up Console Log binders.
  - Label Console Log tabs with the following: Handover, Log, Flight Notes, Entry Deltas, Consumables, Anomaly Reports/FIW's, Data/Plots/Hardcopies, TMBUs/CHITs, Execute Package/Uplinks, Preflight Items, Miscellaneous, any other mission specific items (i.e. FCMS), extra blank tabs
  - EGIL console log will have the training rosters located in the very front before the Handover tab. (training rosters obtained from Lead EGIL)
  - Include a copy of the FRR Data Package under the "Preflight Items" tab
  - Take the latest information from the "Blue Folder" on the console and place it under the "Misc" or "Preflight Items" tab. Trash any old sim packages and tagups.

2. Replenish console supplies.
  - Log paper
  - File folders
  - Pens, Pencils, highlighters, erasers
  - Stapler, staples, tape, post-its, hole savers
  - Scissors
  - Printer paper

**C. Orbit 3/Planning EGIL/EPS Pre/Post Flight Responsibilities**  
(may be the same as the Prelaunch Team)

1. Before the Prelaunch team gets on console, update console flight data file. Compare it against the latest version of the FDF status (on MVP) to ensure that all PCN's are incorporated.

**D. Prelaunch EGIL/EPS Pre-Flight Responsibilities**

1. Check that a copy of the FC V-I predictions, for that flight, are at the EGIL and EPS consoles. Use the measured coefficients to update the delta volts coefficients using the ISP constants application. Build a new file for the mission and save it using the flight ID in the name.
2. Update console flight data file. Compare it against the latest version of the FDF status (on MVP) to ensure that all PCN's are incorporated.
3. Using MVP, update "paperclips" in the OMI S0007 Vol II for the applicable EGIL steps. Following are applicable steps. Exact pages vary from flight to flight. Shown are the approximate page location for each item:

~14-1221 (~page 400)	Fuel Cell Flow Thru Purge Start
~14-1232 (~page 400)	Fuel Cell Flow Thru Purge complete Continue with Pulse Purge
~15-0072 (~page 500)	Pulse Purge Complete
~15-0074 (~page 500)	Proceed with Fuel Cell Activation
~15-0450 (~page 614)	Fuel Cell Activation Complete / Fuel Cell Performance Calibration/PRSD System Integrity Check

- ~15-0644 (~page 660) Perform Fuel Cell 2 hour operational purge
- ~16-0281 (~page 725) Pre-Ingress Switch Reconfig
- ~16-0348 (~page 745) Clear C&W Memory
- ~16-0521 (~page 780) C&W Volume Adjust
- ~16-0567 (~page 790) Fuel Cell Purge (T-01H40M)
- ~16-0617 (~page 800) FCMS cb pull
- ~16-0772 (~page 830) Weather Brief
- ~18-0000 (~page 1000) Recycle Control sequence

4. Verify that the SOCRATES cases are setup correctly.
  - Make sure that the EGIL\_FINAL case has been saved as an "egil\_asflown" case.

\_\_\_\_\_ **Clear out real-time SOCRATES directory for the mission being flown.**

Perform the following to accomplish this:

- Bring up an x-term, type the following "cfr <flight>" and hit return.
- Typing "ll" and return should show files like realdata.raw, realdata.now etc. The dates and times should be past dates and times. The directory you are in should be names something like "/users/egil/rw\_common.socrates/MISSION/<flt>/actual/flight"
- Make sure RT-Manager is not running and putting data in this directory. This can be done by looking for a file named "rt\_history.loc". by typing "cat rt\_history.loc" and return you can see which workstation has this running.
- Type "rm \*" and hit return to remove all the files in this directory.

**NOTE: Make sure you are in the correct directory before using rm \*. This command is very destructive.**

5. Verify X-Goal and FCMS data is flowing (FMCS RTPLOT & XGOAL)
6. Start H-TAB.
7. Verify the KSC Systems (Fuel Cell & EPDC) and ETL loops are active and that two-way talk capability exists.
8. CONSOLE SETUP:

**Constants:**

\_\_\_\_\_ Comps

6.2.1-4

**Verify that this is the correct version before use**

\_\_\_\_ Flight Specific FC delta Volts  
\_\_\_\_ CRYO Tank Configuration

\_\_\_\_ ODRC Comps ( check that they have been implemented properly in ODRC )  
\_\_\_\_ Flight Specific FC delta Volts  
\_\_\_\_ CRYO Tank Configuration

**Pre-launch TMBU's:**

\_\_\_\_ TK 5 Inhibit      \_\_\_\_ FC AUTO PURGE  
\_\_\_\_ OTHER

9. PRELAUNCH ACTIVITIES:

FC Flow thru Purge:    \_\_\_\_ FC1    \_\_\_\_ FC2    \_\_\_\_ FC3  
FC Pulse Purge:    \_\_\_\_ FC1    \_\_\_\_ FC2    \_\_\_\_ FC3  
FC Activation:            \_\_\_\_ FC1    \_\_\_\_ FC2    \_\_\_\_ FC3  
FC performance Calibration and PRSD Integrity Check:  
\_\_\_\_ 2 Hour FC Purge:    \_\_\_\_ FC1    \_\_\_\_ FC2    \_\_\_\_ FC3

\_\_\_\_ **MEWS Plot Requirements:**

\_\_\_\_ **From** FC Flow Thru Purge **to** end of FC Activation:  
FCACTIVATE (Plot Formats -- FC1ST\_P1-4, FC2ST\_P1-4,  
FC3ST\_P1-4)  
\_\_\_\_ Pressure Integrity Check - PRESSCHECK (Required  
Tanks)  
\_\_\_\_ BOILOFF RATE/ PAD HOLD – Use SOCRATES and Boiloff  
Spreadsheet  
\_\_\_\_ MISC: (Limit changes, updates, etc.)

**E. All Teams Flight Responsibilities**

1. Midnight local - Mass Properties due to TRAJ for next PLS TIG calculations
2. 3:30 a.m. local - Projected Consumables Margins (PCM) due to SPAN

**STS-:**

CMP LT	Task description	Time (L- days)
<b>Ascent/Entry EGIL:</b>		
	L-1 Briefing (file under "Preflight items")	1
	Update Padhold numbers at the L-1 Briefing	1
	Verify PC setup at the L-1 Briefing	1
	Check EGIL file server allocation	1
	A/E Limits/Checkpoints	0
	Recheck Comp constants	0
	Recheck Console FDF	0
	Re-verify TMBUs	0
	Coordinate and send BFS SM INIT TMBUs (if reqd.)	0
	Create a Backup Socrates Mission	
	Start RT-Manager	0
	Recycle Kwh/Amp-hr comps	0
	Update SOCRATES with correct L/O time and quantities	x
	TD+45 min hardcopies for Post mission consumables	x
	Post EOM, return LOGs to Lead EGIL	x
<b>Orbit 2 EGIL:</b>		
	Console Log Binders	2
	Console Supplies	2



<b><i>Orbit 3 or Planning EGIL:</i></b>	
Prelaunch P & I, Console FDF Updates	2
<b><i>PreLaunch EGIL:</i></b>	
A/E Limits/Checkpoints (asflown.cp)	0
Prelaunch P & I, Console FDF Updates	0
TMBU Prep FC Auto Purge	0
TMBU Prep for known Problems	0
TMBU Prep TK5 - Inhibit	0
Verify X-Goal and FCMS data active	0
Verify KSC loops (two-way talk capability)	0
Comp Constants Verified	0
Set up OMI in MVP	0
Recalculate padhold numbers	0
Prepare SOCRATES cases and directories	0
Prep for Fuel Cell startup	0
Required MEWS Plots generated	

## TITLE

EPS CONSOLE MCC INTEGRATED LOAD CHECKOUT CHECKLIST

## PURPOSE

The purpose of this SCP is to provide integrated load checkout procedures and integrated load checklist to ensure that all required applications and tools are verified to be operational as new flight loads are generated.

## BACKGROUND

The purpose of this checklist is to do a complete check during load checkouts. Each item is given a space in which to check whether it worked satisfactorily. Any functions that have not worked to the user's satisfaction must have comments with exact problems(s) or discrepancies identified. There is a space for comments at the end of the checklist. This checklist as a whole covers everything to be checked for the Control Center and SMS load. In the case where only the Control Center or the SMS is the new load, only applicable items need to be checked out.

After the load checkout is complete, a report will be written and filed with the group lead by close of business on the following day.

All applicable DRs and issues will be coordinated to ensure coverage. Note that not all items will be completed on one checkout.

## PROCEDURE

1. Obtain a copy of the previous load checkout checklist from the df73/flights/XX/egilead directory (XX represents STS mission number) if this is not the first checkout. Try to complete any items not done previously.
2. Coordinate with training division to verify whether previously open DRs have been corrected. Get list of open DRs for previous loads.
3. Configure console for normal operation to SCP (TBD). Select the correct activity for the integrated load checkout.
4. Select MSK displays and evaluate all parameters on them with respect to operational accuracy. Prepare hard copies of all displays, including history displays pertaining to EPS.
5. Initialize all RTPlot formats and confirm that they are updating. Reset plots. Also change update rates, intervals, and ranges to verify changing capability. Start PIRT and view selected formats. As above, it is sufficient that fuel cell, bus, and cryo data be represented in the plots.
6. Initialize/load computations and verify their operation during the test.

7. Use the ISP limits application to change limits on parameters so that they will be out of limits. At least cryo and EGIL parameters should be selected. Verify that the parameter changes color and up or down arrows appear next to out-of-limits parameters.
8. Use data collected, fill out checklist, and assemble working papers. Place a copy to the keeper of load checkout in the df73/flights/XX egillead directory (XX represents STS mission number) and keep a copy for yourself.

(Example only: Check server for latest revision)

**EPS Console MCC Integrated Load Checkout Checklist**

Load \_\_\_\_\_ Current Date \_\_\_\_\_  
 Flight \_\_\_\_\_  
 Operator \_\_\_\_\_  
 Ascent \_\_\_\_\_ Orbit \_\_\_\_\_ Entry \_\_\_\_\_

ITEM	Satisfied	Dissatisfied (comments_ at end)
1. CCC workstation login	_____	_____
2. Activity Sheet	_____	_____

APPLICATIONS

3. Display Select

Format tested

**MSKView**

- 601 - EGIL FC/EPDC (use for #4)
- 606 - CRYO 5 TANK A/E
- 606 - CRYO 5 TANK ORB
- 608 - CONFIG
- 699 - EGIL PYRO
- APCU (horizontal)
- APCU (vertical)
- Comp Constants (use for #3)

Satisfied?

Y N


4. Load comps

kWh/AmpHr \_\_\_\_\_  
 All comps \_\_\_\_\_  
 Cycle \_\_\_\_\_  
 Initiate \_\_\_\_\_

5. Load limits

Out-of-limits indication \_\_\_\_\_  
 Change limits \_\_\_\_\_

	<u>Satisfied</u>	<u>Dissatisfied</u>
6. ISP Channel		
Manual	_____	_____
Auto	_____	_____
7. FCC	_____	_____
8. Leakman	_____	_____
9. RTPLOT		
Initialize all plots	_____	_____
Initialize FCMS	_____	_____
Change interval	_____	_____
Change range	_____	_____
Set limits		
Change time (x) scale	_____	_____
Change y scale	_____	_____
10. TV-in-box/Stream Capture (FCR only)	_____	_____
11. EDP	_____	_____
12. Onboard Fault Summary	_____	_____
13. CRANS		
Bus	_____	_____
Control Bus	_____	_____
14. ELOG	_____	_____
15. PIRT	_____	_____
16. SOCRATES	_____	_____
17. ODRC	_____	_____
18. MIS	_____	_____

EVENTS

Nominal Procedures	Satisfied?	Yes	No
1. Configuration		_____	_____
2. Power levels		_____	_____
3. Purges		_____	_____
a. Auto		_____	_____
b. Manual		_____	_____
c. DSM Commanded - BFS (Ascent)		_____	_____
5400 V45K0837U FC3 PURGE VLV A/B OP*		_____	_____
5401 V45K0838U FC3 PURGE VLV A/B CL		_____	_____
5402 V45K0839U FC2 PURGE VLV A/B OP*		_____	_____
5403 V45K0840U FC2 PURGE VLV A/B CL		_____	_____
5404 V45K0841U FC1 PURGE VLV A/B OP*		_____	_____
5405 V45K0842U FC1 PURGE VLV A/B CL		_____	_____
5406 V45K0843U FC PURGE HEATERS ON*		_____	_____
5407 V45K0844U FC PURGE HEATERS OFF		_____	_____
5410                 FC PURGE START		_____	_____
*MRT 5410 contains 5400, 5402, 5404, and 5406, so when sending 5410, check these.			
d. TMBU commanded orbit purge		_____	_____
4. Heater reconfig		_____	_____
5. O <sub>2</sub> cryo sensor check		_____	_____
6. TMBU		_____	_____
7. Cryo rise and decay rates (single and dual heaters)		_____	_____

FAILURES (at Training or EGIL/EPS discretion):

GENERAL COMMENTS:

**TITLE**

EGIL POST-MISSION BINDER

**PURPOSE**

The purpose of this brief is to give the work instructions to build the EGIL Post Mission Binder.

**DISCUSSION**

The post mission binder is a complete archive of the mission for EGIL. The lead EGIL will assemble the post mission binder by gathering all the data listed in the Table of contents. The EGIL and EPS flight logs will be consolidated into the binders along with a copy of the Consumables Analysis Post Mission Report, the EGIL Pre-Flight Tagup, the Consumables Analysis Final products, the Engineering Post Mission Reports, the EGIL Quick Look, and an EGIL Mission Summary. The EGIL mission summary will be written by the lead EGIL post mission and should give detail on any anomalies, significant EGIL related mission events, and any significant items that should be documented for future EGIL corporate knowledge.

Table of Contents for the EGIL Post Mission Binder:

- 1. EGIL Manning**
- 2. EGIL Mission Summary**
- 3. EGIL Quick Look**
- 4. Consumables Analysis Post Mission Report**
  - a. Mission Overview Parameters**
  - b. Consumables Mission Summary**
  - c. Mission Events**
  - d. Table - 1 Post Flight Consumables**
  - e. Predicted vs Actual Plot**
  - f. Energy Recalc Plot**
  - g. Supporting Data**
  - h. Timeline Additions & Subtractions**
  - i. Energy Usage**
  - j. O2 Usage**
- 1. EGIL Log**
- 2. EPS Log**
- 3. EGIL Handovers**
- 4. EPS Handovers**
- 5. Flight Notes**
- 6. Anomaly Reports, FIW's, & Associated Data Plots**
- 7. CHIT's**
- 8. TMBU's**
- 9. Significant Data/Plots**

**10. Real-Time Consumables**

- a. PCM (*Launch PCM, & Entry Day PCM only*)
  - b. Padhold Data
  - c. Wave Off Calcs
  - d. TD & TD+45 Quantity Snap Shots
- 1. Pre-Flight Tagup
  - 2. Consumables Analysis Final Products
  - 3. Misc - (*Other documents, information pertaining to flight*)
    - a. ODRC COMP LETTER
    - b. FC V-I Letter
    - c. Pertinent technical e-mail
  - 1. Engineering Post Mission Reports
    - a. Fuel Cells/PRSD
    - b. EPDC

Each Post Mission Binder should be assembled as directed in the Table of Contents. A blank copy of the template for the EGIL Post Mission Binder can be found in the DF73 Shared drive S:\Divisions\DF\Private\DF73\Forms and Templates\EGIL Post Mission Report\EGIL Post Mission Binder.doc.



## TITLE

EGIL/EPS HANDOVER FORM

## PURPOSE

The purpose of this form is to ensure a complete and uniform shift handover during missions and simulations. This form will be used by Electrical Generation and Illumination (EGIL) and Electrical Power System (EPS) to provide handover information to the oncoming team. This will also be a tool for the oncoming EGIL to use for the handover to the Flight Director.

## DISCUSSION

The handover form template should be available as one of the default Microsoft Word templates (if properly configured for EGIL templates). The template can be selected under File – New (template is called HANDOVER.dot). The default template is also located in the DF73/Forms and Templates folder on the share drive. After the handover template is selected, you will be prompted to enter the flight number and the console position. For flight number, you will enter only the flight numbers, not “STS” (e.g., only 105, not STS-105). For console position, enter either EGIL or EPS. When that information has been input (and you have selected OK), you will see that the header information is filled in with the flight number and the console position. The template has been protected to allow transition from one section to another without disturbing the template form itself.

The handover form should be completed prior to the arrival of the oncoming team. The handover form can be worked on throughout the shift, but you must update any items as necessary if the status changes during the shift. The completed handover should be printed out and available for the oncoming EGIL/EPS when they arrive. Your shift handover should be saved in the appropriate folder (typically, D:EGIL\_Flights/ STS-XXX/Handover) on the D drive of the console PC. The entire handover folder should also be saved back to the S drive (DF73/Flights/STS-XXX/Handover) at least once per day during the mission.

**Figure 6.2.4-1** is an example of a completed handover form. The first information to be entered is your name and team and the oncoming EGIL or EPS and their team. This information is available to be selected from a pull-down button located next to those fields. After the Greenwich Mean Time (GMT) and Mission Elapsed Time (MET) information is entered, a page number for the form is entered. This form should become a sequentially numbered page in a specific “Handover” section in the log binder. As shown on the Handover Form, the statements in parenthesis should be used for guidance when filling out the form.

		4/6/2005 4:11 PM
--	--	------------------

Name/Team: **Christy Williams** /Orbit 1      MET: **007/18:10**      HANDOVER PAGE # : **1**  
                  **Preston Easton**                              GMT: **089/19:24**  
H/O to: **Christi Worstell /Orbit 2**  
                  **Jacilyn Wilkins**

**EGIL CONFIGURATION SUMMARY:** (Quick summary to status oncoming Flight Director..)

- **Egil Systems Performance/Anomalies:**
  - > *None*
- **Past EGIL timelined events accomplished:**
  - > *A/L Depress*
  - > *Cabin Repress to 14.7*
- **Open Work:** (Flight Notes, CHIT's, AR's, pull data, update Socrates, publish PCM, etc..)
  - > *FD09 PreSleep Note (WN015A)*
  - > *FD10 Post sleep note Tk 4 (when we go to Tk 3 half htrs)*
  - > *Depletion notes*
- **Items to Look At:** (Data plots, etc.)
  - > *Camera C Failure (IC)*
  - > *F2R JetFail (IC) - FN005*
  - > *IN002 Update to Assy Ops Bus loss matrix*
- **Mission Margin:** (Gained/Lost due to)
  - > *13 hrs O2 limited*

Total Avg Mission KW (PCM):	<b>14.3 (H2)</b>		
Total Avg Mission KW:	<b>14.3 (KWH)</b>	Shift Avg KW	<b>14.0 (KWH)</b>
Predicted Mission KW:	<b>15.1 (KWH)</b>		
Mission Margin:			
@Avg mission use	H2 <b>1 dy 1 hr</b>	O2	<b>0 dy 13 hr</b>
@Ext day use rate	H2 <b>1 dy 3 hr</b>	O2	<b>0 dy 14 hr</b>
Socrates Case used:	<b>EGIL Sim_03_30_05</b>		
New cases to be QA'd:	<i>N/A</i>		
Socrates Updates Summary:	<i>Added 25 lbs to the case - Other O2 for this last EVA</i>		

<b>Timeline Activities for Oncoming Shift:</b>
> <i>7/22:30 ISS Egress for EVA Ingress</i>
> <i>7/23:40 A/L Repress</i>
> <i>3/01:30 Sim only Activity 10.2 depress using depress pump - nominally FD4</i>
> <i>3/03:30 Pre Sleep</i>
> <i>3/04:30 Sleep</i>

<b>TMBU's Uplinked:</b>
> <i>None</i>

<b>Misc:</b>
> <i>Check beginning of the log</i>

S:\Divisions\DF\Private\DF73\Sims\114\March 30 2005\Handover\MET\_189.doc  
Rev E: 7/23/2002

**Figure 6.2.4-1. EGIL/EPS Handover Form**

**Verify that this is the correct version before use**

## **TITLE**

EMERGENCY MISSION CONTROL CENTER

## **PURPOSE**

The purpose of this brief is to familiarize the operator with the procedures and requirements for transferring operational control of a space shuttle mission from the JSC MCC to either the Space Station Training Facility (SSTF) Simulation Control Area (SCA) or the Emergency Mission Control Center (EMCC) at the Kennedy Space Center (KSC) Launch Control Complex (LCC), Cape Canaveral, Florida.

## **REFERENCE DOCUMENTS**

1. JSC 26843, Flight Control Operations Handbook, procedures 2.7, "MCC Emergency Procedures"; 2.8, "JSC Contingency Plan"; 2.10, "Temporary Mission Control Center"; and 6.2.3, "DVIS Contingency Management."
2. 450-CAP-EMCC, Human Space Flight Program Emergency Mission Control Center Activation and Operations Procedures.
3. 450-CAP-EMCC, Human Space Flight Program Emergency Mission Control Center Telephone Reference List.

## **INTRODUCTION**

In a contingency situation at the MCC which severely reduces or completely prohibits support of a space shuttle mission, the Flight Control team will be relocated to continue communications with the orbiter crew. If required, the initial relocation area for a Temporary Mission Control Center (TMCC) will be established. Procedures for establishing the TMCC are in the Flight Control Operations Handbook (FCOH), 2.10. The TMCC Flight Control team should be prepared to follow direction given by the on console flight director.

If an emergency or contingency situation arises the MCC may be relocated to the Emergency Mission Control Center (EMCC), located at KSC. The EMCC provides essential operational capabilities necessary to allow relocated members of the MCC to communicate with the spacecraft crew, monitor flight activities, and interface directly with supporting network elements while completing mission objectives or until safe re-entry. A single team of flight controller personnel (per EMCC CAP-450) will be dispatched from JSC to set up operations and assume control of the space shuttle mission in the LCC. Additional EMCC staffing requirements will be determined by the Flight Director at the time of EMCC activation based on special needs to support flight phase/onboard problems.

## DISCUSSION

### A. TMCC

TMCC will be activated for situations which render the MCC unavailable for a period of 10 hours or less. The TMCC will operate until the MCC has been restored or the EMCC is activated and running.

The initial relocation area for the TMCC is the third floor of building 4N. If the situation continues, the TMCC will be moved to the SSTF SCA in building 5. The MCC will remain in building 5 until either building 30 is declared safe for re-entry or the EMCC is established. The TMCC will utilize available resources (if any) to provide data monitoring and communications.

The EGIL and EECOM will most likely share available resources (workstation or PC). If utilizing building 5 workstations the TMCC EGIL may have limited access displays, elog, rt-plot, and other applications. The TMCC should utilize the resources available for data monitoring.

### B. EMCC

Prior to a flight, each EGIL assigned to a shift is given a pager. If an emergency arises that warrants an EMCC activation, the on console FD will tell the on console team to page the appropriate EMCC flight control team. The EMCC flight control team will be required to report to Ellington field for deployment. The EGIL assigned to the EMCC team is documented in the DF Division Manning Assignments for that flight. The EMCC flight control team consists of 17 team members. A backup flight control team of 17 members will be deployed by a flight director if additional manning is required to maintain two-shift operations. The EMCC team will assemble and leave from Ellington Field Hanger 990, and must be ready to leave by the time designated by the Flight Director who activated EMCC. The EMCC EGIL traveling to KSC to support EMCC operations shall pack an overnight bag to bring with them. The EMCC EGIL will be transported from Ellington Field to KSC via the KC-135, or other available aircraft.

The on console EGIL at the time of EMCC activation is responsible for gathering all necessary documentation to be transported to the EMCC. The on console EGIL will gather and pack the documentation in the area designated by the on console flight director in preparation for EMCC shipment. The on console EGIL should use the EGIL TMCC/EMCC Checklist (figure 6.2.5-1) to ensure completeness of EMCC documentation to be shipped in support of EMCC operations. Also included in the checklist is a listing of recommended handover data preparation for the handover from the MCC EGIL to the EMCC EGIL.

### C. EMCC Flight Control Operations

KSC Systems Engineers will configure the LCC in preparation for EMCC operations. Each EMCC Flight Controller will have their KSC respective counterpart (EGIL's counterparts are FC/PRSD & EPD) to support EMCC operations. The EMCC EGIL will have a least one representative from FC/PRSD and EPD to assist in EMCC operations. Most likely KSC support will include one NASA representative and one USA representative per system. Seating arrangements for EMCC Operations is shown in figure 6.2.5 - 1 EMCC Flight Control Team Seating Chart. The EMCC EGIL will have a whole LPS console set up to support both FC/PRSD data and EPD data. The EMCC EGIL will have data available through PCGOAL and LPS Displays. There is limited plotting capability through the PCGOAL applications. The EMCC EGIL will have access to a PC to utilize programs brought to the EMCC via a CD in EMCC Binder 1.

The KSC Systems Engineers will serve a roll similar to that of a MPSR by providing assistance in data monitoring, OIS voice loop operation, and LPS console operations. The EMCC EGIL should be prepared to monitor digital data. The current real-time plotting tools are limited and do not provide adequate resources for good trend data monitoring. The KSC PC-GOAL displays can plot any six parameters on one plot for real time data analysis. The PC-GOAL plotting can be utilized to analyze data real-time similar to that of how we use PIRT. The ability to pull data is also limited. The data acquisition available at KSC is in tabular form only. It best to utilize the KSC Systems Engineers knowledge to help you decipher the data & resources available. A listing of the on board fault summary messages are not available therefore, the EMCC DPS Officer will report any on board fault summary messages received. Also, situational awareness items such as clocks, world map, etc may be very limited or not available at all.

Communication with in the EMCC will be performed using the KSC Digital Operational Intercommunications System (OIS-D) system. Figure 6.2.6-2 EMCC OIS-D COMM is a listing of the OIS-D loops and their respective function during EMCC operations. Most OIS-D are configured to support only four channels at one time. It is recommended to have A/G-1 up at all times. The other three loops should be configured on a as need basis. Recommend to configure one loop with A/G 1, one loop with the active Flight Loop (during handover this may be the equivalent of AFD), and one loop with the EGIL coordination loop (this will either be the EMCC EGIL/EECOM 6906 loop or the EGIL Handover OIS 151 loop).

Three complete copies of the Flight Data File (FDF) will be provided to the EMCC flight control team for use during EMCC operations. Each complete copy of the FDF contains several copies of each book. The copies will be shared amongst the EMCC team members.

During EMCC operations the EMCC flight control team will have the ability to send Real-time Commands (RTCs) to the orbiter. The same FCOH commanding protocol will be used during EMCC operations as during nominal MCC operations (reference EGIL CHB SCP2.6 Fuel Cell Purge, and FCOH SOP 3.1 Command

Policy for MOD). The EMCC does not have the ability to send BFS SM TMBU's. During operations with PASS SM the ability to change limits is always available with SPEC 60.

The EMCC ACO will handle the Payload activities (APCU, MPLM, Spacehab, etc.). The EMCC EGIL will be able to verify the panel R1 configuration all other insight into the payloads is with ACO and their counterparts.

## EGIL TMCC/EMCC CHECKLIST

The following checklist should be utilized by the on console EGIL for EMCC Activation.

### EMCC Declaration by on console Flight Director

- \_\_\_ Contact/Notify EMCC EGIL personnel of EMCC Activation (call and/or Page)
- \_\_\_ Provide EMCC EGIL this Checklist for them to take to Ellington
  - \_ Overnight gear, (bag needs to be tagged & Marked)
  - \_ EGIL Pager
  - \_ NASA Badge
  - \_ Obtain EMCC EGIL's Social Security Number (SSN is to be provided to the on-console FD for security reasons)

### TMCC/EMCC Documentation to be Packed & Shipped

- \_\_\_ Headset (TMCC Only)
- \_\_\_ EGIL Console Log Binder (entire EGIL Log with at least the following)
  - \_\_\_ Handovers
  - \_\_\_ Log
  - \_\_\_ Flight notes
  - \_\_\_ Last Execute package
  - \_\_\_ Anomaly log
  - \_\_\_ Chits
  - \_\_\_ PCM's
  - \_\_\_ TMBU's
  
- \_\_\_ Hardcopies of the following at time of EMCC Declaration
  - \_ EPDC/FC Display
  - \_ Cryo Display
  - \_ FC Performance trend data plot
  - \_ PCM with Summary

### \_\_\_ EMCC binders, verify binder content for the following:

#### Binder 1

- Current Flight, EGIL Flight Tagup
- CD containing the following:
  - Waveoff.xls calculator
  - FC Delta Volts Comp.xls
- EGIL Flip Book
- EGIL Console Handbook
- EGIL TMCC/EMCC Plan (SCP 6.2.5)

#### Binder 2

- 450-CAP-EMCC Document
- SSSH Sections 2, 3, 4, 5, 20
- Calculator
- Log Paper & Engineering Paper

**MCC EGIL Handover Preparation Checklist**

The following can be used as a guide or checklist for the on-console MCC EGIL for preparation for the handover to the EMCC EGIL.

- Run Current PCM for Handover
- Wave Off Spread-sheet based on current Consumables
  - How many deorbit opportunities are available?
  - How many additional deorbit days are available
  - What powerdown level can be supported on waive off days (Grp B?, Grp C?)
- Perform a FC Purge
  - Provide predicted FC Purge Requirements (time intervals btwn purges performed during mission)
- Review Deorbit Procedures for Deltas & provide inputs as required
  - Review Deorbit Prep
  - Review PL Deact
  - Review PL Entry Switch List Verif
- Through MEWS Trend Data Review
- Provide EMCC EGIL with Average KW's for the following
  - Sleep Grp B
  - Sleep Grp C
  - Docked wake period (if applicable)
  - Undocking day
  - FCS Checkout Day
  - Deorbit Day
  - Waive Off Days
- Coordinate with FDO to provide MASS PROPs
  - Perform Cryo Reset & run CRYSP
  - Provide MASS PROPs for all upcoming PLS & NEOM times
- Provide expected H2 usage from
  - current MET through EOM, EOM+1, EOM+2, etc...



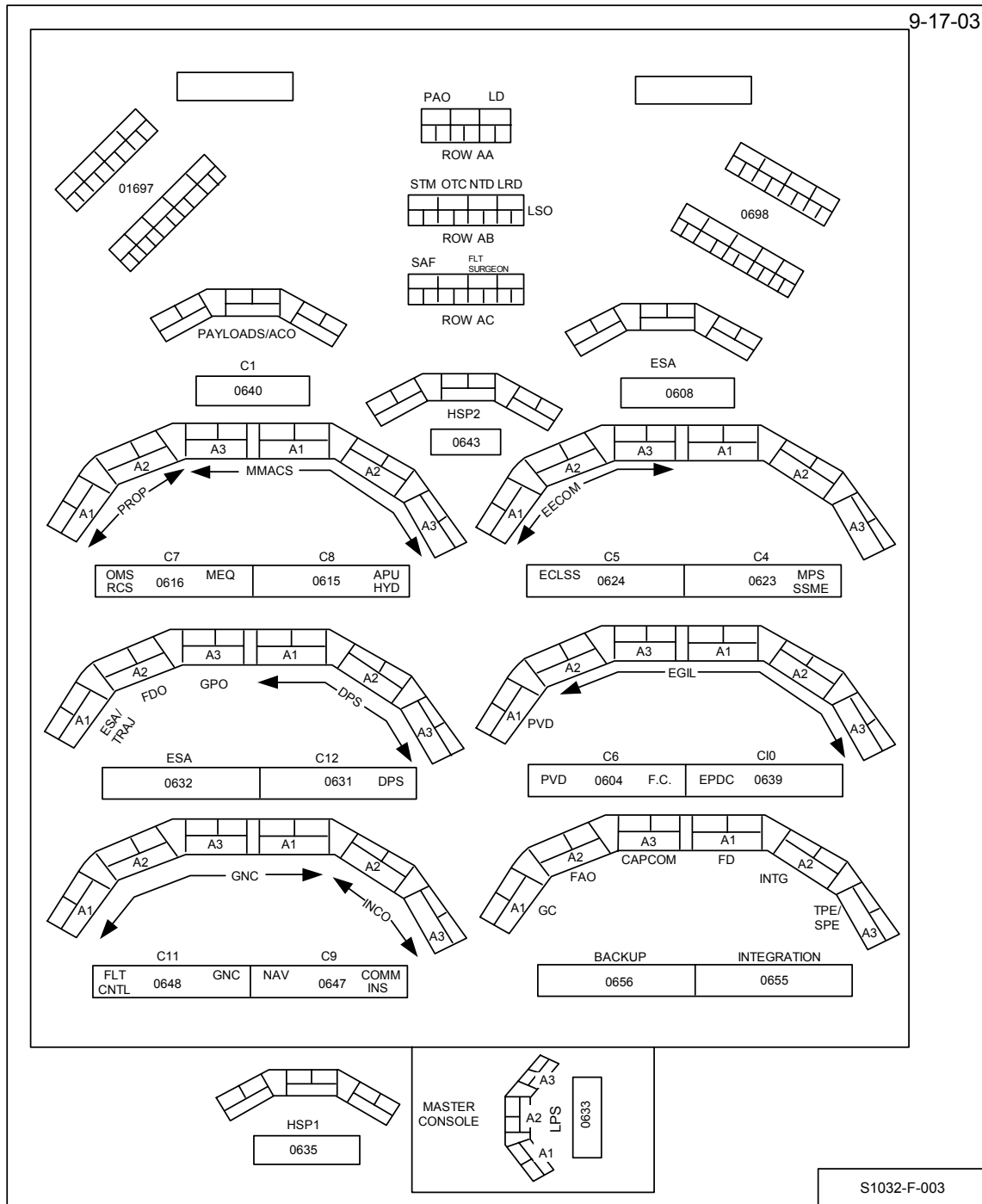


Figure 6.2.5-1 EMCC Flight Control Team Seating Chart

<b>SYSTEM</b>	<b>KSC SYSTEM Call-Sign</b>	<b>JSC SYSTEM Call-Sign</b>	<b>Console Location</b>	<b>KSC /JSC System Comm Channel</b>	<b>EMCC Internal Conference Channels</b>
APU	CAPU	MMACS	0115/0215/0615	182	6905
Capsule Commander	n/a	CAPCOM	0156A3/0256A3/0656A3	245	n/a
COMM	CCSE	INCO	0147/0247/0647	145	6907
DPS	CDPS	DPS	0131/0231/0631	152	6905
ECLSS	CECL	EECCOM	0124/0204/0624	243	6906
Entry Support	n/a	ESE/TRAJ	0132A1/0232A1/0632A1	173	6903
EPDC	CEPD	EGIL	0139/0239/0639	151	6906
Flight Activities	n/a	FAO	0156A3/0256A3/0356A3	175	6901
Flight Director	n/a	EMCC FD (Handover)	0155A1/0255A1/0655A1	161	6908
Flight Director	n/a	EMCC FD	0155A1/0255A1/0655A1		6001
Flight Dynamics	n/a	FDO	0132A2/0232A2/0632A2	173	6903
FLT CNT/GNC	COFC/CGNC	GNC	0148/0248/0648	171	6904
FUEL CELL/PRSD	CFCP	EGIL	0104/0208/0604	151	6906
Ground Controller	n/a	GC	0156A1/0256A1/0656A1	322	6902
Guidance and Procedures	n/a	GPO	0132A3/0232A3/0632A3	252	6903
HYD	CHYD	MMACS	0115/0215/0615	187	6905
INSTRUMENTATION	CISL	INCO	0147/0247/0647	145	6907
Landing Director	LRD	LSO	AB-8	6011	6011
MEQ/MECH	CAFM	MMACS	0116A3/0216A3/0616A3	182	6905
Nav aids	CNSE	GNC	0147A1/0247A1/0647A1	171	6904
OMS/RCS	COOS	PROP	0116/0216/0616	147	6904
Payloads	NPI	Payload/ACO	0140/0234/0640	234	n/a
Public Affairs	PAO	PAO	AA-1	187	6901

**Table 6.2.5-1 EMCC OIS-D COMM**

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**TITLE**

INTRO TO WORKSTATION OPERATIONS - DELETED

## TITLE

WORKSTATION LOGIN AND SETUP PROCEDURES

## PURPOSE

The purpose of this SCP is to define the workstation login procedure, the DVIS login/setup, and the minimum displays, program applications, and plots an EGIL operator needs.

## WORKSTATION LOGIN

Once an ID and password have been assigned, an operator may log into the MCC workstations. An ID can be obtained by filling out and submitting a Computer Access Request (CAR) form. Electrical systems have three consoles available to log in to EGIL, EPS, and SL EPS. Use the corresponding login procedure for each workstation.

### EGIL Console

1. Log into White-FCR-14.
2. Select appropriate activity for the sim/mission (GC can determine correct activity).
3. Log into White-FCR-33.
4. Select appropriate activity for the sim/mission.
5. Deregister White-FCR-33 (EGILdnav: DATA/ISP Control >STOP SERVER & COMPS).

**Note: Deregister only White-FCR-33.**

6. Close the "Configuration" window (click on the Close button).
7. Iconify the "ADVISORY SERVICE" window.
8. Iconify the "Warning: Do Not Close Console" window.

**Note: Iconifying this window is okay, but do not close it.**

### EPS Console

1. Log into White-mprs-21.
2. Select appropriate activity for the sim/mission (GC can determine correct activity).
3. Log into White-mprs-3.
4. Select appropriate activity for the sim/mission.

5. Deregister White-mpsr-3 (EGILdnav: DATA/ISP Control >STOP SERVER & MPS).

**Note: Deregister only White-mpsr-3.**

6. Close the "Configuration" window (click on the Close button).
7. Iconify the "ADVISORY SERVICE" window.
8. Iconify the "Warning: Do Not Close Console" window.

**Note: Iconifying this window is okay, but do not close it.**

### **SLEPS Console**

1. Log into White-mpsr-4.
2. Select appropriate activity for the sim/mission (GC can determine correct activity).
3. Deregister White-mpsr-4. On EGILdnav: DATA/ISP Control >STOP SERVER & COMPS.
4. Close the "Configuration" window (click on the Close button).
5. Iconify the "ADVISORY SERVICE" window.
6. Iconify the "Warning: Do Not Close Console" window.

**Note: Iconifying this window is okay, but do not close it.**

### **SETTING UP THE WORKSTATION**

Table 7.1.2-1 is a checklist of the minimum displays, applications, programs, and plots the operator will need.

**Note: For more information on how to run/use the above applications, refer to that application's SCP.**

**Table 7.1.2-1. Operator checklist**

	Display/program/plot	Position	Phase of flight	Notes
1	MSK-601-EGIL FC/EPDC	All	Prelaunch/A/O/E	
2	MSK-Cryo Display	All	Prelaunch/A/O/E	Mission dependent; determine no. of cryo tanks flown
3	MSK-608-CONFIG	All	Prelaunch/A/O/E	
4	RT-PLOT- EGIL	All	Prelaunch/A/O/E	
5	ELOG	All	Prelaunch/A/O/E	
6	OFS (Onboard Fault Summary)-SM	All	Prelaunch/A/O/E	EGIL also has OFS on the FCR screens
7	OFS (Onboard Fault Summary)-BFS	All	Prelaunch/A/E	EGIL also has OFS on the FCR screens
8	SPECS	All	Prelaunch/A/O/E	
9	Limit Manager	EPS	Prelaunch/A/O/E	Only one Limit Manager should be running at a time
10	PIRT- plot157	All	Prelaunch/A/O/E	
11	PIRT- plot144	All	Prelaunch/A/O/E	
12	PIRT- plot139	All	Prelaunch/A/O/E	
13	PIRT- plot205	All	Prelaunch/A/O/E	
14	EPRAC	All	Prelaunch/A/O/E	
15	CRANS Bus Loss	EGIL	Prelaunch/A/O/E	EGIL should bring up CRANS first to obtain publishing rights. Other copies of CRANS can be brought up for reference
16	Leakman <i>(optional)</i>	All	Prelaunch/A/O/E	
17	Timers/Clocks - Wall Clock Display	EPS	Prelaunch/A/O/E	EGIL has the FCR clocks, and EPS has the option to bring up the clocks on the TV channel 50
18	ISP Channelization	EPS	Prelaunch/A/O/E	Only one ISP channelization should be running at a time.
19	History Tab	All	Prelaunch/A/O/E	
20	FCC	All	Ascent/entry	
21	MSK- APCU	All	Mission dependent	Only required on flights with APCU.
22	RT-PLOT-FCMS	All	Prelaunch	
23	X-Goal--FCMS	All	Prelaunch	

\* If FCR only, these applications need to be run by the EGIL.

## FCR ONLY OPERATIONS

For FCR-only operations, the EGIL should log into the EGIL console and configure to support operations. The EGIL should also log into the EPS console White-mpsr-21 and pause the workstation. The EPS operator usually runs the Limit Manager in the MPSR, so be sure to bring up the Limit Manager on the EGIL console.

## COMP CONSTANTS

The following comp constants need to be sent prior to the start of the sim/mission:

1. Fuel cell delta volt

Mission: send the mission-specific file.

7.1.2-3



Sim: send the FCSSDELTA.val.

2. CRYO tank value

Send CRYO#TK.val, where # is the number of tanks flown for that mission.

3. Amp-hr/kWh

Sim only, and this is optional.

**Note: Refer to the COMP Constant SCP for more information on how to use COMP Constants.**

### DVIS SETUP

Digital Voice Intercom System (DVIS) is the voice loop system that enables us to talk to other operators, while at the same time monitoring several other loops including the air-to-ground and flight director loops. The operator should log into one of the two DVIS sets on the console. To log into DVIS, the operator should touch the screen and type in the position number labeled on the top of the DVIS. Once the operator has logged onto the DVIS, they can select the appropriate page. To monitor a loop, the operator should touch the block they would like to monitor. Once the block is touched it becomes highlighted, indicating that that specific voice loop is being monitored. To gain talk capability, the operator should touch that block again until the highlight is flashing. The volume can be adjusted by touching the *Mon Vol* or the *Head Set Vol*.

The following is a list of DVIS positions available to electrical systems personnel:

Position	Position number	Backup loop
EGIL left	4223	8223
EGIL right	4224	8224
EPS left		N/A
EPS right	4256	N/A
SL EPS left	4257	N/A
SL EPS right	4258	N/A

Each DVIS position has 10 pages. These 10 pages have been predefined and should not be changed. If an operator does change a page, once he or she is finished with that page, that operator should change it back to its previous configuration. If operators choose, they may acquire their own page, and configure it according to their preferences.

**TITLE**

MCC FILE TRANSFER PROTOCOL

**PURPOSE**

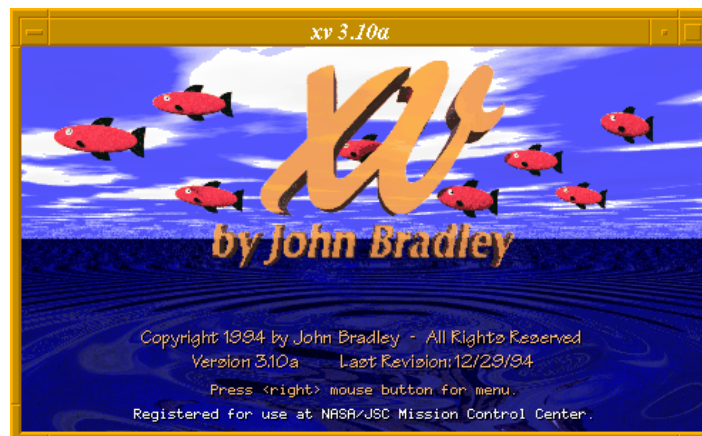
To describe the procedure for capturing an image on console and transferring it to a PC.

**PROCEDURE**

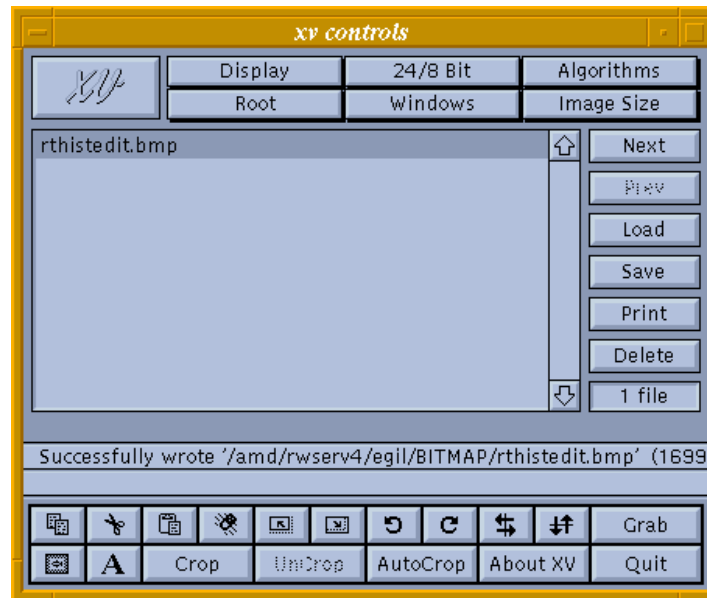
The following procedures should be followed in order for the best results.

