

# EVA Console Handbook

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EMU Operations

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EVA Group

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## **EVA Console Handbook EMU Operations**

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## REVISION LOG

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## **PREFACE**

This document has been prepared by the Extravehicular Activity (EVA) Systems Group under the authority of the EVA and Crew Systems Operations Branch, EVA, Robotics, and Crew Systems Operations Division, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration (NASA).

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## **PURPOSE**

The EVA Console Handbook provides a single authoritative source of primary information for use by EVA flight control personnel. For additional information, the reader should refer to training manuals and other documents referenced in this handbook.

## **SCOPE**

Information in this handbook is not flight-specific. It addresses systems and procedures used during Extravehicular Mobility Unit (EMU) operations.

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## 1.1 EMU PERFORMANCE MONITORING

### PURPOSE

To define information that can be used to analyze the performance of the Extravehicular Mobility Unit (EMU) during nominal and contingency operations. This section summarizes the consumables used by the EMU during the Extravehicular Activity (EVA).

### DESCRIPTION

There are five EMU consumable supplies that restrict the time a crewmember can spend in EVA: primary oxygen, Secondary Oxygen Pack (SOP) oxygen, water, battery power, and Carbon Dioxide (CO<sub>2</sub>) removal. Before an EVA begins, the EMU is supplied with a nominal amount of each of the following consumables. These consumables are listed below along with nominal capacities or design requirements.

**Table 1.1-1. EMU consumable capacity**

Consumable	Capacity
Primary oxygen	Two 240 in <sup>3</sup> bottles store 1.217 lb of usable O <sub>2</sub> at 850 psig and 90° F
Secondary oxygen	Two 89.2 in <sup>3</sup> bottles store 2.631 lb of usable O <sub>2</sub> at 5800 psig and 80° F
Water tanks	Two primary tanks hold 8.35 lb water, and one reserve tank holds 0.83 lb water for a total of 9.18 lb
Battery	Increased Capacity Battery (ICB) – 11 silver-zinc cells provide a minimum of 32 amp-hr at 16.8 V dc Lithium Ion Battery (LIB) – 25 cells provide a minimum of 32 amp-hr
CO <sub>2</sub> removal	LiOH - 2.45 lb minimum LiOH to convert 1.48 lb CO <sub>2</sub> METOX - 1.6 lb CO <sub>2</sub> absorption capacity (8000 BTU) for 55 regeneration cycles. EVA capacity - 1.48 lbs (7400 BTU) plus 30 minute margin @ 1200 BTU/hr

## 1.2 CWS STATUS LIST AND MESSAGES

### PURPOSE

This section describes the status list and explains the criteria used for displaying status list messages. All other messages and message numbers are listed, as well. Every message has an associated message number, which is used by the caution and warning system (CWS) to display the message and to determine priority. Caution and warning (C/W) criteria and priority are discussed in Section 1.6, Volume 4.

### DESCRIPTION

The CWS presents data to the EVA crewmember via the 12-character alphanumeric liquid crystal display (LCD) located on the display and control module (DCM). During normal operations, the status list is accessed to monitor current EMU conditions. The status list data varies, depending on the conditions in the airlock, the operations being performed, and the position of the Power Mode switch. Table 1.2-1 shows the contents of the status list for each Power Mode switch position, and the notes below the table explain the conditions for individual lines in the status list.

Depressing the STATUS switch will display the status list one item at a time. If an item in the status list is displayed for more than 20 seconds, the display returns to the default message (Table 1.2-7). Depressing the STATUS switch again returns the display to the last status list message displayed.

To preclude multiple fault message interference and to control the order in which multiple messages are displayed, each fault message is assigned a priority rating. The message with the highest priority is displayed. Lower priority failures are also displayed without the corrective action statement.

Table 1.2-2 through Table 1.2-8 present all the C/W messages and the associated message numbers used by the CWS. The message number is also part of the serial data stream that is discussed in Section 1.8, Volume 4.



**Table 1.2-1. Status list messages**

VEHICLE POWER		BATTERY POWER	
O2 POS _____	(1)	O2 POS _____	(1)
AIRLK P or SUBLM P	(2)	AIRLK P or SUBLM P	(2)
Lim Consum/TIME LF	(3)	TIME EV	
SUIT P		Lim Consum/TIME LF	(3)
O2 P		O2 LF %	(8)
SOP P		PWR LF %	(9)
BAT VDC		SUIT P	
BAT AMPS		O2 P	
RPM		O2 RATE	(10)
CO2		SOP P	
H2O TEMP		BAT VDC	
H2O GP		BAT AMPS	
H2O WP		RPM	
DATA? _____		CO2	
BATT ___._ AH	(4)	H2O TEMP	
BATT? ___._ AH	(5)	H2O GP	
BTA? ____	(6)	H2O WP	
LEAK CHECK?	(7)	DATA? _____	
END STATUS		BATT ___._ AH	(4)
		BATT? ___._ AH	(5)
		BTA? ____	(6)
		LEAK CHECK?	(7)
		END STATUS	

Notes:

1. If the O2 position is the default display then it will not be repeated in the status list.
2. If the AIRLK P is the default display then it will not be repeated in the status list. In XSTATE 7 this line of the status list will read SUBLM P instead of AIRLK P.
3. This status list message is only available in XSTATE 7. If your limiting consumable is the default display, then it will not be repeated in the status list.
4. This message is displayed when changing the battery amp-hrs is not allowed. This is true in XSTATEs 3, 5, 6, and 7.
5. This message is displayed in XSTATEs 1, 2, 4, and 8.
6. This message is displayed in XSTATEs 1, 2, 3, and 8.
7. This message is displayed in XSTATEs 1, 2, and 4.
8. This message is not displayed if the vehicle power is sensed, or if it is the limiting consumable (it would be listed with the limiting consumable status list message instead).
9. This message is not displayed if it is the limiting consumable (it would be listed with the limiting consumable status list message instead).
10. This message is not displayed if the SCU is connected (vehicle power is sensed).

**Table 1.2-2. Anomaly messages**

102	SOP O2 ON TIME LF' ___'___ SUIT P ___.	165	CO2 SNSR BAD
103	O2 LF ___% TIME LF ___'___	166	CO2 HIGH SET O2 EVA
104	PWR LF ___% TIME LF ___'___	167	CO2 HIGH OPEN PURGE V
105	RESRV H2O ON TIME LF ___'___	168	SET O2 EVA
108	BATT V DECAY BAT VDC ___.	169	SET O2 PRESS AIRLK REPRES
140	___ FAULTS	170	O2 ACT FAULT
141	END FAULTS	171	SUBLM P ___. SET H2O OFF
150	BATT AMPS HI BAT AMPS ___.	172	H2O GP LOW
151	BATT VDC LOW BAT VDC ___.	173	H2O IS OFF
152	SUIT P LOW SUIT P ___.	174	SET H2O OFF
153	SUIT P LOW SET O2 EVA SUIT P ___.	175	H2O WP HIGH H2O WP ___.
154	SUIT P EMERG CLOSE PURG V SUIT P ___.	176	MONITOR CO2 CO2 ___ MM
155	SUIT P LOW REPRES AIRLK SUIT P ___.	177	14V SUP FAIL
156	RLF V FAIL STOP DEPRESS SUIT P ___.	178	5V REF FAIL
157	SUIT P HIGH O2 RATE ___. SOP RATE _____	179	SCU PWR AVAL
158	O2 USE HIGH O2 RATE ___.	180	DRAM FAIL
159	SOP P LOW SOP P _____ SOP RATE _____	181	EE CSUM FAIL
160	SW/FAN FAIL	182	BUS CK FAIL
161	NO VENT FLOW SET O2 EVA	183	BOO CSUM BAD
162	NO VENT FLOW	184	WAT DOG FAIL
163	FAN SW OFF	185	FW ANOMALY
164	VENT SW FAIL	240	O2 IS OFF

**Table 1.2-3. Power restart messages**

001	PWR RESTART VERS ____
002	PWR RESTART
003	BOOT V ____ (Boot Mode only)

**Table 1.2-4. POR Display Test messages**

010	CONT TONE
011	WARBL TONE
012	DISP TEST
013	8888888888888 +++++++ XXXXXXXXXXXXX @ABDHP? (Test Mode only)

**Table 1.2-5. Status messages**

020	O2 POS - ____	055	29.5 AMPHR ?
021	AIRLK P ____ or SUBLM P ____	056	30.0 AMPHR ?
022	TIME EV ' ____	057	30.5 AMPHR ?
023	"LIMITING CONSUMABLE" TIME LF ' ____	058	31.0 AMPHR ?
024	O2 LF ____%	059	31.5 AMPHR ?
025	PWR LF ____%	060	32.0 AMPHR ?
026	SUIT P ____	061	32.5 AMPHR ?
027	O2 P ____	062	33.0 AMPHR ?
028	O2 RATE ____	063	33.5 AMPHR ?
029	SOP P ____	064	34.0 AMPHR ?
031	BAT VDC ____	065	34.5 AMPHR ?
032	BAT AMPS ____	066	35.0 AMPHR ?
033	RPM ____ K	067	35.5 AMPHR ?
034	CO2 ____ MM	068	36.0 AMPHR ?
035	H2O TEMP ____	069	36.5 AMPHR ?
036	H2O GP ____	070	37.0 AMPHR ?
037	H2O WP ____	071	37.5 AMPHR ?
038	DATA?" ____"	072	38.0 AMPHR ?
040	DATA COMBO?	073	38.5 AMPHR ?
041	DATA EMU?	074	39.0 AMPHR ?
042	DATA BIO?	075	39.5 AMPHR ?
047	BATT ____ AH	076	40.0 AMPHR ?
048	BATT ? ____ AH	077	BTA? ____
049	26.6 AMPHR ?	078	DISABLE BTA?
050	27.0 AMPHR ?	079	LEAK CHECK?
051	27.5 AMPHR ?	081	_____
052	28.0 AMPHR ?	082	_____
053	28.5 AMPHR ?	083	_____
054	29.0 AMPHR ?	086	END STATUS
		087	ENABLE BTA?

Leak check messages are displayed during the automatic leak check that is performed by the CWS.

**Table 1.2-6. Leak check messages**

200	SUIT LEAK CK SET O2 PRESS	207	LEAK CK COMP SET O2 PRESS
201	SUIT P _._ PRESSURIZING	208	LEAK CK COMP SET O2 EVA
202	SET O2 IV	209	STABILIZING TIME LF' _' _ SUIT P _._
204	LEAK CK-WAIT MIN LF' _' _ SUIT P _._	215	SUIT P _._ PRESSURIZING
205	LEAKAGE HI SUIT P _._	216	PRESS FAIL SUIT P _._
206	LEAK CK COMP O2 POS IV		

The default message depends on the X-state, time left on consumables, and if the airlock pressure is changing.

**Table 1.2-7. Default messages**

		Message Priority
099	"BLANK"	7
101	BTA ENABLED	6
102	SOP O2 ON TIME LF _' _ SUIT P _._	2
103	O2 LF ___% TIME LF _' _	4
104	PWR LF ___% TIME LF _' _	4
105	RESRV H2O ON TIME LF _' _	4
106	AIRLK P _._	3
107	O2 POS ___	8

The RS485 port is used to program or update the CWS. It can also be used to download a list of malfunction messages. This port is also intended to allow for expansion devices to be added at a later time. This port is not currently used on orbit since the cable required to interface with it has not been built and no expansion devices have been identified.

**Table 1.2-8. RS485 Alert Messages**

080	RS485 +____	084	RS485 -____
-----	-------------	-----	-------------

RS485+ indicates that a device on the RS485 has been found.

RS485- indicates that a device on the RS485 has been lost.

**REFERENCE**

Based on System Version: eCWS Ver: 18.6; 26 May 2006

### 1.3 X-STATE PROFILE

#### PURPOSE

The purpose of this section is to provide necessary information on EMU X-states and how to transition from one state to another.

#### DESCRIPTION

The Caution and Warning System (CWS) software monitors hardware and software to determine the state of the EMU. The state corresponds to the stage or phase of the EMU mission. The state is used to determine particular failure conditions (limits) used by the CWS.

<u>X-State</u>	<u>Operation</u>
1	Stowage and EMU donning operations
2	EMU donned/IV operations
3	Used for BTA operations (see Sec. 3.2)
4	Start of airlock depress
5	Airlock depress below 4.2 psia
6	End of airlock depress
7	EVA operations
8	Airlock repress

As the mission progresses, the CWS automatically transitions to the appropriate X-state, based on suit configuration and environment. During a nominal mission, the X-state increments sequentially. The X-state transition events and the conditions for that transition are outlined in Table 1.3-1.

**Table 1.3-1. X-state transition events for the CWS**

Current X-state	Next X-state	Conditions
Any state	1	<ul style="list-style-type: none"> <li>O2 ACT = OFF</li> <li>FAN = OFF</li> <li>PWR RESTART</li> </ul>
1 →  Unmanned	2	<ul style="list-style-type: none"> <li>FAN = ON</li> <li>O2 ACT = IV, <i>PRESS</i>, or <i>EVA</i></li> </ul>
	4	<ul style="list-style-type: none"> <li>AIRLK P &lt; 7.5 PSIA or AIRLK ΔP ↓ ≥ 0.5 PSIA</li> </ul>
	7	<ul style="list-style-type: none"> <li>O2 ACT = EVA</li> <li>WATER = ON</li> <li>WATER TEMP &lt; 60°F</li> </ul>
2 →  Manned	8	<ul style="list-style-type: none"> <li>AIRLK ΔP ↑ ≥ 0.5 PSIA</li> </ul>
	4	<ul style="list-style-type: none"> <li>AIRLK P &lt; 7.5 PSIA or AIRLK ΔP ↓ ≥ 0.5 PSIA</li> </ul>
4 →  Depress	7	<ul style="list-style-type: none"> <li>O2 ACT = EVA</li> <li>WATER = ON</li> <li>WATER TEMP &lt; 60°F</li> </ul>
	8	<ul style="list-style-type: none"> <li>AIRLK ΔP ↑ ≥ 0.5 PSIA</li> </ul>
5 →  Depress	6	<ul style="list-style-type: none"> <li>AIRLK P &lt; 1.0 PSIA</li> </ul>
	7	<ul style="list-style-type: none"> <li>O2 ACT = EVA</li> <li>WATER = ON</li> <li>WATER TEMP &lt; 60°F</li> </ul>
6 →  Depress	8	<ul style="list-style-type: none"> <li>AIRLK ΔP ↑ ≥ 0.5 PSIA</li> </ul>
	7	<ul style="list-style-type: none"> <li>WATER = ON</li> <li>AIRLK ΔP ↑ = 0</li> </ul> OR <ul style="list-style-type: none"> <li>X = 6 FOR 4 MIN.</li> </ul> OR <ul style="list-style-type: none"> <li>O2 ACT = EVA</li> <li>WATER = ON</li> <li>WATER TEMP &lt; 60°F</li> </ul>
7 →  EVA	8	<ul style="list-style-type: none"> <li>O2 ACT ≠ EVA</li> <li>WATER = OFF</li> </ul> OR <ul style="list-style-type: none"> <li>WATER = OFF</li> <li>O2 ACT = EVA</li> <li>AIRLK P &gt; 1.45 PSIA after AIRLK P &lt; 1.0 PSIA</li> </ul>
	7	<ul style="list-style-type: none"> <li>O2 ACT = EVA</li> <li>WATER = ON</li> <li>WATER TEMP &lt; 60°F</li> </ul>
8 →  Repress	4	<ul style="list-style-type: none"> <li>AIRLK ΔP ↓ ≥ 0.5 PSIA</li> </ul>

## REFERENCES

Based on System Version: eCWS Ver: 18.6; 26 May 2006



## 1.4 CWS INSTRUMENTATION PROFILE

### PURPOSE

This section describes analog and discrete inputs to the CWS. The Oxygen (O2) actuator position indication is also discussed.

### DESCRIPTION

The CWS monitors the configuration of the EMU when power is applied. The CWS collects the value of each parameter and compares it to limits set by the suit configuration. If a failure or operator sequence error is detected, the appropriate fault message is generated. This process is discussed in Section 1.6, Volume 4. The parameters monitored by the CWS are defined in Table 1.4-1 and Table 1.4-2.

**Table 1.4-1. Analog inputs**

Item No.	Sensor Type	Parameter	Range
*112	Pressure sensor	Primary O2 tank pressure	0 - 1100 ±27.5 psia
*114	Pressure sensor	Suit pressure	0 - 6 ±0.15 psid
*138	Pressure sensor	Sublimator feedwater	0 - 16 ±0.4 psia
*132A	Pressure sensor	H2O reservoir O2 pressure	0 - 40 ±1.0 psia
*132B	Pressure sensor	H2O reservoir H2O pressure	0 - 40 ±1.0 psia
*215	Pressure sensor	SOP O2 tank pressure	0 - 7400 ±259 psia
*122	CO2 sensor	CO2 partial pressure	0 - 30 ±2.0 mmHg. See below
*139	Temperature sensor	Sublimator outlet temp	32 - 104 ±1.5°F
*121	Vent flow switch	Ventilation flow	3.7 - 5.4 CFM: switch point
	BATT: voltage	Battery voltage	Analog 0 - 25 ±0.6 VDC
	BATT: voltage(1)	Battery current	Analog 0 - 10 ±0.3 amps
	A/D reference voltage	A/D reference voltage	4.925 - 5.075 ±0.004 VDC
	95% ref. voltage	5V reference voltage	4.77 ±0.10 VDC
	5% ref. voltage	5V reference voltage	0.22 ±0.01 VDC
	Negative supply voltage	Negative analog power	~14.0 ±2.0 VDC (nominal)
	Positive supply voltage	Positive analog power	+14.0 ±2.0 VDC (nominal)
	Motor tach: frequency	Motor RPM	0 - 25,000 RPM ±100 RPM
	Spare 1	TBD	0-5 VDC
	Spare 2	TBD	0-5 VDC

\*Reference EMU integrated schematic.

(1) The voltage across a 0.016-ohm resistor is used to determine the current draw from the system.

**Table 1.4-2. Discrete inputs**

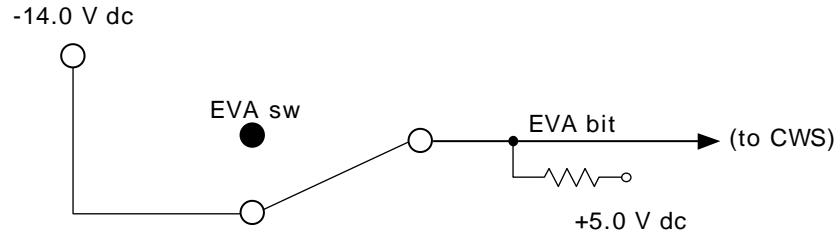
Discrete Input	0	1
CWS Switch In	Normal	CWS IN
CWS Switch Out	Normal	CWS OUT
PWR MODE BATT	SCU	BATT
Vehicle PWR	OFF	ON
Vent Flow Switch	No Flow	Flow
Fan Pump Switch	OFF	ON
O2 Actuator OFF/PRESS (1)	False	True
O2 Actuator IV/PRESS (1)	False	True
O2 Actuator EVA (2)	False	True
BOOT	ACTIVE	INACTIVE
TEST	ACTIVE	INACTIVE
Feedwater Discrete 1	OFF	ON
Feedwater Discrete 2	OFF	ON

(1) Three switches set the state of two inputs to the CWS. See below for details.

(2) In the CWS the discrete value of 0 = O2 Act is EVA, however the CWS reverses this bit prior to packaging it in the serial data stream for downlink. So, on the ground we will see a discrete value of 1 = O2 Act is EVA.