**PART I: Capturing the image**

1. On workstation background, using right button, click and hold **Applications** and select **Xterm**.
2. Change directory to BITMAP by typing: ``cd BITMAP``.
3. Invoke bitmap utility by typing: ``mcc/cots/xv-3.10a/xv &`` or on **MASTER DNAV**, select **Global Apps, XV**



4. Click right mouse button in window to start application.
5. Bring up display to be saved.



6. Click the **`Grab`** button in lower right of xv controls window.
7. Another window appears. Set delay to **`2`** and click **`Grab`**.
8. Click left mouse button in desired display. Note: Display must be on the same monitor as the XV program or it will not work.
9. A copy of display will appear. If you wish to crop the image, double click on the new image and then resize as needed. Then, in the xv controls window, click on **`Crop`**. Otherwise, proceed to step 10.
10. Click on Save. Verify save to BITMAP directory (egil/BITMAP).
11. Click in Format box and select **`bmp`**.
12. Type in a name for display bitmap, i.e.: **filename**
13. Click OK.
14. Repeat steps 5 thru 13 for each display.
15. Directory BITMAP will contain all the display bitmaps copied and saved.
16. Exit the xv program and return to the Xterm window.

*Note: The above procedure can be adapted to generate jpg or gif files instead of bitmaps by selecting the appropriate option in Step 10 and using the appropriate*

*file extension in Step 11. JPG and GIF files are useful if the user only requires a copy of the image. BMP files are more user friendly for editing purposes.*

#### PART II: Transferring the image to the PC

1. Type the following in the BITMAP directory: ``ftp mas-ftp``. (i.e.: `white-mpsr3:/users/egil/BITMAP > ftp mas-ftp`) You should receive a "Connected to opsftp".
2. When Name (mas-ftp:xxxegil): appears, type: ``jsc-mas/username`` and hit enter. This will be your PC login ID
3. When Password: appears, type your jsc-mas ``password``. This will be your PC logon password.
4. When you see `ftp>` type: ``cd EGIL`` and hit enter. This will put you in the appropriate directory on the V: drive on the PC. You should receive a "CWD command successful" and see `ftp>` on the command line.
5. Type ``binary`` and hit enter. You should see "Type set to l" on the command line. This will copy the image file over properly. If this is not done, the image will not be copied correctly.
6. Now type ``put filename filename.bmp`` and hit enter. (If the image was saved as a .jpg or .gif file, then substitute the appropriate file extension in place of .bmp.) This starts the transfer procedure from the BITMAP directory on the workstation to the EGIL directory on the V: drive of the PC. It is important to put `.bmp` after the second filename so the file transfer program knows what to save the file as on the PC. You should see "PORT command successful" and then "Transfer complete" after a short period of time.
7. Once the file is transferred, it will be located in the following directory on the PC: "V:/EGIL/Egil OpsFTP".
8. Remove the image file from the V: drive after it is transferred to your hard drive or email due to the size limitation of this drive.
9. Quit the Xterm window.

## TITLE

LIMIT MANAGER

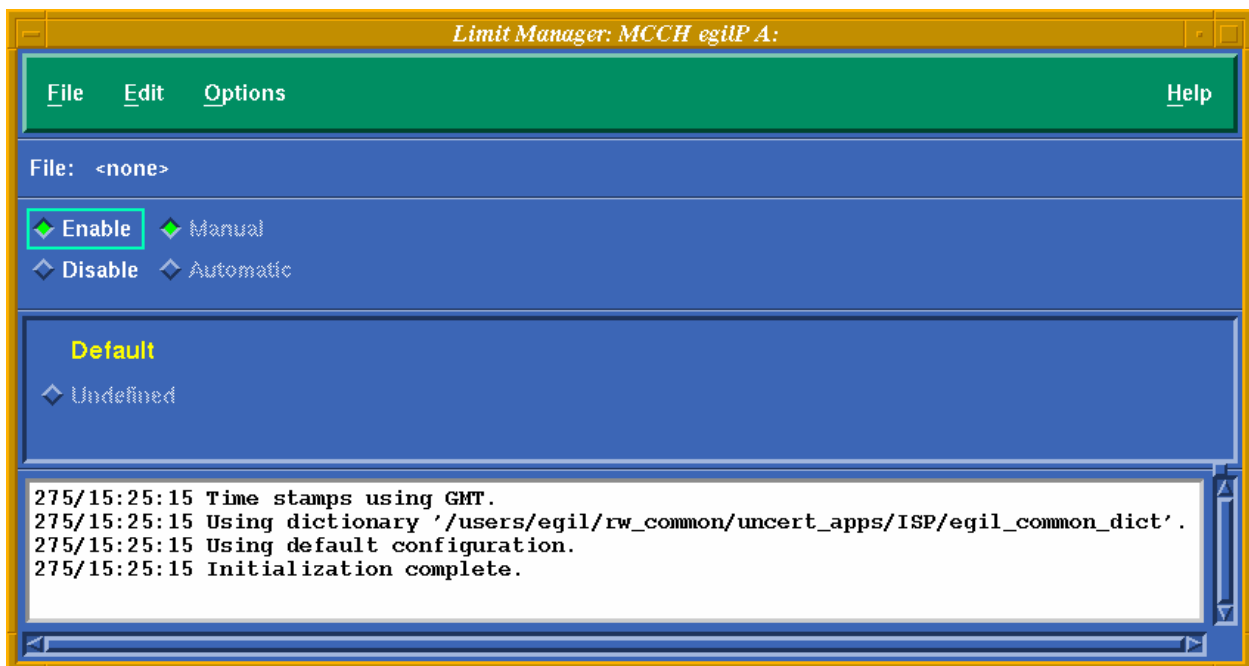
## PURPOSE

This SCP is an EGIL reference for ISP Limit Manager and includes how to start limit manager, how to edit/change limits, how to save checkpoints, and how to edit the checkpoint files.

## USER'S GUIDE

### A. Opening Limit Manager

To open Limit Manager, go to the EGIL DNAV > ISP CLIENTS > EGIL Limits > START EGIL Limits. This will bring up the Limit Manager window (Figure 7.1.4-1).



**Figure 7.1.4-1. Limit Manager window**

### B. Opening a checkpoint

The checkpoint files contain all the parameters for all limit sets in which EGIL chooses to have limits on their ISP server. The checkpoint can have different partitions for different phases of flight when different limit sets are required for the same parameter. The EGIL.cp has been broken out into several partitions, some of which are further divided into subdivisions. For example, the CRYO PRESS partition contains all limits pertaining to cryo pressures. Because different limits are required for the cryo pressures for ascent, the partition is divided into two subdivisions, Ascent and Orbit/Entry. The checkpoint files cannot be changed by

7.1.4-1

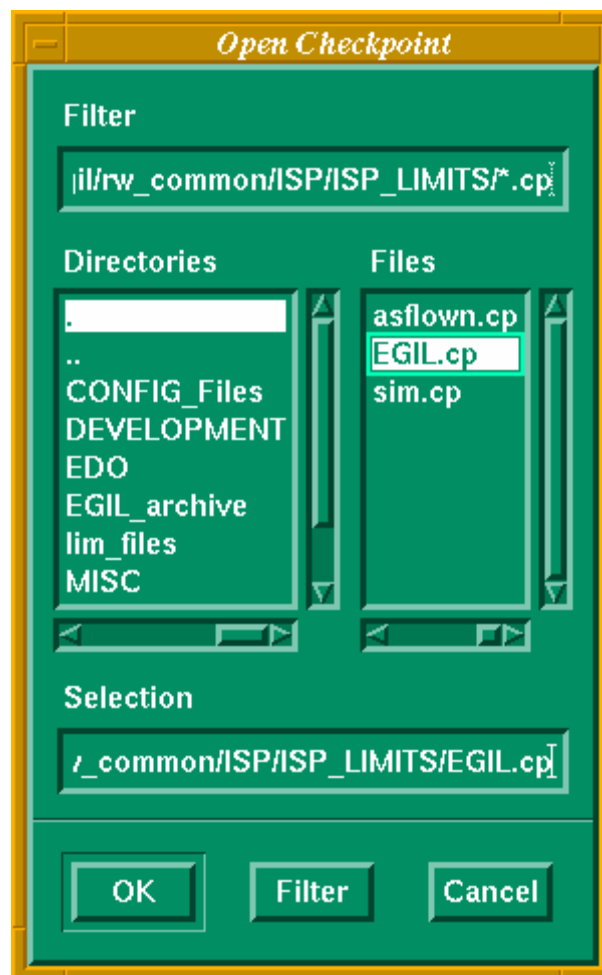
the user (to change the checkpoint there are certain steps that must be performed; see Changing the EGIL.cp file).

Procedure:

1. Main Limit Manager window: File>Open

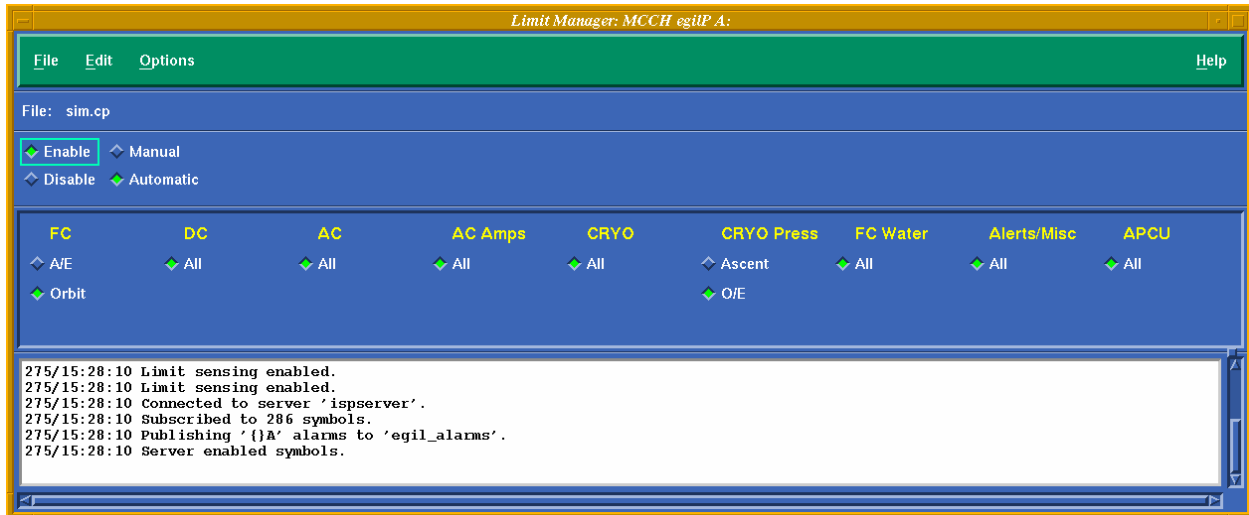
An open checkpoint window appears that lists the available checkpoints (see Figure 7.1.4-2).

2. In the Open Checkpoint window under Files, select the checkpoint to be used. (Use the EGIL.cp unless there is a flight-specific checkpoint to be used.)



**Figure 7.1.4-2. Open Checkpoint window**

3. Click "OK" in the Open Checkpoint window. The Checkpoint is now opened (see Figure 7.1.4-3).



**Figure 7.1.4-3. Limit Manager window with EGIL.cp opened**

4. Now that the correct checkpoint has been opened, in the main Limit Manager window: File>Save As

The Save As window will appear. The operator should save the file as another name. For example: for a sim, save as sim.cp; for STS-90, save as Asflown.cp

**Note: It is important to 'save as' for the day's activities. The EGIL.cp file should never be overwritten.**

- C. Enabling a checkpoint

### Automatic Enabling

Limit Manager has an automatic enable function that can be selected by clicking on the diamond next to Automatic in the Limit Manager window. When in the automatic enabling mode, the partitions are automatically enabled, depending on what OPS Major Mode the PASS is currently in.

For partitions that do not have different subdivisions, for example the DC partition, those limits are enabled for all OPS Major Modes. For partitions that do have different subdivisions, for example the FC partition, set the context to recognize when the appropriate subdivision should be enabled. The Ascent/Entry subdivision of the FC partition will be active when the OPS Major Mode is not MM 106, 201, 202, 801. The Orbit subdivision of the FC partition will be active when the OPS Major Mode is MM 106, 201, 202, 801. The transition between the different subdivisions is performed automatically.

For more information on Automatic Enabling, reference the Information Sharing Protocol (ISP) Release 3.4, Limit Manager User's Guide.

Procedure for automatic enabling:

1. Click on the diamond next to Automatic in the Limit Manager window.
2. To activate the limits, click on the diamond next to Enable in the Limit Manager window or connect using the Limit Manager window command pulldown menu.

**Note:** *When you enable or connect Limit Manager, it will activate the AC amps to the values at that time. To update the AC AMPS, see the procedure in Limit Set Guidelines.*

### Manual Enabling

In the manual enabling mode, the operator has to click on all the partitions that need to be enabled. This is performed by clicking on the diamond next to the appropriate subdivision for each partition. Manual enabling allows you to pick and choose which partitions you want active. It is important to remember that in the manual enable mode, only the partitions you select will have active limits.

Procedure for manual enabling:

1. Click on the diamond next to Manual in the Limit Manager window.
2. Click on the diamonds next to the partitions you would like to have activate limits.
3. To activate the limits, click on the diamond next to Enable in the Limit Manager window or connect using the Limit Manager window command pulldown menu.

**Note:** *When you enable or connect Limit Manager, it will activate the AC amps to the values at that time. To update the AC amps, see the procedure in Limit Set Guidelines.*

### LIMIT SET GUIDELINES

The EGIL.cp limits are set based upon engineering judgment. The user can change these limits real time. The user should perform a File > save once the limits have been updated. The changes made will only affect the checkpoint file that the user 'Saved As' in step 4 of the opening checkpoint procedure.

The AC amps limits are automatically set to be + and -0.2 amps/phase from the actual amp values.



To change limits, use the following procedure:

1. In the Limit Manager window: EDIT > LIST  

The List Editor window will appear (see Figure 7.1.4-4).
2. In the List Editor window, below the tool bar, click on the button labeled “FC” and select the partition that contains the parameter that needs to be changed (see Figure 7.1.4-4).
3. In the List Editor window, click on the button labeled “ALL” (next to the partition choices button). Select the partitions subdivision for the phase of flight limit set that needs to be changed. If no partition subdivision appears, the limits sets in that partition are not subdivided. For example, the FC partition has two subdivisions: (1) Ascent/Entry and (2) Orbit. The DC partition does not have any subdivisions, so its parameters are in the ALL.
4. Once the partition and subdivision have been selected in the List Editor window: Download > merge. This will download all the parameter limit sets for that partition and subdivision. To verify that you are changing the limits in the correct subdivision, look at the description column. The description column will tell you what phase of flight you are changing for each parameter limit set.
5. Update parameters requiring change. If updating AC limits, skip this step.
6. Once updated:  

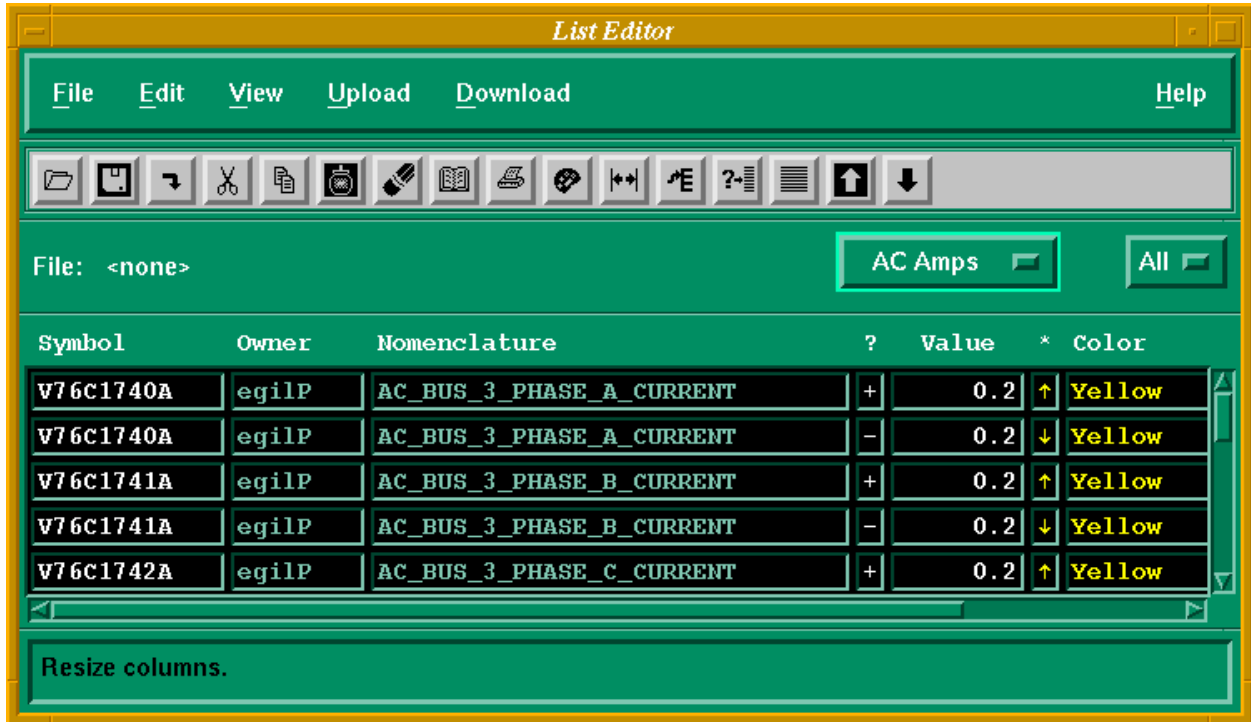
If all parameters have been changed: EDIT > Select All (This will highlight all parameters.)

or

If selected parameters have changed: CNTL + double click on the MSID (this will highlight only that selected parameter). Do this for all parameters changed.
7. In the List Editor window: Upload > Replace > Values, or color, or indicators (This will activate the new limits.)

**Note:** *The value, color, or indicator can be changed one at a time. For example, if you have several parameters for which you want to change the color and the value, you can change all the parameters’ values, Upload > Replace > Value, then change all the parameters’ colors, Upload > Replace > Color.*

Your limits will now be updated.



**Figure 7.1.4-4. List Editor window with the AC Amps partition opened**

### CHANGING THE EGIL.CP FILE

The EGIL.cp should never be changed without a group concurrence. Whenever the EGIL.cp is changed, each change is to be documented in the rcs file. To make changes, give your suggested changes to the Limit Manager coordinator. The Limit Manager coordinator will present your suggested changes to the group. If approved, the Limit Manager coordinator will make the changes.

The procedure for editing the EGIL.cp file is as follows:

1. Obtain the concurrence from the EGIL group on the proposed limit changes.
2. In an X-Term window:

```
>cd /users/egil/rw_common/ISP/ISP_LIMITS
>co -l EGIL.cp
>setenv TEMP /MCC/rw_temp/egil
>ll *.cp      (Verify EGIL.cp is read-write)
```
3. Open Limit Manager and EGIL.cp. In List Editor download merge, sort (to sort by MSID), make changes, upload. Close List Editor (save changes - NO). File> Save, saves to EGIL.cp, exit.
4. In the X-Term window:

```
>ci EGIL.cp
> Write in your comments/changes. Note changes can be multiple lines
> .      (Enter period to finish comments)
>co EGIL.cp      (Makes it read only)
```

The EGIL.cp will now be changed. The user can now go into Limit Manager and verify the changes.

For more information, reference the Information Sharing Protocol (ISP) Release 3.4 Limit Manager User's Guide.

## TITLE

LIMIT ALARMS

## PURPOSE

This SB describes the EGIL limit alarm tones that are generated and identifies the EGIL limits that create these alarms.

## BACKGROUND

Limit alarms are a series of four beeps (de-de-de-de) generated by the ISP server on the MCC platform as an auditory signal to the console operator that a violation of critical limits has occurred. These tones are generated on the operator's Digital Voice Intercom System (DVIS) headset. The MCC console operator can enable, disable, or recycle the process on the EGIL DNAV/ISP/limit alarms.

When the operator logs into the MCC console, the limit alarms are automatically enabled; however, limit manager must be open and running for limit alarms to process EGIL limit violations (reference SCP 6.2.5 for more information on limit manager). The EGIL limit manager places violations into the EGIL alarms buffer. The ISP advisory (ISP ADV) continuously polls the EGIL limit alarms buffer for violations. When the ISP ADV detects a violation in the EGIL alarms buffer, a subsequent limit alarm tone is generated.

The EGIL limit manager parameters with the bold arrows are the parameters that can generate the limit alarm tones. The limit alarm parameters are set to operational limits based on engineering judgment determined by the Electrical Systems Group. Generally, these parameters are set near flight rule limits, SODB constraints, and onboard SM fault summary message limits.

## TITLE

MSK DISPLAY UPDATE PROCEDURE

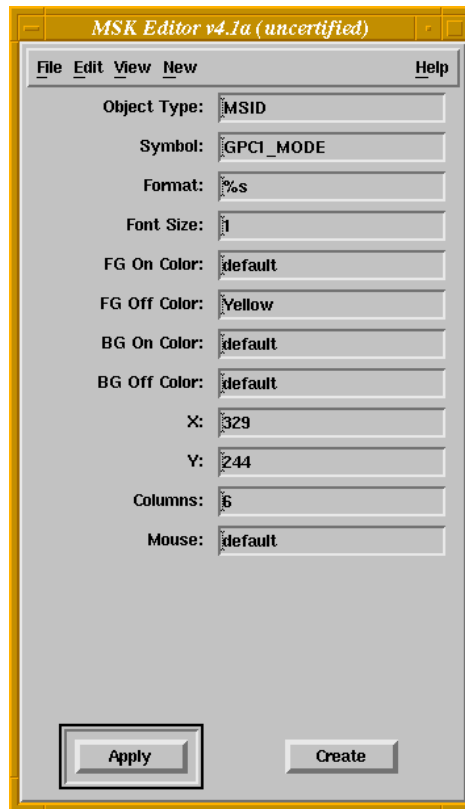
## PURPOSE

This brief describes the procedures required to update or modify EGIL MCC console displays.

## PROCEDURES

1. On the EGIL DNAV, select **Dev-Test**.
2. Select '**Check out File**' in the Dev-Test pulldown menu. The MSKS are locked for editing in the WORKAREA directory until the display is "checked out".
3. Double-click on the MSK directory or select the directory and hit the 'Filter' button at the bottom of the screen.
4. Select the file you want to 'check out' for editing purposes and hit the 'OK' button.
5. A window will appear and prompt the user to enter their workstation password. Hit Enter on the keyboard when complete.
6. An '**Alert pop-up**' window will appear to verify the file was checked out. If the password typed was incorrect, you will be prompted to re-enter the correct password. If the password was typed correctly and the file was checked out, click the 'Dismiss' button.
7. On the EGIL DNAV, select **Dev-Test**.
8. Select the **MSKS** option on the Dev-Test pulldown menu.
9. Select **MSKEDIT**. This will enable the MSKEDIT program to run and bring up the display to be edited. (See Figure 7.1.6-1)
10. Modify the display as required by moving the mouse over the display window and clicking on the desired parameter or text to be edited. The MSK-Edit window will show the parameter name, Text/MSID, color, font size, etc.
11. Click "Apply" on the MSK-Edit window once changes are made.
12. Verify changes took place on display.
13. Save the display.
14. When changes have been completed and verified, the display must be "checked in". On the EGIL DNAV, select **Dev-Test**.
15. Select '**Check in File**' on the **Dev-Test** pulldown menu.
16. Select the file you wish to check in and hit OK.
17. A comment box should appear where changes made to the display can be entered at the >> as a form of record keeping. Hit 'Enter' when complete. At the >> type in a single period to complete the sequence.

18. You can now view the edited MSK by selecting **Dev-Test** on the EGIL DNAV, then **MSKS, MSKVIEW**, and select the MSK to be viewed. Click OK and the MSK will open.
19. The edited MSK will need to be verified using the appropriate verification procedures. Once the changes are verified, the EGIL GA will then move the MSK to the cert-apps directory.



**Figure 7.1.6-1. MSK-Edit window**

## USER INFORMATION

The MSK-Edit window consists of a menu bar providing the File, Edit, View, New, and Help pulldown menus.

File Pulldown:

The File pulldown menu consists of the Open, Close, Save, Save-As and Exit buttons.

The Open button presents a file selection dialog allowing for the user to select an MSK\_View display file to edit. When a valid MSK\_View display file is selected, the display edit window appears providing the current display presentation. The Open button is not selectable when a display file is being edited.

7.1.6-2

**Verify that this is the correct version before use**

The Close button removes the display edit window from the screen. If the display has been modified, the user is prompted to save the edits or cancel. You can not change the name of the display file during the close operation. The Close button is disabled if there is no display file being edited.

The Save button saves the current display as edited. A backup of the previous display file is saved using the original file name with a "~" suffix. This backup is only of the previous version of the display file. If the Save button is pressed twice, the backup file will be identical to the current file. The Save button is disabled if there is no display file being edited.

The Save-As button presents a Save-As file specification dialog box. Enter a new file name in the file selection box. Use the other features of the dialog to specify the desired directory to save the file. The Save-As button is disabled if there is no display file being edited.

The Exit button terminates the MSK-Edit program. If the display has been modified, the user is prompted to save the changes.

Edit Pulldown:

The Edit pulldown menu consists of the Copy, Cut, Paste, and Dele~~t~~e buttons. The Cut button is enabled only after an object on the edit display has been selected.

The Copy button requires an object to be selected from the edit display. When the Copy button is selected, the selected object is saved in the Paste buffer.

The Cut button requires an object to be selected from the edit display. When the Cut button is selected, the selected object is saved in a paste buffer and the original object is deleted from the edit display.

The Paste button requires a previous Cut or Copy operation. When the Paste button is selected, the current object in the paste buffer is displayed on the MSK-Edit main window and a new object is created. Also, each time paste is selected, the newly created object will be displayed slightly offset from the original object or from the previous paste. There is no provision for group copy-and-paste.

The Dele~~t~~e button deletes the currently selected object. The object is removed from the display and deleted from the internal database. There is no verification of the delete operation and it is not possible to "undo" a delete operation.

View Pulldown:

The View pulldown menu consists of Discrete, Static, Outline, and Color Pallet buttons.

The Discrete button toggles the value of all data from 0 to 1. This is beneficial to determine what discrete values look like in their various states.

Selecting the Static button causes all data to change color to cyan, and all the data will be displayed with the suffix "S" appended to help the user determine if enough columns have been allocated to properly display each data object.

The Outline button draws an outline box around all text and MSID objects. This is beneficial to determine if any objects overrun other objects. Line objects are not supported here.

The Color Pallet button displays the MSK-Edit color pallet. The makes color definition for the various objects easy. To use the color pallet, simply click on the color field in the main MSK-Edit window, click on the desired color on the color pallet dialog, then click the apply button on the main MSK-Edit window. The object's color is then updated. Remember on MSID objects, the ON and OFF colors are displayed depending on the current state of the Discrete button.

New Pulldown:

The New pulldown menu contains the following options: MSID, Text, Line, Multi, Enum, and Button. Selecting one of these items causes a blank form to appear on the MSK-Edit main window (and possibly a dialog box containing a blank form to popup as well). Each form contains fields for the required information needed to create an object of each type. Pressing "Create" causes the new object to be displayed on the drawing area, provided the form was filled in correctly.

The Apply button remains disabled until a data object on the drawing area is selected.

Note: Changes made to any object in MSK-Edit will not take effect until the "Apply" button is pressed when the object to be changed is displayed on the MSK-Edit main window edit form.

Symbol Editor Dialog box:

If a Enum or Multi-type object is created or selected, in addition to the information displayed on the main window of the application, MSK-Edit will create a popup dialog box listing the value -relation-text tuples for a Enum object or the name-value pairs for a Multi object. This dialog box contains three buttons: Add, Delete, and Toggle. Pressing Add creates a new empty row of tuples for the user to fill in. Pressing Delete deletes the last row modified or selected by the



user. Pressing Toggle causes the display to cycle through each data item's state, so the user can determine if the number of columns is enough to display the object entirely.

Help Pulldown:

This pulldown provides MSK-Edit help information.

Object Movement:

In the MSK display window, it is possible to dynamically move one or more objects around the display.

Single Selection:

To move a single object to a new location on the screen, first place the mouse pointer over the desired object and press the left mouse key. The information about the object should appear on the edit form on the MSK-Edit main window. Next, press and hold the middle mouse button, and move the mouse pointer to the new location and release the mouse button. The position of the object is not set yet: to set the position, press the middle mouse button again, or, if a finer adjustment is required, use the arrow keys located on the keyboard to "fine tune" the position of the object, then press the middle mouse button or press the "Enter" key to anchor the object's position.

Group Selection:

To select a group of objects, use the left mouse button to define a bounding box surrounding all objects to be moved. To accomplish this, click and hold the left mouse button in the upper left corner of the intended bounding area, then drag the mouse to the lower right. A box graphically appears as you move the mouse. Once the box is set to the desired size, release the mouse button. While pressing the middle mouse button, move the mouse to move the entire group of objects: an image of the objects will move with the mouse cursor. When the object image is in the desired position, click any mouse button or press the "Enter" key to set the position. The objects are then moved from the old location to the new location. To cancel the group move operation, press the letter "Q" or the escape key.

Note: Only the objects within the bounding box are moved; if part of an object is outside the bounding box, it is NOT moved.

To delete a group of objects, select the group as before, and press the "x" key: the group of objects within the bounding box will disappear.

## TITLE

ISP CHANNEL

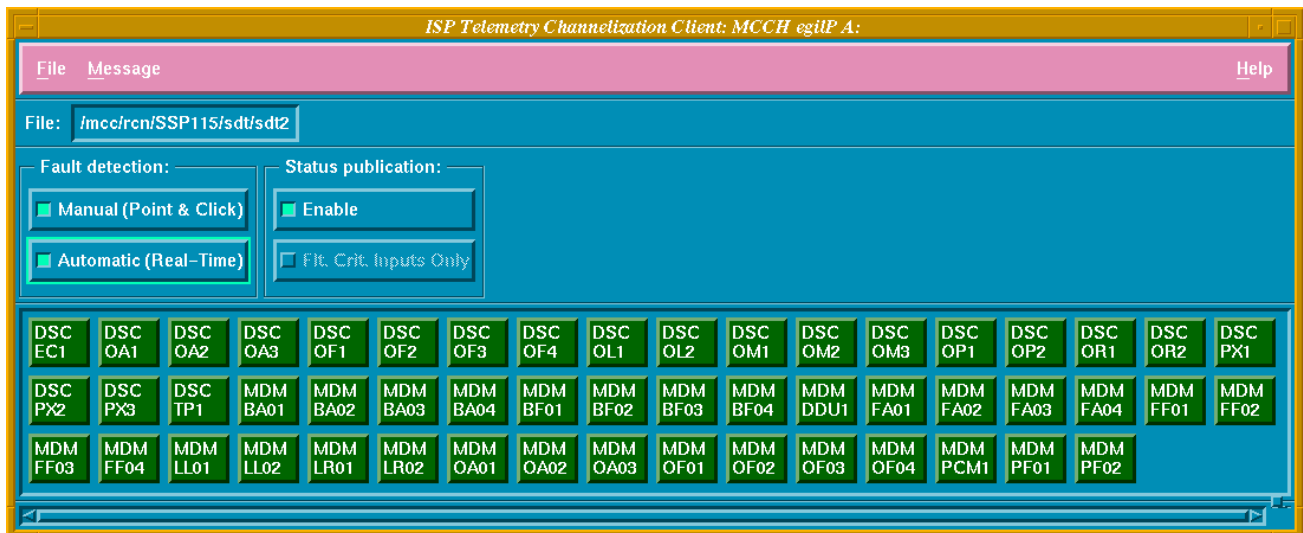
## GENERAL

ISP Channel is an application that monitors the health of all the Dedicated Signal Conditioners (DSCs)/MDMs on the orbiter. If a DSC/MDM is lost, the application automatically changes the color of the data associated with the lost DSC/MDM. The color of the data changes to purple on the EGIL display. If you think you have a telemetry problem, ISP Channel also allows you to select the MDM, DSC, card, and channel from which your equipment receives data. ISP Channel lists all equipment that receives data from that telemetry point, so you can determine whether the problem is due to telemetry error or just a bad transducer.

## PROCEDURE

1. To start, select: **EGIL → ISP Clients → ISPChannel BUILD**
2. Then select: **File → Build (wait while it builds) → Enable → Automatic (Manual)**

**Note: To use the automatic function of ISP channel, INCO must be running O1MON.**



**TITLE**

HISTORY TAB - TBD

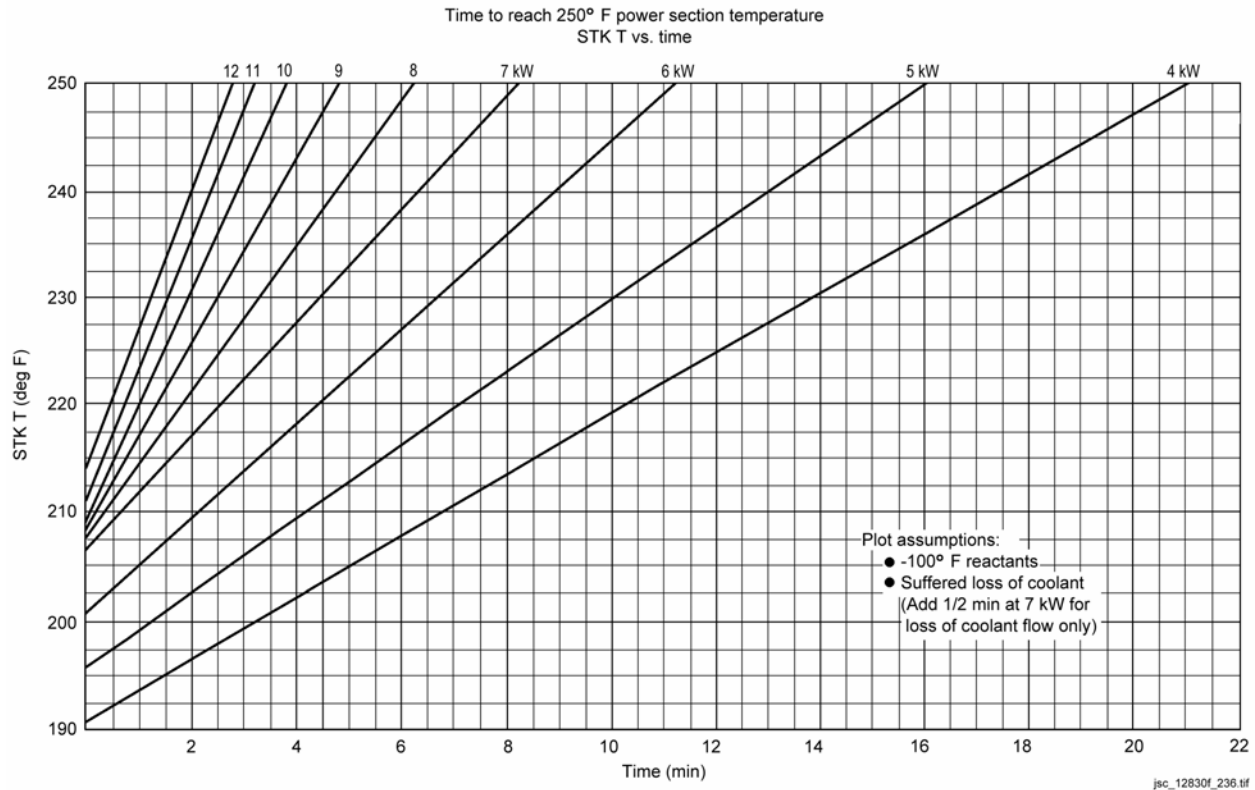
## TITLE

FUEL CELL CAPACITY

## DISCUSSION

In June of 1988, testing was performed to determine how long a fuel cell would last without cooling. Test data was used to create a fuel cell Stack T vs. Time chart (see Figure 7.2.1-1). Flight controllers use this chart to determine the amount of time remaining, on a fuel cell with a failed coolant pump, before the fuel cell stack T reaches 250° F. The operational upper limit for the fuel cell stack is 250°. Before the fuel cell Stack T vs. Time chart was created, a fuel cell with a failed coolant pump was shut down within 6 minutes. Test data was used to determine the 9-minute shutdown limit that is used today for a fuel cell without cooling. The creation of the fuel cell Stack T vs. Time chart allows the flight controllers to determine when it is necessary to shut down a fuel cell for a loss of cooling, caused by the loss of the coolant pump. Typically for the loss of fuel cell cooling (coolant pump failure), the fuel cell will be shut down as soon as possible. However, for critical phases of flight (i.e., ascent and entry), the fuel cell can be run longer to maintain the best possible bus configuration or fuel cell support during that phase (e.g., allowing the fuel cell to run until post-MECO with a failed pump). With a failed coolant pump or loss of fuel cell coolant, the fuel cell stack out temperature telemetry will become static due to the lack of coolant flow past the transducer. The fuel cell Stack T vs. Time chart estimates the time remaining until the fuel cell reaches 250°. The estimates are based on the current fuel cell power (kW) level.

The Fuel Cell Capacity (FCC) application was created to incorporate this “time remaining” data into an electronic console tool that would continuously update to provide the most recent information. The FCC application provides the EGIL flight controller with a graphical representation of time remaining on a fuel cell that has lost cooling or water removal capability. Should a coolant pump fail, the FCC will calculate a fail time based on the power level (kW) the fuel cell is supporting. The FCC also calculates a fail time for a 1-kW (“1Kw fail”) and a 2-kW (“2Kw fail”) powerdown. These 1-kW and 2-kW fail times are reflections of the time remaining that would result from a 1-kW or a 2-kW powerdown, respectively. The active FCC display updates continuously based on the current fuel cell power level and the stack out temperature. The FCC will start sequencing automatically at the onset of a failure. However, an FCC sequence can also be started manually by selecting the SEQ button. This function could be used if an FPC failure or a main bus failure occurs that might initially cause the loss of fuel cell data.



**Figure 7.2.1-1. Fuel cell stack temp vs. time chart**

The FCC application can be started from the EGIL DNAV under the Applications header (EGIL DNAV – Applications – FCC). Referencing Figure 7.2.1-2, the default FCC window consists of three buttons, which correspond to each of the fuel cells. The background color for these buttons is normally light blue (nominal conditions). When the FCC application detects a fuel cell failure, the application starts sequencing automatically. The application outputs a “beep” and turns the appropriate fuel cell button background color to red. Any of the fuel cell buttons can be depressed to bring up the detail fuel cell window (see Figure 7.2.1-3). When there is no failure and an individual fuel cell button is selected, the color of the fuel cell pushbutton changes to green. Only one detailed fuel cell window can be brought up at a time (as you reselect a new button on the main FCC window, the detailed window automatically changes to the selected fuel cell). To drop the detailed fuel cell window, the corresponding fuel cell button should be deselected on the main window (pushbutton color changes back to light blue if conditions are nominal, red if failure is detected).

In the main FCC window (Figure 7.2.1-2), the background color of the line showing “FCC Version X.X” is green when data is flowing to the application. The background color changes to black when the data is unavailable (e.g., Loss of Signal (LOS)). Under “File” on the main window, a RESET option is available to clear any past failures that may have been transient (data hit) or recovered. This RESET function is also available on the individual fuel cell window (lower right corner of display).

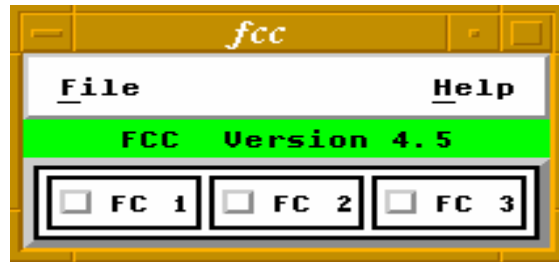


Figure 7.2.1-2. Main FCC window

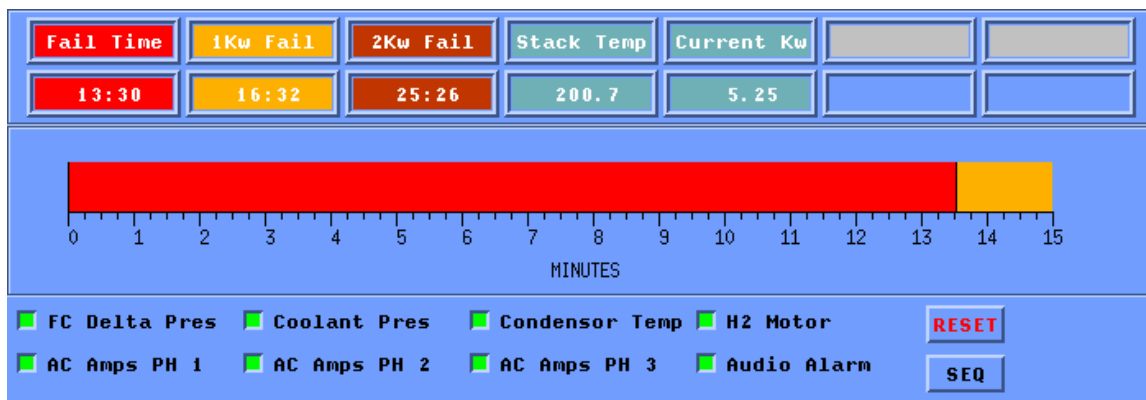


Figure 7.2.1-3. Individual fuel cell monitoring window

The primary objective of the FCC application is to establish the time remaining to shut down a fuel cell in the event of a coolant pump failure. The FCC application uses various methods to monitor for a coolant pump failure. For example, the FCC application monitors several of the fuel cell parameters and the associated AC currents (see Figure 7.2.1-3).

To determine a coolant pump failure, the FCC is looking at the fuel cell coolant pump  $\Delta P$  low indication and the associated AC currents (AC1 for FC1, AC2 for FC2, and AC3 for FC3). If the FCC application detects a coolant pump  $\Delta P$  low indication, it also needs to see a change in the AC currents at that time. Any change (increase or decrease) of the associated AC currents of  $>0.3$  amps per phase (all three phases) in conjunction with a coolant pump delta low indication starts the FCC countdown sequence.

For the case in which the coolant pump  $\Delta P$  low telemetry has failed, the FCC application is also monitoring other fuel cell parameters to determine a possible coolant pump failure. The FCC is monitoring the fuel cell H<sub>2</sub> motor status (for a possible loss of the entire fuel cell pump package). For a change in the H<sub>2</sub> motor status to  $<0.2$  or  $>0.8$  and a change of the associated AC currents of  $>0.3$  amps per phase, the FCC will start a countdown sequence. One downside of this sequence is that for the case in which only an H<sub>2</sub> pump has failed (coolant pump still running), the FCC will sequence based on the loss of cooling data (fuel cell Stack T vs. Time; i.e., 9 minutes at 7 kW). For a

7.2.1-3

failed H<sub>2</sub> pump only, the time remaining before a fuel cell shutdown is required is based on 110 amp-hours (~30 minutes at 7 kW).

The FCC is also monitoring the Fuel Cell Condenser Exit Temperature (FC Exit T) telemetry. When only the coolant pump fails (H<sub>2</sub> motor still running), the FC Exit T is expected to increase because of the lack of coolant heat exchange at the condenser. The FCC is monitoring for an FC Exit T increase of greater than 0.5 deg/sec over a 10-second interval and a change of the associated AC currents of >0.3 amps per phase. If both of these conditions are detected, the FCC starts a countdown sequence.

Last but not least, the FCC is monitoring the fuel cell coolant pressure telemetry for the possibility of a fuel cell coolant loop leak. When the fuel cell coolant loop leaks out, the coolant pressure eventually drops (after the accumulator bottoms out) and the coolant pump cavitates. If a decrease in fuel cell coolant pressure to below 50 psia is detected, the FCC starts a countdown sequence.

When any of the above conditions causes an FCC sequence to start, the main FCC window will turn the associated fuel cell button red and generate an audible beep. If any of the first three conditions (coolant pump  $\Delta P$ , H<sub>2</sub> motor status, and Exit T) occurs without a change in the AC currents, the FCC turns the associated fuel cell button yellow but does not start a countdown sequence.

When a condition has been detected, any subsequent change in the three-phase AC currents causes a countdown sequence. For example, if the fuel cell coolant pump  $\Delta P$ ducer fails to low, a change in the AC currents 30 minutes later causes an FCC countdown sequence to start. To avoid this situation, any parameter you wish to take out of the FCC monitoring (e.g., failed transducer) can be deselected on the associated fuel cell window (Figure 7.2.1-3) by clicking the corresponding button. When the parameters are active, the pushbutton box next to the parameter name is green. When deselected, the color changes to light blue.

The FCC detailed fuel cell window always shows active time remaining conditions (if a fuel cell failure were to occur) for the current time, based on the current fuel cell kW level and stack out temperature. This information is displayed both digitally and graphically. Once a countdown sequence has started, the time remaining decreases until it reaches zero or until the fuel cell is shut down. The data updates continuously, based on the current power level on the affected fuel cell. The FCC stops sequencing when the fuel cell has been shut down. In Figure 7.2.1-3, the two boxes shown on the top row, far right, are used to display the sequence time (how long it has been since the sequence started) and the shutdown time (time past when the fuel cell should have been shut down). For the shutdown time, if the countdown sequence reaches zero and the fuel cell has not been shut down, the shutdown time starts to count up until the fuel cell is shut down.

## TITLE

PLOTTING IN REAL TIME

## PURPOSE

This user's guide provides the documentation necessary for a user to learn the mechanics of the Plotting in Real-Time (PIRT) program. This program is normally executed on a Concurrent Computer workstation with real time (Local Area Network (LAN)) connectivity in the building 30 MCC. The guide will contain the procedures necessary to operate the program.

## BACKGROUND

PIRT is used to emulate the Gould SCRs currently used in the MCC. The initial plot formats created are those currently defined for use on the Gould SCRs. The procedures to operate the program show how the program should be used on console. All user prompt messages are described in this guide, as well as the appropriate selections expected by the user. Program warning and error messages are displayed in a popup window and in the WEX advisory window.

## PROCEDURE

### A. Execution

There are two methods of executing PIRT.

1. The first method is by setting the current directory and typing the executable file name from an Xterm command line. The command has the following syntax:

```
cd <data_directory>  
/WEX/<position>/port  [<format file> | <format ID>]
```

Where:

<data\_directory> - the directory where the "Formats" subdirectory resides. The "Formats" subdirectory all contains current format files and will receive any newly created format files.

<position> - is your workstation's position, i.e.: egil, eecom.

format file - is the actual PIRT format file name located under the 'Formats' directory.

format ID - is the unique format ID number of the format file located under the 'Formats' directory.



If a format file/ID is specified, the SETUP window is NOT displayed and the PLOT window is displayed immediately. If a format file parameter is not specified, PIRT's SETUP window is displayed for user input.

2. The second method of execution must be previously configured on the workstation by someone knowledgeable on window manager setup syntax. Use the window manager to bring up your position's workstation applications. If PIRT is present, select it. In the root window, the mouse cursor changes to a clock cursor (indicating PIRT is initializing) until PIRT's SETUP window appears.

#### B. PIRT SETUP window

The SETUP window provides the required interfaces to begin plotting. Figure 7.2.2-1 depicts the contents of the SETUP window. From the SETUP window, the user may select the desired data source. To select a data source, click on the radio button to the left of the data source name.

##### 1. REAL TIME

This is the default data source. For every second of time, data from the real time LAN are read, interpreted, and plotted against the orbiter MET.

##### 2. PLAYBACK DATA

If this option is selected, a secondary list of radio buttons appear. Select one of the time lengths for playback. If no time is selected, real-time data are displayed. If a valid playback time is selected, the data for that time period are displayed. When playback data have completed, processing reverts back to real-time data. Plotting of playback data is distinguished by a magenta PLAYBACK MET label at the bottom of the window. When the plotting reverts back to real-time data, a white MET label appears at the bottom of the window.

##### 3. MEWS DATA

Not implemented yet.

##### 4. ASCII DATA

Not implemented yet.

##### 5. FORMAT SELECTION

From the SETUP menu, a desired plot format may be selected. To select a plot format, move the cursor to the available format list provided on the SETUP menu and click on the desired format line. If more formats exist than can be completely displayed in the list, use the scroll bars on the right side to

access the remaining formats. When a format is selected, only the format name appears in the text entry box displayed on the list of available formats.

After selecting a format file, the user may begin plotting, delete the format, or edit the format file.

6. START PLOT

Click on the START PLOT button to begin plotting data from the selected data source(s) with the selected format file.

7. EDIT FORMAT

Click on the EDIT FORMAT button to display the FORMAT EDITOR window loaded with the contents of the selected format.

8. DELETE FORMAT

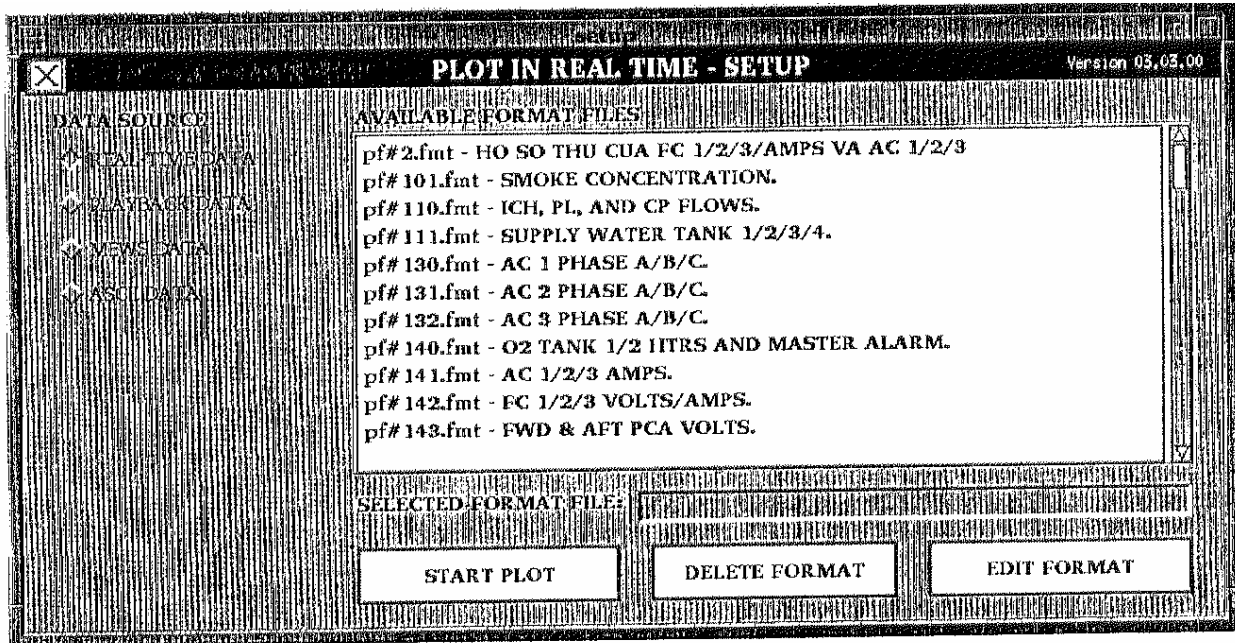
Click on the DELETE FORMAT button to delete the selected format. A popup window appears requiring user confirmation prior to format deletion. See Figure 7.2.2-2.

C. Startup execution errors

Upon user execution of PIRT, errors may occur under certain conditions. Sometimes a red popup window appears in the upper left corner of the display stating: "Unable to open the format description data file: 'Formats/fmt\_desc'".

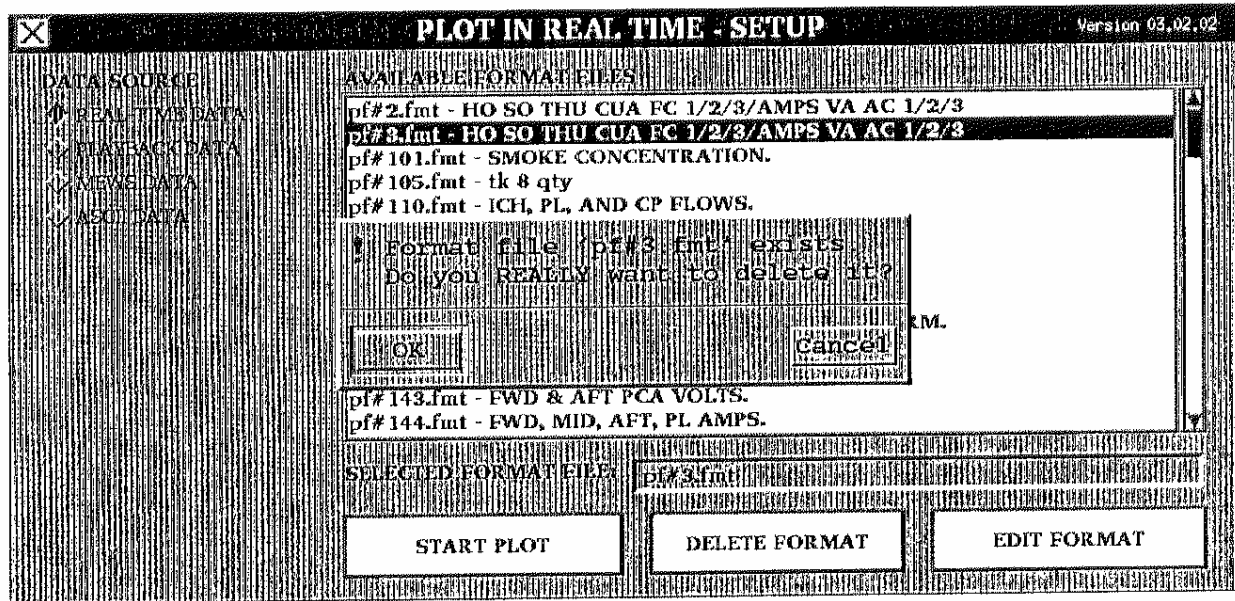
This error is a result of one of the following conditions:

- The user is executing PIRT from the wrong directory. Prior to PIRT execution, the current directory MUST be set to the directory where the 'Formats' directory resides. For example, if the PIRT format files reside in '/user/eecom/Formats', the current directory must be set to '/user/eecom'.
- The user does not have the required format description file in the 'Formats' directory. The user must create this file and place it in the same directory with all the PIRT format files (Formats). The easiest way to create this file is to set your current directory to the 'Formats' directory and enter the following UNIX command: 'ls -1 pf#\* .fmt\_desc'. This will create the 'fmt\_desc' file with only a list of format file names. The associated format descriptions may be added to each format via PIRT's format editor.



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Figure 7.2.2-1. Setup window



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Figure 7.2.2-2 . Delete format

D. Plotting with PIRT

1. Plot initialization

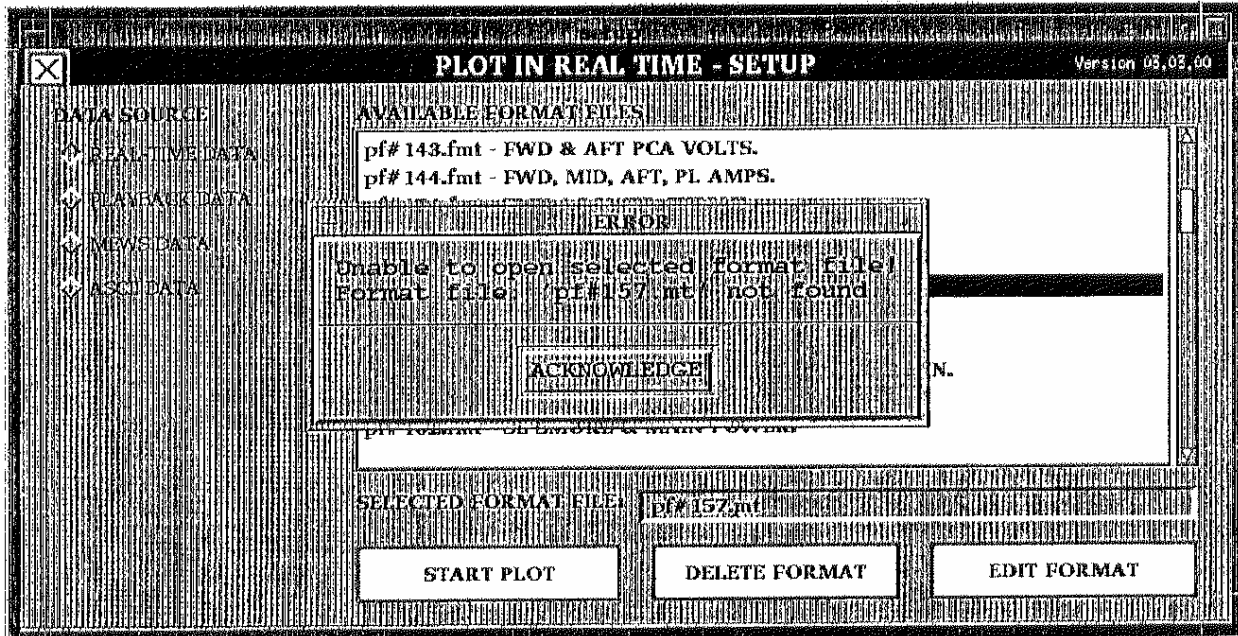
When the START PLOT button from the SETUP window is pressed, the system first checks if the specified format file exists. If an invalid format file was manually entered in the selected format field, a yellow popup message appears informing the user of the problem. The user must acknowledge this message to continue. Refer to Figure 7.2.2-3 for an example of the invalid format file popup message. When a valid format file is found, PIRT next checks if the MSIDs specified in the format file are present for the flight ID specified during operational sign-on of the workstation. If invalid MSIDs are found, a yellow warning message is displayed informing the user. After the user acknowledges the message, the PLOT window is displayed. The invalid MSIDs will provide erroneous results in the PLOT window. See Figure 7.2.2-4 for an example of the yellow warning message when invalid MSIDs exist in a format.

If Record and Playback System (RAPS) data are being plotted and one or more MSIDs in the format file do not reside in the list of recorded MSIDs in RAPS, an error message appears in a popup and in the WEX advisory messages.

During a PIRT session, the first time the START PLOT button is selected, the user is required to position and optionally size the PLOT window. When this is required, the mouse cursor changes from the clock cursor to the window placement cursor (a small upper left corner symbol). Subsequent requests for plots during the same PIRT session position the PLOT window in the original configuration.

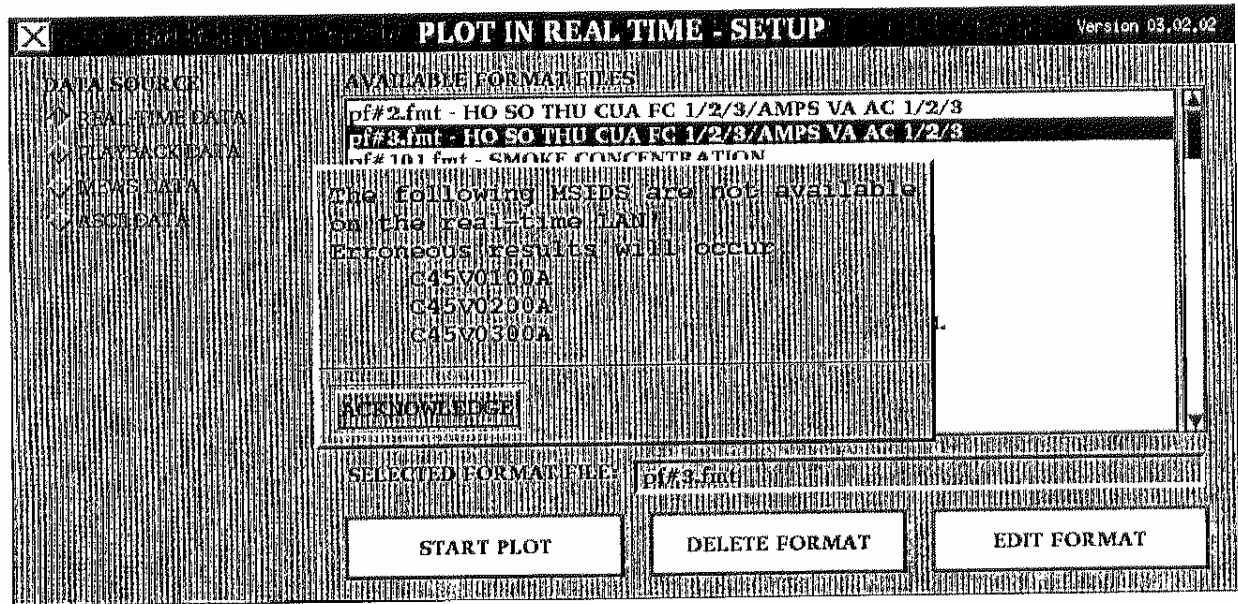
2. Placing the PLOT window

To position the PLOT window using the default window size, move the mouse window placement cursor to the upper left corner of the screen and press the left mouse button. To position the PLOT window using a modified window size, position the mouse placement cursor to a desired upper left corner, then press and hold the middle mouse button. Drag the mouse window size cursor to the lower right, defining a desired window size. When the window is defined as desired, release the middle mouse button. Sometimes, if the PLOT window is defined too small, the placement of various text information may overwrite each other. When the PLOT window is displayed, the program automatically begins plotting data, if available. Figure 7.2.2-5 presents an example of a PLOT window.



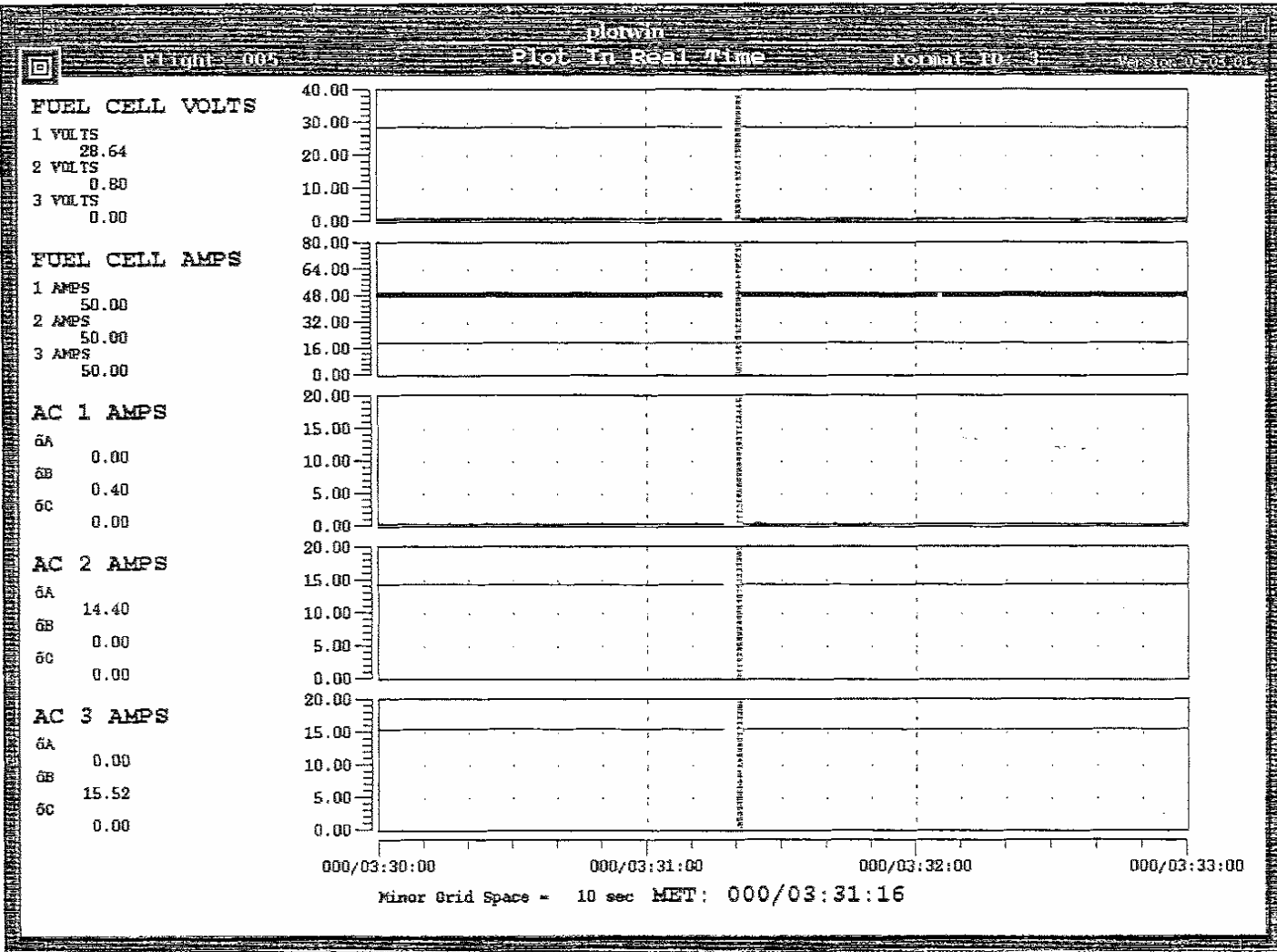
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Figure 7.2.2-3. Invalid format file warning popup



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Figure 7.2.2-4. Invalid MSID warning popup



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Figure 7.2.2-5. Plot window

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3. Plot processing

As normal plot proceeds, the displayed MET is presented white in color. When data is lost, the color of the MET turns cyan (greenish blue) and the value remains static. If for some reason the MET value provided to PIRT exceeds 3 seconds per interval, it is assumed to be ratty data.

When ratty data is sensed, the MET color changes to yellow and displays the ratty value.

If RAPS data is being plotted, the MET time label and color change to indicate that RAPS data is being plotted.

A blue separator bar moves across each plot area as time progresses. To the left of the bar is the most recent data. To the right of the bar is data from the previous time interval. The only time this is misleading is after launch.

Prior to launch, the MET value provided is the same as GMT. After launch, MET resets to zero. In this situation, the data to the right of the separator bar is not necessarily data from the previous time interval. The time of launch must be considered in determining the time of data presented to the right of the separator bar.

4. Exit plotting

To exit the PLOT window, move the cursor to the close icon located in the upper left corner of the window. Press the left mouse button. The SETUP window appears again. If a plot is requested again, the window will automatically be positioned and sized in the original configuration of the PLOT window.

E. Format editing

1. Format editor initialization

When the EDIT FORMAT button is clicked from the SETUP window, the mouse cursor changes to a clock cursor. After a brief pause, the FORMAT EDITOR window appears. This window should not be resized. Figure 7.2.2-6 is an example of the FORMAT EDITOR window.

If the user did not select a format prior to clicking the FORMAT EDIT button, the FORMAT EDITOR window appears with all fields blank. If the user selected a format prior to selecting the EDIT FORMAT button, the FORMAT EDITOR window appears displaying the contents of the format file. Using an existing format is an easy way to create a new format by simply changing the format ID number to an unused number.

2. Using the format editor

All text entry fields are changed by the user. The user fills in the various data entry fields with the desired information for the format being built. The data entry field currently being edited is indicated with a green border. There are various keystrokes used to edit data in a text field and for traversal between fields.



**PIRT-FORMAT EDITOR**

Version: 02/02/02

Format ID:       Plot Area Description:

Display Time:  minutes      Plot Area 1:       Unit:

Ac Plot Area 1:       Plot Area 2:       Unit:

Format Description:       Plot Area 3:       Unit:

Plot Area 4:       Unit:

Plot Area 5:       Unit:

MON	LABEL	LOWER LIMIT	UPPER LIMIT	SCALE	COLOR	LOWER VALU	UPPER VALU
V45V010A	1 VOLTS	0.0	40.0	1	COLOR	0.0	40.0
V45V0200A	2 VOLTS	0.0	40.0	1	COLOR	0.0	40.0
V45V0300A	3 VOLTS	0.0	40.0	1	COLOR	0.0	40.0
V45C010A	1 AMPS	20	350.0	2	COLOR	0.0	400
V45C020A	2 AMPS	20	350.0	2	COLOR	0.0	400
V45C030A	3 AMPS	20	350.0	2	COLOR	0.0	400
V76C150A	5A	0.0	20.0	3	COLOR	0.0	20.0
V76C150A	5D	0.0	20.0	3	COLOR	0.0	20.0
V76C152A	5C	0.0	20.0	3	COLOR	0.0	20.0
V76C160A	6A	0.0	20.0	4	COLOR	0.0	20.0
V76C164A	6B	0.0	20.0	4	COLOR	0.0	20.0
V76C162A	6C	0.0	20.0	4	COLOR	0.0	20.0
V76C170A	6A	0.0	20.0	5	COLOR	0.0	20.0
V76C170A	6B	0.0	20.0	5	COLOR	0.0	20.0
V76C172A	6C	0.0	20.0	5	COLOR	0.0	20.0

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Figure 7.2.2-6. Format editor window

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->	Move text cursor within a field to the right.
<-	Move text cursor within a field to the left.
<CTRL> a	Move text cursor to beginning of field.
<CTRL> e	Move text cursor to end of field.
<CTRL> k	Delete one word of text in a field.
<CTRL> d	Delete current character in field.
<BACKSPACE>	Deletes the previous character in field.
<ESC>	Clears the text entry field.
TAB	Traverses to the next text entry field.
<return>	Traverses to the next text entry field.
<shift> TAB	Traverses to the previous text entry field.

The FORMAT EDITOR window permits only data entry of the expected data types for that data entry field. For example, the user is prohibited from entering alphabetical characters in a lower limit field.

The following defines each field in the FORMAT EDIT window.

a. Format ID

Defines the number of the format which contains the data on this window. Valid values for this field are 0 to 999. If the user enters an existing format ID, the system will verify the user's intent during format saves. If the user enters a unique format ID number, when format saves are requested, the file is considered saved when the SETUP window appears.

b. Number of plot areas

Specifies the number of plot areas to be displayed on the PLOT window. Valid values are 1, 2, 3, 4, or 5.

c. Display time

Specifies the number of minutes a plot is displayed. Minimum value is 1 minute.

d. Description

A 50-character description of the format file.

e. Plot area description

There are five plot area description data entry fields that correspond to each possible plot area displayed on the PLOT window. A plot area description (26 chars max) should be specified for each plot area specified in Number of Plot Area.

f. Y-ticks

There are five plot area Y-tick data entry fields that correspond to each possible plot area displayed on the PLOT window. A Y-tick value should be specified for each plot area specified in number of plot areas. This value is the number of intervals between major tick marks in the Y direction for each plot area. Though not limited, a value from 2 to 8 is recommended.

The following fields are the same for each variable plotted on the PLOT window.

g. MSID

This is the 10- or 11-character MSID being read from the real-time LAN and plotted on the PLOT window. If eight or fewer characters are specified in this field, the entire row of associated information is skipped. This effectively deletes an MSID from a format.

h. Variable

This is a 20-character name associated with the MSID. This is displayed on the PLOT window to the left of the associated plot area. If this field is left blank for a valid MSID, no viable name is displayed on the plot.

i. Min Value

This is the minimum value of the Y-axis for the associated plot area. The smallest minimum value defined for the associated plot area actually defines the minimum Y-axis value. If this field is left blank for a valid MSID, a default value of 0.0 is used.

j. Max Value

This is the maximum value of the Y-axis for the associated plot area. The largest maximum value defined for the associated plot area actually defines the maximum Y-axis value. If this field is left blank for a valid MSID, a default value of 10.0 is used.

k. Plot Area

This value defines which plot area this set of data is associated with. Valid values are 1 to 5. It may not be greater than the value specified in Number of Plot Areas. If this field is left blank for a valid MSID, the default value of 1 is used. If more than three MSIDs are associated with plot area 1, the remaining MSIDs are not plotted.

I. COLOR

This is not a text entry field. Use the mouse to click on this pulldown button to display the list of available colors. Click on the desired color. The background color of this button indicates the current line color of the variable.

m. Min Limit

This is the minimum limit value of the associated plot area. The smallest minimum limit value associated with a plot area actually defines the minimum limit value. If this field is left blank for a valid MSID, the value -99999.9 is used.

n. Max Limit

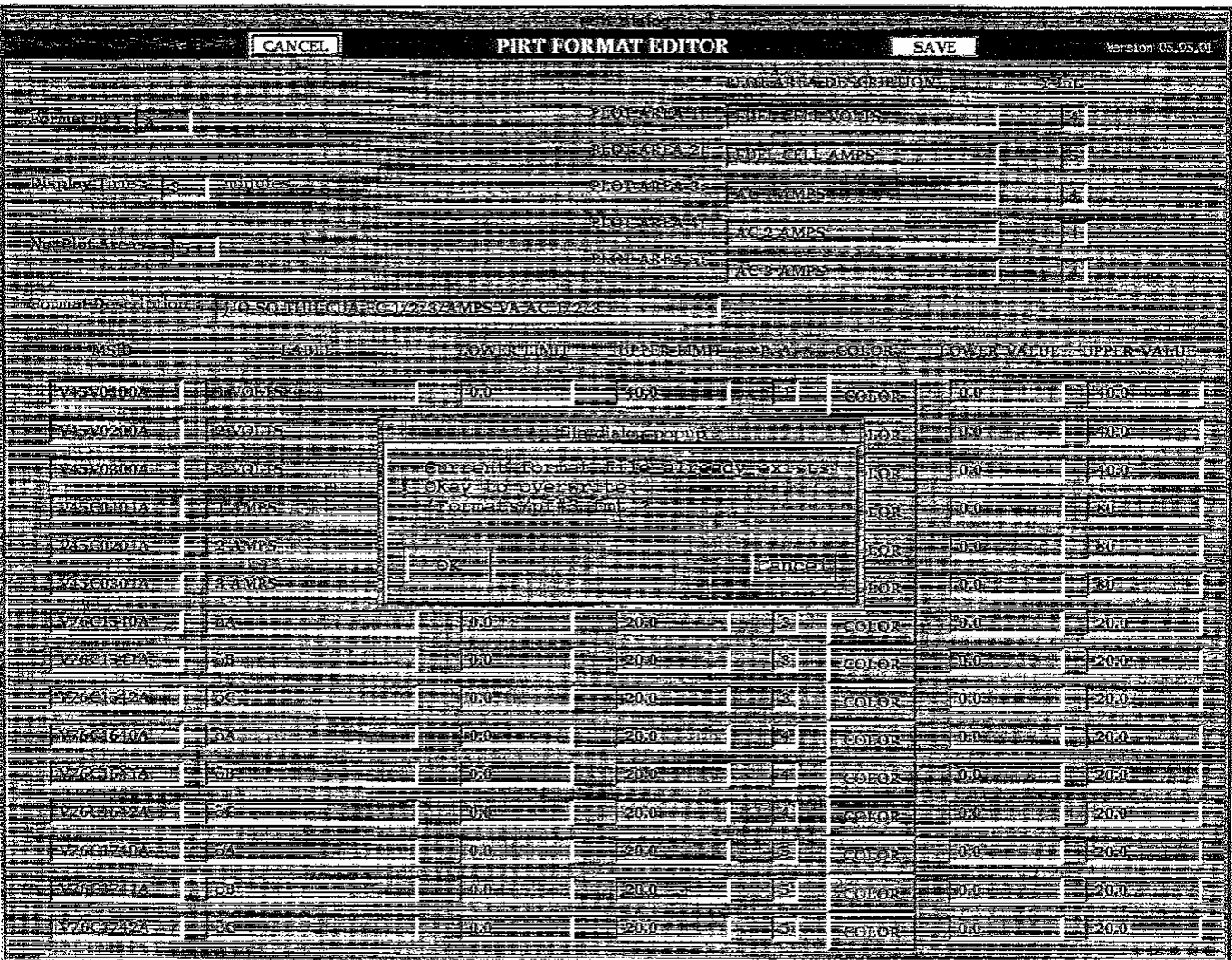
This is the maximum limit value of the associated plot area. The largest maximum limit value defined for the associated plot area actually defines the maximum limit value. If this field is left blank for a valid MSID, the value 99999.9 is used.

3. Cancel edit

If the user decides to cancel the edit session and not save any changes, move the mouse to the CANCEL button located in the FORMAT EDITOR window header and press the left mouse button. The FORMAT EDIT window disappears and the SETUP window reappears.

4. Save edit

The user may save changes made in the format editor. Move the mouse cursor to the SAVE button located in the window header and press the left mouse button. If a new format ID number is specified in the format number field, a new format file is created. If an existing format ID is used, a yellow popup message appears. This popup queries the user whether to overwrite an existing file. The user may select OK or CANCEL buttons. Refer to Figure 7.2.2-7 for an example of the yellow popup window. If the OK button is selected, the existing format file is overwritten with the contents of the EDIT window. The EDIT window is erased and the SETUP window reappears. If the CANCEL button (on the yellow popup window) is selected, the popup window is erased from the display. The EDIT window remains on the display.



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Figure 7.2.2-7. Overwrite format warning popup

Verify that this is the correct version before use

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## MISCELLANEOUS NOTES

### 1. PIRT PROGRAM EXECUTION OPTIONS

As the PIRT program is plotting data on the screen, the user can use certain options built into the program.

#### a. Function key definitions

There are NO function key definitions in the X-window version of PIRT. This may be a future enhancement if users have a strong need for keyboard backup for mouse hardware problems.

#### b. Mouse button definitions

##### (1) Left button:

- a. Inside the CLOSE icon causes the program to stop real-time data acquisition, remove the PLOT window, and display the PIRT SETUP window.
- b. Pressing the left mouse button inside the root window causes the X-window manager to appear. One of the options in the default window manager popup is a hard copy capability. Selection of the hard copy capability provides either a screen dump or window dump output to the black and white laser printer.
- c. The left button is used for initial positioning of the PLOT window. The mouse cursor is positioned as desired for placement of the upper left corner of the plot window. When the left mouse button is pressed, the PLOT window is displayed using the default window size.

##### (2) Middle button:

The middle mouse button is used for initial positioning and sizing the PLOT window after the START PLOT button is selected from the SETUP window. The mouse cursor is positioned as desired for placement of the upper left corner of the plot window. When the middle mouse button is pressed and held down, the mouse cursor changes and may be moved to define the size of the PLOT window. When the middle mouse button is released, the PLOT window is displayed.

### 2. PIRT FORMAT FILE STRUCTURE

Workstation knowledgeable users have the option to manually edit PIRT format files. Use an available text editor and specify the format to be edited. Edit as desired.

The following is the structure of a PIRT format file.

Format ID Number  
Number of minutes displayed on plot areas  
# of Plot Areas

For each plot area, there is a record in the following format:

“Window Titles”/# Y intervals

Number of MSIDs:

The following records define the fields and are all found on the same line in the format file. Except for the MSID and Label, these fields are in a “free format.” The MSID and Label must be separated by a “/”. The number of MSIDs previously specified determines the number of the following records.

MSID/Label Low\_Limit Up\_Limit PA# COLOR Low\_Value Up\_Value

The description is defined after all variable entries.

Description: character (40 chars max.)

**Note 1:** *Only three variables may reference the same plot area number (PA#). If there is the maximum of 15 variables defined, there should be 5 different sets of variables referencing the same plot area number. Each plot area would have three associated variables. The PA# field cannot be greater than the value specified in the “# of Plot Areas” record.*

**Note 2:** *The COLOR input is an integer number representing the color to use to plot the MSID. The available colors are*

0	Black	19	Orange
1	Dark Blue	21	Light Purple
2	Red	22	Blue Green
3	Yellow	27	Blue
4	Dark Green	28	Light Blue
5	Green		

The recommended colors to use for plotting in the same window are

First MSID	5	(Green)
Second MSID	19	(Orange)
Third MSID	28	(Light Blue)

### 3. PIRT OPERATIONAL NOTES

The following are operational notes on the use of PIRT. These notes should be reviewed by the user prior to seeking software support on a suspected problem.

- Version 03.02.00 of PIRT now handles full rate data. Because of this requirement, a performance degradation will probably be noticed during heavy workstation use.
- On PIRT 2.1 under WEX 2.3 the vertical blue bar continues to travel using a predicted MET during a Loss of Signal (LOS). On the new version of PIRT under WEX 2.5, the locator bar stops when data is lost. Stopping the locator bar during LOS gives users the opportunity to review data if desired. If the locator bar is moved as it did in the old PIRT, the previous displayed data would be erased with the last known value for the plot variables.
- The old version of PIRT allows for clearing of the plot display. The WEX 2.5 version of PIRT does not provide for this capability but is considered as a future enhancement.
- Under the old version of PIRT, function keys were used as a backup to certain mouse selections. PIRT 03.01.00 under WEX 2.5 does not support function key usage. This feature could be installed if specified as a desired requirement by users.
- PIRT 03.01.00 does not allow for real-time window resizes. However, there are ways to size the PLOT window. Upon initial placement of the PLOT window, the user may press the middle mouse button and define a window size. The plot is sized as required to fit into the specified window size. While plotting, it is also possible to resize the PLOT window. Use the workstation's window manager to resize the PLOT window to a desired size. The window resizes, but the contents of the window are NOT resized. Close the PLOT window by clicking on the close icon in the upper left corner of the window. Restart the plot by clicking the START PLOT button on the SETUP window. The PLOT window is displayed again with the contents of the PLOT window sized as required. A real-time window resize requirement is a capability destined for a future release of PIRT. Keep in mind, whenever the PLOT window is sized smaller than the default window size, some items in the window may overwrite each other due to space limitations within the PLOT window.
- There has been some discussion as to the maximum number of variables permitted on a plot area. Some thought it was four, others said it was three. PIRT 03.01.00 was developed limiting the number of variables on one plot area to three. If an old PIRT format file has four or more variables specified for a plot area, only the first three variables are used for that plot area. With the maximum of 5 plot areas possible, up to 15 variables may be specified in a PIRT format.



## TITLE

LEAKMAN SOFTWARE APPLICATION

## GENERAL

Leakman is a real-time Information Sharing Protocol (ISP) application used for monitoring the usage of H<sub>2</sub> and O<sub>2</sub> from the cryo system and for the detection of cryo leaks. To detect leaks in the cryo reactant distribution system, the Leakman application models the expected pressure change over a 1-second period and compares it to the actual pressure change in the tanks. Any significant difference could indicate a leak or excess usage by a system not accounted for in the Leakman application. The expected pressure change in the cryo tanks is computed using a simplified model of the cryo distribution system in the shuttle. Leakman also contains various "tools" that can be used for playing "what if" games with the cryo system; for example, if I turn on O<sub>2</sub> tank 2 heaters, what is the flow capacity of the tank? Tank stratification can also be detected to some extent by the program, but this is NOT a fully developed capability at this time.

For more detailed instructions on the operation of Leakman and formula descriptions, refer to the Leakman application guide located at

S:\DF73\SOFTWARE\CERTDOCS\LEAKMAN\LEAKMAN.DOC

## PROCEDURE

The steps required to detect leaks and to calculate cryo usage are as follows:

1. The amount of H<sub>2</sub> and O<sub>2</sub> used by the fuel cells to generate power is calculated each second. This calculation can be made using a formula relating power to cryo or relating the current produced by the fuel cells to cryo consumed. Leakman uses the current generated by each fuel cell to compute the amount of cryo consumed. For O<sub>2</sub>, the crew consumption is added to the fuel cell demand to get a total O<sub>2</sub> demand per second. H<sub>2</sub> is computed using only the fuel cell current. Along with the cryo quantity used by the fuel cells, Leakman keeps a second quantity internally. This is the quantity driven out of each tank due to heater operation. As the heaters in a tank turn on and off, cryo is driven out of the tank. This quantity is kept separately from the quantity used by the fuel cells. In ideal conditions, the amount used by fuel cells should equal the amount driven out by heating. When these quantities do not agree, the tanks are stratified. In theory, it should be possible to determine the amount of stratification from the difference in these two quantities. The logic to do this has not been implemented at this time, but Leakman currently keeps all the necessary information.
2. Leakman determines how much of the total quantity of cryo consumed by the fuel cells is provided by each feeding cryo tank. The amount of cryo provided by each tank depends upon the current quantity in the tank and the total amount used. Feeding tanks are determined using logic that takes into account manifold pressures, heater configurations, current cryo tank pressures, and manifold valve

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configuration. Tanks can feed cryo only if their pressure is at or above the current manifold pressure. Cryo flows through a check valve, so the flow is one way to calculate cryo usage. Cryo cannot flow back into a tank except through manifold relief valves.

3. Using the amount of cryo used out of each tank, if any, the change in pressure for that tank is calculated using the K curves. Additionally, if heaters are on in a tank, the pressure increase or decrease (due to heat input into the tank) is added to the pressure decrease (due to cryo usage) to calculate a net pressure change for that second.
4. This pressure change in each tank is compared to the actual pressure change. The actual values can be provided by the controller or automatically computed by Leakman. Any difference between the predicted pressure decay and the actual pressure decay could indicate a leak or some other excess usage.

The Leakman application also calculates the flow capacity of any selected cryo tank for any selected heater configuration. The flow capacity gives the amount of cryo that can be supplied in lb/hr for a given tank quantity and heater configuration combination.

The application provides some capability to play hypothetical "games" with the cryo configuration. For example, manifold valve positions can be set internally in the Leakman application, and the application will respond with the expected manifold decay in each manifold at the current power level. Individual tank quantities can be adjusted, with the result displayed in the Leakman user interface. The heater switch setting can be adjusted to determine the flow capacities of tanks.

**TITLE**

ELOG - TBD

## TITLE

CRANS — CONFIGURABLE REAL-TIME ANALYSIS SYSTEM

## DESCRIPTION

The program provides a means of representing logically interconnected items in a matrix format. A matrix consists of rows and columns of item names with colored backgrounds that show the item's logic status (failed/on or not-failed/off). The program allows for toggling of an item's logic status by selection of the item within a matrix via the mouse device. Upon selection of an item, the entire logic framework is tested for further status changes, and the results of these changes are displayed in the matrix or matrices as appropriate. A "help" mode and a reference check provide the user with a means of exploring an item's underlying logic from within the program. A commonality check determines single-point failures for an item or group of items. On WEX 2.5 or RTDS workstations, real-time telemetry can be accessed by the program for use in the logic (i.e., MSIDs can be logic items). Examples of program applications include orbiter systems failure analysis, runway selection, and flight rule location.

## PROCEDURE

Information regarding MSIDs and real-time data refers only to the real-time data **RT** version of **crans** (**crans\_rt**). Lines below containing real-time specific information are denoted by an 'RT' in the right margin. The program uses four data files: (1) logic, (2) matrix, (3) help, and (4) configuration. The logic file describes the logic tree; i.e., how all the logic items are interconnected. The matrix file defines the placement of logic items in the matrices. This file also has entries to change certain program default values (described below). The help file contains text messages associated with a logic item that are displayed in the program's help mode. The configuration file contains matrix position information and is generated by the program via user request. This information is used to restore the matrix configuration for subsequent sessions. The logic and matrix files are required (unless the application is compiled); the help and configuration files are optional. Additionally, the program writes a temporary file, **crans.temp**, to the current directory when a print command is issued. This file is erased when the program exits. When compiling an application, three temporary files are created: **crans\_cmp1.h**, **crans\_cmp2.h**, and **crans\_cmp3.h**. These files are erased when the program compile is completed. They include file, **crans.h**, and the object code, **crans.o** (**crans\_rt.o** for the real-time version) are also required when compiling.

The user is allowed to change a number of the program parameters. These parameters, and their default values, are as follows:

Parameter	Default	
logic file name	DATA/crans.logic	
matrix file name	DATA/crans.matrix	
help file name	DATA/crans.help	
configuration file name	DATA/crans.config	
show duplicate items	TRUE	
move matrix outlines	TRUE	
real-time update rate	1 second/sample	RT
start iconified	FALSE	
alert tone volume	100%	
font name	9x15	
icon font name	8x13	
background color	black	
border color	white	
border width	2 pixels	
window size and position	9/10 screen size	
display name/ID	NULL	

Two methods are available for changing the parameter default values; command line inputs and entries in the **.Xdefaults** file.