## O2 ACTUATOR POSITION INDICATIONS

The O2 actuator position is determined by three discrete inputs or bits sent to the CWS. These discretely reflect the OPEN or CLOSED positions of four microswitches: PRESS, OFF, IV, and EVA. The PRESS, OFF, and IV microswitches set the **OFF/PRESS** and **IV/PRESS** bits. The EVA microswitch is dedicated to indicating the EVA position and sets only the **EVA** bit. When the O2 actuator is not in EVA (EVA bit = 0, FALSE), the CWS uses the OFF/PRESS and IV/PRESS bits to determine the O2 actuator position. For the DCM status, the CWS will ignore OFF/PRESS and IV/PRESS bits when it detects that the O2 actuator is in the EVA position (EVA bit = 1, TRUE), indicating "O2 ACT EVA." See Figure 1.4-1 to Figure 1.4-5 for switch contact diagrams depicting the O2 actuator in all possible positions. Also, see Table 1.4-3 and Table 1.4-4 for switch and CWS logic for EVA and OFF/PRESS/IV/In-Between switch positions.



Switch indicates O2 ACT = EVA

● - Indicates the normally closed terminal

jsc\_20597\_030.cvs

**Figure 1.4-1. O2 ACT in EVA position**

**Table 1.4-3. CWS logic for EVA switch position**

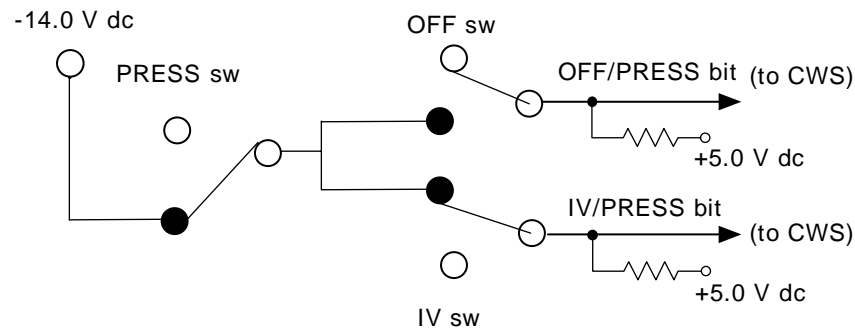
O2 ACTUATOR	EVA sw *	EVA bit *
EVA	0	1
not EVA	1	0

Note: CWS Logic for EVA bit

CLOSED = -14.0 VDC
OPEN = +5.0 VDC

on workstation display, 1 = ON, 0 = OFF

\* The low indication from the microswitch indicates to the CWS that the O2 Act is EVA. This is a discrete value of 0 to the CWS. When the CWS packages this information in the serial data stream for downlink it reverses this bit indication. This means that in MCC we will see a discrete value of 1 when the O2 Act is in the EVA position.

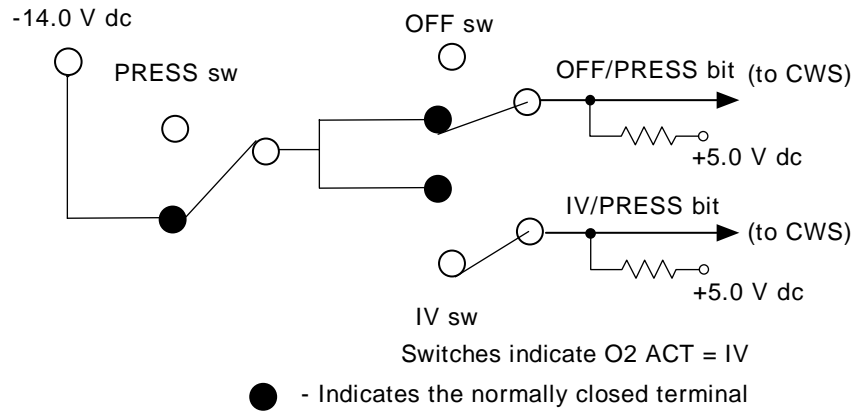


Switches indicate O2 ACT = OFF

● - Indicates the normally closed terminal

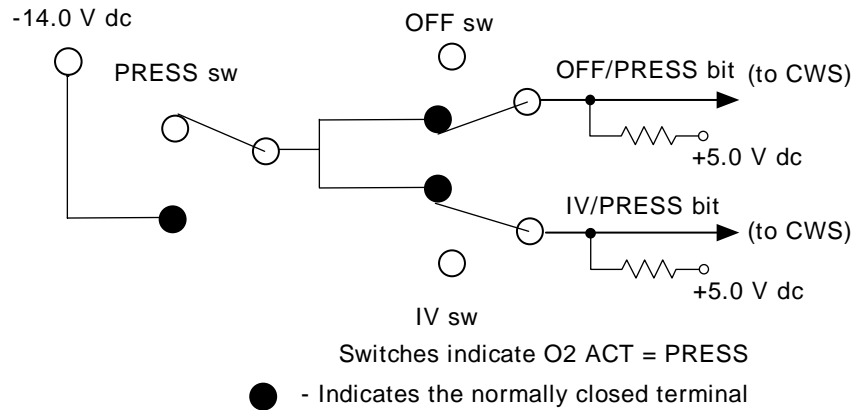
jsc\_20597\_031a.cvs

**Figure 1.4-2. O2 ACT in OFF position**



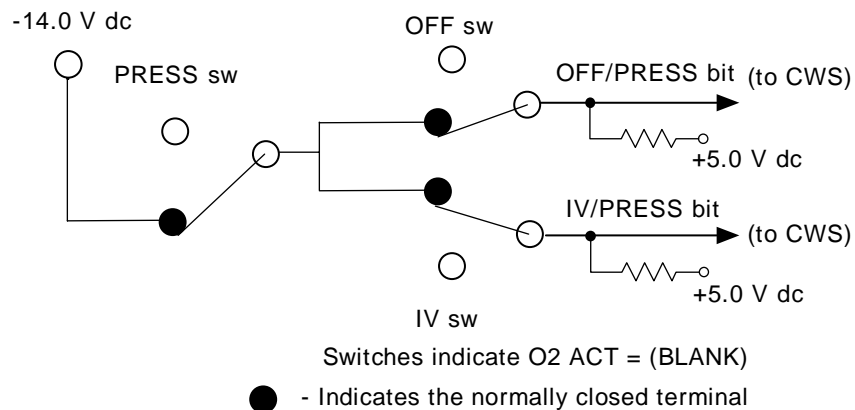
jsc\_20597\_031b.cvs

**Figure 1.4-3. O2 ACT in IV position**



jsc\_20597\_031c.cvs

**Figure 1.4-4. O2 ACT in PRESS position**



jsc\_20597\_031d.cvs

**Figure 1.4-5. O2 ACT in-between positions**

**Table 1.4-4. CWS logic for OFF/IV/PRESS/in-between switch positions**

O2 ACTUATOR	OFF/PRESS bit	IV/PRESS bit
OFF	1	0
IV	0	1
PRESS	1	1
In-between	0	0

Note: CWS Logic for OFF/PRESS and IV  
PRESS bits

CLOSED = -14.0 VDC = 0 = FALSE
OPEN = +5.0 VDC = 1 = TRUE

On workstation, TRUE = **ON**, FALSE = **OFF**

The CWS interprets discrete inputs in the following manner. For the OFF/PRESS and IV/PRESS discrettes, -14.0 V dc sets the bit = 0 or FALSE, +5.0 V dc sets the bit =1 or TRUE. On the MCC console EMU data display, OFF means FALSE, and ON means TRUE. The PRESS, OFF, and IV microswitches are normally CLOSED. When the O2 actuator is placed in one of the valid positions (i.e., not in-between positions) one or more switch contacts OPEN to indicate the position selected. The EVA microswitch, located in the PLSS, is OPEN until the O2 actuator is placed in the EVA position, changing the EVA bit from 0 to 1, or FALSE to TRUE. These data are also transmitted in the serial data stream (Volume 4, Section 1.8).

### **ANALOG SENSOR CALCULATIONS**

With the exception of the CO<sub>2</sub> partial pressure transducer, the remaining EMU analog suit sensors produce linear output throughout their range. In this section, the conversion from analog voltage at the sensor to a digital or binary representation, and finally to a decimal (real world) value, in the appropriate engineering units for each linear sensor, will be shown. See Table 1.4-5.

**Table 1.4-5. Suit sensors linear output**

Analog parameter	Sensed units	Sensor output	No. of bits assigned parameter	No. of unique values	Resolution	Conversion from binary (counts) to volts
Suit pressure	0 - 6 psid	0 - 5 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Primary O <sub>2</sub> pressure	0 - 1100 psia	0 - 5 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
SOP pressure	0 - 7400 psia	0 - 5 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Sublimator pressure	0 - 16 psia	0 - 5 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Battery volts *	0 - 25 Volts	0 - 10 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Battery current *	0 - 10 amps	0 - 10 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Sublimator temp.	0 - 40 deg. C	5 - 0 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
H <sub>2</sub> O gas pressure	0 - 40 psia	0 - 5 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
H <sub>2</sub> O water pressure	0 - 40 psia	0 - 5 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
5 Volt Reference *	0 - 5 V	0 - 10 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Positive Supply Volts *	0 to 17.15 V	0 - 10 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Negative Supply Volts *	0 to -16.91 V	0 - 10 V	12	$2^{12} = 4096$	4096 counts / 10 V	Counts * (10 V / 4096)
Motor tach	0 - 25 k RPM	0 - 255	8	$2^8 = 256$	1 count / 100 RPM	Counts * 100 RPM
CO <sub>2</sub> partial pressure**	0 - 30 mmHg	0 - 5 V***	12	$2^{12} = 4096$	4096 counts / 5 V	Counts * (5 V / 4096)

\* Not a transducer, just a voltage that is scaled to 0 to 10 volts at the A/D converter; 0 to 10 volts is the limit of the A/D converter. For the battery current, the voltage across a 0.016-ohm resistor is used to determine the current draw from the system.

\*\* Conversion to mmHg is not linear.

\*\*\* The CWS and ICD for MCC define voltages of less than 0.5 V as 0 mmHg.

The Infrared CO<sub>2</sub> sensor is sensitive to absolute suit pressure and the CWS nominally corrects the CO<sub>2</sub> level to provide a pressure compensated value in the CWS status list (reference Section 2.1, CWS Calculations, for detailed CO<sub>2</sub> Partial Pressure Calculations). The actual CO<sub>2</sub> range for a particular CWS value includes CO<sub>2</sub> sensor error, calculation errors, as well as suit pressure and sublimator pressure sensor errors and unit conversion errors. All CO<sub>2</sub> transducers are calibrated at 8 psia. If pressure compensation is not available due to the loss of either the Suit P sensor or the Sublimator P sensor, the CWS will automatically revert to the nonpressure compensated limits (3mmHg and 8mmHg). Table 1.4-5 illustrates these two scenarios of pressure compensated vs. nonpressure compensated CO<sub>2</sub> levels and the actual CO<sub>2</sub> range associated with each CWS message.

**Table 1.4-6. CO<sub>2</sub> sensor indication vs. actual PPCO<sub>2</sub> – with pressure compensation and without pressure compensation**

Suit operating pressure (psia)	PPCO <sub>2</sub> levels with suit pressure compensation		PPCO <sub>2</sub> levels without suit pressure compensation	
	CWS Indicated (mmHg)	Actual CO <sub>2</sub> (mmHg)	CWS Indicated (mmHg)	Actual CO <sub>2</sub> (mmHg)
4.3 EVA	8.0 (MONITOR CO <sub>2</sub> )	6.4 – 9.6	3.0 (MONITOR CO <sub>2</sub> )	3.6 – 5.6
	12.4 (CO <sub>2</sub> HIGH)	10.3 – 14.7	8.0 (CO <sub>2</sub> HIGH)	10.6 – 13.0
	44.9 (saturated)	--	30 (saturated)	--
11.1 (10.2 Cabin)	8.0 (MONITOR CO <sub>2</sub> )	6.7 – 9.6	3.0 (MONITOR CO <sub>2</sub> )	1.3 – 3.6
	12.4 (CO <sub>2</sub> HIGH)	10.7 - 14.7	8.0 (CO <sub>2</sub> HIGH)	5.8 – 7.8
	23.9 (saturated)	--	30 (saturated)	25.0
15.6 (14.7 Cabin)	8.0 (MONITOR CO <sub>2</sub> )	6.9 – 9.6	3.0 (MONITOR CO <sub>2</sub> )	1.0 – 3.0
	12.4 (CO <sub>2</sub> HIGH)	11.1 – 14.7	8.0 (CO <sub>2</sub> HIGH)	4.3 – 6.3
	18.3 (saturated)	--	30 (saturated)	19.0
23.5 BTA (14.7 Cabin + 8.8 psi)	8.0 (MONITOR CO <sub>2</sub> )	6.3 – 10.2	3.0 (MONITOR CO <sub>2</sub> )	0.5 – 2.5
	12.4 (CO <sub>2</sub> HIGH)	10.1 - saturated	8.0 (CO <sub>2</sub> HIGH)	3.0 – 5.0
	12.3 (saturated)	--	30 (saturated)	13.8

## REFERENCES

NASA EMU LSS and SSA Data Book

SVHS10105, 1992

EMUM – 1388

EVAM-0215, IRCO<sub>2</sub> Sensor Pressure Compensation with ECWS

SVHSER21080 Software Requirements Specification for the EMU Enhanced Caution and Warning System, Rev. G, 31 March 05

Based on System Version: eCWS Ver: 18.6; 26 May 2006



## 1.5 CWS FAULT STACK AND MESSAGE PRIORITY

### PURPOSE

This section describes Caution and Warning System (CWS) message priority and the conditions that cause these messages to be displayed.

### DESCRIPTION

When the CWS detects an anomalous condition, the corresponding anomaly message is displayed on the DCM LCD and the warning (warble) tone is activated. Table 1.6-1 lists the anomaly messages, the applicable x-states, and the conditions required for anomaly annunciation. Multi-line messages are displayed for 2 seconds per message line. If the anomaly is a BITE failure, the BITE light is illuminated in addition to the message text. The warning tone and message continue for 5 minutes unless acknowledged by sw DISP → PRO. The tone ceases after 5 minutes, however, the message continues to be displayed until acknowledged or another message comes into alarm.

Once a message has been acknowledged by the crewmember, the message continues to be displayed for 20 seconds and then the DCM display returns to the appropriate default display. For the majority of messages, if sw DISP → PRO or sw DISP → STATUS, the display jumps to the most applicable parameter in the status list (noted in the comments column in Table 1.5-1).

The Fault Stack is a prioritized list of all warning messages currently in alarm. It is accessed from the default display by sw DISP → YES (hold for 2 seconds). If no other switch throws are made, the Fault Stack is displayed in an automatic mode, with each line displayed for 2 seconds.

If no messages are currently in alarm:

NO FAULTS

END FAULTS

Default Display

If messages are currently in alarm:

1 FAULT or ## FAULTS

FAULT 1

Highest Priority Warning Message

FAULT #

Next Highest Warning Message

(Pattern repeats until all Warning Messages have been displayed)

**END FAULTS**

Default Display

The crewmember can also elect to navigate the Fault Stack manually. While in the Fault Stack, sw DISP → STATUS moves down the stack line-by-line. Conversely, sw DISP → PRO moves up the stack FAULT # - by - FAULT #. Inactivity on the sw DISP for 20 seconds or sw DISP → NO (hold for 2 seconds) exits the Fault Stack manual mode and returns to the default display. The automatic mode can be restored at any point in the Fault Stack by sw DISP → YES (hold for 2 seconds).

**Table 1.5-1. Anomaly messages**

Display ID	Message	X-State	Conditions	Comments
178	5V REF FAIL * 5V REF FAIL * 5V REF FAIL *	ALL	<ul style="list-style-type: none"> <li>5% and/or 95% reference is outside of acceptable limits</li> </ul>	<ul style="list-style-type: none"> <li>95% Limits = 4.77 V ± 0.10 V</li> <li>5% Limits = 0.227 V ± 0.01 V</li> <li>Cold restart required to clear BITE light</li> </ul>
150	BATT AMPS HI BAT AMPS ___	ALL	<ul style="list-style-type: none"> <li>BAT AMPS &gt; 5.0 [4.8] for &gt; 5 sec</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to BAT AMPS ___</li> </ul>
151	BATT VDC LOW BAT VDC ___	ALL	<ul style="list-style-type: none"> <li>BAT V dc &lt; 16.5 [16.7]</li> <li>BAT AMPS &lt; 5.0 [4.8]</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>BAT V dc &lt; 16.5 [16.7]</li> <li>BAT AMPS &gt; 5.0 [4.8] for ≤ 5 sec</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to BAT VDC ___</li> </ul>
152	SUIT P LOW SUIT P ___	ALL	<ul style="list-style-type: none"> <li>O2 POS = EVA</li> <li>3.20 [3.10] &lt; SUIT P &lt; 4.05 [4.1] psid</li> <li>SOP RATE &lt; 24 [36] psid/min</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUIT P ___</li> </ul>
153	SUIT P LOW SET O2 EVA SUIT P ___	1,2,4,6,7,8	<ul style="list-style-type: none"> <li>O2 POS ≠ EVA</li> <li>SUIT P &lt; 4.05 [4.1] psia</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUIT P ___</li> </ul>
154	SUIT P EMERG CLOSE PURG V SUIT P ___	5,6,7,8	<ul style="list-style-type: none"> <li>O2 POS = EVA</li> <li>SUIT P ≤ 3.10 [3.20] psid</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUIT P ___</li> <li>Invalidates CO2 Sensor pressure compensation</li> <li>CWS assumes SOP is on</li> </ul>
102	SOP O2 ON TIME LF' ___ SUIT P ___	1, 2, 4	<ul style="list-style-type: none"> <li>O2 POS = EVA</li> <li>SUIT P &lt; 3.1 [3.2] psid</li> </ul>	<ul style="list-style-type: none"> <li>Becomes the default display</li> </ul>
102	SOP O2 ON TIME LF' ___ SUIT P ___	5, 6, 7, 8	<ul style="list-style-type: none"> <li>O2 POS = EVA</li> <li>SUIT P &lt; 4.05 [4.1] psid</li> <li>SOP RATE &gt; 36 [24] psid/min</li> </ul>	<ul style="list-style-type: none"> <li>Becomes the default display</li> </ul>
155	SUIT P LOW REPRES AIRLK SUIT P ___	5	<ul style="list-style-type: none"> <li>O2 POS ≠ EVA</li> <li>SUIT P &lt; 4.05 [4.10] psid</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUIT P ___</li> </ul>