The **.Xdefaults** file, found in the user's home directory, can contain parameter values for a number of programs. The syntax for a parameter setting in this file for the **crans** program is as follows:

**crans\*`<parameter name>`: `<value>`**  
**crans\_rt\*`<parameter name>`: `<value>`** RT

**<parameter name>** is one of the valid parameter names, and **<value>** is the new value of the parameter. The parameter names are the same as the command line options (without the preceding - character; see below); however, the abbreviated forms cannot be used in the **.Xdefaults** file. An example entry to set the background color would be

**crans\*background: midnightblue**

The command line options to change the parameter defaults can appear in any order on the command line. The syntax for these commands is as follows:

**-logic (or -l) `<logic file name>`**

Instructs the program to use the file, **<logic file name>**, as the logic file. Multiple logic files may be concatenated by separating the names by a + character with no intervening spaces (e.g., **-logic `<file name 1>+<file name 2>`...**).

**-matrix (or -m) <matrix file name>**

Instructs the program to use the file, **<matrix file name>**, as the matrix file. Multiple matrix files may be concatenated by separating the names by a + character with no intervening spaces (e.g., **-matrix <file name 1>+<file name 2>...**).

**-help (or -h) <help file name>**

Instructs the program to use the file, **<help file name>**, as the help file. Multiple help files may be concatenated by separating the names by a + character with no intervening spaces (e.g., **-help <file name 1>+<file name 2>...**).

**-config (or -c) <configuration file name>**

Instructs the program to use the file, **<configuration file name>**, as the configuration file.

**-showduplicates (or -sd) <FALSE>**

Instructs the program to ignore duplicate logic item names and suppress the duplicate item warning message(s). If two or more items have the same name, only the first one encountered is used. This option is useful when concatenating logic files that contain common items.

**-moveoutline (or -mo) <FALSE>**

Instructs the program to move the matrices/icons instead of their outlines when (re)positioning the matrices/icons with the mouse.

**-rate (or -r) <update rate>**

Sets the initial real-time data acquisition rate in seconds per sample. Values less than 1 will cause the program to update as fast as possible. The rate can be changed via command menu option (see below).

RT  
RT  
RT  
RT

**-iconic (or -i) <x,y>**

Instructs the window manager to iconify the program window initially; the x-y coordinates specify the location of the icon.

**-volume (or -v) <volume>**

Sets the volume of the alert tone given whenever a dialog box is generated. The volume should be from 0 (no tone) to 100 (full volume) percent; values outside this range are adjusted to the nearest valid value.

**-font (or -fn) <font name>**

The program uses the font specified for drawing the main title bar, command menu, and help, commonality, and reference mode displays.

**-iconfont (or -ifn) <icon font name>**

The program uses the font specified to draw the icon window text.

**-background (or -bg) <background color>**

Specifies the background color of the main window. RGB values are accepted.

**-bordercolor (or -bd) <border color>**

Specifies the color of the main window border. RGB values are accepted.

**-borderwidth (or -bw) <border width>**

Specifies the width, in pixels, of the main window border.

**-geometry (or -gm) <widthxheight+x+y>**

Instructs the program to set the initial main window size (in pixels) and/or position. The entire set of values need not be specified (e.g., just the size could be set). For initial main window size, the precedence is (lowest to highest): the default size, the -geometry specified size, the mouse-selected size (using the middle mouse button), then the size saved in the configuration file. The window can be resized as desired using the mouse once the program is running. The window manager will prevent sizing the window smaller than the area required to display the main title bar and all the matrices in an iconified state.

**-display (or -ds) <display name/ID>**

Sets the display on which the program window is shown. This option cannot be used in the .Xdefaults file.

**-compile <executable name>**

This command is only valid on the command line. The program compiles the crans logic and matrix files creating a dedicated, standalone application. The files **crans.h** and **crans.o (crans\_rt.o)** must be in the current directory. The message "CRANS: Compile start" is displayed once the logic and matrix information has been converted to C code. The compilation takes place as a background process, thus freeing the command line for other use. "CRANS: Compile complete" is displayed when compilation has successfully completed. The new application, **<executable name>** does not require the logic and matrix files.

## LOGIC FILE FORMAT

Every logic item used in the logic and matrix files must have a logic item definition. A logic item definition begins with the logic item name itself (see logic item name operator description below). The name must be placed on a line by itself, starting in the first column. The item's logic statement (if it has one) is placed on a subsequent line or lines that are indented at least one space/tab. The format, therefore, is as follows:

**LOGIC ITEM NAME****LOGIC ITEM STATEMENT**

The logic statement defines the conditions by which the logic item is failed: if the statement evaluates to TRUE/1, then the logic item fail state is set to failed/on; if the statement evaluates to FALSE/0, then the logic item fail state is set to not failed/off. The logic statement generally consists of logic item names separated by operators. It can be broken into multiple lines if desired; the only restrictions are that an item name cannot be split over multiple lines, and a logic statement cannot be split between multiple files. The operators are explained below in the logic operator reference guide. The format for this reference guide is given below.

- Operator : Character(s) used to denote operation in logic statement.
- Operation : Title of operation.
- Usage : Generic method of use.
- Description : Explanation of operation and special restrictions.
- Syntax : Legal operators that can precede the operator in question (within braces {} ), the operator itself, then those operators that can follow it (within braces {} ). "None" indicates that a logic statement can begin and/or end with that operator.
- Examples : Examples of operator use within a logic statement.

- 
- Operator : **{ITEM}**
- Operation : **Logic Item Name**
- Usage : {OPERATOR} **{ITEM}** {OPERATOR}
- Description : A logic item name in a logic statement represents the fail state of that logic item (TRUE/1 or FALSE/0) which in turn is used in interpreting the logic statement. Almost any character can be used within a logic item name with the following exceptions/restrictions:
- An item name cannot begin with a @, space, or tab character. These characters can be used within a name.
  - A name beginning with a ' (forward quote) must be placed within ` (backward quote) characters. A name beginning with a ` must be placed within ' characters. This applies only to names referenced in a logic statement or in the matrix file.
  - Only those spaces/tabs within logic item names (i.e., bounded by other valid characters) are significant; other spaces/tabs within the logic statement are ignored, but are useful for improving readability.



- A name beginning with a \* or {, or containing the characters , or : must be placed within single quotes when referenced in the matrix file.
- Names containing the characters ()&|^~\*:><= must be placed within single quotes when referenced in a logic statement (see quoted logic item name operator description).
- Item names that begin with a number, -, ., or " must be placed within single quotes when following a comparison operator (><=) (see quoted logic item name operator description).
- Names beginning with the # character are considered MSIDs (see MSID logic item name operator description). This applies even if the name is quoted.
- Logic item names are case-sensitive (e.g., ITEM, Item, and item are treated as separate logic items).

Syntax : {None, (, &, |, ^, ~, \*, >, <, =} **{ITEM}**  
{None, ), &, |, ^, ~, :, >, <, =}

Examples : **MNA DA1| MDM FF1**  
**~' < 6 MID VENTS '**

Operator : ' , `

Operation : **Quoted Logic Item Name**

Usage : **' {ITEM} '**  
**` {ITEM} `**

Description : A logic item name can be placed within forward or backward single quotes (only when referenced in a logic statement, not when the logic item is defined) to ensure that the name is correctly interpreted. The quote characters and any surrounding spaces or tabs are not considered part of the item name. The cases where quotes must be used are as follows:

- Logic item names containing the characters ()&|^~\*:><= must be placed within quotes to avoid having the special character evaluated as an operator.
- Names beginning with 0-9, ., or - must be quoted when following a >, <, or = operator to avoid being evaluated as constants.
- Names beginning with a ' (forward quote) must be placed within ` (backward quote) characters. Names beginning with a ` must be placed within ' characters.

---

Syntax : {None, (, &, |, ^, ~, \*, >, <, =} ‘ {ITEM} ‘  
          {None, ), &, |, ^, ~, :, >, <, =}  
  
          {None, (, &, |, ^, ~, \*, >, <, =} ` {ITEM} `  
          {None, ), &, |, ^, ~, :, >, <, =}

Examples : ITEM A ^ ' ITEM(1) '  
          `015&R13 ITEMS` & #V46S0123E  
          ' `ITEM A ` '

---

Operator : #

Operation : **MSID Logic Item Name (real-time version)**

Usage : **# {MSID}**

Description : A logic item name preceded by a # character is treated as an MSID. Note that the # character and any intervening spaces or tabs are considered part of the item's name (but not part of the MSID). The telemetered value of the MSID is used in logic statements using comparison operators (>, <, =, and combinations of these). In other operations (&, |, etc.) the MSID logic items are treated as "normal" logic items (TRUE/1 or FALSE/0). MSID values are set to zero at program start-up.

Syntax : {None, (, &, |, ^, ~, \*, >, <, =} # {MSID}  
          {None, ), &, |, ^, ~, :, >, <, =}

Examples : **#V46P0100A > 110**  
          **# V46S1199E & # V46S1299E & # V46S1399E : 2**

---

Operator : **0-9, ., -**

Operation : **Constant (Numeric) Value**

Usage : {OPERATOR} **{CONSTANT}** {OPERATOR}

Description : Constants can contain the characters 0 - 9, ., and -. Any fractional component in a filter value (see fractional AND operator description) is ignored.

Syntax : {:, >, <, =} **{CONSTANT}**  
          {None, ), &, |, ^, ~, >, <, =}

Examples : **#V58P0105A >= -32.2**  
          **ITEM A & ITEM B & ITEM C : 2**

Operator : “

Operation : **Constant (Character) Value**

Usage : {#MSID} = “{CHARACTER/STRING}”

Description : Strings may be up to seven characters in length.

Syntax : {=} “{CHARACTER/STRING}”  
{None, ), &, |, ^, ~, >, <, =}

Examples : #V58P0105A = “\*”

---

Operator : **&**

Operation : **Logical AND**

Usage : {RESULT A} & {RESULT B}

Description : The statement evaluates TRUE if RESULT A is TRUE (failed/on) and RESULT B is TRUE (failed/on).

Syntax : {ITEM, ), #MSID} **&**  
{ITEM, (, #MSID, /, \, ~, \*}

Examples : ITEM **&** #V46P0110A  
( ITEM A | ITEM B ) **&** ~ITEM C

---

Operator : **|**

Operation : **Logical OR**

Usage : {RESULT A} | {RESULT B}

Description : The statement evaluates TRUE if RESULT A is TRUE (failed/on) and/or RESULT B is TRUE (failed/on).

Syntax : {ITEM, ), #MSID} **|**  
{ITEM, (, #MSID, /, \, ~, \*}

Examples : #V46S0222E | ITEM  
ITEM A | ( ITEM B & ~ITEM C )

---

Operator : ^

Operation : **Exclusive OR**

Usage : {RESULT A} ^ {RESULT B}

Description : The statement evaluates TRUE if RESULT A is TRUE (failed/on) or RESULT B is TRUE (failed/on). If both RESULT A and RESULT B are TRUE (or FALSE) then the statement evaluates FALSE.

Syntax : {ITEM, }, #MSID} ^  
{ITEM, (, #MSID, /, \, ~, \*}

Examples : #V46S0222E ^ ITEM  
ITEM A ^ ( ITEM B & ~ITEM C )

---

Operator : ~

Operation : **Logical NOT**

Usage : ~ {RESULT}

Description : The statement evaluates TRUE if RESULT is FALSE (not failed/off).

Syntax : {None, (, &, |, ^, >, <, =} ~  
{ITEM, (, \*, >, <, =, #MSID}

Examples : #V58S0100E ~>= 100  
~( ITEM A | ITEM B )

---

Operator : :

Operation : **Fractional AND**

Usage : {RESULT A} & ... & {RESULT n} : {**CONSTANT**}

Description : The statement evaluates TRUE if the number of preceding ANDed RESULTS (on the same nest level) that are TRUE equals or exceeds CONSTANT. CONSTANT must be greater than or equal to 2. See left/right parenthesis operator descriptions for definition of nest level.

Syntax : {ITEM, #MSID, CONSTANT, )} :  
{CONSTANT}

Examples : ITEM A & ( #V46P0100A > 180.0 ) & ~ITEM B : 2  
(#V58P0315A>-5&ITEM A&ITEM B&ITEM C : 3 ) | ITEM C

---

Operator : \*

Operation : **Hard-fail**

Usage : \* {ITEM}

Description : The statement evaluates TRUE if the logic item indicated has been hard-failed (i.e., failed by direct mouse input as opposed to soft-failed, where an item is failed indirectly due to its logic).

Syntax : {None, (, &, |, ^, ~, >, <, =} \*  
{ITEM, #MSID}

Examples : \* #V46S1199E  
ITEM A | ~ \*'ITEM B'

---

Operator : (

Operation : **Left Parenthesis**

Usage : ( {RESULT} )

Description : Start a new nest level. The logic within a nest level is evaluated prior to being used in the level above and is always interpreted from left to right.

Syntax : {None, (, &, |, ^, ~, >, <, =} (  
{ITEM, (, \*, ~, #MSID}

Examples : ITEM A & ( ITEM B | ITEM C )  
( ( ITEM A | ITEM B ) & ITEM C ) | ITEM D

---

Operator : )

Operation : **Right Parenthesis**

Usage : ( {RESULT} )

Description : End the current nest level. The boolean result of the logic within the parentheses is passed to the preceding level for incorporation. The number of left and right parentheses in a logic string must be the same.

Syntax : {ITEM, #MSID, CONSTANT, )} )  
{None, &, |, ^, :, ~, >, <, =}

Examples : ( ITEM A | ITEM B ) & #V72X2123Y  
ITEM & ( #V46P0100A > 100 )

---

Operator : >

Operation : **Greater Than**

Usage : {RESULT A} > {RESULT B}

Description : The statement evaluates TRUE if RESULT A is greater than RESULT B. When the > operator is followed by the = operator (>=), the logic is TRUE if RESULT A is greater than or equal to RESULT B. Additionally, the ~ operator may precede the > operator (for “not greater than”, etc.). When MSIDs or constants are involved, the actual values are used; otherwise, the failure state of the logic item is compared (TRUE/1 or FALSE/0).

Syntax : {ITEM, #MSID, }, ~} >  
{ITEM, #MSID, CONSTANT, ~, \*, =}

Examples : #V58T0393A > # V58T0293A  
ITEM A ~>= ( ITEM B | #V37S0123E )

---

Operator : <

Operation : **Less Than**

Usage : {RESULT A} < {RESULT B}

Description : The statement evaluates TRUE if RESULT A is less than RESULT B. When the < operator is followed by the = operator (<=), the logic is TRUE if RESULT A is less than or equal to RESULT B. Additionally, the ~ operator may precede the < operator (for “not less than”, etc.). When MSIDs or constants are involved, the actual values are used; otherwise, the failure state of the logic item is compared (TRUE/1 or FALSE/0).

Syntax : {ITEM, #MSID, }, ~} <  
{ITEM, #MSID, CONSTANT, ~, \*, =}

Examples : #V09T1600A < 275  
( ITEM A | ITEM B ) <= # V46S1399E

---

Operator : =

Operation : **Equal To**

Usage : {RESULT A} = {RESULT B}

Description : The statement evaluates TRUE if RESULT A is equal to RESULT B. This operator can follow the > or < operators (see greater than and less than operator descriptions). Additionally, the ~ operator may precede the = operator (for “not equal to”). When MSIDs or constants are involved, the actual values are used; otherwise, the failure state of the logic item is compared (TRUE/1 or FALSE/0).

Syntax : {ITEM, #MSID, }, ~, >, < } =  
{ITEM, #MSID, CONSTANT, ~, \* }

Examples : ITEM = ~( #V46S0333E & ~ \*#V46S0333E )  
#V46R0135A ~= 103

---

Operator : %

Operation : **Bit Mask**

Usage : {#MSID A} % {#MSID B} or {CONSTANT}

Description : The statement evaluates TRUE if the result of bitwise-ANDing MSID A with MSID B (or CONSTANT) is equal to MSID B (or CONSTANT). In other words, if the ON bits represented by MSID B (or CONSTANT) are ON in MSID A, the statement is TRUE. The ~ operator may precede the % operator, in which case the statement is TRUE if none of the ON bits in MSID B (or CONSTANT) is ON in MSID A. The values of the MSIDs are used. CONSTANT in this case is a one- or two-word hexadecimal value with up to eight digits per word (if two words, separate by spaces; if less than eight digits, leading zeros are assumed).

Syntax : {#MSID} %  
{#MSID, CONSTANT}

Examples : #V72M7919P % 1000  
#V72M7926P ~% 20000000 a0fff

---

Operator : /

Operation : **Out of Limits - High**

Usage : / {#MSID}

Description : The statement evaluates TRUE if MSID is greater than its upper operational limit in the MOC. The failure state and actual MSID value do not affect the evaluation.

Syntax : {None, (, &, |, ^, ~, >, <, =} / {#MSID}  
{None, ), &, |, ^, ~, :, >, <, =}

Examples : ITEM & ~(/#V46S0333E & ~ \*#V46S0333E )  
/ #V46R0135A | ITEM

---

Operator : \

Operation : **Out of Limits - Low**

Usage : \ {#MSID}

Description : The statement evaluates TRUE if MSID is less than its lower operational limit in the MOC. The failure state and actual MSID value do not affect the evaluation.

Syntax : {None, (, &, |, ^, ~, >, <, =} \ {#MSID}  
{None, ), &, |, ^, ~, :, >, <, =}

Examples : ITEM & ~(#V46S0333E & ~ \*#V46S0333E )  
\ #V46R0135A | ITEM

---

The arrangement of the logic item definitions in the file can determine the interpretation of the logic. An example is:

```
ITEM 1
~ITEM 2
ITEM 2
~ITEM 1
```

On the first pass through the logic (no items failed) ITEM 1 would be failed since ITEM 2 is not failed. Then, ITEM 2 will take on the inverse of ITEM 1's logic state (i.e., not failed). If the order was changed to:

```
ITEM 2
~ITEM 1
ITEM 1
~ITEM 2
```



The outcome would instead be ITEM 2 failed and ITEM 1 not failed. Though the logic statements are the same for the individual items, the position in the file caused the opposite result to happen. This “positional interpretation” can occur only when inverse (NOT) logic is involved.

Inverse logic can also result in an infinite logic loop (the program detects this condition; see ERROR MESSAGES below). An example is:

```
ITEM 1
~ITEM 1
```

Blank lines can be used to separate logic item definitions and statements for clarity. Lines with the @ character in the first column are ignored and are used to denote comment lines. Maximum line length in the logic file is limited to 3000 characters. A sample logic file is shown in Figure 7.2.5-1.

### MATRIX FILE FORMAT

The matrix file contains the information regarding placement of logic items in the matrices, the color map for the matrix boxes, the main window title, and the main window’s icon name. The color map is required and must precede any matrix definitions. At least one matrix definition is required (the total number of matrices allowed is limited only by the amount of memory available). The title and icon name are optional (see below for default values). The matrix file commands must begin in the first column and are described below.

---

Command	:	<b>TITLE</b>
Usage	:	TITLE: <main window title>
Description	:	Set the main window title. The text given is displayed in the center portion of the main window header bar. This command is optional; no title (null string) is used if none is specified. The title cannot begin with a .: . If more than one title is defined, the latter one is used.
Examples	:	TITLE: Systems Failure Analysis

---

Command : **ICON NAME**

Usage : ICON NAME: <main window icon name>

Description : Set the program's icon name. The icon name given is displayed when the program window is iconified. The name length is essentially unlimited, but shorter names are preferred since they determine the icon's size. The default icon name is "CRANS". The icon name cannot begin with a .: If more than one icon name is defined, the latter one is used.

Examples : ICON NAME: FAILURES

---

Command : **COLOR MAP**

Usage : COLOR MAP: <box> [= <#RGB or color>] : <text>  
[<box> [= <#RGB or color>] : <text>]  
etc.

Description : This command defines the box/text color combinations used in the matrices: a box of color **<box>** will have text of color **<text>** drawn on it. The color map is made up of one or more color definition statements in the format shown above (only the first line must contain the color map command "**COLOR MAP:**", with subsequent lines indented at least one space/tab). The box colors are those referenced in the matrix definitions for the failed and not-failed colors (see the **MATRIX** command definition). The color map must precede any matrix definitions, and any color referenced in a matrix must be defined in the color map. Multiple color map commands are allowed, but should be unnecessary. The various components of this command are as follows:

- **<box>** can be a name from the standard X-Windows color database, in which case the optional **<#RGB>** and **<color>** are not used. See Figure 7.2.5-2 for a listing of the standard color database, or look in the file **/usr/lib/X11/rgb/rgb.txt** on the machine being used; color names from this database are case-insensitive. If **<#RGB>** or **<color>** is supplied, then **<box>** can be any name the user chooses.
- If **<color>** is used, it must be a name from the standard color database; in this case, **<box>** will be identical to the color named (this is useful to shorten a name from the database; e.g., Green = DarkOliveGreen).

- **<#RGB>** is used to set the actual red/green/blue intensities. The RGB format (signified by a leading # character) must be either **#RGB**, **#RRGGBB**, **#RRRGGG BBB**, or **#RRRRGGGGBBBB** where **R**, **G**, and **B** are single-digit hexadecimal values (the higher the number, the stronger the color). Values are automatically filled out to 12 digits by adding trailing zeroes so that **#RGB** becomes **#R000G000B000**, etc.
- **<text>** must come either from the standard color database, be an RGB value in the format listed above, or be one of the box color names (upper/lower case must match in the last case).

Color names cannot contain the characters :, =, ., or }. Names beginning with a # are treated as RGB values.

Examples : COLOR MAP:       Black                       : Blue  
                          Red = #cf0000       : White  
                          Blue = mediumblue : #888

---

Command : **MATRIX**

Usage : MATRIX: [<group>], <name>, <font> [, <minimum width>]

Description : Define a matrix of logic items. **<group>** is an optional name that can be supplied that is displayed in the matrix icon. It can be used to identify several matrices as containing related logic items, for example. If no name is supplied, no group name is displayed. Note that the command must contain the trailing comma whether a group name is supplied or not. **<name>** is the name displayed in the matrix header bar when the matrix is deiconified and is also used to identify the matrix when iconified. Different matrices can have the same name. **<font>** is the name of the font used to draw the matrix, and thus determines the size of the matrix (upper and/or lower case is acceptable). Any X-Windows font is allowed. The optional **<minimum width>** instructs the program to draw the boxes no smaller than the width (in characters) specified. However, if the item names or the header dictate larger boxes, the larger size is used.

Matrix box definition entries follow the matrix command on separate lines and must be indented at least one space/ tab. The box definition format for a single box is:

**{<item name>, <not-failed color>, <failed color>}**

where **<item name>** is an item name from the logic file (all item names referenced must be defined in the logic file; item names are case sensitive). A blank box is allowed; just leave out the item name between the { and ,. Preceding the logic item name with a \* character will cause that item in that matrix box to be hard-fail protected (i.e., the item cannot be directly failed). Item names that begin with a \* or {, or contain a , or : must be enclosed within single quotes (the quotes are not displayed in the matrix). Spaces after the initial quote are used when positioning the item name within the matrix box, allowing for centering, etc.

The **<not-failed color>** is the name of the color (one of the box colors from the color map; see **COLOR MAP:** command above) that the box background will show when the logic item is not failed. The **<failed color>** is the color that the background shows when the logic item is failed. The not-failed/failed colors for an empty box must still be given. The arrangement in the file of the box definitions directly correlates with the displayed position. A matrix with three rows of four columns would be placed in the file as:

```
{ } { } { } { }  
{ } { } { } { }  
{ } { } { } { }
```

Each '{ }' represents a single box definition (boxes on the same row must be defined on the same line in the matrix file; box definitions for boxes in the same column do not have to align as shown). Each matrix may contain any number of box definitions in any combination of rows and columns.

A special type of box definition is the **multilevel box**. This type of box is driven by two or more logic items in a prioritized manner (the highest priority item failed is displayed; if no item is failed, the highest-priority item name is displayed using the not-failed color). The format for a multilevel is similar to a normal box:

```
{<logic item name 1> [: <logic item name x>],  
  <not-failed color>, <failed color 1>  
  [: <failed color x>]}
```

where the item names are separated by colons (:). A fail color must be specified for each item and separated by colons (or commas). The priority is first name (highest) to last name (lowest). There is no limit to the number of levels that can be defined in a single box. Blank items can be placed in multilevel boxes; just leave out the item name (a failed color must still be specified).

Examples : MATRIX: EPS, Bus, 7x9  
: {MNA DA1,Green,Red}{,Black,Black}{CNTLAB1,Green  
: ,Yellow} MATRIX:.,Systems,9x15,10  
: {A:\*B:C,Blue,Red:Orange:Yellow}{D, Grey, Black}  
{E : ' F', Blue, Red: Orange} { ,Blue,Blue}

---

Blank lines, spaces, and tabs can be inserted in the matrix file, except where noted above, to improve clarity. Lines with the @ character in the first column are ignored and are used to denote comment lines. Maximum line length in the matrix file is limited to 3000 characters. A sample matrix file is shown in Figure 7.2.5-2.

### HELP FILE FORMAT

The help file contains text messages to be displayed with a logic item while the program is in the help mode (described below). Only those items with messages need an entry in the help file. A help file entry is shown below.

```
<logic item name>  
  <text message line 1>  
  [<text message line x>]  
  etc.
```

The <logic item name> is a name from the logic file (case sensitive) and must begin in the first column. The text message line(s) must be indented at least one space/tab (this first character is ignored; further spacing is assumed to be part of the message). Before displaying the text, all tab characters are converted to single spaces. The size of the message is limited by the size of the program window. All characters are allowed. When the help mode is active and the item selected has a text message reference in the help file, the message will be displayed along with the item, just as it appears in the file.

Blank lines can be used to separate lines for clarity. Lines with the @ character in the first column are ignored and are used to denote comment lines. Maximum line length in the help file is limited to 500 characters. A sample help file is shown in Figure 7.2.5-3.

### CONFIGURATION FILE FORMAT

The configuration file is created/updated by the program when the user selects the "Save Config" option from the command menu (described below). The program saves the total number of matrices, the main window width and height, and for each matrix it saves the iconification state and matrix/icon x-y coordinates. When the program is executed it looks for the configuration file (either the default or the user-specified file name). If found, the file is read and the saved window size and matrix/icon positions are restored; otherwise, the matrices are initially iconified and placed along the right side of the main window.

## PROGRAM OPERATION

When the program is executed, the user is allowed to position/size the main program window using the mouse (unless the –iconic option is used; the program icon appears in this case). There is a brief delay while the program reads the logic, matrix, and configuration file contents and checks for errors. If no errors are detected, the main window header is displayed containing the program name, the user-specified title (from the matrix file), and the command menu title. The matrices are positioned as described above in ‘Configuration File Format’. The matrix icons show the matrix group name (if any) and the matrix name (from the matrix definition). The mouse pointer turns into an orbiter while within the main program window.

Error and warning messages are displayed in a dialog box that appears, as required, centered over the program window. When a dialog box is displayed, no further processing is possible until the message is acknowledged. See ‘Dialog box “OKAY”/“NO”/“EXIT” button’ descriptions below.

The mouse button and keyboard now perform the following functions (other pointer/button/keyboard combinations are ignored by the program):

---

Location : Matrix logic item box

Button : Left button

Action : If the box is a multilevel, see ‘Matrix multilevel pop-up menu’ below on logic item selection. In either case (multilevel or single item box) the logic item selected has its fail state toggled (off -> on or on -> off) if the item has not been hard-fail protected in the matrix box definition.

The box color changes, depending on the box definition in the matrix file, to reflect the new logic state (not-failed or failed). A \* character is displayed in the first column of the box if the item displayed is hard-failed in this manner (the \* is removed when the fail state is toggled off). A logic check is performed to reflect changes in other items’ logic states. Failed items that are tagged (see ‘Matrix logic item box – Right button’ below) have the tag removed. The results are reflected immediately in the matrices and the matrix icons (the icon name color is green if no items in the matrix are failed and red; otherwise, unless the failed items are suppressed; see below).

---

Location : Matrix logic item box

Button : Two or more buttons simultaneously

Action : The box suppression state is toggled on/off. When a box is “suppressed” the text color is changed to the background color and the background color is changed to black. Reselecting the box restores the normal color configuration. If a box is suppressed and the item or items (if the box is a multilevel) driving that box change logic state, the normal color mode takes affect. The box can then be resuppressed if desired. If all of the failed boxes in a matrix are suppressed and the matrix is iconified, the matrix name is drawn in white. Box suppression is a means of acknowledging a failure and helps to unclutter a “busy” matrix. For iconified matrices, suppression can be used to detect when “new” failures (or changes in failure state) have occurred.

---

Location : Matrix logic item box

Button : Middle button

Action : If the box is a multilevel, see ‘Matrix multi-level pop-up menu’ below on logic item selection. In either case (multilevel or single item box), the help mode is initiated for the item selected. A box that does not contain an item name cannot be selected. The main header changes to reflect that the help mode is in effect. The command menu item “Save Config” changes to “Help Off” (see below). The matrices are erased and the display shows the logic item with its associated logic (or sub-items) underneath, similar to its arrangement in the logic file (“or” is used in place of:, etc., to improve readability). The color of the item names reflect the item’s fail state: green = not-failed, red=failed. Hard-fail and tag status is shown as in the matrices (\* and ~ characters). Constant values are shown in white. If real-time data is active, MSID items are displayed with their current values beside them. If the help file exists and contains a reference for the logic item selected, the text message is displayed to the right side of the logic. To review an item’s logic tree, see ‘Help mode logic item - Middle button’ below.

---

Location : Matrix logic item box

Button : Right button

Action : If the box is a multilevel, see ‘Matrix multi-level pop-up menu’ below on logic item selection. In either case (multilevel or single item box) the selected logic item’s tagged state is toggled on/off if the item is not failed. A box that does not contain a name cannot be tagged. A ~ character is displayed in the last column of the box when it is tagged (the ~ is removed

---

when the fail status is toggled on). The tag determines which item(s) is used for a commonality, failure result, or reference check. See 'Command menu item "Commonality"', 'Command menu item "Fail Result"', and 'Command menu item "Reference"' below on how to perform these checks.

---

Location : Matrix multilevel pop-up menu

Button : Any button

Action : If a multilevel box is selected, a pop-up menu showing all the items represented by the box is displayed. Item failure state is depicted by name color (green = not-failed, red = failed). The pointer is used to indicate the item desired (the item is highlighted), and the mouse button is released to select the item. Some items may not be selectable depending on which button is pressed. Items that are hard-fail protected cannot be selected if the left button is pressed, and failed items are not taggable with the right button. Empty (no item name) positions specified in the multilevel are not selectable.

---

Location : Help mode logic item

Button : Left button

Action : The logic item selected has its fail state toggled (off -> on or on -> off). An item that is hard-fail protected in a matrix can be hard-failed in this mode. A logic check is performed to reflect changes in other items' logic states, and the results are reflected immediately in the help display.

---

Location : Help mode logic item

Button : Middle button

Action : To travel forward through a logic item's logic tree, position the pointer over one of the sub-items displayed (an outline surrounds the sub-item name) and press the middle button. The program window is cleared and the sub-item selected has its logic displayed as described above. Repeat this procedure to continue down the logic tree. Selecting the item name itself has no effect. To travel back through the tree see 'Help mode BACK box' below. An item's entire logic tree can be examined in this way.

---

Location : Help mode logic item

Button : Right button

Action : The selected logic item's tagged state is toggled on/off if the item is not failed. A ~ character is displayed at the end of the item name when it is tagged. The tag determines which item(s) is used for a commonality, failure result, or reference check. See 'Command menu item



---

“Commonality”’, ‘Command menu item “Fail Result”’, and ‘Command menu item “Reference”’ below on how to perform these checks.

---

Location : Help mode BACK box

Button : Any button

Action : When a sub-item is selected, the ‘BACK’ box appears to the left of the logic information. When this box is selected then the preceding logic item from which the current item was chosen is redisplayed. Repeat this procedure to continue back up the logic tree. When the original item is reached the ‘BACK’ box will disappear. This box is also removed if either the reference, failure result, or commonality mode is entered.

---

Location : Help mode constant value

Button : Any button

Action : Constant values (not including filter numbers used in fractional AND statements and bit masks) can be changed while the program is operating. Select a constant by placing the pointer over the number (an outline surrounds it) and press a button. A dialog box appears that displays the current value. The keyboard is then used to change the constant. Using the pointer, select the dialog box “OKAY” button to accept the change, or the “NO” button to ignore it. The logic is then reevaluated, and the help display is updated to reflect the change.

---

Location : Commonality mode logic item

Button : Middle button

Action : The help mode (as described above) is initiated for the item selected (an outline surrounds the item name). The ‘BACK’ box, if present, is removed. To return to the commonality mode, see ‘Command menu item “Commonality”’ below.

---

Location : Commonality mode logic item

Button : Right button

Action : The selected logic item’s tagged state is toggled on/off. A ~ character is displayed at the end of the item name when it is tagged. The tag determines which item(s) is used for a commonality, failure result, or reference check. See ‘Command menu item “Commonality”’, ‘Command menu item “Fail Result”’, and ‘Command menu item “Reference”’ below on how to perform these checks.

---

Location : Commonality mode BACK box

Button : Any button

Action : When a commonality check is performed from within the commonality mode (and the item(s) tagged have changed) the 'BACK' box appears to the left of the commonality information. When this box is selected, the preceding commonality check is reinstated (the former tags are restored). Repeat this procedure to continue back up the 'commonality' tree. When the originally performed check is reached, the 'BACK' box will disappear. This box is also removed if the failure result, reference, or help mode is entered.

---

Location : Failure Result mode logic item

Button : Middle button

Action : The help mode (as described above) is initiated for the item selected (an outline surrounds the item name). The 'BACK' box, if present, is removed. To return to the failure result mode, see 'Command menu item "Fail Result" ' below.

---

Location : Failure Result mode logic item

Button : Right button

Action : The selected logic item's tagged state is toggled on/off. A ~ character is displayed at the end of the item name when it is tagged. The tag determines which item(s) is used for a commonality, failure result, or reference check. See 'Command menu item "Commonality" ', 'Command menu item "Fail Result" ', and 'Command menu item "Reference" ' below on how to perform these checks.

---

Location : Failure Result mode BACK box

Button : Any button

Action : When a failure result check is performed from within the failure result mode (and the item(s) tagged have changed) the 'BACK' box appears to the left of the commonality information. When this box is selected, the preceding failure result check is reinstated (the former tags are restored). Repeat this procedure to continue back up the 'failure result' tree. When the originally performed check is reached, the 'BACK' box will disappear. This box is also removed if the commonality, reference, or help mode is entered.

---

Location : Reference mode logic item

Button : Middle button

---

Action : The help mode (as described above) is initiated for the item selected (an outline surrounds the item name). The 'BACK' box, if present, is removed. To return to the reference mode, see 'Command menu item "Reference"' below.

---

Location : Reference mode logic item

Button : Right button

Action : The selected logic item's tagged state is toggled on/off. A ~ character is displayed at the end of the item name when it is tagged. The tag determines which item(s) is used for a commonality, failure result, or reference check. See 'Command menu item "Commonality"', 'Command menu item "Fail Result"', and 'Command menu item "Reference"' below on how to perform these checks.

---

Location : Reference mode BACK box

Button : Any button

Action : When a reference check is performed from within the reference mode (and the item(s) tagged have changed) the 'BACK' box appears to the left of the reference information. When this box is selected, the preceding reference check is reinstated (the former tags are restored). Repeat this procedure to continue back up the 'reference' tree. When the originally performed check is reached, the 'BACK' box will disappear. This box is also removed if commonality, failure result, or help mode is entered.

---

Location : Matrix icon

Button : Any button

Action : This “deiconifies” a matrix; the icon is removed and the matrix it represents is displayed. If the button is held, the pointer turns into a four-pointed arrow and a full-sized dashed outline of the matrix appears (the outline does not appear if the **moveoutline false** option is used,; in this case the matrix itself appears). The mouse can then be used to position the deiconified matrix. The matrix outline (or the matrix itself) cannot be moved such that any portion of the matrix extends outside of the main program window or over the main window header. Releasing the button returns the pointer to its previous shape and the matrix is drawn. The matrix window is raised to the top of the matrix stack if it is overlapped by another matrix. If insufficient window space is available, a dialog box to this effect is displayed and the matrix remains in icon form.

If the control key was pressed in unison with the button, instead of deiconifying the matrix, the icon itself enters the “move” mode. The icon’s outline (or the icon itself) is displayed and can be repositioned as described above for the matrix. The icon window is placed at the bottom of the stack of matrices/icons (if applicable).

---

Location : Matrix iconify box

Button : Any button

Action : When the pointer is positioned over the iconify box (located at the right side of the matrix header), the box is highlighted. Pressing a button at this point causes the matrix to be reiconified (it returns to its former icon position). The icon window is placed at the bottom of the stack of matrices/icons (if applicable).

---

Location : Matrix header

Button : Any button

Action : If the button is pressed and held, the pointer turns into a four-pointed arrow, and a full-sized outline of the matrix appears (if the option **moveoutline false** is specified, the outline does not appear and the matrix itself is moved). The mouse can then be used to reposition the matrix. The matrix outline (or the matrix itself) cannot be moved such that any portion of the matrix extends outside of the main program window or over the main window header. Releasing the button returns the pointer to its previous shape and moves the matrix to the outline's position. The matrix window is raised to the top of the matrix stack if it is overlapped by another matrix.

If the control key was pressed in unison with the button, the pointer can be anywhere within the matrix window for repositioning to take place as described.

---

Location : Command menu title ("Commands") in main window header

Button : Any button

Action : When the pointer is positioned over "Commands" (located at the right side of the main window header), the text is highlighted. If a button is then pressed, the command pull-down menu appears and the pointer turns into a hand (the button must be held down). Position the pointer over one of the commands (only those commands that highlight can be executed) and release the button pressed to initiate the command. See below for descriptions of the various commands. Releasing the button elsewhere performs no action. The pull-down menu is erased and pointer restored in either case.

---

Location : Command menu item "Commonality"

Button : Any button

Action : If at least one item is tagged, a check is performed to determine if any single-point failures exist for the tagged item or common to the tagged items (see 'Matrix logic item box - Right button', above). The program takes into account the current failure state of all the logic items when searching for single-point failures (i.e., an item that normally is not a single-point failure for the item(s) tagged could become so if other failures are input). The matrices are replaced (if the normal mode is active) by a window showing the item(s) tagged and the single-point failures ("None" is displayed if there are no single-point failures). Only the lowest common items are shown; common items further up the logic

tree are not displayed (see 'Commonality mode logic item - Right button', above, on how to tag items and continue down a commonality tree). If a commonality check is performed from within the commonality mode (and the item(s) tagged have changed), the 'BACK' box appears to the left of the commonality information (see 'Commonality mode BACK box' above).

The main header changes to reflect that commonality mode is in effect. The command menu item "Save Config" changes to "Common Off" (see below).

---

Location : Command menu item "Common Off"

Button : Any button

Action : Commonality mode is turned off and the normal mode is resumed (the matrices/icons reappear). Pressing the control key and any button simultaneously while the pointer is in the commonality display area also terminates commonality mode.

---

Location : Command menu item "Fail Result"

Button : Any button

Action : If at least one item is tagged, all logic items not currently failed that would be failed if the tagged item(s) was failed are displayed ("None" is displayed if the tagged item(s) does not fail any other items). See 'Failure Result mode logic item - Right button', above, on how to tag items and continue down a failure result tree). If a failure result check is performed from within the failure result mode (and the item(s) tagged have changed) the 'BACK' box appears to the left of the failure result information (see 'Failure Result mode BACK box' above).

The color of the item names reflects the item's fail state: green = not-failed, red = failed (by definition the tagged item(s) cannot be in a failed state). The main header changes to reflect that failure result mode is in effect. The command menu item "Save Config" changes to "Fail Off" (see below).

---

Location : Command menu item "Fail Off"

Button : Any button

Action : Failure result mode is turned off and the normal mode is resumed (the matrices/icons reappear). Pressing the control key and any button simultaneously while the pointer is in the failure result display area also terminates failure result mode.

---

Location : Command menu item "Reference"

Button : Any button

Action : If at least one item is tagged, all logic items that directly reference all the tagged items are displayed ("None" is displayed if the tagged item(s) is not referenced by any of the logic items in the logic file). Note that the tagged item is not necessarily a single-point failure for the items displayed. See 'Reference mode logic item - Right button', above, on how to tag items and continue down a reference tree). If a reference check is performed from within the reference mode (and the item(s) tagged have changed) the 'BACK' box appears to the left of the reference information (see 'Reference mode BACK box' above).

The color of the item names reflects the item's fail state: green = not-failed, red = failed (by definition the tagged item(s) cannot be in a failed state). The main header changes to reflect that reference mode is in effect. The command menu item "Save Config" changes to "Refer Off" (see below).

---

Location : Command menu item "Refer Off"

Button : Any button

Action : Reference mode is turned off and the normal mode is resumed (the matrices/icons reappear). Pressing the control key and any button simultaneously while the pointer is in the reference display area also terminates reference mode.

---

Location : Command menu item "Help Off"

Button : Any button

Action : Help mode is turned off and the normal mode is resumed (the matrices/icons reappear). Pressing the control key and any button simultaneously while the pointer is in the help display area also terminates help mode.

---

Location : Command menu item "Clear Fails"

Button : Any button

Action : The user is asked to verify this command via a dialog box before continuing. If verified, all failure statuses are set to "not-failed", and a logic test is performed to reset the logic states. The results are reflected immediately in the matrices, the matrix icons, and in the help, failure result, or reference modes (if active).

---

---

Location : Command menu item "Clear Tags"

Button : Any button

Action : All tagged statuses are reset (to untagged). The results are reflected immediately in the matrices. If the help mode is active, any tags shown are removed. If the commonality, failure result, or reference mode is in effect, the normal mode is resumed (the matrices/icons reappear).

---

Location : Command menu item "Print Data" - main mode

Button : Any button

Action : A summary of input and resultant failed item names is output to the printer. If real-time data is active, the current values of all MSIDs are output, along with status flags indicating out-of-limits high and low if applicable. Failure status of MSIDs is also indicated.

---

Location : Command menu item "Print Data" - help mode

Button : Any button

Action : The contents of the help display are output to the printer (items truncated due to the size of the program window will be printed).

---

Location : Command menu item "Print Data" – commonality mode

Button : Any button

Action : The contents of the commonality display are output to the printer (items truncated due to the size of the program window will be printed).

---

Location : Command menu item "Print Data" – failure result mode

Button : Any button

Action : The contents of the failure result display are output to the printer (items truncated due to the size of the program window will be printed).

---

Location : Command menu item "Print Data" – reference mode

Button : Any button

Action : The contents of the reference display are output to the printer (items truncated due to the size of the program window will be printed).

---

Location : Command menu item "Save Config"

Button : Any button

---



Action : The user is asked to verify this command via a dialog box before continuing. If verified, the current main window size and matrix/icon state/position information is saved to the configuration file (either the file name specified with the command line or **.Xdefaults** option, or the default file name, **DATA/crans.config**).

---

Location : Command menu item "Update Rate"

Button : Any button

Action : If real-time data is being taken by the program, a dialog box is generated with an input window showing the current real-time data acquisition rate in seconds per sample. The update rate must be 1 second/sample or greater, or a warning message is generated. The user types in the new rate and selects the "OKAY" box to accept it. Selecting the "NO" box causes the update rate to remain unchanged.

---

Location : Command menu item "Exit CRANS"

Button : Any button

Action : The user is asked to verify this command via a dialog box before continuing. If verified, the program window is erased and the program exits.

---

Location : Dialog box "OKAY" button

Button : Any button

Action : Acknowledging a dialog box message is done by placing the pointer (which now resembles a hand) over the "OKAY" button (which highlights to show its selection) and pressing any button. The dialog box disappears and the program continues (or exits, depending on the circumstances). See ERROR MESSAGES below for a description of the dialog box error and warning messages.

---

Location : Dialog box "NO" button

Button : Any button

Action : The "NO" button is displayed when the dialog box requires a yes-or-no answer to the dialog box message. Selecting the "NO" box indicates a negative response to the message and is done by placing the pointer (which now resembles a hand) over the "NO" button (which highlights to show its selection) and pressing any button. The dialog box disappears and the program continues operation.