**Table 1.5-1. Anomaly messages (continued)**

Display ID	Message	X-State	Conditions	Comments
156	RLF V FAIL STOP DEPRESS SUIT P _._	1,2,4,5,6,7,8	<ul style="list-style-type: none"> <li>SUIT P &gt; 5.7 psid</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to O2 P ____</li> <li>Invalidates CO2 Sensor pressure compensation</li> <li>Requires cold restart to clear message</li> </ul>
157	SUIT P HIGH O2 RATE _._ SOP RATE ____	1, 2	<ul style="list-style-type: none"> <li>SUIT P &gt; 4.55 [4.50] psid</li> <li>X-State = 1 or 2 for &gt; 30 sec</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUIT P _._</li> </ul>
157	SUIT P HIGH O2 RATE _._ SOP RATE ____	7	<ul style="list-style-type: none"> <li>SUIT P &gt; 5.10 [5.05] psid</li> <li>X-State = 7 for &lt; 10 min</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>SUIT P &gt; 4.55 [4.50] psid</li> <li>X-State = 7 for &gt; 10 min</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUIT P _._</li> </ul>
157	SUIT P HIGH O2 RATE _._ SOP RATE ____	8	<ul style="list-style-type: none"> <li>SUIT P &gt; 4.55 [4.50] psid</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUIT P _._</li> </ul>
158	O2 USE HIGH O2 RATE _._	1,2,3,4,5,6,7	<ul style="list-style-type: none"> <li>Vehicle volts not sensed</li> <li>O2 RATE &gt; 10.2 [7.0] psi/min</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>Vehicle volts not sensed</li> <li>O2 P &lt; 150 [160] psi</li> <li>TIME EV &lt; 5 hours</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to O2 P ____</li> </ul>
159	SOP P LOW SOP P ____ SOP RATE ____	All	<ul style="list-style-type: none"> <li>SOP O2 ON is not present</li> <li>SOP P &lt; 4500 [4700] psia</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>SOP O2 ON is not present</li> <li>SOP is off per the CWS</li> <li>SOP P decrease &gt; 600 [500] psi since last cold restart</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SOP P ____</li> </ul>
108	BATT V DECAY BAT VDC _._	All	<ul style="list-style-type: none"> <li>sw POWER = BATT</li> <li>BAT V dc &lt; 17.5 [17.7] V</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to BAT V dc _._</li> </ul>
160	SW/FAN FAIL	All	<ul style="list-style-type: none"> <li>sw FAN = ON for &gt; 7 sec</li> <li>RPM ≤ 11.0 K</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>sw FAN = OFF for &gt; 7 sec</li> <li>RPM &gt; 11.0 K</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to RPM _._ K</li> </ul>
161	NO VENT FLOW SET O2 EVA	6, 7	<ul style="list-style-type: none"> <li>O2 POS ≠ EVA</li> <li>SOP is off per the CWS</li> <li>O2 RATE &lt; 24.0 psi/min</li> <li>sw FAN = ON</li> <li>Vent Flow Sensor = NO FLOW</li> <li>&gt; 7 sec since last sw FAN or Vent Flow Sensor change</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to RPM _._ K</li> </ul>

**Table 1.5-1. Anomaly messages (continued)**

Display ID	Message	X-State	Conditions	Comments
162	NO VENT FLOW	All	<ul style="list-style-type: none"> <li>SOP is off per the CWS</li> <li>O2 RATE &lt; 24.0 psi/min</li> <li>sw FAN = ON</li> <li>Vent Flow Sensor = NO FLOW</li> <li>&gt; 7 sec since last sw FAN or Vent Flow Sensor change</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to RPM __ _ K</li> </ul>
163	FAN SW OFF	2,3,4,5,6,7,8	<ul style="list-style-type: none"> <li>SOP is off per the CWS</li> <li>O2 RATE &lt; 24.0 psi/min</li> <li>sw FAN = OFF</li> <li>SUIT P &gt; 0.25 psid</li> <li>&gt; 7 sec since last sw FAN or Vent Flow Sensor change</li> </ul>	
164	VENT SW FAIL	All	<ul style="list-style-type: none"> <li>SOP is off per the CWS</li> <li>O2 RATE &lt; 24.0 psi/min</li> <li>sw FAN = OFF</li> <li>Vent Flow Sensor = FLOW</li> <li>&gt; 7 sec since last sw FAN or Vent Flow Sensor change</li> <li>SW/FAN FAIL is not present</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to RPM __ _ K</li> </ul>
165	CO2 SNSR BAD	All	<ul style="list-style-type: none"> <li>CO2 Sensor Volts &lt; 0.3 V after 30 seconds of warm up</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>Uncompensated CO2 &gt; 25 mmHg</li> <li>Uncompensated CO2 has increased from 5 to 25 mmHg in less than 2 minutes</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to CO2 __ _ MM</li> <li>Disables CO2 HIGH / SET O2 EVA, CO2 HIGH / OPEN PURGE V, and MONITOR CO2 / CO2 __ _ MM messages</li> </ul>
166	CO2 HIGH SET O2 EVA	6,7	<ul style="list-style-type: none"> <li>O2 POS ≠ EVA</li> <li>CO2 SNSR BAD is not present</li> <li>Compensated CO2 &gt; 12.4 [11.9] mmHg</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>O2 POS ≠ EVA</li> <li>CO2 SNSR BAD is not present</li> <li>Uncompensated CO2 &gt; 8.0 [7.5] mmHg</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to CO2 __ _ MM</li> </ul>
167	CO2 HIGH OPEN PURGE V	1,2,3,4,5,8	<ul style="list-style-type: none"> <li>CO2 SNSR BAD is not present</li> <li>Compensated CO2 &gt; 12.4 [11.9] mmHg</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>CO2 SNSR BAD is not present</li> <li>Uncompensated CO2 &gt; 8.0 [7.5] mmHg</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to CO2 __ _ MM</li> </ul>
167	CO2 HIGH OPEN PURGE V	6,7	<ul style="list-style-type: none"> <li>O2 POS = EVA</li> <li>CO2 SNSR BAD is not present</li> <li>Compensated CO2 &gt; 12.4 [11.9] mmHg</li> </ul> <p>OR</p> <ul style="list-style-type: none"> <li>O2 POS = EVA</li> <li>CO2 SNSR BAD is not present</li> <li>Uncompensated CO2 &gt; 8.0 [7.5] mmHg</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to CO2 __ _ MM</li> </ul>
168	SET O2 EVA	5,6,7	<ul style="list-style-type: none"> <li>O2 POS ≠ EVA</li> <li>SUIT P LOW (message 153) is not present</li> </ul>	

**Table 1.5-1. Anomaly messages (continued)**

Display ID	Message	X-State	Conditions	Comments
169	SET O2 PRESS AIRLK REPRES	8	<ul style="list-style-type: none"> <li>SOP is off per the CWS</li> <li>O2 POS = EVA</li> </ul> OR <ul style="list-style-type: none"> <li>SOP is off per the CWS</li> <li>O2 POS ≠ PRESS</li> <li>AIRLK P &lt; 4.0 [4.2] psia</li> </ul>	
170	O2 ACT FAULT	All	<ul style="list-style-type: none"> <li>O2 Actuator discrete inputs are all high or low for &gt; 30 sec</li> </ul>	
171	SUBLM P ___ SET H2O OFF	7	<ul style="list-style-type: none"> <li>sw WATER = ON</li> <li>SUBLM P &gt; 5.3 [5.1] psia for ≥ 15 sec</li> </ul> OR <ul style="list-style-type: none"> <li>sw WATER = ON</li> <li>SUBLM P &lt; 1.5 [1.7] psia for ≥ 15 sec</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to SUBLM P ___</li> </ul>
172	H2O GP LOW	2,3,4,5,6,7	<ul style="list-style-type: none"> <li>O2 POS ≠ OFF</li> <li>H2O GP &lt; 13.5 [14.0] psid for ≥ 25 sec</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to H2O GP ___</li> </ul>
173	H2O IS OFF	7	<ul style="list-style-type: none"> <li>sw WATER = OFF</li> <li>Vehicle volts not sensed</li> </ul>	
174	SET H2O OFF	All	<ul style="list-style-type: none"> <li>sw WATER = ON</li> <li>X-State ≠ 7 and AIRLK P &gt; 0.3 psia</li> </ul> OR <ul style="list-style-type: none"> <li>sw WATER = ON</li> <li>X-State = 7 for &gt; 2 min</li> <li>Vehicle volts sensed for &gt; 10 min</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to AIRLK P ___ or SUBLM P ___</li> </ul>
175	H2O WP HIGH H2O WP ___	1,7	<ul style="list-style-type: none"> <li>H2O WP &gt; 17.0 psid</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to H2O WP ___</li> </ul>
176	MONITOR CO2 CO2 ___ MM	All	<ul style="list-style-type: none"> <li>CO2 SNSR BAD is not present</li> <li>Compensated CO2 between 8.0 [7.5] and 12.4 [11.9] mmHg</li> </ul> OR <ul style="list-style-type: none"> <li>CO2 SNSR BAD is not present</li> <li>Uncompensated CO2 between 3.0 [2.7] and 8.0 [7.5] mmHg</li> </ul>	<ul style="list-style-type: none"> <li>sw DISP → PRO or STATUS to CO2 ___ MM</li> </ul>
177	14V SUP FAIL ✱	All	<ul style="list-style-type: none"> <li>The ±14 V supply is outside acceptable limits</li> </ul>	<ul style="list-style-type: none"> <li>+14 V limits = +14 V ± 2 V</li> <li>-14 V limits = -14 V ± 2 V</li> <li>Cold restart required to clear BITE light</li> </ul>
179	SCU PWR AVAL	All	<ul style="list-style-type: none"> <li>sw POWER = BATT</li> <li>Vehicle volts sensed for the last minute</li> </ul>	
103	O2 LF ___% TIME LF ___'	All	<ul style="list-style-type: none"> <li>Calculated O2 remaining is ≤ 30 [33] min</li> </ul>	
104	PWR LF ___% TIME LF ___'	All	<ul style="list-style-type: none"> <li>sw POWER = BATT</li> <li>Calculated power remaining is ≤ 30 [33] min</li> <li>Vehicle volts not sensed</li> </ul>	

**Table 1.5-1. Anomaly messages (concluded)**

Display ID	Message	X-State	Conditions	Comments
105	RESRV H2O ON TIME LF __'__	All	<ul style="list-style-type: none"> <li>(H2O GP - H2O WP) &gt; 2.1 psid</li> <li>Vehicle volts not sensed</li> </ul>	<ul style="list-style-type: none"> <li>30 minute timer reset only on cold restart</li> <li>Countdown timer begins when (H2O GP - H2O WP) &gt; 2.1 psid and vehicle power is not available</li> <li>sw WATER - ON is not a criterion in order to allow for a failed open Feedwater Shutoff Valve (Item 137)</li> </ul>
180	DRAM FAIL [✱]	All	<ul style="list-style-type: none"> <li>Dynamic RAM test has failed</li> </ul>	<ul style="list-style-type: none"> <li>Cold restart required to clear BITE light</li> </ul>
181	EE CSUM FAIL [✱]	All	<ul style="list-style-type: none"> <li>EE CheckSum has failed</li> </ul>	<ul style="list-style-type: none"> <li>Cold restart required to clear BITE light</li> </ul>
182	BUS CK FAIL [✱]	All	<ul style="list-style-type: none"> <li>Bus Check has failed</li> </ul>	<ul style="list-style-type: none"> <li>Cold restart required to clear BITE light</li> </ul>
183	BOO CSUM BAD	All	<ul style="list-style-type: none"> <li>BOOT page checksum has failed</li> </ul>	<ul style="list-style-type: none"> <li>BITE light is not activated because this does not affect flight mode</li> </ul>
184	WAT DOG FAIL [✱]	All	<ul style="list-style-type: none"> <li>Watch Dog not ready in required time</li> </ul>	<ul style="list-style-type: none"> <li>Cold restart required to clear BITE light</li> </ul>
185	FW ANOMALY	All	<ul style="list-style-type: none"> <li>Feedwater discretes in disagreement for &gt; 5 sec</li> </ul>	<ul style="list-style-type: none"> <li>CWS assumes FW is on if discretes disagree</li> </ul>
240	O2 IS OFF	2,4	<ul style="list-style-type: none"> <li>O2 POS = OFF for ≥ 5 sec</li> </ul>	
240	O2 IS OFF	8	<ul style="list-style-type: none"> <li>O2 POS = OFF for ≥ 5 sec</li> <li>4.0 [3.8] &lt; AIRLK P &lt; 7.3 [7.5] psia</li> <li>SET O2 PRESS message is not active</li> </ul>	

- Notes:
1. Messages are listed in priority order. Display ID number does not indicate priority.
  2. The number enclosed in [ ] is the deadband limit. It is the limit used to determine the presence of a malfunction once the condition exists.

### 1.5.1 Related Documentation References

SVHSER21080 Software Requirements Specification for the EMU Enhanced Caution and Warning System, Rev. G, 31 March 05

Based on System Version: eCWS Ver: 18.6; 26 May 2006

## 1.6 BITE INDICATION

### PURPOSE

To define the operation of the Built-In Test Equipment (BITE) light, its associated circuitry, and fault messages.

### DESCRIPTION

The BITE light is intended to indicate a problem with the CWS electronics or software. When the CWS is operating nominally, the BITE light should not be illuminated and a handshake between the CWS Central Processing Unit (CPU) and the BITE circuitry should occur periodically. This handshake consists of a logic timer, which is required to be reset periodically by a signal from the CPU, and is monitored by the watchdog circuitry. In addition, the CPU monitors the watchdog circuitry to see that it sends a watchdog ready indication at the proper time. So, as the logic timer requires a reset, the watchdog circuitry sends a ready indication to the CPU, which then sends a signal to the logic timer to reset.

The BITE light is illuminated under four conditions:

1. The CWS detects one of the Self Health Tests listed below has failed. The associated message would be displayed with the BITE light.
2. The CPU fails to send a signal to the logic timer at the specified time. The most likely cause is the CPU being hung up and in this condition it is likely that no message will be issued with the BITE light.
3. The CPU does not receive the signal from the watchdog circuit that says it is ready for an update to the logic timer. In this condition the WAT DOG FAIL message would be displayed with the BITE light as described below.
4. During a power restart, the BITE light is illuminated for 4 seconds to verify proper operation of its activation circuitry. For a cold restart, the BITE is also illuminated during the display test in addition to the 4 seconds at the beginning of the restart sequence.

The CWS performs a series of self-health tests. If any of these tests fail, a BITE light and fault message is displayed on the DCM. These faults are available for review in the fault stack as long as the faults are present. The BITE light remains illuminated until a cold restart has occurred. The following is a list of possible anomaly messages that are displayed with the BITE light should a problem with the CWS develop.

- A. **14V SUP FAIL:** Indicates the secondary voltage supplies +/- 14V are out of specification.

Details: This is caused by either the +14 V being below +12 V or above +16 V, or the -14 V being below -12 V or above -16 V. When these voltages are incorrect the

analog to digital converters read incorrectly. Also, if the +14 volt supply fails the CWS, memory may be corrupted after a power cycle. This would require a CWS download of the system software or a CWS changeout. To avoid this should a +14 V supply failure occur, a power restart is not suggested because it will corrupt the memory and render the CWS useless until we can reload the software on the ground. If this failure occurs while EVA (+14 V failure), every effort should be made to remain in the same power switch configuration (BATT or SCU) as when the failure occurred, and power off the suit when inside. This will avoid corrupting the memory and an ORU changeout of the DCM can be performed to possibly recover the EMU. The most likely cause of a +14 V supply failure mode is malfunctioning DCM electronics.

- B. **5V REF FAIL:** Indicates a failure of the 5 V reference used for the sensors and Analog-to-Digital (A/D) conversion.

Details: Two analog inputs based on the 5 volt reference are checked, a 95 percent signal checked to 4.77 +/- 0.10 V, and a 5 percent signal checked to 0.227 +/- 0.01 V.

- C. **BUS CK FAIL:** An internal data and address bus wraparound test has failed.

Details: One of the three daughter boards contains a data bus latch that permits the CPU board to write a pattern out to the mother board and respective (communications) daughter board, and then read back the value to determine if there is a problem with the mother board, address bus, data bus, or respective bus buffers, and latches. It is possible that a single event caused an upset and additional verification by the crewmember can establish the magnitude of the failure.

- D. **DRAM FAIL:** Indicates that the Dynamic Random Access Memory (DRAM) test has failed.

Details: The scratch pad memory, which stores variables, is checked in the background during operation. This region of memory is similar to the dynamic memory of a Personal Computer (PC) used during the operation of a program. If the Random Access Memory (RAM) "write and then read-back test" fails, then the DRAM FAIL message and BITE light are issued. Performing a cold restart reinitializes the memory, clears the warm restart parameters, and possibly clears the DRAM fault if caused by a single-event upset.

- E. **EE CSUM FAIL:** Indicates the Electronically Erasable region of memory, used to store the executable program, is corrupted.

Details: Corruption of the executable can have many results. If the corruption is in an unused section of memory, no functional problems occur. If the flow of execution is corrupted, the CWS will likely hang up. More subtle errors such as incorrect measurements are possible.



Performing a cold restart may clear the fault. The fault will reoccur within 10 seconds after completion of the restart if it is not a single event upset.

Note: BOO CSUM BAD is not a BITE failure because this code is not executed during flight operations.

F. **WAT DOG FAIL:** The watchdog circuit was not ready in the required time.

Details: The design contains a separate logic timer and watchdog circuit, which requires an update at specific intervals. The watchdog circuit also provides a signal to the CPU stating that the timer is ready for an update. This is similar to a handshake. If the "watchdog ready" signal is not received, the CPU issues this message and BITE. This probably indicates a failure of the watchdog circuit. If the watchdog circuit actually trips, then the BITE is issued without the message. This would indicate that the software update did not occur at the required interval. It is possible for the software to miss an update but perform in a degraded mode of operation still providing status and anomaly messages to the crew.

**REFERENCES**

Based on System Version: eCWS Ver: 18.6; 26 May 2006

EVA Engineering Memorandum - EVAM 0047; One EVA, 4 Feb 2005

SVHSER21080 Software Requirements Specification for the EMU Enhanced Caution and Warning System, Rev. G, 31 March 05

## 1.7 EMU TELEMETRY/DOWNLIST DATA

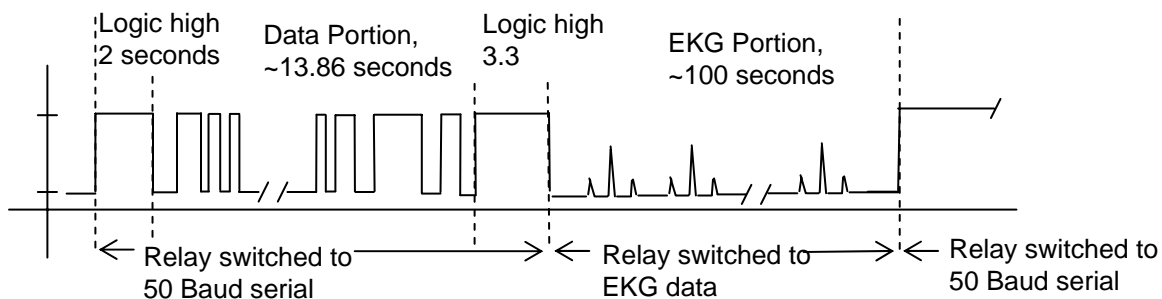
### PURPOSE

This section describes how the EMU Enhanced CWS organizes and formats its telemetry stream to provide EMU data to MCC.

### CWS DATA RECORD

The Enhanced CWS collects analog data from the EMU's sensors and converts the data to digital format for downlink. This information is sent from the communication board to the serial data port at 4800 baud (bits/second), and to the SSER at 50 baud. The digitized data that the CWS has obtained is sent to the serial data port and to the Space-to-Space EMU Radio (SSER) as serial data. This means that all the bits are sent in single file, 1 bit at a time. Therefore, in order for the ground processing software to recognize what this data is and how to process it, it must be known how the CWS packages all this data before it sends it.