---

Location : Dialog box "EXIT" button

Button : Any button

Action : The "EXIT" button is displayed when an error has been detected that results in program termination. Selecting the "EXIT" box acknowledges the message and is done by placing the pointer (which now resembles a hand) over the "EXIT" button (which highlights to show its selection) and pressing any button. The dialog box disappears and the program exits.

---

Location : Scroll bar up button

Button : Any button

Action : Pressing a button while the pointer is within the scroll bar up button causes it to highlight. The information displayed (help, commonality, failure result, or reference) scrolls up one row unless the last row has been reached. The scroll bar slide box position is updated accordingly (see below). In the help mode, only the logic statement information is scrolled.

---

Location : Scroll bar down button

Button : Any button

Action : Pressing a button while the pointer is within the scroll bar down button causes it to highlight. The information displayed (help, commonality, failure result, or reference) scrolls down one row unless the first row has been reached. The scroll bar slide box position is updated accordingly (see below). In the help mode, only the logic statement information is scrolled.

---

Location : Scroll bar slide box

Button : Any button

Action : Pressing and holding a button while the pointer is within the scroll bar slide box causes it to highlight. The cursor changes to the shape of a hand and the slide box can now be moved. Moving the slide box causes the information displayed to be scrolled accordingly. In the help mode, only the logic statement information is scrolled. Releasing the button stops slide box movement and restores the cursor.

---

Location : Scroll bar slide area

Button : Any button

Action : If the pointer is positioned outside the scroll bar slide box but within the area that the box can move and a button is pressed, the slide box jumps to the position indicated. The information displayed is scrolled to reflect the new slide position. In the help mode, only the logic statement information is scrolled.

---

The X-Windows window manager can be used to move, resize, and (de)iconify the entire **crans** program window. Depending on the window manager, the window cannot be sized smaller than is allowed to contain the main header information and all of the matrices in icon form. When a resize occurs, the matrices and icons are moved an amount proportional to the window size change. If the control key is held down when the mouse button is released during resizing, the matrix icons are repositioned along the right side of the program window. If the window is sized too small to contain a matrix, a dialog box message is issued and the matrix is automatically reiconified. When the entire program is iconified, the main window disappears and is replaced by the crans icon with the icon name (defined in the matrix file) underneath. When deiconified, the main window returns with all the matrices/icons positions unchanged.

## EXAMPLES

The following are examples of the three file types (logic, matrix, and help). The files are not complete, but they demonstrate the various formats described above.

```
@ CRANS logic file
MNA DA1
MNA FPC1
  MNA DA1
MNA FLC1
  MNA FPC1
AC1
  (AC1 A & AC1 B & AC1 C)|
  MNA FPC1

@ This is failed when 2 of the 3 AC phases are filed
@ At least 2 of 3 are required for motor operations
AC1 2/3
  AC1 A & AC1 B & AC1 C: 2

@ PLBD motor logic
C/L 1-4 M1
  MNA MMC3 |
  AC1 MMC3 |AC1 2/3 |
  CNTLAB2 |
MDM PL1

@ This determines number of landing gear deploy
@ methods lost
1 GEAR DEPLOY LOST
  ' HYD DEPLOY | PYRO SYS 1| PYRO SYS 2
2 GEAR DEPLOY LOST
  HYD DEPLOY & PYRO SYS 1 & PYRO SYS 2 : 2
NO GEAR DEPLOY
  HYD DEPLOY & PYRO SYS 1 & PYRO SYS 2

@ This determines if APU 1 has insufficient tank
@ pressure for a restart and handles bad telemetry

MDM OA1
#V46 P0100A
  MDM OA1
APU 1 LOW TANK P
  (#V46P0100A < 107) & ~V46P0100A
```

**Figure 7.2.5-1. Example logic file**

```
@ CRANS matrix file
@ Main window title definition
TITLE: Mechanical Systems
@ Main window icon name
ICON NAME: FAILURES
@ Matrix color map
COLOR MAP: Green      : Black
           Red = #d00000 : White
@ Use dark grey text over yellow
           Yellow      : #111
@ The blue used is the one below (= mediumblue)
           Orange = #c00050 : Blue
@ Use standard map's medium blue for just 'blue'
           Blue = mediumblue: White
@ This matrix would be 2 rows by 3 columns
MATRIX: , Bus/MDM, 7x9
      {MNA DA1,Green,Red} {MNB DA2,Green,Red} {MNB DA3,Green,Red}
@ Put an empty (blank) box under MNB DA2
      {MNA FPC1,Green,Red} { ,Green,Black} {MNC FPC3,Green,Red}
@ This matrix has a single multi-level box
@ The first two items are hard-fail protected
@ Force the box to a larger size
MATRIX: Entry, Brakes, 9x15, 30
      {'*GEAR DEPLOY' : *NO GEAR DEPLOY : 2 GEAR DEPLOY LOST
      : 1 GEAR DEPLOY LOST,Blue, Blue: Red : Orange : Yellow}
```

**Figure 7.2.5-2. Example matrix file**

```
@ CRANS help file
1 GEAR DEPLOY LOST
One of the following methods
of gear deploy has been lost:
  Hydraulic (System 1 only)
  Pyro System 1
  Pyro System 2
2 GEAR DEPLOY LOST
Two of the following methods
of gear deploy have been lost:
  Hydraulic (System 1 only)
  Pyro System 1
  Pyro System 2
Enter first day/next PLS per
flight rule 10-174
No GEAR DEPLOY
No method remains for deploying
the landing gear!
```

**Figure 7.2.5-3. Example help file**

## ERROR MESSAGES

The following error and warning messages can be generated within the program. Causes and corrective actions are given. The error messages are listed below in alphabetical order.

**ERROR: Bad color '<color name>' RGB format in matrix file '<file name>'**

Cause: The RGB color definition shown is in the wrong format (too many/few R's, G's, and/or B's). Program terminates.

Resolution: Correct the RGB format.

**ERROR: Cannot access MSID keys**

Cause: The ds\_getkeys() call to obtain MSID information for real-time data access was unsuccessful. Program terminates.

Resolution: Check real-time data source status and MSID names.

**ERROR: Cannot connect to X server**

Cause: Program executed outside of the X-Windows environment, or server error. Program terminates. Since the program window is never displayed this message does not appear in a dialog box, but in the standard output window (if it exists).

Resolution: Execute the program while in X-Windows.

**ERROR: Cannot open file '<file name>'**

Cause: The logic or matrix file specified could not be opened. Program terminates.

Resolution: Check for correct file name spelling and path.

**ERROR: Cannot open output file 'crans\_cmp1.c'**

Cause: The temporary compiler file could not be opened. Program terminates.

Resolution: Check for correct directory permissions.

**ERROR: Cannot open output file 'crans\_cmp2.c'**

Cause: The temporary compiler file could not be opened. Program terminates.

Resolution: Check for correct directory permissions.

**ERROR: Cannot open output file 'crans\_cmp3.c'**

Cause: The temporary compiler file could not be opened. Program terminates.

Resolution: Check for correct directory permissions.

**ERROR: Cannot open '<font name>' font**

Cause: The font listed cannot be found. Program terminates.

Resolution: Check current font path (to make sure all available font directories are included) and font name spelling.

**ERROR: Color '<color name>' undefined in matrix file '<file name>'**

Cause: The color name shown cannot be found in the standard color database or the '#' character was left off the RGB format. Program terminates.

Resolution: Check spelling/syntax (add '#' to RGB format).

**ERROR: Color map syntax error in matrix file '<file name>'**

Cause: The matrix file color map has incorrect syntax (too few or too many color names). Program terminates.

Resolution: Correct the color map syntax.

**ERROR: Configuration file '<file name>' data missing**

Cause: The number of matrix data sets in the configuration file does not match the total number of matrices. Program terminates.

Resolution: Remove the configuration file or save the current configuration.

**ERROR: Illegal command line option/syntax**

Cause: Excess character(s) or no value listed after option on command line, or illegal command line option. Program terminates.

Resolution: Correct the command line syntax.

**ERROR: Infinite loop found**

Cause: Logic that would result in an infinite loop (e.g., A is failed by NOT A) has been detected. This is determined in the program by the logic routine being unable to 'converge' within a specified number of loops. This can occur only with the use of inverse (NOT) logic.

Resolution: Remove the logic causing the loop from the logic file.

**ERROR: Insufficient memory space available**

Cause: Insufficient memory could be allocated for program variables. Program terminates.

Resolution: Terminate other processes and/or clear some disk space.

**ERROR: Item '<name>' filter value < 2 in logic file '<file name>'**

Cause: The filter value for the item named is less than 2. Program terminates.

Resolution: Increase the filter value.

**ERROR: Item '<name>' has illegal '<operator>' in logic file '<file**

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**name>'**

Cause: The logic statement for the item named contains the operator shown in an illegal context. Program terminates.

Resolution: Correct the logic syntax.

**ERROR: Item '<name>' has illegal constant in logic file '<file name>'**

Cause: A filter number or constant value is placed illegally in the logic item named. Program terminates.

Resolution: Correct the logic syntax.

**ERROR: Item '<name>' has illegal ending operator in logic file '<file name>'**

Cause: The logic string for the item referenced is terminated with an operator that is illegal in that context. Program terminates.

Resolution: Correct the logic syntax.

**ERROR: Item '<name>' has illegal item name in logic file '<file name>'**

Cause: A logic item name is placed illegally in the logic for the item named. Program terminates.

Resolution: Correct the logic syntax.

**ERROR: Item '<name>' has illegal MSID item in logic file '<file name>'**

Cause: An MSID item name is placed illegally in the logic for the item named. Program terminates.

Resolution: Correct the logic syntax.

**ERROR: Item '<name>' has no name following quote in logic file '<file name>'**

Cause: An item name was expected following a single quote in the logic file. Program terminates.

Resolution: Delete the quote or put an item name after it.

**ERROR: Item '<name>' has too few ('s in logic file '<file name>'**

Cause: The number of right parentheses exceeds the number of left parentheses at some point in the logic string for the item named (reading left to right). Program terminates.

Resolution: Add/subtract parentheses as required to correct syntax.

**ERROR: Item '<name>' has too few )'s in logic file '<file name>'**

Cause: The number of left parentheses exceeds the number of right parentheses in the logic string for the item named. Program terminates.

Resolution: Add/subtract parentheses as required to correct syntax.



**ERROR: Item '<name>' undefined in logic file '<file name>'**

Cause: A sub-item is not listed as a separate item in the logic file.  
Program terminates.

Resolution: Put an entry for the item in the logic file or check spelling.

**ERROR: Item '<name>' is not a valid MSID in logic file '<file name>'**

Cause: An MSID logic item name (an item beginning with a #) is not a valid MSID. Program terminates.

Resolution: Correct the item name indicated

**ERROR: Item '<name>' mask value missing in logic file '<file name>'**

Cause: The logic statement of the item indicated is missing the required mask value. Program terminates.

Resolution: Correct the bad logic statement.

**ERROR: Item '<name>' mask value too large in logic file '<file name>'**

Cause: The logic statement of the item indicated contains a mask word value larger than eight digits. Program terminates.

Resolution: Correct the bad logic statement.

**ERROR: Item '<name>' string constant too long in logic file '<file name>'**

Cause: The logic statement of the item indicated contains a string constant longer than seven characters. Program terminates.

Resolution: Correct the bad logic statement.

**ERROR: Matrix '<matrix name>' box definition color name missing in matrix file '<file name>'**

Cause: Insufficient color names are given in a box definition in the matrix indicated.

Resolution: Provide a fail color for each item represented in the matrix box in addition to a single not-fail color.

**ERROR: Matrix '<matrix name>' box definition syntax error in matrix file '<file name>'**

Cause: A box definition in the matrix indicated contains too many color names or has excess characters.

Resolution: Remove the excess characters.

**ERROR: Matrix '<matrix name>' color '<color name>' undefined in matrix file '<file name>'**

Cause: The color name in the specified matrix has not been defined in the matrix file color map. Program terminates.

Resolution: Add an entry for the color, or check spelling.

**ERROR: Matrix '<matrix name>' font name missing in matrix file '<file name>'**

Cause: The matrix indicated does not have a font name specified.  
Resolution: Provide the missing font name.

**ERROR: Matrix '<matrix name>' has no boxes defined in matrix file '<file name>'**

Cause: No box definitions exist in the matrix file for the matrix specified. Program terminates.  
Resolution: Define boxes for the matrix or remove the matrix command.

**ERROR: Matrix '<matrix name>' item '<item name>' in matrix file '<file name>' undefined in logic file**

Cause: Matrix item specified in matrix file could not be found in the logic file. Program terminates.  
Resolution: Add entry in logic file for matrix item, delete matrix item, or check spelling.

**ERROR: Matrix '<matrix name>' rows have unequal number of columns in matrix file '<file name>'**

Cause: Number of columns in one row of a matrix does not equal the number of columns in the preceding rows of that matrix. Matrices must be symmetrical. Program terminates.  
Resolution: Fill out columns with empty boxes (no name, and not fail/fail colors set to black).

**ERROR: Matrix definition name missing in matrix file '<file name>'**

Cause: A matrix definition does not include a matrix name.  
Resolution: Provide the missing matrix name.

**ERROR: MSID '<MSID name>' has invalid type**

Cause: An MSID logic item does not return with a binary, integer, floating point, or parent word value. Program terminates.  
Resolution: Remove the MSID specified from the files.

**ERROR: MSID item name '<MSID name>' too long in logic file '<file name>'**

Cause: The MSID portion of the MSID logic item (item's beginning with a '#' character are assumed to be MSIDs) indicated contains too many characters (10 characters maximum). Program terminates.  
Resolution: Correct the MSID logic item name specified.

**ERROR: No color map defined before matrix definition**

Cause: A matrix definition precedes the color map, or no color map is present in the matrix file. Program terminates.

Resolution: Place the color map ahead of any matrix definitions in the file.

**ERROR: No logic items defined in logic file(s)**

Cause: The logic file(s) does not contain any logic item definitions (item names beginning in the first column). Program terminates.

Resolution: Supply correctly formatted logic file.

**ERROR: No matrices defined in matrix file(s)**

Cause: No matrix definitions were found in the matrix file. Program terminates.

Resolution: Add at least one matrix definition to the matrix file.

**ERROR: No room in color map**

Cause: The color map is full and no new colors can be defined (box or text). Program terminates.

Resolution: Reduce the number of colors defined. Try to use names from the standard color database if possible to increase the chance of interclient color sharing.

**ERROR: Syntax error in matrix file '<file name>'**

Cause: A line in the matrix file that is not an identifier or a comment line was found. Program terminates.

Resolution: Delete excess lines.

**WARNING: Bad input value; ignored**

Cause: A number entered in the input dialog box is incorrectly formatted (imbedded spaces, improperly placed decimal points or minus signs). The bad value is ignored and the dialog box is removed.

Resolution: Reenter the constant value correctly.

**WARNING: Cannot connect to data source; continue (no real-time)?**

Cause: The ds\_connect() call to connect to the real-time data source was unsuccessful. If the dialog 'OKAY' box is selected, the program continues operation, but no real-time data is processed (all MSID logic items are initialized to not-failed). If 'NO' is selected, the program terminates.

Resolution: Check real-time data source status.

**WARNING: Cannot initialize WEX; continue (no real-time)?**

Cause: The EXwexinit() call to initialize WEX was unsuccessful. If the dialog 'OKAY' box is selected, the program continues operation, but no real-time data is processed (all MSID logic items are initialized to not-failed). If 'NO' is selected, the program terminates.

Resolution: Execute program in the WEX 2.5 environment.

**WARNING: Cannot obtain flight number; continue (no real-time)?**

Cause: The EXflight( ) call to obtain the current flight number was unsuccessful. If the dialog 'OKAY' box is selected, the program continues operation, but no real-time data is processed (all MSID logic items are initialized to not-failed). If 'NO' is selected, the program terminates.

Resolution: Select a flight number for real-time data access.

**WARNING: Cannot open configuration file '<file name>'**

Cause: Configuration file cannot be opened. Program continues operation (configuration is not saved).

Resolution: Bad subdirectory; check file pathname.

**WARNING: Cannot open output file 'crans.temp'**

Cause: The temporary output file used for print requests could not be opened. No output is generated. Program continues operation.

Resolution: Reattempt request. Possible Unix problem.

**WARNING: Configuration file '<file name>' data mismatch**

Cause: The number of matrices saved in the configuration file does not match the number of matrix definitions in the matrix file. Program continues operation (the configuration file is ignored).

Resolution: Remove the configuration file, save the current configuration, or specify another configuration file name on the command line.

**WARNING: Insufficient window size for matrix '<matrix name>'**

Cause: The size of the main window is too small to contain the matrix when deiconified. Program continues operation (the matrix remains iconified).

Resolution: Resize the main window larger.

**WARNING: Insufficient window size to display all information**

Cause: The program window size is too small to contain all the help, commonality, failure result, or reference display information. A scroll bar appears that allows the truncated information to be reviewed. The program continues operation.

Resolution: Resize the program window larger.

**WARNING: Item '<name>' in logic file '<file name>' already defined; continue (ignore)?**

Cause: A logic item has two (or more) definitions in the logic file(s). If the dialog 'OKAY' box is selected, the program continues operation and the duplicate entry is ignored. If 'NO' is selected, the program terminates.

Resolution: Remove duplicate logic item entries from the logic file(s). The option "-showduplicates FALSE" will inhibit this warning message.

**WARNING: Main window too small**

Cause: The program window is too small to contain the main window header or the largest icon. The program continues operation.

Resolution: The window manager should prevent resizing the window too small to contain the header or largest icon. Start the program with a larger window size, or shorten the main title or matrix name(s).

**USAGE NOTES**

Except for error checking noted above, the program expects to find correct file syntax. Incorrect syntax could produce unexpected results (program hangs, error messages, etc.).

In the real-time version, the program can exit inadvertently due to an interrupt handling problem in the Masscomp UNIX. Restart the program if this occurs. This problem has been seen infrequently, and only when the program has been inactive for long periods.

**TITLE**

RT PLOT - TBD

## TITLE

EGIL COMPUTATIONS

## PURPOSE

The purpose of this console software aid is to provide a list with some general information about the computations that are being displayed on the EGIL workstation MSK displays.

## DESCRIPTION

Several different mathematical computations are done by the EGIL workstation server that provide useful flight controller data. This console aid will identify the data computations being performed and provide the general equations used to calculate this data.

## DETAILS

- A. Fuel cell kilowatts (FC KW) - The amount of power each individual fuel cell is supplying is calculated as the product of the fuel cell voltage and fuel cell ampere.

$$\text{FC KW} = V * I$$

FC1 kW - W01I1001C  
FC2 kW - W02I1001C  
FC3 kW - W03I1001C

- B. Fuel cell load percentage (FC % LD) - The percent of the total orbiter being supplied by each individual fuel cell is calculated as the fuel cell power divided by the orbiter power.

$$\text{FC\%LD} = [(\text{FC KW})/\text{TOTAL KW}] * 100$$

FC1 % LOAD - W01I1008C  
FC2 % LOAD - W02I1008C  
FC3 % LOAD - W03I1008C

- C. Fuel cell total amps (TOTAL AMPS) - The total amperes being supplied to the orbiter by all three fuel cells is the sum of individual fuel cell amperes.

$$\text{TOTAL AMPS} = \text{FC1 AMPS} + \text{FC2 AMPS} + \text{FC3 AMPS}$$

TOTAL AMPS - W01I1003C

- D. Total kilowatts (TOTAL KW) - The amount of power being used by the orbiter is the sum of the power being supplied by all three fuel cells.

$$\text{TOTAL KW} = \text{FC1 KW} + \text{FC2 KW} + \text{FC3 KW}$$

TOTAL KW - W01I1002C

- E. Oxygen calculated flow (O2 CAL FL) - The amount of cryogenic oxygen being consumed by each fuel cell is directly proportional to the amount of current being supplied by that fuel cell.

$$\text{O2 CAL FL} = (\text{FC AMPS}) * (1/47.5 \text{ lbm O2/AMP})$$

FC1 O2 CAL FLOW - W01I1009C  
FC2 O2 CAL FLOW - W02I1009C  
FC3 O2 CAL FLOW - W03I1009C

- F. Hydrogen calculated flow (H2 CAL FL) - The amount of cryogenic hydrogen being consumed by each fuel cell is directly proportional to the amount of current being supplied by that fuel cell.

$$\text{H2 CAL FL} = (\text{FC AMPS}) * (1/377 \text{ lbm H2/AMP})$$

FC1 H2 CAL FLOW - W01I1010C  
FC2 H2 CAL FLOW - W02I1010C  
FC3 H2 CAL FLOW - W03I1010C

- G. Delta amps (AMPS X-X) - This computation is an onboard comp done by the orbiter general purpose computers and not the EGIL server. The difference between the amount of current being supplied by each fuel cell is the delta amp value. This calculation is done for each fuel cell. For a better understanding on how this value is used, refer to the delta amps SCP 2.14.

$$\text{AMPS 1-2} = \text{FC1 AMPS} - \text{FC2 AMPS}$$

FC 1-2 - V92C2142C  
FC 2-3 - V92C2143C  
FC 3-1 - V92C2144C

- H. Fuel cell delta voltage (VOLTS) - The delta volts is calculated as the difference of calculated voltage value obtained from the fuel cell V-I curve formula, using the fuel cell amps as the input, and the actual measured fuel cell voltage. The V-I formula is a third-order polynomial whose coefficients are provided by the BNA engineering fuel cell personnel. These coefficients must be sent as comp constants (refer to the comp constant console procedure).

$$\text{VOLTS} = \text{FC VDC} - (A_0 + A_1 * I + A_2 * I^2 + A_3 * I^3)$$

FC1 DV - W01G1044C  
FC2 DV - W02G1044C  
FC3 DV - W03G1044C



- I. Total quantity of cryogenic oxygen (TOTAL:O2) - The total quantity of oxygen is the calculated sum of all the tank quantities in percent multiplied by quantity in a full tank in pounds (781 lbm). Since the number of tanks varies with missions, it is necessary to send a comp constant indicating which tanks are being flown for that mission. This prevents the non-zero valued tanks that are not manifested from biasing the quantity (refer to the comp constant console procedure).

TOTAL O2 - W0111025C

- J. Total quantity of cryogenic hydrogen (TOTAL:H2) - The total quantity of hydrogen is the calculated sum of all the tank quantities in percent multiplied by quantity in a full tank in pounds (92 lbm). Since the number of tanks varies with missions, it is necessary to send a comp constant indicating which tanks are being flown for that mission (refer to the comp constant SCP).

TOTAL H2 - W0111026C

- K. Total orbiter energy kilowatt hours (KW-H) - The total amount of energy (kWh) that is being used during a mission is calculated as the sum of the energy from each individual fuel cell. The energy supplied by a fuel cell is computed every 6 seconds. The energy is calculated using the average power (FC kW) multiplied by the time interval. This computation is done for each fuel cell, and the results are added to the previous value stored. The total orbiter energy is the sum of energy from all three fuel cells.

$$\begin{aligned} kWh_1 &= kWh_{1L} + (t - t_L)(kW_1 + kW_{1L})/2 \\ kWh_2 &= kWh_{2L} + (t - t_L)(kW_2 + kW_{2L})/2 \\ kWh_3 &= kWh_{3L} + (t - t_L)(kW_3 + kW_{3L})/2 \\ kWh_T &= kWh_1 + kWh_2 + kWh_3 \end{aligned}$$

where

t = Current time in decimal hours

t<sub>L</sub> = Time last valid computation was performed

kWh<sub>1L</sub>, kWh<sub>2L</sub>, and kWh<sub>3L</sub> are the values stored last time comp was performed

kWh<sub>1</sub>, kWh<sub>2</sub>, and kWh<sub>3</sub> is the kilowatt comp at the current time

KWH - W0411045C

- L. Total orbiter ampere hours (AMP-H) - The total amount of current over time that is being supplied to the orbiter during a mission is calculated as the sum of the amp-hours from each individual fuel cell. The amp-hours supplied by each fuel cell are calculated every 6 seconds. The amp-hours are calculated using the fuel cell amps multiplied by the time interval. This calculation is done for each fuel cell, and the result is added to the previous amp-hour value stored. The total orbiter amp-hours are the sum of all three fuel cells.

$$\begin{aligned} AmpH_1 &= AmpH_{1L} + (t - t_L)(Amp_1 + Amp_{1L})/2 \\ AmpH_2 &= AmpH_{2L} + (t - t_L)(Amp_2 + Amp_{2L})/2 \end{aligned}$$

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$$\text{AmpH}_3 = \text{AmpH}_{3L} + (t - t_L)(\text{Amp}_3 + \text{Amp}_{3L})/2$$

$$\text{AMP-H}_T = \text{AmpH}_1 + \text{AmpH}_2 + \text{AmpH}_3$$

where

t = Current time in decimal hours

t<sub>L</sub> = Time last valid computation was performed

AmpH<sub>1L</sub>, AmpH<sub>2L</sub>, and AmpH<sub>3L</sub> are the values stored last time comp was performed

AmpH<sub>1</sub>, AmpH<sub>2</sub>, and AmpH<sub>3</sub> is the amp-hour comp at the current time

AMPH - W04I1044C

- M. Potassium hydroxide average concentrations (KOH IN/OUT AV) - The KOH average concentration is calculated as an average of 26 samples taken over a 5-minute period (i.e., approximately 1 sample every 12 seconds); this is a default sample rate that can be changed by sending new comp constants (refer to the comp constant CSA). The value is continually updated averaging the instantaneous KOH over the previous 5 minutes.

FC1	KOH IN AV - W01I1601C	OUT AV - W04I1601C
FC2	KOH IN AV - W02I1601C	OUT AV - W05I1601C
FC3	KOH IN AV - W03I1601C	OUT AV - W06I1601C
	SAMPLES - W09I1601C	MIN - W07I1601T

The instantaneous KOH IN/OUT concentration is a detailed computation that is dependent upon several other parameters. Input parameters for the equations are shown in Table 7.2.7-1.

**Table 7.2.7-1. Input parameters for calculating KOH IN/OUT concentration**

Input variables	Identification	Operational flight measurement numbers for fuel cells 1,2,3 or other data sources
TCE	Condenser exit temperature, °F	V45T0130A, 0230A, 0330A
TCOOL1	Stack coolant inlet temperature, °F	SODB: P.4.4.1-3
TCOOL2	Stack coolant exit temperature, °F	V45T0120A, 0220A, 0320A
AMPS	Fuel cell current, amperes	V45C0101A, 0201A, 0301A
CFM	Hydrogen pump flow rate, ft <sup>3</sup> /min	SODB, P.4.4.1-2
PCOOL	Coolant pressure, psia	V45P0147A, 0247A, 0347A

## Equations

If  $TCE < 32$ , then  $TCE = 32$

$$S1 = (TCE - 32) / 1.8$$

$$S2 = 654.291 / (S1 + 266.788)$$

$$S3 = \text{LOG}_e(2 * S2) / 2.30259 - (0.25/S2^2) - (0.9375/S2^4) - (0.5208/S2^6) - (0.34179/S2^8)$$

$$S4 = -1.87 + (3.74 * (1.15239 - 0.74579S3))$$

$$S5 = (S4^2 * ((1.87^2 - S4^2) / (0.30232 + (0.30232 * 0.0033775 * S1)))$$

$$X1 = 0.01(S1 - 187)$$

$$X2 = (0.015 * 3^X) / 1.87^3$$

$$X3 = (X1 - 0.01S5) * (1.87^2 - (X1 - 0.01S5)^2)$$

$$X4 = X2 * X3$$

$$X5 = 4.16385 * (S1 - 187) / (S1 + 237.098)$$

$$Y1 = 10 ** ([1.06425 + X5 - 1.01379 * (1 + (S1 * 0.000583531)) * X4])$$

$$PH201 = Y1 * 14.696$$

$$TCER = TCE + 459.69$$

$$RH201 = PH201 * 100.75 * CFM / TCER$$

$$RH20P = 0.0237 * AMPS$$

$$RH202 = RH201 + RH20P$$

$$RHYC = RH20P / 8.94$$

$$PT = PCOOL - 4$$

$$RHY1 = 11.274 * CFM * (PT - PH201) / TCER$$

$$RHY2 = RHY1 - RHYC$$

$$PH202 = PT * RH202 / (RH202 + (8.94 * RHY2))$$

Subroutine "CONCEN" which follows has input arguments TCOOL and PH20. The output is CON.

Perform "CONCEN with: TCOOL = TCOOL1 and PH20 = PH201  
Final output: CON = CON1 = inlet KOH concentration

Perform CONCEN a second time with: TCOL = TCOOL2 and PH20 = PH202  
Final output: CON = CON2 = outlet KOH concentration  
Average concentration: CAVE = (CON1 + CON2) / 2

**Subroutine "CONCEN"**

$$M1 = 11.77 + (7006.1 * 0.0003775)$$

$$M2 = 11.77 / 7006.1$$

$$M3 = (1 / M2) - 383$$

$$M4 = \text{LOG}_e(\text{PH20} / 14.696)$$

$$M5 = 1 / (\text{TCOOL} + 383)$$

$$M6 = ((M4 - 11.77) / (-7006.1) - M5) / (1 - M4/M1)$$

$$X11 = M2 - M6$$

$$X12 = (1/X11) - 383$$

$$X13 = X12 - M3$$

$$T = X13 / 1.8$$

$$A1 = T^2 * (-0.000001222208)$$

$$A2 = T * (-0.00009144755)$$

$$A3 = T^2 * 0.0002342567$$

$$A4 = T * (-0.004398145)$$

$$AX1 = A1 + A2$$

$$AX2 = A3 + A4 - 0.1201025$$

$$AX3 = A5 + T$$

$$D1 = AX2^2 - (4 * AX1 * AX3)$$

$$\text{CON} = (-AX2 - D1^{1/2}) / (2 * AX1)$$

## NOMENCLATURE

AMPS	Fuel cell current, amperes
CFM	Hydrogen pump flow rate
C1	KOH concentration at stack inlet, percent
C2	KOH concentration at stack exit, percent
CAVE	Average stack KOH concentration, percent
RH20P	Water generation rate in stack, lb/hr
RH201	Water vapor flow rate at stack inlet, lb/hr
RH202	Water vapor flow rate at stack outlet, lb/hr
RHYC	Hydrogen consumption rate in stack, lb/hr
RHY1	Hydrogen flow rate at stack inlet, lb/hr
RHY2	Hydrogen flow rate at stack exit, lb/hr
PCOOL	Coolant pressure, psia
PH201	Water vapor partial pressure at stack inlet, psia
PH202	Water vapor partial pressure at stack outlet, psia
PT	pcool minus 4.0, psia
TCE	Water vapor emperature at condenser exit, °F
TCER	TCE, °R
TCOOL1	Coolant temperature at stack inlet, °F
TCOOL2	Coolant temperature at stack outlet, °F

## Title

### **SOCRATES OPS NOTES**

## Purpose

This SCP describes some of the basic functions of the SOCRATES application and provides operational notes for use on console during mission support. This SCP also provides a section that outlines the steps required to delete bad data points from the SOCRATES Real Time History program.

## SOCRATES Basics

Software for Orbiter Consumables in Realtime for Atmospheric, Thermal, and Electrical Systems (SOCRATES) is a set of software tools. These tools are for EECOM and EGIL flight controllers to use on console for real-time orbiter electrical and environmental consumables management and for preflight analysis. The modeling tools allow the flight controllers to change initial parameters and reschedule events that affect the results of simulation models which project consumables usage. The simulation's results can be compared to the results from the preflight analysis and to the real-time consumables data from the vehicle. Data for different "what if" scenarios may be generated for mission analyses, decision making, and planning.

Some of these SOCRATES software tools have additional features to automate routine reporting tasks such as production of the Projected Consumables Margins or Mass Properties.

The SOCRATES user applications consist of one or more underlying programs. The common elements include the programs for the manipulation of timeline data, the acquisition of real-time data, and the generation of output plots and tables. Each of the simulation models can take advantage of outputs from the other models to improve the accuracy of their results.

## Logon

To access SOCRATES, users must log in to the MCC workstation. Once logged in, execution of SOCRATES applications may be invoked via EGIL/EECOM Applications pulldown menu.

## Real-Time Data Management

The realtime data acquisition consists of the real-time history process (rt\_manager/rt\_history). The rt\_history process reads the data made available from the ISP server and stores the data in the proper actual data files. There is an actual data file for the application mission called "realdata.raw". The rt-history process is started via

the RT-Manager application off the EGIL applications pulldown, and the data will be recorded in the SOCRATES mission that RT-Manager is started in.

### **The Timeline**

The SOCRATES timeline is simply a file containing information about a mission event at a given time. Each event has a start time and may also have additional information. The timeline file is edited via the Timeline Editor (TLEDIT). The timeline editor is available in most SOCRATES applications under the “Edit” pull down menu. Note: the timeline file is a binary file and cannot be manipulated like an ascii file.

### **EPRAM and CRYSP**

The EPRAM Application is a software tool to aid EGIL flight controllers in performing EPS analyses. It provides the user with the capability to manipulate the timeline (using the timeline editor or TLEDIT), to set parameters for the mission, to monitor real-time data, and to generate the EPS PCM form. Moreover, this tool is a menu-driven front-end for executing the electrical and cryogenic model programs, which are called the EPRAM and the CRYSP programs, respectively. The EPRAM program computes the power needs of the EPS, based on the status of components and fuel cells. CRYSP models the PRSD system and computes cryogenic tank quantities and pressures and tank heater powers.

### **Minimal Inputs for EPRAM/CRYSP**

The following paragraphs describe the minimal inputs required to execute the model programs, EPRAM and CRYSP.

- Before running EPRAM
  - Schedule at least one electrical component or EPRAM activity in the timeline using TLEDIT and one electrical component at analysis stop of zero power.
  - Schedule touchdown, EOM, or Analysis Stop in the timeline using TLEDIT.
- Before running CRYSP
  - Check and correct (if necessary) the following values in the Initial Values Window:
    - Crew O2 usage and cabin leakage.
    - Number of cryogenic H2 tanks.
    - Number of cryogenic O2 tanks.
  - Schedule at least one CRYSP reset tank event (to load the cryogenic H2 and O2 tanks) in the timeline using TLEDIT at or before liftoff.

- Schedule at least one CRYSP system reconfiguration event (to configure cryo heaters and manifolds) in the timeline using TLEDIT.
- Schedule touchdown, EOM, or Analysis Stop in the timeline using TLEDIT.

### **Minimal Procedure for Generating the PCM Form**

The following bullet items describe the minimal procedure required to generate the EPS PCM Form.

- Run the EPRAM model and the CRYSP model.
- You must schedule Deorbit TIG.
- Schedule touchdown, EOM, or Analysis Stop in the timeline using TLEDIT. EOM is preferable.
- Schedule and timeline the two extension days electrically along with the 2 extension day TIGs.
- Complete the PCM Input Window. This window is obtained by selecting the Output option from the main menu bar of the EPRC Application. Then, select PCM Output in the pulldown menu that is displayed.

### **SOCRATES Ops Notes and Workarounds**

The following sections describe unique procedures for the various SOCRATES applications. Some of these procedures may be temporary workarounds. The following procedures are for all SOCRATES applications.

- To properly output Real-Time data, liftoff GMT must be a time that is consistent with the mission data.
- For model calculations to perform as expected, any time a change is made to the application's Initial Values or Timeline events affecting model output, the 'Run' option must be re-invoked.

### **EPRAM / EPRAM**

- When a new mission is created and initial data is entered manually, the vehicle configuration is not saved and the O2 cabin leak rate is not saved. The cabin leak rate goes back to the default rate for that vehicle and the configuration remains with nothing checked. Workaround: These values can still be changed and saved in the Edit Initial Values option, but this must be done after the mission has been created. This problem does not affect the overall accuracy of the model.



- The Analysis Stop event must be scheduled at least 6 seconds after the EOM event, or the Budget Tables may not reflect cryo usage for descent and postlanding.
- Selecting "Cancel" at the end of an EPRAM run still replaces one of the output files, so your Component Timeline tabular listing will show results from the cancelled model run. The Component Status results and Component/Subsystem plots are not affected, nor are any other calculations or outputs.
- If a Heater Block is scheduled to start during an OMS B Heater block, the OMS B block (appropriate for the new attitude) must be scheduled again 1 second after the Heater Block to avoid double-bookkeeping 4 heaters.
- Because there are only a few choices of OMS B Heater blocks, it may be necessary to perform a case-level edit of the OMS B block used. This is because the end list of the OMS B block turns on 4 A heaters which were turned off by the start list. However, the duty cycle that the end list turns them on at may be much higher or lower than the currently-scheduled orbiter heater block. For long missions and/or missions with tight margins, the total error may be significant.
- For the new default FC degradation of 65%, select Curve 13 and edit the first field to 32.35, and change the description from STD13 to 65PCT to indicate that you have modified one of the standard curves. The first coefficient needs to be edited because Curve 13 does not equate to an exact 65% degradation.
- **Budget Tables / Summary Chart -**
  - For an additional day mission, if any O2 leakage is timed over that day (e.g. EVA), the budget table (in EPRAM Version 5) will double-bookkeep the leakage.  
Workaround:
    1. Delete the additional day flag from the timeline.
    2. Generate the O2 budget table. Print the O2 budget table to save a record of the O2 usage factor.
    3. Replace the additional day flag in the timeline.
    4. Calculate the leakage over the additional day and subtract it from the Other O2.
    5. Generate the budget tables.
    6. Add the leakage (over the additional day) back into the Other O2.
    7. Replace the O2 usage factor with the correct usage factor obtained in Step 2.
    8. Generate PCM.
    9. Open the saved O2 budget table in a text editor and edit the usage factor, changing it to the correct usage factor obtained in Step 2.
  - Budget table notes need to be changed to reflect 2-1-1 or 2-2-2 deorbit opportunities
  - Double-check the mission requirements in pounds calculation
  - On all charts, change the analysis date year field from 102 to 2002

- **PCM** - When the margins go negative, the results are not rounded correctly and the extension day margin numbers are not correct. When calculating the margins in times, all results should be rounded down to the Integer hour. This works for positive numbers but not for negative numbers.
- **Mass Properties** -
  - **!! WARNING !!** If a period is used as a separator for time input, the wrong data is given for the intended timepoint.
  - In EPRAM Version 5, the window recalculates the Mass properties every time you move the mouse in and out of the window. Workaround: Enter time and hit the Tab key.
- If a mission name is longer than 13 characters, trying to create a Summary Table with EPRAM will cause EPRAM (Version 5) to segment abort.
- When you select File → Print and choose the Local option from the print menu, this action will print the file you select – however, it will also kill the EPRAM application. Current work around is to restart EPRAM (or just specify a named printer other than “Local”)

## CRYSP

- Selecting "NO" when a tank reaches residuals and asks for a reset will result in a segment abort and CRYSP will go away.
- **Cryo Tanks Reset EDO** – In some cases the EDO boiloff will not be modeled or calculated correctly on the budget tables, even though the correct pressures are specified in the reset event. Increase the pressure (ex. O2 from 900 to 905 psi) in the reset event and re-run CRYSP.

## TLEDIT

- As a statement of clarification, the retrieve option for TLEDIT does not retrieve a new Mission/Case. It simply loads the timeline for the selected Mission/Case into the TLEDIT memory. When the timeline file is saved, it is saved under the Mission/Case that was established by the calling SOCRATES application. Basically, the TLEDIT retrieve operation provides a capability to copy a timeline file from another Mission/Case to the current Mission/Case.
- **!! WARNING !!** Merging another timeline will always overwrite the current case saved timeline.
- User cannot modify or copy a group of events highlighted by using the Search All feature.
- The number of H2/O2 tanks specified in the "crysp.init" file in the case directory, if the file exists, will always override the number of tanks specified in the Initial Values

for that case, when there is a disagreement between the two numbers. This results in TLEDIT presenting too many or too few tanks for Cryo Reset and Cryo System Reconfig events. Delete the "crysp.init" file and re-start TLEDIT to correct the problem. The file will be re-created with the correct numbers from the Initial Values the next time that EPRAM invokes CRYSP.

## THORTIF

- **!! WARNING !!** If the Restart button is selected, the user must exit THORTIF and bring it back up or unexpected results will happen.
- If selecting a parameter and then which phase for that parameter (i.e. Actual, Projected, Preflight), and then selecting "Add", the last parameter selected is added. The user has to select the parameter again after selecting the phase, then click Add.
- The interface does not allow GMT to cross from the end one year to the beginning of the next.
- Sometimes zooming into a plot into a very small area will show unpredictable results based on the number of plot points in the data file provided. User can zoom back out by pushing the center mouse button.
- Occasionally THORTIF will just vanish. Workaround: Have to just restart it.

## **SOCRATES Tips**

Miscellaneous help information for TLEDIT, EPRAM, and ECLSS.

### **Selecting Items From a List**

There are two types of lists, one allows only a single selection, while the other allows multiple selections.

To select an item from any list, you press the left mouse button and release it. If the list allows multiple selections you can drag the mouse while holding the left button down and select a range of items. You can also select a range of items by selecting the first item, then while pressing both the 'Ctrl' and 'Shift' keys simultaneously select the last item in the range.

You can select several non-contiguous items in a list by selecting the first item, and then while holding the 'Ctrl' key down select each of the remaining items you want selected in the list.

## **TLEDIT Tips**

### **LOCK Files**

The Timeline Editor creates a lock file to protect against two users overwriting each others timeline files. This dialog will allow a user to become the new owner of the lock file in the current case. The original owner will still be able to save the timeline in the current case, possibly replacing the timeline file saved by the new owner or vice versa. Always notify the original owner identified on the dialog when you override the protection.

### **RELOAD Warning**

The current timeline in memory has been changed. If reloaded the last saved timeline will be read in from the timeline file and overwrite the changes in memory. If this is ok then continue with the operation, otherwise cancel and save the timeline before reloading.

### **ATL File Selection**

Select an ATL 2 file to merge in with the current timeline. The existing Attitudes and Orbital Manuevers will be removed from the current timeline and replaced with those in the ATL 2 file.

## **SOCRATES TIMELINE SELECTION**

Select a SOCRATES timeline to merge in with the current timeline.

## Last Used Files

The Timeline Editor reads the EPRAM last used file when it is first started and each time the [Re-Load](#) option is used. The last used file contains initialization parameters for TLEDIT, such as the number of crew, the number of O2 and H2 tanks, etc. of the current Case.

## EPRAM Tips

### Running the EPRAM Model

Before running the EPRAM model program, the user may use the Component Timeline option to view the times a component is scheduled in the timeline. This may be helpful in preventing the double scheduling of a component.

After the EPRAM model program is run, the user may use the Component Status option to view a "component snapshot" at a certain time. The component snapshot provides the status of all the components that have a non-zero power. This will provide an approximate breakdown of the power requirements at the designated time.

## DELETING A BAD DATA POINT IN SOCRATES REAL TIME HISTORY

### Purpose

This brief describes the procedures required to delete a bad data point(s) from the Socrates Real Time History program.

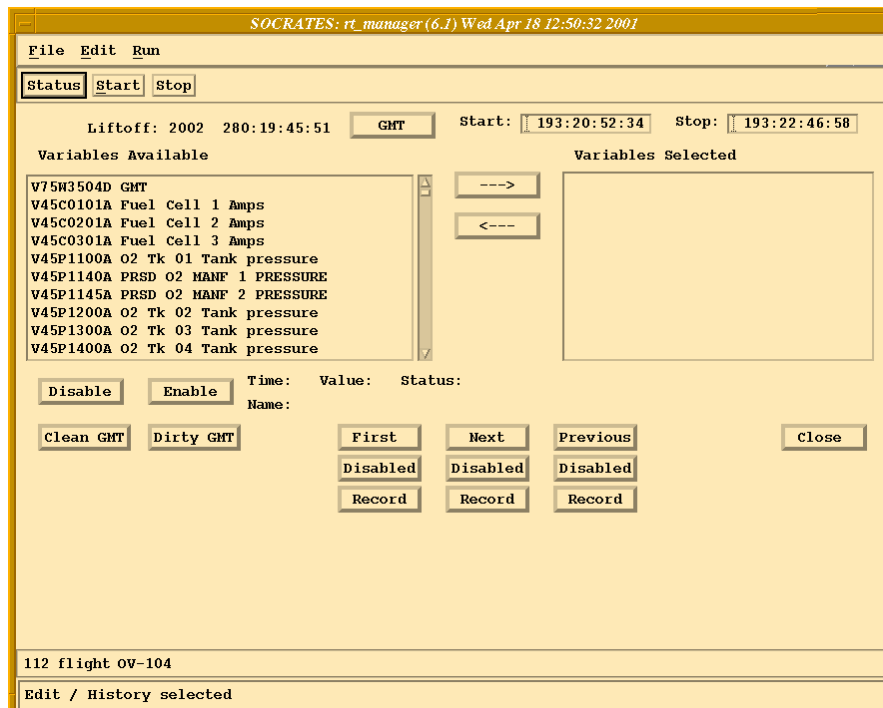
### Procedure

Often times during a mission, bad data points from ratty data are pulled into the Real Time History program. The data that is pulled into the Real Time History program is used by the Socrates Electrical Power Reconfiguration and Cryogenics (EPRAM) analysis model. This bad data corrupts the EPRAM analysis model and has to be deleted.

1. Retrieve the mission elapsed time (MET) of the bad data point from the SOCRATES real-time data by using the THORTIF application. Bad data points will show up as an unexpected flat line on a plot.
2. Locate RT\_Manager and open the program. On DNAV, click `**Applications / RT\_Manager**`. During a mission, RT\_Manager will always be running in the background. The standard configuration is for EGIL to run the RT\_Manager program up front with the Flight Specific Socrates case and for EPS to run an RT\_Manager backup format.
3. From the pull down menu, click `**File / Mission/Case**`.
4. Select the mission then press okay. For EGIL, select the `_asflown` case; for EPS, select the `asflown_backup` case. **Do not** select the **start** or **stop** button. This would stop recording the real-time data.
5. From the pull down menu, click `**Edit / History**`. (See Fig XXX: RT\_Manager History)
6. Resize the window so all of the buttons and windows are visible.
7. Change from GMT to MET by clicking on the box labeled GMT.
8. In the "Start Time" box, type in an MET time about a minute before the MET of the actual bad data point.
9. Select the parameter to be checked for a bad data point from the 'Variables Available' box (left box), and then click the right arrow button to send it to the 'Variables Selected' box (right box). This version (Version 6.1) of RT\_Manager will not delete all data from a specific MET at once. For each MET, every plotted parameter must be selected to have its data point evaluated and deleted. For example, Total KW must be selected as well as FC1,2,3 KW, FC AMPS, etc.
10. Click `**First**`. This will execute RT\_Manager to go the first data point from the MET time indicated in the "Start Time" box. At the bottom of the screen, the value of the selected data point is shown, which is on the real-time plot at the MET indicated. The bad data points typically have a value of 0 (zero). It also

shows the status of that data point (24 = good point). Do not use the status value as a good point, bad point indicator. If the first point is not the bad data point, click *Next*. The application will cycle through all the selected parameters for the current MET one at a time. Then it will cycle through all the parameters for the next MET.

11. Once the bad data point is found (indicated by the MET obtained from the SOCRATES real-time data or THORTIF plot application and the value of the parameter being out of family ), click **Disable** under the Variables Available box. This function will basically inhibit or hide this point (not delete it). After it is disabled , it will be indicated by the status value changing to a negative value (-24). To enable it or not hide it, click *Enable* . Repeat this for each bad parameter
12. It is also possible that a bad GMT is causing the bad data points. To disable bad GMT data points, click **Clean GMT**. This will disable all data points due to bad GMT.
13. Click **Close**. At this point, RT\_Manager can be minimized for later use.  
Note: Now that the changes have been saved to the file, the data can be re-plotted.
14. If this process does not disable the bad data point(s) in the SOCRATES plot, repeat the process.



**Figure 7.2.8-1: RT\_Manager History**

## TITLE

EGIL/EPS MCC DISPLAYS

## PURPOSE

The purpose of this brief is to provide flight controllers with a general knowledge of each of the Mission Control Center (MCC) displays used at the Electrical Generation and Illumination (EGIL) or Electrical Power System (EPS) console.

## DESCRIPTION

### A. EGIL\_FC\_EPDC

The EGIL\_FC\_EPDC display shown in Figure 7.2.9-1 is the primary high-density digital display used to monitor the space shuttle fuel cells and Electrical Power Distribution and Control (EPDC) subsystems. The display is separated into two vertical columns. The upper left column contains information about the vehicle's three distributed DC and AC electrical distribution systems and includes the following buses: main, forward, aft, control, essential, and AC. The lower left column provides insight into the Motor Control Assembly (MCA) status and the Environmental Control and Life Support (ECLS) rotating equipment. The upper right column contains information about the three fuel cells, including temperature, pressure, valve status, and purge operation. The lower right column provides status on the fuel cell water system and vehicle alarms.

7.2.9-1



FC_EPDC.msk									
OGMT 257/05:57:10					F/V 114 /104				
OMET 000/06:34:37					GN 22				
PASS MECO 00:01			OI TFL 199		MM PASS 201		SM 24		
BFS MECO D					MM BFS D		BF D		
DC -1/A- -2/B- -3/C-					TOTAL AMPS 498.0 KW 15.51				
FC KW 5.28 5.12 5.12						FUEL CELL -1- -2- -3-			
FC AMPS 170 164 164						STK OUT T 203 203 203			
FPC AMPS 83 73 113						STK IN T 182 182 182			
MPC AMPS 38 36 9						EXIT T 151 151 151			
APC AMPS 33 23 17						CL RTN T 70 70 70			
FC % LD 34.1 32.9 32.9						CL PRESS 62.0 62.0 62.0			
BUS TIE						CL PMP P			
FC VDC 31.0 31.2 31.2						H2 MTR 0.40 0.40 0.40			
MN VDC 31.0 31.0 31.0						O2 VLV			
FWD VDC 30.6 30.6 30.6						O2 FLOW 2.83 2.67 2.67			
AFT VDC 30.7 30.9 30.7						O2 CAL FL 3.58 3.45 3.45			
R SRB - DC D -/-						H2 VLV			
L SRB - DC D -/-						H2 FLOW 0.54 0.50 0.51			
ESS VDC 29.8 29.9 29.9						H2 CAL FL 0.45 0.44 0.44			
ESS RPC						1-2 2-3 3-1			
CNTL A B C A						AMPS 5 0 -5			
-1 29.3 29.3 29.3						VOLTS 0.12 0.23 0.23			
-2 29.3 29.3 29.3						SUBSTK 1 12 16 16			
-3 29.3 29.3 29.3						2 24 28 18			
-AC- -1- -2- -3-						3 16 20 20			
AMPS A 3.60 4.96 3.68						KOH IN AV 36.55 36.47 36.49			
B 3.44 4.64 3.76						OUT AV 36.33 36.38 36.42			
C 3.44 4.80 3.60						SAMPLES/MIN / 25.0 4.80			
VAC A 117.0 117.0 117.0						CNTLR PWR -- -- --			
B 117.0 117.0 117.0						READY -- -- --			
C 117.0 117.0 117.0						STRTUP HTR -- -- --			
INV/BUS A --/-- --/-- --/--						PRG SEQ -- -- --			
B --/-- --/-- --/--						VLV GP-- GP-- GP--			
C --/-- --/-- --/--						HTR GPC-- -- --			
SENSOR AUTO AUTO AUTO						O2 VLT 49			
O/L ----						H2 VLT-1 49			
O/UV ----						H2 VLT-2 49			
-MTRS- -AC1- -AC2- -AC3-						-WATER- -1- -2- -3-			
AV BAY 13.78 - B -						PH FC ---- ---- ----			
23.74 A -						H2O LN			
33.90 B -						SUP H2O P 32.8			
IMU FAN 4.56 - B -						ALT H2O P 34.2			
HUM SEP - B -						PRD H2O T 143 143 143			
CAB FAN 5.50 - A						ALT H2O T 90 79 90			
FRN LP 12189 - B -						RLF VLV T 77 77 77			
22258 B -						RLF LN T 70			
H2O LP 123 -G -- B-						RLF NOZ T 243 243			
262 -- ON						NOZ HTR STATUS -- --			
----- MCA STATUS -----						LN/RLF SW CONF A- A-			
FWD 1 ---- AFT 1 ----						MASTER ALARM-- --			
2 ---- 2 ----						ALERT B- -- -- D			
3 ---- 3 ----						BU C/W B- -- -- D			
MID 1 ---- AC --						ALERT A1 A2 A3 A4			
2 ----						.TONE -- -- --			
3 ----						.LIGHT -- -- --			
4 ----						BU C/W -- -- --			
Ver 2.0									

Figure 7.2.9-1. EGIL\_FC\_EPDC display

B. CRYO\_5TK\_ORB

The cryo 5 tank displays are the primary high-density digital displays used to monitor the space shuttle Power Reactant Storage and Distribution (PRSD), or cryogenic, system. The format shows a five-cryo-tank-set vehicle, which is the most standard configuration. Oxygen tanks are on top with the hydrogen tanks below. Information on each tank set includes pressure sensors, heater and fluid temperatures, heater ON discrete, tank quantities, and current level-detector trip status for oxygen tanks. The lower left corner of the display includes information about the payload bus configuration (see Figure 7.2.9-2).

CRYO_ORBIT.msk						
F/V 114 / 104		OGMT 256/23:20:25		OMET 256/23:20:25		
CRYO O2	1	3	4	5	2	
TANK P	950	950	950	950	950	
CNTL P	949	951	951	951	949	
MANF P-VLV	950	- OP		OP		- 950
PCS VLV/P	OP / 948					OP / 948
Q(%)	99.6	99.6	99.6	99.6	99.6	
FLUID T	-250	-250	-250	-250	-250	
HTR 1 T	-250	-257	-257	-257	-250	
HTR 2 T	-250	-257	-257	-257	-250	
HTR A1/B1	-- /--	-- /--	-- /--	-- /--	-- /--	
HTR A2/B2	-- /--	-- /--	-- /--	-- /--	-- /--	
SNSR 1 A/B	- / -	- / -	- / -	- / -	- / -	
SNSR 2 A/B	- / -	- / -	- / -	- / -	- / -	
HTR SW A	-- AUTO	-- ----	-- ----	-- ----	-- AUTO	
HTR SW B	-- ----	-- ----	-- ----	-- ----	-- ----	
CRYO H2	1	3	4	5	2	
TANK P	249	249	249	249	249	
CNTL P	249	249	249	249	249	
MANF P-VLV	248	- OP		OP		- 248
Q(%)	99.3	99.3	99.3	99.3	99.3	
FLUID T	-416	-416	-416	-416	-416	
HTR T	-416	-416	-416	-416	-416	
HTR A/B	-- /--	-- /--	-- /--	-- /--	-- /--	
HTR SW A	-- AUTO	-- ----	-- ----	-- ----	-- AUTO	
HTR SW B	-- ----	-- ----	-- ----	-- ----	-- ----	
PAYLOAD POWER			TOTAL: O2 3890.21		KW-H 18.61	
FC3	MNA	MNB	MNC	H2 456.56		AMP-H 600.48
PRI	--	--	--	CABIN P	14.7	-1- -2-
AUX	--	--	--	AIRLOCK P	0.2	EMU VOLTS 0.0 0.0
CABIN	--	--	--	CABIN A/L dP	0.0	AMPS -0.22 -0.22
AFT P/L	--	--	--	CABIN dP/dT	0.0	
AFT AMPS		0.0	0.0	PPO2 A	3.2	EVAP OUT T 41 41
AFT KWH		0.00	0.00	B	3.2	
PL/MNC GND			MNC	C	3.2	
				EVLS PRESS	948	
Ver 2.0						

Figure 7.2.9-2. CRYO\_5TK\_ORB display

C. CRYO\_5TK\_ASC

This display, shown in Figure 7.2.9-3, is very similar to the five-tank orbit display, with minor changes. The top of the display has a discrete for abort sites and shows the time to Main Engine Cutoff (MECO). Information about Ground Support Equipment (GSE) O<sub>2</sub>/H<sub>2</sub> supply is provided in the bottom right quadrant. Data used during Extravehicular Activities (EVAs), such as Extravehicular Mobility Unit (EMU) pressure and airlock pressure, are not found on this display. This display is used only during ascent and entry.

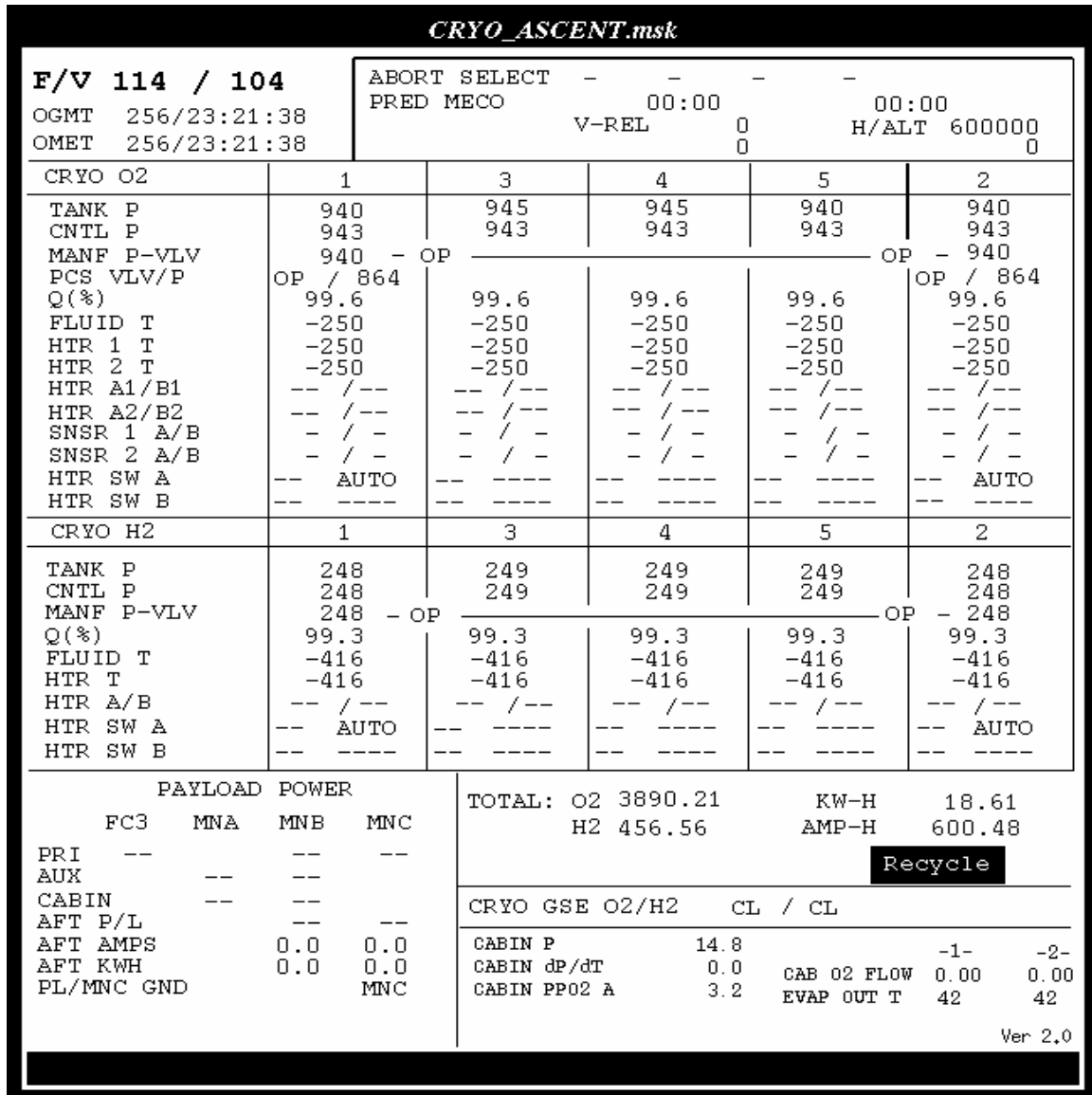


Figure 7.2.9-3. CRYO\_5TK\_ASC display

D. CRYO\_5TK\_APCU

Figure 7.2.9-4 is similar to the five-tank orbit display, with one addition. The bottom of the display includes Assembly Power Converter Unit (APCU) information (converter-out amps, temperatures, and voltages).

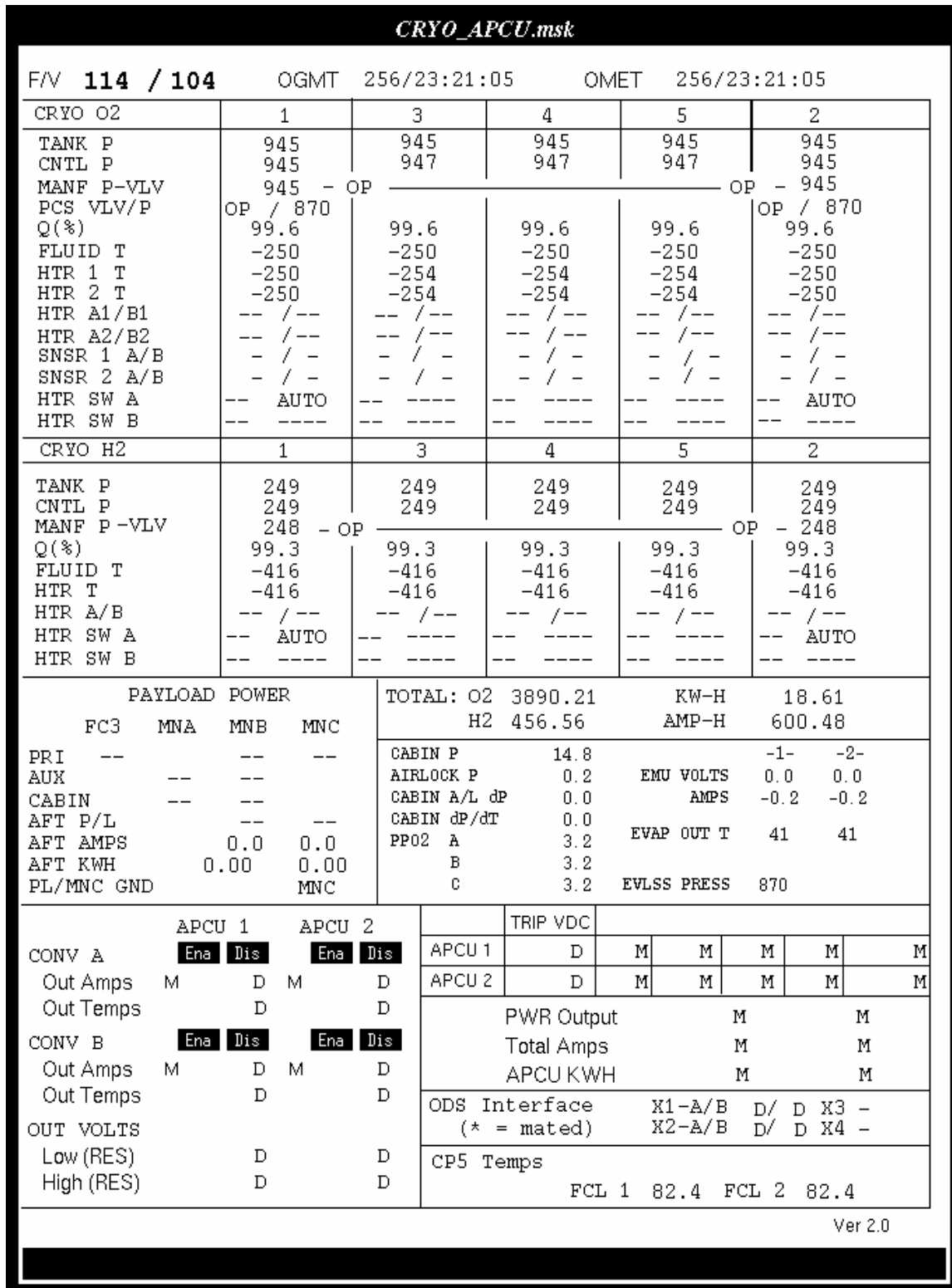


Figure 7.2.9-4. CRYO\_5TK\_APCU display

The CRYO\_5TK-APCU display also shows APCU trip status, total power draw, an energy computation for kWh, status of the Orbiter Docking System (ODS) interface, and Freon loop temperatures.

E. Systems\_Configuration

The Systems\_Config display (Figure 7.2.9-5) is used primarily during powerdowns and powerups. The display pulls in telemetry from a variety of systems for EGIL to reference. The status of orbiter equipment provides insight into orbiter power levels and can be used to determine when a procedure has been completed.

SYSTEMS_CONFIG.msk																		
OGMT	256/23:18:49	MM PASS	101	SYSTEMS CONFIGURATION					SITE TDR	OI	129	SM	D					
OMET	256/23:18:49	MM BFS	101						GN	21	BF	12						
-GNC-				-INCO-				-MMACS-				-PDRS-						
TACAN	ON	ON	ON	NSP	1	MN	A	B	C	BRAKES	A	B	C	RMS PWR	PRI	---		
RA	ON	ON	ON	2						PWR	ON	ON	ON	B/U	---			
MLS	-	-	-	PCMMU	1	ON	*		*	CA RPC	ON	ON	ON	MCIU I/O		D		
IMU PWR SW	ON	ON	ON	2						BC RPC	ON	ON	ON	EE MODE		D		
IMU A	ON	ON	ON	PWR AMP	1	-	-	-	-	ANTISKID	ON			HTR A		D		
IMU B	ON	ON	ON	2						CIRC PUMP	1	-	-	76		---		
IMU C	ON	ON	ON	MSTR	MADS	PWR	-			3	-	-	-	76		---		
IMU OPER	OPER	OPER	OPER							-APU-	-1-	-2-	-3-					
RG A PWR	ON	ON	ON	-DPS-				TK/PU LN	-	-	-	-	-					
RPC A	ON	ON	ON	GPC	1	RUN	ON	ON	ON	LUBE OIL	-	-	-	-				
B	ON	ON	ON	2	RUN	ON	ON	ON	ON	GG/PU PMP	-	-	-	-				
C	ON	ON	ON	3	RUN	ON	ON	ON	ON	MECH PWR	1	---	---					
AA PWR SW	ON	ON	ON	4	RUN	ON	ON	ON	ON	2	---	---	---					
AA RPC A	ON	ON	ON	5	M	ON	ON	ON	ON	-EECOM-								
B	ON	ON	ON	BFC/CPU	1A	ON	ON	ON	ON	HI LD DT	A	-	-	-SMOKE ALM CONC-				
C	ON	ON	ON	1B	ON	ON	ON	ON	ON	TOP DUCT	A	-	-	BAY 1A	---	361.1	0.0	FUL
ASA PWR SW	ON	ON	ON	2A	ON	ON	ON	ON	ON	TOP NZ L	A	-	-	B	---	293.7		
RPC A	ON	ON	ON	2B	ON	ON	ON	ON	ON	R	A	-	-	2A	---	113.7	0.0	FUL
B	ON	ON	ON	3A	ON	ON	ON	ON	ON	FDLN PRI	A/B	-	-	B	---	401.6		
C	ON	ON	ON	FF	1	ON	ON	ON	ON	SEC	A/B	-	-	3A	---	378.7	0.0	FUL
ATVC PWR	ON	ON	ON	2	ON	ON	ON	ON	ON	PRI	A	-	-	GPC	---	378.7		
RPC A	ON	ON	ON	3	ON	ON	ON	ON	ON	B	-	-	-	B	---	249.9		
B	ON	ON	ON	4	ON	ON	ON	ON	ON	NH3	1	-	-	LFDK	---	113.7		
C	ON	ON	ON	FA	1	ON	ON	ON	ON	2	-	-	GPC	RFDK	---	394.3		
ADTA	ON	ON	ON	2	ON	ON	ON	ON	ON	GALLEY OVEN	-	-	-	CABIN	---	351.5		
DDU	-A-	-B-	-C-	3	ON	ON	ON	ON	ON	H2O HTR	-	-	-					
L *	ON	ON	ON	4	ON	ON	ON	ON	ON	GALLEY SUP V	CL							
R *	ON	ON	ON	PL	1	ON	ON	ON	ON	AV BAY 1 AIR	T99.8							
A -	-	-	-	2	ON	ON	ON	ON	ON	2	95.8							
STAR TKR	-Y	-	-	MMU	1	ON	ON	ON	ON	3	84.2							
-Z	-	-	-	IDP/CRT	1	ON	ON	ON	ON	CABIN T	70.5							
COAS PWR	-	-	-	2	ON	ON	ON	ON	ON	-FC H2O PROD-								
-PROP-				3	ON	ON	ON	ON	ON	FC KW	-1-	-2-	-3-	15.1				
-1A-	-1B-	-2A-	-2B-	4	ON	ON	ON	ON	ON	TOT KW	6.51	6.36	6.70					
RJDf-				-BITE INDICATIONS-														
LGC	ON	ON	ON	DSC OF	1	-	-	-	-	MDM OF	1	-	-	-	-	-	-	-
DRVR	ON	ON	ON	2	-	-	-	-	-	MDM OF	2	-	-	-	-	-	-	-
RJDA-				3	-	-	-	-	-	MDM OF	3	-	-	-	-	-	-	-
LGC A	ON	ON	ON	DSC OM	1	-	-	-	-	MDM OF	4	-	-	-	-	-	-	
B	ON	ON	ON	2	-	-	-	-	-	DSC OM	2	-	-	-	-	-	-	
C	ON	ON	ON	3	-	-	-	-	-	DSC OM	3	-	-	-	-	-	-	
DRVR A	ON	ON	ON	DSC OA	1	-	-	-	-	MDM OA	1	-	-	-	-	-	-	
B	ON	ON	ON	2	-	-	-	-	-	MDM OA	2	-	-	-	-	-	-	
C	ON	ON	ON	3	-	-	-	-	-	MDM OA	3	-	-	-	-	-	-	
OMS POD L	A/B	---	---															
R	A/B	---	---															
FWD RCS	A/B	---	---															
XFD LINES	A/B	AUTO/	AUTO															

Figure 7.2.9-5. Systems\_Config display

F. EGIL Pyro

The EGIL pyrotechnic display (Figure 7.2.9-6) shows pyrotechnic indications for the Solid Rocket Boosters (SRBs), landing gear, Remote Manipulating System (RMS), and Ku jettison function. The lower center column contains smoke concentrations throughout the avionics bays. The right column displays range safety information. This display is used primarily during ascent and entry phases of flight.

PYRO.msk											
F/V 114 / 104			SHUTTLE PYROTECHNIC								
OGMT	256/23:22:23	OMET	256/23:22:23	OI	129	GN	21	SM	D		
-SRB PIC V-	L	R	-LANDG GEAR-	A	B	RANGE SAFETY			SRB/ET		
IGNITION A	37.7	37.7	NLG EXT	0.0	0.0	LH A LH B RH A RH B			BAT V 0.0 0.0		
IGNITION B	37.7	37.7	NLG DPY	0.0	0.0	BAT C 0.00 0.00			RCVR S 0.0 0.0 0.0 0.0		
FWD SEP A	0.0	0.0	LMG DPY	0.0	0.0	DCDR P OFF OFF OFF OFF			PIC V 0.0 0.0 0.0 0.0		
FWD SEP B	0.0	0.0	RMG DPY	0.0	0.0	ARM CMD --- NLG tb UP			DWN CMD --- RMG tb UP		
AFT U SEP A	0.0	0.0	PORT RMS JETT A B			INHIB --- --- --- ---			ARM --- --- --- ---		
AFT U SEP B	0.0	0.0	SHLDR GUILL	0.0	0.0	FIRE --- --- --- ---			S/A --- --- --- ---		
AFT M SEP A	0.0	0.0	F LAT GUILL	0.0	0.0	ET TUMBLE ARM CMD ---					
AFT M SEP B	0.0	0.0	M LAT GUILL	0.0	0.0						
AFT L SEP A	0.0	0.0	A LAT GUILL	0.0	0.0						
AFT L SEP B	0.0	0.0	SHLDR RETEN	0.0	0.0						
F SEP MTR A	0.0	0.0	F BLT RETEN	0.0	0.0						
F SEP MTR B	0.0	0.0	M BLT RETEN	0.0	0.0						
A SEP MTR A	0.0	0.0	A BLT RETEN	0.0	0.0						
A SEP MTR B	0.0	0.0	P RMS-GLTN	---	JETT						
SRB DISCRETES	L	R									
IGN S&A ARMD	ARM	ARM									
IGN S&A SAFE	---	---									
SRB RECOVERY	L	R	--KU JETT--	A	B						
NOSE CAP PIC	0.0	0.0	GLTN CAP V	0.0	0.0						
FRM SEP PIC	0.0	0.0	BOLT CAP V	0.0	0.0						
NOZL SEV PIC	0.0	0.0	KU JETT ARM	----							
MN CHUTE PIC	0.0	0.0									
BATT CURRENT	H H										
BATT TEMP	59	59									
BATT VOLTS	32.0	32.0									

Figure 7.2.9-6. EGIL pyro display



G. EGIL\_APCU

The EGIL\_APCU display (Figure 7.2.9-7) is identical to the bottom section of the CRYO\_5TK\_APCU display.

<i>APCU.msk</i>											
		APCU 1		APCU 2		STS-114 / OV-104				Ver 2.0	
CONV A		Ena	Dis	Ena	Dis	OGMT: 256/23:23:08					
Out Amps	M	D	M	D	OMET: 000/00:00:35						
Out Temps		D		D	TRIP VDC						
CONV B		Ena	Dis	Ena	Dis	APCU 1	D	M	M	M	M
Out Amps	M	D	M	D	APCU 2	D	M	M	M	M	M
Out Temps		D		D	PWR Output		M		M		
OUT VOLTS					Total Amps		M		M		
Low (RES)		D		D	KWH		M		M		
High (RES)		D		D	ODS Interface X1-A/B D/ D X3 - CP5 Temps						
	(* = mated)	X2-A/B	D/ D	X4 -	FCL 1 82.8 FCL 2 82.8						

Figure 7.2.9-7. EGIL\_APCU display

H. EGIL Comp Constants

Figure 7.2.9-8 shows the current values for EGIL comp constants.

```
compconst.msk
OGMT 256/23:24:24      EGIL COMP CONSTANTS
OMET 000/00:01:51

FUEL CELL delta V
W01G1044M FC1 Const 1      32.51907000000
W02G1044M FC1 Const 2     -0.01081172000
W03G1044M FC1 Const 3      0.00000820000
W04G1044M FC1 Const 4      0.00000000000
W05G1044M FC2 Const 1      32.51907000000
W06G1044M FC2 Const 2     -0.01081172000
W07G1044M FC2 Const 3      0.00000820000
W08G1044M FC2 Const 4      0.00000000000
W09G1044M FC3 Const 1      32.51907000000
W10G1044M FC3 Const 2     -0.01081172000
W11G1044M FC3 Const 3      0.00000820000
W12G1044M FC3 Const 4      0.00000000000

AC % LOAD
W01I1011M AC % LOAD CONSTANT  6.7

FC ADDITONAL CONSTANTS
W01I1009M CRYO O2 CONSUMPTION      M
W01I1010M CRYO H2 CONSUMPTION      M
W01I1600M FC1 COOLANT FLOW (CFM) 10.500
W03I1600M FC2 COOLANT FLOW (CFM) 10.500
W05I1600M FC3 COOLANT FLOW (CFM) 10.500

CRYO
W01I1023M O2 Conv Factor 1      M
W02I1023M O2 Conv Factor 2      M
W03I1023M O2 Conv Factor 3      M
W04I1023M O2 Conv Factor 4      M
W05I1023M O2 Conv Factor 5      M
W06I1023M O2 Conv Factor 6      M
W01I1024M H2 Conv Factor 1      M
W02I1024M H2 Conv Factor 2      M
W03I1024M H2 Conv Factor 3      M
W04I1024M H2 Conv Factor 4      M
W05I1024M H2 Conv Factor 5      M
W06I1024M H2 Conv Factor 6      M
W01I1025M CRYO O2 TKS SELECTED  248
W02I1025M O2 Tk Bias MED      M
W03I1025M EDO O2 TKS SELECTED  0
W01I1026M CRYO H2 TKS SELECTED  248
W02I1026M H2 TK Bias MED      M
W03I1026M EDO H2 TKS SELECTED  0

KOH STUFF
W08I1601M Max Time Calc Avg's      0.083
W10I1601M Max Delta Between Samples  0.033
W11I1601M Standard Time Between Samples  0.003

Ver 2.0
```

Figure 7.2.9-8. EGIL Comp Constants display

I. EDOMEGA

Figure 7.2.9-9 displays data about the space shuttle PRSD, or cryo, system. It is similar to the cryo 5 tank displays. This display is used when the Extended Duration Orbiter (EDO) cryo pallet is flown, which contains an additional four oxygen and four hydrogen tank sets. The EDOMEGA display provides information for all nine tank sets, in addition to the EDO pallet electrical power.

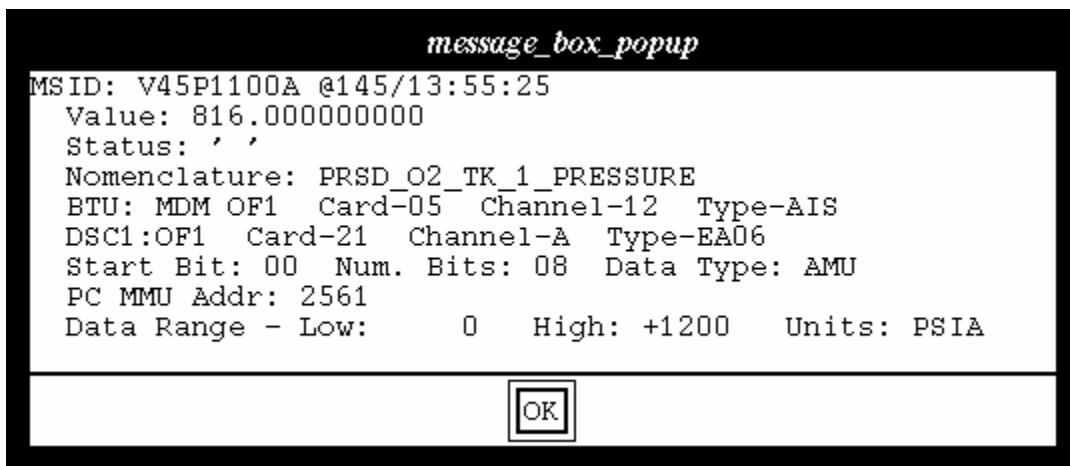
<b>F/V 087 / 102</b> OGMT 324/01:04:39 OMET 000/05:18:39		TOTAL:O2 6995.53 H2 804.73 KW-H 90.52 AMP-H 2956.07				
<b>CRYO O2</b>		1	3	4	5	2
TANK P		844	825	844	849	840
CNTL P		839	823	835		843
MANF P-VLV		844	-OP			OP - 835
PCS VLV/P	OP / 876					OP / 882
Q(%)		99.6	100.1	98.7	99.6	100.1
FLUID T		-278	-285	-271	-271	-278
HTR 1 T		-282	-285	-271	-271	-282
HTR 2 T		-282	-282	-271	-268	-282
HTR A1/B1	-- /--	-- /--		ON /ON	-- /--	-- /--
HTR A2/B2	-- /--	-- /--		ON /ON	-- /--	-- /--
SNSR 1 A/B	-- / -	-- / -		-- / -	-- / -	-- / -
SNSR 2 A/B	-- / -	-- / -		-- / -	-- / -	-- / -
HTR SW A	-- AUTO	--		-- AUTO	--	-- AUTO
HTR SW B	-- AUTO	--		-- AUTO	--	-- AUTO
<b>CRYO H2</b>		1	3	4	5	2
TANK P		217	217	214	216	216
CNTL P		214	216	218		216
MANF P-VLV		214	-OP			OP - 212
Q(%)		99.7	98.4	96.2	97.0	99.7
FLUID T		-413	-413	-413	-416	-413
HTR T		-413	-413	-416	-413	-416
HTR A/B	-- /--	-- /--		-- /--	-- /--	-- /--
HTR SW A	-- AUTO	--		-- AUTO	--	-- AUTO
HTR SW B	--	--		-- AUTO	--	--
<b>EDO CRYO PALLET</b>			6	7	8	9
-EPDC-			835	835	835	835
	MNA MNB		831	841	831	841
PPC PWR	OFF! OFF!					
PPC V	0.0↓ 0.0↓		100.1	98.3	100.1	98.3
PPC AMP	0 0		-282	-282	-282	-282
			-285	-282	-285	-282
			-282	-282	-282	-282
-HEATERS-			-- /--	-- /--	-- /--	-- /--
	A B		-- /--	-- /--	-- /--	-- /--
HTR SW	OFF. OFF.		-- /--	-- /--	-- /--	-- /--
HTR T STBD	57 57		-- / -	-- / -	-- / -	-- / -
HTR T PORT	58 58		-- / -	-- / -	-- / -	-- / -
			--	--	--	--
			--	--	--	--
<b>CABIN P</b> 14.7			6	7	8	9
AIRLOCK P	15.0		220	216	220	216
CABIN A/L dP	0.3		217	216	217	216
EVAP OUT T	37 37					
EMU VOLTS	0.0 0.0		96.2	96.6	96.2	96.6
AMPS	-0.22 -0.22		-413	-416	-413	-416
			-416	-413	-416	-413
			-- /--	-- /--	-- /--	-- /--
			--	--	--	--
			--	--	--	--
<b>PAYLOAD POWER</b>						
PRI	FC3 MNA MNB MNC					
AUX	OFF ON ON ON					MASTER ALARM- --
CABIN	ON OFF					--
AFT P/L	OFF					ALERT B- -- D-
AFT AMPS	0.0					BU C/W B- -- D-
AFT KWH	0.00					--
PL/MNC GND						MNC

ISP data server connection established

Figure 7.2.9-9. EDOMEGA display

J. Mouse functions

The EGIL MCC displays incorporate some point and click mouse functions. If the pointer is placed over a value and the left mouse button is clicked, the Measurement Stimulus Identification (MSID) of the value is shown at the bottom of the window. The Greenwich Mean Time (GMT), value, status, and nomenclature of the item are also shown at the bottom of the window. If the pointer is placed over a value and the middle button is clicked, a small window appears (see Figure 7.2.9-10). The window is titled `message_box_popup`. It displays the MSID, value, GMT, status, nomenclature, MDM information, DSC information, data range (upper and lower limits), and units.



**Figure 7.2.9-10. Display seen when a value is selected with middle mouse button**

RESERVED

7.3.1-1

RESERVED

7.3.1-2

## **TITLE**

FLIGHT DIRECTOR STATUS (IMGO)

## **PURPOSE**

The purpose of this SCP is to explain the user interface of the flight director status application.

## **BACKGROUND**

This application was designed to replace the hardwired, color-coded status buttons that were available in the old Flight Control Room (FCR). This tool is used by the flight directors to ensure that the entire Flight Control Team (FCT) is paying attention by requesting that all positions select a specified color. Then, when all disciplines are listening, the flight director can make announcements, or ensure that everyone is prepared for a particular phase of the flight.

## **PROCEDURES**

The application is accessed through the Master/Shuttle/Flight Director menu. The three color buttons are mutually exclusive, and the selected button's background turns to the selected color with a timetag distinguishing it from the other two buttons. The CLR button is used to clear the selected color. The flight directors will request color selection via voice loops or the "REQUEST" bar just below the three color buttons. This bar will also display a timetag of the request. The flight directors can also add a short text message to indicate the purpose of the color selection.

If the application is called up on more than one workstation per discipline, the most recently selected action for that discipline will be published regardless of workstation. The FCR operator and the MPSR operator can both call up the monitor function. For example, the MPSR operator can call up the application simultaneously with the front room and change or clear the published color. For normal operations, only the front-room operator will call up the application. For situations when a front-room operator is not present or their workstation is not operational, the MPSR operator can call up the application to respond to the flight director's requests. Also, whenever the application is terminated, regardless of whether or not it is the publisher, that discipline's published color is cleared. This can be seen by the flight directors on the FD\_Monitor application.

The FD\_Monitor application is used to monitor which color each discipline has selected. This application is accessed through the Master/Shuttle/Flight Director menu. When first called up, the application will consist of all gray boxes and the disciplines will be "N/A." The operator must use the applications window manager menu to select the correct format. When this is complete, all disciplines and their selected colors with timetags will be displayed.



## TITLE

MISSION INFORMATION SYSTEM

## PURPOSE

This SCP provides the basic instructions for use of the Mission Information System (MIS) application on console.

## DESCRIPTION

The MIS application is actually several subprograms grouped together. The subapplications that apply to an EGIL flight controller are the Anomaly Report (AR) Processor, Chit Report Processor (CHIT), and Query. A brief description of these applications follows with an introduction on how to use them.

### A. Anomaly reports

An AR is a record of an anomaly that has occurred on the shuttle during a flight. The report is generated by the AR Processor in MIS and is stored in the MIS database.

To create an AR, complete the following steps:

1. Open the AR Processor

Master DNAV • Global Apps • MIS • Anomaly Report

The window shown in Figure 7.3.3-1 appears.

2. Fill in the appropriate sections: Author, Title, Description, Impact, and Resolution. Navigation of the page can be done via tab key or the mouse. The Greenwich Mean Time (GMT) and Mission Elapsed Time (MET) also need to be added.
3. The AR becomes a preliminary AR by saving the report. This is done by selecting File • Save.
4. The AR now needs to be approved; this is done by the Mission Evaluation Room (MER).

At this point, the flight controller has completed the AR process unless changes need to be made to the AR.

**Note: The normal on-console AR process takes a full day. After the preliminary AR is written, the report is verified by each team before it is submitted to the MER.**

A completed AR is shown in Figure 7.3.3-2.

*New Anomaly*

File Edit Options Reports Document State Help

PRELIMINARY **ANOMALY REPORT** Date Created: 10/02/03

Flight: STS-115  
Vehicle ID: OV-105 (25)

Discipline/No./Rev	Revision	In-Flight Status	Orbiter Impact	Payload Impact	Track No.
EGIL	Yes No	Open Close	Yes No	Yes No	

Author: [ ] GMT

Title: [ ] MET

Description: [ ]

Impact: [ ]

Resolution: [ ]

NOTE: SIMs use SGMT/SMET. OPS use GMT/MET. (DDD:HH:MM:SS)  
If reference is made to instrumentation, please include MSID's.

Edit Mode: ON Zoom: z Z Activity: STS-115 Discipline: EGIL

0 graphical attachments.  
No MSID lists.

Figure 7.3.3-1. Anomaly Report window

<b>Flight STS-102 (32)</b>		<b>ANOMALY REPORT</b>			Date <b>03/18/01</b>	Page <b>1</b>
<b>EGIL 002A</b>	GMT: 2001/077:12:50 MET: 010:01:07:52	In-flight Status CL	Orbiter Impact N	Payload Impact N	Vehicle ID OV-103	Track No. MER-13
<p><b>AUTHOR:</b> Angela L. Bauer</p> <p><b>TITLE:</b> Airlock Fan B Phase B Not Working</p> <p><b>DESCRIPTION:</b> When Airlock Fan B was turned on at GMT 077/12:15, it only started and ran on phases A and C (AC2). The crew confirmed the Airlock Fan B AC2 phase B circuit breaker on MA73C row G was closed. At approximately GMT 77/12:21, the crew cycled the phase B circuit breaker once with a "Mark". No changes in AC2 currents were observed. The crew cycled the phase B circuit breaker 5 more times. No changes in AC2 current were observed during these subsequent cycles. At GMT 77/12:25, Airlock Fan B was turned off to protect the fan from potential damage caused by the possibility of the fan outlet check valve closing (back pressure from Fan A).</p> <p><b>IMPACT:</b> None. Airlock Fan A (only) is the nominal config. Adequate air mixing for the Stack O2 repress was accomplished with Fan A. Airlock Fan B can start and run on 2 phases.</p> <p><b>RESOLUTION:</b> Airlock Fan B will not be used during nominal operations. As a contingency, the Airlock Fan B may be used (2-phase ops).</p>						

APPROVED

jsc\_12830f\_254.tif

Figure 7.3.3-2. Completed AR

7.3.3-3

Verify that this is the correct version before use

B. CHIT reports

A CHIT is a request for changing the planned/agreed-to mission actions that are to occur during a flight. These reports require responses and signatures by different organizations before they can be closed out.

To create a CHIT, complete the following steps:

1. Open the CHIT Processor

Master DNAV • Global Apps • MIS • CHIT Report

The window shown in Figure 7.3.3-3 appears.

2. Fill in the appropriate sections: GMT Time, Action Time, Request Org, Response Org (CSR or MER), title of the request, author, and the request that is being made.
3. The CHIT is now ready to become a preliminary. This is done by selecting File • Save. The CHIT receives a temporary control number (ex. T01).