The CWS multiplexes the Electrocardiogram (EKG) signal and the EMU data in the 50 baud signal in COMBO mode. This mode sends 100.84 seconds of EKG data, a relay switches to send EMU data for 19.16 seconds, and then the relay switches back to transmitting EKG data. This relay is the same physical switch as that used in the old CWS RTDS, which was prone to locking up due to a signal problem in the old microprocessor. It is unknown at this time if this is still a credible failure mode with the enhanced microprocessor. In order for the ground to recognize that EMU data is being sent, a sync signal is sent (logic high) for 2 seconds follow by the start word. The start word (DFFF hex) is critical for the ground daemon to know where to start parsing the data from a single serial stream into manageable and recognizable bytes of information. Once the data is done transmitting, another logic high signal is sent for 3.3 seconds to let the daemon know that it is done getting this pass of EMU data, and can start processing the data. Figure 1.7-1 represents how this data stream looks in "Default" mode. There is a "Classic" mode discussed below in Section 1.8.3.



**Figure 1.7-1. CWS default data profile in COMBO mode**

The CWS data frame is essentially a snapshot of all the values that the CWS reads from the EMU when sending data. This data frame consists of 63 bytes. Each byte is transmitted as 1 start bit + 8 data bits + 1 even parity bit + 1 stop bit. Table 1.7-1 shows the data that each byte consists of. The data can be classified into several types.

Type	Description	No. of bytes
Start Word	first bit sent → 1111111111011111 ← last bit sent	2
Discrete Words	Switch positions, On/Off, Flags	3
Motor tach	0-25500	1
X State	1, 2, 3, 4, 5, 6, 7, 8	1
EMU Analog Sensors	12-bit filtered raw data (counts)	1.5 each
Checksums	1 <sup>st</sup> half and 2 <sup>nd</sup> half of the EMU data record	1 each
Time Words	Time Mark, Time EVA, Batt Time Left, O2 Time Left, H2O Time Left, Time X-State	2 each
Message number	Number of message currently on DCM display	1
CWS id number	Unique number to identify CWS (ground resetable)	1
Use Rates	Primary and Secondary O2 use rates	2 each
RS-485	Future expansion slots (3)	2 each
Fault Stack	Each bit represents a fault in the fault stack	6

**Table 1.7-1. CWS default data stream**

Byte no.	Contents	Bit Identification
1	Start Word	(Initiates Daemon parsing)
2	Start Word	(Initiates Daemon parsing)
3	EMU Discrete Word	(discussed in subsequent text)
4	EMU Discrete Word	(discussed in subsequent text)
5	Motor Tachometer	(discussed in subsequent text)
6	X State	(discussed in subsequent text)
7	Suit Pressure	(A/D bits 0 -> 7)
8	Suit Pressure Primary Oxygen Supply Pressure	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
9	Primary Oxygen Supply Pressure	(A/D bits 0 -> 7)
10	Secondary Oxygen Supply Pressure	(A/D bits 0 -> 7)
11	Secondary Oxygen Supply Pressure Sublimator or Ambient Pressure	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
12	Sublimator or Ambient Pressure	(A/D bits 0 -> 7)
13	Battery Voltage	(A/D bits 0 -> 7)
14	Battery Voltage Battery Current	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
15	Battery Current	(A/D bits 0 -> 7)
16	Carbon Dioxide Partial Pressure	(A/D bits 0 -> 7)
17	Carbon Dioxide Partial Pressure Sublimator Outlet Temp	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
18	Sublimator Outlet Temp	(A/D bits 0 -> 7)
19	Reservoir Gas Pressure	(A/D bits 0 -> 7)
20	Reservoir Gas Pressure Reservoir Water Pressure	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
21	Reservoir Water Pressure	(A/D bits 0 -> 7)
22	A/D Converter 95% Vref	(A/D bits 0 -> 7)
23	A/D Converter 95% Vref Positive Analog Supply Voltage	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
24	Positive Analog Supply Voltage	(A/D bits 0 -> 7)
25	Negative Analog Supply Voltage	(A/D bits 0 -> 7)
26	Negative Analog Supply Voltage A/D Converter 5% Vref	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
27	A/D Converter 5% Vref	(A/D bits 0 -> 7)
28	Spare A to D 1 voltage	(A/D bits 0 -> 7)
29	Spare A to D 1 voltage Spare A to D 2 voltage	(A/D bits 8 -> 11, serial data bits 0 -> 3) (A/D bits 8 -> 11, serial data bits 4 -> 7)
30	Spare A to D 2 voltage	(A/D bits 0 -> 7)
31	Checksum for first half of record	
32	Time Mark (LSB)	
33	Time Mark (MSB)	
34	Time EVA (LSB)	
35	Time EVA (MSB)	
36	Time Left on Battery (LSB)	
37	Time Left on Battery (MSB)	
38	Time Left on Oxygen (LSB)	
39	Time Left on Oxygen (MSB)	

**Table 1.7-1. CWS default data stream (concluded)**

Byte no.	Contents	Bit Identification
40	Message Number	
41	Discrete Flags Word 5	
42	water_seconds_left (LSB)	
43	water_seconds_left (MSB)	
44	filtered_pri_o2_use_rate (LSB)	
45	filtered_pri_o2_use_rate (MSB)	
46	filtered_sop_o2_use_rate (LSB)	
47	filtered_sop_o2_use_rate (MSB)	
48	cws_id_number	
49	RS-485 INSTRUMENT_1 (LSB)	
50	RS-485 INSTRUMENT_1 (MSB)	
51	RS-485 INSTRUMENT_2 (LSB)	
52	RS-485 INSTRUMENT_2 (MSB)	
53	RS-485 INSTRUMENT_3 (LSB)	
54	RS-485 INSTRUMENT_3 (MSB)	
55	time_since_last_state_change (LSB)	
56	time_since_last_state_change (MSB)	
57	fault_bits (LSB)	
58	fault_bits	
59	fault_bits	
60	fault_bits	
61	fault_bits	
62	fault_bits (MSB)	
63	Checksum for second half of record	

From Table 1.7-1, it can be seen that the EMU Discrete word is the next pair of bytes (Bytes 3 and 4) after the Start Word. These two bytes have a combined total of 16 data bits. Each bit represents a switch position or something that can be represented as on or off in the CWS. The following shows what each byte of the EMU discrete word carries.

**EMU Discrete Word - Byte 3**

Bit	Signal Description	0	1
0	Status Switch Position	NORMAL	STATUS
1	Proceed Switch Position	NORMAL	PROCEED
2	Vehicle Power	OFF	SENSED
3	Power Mode Switch Position	SCU	BATTERY
4	Feedwater 1 Valve Switch Position	OFF	ON
5	Fan/Pump Switch Position	OFF	ON
6	O2 Actuator Position - OFF/PRESS	FALSE	TRUE
7	O2 Actuator Position - IV/PRESS	FALSE	TRUE

**EMU Discrete Word - Byte 4**

Bit	Signal Description	0	1
0	Vent Flow Switch Position	NO VENT	VENT
1	Oxygen Actuator Position - EVA	FALSE	TRUE
2	Short Tone within last 3 minutes	Not Active	Active
3	Long Tone within last 3 minutes	Not Active	Active
4	BITE light	OFF	ON
5	Warble Tone within last 3 minutes	Not Active	Active
6	BOOT Discrete	Active	Inactive
7	TEST Discrete	Active	Inactive

The tones will show active if they were annunciated in the last 3 minutes. This is so the ground can see it in the telemetry. The other discrete word, Discrete Flags Word 5, is located on Byte 41. This is on the second half of the checksum.

**Discrete Flags Word 5 - Byte 41**

Bit	Signal Description	0	1
0	Feedwater Discrete 2	WATER OFF	WATER ON
1	Battery Capacity0	These bits are combined to make a number from 0 – 31. 0: 26.6 Amp Hours    1:27.0 AH 2: 27.5 AH    →    → 31: 40.0 Amp Hours Increases in 0.5 AH increments from 27 - 40.	
2	Battery Capacity1		
3	Battery Capacity2		
4	Battery Capacity3		
5	Battery Capacity4		
6	Airlock Pressure Direction 0	0: Not Sampled	1: Stable
7	Airlock Pressure Direction 1	2: Increasing	3: Decreasing

The motor tachometer byte (byte 5) sends the speed of the motor in 100 rpm increments. With 8 bits, and counting in binary,  $2^8 = 256$ . So there are 256 values, but remember 0 is a value, and it follows that the range is 0 to 255. The number sent down multiplied by 100 is the speed of the motor in rpms.

The X State byte (byte 6) uses the 8 bits to simply send an integer, 1 through 8. It only needs 5 bits to send the integer 8, so 3 bits are unused.

The EMU analog words are on bytes 7 to 30. These represent the analog sensors the CWS reads and converts to counts, a digitized format. These words are 12 bits long, so each word takes up 1.5 bytes. As can be seen on Table 1.7-1, two EMU analog words will use one and a half bytes each, the two halves being shared in the same third byte. Thus two analog words will use a total of three bytes. For example, bytes 7 and 9 contain the first 8 bits of the words associated with Suit Pressure and Primary Oxygen Supply Pressure respectively. The last four bits of each of these two words are contained in byte 8. Packing the bytes in this more efficient way allows for more data to

be sent to the ground. The counts digitally represent 0 to 10 volts. 0 counts equals 0 volts; 4095 counts equals 10 volts. Table 6-17 in the Software Requirements Specification for EMU Enhanced Caution and Warning System (SVHSER21080) shows the analog sensors and their engineering unit ranges compared to the 0 to 10 volts and counts. The sensor's output range is 0 to 5 volts, but the CWS converts those 0 to 5 volt readings to 0 to 10 volts at the Multiplexer (MUX).

Two checksums are needed because of the length of the serial data record. The first checksum is sent down on byte 31 and the second checksum is sent down on byte 63, the last byte. The first checksum is calculated by summing up the first half of the record. Each byte is considered an integer when summed up. Then the sum is truncated to fit onto a single byte. The checksum byte itself is not included in the checksum calculation. The second checksum is calculated the same way but for the second half of the serial data.

The time bytes (32 to 39, 42 to 43, and 55 to 56), which represent Mark Time, Time EVA, Battery Time Left, O2 Time Left, H2O Time Left, and Time in X-State are 2 bytes each. They are also 12 bit words, but use 2 bytes, leaving 4 bits unused for each word. At this point there is enough room to send the data, and combining the bytes like the analog data is not necessary. Having 12 bits means the time values are sent as 0 to 4095 counts.