After a preliminary CHIT has been generated, it has to be officially opened at the MER; at this point, all needed organizations can respond and sign off. When all organizations have reviewed and responded to the CHIT, the MER will close out the CHIT.

For every flight, a CHIT is written for the baseline Cell Performance Monitor (CPM) values. The CHIT is used for comparisons throughout the flight. See Figure 7.3.3-4 for a completed CHIT form.

C. Query

Query is an application that allows a flight controller to research Measurement Stimulus Identifications (MSIDs) for the shuttle. EGIL flight controllers use this application to find out the sample rates for MSIDs in different Telemetry Format Loads (TFLs).

To initiate a Query, complete the following steps:

1. Open the Query application

Master DNAV • Global Apps • MIS • QUERY

The window appears as shown in Figure 7.3.3-5.

2. Make sure the following are highlighted in the Query window:

Discipline      Users      File Name

**egil      egil      MSIDSearch**

7.3.3-4

**Verify that this is the correct version before use**

Then click on Search.

- Another window opens (Figure 7.3.3-6).

STS-105\_7A1      **MISSION ACTION REQUEST (CHIT)**      Launch Date 07/12/01  
 Vehicle ID OV-104 (28)

GMT TIME	ACTION TIME	REQUEST ORG MOD	RESPONSE ORG	CONTROL NUMBER
SUBJECT:				
Request (MOD): <b>EGIL</b>				
0 Pages in hardcopy file.		0 Graphics Attachments.		Page 1
SPAN MANAGER:				
*** END OF MOD REQUEST ***				
SPAN MANAGER:				
PRELIMINARY				

**Figure 7.3.3-3. CHIT report form**

7.3.3-5

**Verify that this is the correct version before use**

STS-100\_6A

**MISSION ACTION REQUEST (CHIT)**

Launch Date 04/19/01  
Vehicle ID OV-105 (16)

GMT TIME	ACTION TIME	REQUEST ORG	RESPONSE ORG	CONTROL NUMBER
2001/109:08:48:24	INFO-ONLY	MER	MOD	<b>STS0060</b>
SUBJECT: <b>STS-100 Fuel Cell Baseline CPM Values</b>				
Request (MER): <b>MER/K. Adams</b>				
0 Pages in hardcopy file.		1 Graphics Attachments.		Page 1
<p>The fuel cell substack delta voltage steady-state prelaunch baseline values are as follows:</p> <p>FC 1, s/n 109, substack 1, 2, and 3, respectively: 10, 14 and 20 mV.</p> <p>FC 2, s/n 116, substack 1, 2, and 3, respectively: 10, 4 and 50 mV.</p> <p>FC 3, s/n 121, substack 1, 2, and 3, respectively: 18, 8 and 8 mV.</p> <p>These values were established at 109:08:30 GMT, approximately one hour after the completion of the fuel cell high load calibration.</p>				
MER MANAGER: <b>Don L. McCormack Jr./2001/109:15:10:02</b>				
CONTRACTOR <b>Barbara K. Bitner/2001/109:15:08:24</b>				
REP:				
TEAM LEADER 1: <b>Walter Scott/2001/109:14:37:32</b>				
<b>*** END OF MER REQUEST ***</b>				
SPAN MANAGER: <b>James T. Ruskowski, 281-483-8133, 8/2001/109:15:16:45</b>				
Response (MOD): <b>EGIL/T. North</b>				
0 Pages in hardcopy file.		0 Graphics Attachments.		Page 1
Concur. Thank You.				
SPAN MANAGER: <b>James T. Ruskowski, 281-483-8133, 8/2001/109:16:45:06</b>				
<b>*** END OF MOD RESPONSE ***</b>				

**Figure 7.3.3-4. Completed CHIT report**

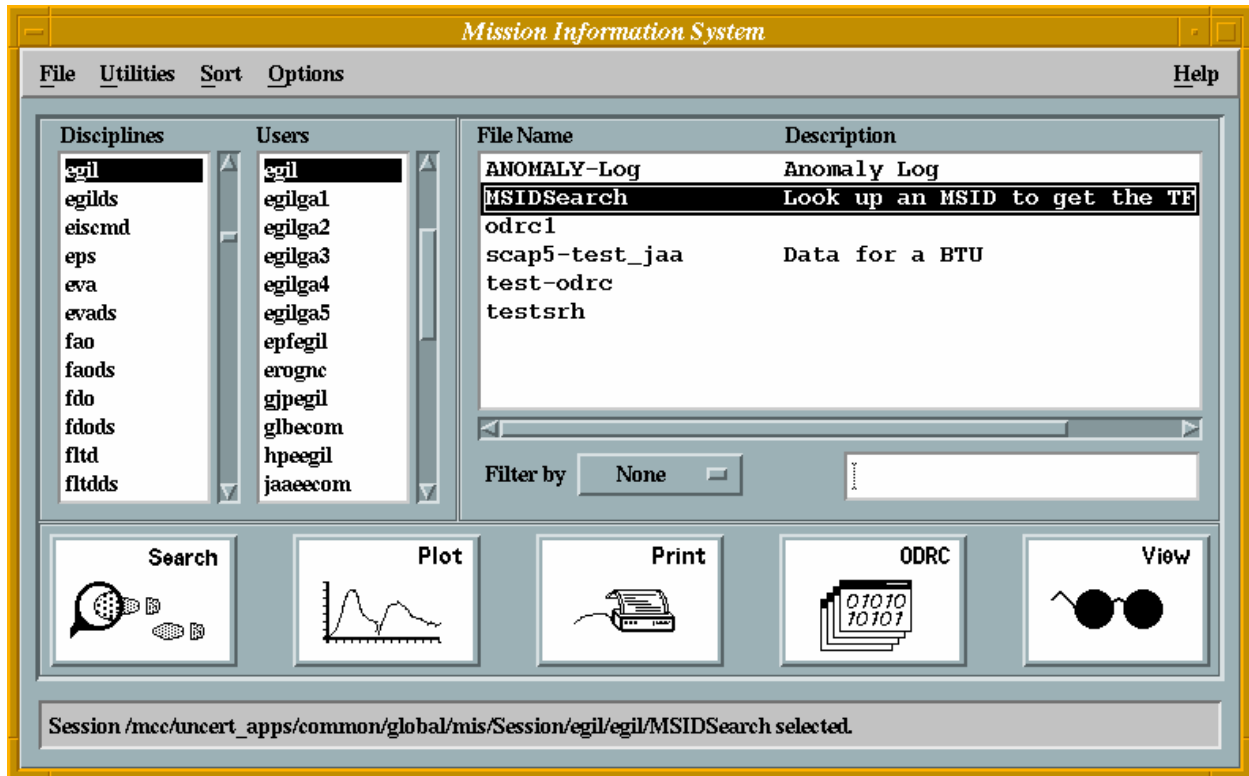


Figure 7.3.3-5. Query window

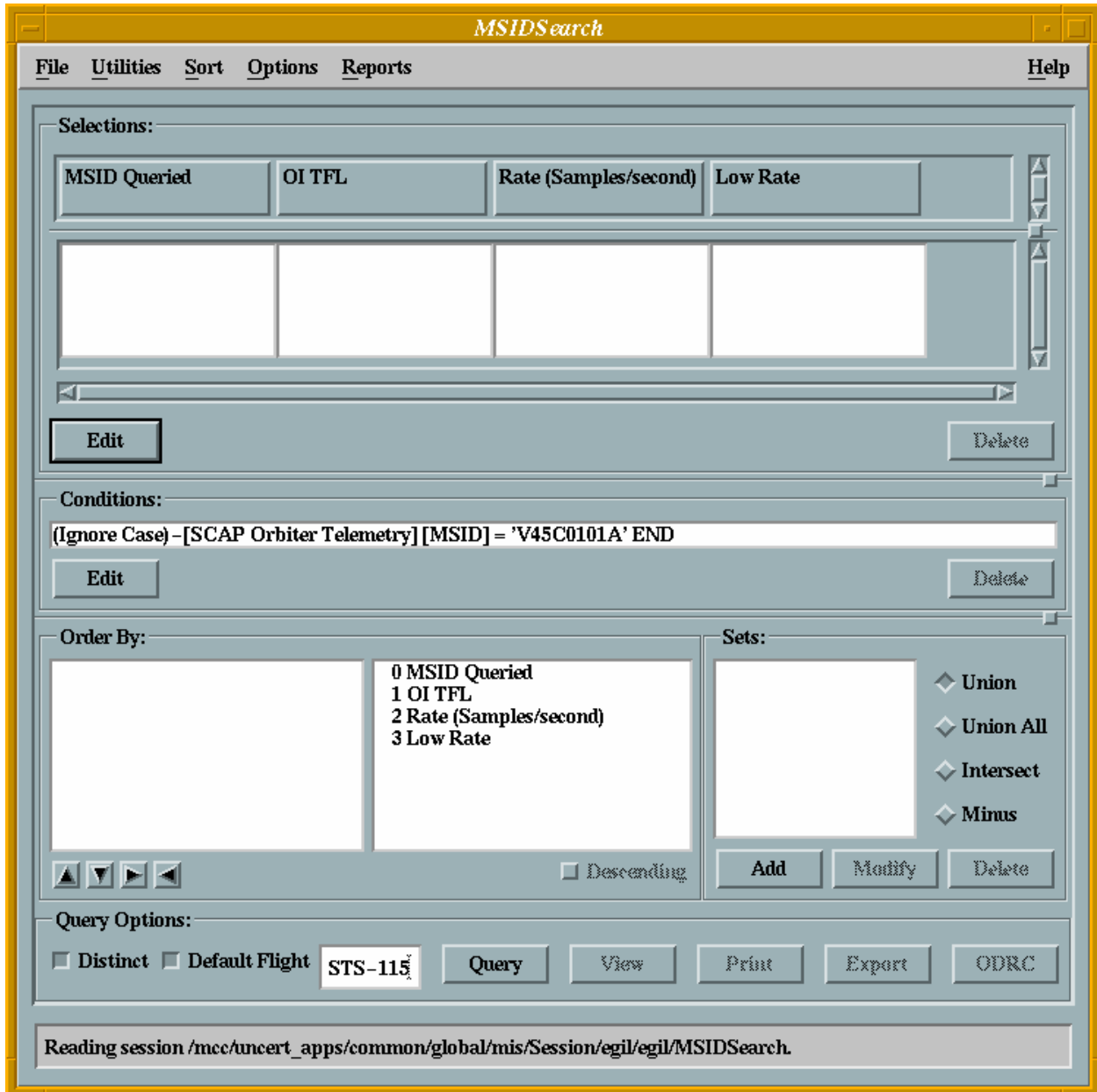


Figure 7.3.3-6. MSID queried

4. Click on the line in the CONDITIONS window.

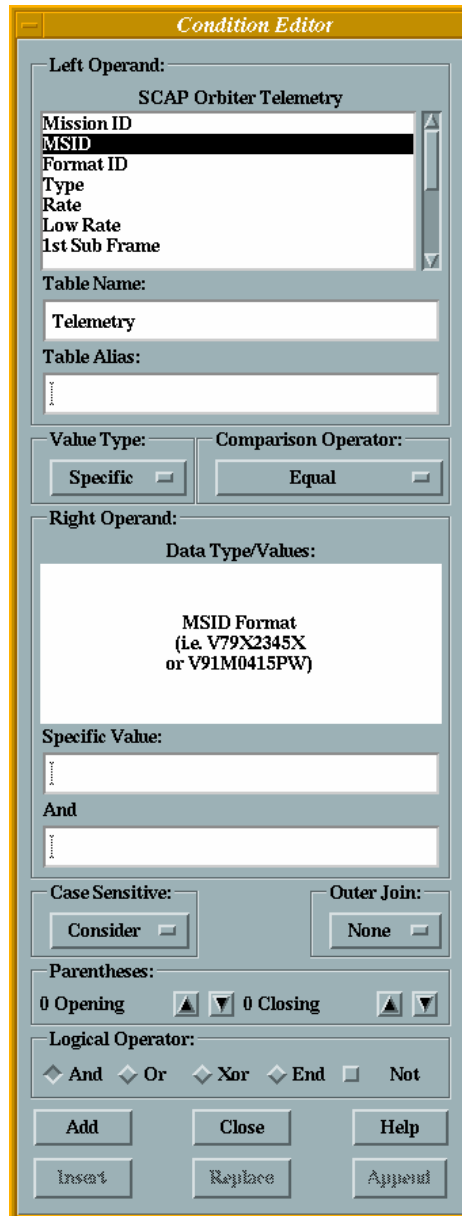
Click DELETE.

Click EDIT.

The Condition Editor window appears (see Figure 7.3.3-7). If all sections in the window are blank, right click in the SCAP box (the top section) and select SCAP Data, SCAP Orbiter Telemetry. The editor window should then look like the sample shown in Figure 7.3.3-7.

**Verify that this is the correct version before use**





**Figure 7.3.3-7. Condition editor window**

5. In the top box, click MSID.

In the SPECIFIC VALUE window, type the MSID you want to look up (example shown for V45C0101A).

For Outer Join, select None.

Logical Operator should be END.

Click ADD.

**Verify that this is the correct version before use**

Click CLOSE.

This takes you back to the previous window (the MSID should not be in the conditions window (Figure 7.3.3-7)).

6. Click Query (and wait).

The desired information then appears. Examples are shown for window view (Figure 7.3.3-8) and for file print (Figure 7.3.3-9).

The process starts over at step 4 if information on another MSID is needed.

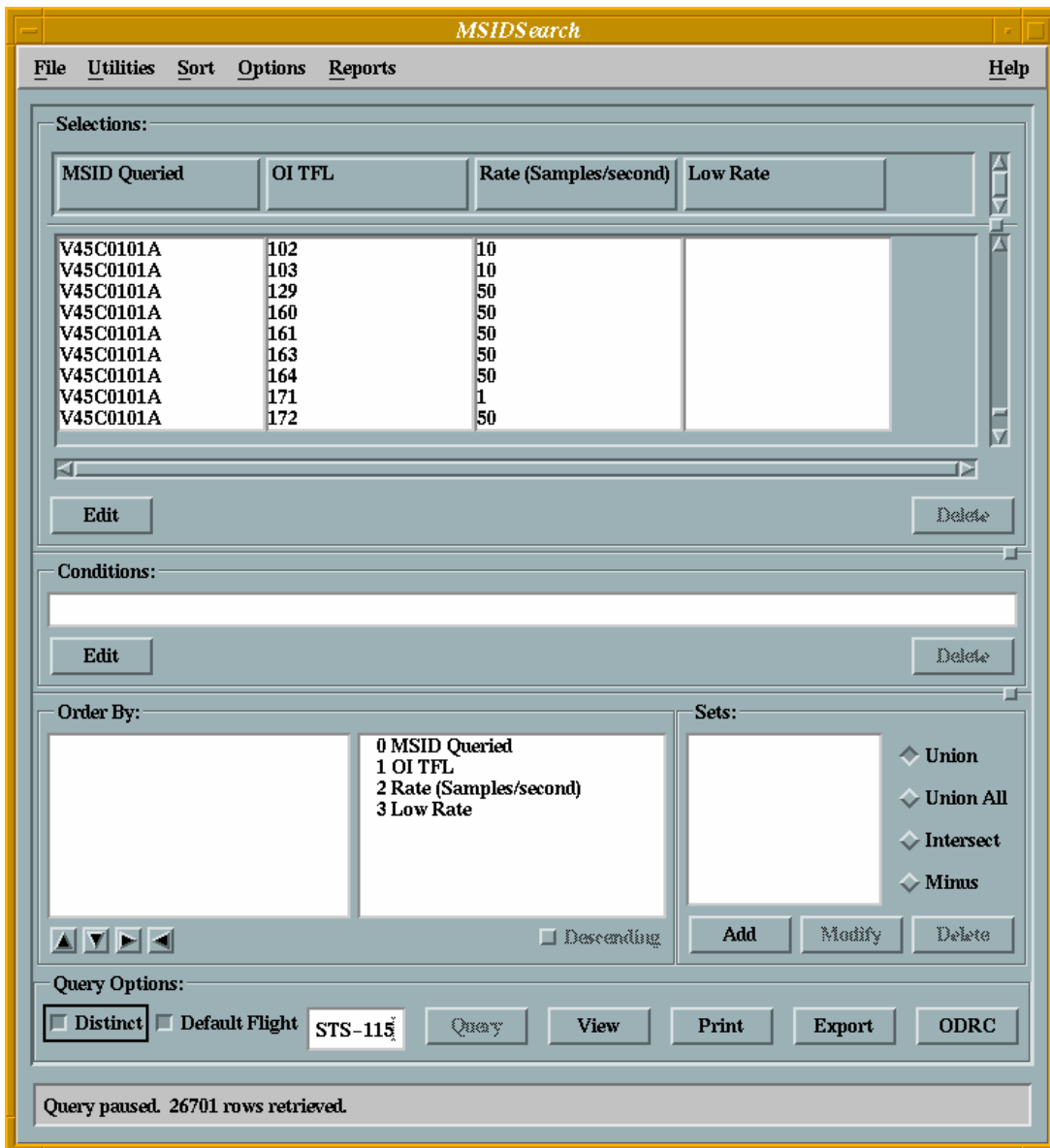


Figure 7.3.3-8. MSID window

---

MSID Queried	OI TFL	Rate (Samples/second)	Low Rate
V45C0101A	102	10	
V45C0101A	103	10	
V45C0101A	129	50	
V45C0101A	160	50	
V45C0101A	161	50	
V45C0101A	163	50	
V45C0101A	164	50	
V45C0101A	171	1	
V45C0101A	172	50	
V45C0101A	179	10	
V45C0101A	180	1	
V45C0101A	184	50	
V45C0101A	188	50	
V45C0101A	192	50	
V45C0101A	199	50	
V45C0101A	203	10	
V45C0101A	205	50	
V45C0101A	208	50	
V45C0101A	211	50	
V45C0101A	212	50	
V45C0201A	102	10	
V45C0201A	103	10	
V45C0201A	129	50	
V45C0201A	160	50	
V45C0201A	161	50	
V45C0201A	163	50	
V45C0201A	164	50	
V45C0201A	171	1	

*Figure 7.3.3-9. Print file for MSID search*

**TITLE**

ONBOARD FAULT SUMMARY

**PURPOSE**

The purpose of this SCP is to give a functional overview of the Onboard Fault Summary (OFS) application.

**BACKGROUND**

OFS is a workstation application that provides a scrollable history list of orbiter and Spacelab fault messages, as well as real-time annunciation of fault messages. The user may select PASS, BFS, or Spacelab views of fault messages. Fault messages are maintained for the following onboard systems: PASS, BFS, SCOS FSP, SCOS SOE, ECOS FSP, and ECOS LOE. Incoming fault messages are displayed at the top of the lists. Users can scroll through the lists, print a range of faults, and control how the current list position is affected when new faults arrive. This application belongs to the Data Processing Systems (DPS) group.

**PROCEDURE**

The OFS user interface can be started from the Display Navigation (DNAV) menu, which appears at the top of the workstation display following a successful login and activity selection. The recommended procedure is to click “**Shuttle**” from the Master Menu, followed by “**DPS**,” then “**Real-Time (data from DPS)**” followed by “**Onboard Faults Summary (OFS)**” (see Figure 7.3.4-1). Following these startup procedures will ensure that the OFS user interface will connect to the appropriate data server (i.e., the OFS server running on one of the DPS workstations). It is permissible to start more than one application of the user interface, though there is a limit to the number of user interfaces that connect to the OFS server.

STS080		Onboard Fault Summary v2.00.00				
<u>F</u> ile		<u>V</u> iew		<u>D</u> ownlister		<u>A</u> cknowledge
				<u>T</u> imetag		<u>H</u> elp
<b>PASS</b>		<b>Faults (GNC Auto)</b>		<b>GPC</b>	<b>Time (GMT)</b>	
24	F	RCS	PVT	1 2 3 4	299/19:13:29.04	
23	F	RCS	LEAK	1 2 3 4	299/19:13:18.49	
22	BCE	STRG 2	D	1 2 3 4	299/19:13:12.72	
21	F	RCS	LEAK	1 2 3 4	299/19:12:33.36	
20	RM	FAIL	IMU	1 2 3 4	299/19:12:11.28	

i\_12830\_513.cv5

**Figure 7.3.4-1. Typical OFS fault display**

Figure 7.3.4-2 illustrates the error message when the interface does not connect to the data server.



j\_12830\_514.cv5

**Figure 7.3.4-2. Error message displayed when the OFS server is not running**

This generally indicates that the OFS data server is not running for some reason. Since the server runs from a DPS workstation, the DPS position must be fully configured before the interface will connect to a server. No action is required on this dialog box because the user interface will automatically attempt to connect to the server periodically until it is successful.

**Local Mode** - avoid running locally

OFS may run in a “local” mode. This means that all the OFS computations, a local OFS data server, and the OFS user interface all execute from the user’s workstation. Running locally is intended only for test runs when DPS is not available and is not intended for simulations or missions.

### Startup View Display

The default initial view for OFS is the PASS view. BFS or Spacelab views are other options. Each line of the PASS OFS display will contain:

# text            GPC (if PASS)    Time (GMT)

where

#                    signifies that the message is the #th message received since the log was cleared

text                is the decoded error message (e.g., I/O ERROR CRT 2)

GPC is the GPC annunciating the message

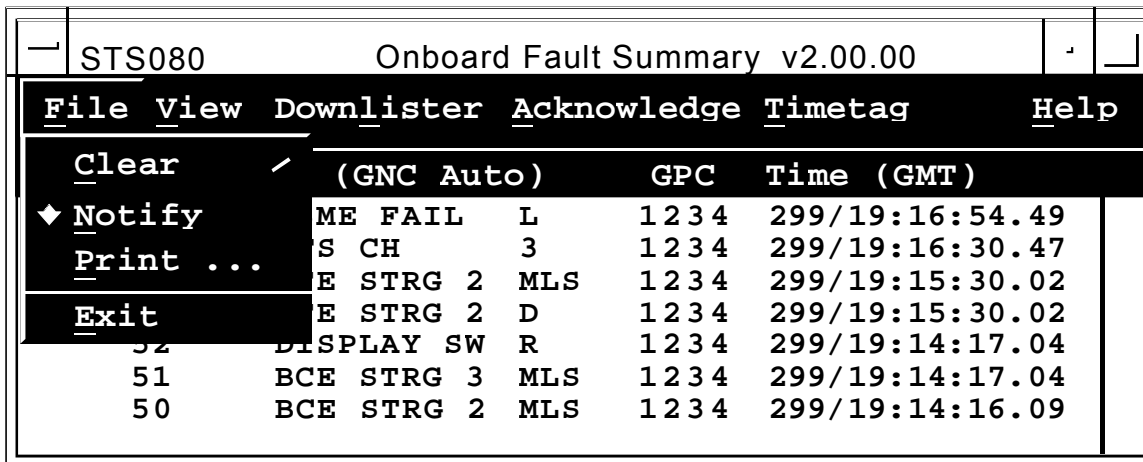
Time (GMT) is the time the fault was annunciated

The BFS OFS display is the same, except the annunciating GPC is not specified, since it is understood to be BFS.

### Menu Options

OFS has the following top-level menu choices: **File**, **View**, **Downlister**, **Acknowledge**, **Timetag**, and **Help** (see Figure 7.3.4-3).

Each of these options, once selected, will pop down a submenu of additional options. To pop down a submenu, single-click on a top-level option with the mouse, or you can hold down the **<Alt Function>** key with the single character that is underlined. For example, holding down **<Alt Function>** and **<F>** at the same time will pop down the File submenu, as illustrated in Figure 7.3.4-3.



L\_12830\_515.cv5

**Figure 7.3.4-3. File menu options**

#### File

Under this option, fault messages may be cleared, controlled, or printed, or application may be exited. Each of these options is discussed in more detail below.

#### Clear

This option is available only to DPS controllers. Non-DPS users will see this option as non-selectable.

#### Notify

This option controls how the current fault message list position is affected when new faults messages are annunciated. The option is asserted by default and causes

incoming messages to “notify” the user of their arrival by automatically positioning the fault message to the very top of the list. This option can be disabled. In the disabled state, incoming fault messages will not affect your current list position. This makes it easier to scroll down into the fault message list and have it hold steady as you study the list. As new faults come in, a count of unviewed fault messages is displayed at the upper right-hand portion of the fault list. Scrolling to the top of the fault message list resets this count.

#### Print

This option calls up a dialog box that allows you to specify a range of fault messages to print. Output can also be sent to file. For example, to print the 13 most recent fault messages in the list, specify a range of 1 to 13. A count of the maximum number of faults currently in the list is provided for reference.

#### Exit

Select to exit the interface.

#### View

This option will change the fault message list to view. The following choices are available: **PASS**, **BFS**, and **Spacelab**.

#### Downlister

This option is available for DPS flight controllers only.

#### Acknowledge

Each OFS fault item on the selected view can be acknowledged by clicking the item using the mouse; however, the Acknowledge menu provides options to either acknowledge all faults for each individual view or to acknowledge faults for all views. When Auto-Acknowledge is enabled, all current faults are acknowledged and all future messages will be acknowledged without further user interaction.

#### Timetag

Each displayed fault message is tagged with GMT or MET. GMT is displayed by default, and the user can switch between GMT and MET by simply choosing GMT or MET selection on the Timetag menu.

#### Help

Help menu option displays a list of online help topics.

## **TITLE**

TIMERS/CLOCKS

## **PURPOSE**

The purpose of this SCP is to explain operation of the wall clocks display and the timers control panel client.

## **WALL CLOCK DISPLAY**

### **BACKGROUND**

The wall clock display is used to monitor times in the MCC. The times to be displayed are controlled by the GC and contain, for example, Greenwich Mean Time (GMT), Mission Elapsed Time (MET), Acquisition of Signal (AOS), Loss of Signal (LOS), Time Before Ignition (OIGN), Payload Events Time (PET), and others requested by the flight director.

### **PROCEDURES**

The wall clocks display is obtained by using the DNAV menu:

MASTER/GLOBAL/APPS/TIMERS/CLOCKS/WALL CLOCK DISPLAY

The display will come up in the default configuration, two columns, which may be obtained using the "Layout" pulldown menu. The available configurations are

- A. One column by eight rows
- B. Two columns by four rows (default)
- C. Four columns by two rows

To exit the display, use the "File/Exit" pulldown menu.

## **TIMING SERVICES CONTROL PANEL (CLIENT)**

### **BACKGROUND**

The timing services control panel is used to invoke the user interface for the timer applications. The control panel main window provides the capability to create, modify, delete, pause, resume, move to different locations, and view event timers. Only one control panel may be displayed by a workstation at one time. Any further attempts will cause a popup window to appear to indicate that the control panel is already running. The control panel can be exited and then restarted with no adverse effects. All changes made to the timer displays will persist until a workstation reconfiguration takes place.



All information messages will be displayed in the messages section of the main window. Any message that requires a user will be displayed in a popup window dialog. These displays have an interactive help function that is very useful.

## PROCEDURES

The following procedures describe how to set up an event timer.

- A. From the DNAV menu, select: MASTER/GLOBAL APPS/TIMERS/CLOCKS/CONTROL PANEL.
- B. The Timing Services Control Panel - Client Display will appear.
- C. Under: "Clock Type", select "Create/Event Timer....".
- D. The Create Event Timer Display will appear.
  1. Select a Time Reference. The options are: GMT, SGMT, MET, and Mir.
  2. Verify that location is set to: "Local Timer Label". This will maintain the timer on the local workstation. The timer will then be deleted when a shift change, configuration change, or logout occurs.
  3. Enter a title into the label field. The label cannot start with a blank or contain any character that could be used as a conversion character in a print statement (e.g., "\$"). All other characters (including blanks after the first character), numbers, and symbols may be used. The label may not exceed 16 characters, including imbedded blanks. Timing Services does not allow the user to create multiple event timers with identical labels in the same event timetable.

Note: The following labels are reserved for Timing Services internal use only: GMT, SGMT, MET, Local, T-Minus, \_RS-SGMT-START\_, and \_TS-Leap.
  4. Select time display format. The options are: "ddd:hh:mm:ss", "yyyy:ddd:hh:mm:ss", "hh:mm:ss", and "mm:ss"
  5. Select Start Target Type. This field is used to interpret the Start Time fields. "Immediate Start" is the default. The Immediate Start option indicates that the event timer will start counting upon creation. The "Start Target" option indicates that an event timer will be created using a specific target time for startup. The "Past Start Duration" and "Future Start Duration" option indicates that an event timer will be started at a target time equal to the length of the duration plus or minus the current time. The "Startup Paused" option indicates that the event timer will remain static upon creation and can later be started by using the "Resume" option from the control panel lists.

6. Input the Start Time for the event timer (not required for Immediate Start). The fields represent the year, day of the year, hours, minutes, and seconds. The ranges of the fields depend on the Reference Time and Start Timer Type options.
7. Select the Expiration Target Type. This is used to interpret the Expiration Time fields. The “Target Expiration” option indicates that an event timer will be created using a specific target time for expiration. The “Duration Expiration” option indicates that an event timer will expire at a target time equal to the length of the duration plus the amount of time specified in the Start time.
8. Input the Expiration Time for the event timer. The fields represent the year, day of the year, hours, minutes, and seconds. The ranges of the fields depend on the Reference Time and the Expiration Timer Type options.
9. Select “Count Down” or “Count Up” options.
10. Select the notification option. This option allows the user to specify how the user wants to be notified upon timer expiration. Select “No Notification” or “DVIS 2 Sec.” Options.
11. Leave the “Auto Delete” and “Auto Display” options selected.
12. Click on the “Create” button and your timer will appear or be added to the existing timer if it has already been created.

Repeat steps 1 through 12 to create additional timers.

**TITLE**

SM TABLE MAINTENANCE OPERATIONS

**PURPOSE**

The Table Maintenance Block Update (TMBU) command load is used by the MCC to update Fault Detection and Annunciation (FDA) analog parameter limits, discrete values, and special constant values in the Backup Flight System (BFS), Systems Management (SM), and Primary Avionics Software System (PASS) SM compool tables. During on-orbit PASS SM operations, the TMBU uplink provides ground access to the same FDA capabilities provided to the crew via SPEC 60 (table maintenance). Since no such SPEC exists in the BFS, a BFS TMBU provides the only access to FDA other than a Change Request (CR) to the software tape build process.

A TMBU request is initiated by the responsible MCC position in order to manipulate parameter limits, constant values, noise filters, and enable/inhibit parameters. These updates may be required to update limits for a changed vehicle state or configuration, to accommodate erratic/failed subsystem behavior or sensor shifts, to implement late requirements defined by a CR, or to initialize onboard comps.

**RESTRICTIONS/CONSTRAINTS**

CMD CR# Baseline Date: 11/12/87

A. Onboard software command legality tables

1. PASS

MC (MF/OPS) or GPC ID	CMD legal
MC0 (Post-IPL OPS0)	
MC1 (GNC1/6)	
MC2 (GNC2)	
MC3 (GNC3)	
MC4 (SM2)	X
MC5 (SM4)	X
MC6 (PL9)	
MC7 (ILLEGAL)	
MC8 (GNC8)	
MC9 (GNC9)	
GPC ID	

2. BFS

MC (MF/OPS) or GPC ID	CMD legal
Prelaunch OPS0	X
GNC1	X
Predeorbit OPS0	X
GNC3	X
GNC6	X

- B. Valid OI loads - All PASS and BFS.
- C. Vehicle, LRU/hardware version constraints – None.
- D. Time constraints, crew coordination requirements - TMBUs are generally not time-critical. However, the potential exists for mission/payload-dependent, time-critical TMBUs.

A TMBU REJECT will result if PASS SPEC 60 (SM TABLE MAINT) is active when a PASS SM TMBU is uplinked. An active SPEC 60 can be detected via downlisted (variable parameter) data.

- E. Hazard/safety implications – None.
- F. Other requirements – None.

**BACKGROUND**

The TMBU load is a two-stage command load that uplinks a maximum of 10 table maintenance dataset changes. Each dataset is composed of a parameter ID, a dataset type, and the desired new value. The dataset type is an 8-bit integer field; the parameter ID is a 24-bit integer field, and the new value is a 64-bit, double precision, floating-point field. Each dataset, therefore, is six 16-bit words.

A TMBU load can be sent to the PASS or BFS, but the software designs are different and, consequently, the loads are different. The following discussions are separated into PASS and BFS.

**PASS TMBU**

- A. Dataset type

The dataset type is a two-digit decimal number that defines the update as a constant, an enable/inhibit, a noise filter, or one of eight FDA limit changes (Table 7.3.6-1). By referring to the PASS SM SPEC 60 (Figure 7.3.6-1), it is seen that these codes correspond to item numbers on that display.

Table 7.3.6-1. PASS dataset types

Parameter	Class	Limit	Type code
Alert limit set 1	3*	Low limit	02
		High limit	03
Alert limit set 2	3*	Low limit	04
		High limit	05
Alert limit set 3	3*	Low limit	06
		High limit	07
Alert noise filter	3*		08
Alert enable	3*		09
Alert inhibit	3*		10
Backup C&W limit	2	Low limit	11
		High limit	12
BU C&W noise filter	2		13
BU C&W enable	2		14
BU C&W inhibit	2		15
Constant	N/A	Constant	17

\*Can also have class 4 parameters.

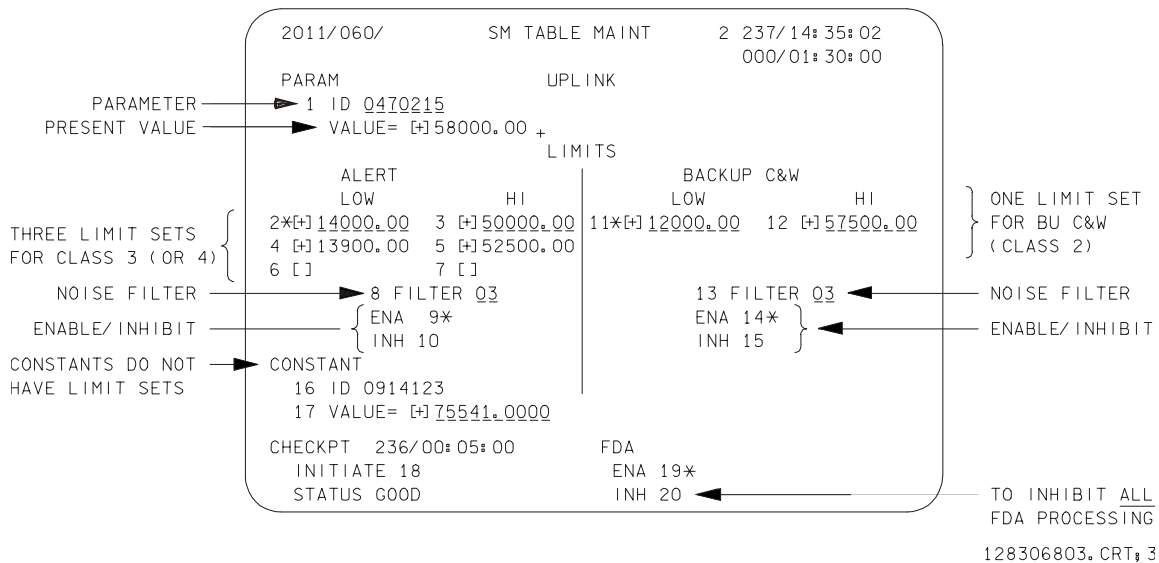


Figure 7.3.6-1. PASS table maintenance SPEC 60

1. Alert limit sets

Alert limit sets correspond to SM alert indications (class 3 alerts and some class 4 alerts) and can be used to modify both analog high- and low-limit annunciation points, in addition to bilevel discrete values.

Alert limit set parameters are preconditioned, which means that one of up to three sets of limits can be selected for use, depending upon the conditions present; i.e., if the Auxiliary Power Unit (APU) is in high speed, use limit set 1; if it is not in high speed, use limit set 2. Three limit sets are available for conditional FDA processing.

2. Backup caution and warning

Backup Caution and Warning (BU C&W) limits correspond to software C&W (class 2 alert). BU C&W does not support multiple limits sets as alert limit sets do, but does support both high- and low-limit annunciation points and bilevel discrettes.

3. Discrettes

Both alert limit sets and BU C&W support bilevel discrettes. The discrete is changed using either the Low-Limit (LL) or High-Limit (HL) option with the undesired state being entered, so that the appropriate alarm annunciates when the current state changes to the undesired FDA state. Both upper and lower limit values are high or low limited tested.

4. Noise filters

Both SM alert and BU C&W support noise filters. A noise filter specifies how many consecutive measurements must be out of limits before FDA will annunciate the out-of-limit condition. The possible range of noise filter values is from 1 to 15, with 2 being the nominal I-loaded value.

5. Inhibit/enable

Individual SM alert or BU C&W parameters can be inhibited or enabled via the TMBU function. This function is equivalent to taking a parameter lower limit offscale low and the upper limit offscale high (a new value of 1.0 should be entered when doing an enable or inhibit).

6. Constants

Constants are values that are used for purposes such as computations and special processes. A constant does not have a corresponding alarm class as do alert limit sets and BU C&W.

B. Parameter ID

In SM OPS 2, the parameter ID is formed from the MSID Master Measurement List (MML) number by converting the first alphabetic field to a one-digit decimal number (see Table 7.3.6-2) and dropping subsequent alphabetic fields. The numeric conversions for the first alphabetic field are as follows:

Example: V45C0100A = 0450100

**Table 7.3.6-2. PASS parameter ID conversion**

V	0	ORBITER VEHICLE
A	1	GROUND TEST ARTICLE
B	2	SRB
E	3	SSME
F	4	FSE
G	5	GSE
P	6	PAYLOAD
T	7	ET
U	8	SSUS (IUS)
L	9	SPACELAB

C. New value

The new value is the new desired value of the limit, or constant, specified. This value must not exceed the software range of that parameter as specified by the calculated Offscale High (OSH) Offscale Low (OSL) values. PASS linearly sloped curve parameters are uplinked in Engineering Units (EUs) and stored in Pulse Code Modulation (PCM) counts. Nonlinear and negatively sloped calibration curve parameters and constants are uplinked and stored in EU.

Enable/inhibits require that a value of 1.0 be entered for the new value. All other dataset types use the desired value specified on the TMBU form.

The calibration curve for each transducer reflects the relationship between the physical measurement (temperature, pressure) and the voltage provided to the MDM by the signal conditioner. The MDM generates an integer called PCM count that corresponds to an analog measurement. The conversion of PCM to EU is given by the equation below, where  $A_0$ ,  $A_1$ ,  $A_2$ ,  $A_3$  are the coefficients of the calibration curve. Usually, this equation is no more than third order.

$$EU = A_0 + A_1 (PCM) + A_2 (PCM)^2 + A_3 (PCM)^3$$

The calibration curve for each transducer and the associated parameters are located on the PASS fiche (SM/PM Database Information Listing (DBIL)) and BFS fiche (BFS TMBU TABLES). In most cases, the BFS counterpart parameter uses

the same PASS calibration curve. There are only a few BFS-unique calibration curves.

**TMBU REJECT**

The primary indicator available in the MCC to monitor PASS TMBU operations is the TMBU reject word (V92J0660C). Whenever the value of the word is greater than zero, the TMBU REJECT indication is displayed on the DPS caution and warning display. The nonlatching light is reset as soon as a valid TMBU load is received. A TMBU RUN discrete (V92X0661X) is also available in the downlink, but it is not currently believed to be useful. It is set to 1 while SM OPS 2 is processing the uplink. The TMBU reject word, displayed as two decimal digits on MSK 1303, has the following meanings, shown in Table 7.3.6-3.

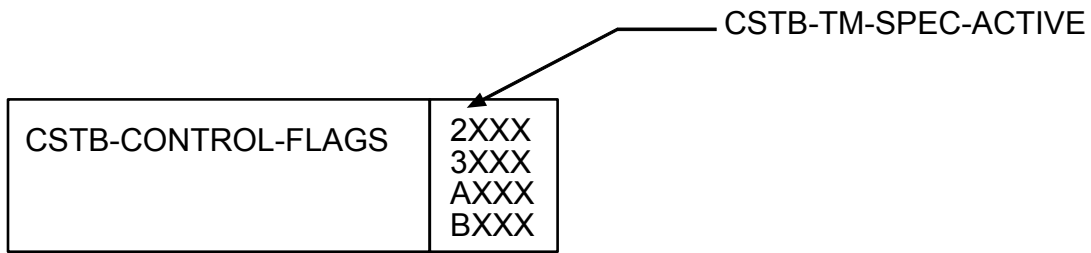
**Table 7.3.6-3. PASS TMBU reject word**

Reject value	Reason for reject
0	Last load received by SM OPS 2 was executed with no errors
1 through 10	Last dataset that was rejected for one of the following reasons: <ul style="list-style-type: none"> <li>a. If class 2 limit change is requested and no class 2 limit set is defined for FDA parameter</li> <li>b. If class 0, 3, 4 limit change is requested and no class 0, 3, 4 limits are defined for FDA parameter</li> <li>c. If class 0, 3, 4 limit change is requested and specified limit set does not exist</li> <li>d. If requested change is a high limit and changed parameter is a discrete</li> <li>e. If parameter of a limit change is not processed by FDA</li> <li>f. If analog or EU limit value exceeds allowable range</li> <li>g. If parameter of a constant change is not a valid constant parameter</li> </ul>
11	Entire load was rejected for either of the following reasons: <ul style="list-style-type: none"> <li>a. If TM spec is active when the load reaches the application</li> <li>b. If the number of datasets is less than 1 or greater than 10</li> </ul>

A TMBU REJECT resulting from SPEC 60 being active or underlying can be prevented by monitoring the parameter CSTB-CONTROL-FLAGS via the variable parameter downlist. Within the CSATB-CONTROL-FLAGS is a flag, CSTB-TM- SPEC-ACTIVE, that is set if SPEC 60 is active. As shown in Table 7.3.6-4, if the first digit of the hex value is a 2, 3, A, or B, SPEC 60 is active and a TMBU should not be sent.



**Table 7.3.6-4. SPEC 60 active variable parameter**



### **BFS TMBU**

The BFS TMBU design is different. The PASS SM TMBU design was made to take advantage of programming already in place to support the SM Table Maintenance SPEC. The SM FDA design allowed use of a parameter ID to identify the FDA parameter, as well as an indexing system into the scaling process, so that a new limit could be entered as an EU value and then automatically backscaled to PCM count, which is the storage format of most limits. The BFS, on the other hand, had no such related processing. First, the parameter ID, instead of being MML-derived, represents an offset in one of eight tables. Also, there is no EU-to-PCM conversion capability in the BFS. All new values are input for uplink in the format in which they are stored. This means that all FDA limits must be input in a specialized decimal PCM count form, which is uplinked in the double precision floating-point format. Last, the dataset type will indicate which of the eight tables contains the value being updated. The following items illustrate the details of this structure.

Comprehensive verification of table maintenance activities may be performed with a main memory dump (ref. FCOH SOP 4.6) or variable parameter downlink.

#### **A. Dataset type**

The dataset type indicates in which of eight tables the value of interest is located (see Table 7.3.6-5).

**Table 7.3.6-5. BFS dataset types**

<i>Dataset type</i>	<i>BFS table</i>
255	FDA high limits
254	FDA low limits
253	SM and special processes constants
252	Sequencing constants
251	GN&C constants 1
250	GN&C constants 2
249	Payload high limits
248	Payload low limits

**B. Parameter ID**

The parameter ID for a BFS parameter is a decimal number that represents the offset (index) into the appropriate table (array) of limit, constant, or discrete values. The parameter type (integer, scalar, etc.) determines the format of its ID, based upon how many half-words are required to store its limit value in the array. See Table 7.3.6-6 for these definitions. Specifically, a parameter that occupies one 16-bit halfword will have an ID created by decimally adding the array offset to 1114112. (1114112 DECIMAL is equivalent to 110000 hex.) The parameter type is apparent from the 11 in the left two places (11XXXX), where XXXX is the array offset. Parameters that occupy a full word (32-bit floating point) are represented by an ID that is the direct array offset (since the offset is implicitly added to 0000000, which can be thought of as the decimal equivalent to 00XXXX hex).

**Table 7.3.6-6. BFS parameter ID**

Parameter type	No. half-words for array data type	ID hex format	ID decimal format
Single precision integers	1	110000	1114112 + offset
Double precision integers	2	000000	Offset
S.P. scalars	2	000000	Offset
D.P. scalars	4	000000	Offset
Bit string variables	1 or 2	110000 or 000000	(Either method)
Boolean (1 bit)	1	110000	1114112 + offset

C. New value

1. Discretes (1 or 0) are stored as 16-bit integer 1 or 0 values and may be entered into the uplink system as 1 or 0.
2. Analog FDA limits (nonpayload) are stored in PCM \* 64 format. The GPC left-justifies the 10-bit parameter (9 bits plus sign) in a 16-bit word. This shift-left is accomplished by multiplying the PCM value by 64. Because BFS FDA processing of integers directly converts the uplink double precision floating-point value to the integer format, the uplinked value must be multiplied by 64 prior to uplink.

FDA parameters are received from an MDM as 10-bit binary numbers that are left-justified within a 16-bit word. In order to save General Purpose Computer (GPC) processing, the values are not right-justified; i.e., divided by 64. Therefore, ground-initiated changes have to be uplinked as PCM x 64.

The following formula, derived from the calibration curve equation, is used for linear analog parameters to convert the desired EU value to PCM counts:

$$PCM = \frac{(New\ Value - A_0)}{A_1 \times 64}$$

The A<sub>1</sub> coefficient must also be multiplied by 64. The I-loaded value of A<sub>1</sub> (which is the value that is listed on the fiche) is predivided by 64. When BFS displays a parameter on a CRT, the PCM counts must be converted to EU. Since PCM is stored as PCM x 64, predivision of the I-loaded A<sub>1</sub> coefficients has the effect of dividing PCM by 64. Therefore, the PCM count is adjusted to the correct value without an additional division operation.

This PCM value must be rounded to a whole PCM count before multiplying by 64. This ensures that the remaining six bits (least significant) are all zero. The rule for rounding is, for an upper limit, round down to the next integer; for a lower limit, round up to the next integer.

Linear analog parameters are set OSH by using OSH = +32,704 PCM counts or OSL by using OSL = -32,768 PCM counts (see Table 7.3.6-7).

3. Analog nonlinear parameters are handled the same way as linear parameters, except that the increased complexity of trying to solve a cubic equation for PCM has been done already, and the PCM versus EU values are given in tabular form in the back of the DBIL. For a lower limit, select the PCM count value that corresponds to the EU value just above the input EU value. For an upper limit, select the PCM count value that corresponds to the EU value just below the input EU value.
4. Analog constants are most often stored as single precision floating-point values and are entered into the uplink system in EUs; some are stored as integers.

**Table 7.3.6-7. BFS offscale values**

ANALOG FDA (LINEAR AND CONSTANTS)	OSH = +32,704 (STORED PCM * 64)	SIGN BIT ↓ 2 <sup>14</sup> <span style="float: right;">2<sup>0</sup></span> <div style="border: 1px solid black; padding: 2px; display: inline-block;">X 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0</div> = +32,704 X = 0 = POS      SHL 6 BITS
	OSL = -32,768 (STORED PCM * 64)	2 <sup>15</sup> <span style="float: right;">2<sup>0</sup></span> <div style="border: 1px solid black; padding: 2px; display: inline-block;">X 0 0 0 0 0 0 0 0 0 0 0 0 0 0</div> = -32,768 X = 1 = NEG      SHL 6 BITS
PYLD_APP_FUNC TYPE 249, 248	OSH = +511 (STORED PCM)	2 <sup>0</sup> <span style="float: right;">SIGN BIT</span> ↓ 2 <sup>8</sup> <div style="border: 1px solid black; padding: 2px; display: inline-block;">0 0 0 0 0 0 X 1 1 1 1 1 1 1 1</div> = +511 X = 0 = POS
	OSL = -512 (STORED PCM)	2 <sup>9</sup> <span style="float: right;">2<sup>0</sup></span> <div style="border: 1px solid black; padding: 2px; display: inline-block;">0 0 0 0 0 0 X 0 0 0 0 0 0 0 0</div> = -512 X = 1 = NEG

5. Payload parameters that are processed by PYLD\_APP\_FUNC are already shifted left and are stored in PCM counts (not PCM \* 64). Therefore, it is not necessary to multiply the rounded PCM value by 64 prior to uplink. The new value for uplink is calculated using the same equation given previously for linear analog parameters and the same rounding technique is employed. The whole PCM value is then uplinked.

D. Payload parameters

BFS software release 09.21 (STS-9) introduced a new module, PYLD\_APP\_FUNC, which performs downlist processing, FDA, and scaling for display for up to 50 payload-dependent parameters. The parameters are restricted to two types: discretets and linear analogs, where limit values are contained in either the upper limit table (data type 249) or lower limit table (data type 248).

All the parameters are downlisted. Because only 25 half-words of the BFS downlist are allocated to payloads, this dictates the possible combination of analog and discrete parameters. An analog equals one half-word, and 16 discretets equal one half-word. Therefore, maximum contents could be 50 discretets (although 400 discretets could be packed into 25 H/Ws), 25 analogs, or some combination thereof that does not exceed 50 parameters (TMBU storage locations) or 25 half-words.

This module differs from other BFS FDA processing in two significant ways. First, the analog limits are stored in PCM counts (not PCM \* 64) because the 10-bit parameter has already been shifted left 6 bits. The offscale range, however, is still -512/+511 PCM counts. Second, all the FDAs performed by this module can be inhibited by setting the parameter PYLD\_PARM\_CNT equal to zero. This can be accomplished via TMBU.

E. MCC TMBU application instructions

A software application entitled TMBU is available on the MCC UNIX workstations to facilitate the building and sending of a software command load. Following is a list of instructions used to successfully build and/or send a command load to the orbiter. A command manager must be started prior to accessing the TMBU application. The command manager provides an interface to the command server, which is used to send command loads to the orbiter. The TMBU program was written to automate much of the work that is defined in FCOH SOP 3.3.2. This program allows the operator to read the TMBU database, automatically process a TMBU request, transmit a TMBU to the command server, and perform other miscellaneous functions. The TMBU program is maintained by the Data Processing System (DPS) section (DF22).

**1. Start command manager.**

To start a command server, go to

MASTER DNAV

Choose GLOBAL APPS, COMMAND SERVER

Then START COMMAND MANAGER

After the command manager start has been selected, a status window will appear showing the status of the command server. The status window will appear yellow when it is initializing. When the command server has successfully started and is running, the status window will turn green; a red status window indicates that the command server is no longer running.

***Note: The command manager must be running before TMBUs can be sent to the server.***

**2. Start the TMBU program.**

To start the TMBU program, wait until the command manager status window is displaying the Running indication, then go to

MASTER DNAV

Choose GLOBAL APPS, COMMAND SERVER

Then TMBU

**3. General instructions.**

Select File from the drop-down menus. Select Flight, then click on the desired flight load.

***Note: The correct flight or SIM load should appear when the TMBU program is started.***

Select File from the drop-down menus. Choose New, then click on PASS or BFS, depending on the mission phase.

Select File from the drop-down menus. Choose Open and click on the desired TMBU.

To change a limit, enter the MSID in the MSID slot and hit enter. The associated parameter will come up. New limits can be entered. Then hit the "ok" button to return to the TMBU screen. The MSID and its information will appear on the TMBU screen.

Move the mouse to the line you wish to delete from the TMBU. Highlight the parameter by left-clicking the mouse. Then click on the DELETE button, and the line will be deleted. More than one line can be selected for deletion.

Editing a line by double-clicking: Move the mouse to the parameter you wish to edit. Double-click the left mouse button, and the associated parameter will come up. New limits can be entered here, then hit the ok button to return back to the TMBU screen.

Editing a line by entering the MSID: Retype the MSID of a parameter that is already listed in the current TMBU and press the Enter key. The associated parameter will come up. New limits can be entered here, then hit the ok button to return back to the TMBU screen. The new values will replace the previous ones.

Select File from the drop-down menus and choose Save. A question box will appear with three choices: SAVE, CANCEL, and OVERWRITE.

**Save** will save the TMBU with a different extension.

**Cancel** will exit from the question window.

**Overwrite** will copy over the existing TMBU with the same number.

When the TMBU is ready to be sent to the command server, go to the Command drop-down menu and select Send. A message will appear in the bottom of the screen stating "Command Built (TMBU#) Successful."

After a TMBU has been sent to the server, go to the Command drop-down menu and select Verify. The top half of the TMBU screen will turn dim, and the lower half will light up. The TMBUs can be viewed by clicking on the up or down arrows beside the DSM window.

***Note: Most commanding options will be halted until you exit the Verify mode.***

Go to the Command drop-down menu and select Edit. The lower portion of the TMBU screen will blank out, and the upper half will become active again.

Go to the Command drop-down menu and select Delete Load. The Delete Load Command Manager window will appear. Enter the TMBU number you wish to delete from the command server in the Digital Select Module (DSM) area, then hit the ok button.

Messages will appear at the bottom of the screen: "Delete sent: (TMBU#)" followed by "Command Instance Delete (TMBU#) Successful."

To view a TMBU going onboard

MASTER DNAV

GLOBAL APPS

TELCOM DISPLAYS

Choose Prime

Then Command Tracking

A window will be displayed that shows all commands that are being loaded into the buffer. The DSM numbers and the GMT when the command is received and completed are shown on the window. The command load is complete when a buffer execute command is sent, as indicated by the GMT being displayed under the complete section in the window. When a TMBU has been successfully sent, the TMBU should be deleted from the command server and the command manager should be stopped.



## TITLE

TV VIDEO AND WORLD MAP

## PURPOSE

The purpose of this SCP is to give a functional overview of the Video User Interface application and the X-Windows View World Map application.

## BACKGROUND

The Video User Interface application is used to perform video functions in the MCC flight control rooms. This application is functional only on the White FCR workstation and allows the FCR operator the ability to view and switch the video in the picture-in-picture window. This application is also used by GC to send video to the large screen displays.

The X-Windows View World Map application shows the location of the space shuttle on a two-dimensional map of the world. It displays a trace of approximately one-half of an orbit where the shuttle has been and where it is going. The map can be resized, cleared of data points, and refreshed. The map can also display the Tracking and Data Relay System (TDRS) satellites, TDRS footprints, a number of ground stations and their footprints with keyholes, other satellites, the South Atlantic anomaly, and the Sun's day and night terminator.

## Procedures

The TV Video and World Map programs are executed from the MASTER DNAV menu bar under the Global Apps pulldown menu.

### TV Video

The TV Video display comes up with just a menu bar. There are three pulldown options on this menu bar: File, Commands, and Help. The File option should be selected if the user wants to exit the program. Exit is the only option under the File menu. The Command menu options are used to perform video functions. These options are Picture-in-Picture, NTSC to Large Screen, and IPS SMILP.

The Picture-in-Picture command should be selected if the user wants to view and switch video at the workstation in the picture-in-picture window. This option is available only in White FCR-1. When the Picture-in-Picture option is selected, the program will automatically connect to the last channel that was selected, and this channel will be displayed on a picture-in-picture labeled Stream Capture. The user can move this screen to the desired position on the workstation by dragging it with the left mouse button. This window must be moved in order to display the NTSC channel selection popup box that is hidden behind it. This popup box allows the user to select any of the available channels for viewing on the picture-in-picture window.

***Note: At this time, there will be three windows associated with this program on the workstation: the main menu bar, the selection popup box, and the picture-in-picture window. The main menu bar may be closed without closing the other screens by selecting Exit under the File menu.***

The video may be changed on the stream capture screen by highlighting the desired channel on the channel selection popup box and then clicking on the OK button. The video will then change to the selected channel. The user may toggle between the last two selected channels by clicking on the toggle button. Channels may also be selected by using the arrow keys on the workstation keyboard to highlight the desired channel and then pressing the Return key. This is a quick way to “surf” the channels.

The channel selection popup box is closed by either clicking on the Cancel button or double clicking on the box in the top left-hand corner of the window. Closing the channel selection box will not close the picture-in-picture window. This window is closed by double clicking on the box in the top left-hand corner of this screen.

All the other command options will appear desensitized for non-GC users. For more information on these command options, see the user’s guide under the Help menu.

## **World Map**

The overall display contains three buttons and four data lines. The buttons are Options, Quit, and Help. The four data lines are current GMT, current orbit number, current shuttle latitude, and current shuttle longitude. When the Option button is selected, a pulldown menu will appear containing 10 to 12 options. These options are used to change the attributes of the map. The Quit button is used to exit the World Map display program, and the Help button is used to view the help file. This Help file contains a detailed user’s guide which should be referenced for any additional information about this program.

**TITLE**

MEWS/ODRC - TBD

7.3.8-1

## TITLE

UTILITY OUTLET SPREADSHEET PROGRAM

## PURPOSE

Provide the reader with a general understanding of how the utility outlet program is used by the EGIL flight controller.

## DISCUSSION

The utility outlet program is an Excel spreadsheet that is used to evaluate the acceptability of a utility outlet-loading configuration. The Excel application is located on the share drive using the following directory structure:

S:\Divisions\DF\Private\DF73\EGL\_APPS\Utility Outlet Spreadsheets.

It is recommended that the lead EGIL/EPSS assigned to a flight use this spreadsheet to evaluate the outlet-loading configuration shown in the plug-in plan. The baseline plug-in plan is documented in the Flight Requirements Document (FRD). If potential problems are found with the scheduled configuration, the shuttle crew compartment flight engineer assigned to that flight should be contacted and informed of the problems. Currently, only the main bus utility outlets have spreadsheets. The Middeck Accommodations Rack-Middeck Utility Panel (MAR-MUP) utility outlets spreadsheet is currently in work and will soon be available; an M063P panel utility outlet will also be created.

The utility outlet spreadsheet should also be used in real time during a flight to evaluate plug-in plan changes. If a utility outlet configuration change is required during a mission, the changes should be entered into the spreadsheet to verify that these changes are acceptable.

## APPLICATION

When you start the Utility Outlet Check Spreadsheet, you will be prompted for a password or allowed to open the file as "Read Only." Open as "Read Only" and select the correct sheet for the utility outlets being evaluated. For all payloads that are shown on the plug-in plan, enter the appropriate cable lengths and power levels into the appropriate cells on the spreadsheet. If a Y-cable or Power Distribution Box (PDB) is being used, be sure to enter both cable lengths indicated. If an outlet is not being used, the power value listed in the cell must be zero watts, and the resistance (R) value should be 10,000 ohms. The utility outlet should first be evaluated using a 28-V input at the main bus (i.e., MNA). Verify that with all payloads scheduled, the outlet voltage at each connector is providing a 24-volt (V) minimum payload interface and that no current levels are greater than the circuit protection indicated. If the 24-V minimum is not being met, further evaluation will be required. Flight-specific details, such as fuel cell performance and payload scheduling, can be taken into consideration when evaluating

outlet voltages. The resistance value used (0.0061 ohms/ft) in the calculation is the resistance of a 16-gage copper wire at 200° F.

**TITLE**

PADHOLD

**PURPOSE**

The purpose of this SCP is to provide an overview of the Padhold Ground Boiloff Spreadsheet application.

**BACKGROUND**

The Padhold Ground Boiloff Spreadsheet application calculates the launch hold hours given the tank quantities and also the L-time. Padhold hours (launch hold hours) are defined as the amount of time the orbiter can hold on the launch pad and still make NEOM+2 without topping off the cryo tanks. This spreadsheet is used on console to obtain cryogenic H<sub>2</sub> and O<sub>2</sub> loaded quantities before launching a shuttle mission.

When the orbiter is on the launch pad, reactants (H<sub>2</sub> and O<sub>2</sub>) in the cryogenic tanks boil off. Boiloff occurs when heat leaks into the cryo tanks. The tanks are designed to minimize heat leak into the tank; they are double walled, consisting of an inner pressure vessel and an outer shell. The volume between these shells is evacuated on the ground by a vacuum pump that is mounted on the side of the tank to minimize convective heat transfer between the shells. The inner shell is mounted to the outer shell with nonconductive supports to minimize conductive heat transfer. These design features minimize heat leak into the tank, but they do not completely stop the heat leak into the tank. Therefore, when the orbiter is sitting on the launch pad, the reactants will boil off. Boiloff rate is the amount of reactants (lb) that boils off per hour per tank.

Padhold capability can be calculated using the boiloff rate, tank quantity, and number of tanks.

$$Padhold = \frac{QTY(lb)}{(Boiloff\ Rate\ (lb/hr/tks)) * (no.\ of\ tks)}$$

For preflight consumable predictions, boiloff rate is obtained from a linear curve that is based on quantity of tanks. However, when using the spreadsheet, the boiloff rate is not calculated using this linear curve; instead, the actual curve is used, which can be obtained from the SODB.

**PROCEDURE**

The Padhold Ground Boiloff Spreadsheet is located at:

S:/Divisions/DF/Private/DF73/Egl\_apps/Boiloff/Boiloff.xls

The spreadsheet is shown in Figure 7.4.2-1.

- A. Minimum lift-off quantities for both H<sub>2</sub> and O<sub>2</sub> can be obtained from the budget tables. Minimum L/O QTY is the amount of cryogenics required to support that particular mission, including redlines.
- B. Under the H<sub>2</sub> and O<sub>2</sub> columns, the tank quantities (in percent) have to be typed in. These values can be obtained from the CRYO SYSTEMS DISPLAY on console.
- C. "L-" Input the launch minus time into this block.
- D. When the spreadsheet receives these inputs, it will calculate the padhold for the mission.

PADHOLD GROUND BOILOFF CALCULATOR										VER 1.0 10/12/95	
ENTER H2 MIN LIFTOFF QTY (LBS)		755.8		STS-90							
ENTER O2 MIN LIFTOFF QTY (LBS)		6643									
H2	L-	L/O QTY	MIN QTY	TANK	O2	L-	L/O QTY	MIN QTY			
99.7	12.0	90.95	85.91	1	100.5	12.0	782.6	741.44			
99.7	12.0	90.95	85.91	2	100.9	12.0	785.7	744.72			
98.8	12.0	90.11	85.01	3	99.6	12.0	775.5	734.05			
98.8	12.0	90.11	85.01	4	100.5	12.0	782.6	741.44			
99.3	12.0	90.58	85.51	5	101.4	12.0	789.6	748.82			
96.2	12.0	87.69	82.38	6	100.1	12.0	779.4	738.16			
96.6	12.0	88.07	82.78	7	98.7	12.0	768.5	726.64			
95.7	12.0	87.23	81.87	8	99.6	12.0	775.5	734.05			
95.3	12.0	86.86	81.46	9	99.6	12.0	775.5	734.05			
<b>TOTAL</b>		<b>802.55</b>	<b>755.85</b>			<b>TOTAL</b>	<b>7014.9</b>	<b>6643.4</b>			
<b>H2 PADHOLD</b>		<b>75 HRS</b>				<b>O2 PADHOLD</b>		<b>206 HRS</b>			
<p>-H2 PADHOLD BASED UPON SODB BOILOFF RATE.                      -PADHOLD TIMES ARE NOT VALID FOR H2 IF ANY H2 TK MIN QTY IS LESS THAN 48 LB.</p> <p>-O2 PADHOLD BASED UPON HISTORICAL BOILOFF RATE.                      -PADHOLD TIMES ARE NOT VALID FOR O2 IF ANY O2 TK MIN QTY IS LESS THAN 312 LB.</p> <p>-PADHOLD BEYOND 400 HOURS MAY NOT BE VALID.</p>											

J\_12830\_516.cv5

**Figure 7.4.2-1. Padhold Ground Boiloff spreadsheet**

7.4.2-2

**Verify that this is the correct version before use**

## TITLE

WAVEOFF

## PURPOSE

This SB describes the Waveoff Calculator application used to determine consumable margins for different deorbit opportunities.

## BACKGROUND

Waveoff Calculator is used during missions by EGIL to estimate the power requirements and the cryogenic O<sub>2</sub>, H<sub>2</sub> consumables remaining for different combinations of deorbit opportunities.

Waveoff Calculator is a Microsoft Excel spreadsheet program (see Figure 7.4.3-1). It was written with Microsoft Excel version 5.0 and should be run using Microsoft Excel version 5.0 or later. Waveoff Calculator can be found on the Private\DF73\EGL\_APPS\MISC\Waveoff.XLS.

Waveoff Calculator's calculations are based on the following inputs provided by the user. The inputs necessary are: nominal EOM TIG MET, deorbit opportunities, EOM+1(2,3) first TIG MET, deorbit prep power, EXT day 1(2,3) power, waveoff power, deorbit prep backout power, entry power, postlanding power, conversion factors, metabolic O<sub>2</sub> and leak rate, H<sub>2</sub>/O<sub>2</sub> redlines, postlanding hours, current MET, estimated average kW until deorbit prep, and current H<sub>2</sub>/O<sub>2</sub> tank quantities. Most of the above inputs can be obtained from SOCRATES preflight analysis.

Waveoff Calculator uses the inputs to generate the following output data: total energy required, equivalent H<sub>2</sub>/O<sub>2</sub>, available H<sub>2</sub>/O<sub>2</sub> at EOM, and summary of events.

## PROCEDURE

Permission extension day power requirements assume one deorbit prep backout from the nominal deorbit prep and one additional deorbit opportunity on the second extension day (1-0-1 deorbit opportunities). During real-time mission operations, it is often requested to determine the maximum number of deorbit opportunities available, based upon actual cryo quantities. It can also provide deorbit opportunity data assuming orbiter power levels different from the typical extension day group C and payload survival power.

The procedure is as follows.

Open the MS EXCEL Waveoff.XLS program.

Enter the following parameters data:



- A. TIG MET/number of opportunities each day
1. Nominal EOM TIG MET: Enter the TIG MET in days and decimal hours.
  2. Opportunities: Enter the number of deorbit opportunities on a particular day (if no deorbit prep assumed, enter 0). Only one opportunity per orbiter rev should be entered (e.g., KSC and EDW opportunity on same rev will only count as one opportunity), and if a full rev is skipped between opportunities, that rev will count as an opportunity (e.g., EDW, no opportunity, KSC will count as three opportunities).
  3. EOM+1(2,3) first TIG MET: Enter the TIG MET in days and decimal hours of the first deorbit opportunity.

**Note: The user is limited to 3 full extension days beyond the nominal EOM time. To go beyond EOM+3, the nominal EOM deorbit TIG must be adjusted to reflect the EOM+1 (or later) deorbit TIG, and all other inputs should be adjusted accordingly.**

- B. Power levels, conversion factors, and redline
1. Deorbit prep power: Enter the expected average total power level during the deorbit prep time period (TIG-4 hours to TIG). This power level can be obtained from SOCRATES predicted power or based upon actual observed power levels (includes orbiter and payload power).
  2. Extension day 1(2,3) power: Enter the expected total power for each extension day, not including deorbit prep power.
  3. Waveoff power: Enter the expected average total power level from deorbit TIG until wheel stop.
  4. Postlanding power: Enter the average total power level from wheel stop through TD+45 minutes or for the time period which orbiter power is required postlanding to destow payload equipment.
  5. Conversion factor: Enter the H<sub>2</sub> and O<sub>2</sub> conversion factors for average mission power and extension day power.
  6. Metabolic O<sub>2</sub> and leak rate: Enter the rate, in lb/hr, of metabolic O<sub>2</sub> usage and cabin O<sub>2</sub> leakage.
  7. H<sub>2</sub>, O<sub>2</sub> redline: Enter the H<sub>2</sub> and O<sub>2</sub> redline values. Redline values are sum of the residuals and measurement uncertainty.
  8. Postlanding hours: Enter the number of hours, in decimals, in which orbiter power is required postlanding.
  9. Current MET: Enter the current MET in days and decimal hours.

10. Estimated average kW until deorbit prep: Enter the predicted or projected average total power from current MET until the start of the first deorbit prep.
11. Current quantity: Enter the current total H<sub>2</sub> and O<sub>2</sub> quantities in lb.

### Summary of Deorbit and Extension Day Events

This is a table that summarizes all events, event times, duration, energy, and cryo requirements from which the total energy and cryo requirements are calculated. This table can be used as a sanity check to ensure that all user inputs have been entered correctly.

After entering the above data, the resultant output data is as follows:

- A. Total energy required: The total orbiter energy requirement from the start of the first deorbit prep opportunity until the end of the required postlanding hours on the last extension day opportunity deorbit, in kWh.
- B. Equivalent H<sub>2</sub>: The quantity of H<sub>2</sub> required, in lb, to supply the total energy required.
- C. Equivalent O<sub>2</sub>: The quantity of O<sub>2</sub> required, in lb, to supply the total energy, metabolic, and cabin leak.
- D. Available H<sub>2</sub>, O<sub>2</sub> at EOM: The remaining cryo margin available.

**Note: Any negative value will result in an "\*\*\*INSUFFICIENT CRYO\*\*\*" message displayed.**

For any additional information needed for Waveoff Calculator, refer to Shuttle EGIL Software Documentation for WAVEOFF, version 2.2.

WAVEOFF CALCULATOR		VER 2.1 11-14-94			
<u>ENTER TIG MET AND NUMBER OF OPPY'S EACH DAY (0 OPPY'S IF NO D/O PREP)</u>					
NOMINAL EOM TIG MET	8	DAYS	23.7	HOURS	(OR 215.7 HOURS)
OPPORTUNITIES - NOM EOM	<input type="text" value="2"/>				
EOM + 1 FIRST TIG MET	9	DAYS	23.7	HOURS	(OR 239.73 HOURS)
OPPORTUNITIES - EOM + 1	<input type="text" value="2"/>				
EOM + 2 FIRST TIG MET		DAYS	23.8	HOURS	(OR 23.75 HOURS)
OPPORTUNITIES - EOM + 2	<input type="text" value="2"/>				
EOM + 3 FIRST TIG MET	11	DAYS	23.8	HOURS	(OR 287.8 HOURS)
OPPORTUNITIES - EOM +3	<input type="text" value="2"/>				
(NOM D/O PREP START TIME	211.7		HOURS)		
TOTAL ENERGY REQUIRED	1217.01	KWH			
EQUIVALENT H2	105.30	LBS	AVAIL H2 AT END	44.69	LBS
EQUIVALENT O2	873.153	LBS	AVAIL O2 AT END	298.66	LBS
<u>ENTER POWER LEVELS, CONVERSION FACTORS, AND REDLINES</u>					
D/O PREP POWER	19.0	H2 CONVERSION FACTOR - Avg kW			0.0872
EXT DAY 1 POWER	15.2			- Ext day kW	0.0861
EXT DAY 2 POWER	12.2	O2 CONVERSION FACTOR - Avg kW			0.6923
EXT DAY 3 POWER	12.2			- Ext day kW	0.6836
WAVEOFF POWER	19.0	METAB O2 AND LEAK RATE			0.523
BACKOUT POWER	19.0	H2 R/L (NOT INCL EXT DAY)			16.56
ENTRY POWER	19.0	O2 R/L (NOT INCL EXT DAY)			276.49
POSTLANDING POWER	14.0	POSTLANDING HOURS			2
ENTER CURRENT MET	9	DAYS	9.1	HOURS	(OR 225.1 HOURS)
EST AVG KW UNTIL D/O PREP:	16.0	kW			
CURRENT H2 QTY	147.85	LBS	H2 AT D/O PREP	167	LBS
CURRENT O2 QTY	1297.9	LBS	O2 AT D/O PREP	1453	LBS

**Figure 7.4.3-1. Waveoff Calculator**

SUMMARY OF DEORBIT AND EXTENSION DAY EVENTS						
HRS	EVENT	EVENT END HRS		KWH	O2 (Not Incl Meta)	'12
4	D/O PREP PWR	215.7	19	76	52.61	6.63
1.5	NOM EOM W/O	217.2	19	28.5	19.73	2.49
1	BACKOUT PWR	218.2	19	19	13.15	1.66
17.53	EXT DAY 1 PWR	235.73	15.2	266.5	182.15	22.94
4	D/O PREP PWR	239.73	19	76	52.61	6.63
1.5	EXT DAY 1 W/O	241.23	19	28.5	19.48	2.45
1	BACKOUT PWR	242.23	19	19	13.15	1.66
-222.48	EXT DAY 2 PWR	19.75	12.22	-2719	-1858.51	-234.08
4	D/O PREP PWR	23.75	19	76	52.61	6.63
1.5	EXT DAY 2 W/O	25.25	19	28.5	19.73	2.49
1	BACKOUT PWR	26.25	19	19	13.15	1.66
257.55	EXT DAY 3 PWR	283.8	12.22	3147	2151.47	270.98
4	D/O PREP PWR	287.8	19	76	52.61	6.63
1.5	EXT DAY 3 W/O	289.3	19	28.5	19.73	2.49
1	ENTRY PWR	290.3	19	19	13.15	1.66
2	POSTLANDING	292.3	14	28	19.14	2.41

TOUCHDOWN      290.3      HRS OR      12      DAYS      2.3      HRS

**Figure 7.4.3-1. Concluded**

## TITLE

FUEL CELL MONITORING SYSTEM SPREADSHEET

## PURPOSE

Provide the user with a general understanding of how to process and view the fuel cell single-cell voltage data file generated by the crew Fuel Cell Monitoring System (FCMS) application.

## BACKGROUND

The crew onboard FCMS application provides fuel cell single-cell voltage data used to evaluate the health of the fuel cells. The crew FCMS application generates a data file that comprises the fuel cell single-cell voltages recorded at a specified time interval. The FCMS spreadsheet application is used to process and display the fuel cell single-cell data so that it can be easily evaluated to determine the health of a fuel cell.

## REFERENCES

JSC-48027, Malfunction Procedures EPS SSR-1.

## OVERVIEW

The FCMS spreadsheet application is an Excel spreadsheet that uses Visual Basic macros to process the FCMS data file generated by the onboard crew FCMS software application. The onboard FCMS application records the GMT and the 96 individual cell voltages of all three fuel cells into a data file. When recording the data file, the user enters the time between samples and the duration to record data into the file. Each line of the recorded data file starts with the GMT, followed by all 288 cell voltages formatted as comma-separated values.

The spreadsheet process macro will initially check each line for correct format. If any line errors are found, a file error box will display how many errors were found. Any line found with an error will not be displayed on the spreadsheet. The data for each individual fuel cell is displayed on a separate sheet. The first column of the spreadsheet displays the GMT. The next nine columns contain computational data that are used to help evaluate fuel cell health. All fuel cell individual cell voltages are displayed after the computational data.

## APPLICATION USAGE

To use the FCMS spreadsheet application to process or view an FCMS data file, the current application version is started. The FCMS spreadsheet application is titled Fcms\_XXX.xls, where XXX is the version number. On the MCC PCs, the application is typically located in the following directory: D:\Fcms\Apps. After the application has been started, choose the "Change Mission" option from the FCMS toolbar. The default directory structure that is displayed is FCMS\DATA\87. Change the number 87 to the current mission number. If the current mission data folder does not exist, you will be

asked if you want to create it. Select YES, and the mission data file folder will be created.

The next step is to process the FCMS data file. After the FCMS data file is recorded by the crew, it is transferred to the OCA down directory so that the Flight Activities Officer (FAO) can retrieve it and place it in the EGIL INBOX on the work drive. The FCMS data file should be copied to the current mission folder in the Fcms\Data directory. Data file names have the format FCXXXXXX.fcv or FCXXXXXX.zip, where the XXXXXX references the GMT of the first datapoint in the file with the hundreds digit of the GMT day dropped. If the data file is a zipped file (extension “.zip”), unzip the file by double-clicking on it. This should start the WINZIP application and save the unzipped data file in the data directory. To process the FCMS data file, select “Process OCA Downlink” from the FCMS toolbar and select the correct FCMS data file.

After the FCMS data file has been processed and displayed, two additional options are available to help determine the health of the fuel cell. The FCMS toolbar has an outlier calculation option. The outlier calculation starts a macro that evaluates standard statistical data (average, mean, and standard deviation) for the 96 cells of the fuel cell. Any cells that are considered “outliers” (three standard deviations from the mean cell value), are flagged by turning the value red. After the macro has evaluated all the data on that fuel cell’s spreadsheet, it will display how many outlier cells were found. This option must be performed individually on each fuel cell.

***Note: If the data file is large, the outlier calculation will take time and will initially tie up the Central Processing Unit (CPU) resources. You may be able to minimize the application and let it run in the background. Newer PCs should have enough resources for this to not be an issue.***

The Plot menu option can also be used to help evaluate the fuel cell health. Using the mouse, highlight any block of data you wish to plot, and select the plot option. This option will automatically add the GMT reference to the plot file. If other data plots are desired, choose the Clear Plot option from the PLOT menu.

When a raw FCMS data file is processed, four data files are created: An FCMS application spreadsheet file named XXXXXX.xls and three individual fuel cell Excel spreadsheet files named fc#XXXXXX.csv. The created data files can be opened and viewed using the Excel application. However, to run the outlier and plot macros, you must first open the FCMS spreadsheet application.

**APPENDIX A**

**ACRONYMS**

AC	Alternating Current
ACA	Annunciation Control Assembly
ACCU	Audio Central Control Unit
ADTA	Air Data Transducer Assembly
AESP	Ascent/Entry Systems Procedures
AFO	Abort From Orbit
ALCA	Aft Load Control Assembly
AMCA	Aft Motor Control Assembly
AOS	Acquisition of Signal
APC	Aft Power Control
APCA	Aft Power Control Assembly
APCL	Ascent Pocket Checklist
APCU	Assembly Power Converter Unit
APDS	Androgynous Peripheral Docking System
APU	Auxiliary Power Unit
AR	Anomaly Report
ASP	Astronaut Support Personnel
ATP	Acceptance Test Procedure
ATU	Audio Terminal Unit
AWL	Automated Wire List
B/NA	Boeing/North American
B/U	Backup
batt	battery
BDPU	Bubble Drop and Particle Unit
BFS	Backup Flight System
BOS	BFS Operating System
bp	barberpole
C&W	Caution and Warning
C&WE	Caution and Warning Electronics
C/V	Check Valve
C/W	Caution and Warning
CAPCOM	Capsule Communicator
CAR	Computer Access Request
	Corrective Action Request
cb	circuit breaker
CBT	Computer Based Trainer
CCB	Configuration Control Board
CCFT	Controlled Current Feedback Transformer
CDF	Confined Detonating Fuse
CDR	Commander
c.g.	center of gravity
CHB	Console Handbook

CNTL	Control
COA	Console Operations Aid
CPG	Consumables Products Generator
CPH	Command Procedures Handbook
CPM	Cell Performance Monitor
CPU	Central Processing Unit
CR	Change Request
CRANS	Configurable Real-Time Analysis System
CRT	Cathode-Ray Tube
cryo	cryogenic
CRYSP	Cryo System Pressure
CWA	Caution and Warning Annunciator
CWE	Caution and Warning Electronics
CWEU	Caution and Warning Electronics Unit
CWS	Caution and Warning System
D&C	Display and Control
DA	Distribution Assembly
DBIL	Database Information Listing
DC	Direct Current
DDD	Digital Display Driver
DIGI	Digital
DNAV	Display Navigation
DP	Differential Pressure
DPS	Data Processing Systems
DS	Data Storage
DSC	Dedicated Signal Conditioner
	Differential Scanning Calorimetry
DSM	Digital Select Module
DTE	Digital Television Equipment
DTO	Detailed Test Objective
DVIS	Digital Voice Intercom System
DWV	Dielectric Withstanding Voltage
ECLS	Environmental Control and Life Support
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control System
ECU	Electronic Control Unit
EDO	Extended Duration Orbiter
EDP	Electronic Document Project
EDTE	Emulation Digital Television Equipment
EEL	Electronic Equipment List
EGIL	Electrical Generation and Illumination
EI	Entry Interface
EMCC	Emergency Mission Control Center
EMF	Electromagnetic Field



EMI	Electromagnetic Interference
EMU	Extravehicular Mobility Unit
EOM	End of Mission
EPCL	Entry Pocket Checklist
EPDC	Electrical Power Distribution and Control
EPDS	Electrical Power Distribution System
EPS	Electrical Power System
ESMC	Eastern Space and Missile Center
ET	External Tank
ETRSO	Eastern Test Range Safety Officer
EU	Electronics Unit Engineering Unit
EVA	Extravehicular Activity
F/C	Flight Controller
FAO	Flight Activities Officer
FC	Fuel Cell
FCC	Fuel Cell Capacity
FCL	Freon Coolant Line
FCMS	Fuel Cell Monitoring System
FCOH	Flight Control Operations Handbook
FCP	Fuel Cell Powerplant
FCR	Flight Control Room
FCT	Flight Control Team
FD	Flight Director
FDA	Fault Detection and Annunciation
fdf	Flight Data File
FEA	Floodlight Electronics Assembly
FES	Flash Evaporator System
FET	Field Effect Transistor
FIDO	Flight Dynamics Officer
FLC	Forward Load Control
FLCA	Forward Load Control Assembly
FMC	Forward Motor Control
FMCA	Forward Motor Control Assembly
FOIG	Flight Operations Integration Group
FPC	Forward Power Control
FPCA	Forward Power Control Assembly
FRD	Flight Requirements Document
FRR	Flight Readiness Review
FSE	Flight Support Equipment
FSSR	Flight Systems Software Requirements
GMT	Greenwich Mean Time
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer

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GRTLS	Glide Return to Landing/Launch Site
GSE	Ground Support Equipment
GSI	G2 Standard Interface
HDC	Hybrid Driver Controller
HL	High Limit
HSD	Historical System Data
I/O	Input/Output
ICD	Interface Control Document
IDCA	Inverter Distribution and Control Assembly
IDP	Initialization Datapack
IFA	In-Flight Anomaly
IFC	International Fuel Cells
IFM	In-Flight Maintenance
IGP	Integrated Graphics Processor
IMU	Inertial Measurement Unit
IR	Infrared
IRD	Integrated Receiver Decoder
ISP	Information Sharing Protocol
ISS	International Space Station
IUV	Input Undervolt
JSC	Johnson Space Center
KOH	Potassium Hydroxide
KSC	Kennedy Space Center
L/O	Lift-Off
LAN	Local Area Network
LCA	Load Controller Assembly
LCC	Launch Commit Criteria
	Launch Control Complex
LES	Launch/Entry Suit
LF	Launch Forward
	Low Frequency (30 to 300 kHz)
LG	Landing Gear
LL	Low Limit
LOS	Loss of Signal
LPS	Launch Processing System
LRU	Line Replaceable Unit
LSC	Linear-Shaped Charge
MA	Master Alarm
MADS	Modular Auxiliary Data System
MAR	Middeck Accommodations Rack
MCA	Motor Controller Assembly

MCC	Mission Control Center
MDAC	McDonnell Douglas Aeronautics Company
MDF	Mild Detonating Fuse
	Minimum-Duration Flight
MDM	Multiplexer/Demultiplexer
MDRF	Mission Data Request Form
MDU	Multifunction Display Unit
MEC	Master Events Controller
MECO	Main Engine Cutoff
MED	Manual Entry Device
MEDS	Multifunction Electronic Display Subsystem
MER	Mission Evaluation Room
MET	Mission Elapsed Time
MEWS	Mission Evaluation Workstation System
MHz	Megahertz
MIS	Mission Information System
MJCA	Midbody Jettison Control Assembly
MMCA	Midmotor Control Assembly
MML	Master Measurement List
MMT	Mission Management Team
MNDA	Main Distribution Assembly
MOC	Mission Operations Computer
MOD	Mission Operations Directorate
MPC	Midpower Controller
MPCA	Midpower Control Assembly
MPS	Main Propulsion System
MPSR	Multipurpose Support Room
MRL	Manipulator Retention Latch
MRTC	Multiple Real-Time Command
MSID	Measurement Stimulus Identification
MSK	Manual Select Keyboard
MUP	Middeck Utility Panel
MV	Megavolt
NBS	National Bureau of Standards
NC	Normally Closed
NGT	NASA Ground Terminal
NOI	Note of Interest
NRT	Near Real Time
NSD	NASA Standard Detonator
NSI	NASA Standard Initiator
O/UV	Overvoltage/Undervoltage
OC	Overcurrent
OCA	Orbiter Communications Adapter
ODRC	Orbiter Data Reduction Center

ODS	Orbiter Docking System
OFS	Onboard Fault Summary
OI	Operational Instrumentation
OIGN	Orbiter Ignition (time before ignition)
OIT	Orbiter Integration Test
OL	Overload
OMI	Orbiter Maintenance Instruction
OMRS	Operations and Maintenance Requirements and Specifications
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	Orbital Maneuvering System
OOV	Output Overvolt
OPCL	Orbit Pocket Checklist
OPF	Orbiter Processing Facility
OSH	Offscale High
OSL	Offscale Low
OSTA	Office of Space and Terrestrial Applications
OV	Overvoltage
PAPA	Payload Ascent Power Assessment
PASS	Primary Avionics Software System
pbi	pushbutton indicator
PCA	Power Controller Assembly
PCM	Projected Consumables Management
	Pulse Code Modulation
PCMMU	Pulse Code Modulation Master Unit
PCS	Pressure Control System
PDB	Power Distribution Box
PDU	Power Drive Unit
PET	Payload Events Time
PF	Power Factor
PGSC	Payload General Support Computer
PIC	Pyrotechnic Initiator Controller
PIND	Particle Impact Noise Detection Test
PIRT	Plotting in Real Time
PL	Payload
PLB	Payload Bay
PLBD	Payload Bay Door
PLBF	Payload Bay Floodlight
PLS	Primary Landing Site
PPC	Pallet Power Control
PPCA	Pallet Power Control Assembly
PPH	Pounds Per Hour
PRG	Purge
PRLA	Payload Retention Latch Assembly

PROM	Programmable Read-Only Memory
PRSD	Power Reactant Storage and Distribution
PTC	Power Transfer Cable
PWM	Pulse Width Modulator
pyro	pyrotechnics
QA	Quality Assurance
QD	Quick Disconnect
R/T	Real Time
RAM	Random Access Memory
RAPS	Record and Playback System
RCS	Reaction Control System
RDCS	Reconfiguration Data Collection System
RF	Radio Frequency
RMS	Remote Manipulating System
ROEU	Remotely Operated Electrical Umbilical
RPC	Remote Power Controller
RR	Range Rate
RSO	Range Safety Officer
RSS	Range Safety System
RTC	Real-Time Command
RTL	Return to Launch Site
RTV	Room Temperature Vulcanizing
S&A	Safe and Arm
S/W	Software
SB	System Brief
SCA	Simulation Control Area
SCAP	Shuttle Configuration and Analysis Program
SCCM	Standard Cubic Centimeters Per Minute
SCCS	Standard Cubic Centimeters Per Second
SCP	Standard Console Procedure
SCR	Strip Chart Recorder
SDP	Shuttle Data Processor
SDRS	Shuttle Display Reconfiguration System
SDS	Shuttle Drawing System
SEM	Scanning Electron Microscope
SM	Systems Management
SMEK	Summary Message Enable Keyboard
SMS	Shuttle Mission Simulation/Simulator
SOCRATES	Software for Orbiter Consumables in Real Time for Atmospheric, Thermal, and Electrical Systems
SODB	Shuttle Operations Data Book
SOP	Standard Operating Procedure
SP	Special Process

SPT	Support
SRB	Solid Rocket Booster
SSDV	Substack Delta Volt
SSME	Space Shuttle Main Engine
SSP	Standard Switch Panel
SSR	Shop Support Request
SSSH	Space Shuttle Systems Handbook
SSTF	Space Station Training Facility
STP	Subsystem Test Plan
SU	Speaker Unit
T-O	Takeoff
TAL	Transoceanic Abort Landing
tb	talkback
TCE	Thermal Canister Experiment
TCP	Test and Checkout Procedure
TCS	Thermal Control System
TD	Touchdown
TDRS	Tracking and Data Relay System
TFL	Telemetry Format Load
THRIFT	Telemetry History Reports in Formatted Tabulations
TIG	Time to Ignition
TIPS	Thermal Impulse Printer System
TLM	Telemetry
TMA	Table Maintenance "A"
TMBU	Table Maintenance Block Update
TMCC	Temporary Mission Control Center
TOC	Table of Contents
TRAM	Tools for Resource Analysis
TT&E	Test, Teardown, and Evaluation
U/L	Uplink
UP	Universal Plot
USA	United Space Alliance
VAB	Vehicle Assembly Building
VED	Visual Text Editor
VFI	Verification Flight Instrumentation
VLT	Vent Line Temperature
W/S	Workstation
WEX	Workstation Executive
WMC	Waste Management Compartment
WOW	Weight on Wheels
WSGT	White Sands Ground Terminal
WSMC	Western Space and Missile Center

TITLE: EGIL Console Handbook

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