- Mark Time is the elapsed time in 10-second increments since the last Power Restart.
- Time EVA is the elapsed time in minutes since the Power went to Battery after the last cold restart.
- Battery Time Left is the time left in minutes for the battery in X-state 7. It is zero in all other X-states.
- O2 Time Left is the combined time left in minutes for Primary O2 and SOP if SOP is on. If SOP is OFF and X-State is 7, then this parameter is the time left for Primary O2. It is zero in all other conditions.
- H2O Time Left is the time left on Reserve H2O. Multiply this value by 10 to get number of seconds left. Value starts at 1800 seconds.
- Time in X-State records time of being in the current X-state in 10-second intervals. Multiply the value by 10 to get the number in seconds.

Message number on byte 40 is the number of the current message displayed on the DCM.

Bytes 44 to 47 are the O2 Use rate and the SOP Use rate respectively. They use 2 bytes each. The values are divided by 10 to get the use rates in psi/min.

CWS ID number on byte 48 is just a parameter that the ground can set to uniquely identify the CWS serial data.

RS-485 Instruments 1, 2, and 3 on bytes 49 to 54 are values that can be provided by future add-ons to the EMU. The CWS is scarred (expansion ready) so that it would be easier to incorporate new instrumentation and send its telemetry.

The fault bits on bytes 57 to 62 downlink the entire fault stack. Each bit on those bytes represents a fault in the fault stack. The fault stack has all the faults listed in priority order except for the limiting consumables messages of O2, PWR, and H2O, which are listed on the bottom of the stack. In the fault bits, whichever bit is "on" (on = 1), then that means that fault is present in the fault stack (see the table below). The last fault bit in the table does not represent an anomaly message, but an indication that when the SOP is ON, that the Beattie-Bridgeman correlation is running correctly.

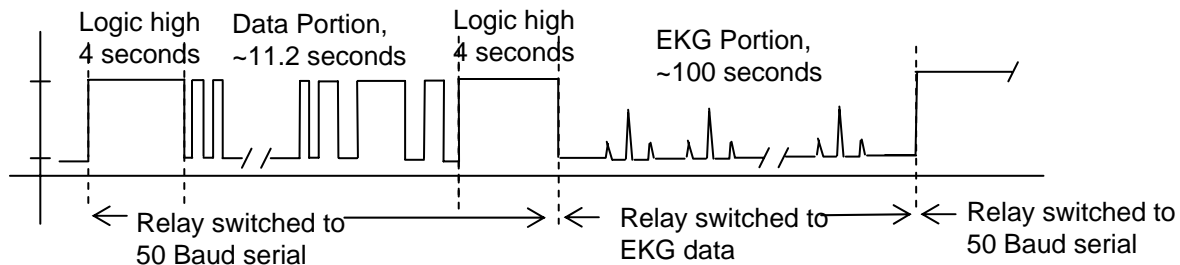


Fault Byte # (LSB=0)	Bit # (LSB=0) (hexadecimal)	Message #	Line 1	Line 2	Line 3
57	0 (01)	178	5V REF FAIL		
57	1 (02)	150	BATT AMPS HI	BAT AMPS #.#	
57	2 (04)	151	BATT VDC LOW	BAT VDC #.#	
57	3 (08)	152	SUIT P LOW	SUIT P #.#	
57	4 (10)	153	SUIT P LOW	SET O2 EVA	SUIT P #.#
57	5 (20)	154	SUIT P EMERG	CLOSE PURG V	SUIT P #.#
57	6 (40)	102	SOP O2 ON	TIME LF'###	SUIT P #.#
57	7 (80)	155	SUIT P LOW	REPRES AIRLK	SUIT P #.#
58	0 (01)	156	RLF V FAIL	STOP DEPRESS	SUIT P #.#
58	1 (02)	157	SUIT P HIGH	O2 RATE #.#	SOP RATE #.#
58	2 (04)	158	O2 USE HIGH	O2 RATE #.#	
58	3 (08)	159	SOP P LOW	SOP P #####	SOP_RATE #.#
58	4 (10)	108	BATT V DECAY	BAT VDC #.#	
58	5 (20)	160	SW/FAN FAIL		
58	6 (40)	161	NO VENT FLOW	SET O2 EVA	
58	7	162	NO VENT FLOW		
59	0 (01)	163	FAN SW OFF		
59	1 (02)	164	VENT SW FAIL		
59	2 (04)	165	CO2 SNSR BAD		
59	3 (08)	166	CO2 HIGH	SET O2 EVA	
59	4 (10)	167	CO2 HIGH	OPEN PURGE V	
59	5 (20)	168	SET O2 EVA		
59	6 (40)	169	SET O2 PRESS	AIRLK REPRES	
59	7 (80)	170	O2 ACT FAULT		
60	0 (01)	171	<SUBLMP/AIRLKP>	SET H2O OFF	
60	1 (02)	172	H2O GP LOW		
60	2 (04)	173	H2O IS OFF		
60	3 (08)	174	SET H2O OFF		
60	4 (10)	175	H2O WP HIGH	H2O WP #.#	
60	5 (20)	176	CO2 #.# MMHG	MONITOR CO2	
60	6 (40)	177	14V SUP FAIL		
60	7 (80)	179	SCU PWR AVAL		

Fault Byte # (LSB=0)	Bit # (LSB=0) (hexadecimal)	Message #	Line 1	Line 2	Line 3
61	0 (01)	103	O2 LF ##%	TIME LF'###'##	
61	1 (02)	104	PWR LF ##%	TIME LF'###'##	
61	2 (04)	105	RESRV H2O ON	TIME LF'###'##	
61	3 (08)	180	DRAM FAIL		
61	4 (10)	181	EE CSUM FAIL		
61	5 (20)	182	BUS CK FAIL		
61	6 (40)	183	BOO CSUM BAD		
61	7 (80)	184	WAT DOG FAIL		
62	0 (01)	185	FW ANOMALY		
62	1 (02)	240	O2 IS OFF		
62	2 (04)				
62	3 (08)				
62	4 (10)				
62	5 (20)				
62	6 (40)				
62	7 (80)		SOP CONVERGED		

**1.7.1 CWS Classic Data Record Mode**

The CWS classic data record is a mode in which the CWS can send its data to the ground in the same format as the old CWS. It was intended that this data record be identical to the old CWS and that the old daemon would be able to decomm it in the event that a new daemon was not ready to support the default data mode (described above) in time. The old daemon can decomm it, but due to the new design of the CWS, the data record is not identical to the old. In Figure 1.7-2 below, the structure of the Classic data record is seen to be the same as the old CWS.



**Figure 1.7-2. CWS classic data profile in COMBO mode**

This mode will never be used intentionally. The only way to get into this mode is to use a computer and a special cable to plug into the RS-485 connector of the CWS. Then the EMU is put into Test mode, and the classic data record mode can be selected. On

orbit, there is no cable to be able to change to classic data mode, and since the new daemon can successfully decomm the default data record there is no reason to have suits launch with classic data selected. The CWS in classic data mode does not behave any differently to the crewmember than it does in its default data mode. Only the data transmission to the ground is affected.

The classic data record does not send as much data as the normal data record. It only has 49 bytes verse 63 bytes in default mode. In classic mode, the bytes are not used as efficiently either. Each of the 12-bit analog words uses up 2 bytes (16 bits), leaving 4 empty bits per analog word. Table 1.7-2 shows the content of the classic data record.

**Table 1.7-2. CWS classic data stream**

Byte no.	Contents
1, 2	Start Word
3, 4	EMU Discrete Word
5	Motor Tachometer
6	EMU State
7, 8	BITE Status
9, 10	Suit Pressure
11,12	Primary Oxygen Supply Pressure
13, 14	Secondary Oxygen Supply Pressure
15, 16	Sublimator/Ambient Pressure
17, 18	Battery Voltage
19, 20	Battery Current
21, 22	Carbon Dioxide Partial Pressure
23, 24	Sublimator Outlet Temperature
25, 25	Reservoir Gas Pressure
27, 26	Reservoir Water Pressure
29, 30	A/D Converter Reference Voltage
31, 31	Positive Analog Supply Voltage
33, 34	Negative Analog Supply Voltage
35, 36	Spare 1/ECWS 5% Ref Voltage
37, 38	Spare 2
39, 40	Spare 3
41, 42	Time Stamp
43, 44	Time EVA
45, 46	Time Left on Battery
47, 48	Time Left on Oxygen
49	Message Number

- A. The start word is different than default. Just FFFF hex, or in binary, 1111111111111111.
- B. With this start word and the equal time length start sync and trailing sync, the EMU daemon can get caught in an endless loop of not decomming data in continuous mode (DATA? EMU). The daemon can mistake the trailing sync for the start sync and, therefore, attempt to synchronize on the trailing sync. Since it is the trailing sync, there will not be any data following, and then the daemon will reset and try again. It takes time to reset, and when it tries again, it will be right back on the trailing sync again. To break out of this loop, stop the daemon and restart it. Hopefully it will pick up on the leading sync correctly.
- C. The discrete word is the same as default mode above except it will send zeroes for short tone, long tone, warble tone, boot, and test discrete.
- D. Motor tach is the same.
- E. X-State is the same except that X-State 3 will show up as INVALID since the old CWS did not have an X-State 3.
- F. The BITE status word is shown below. These are just in the fault stack for the default mode, but classic mode imitates the old CWS, where it had a BITE word to list any BITE failures. It is not presently clear how the real self-health (BITE) tests that the EMU now runs would be mapped to the categories on Data Page 3 in classic mode.

**BITE Status Word – First Byte**

Bit	Signal Description 0=PASS, 1=FAIL
0	EPROM Checksum
1	Limits Checksum
2	CPU Check
3	Bus Check
4	Background Timer
5	Volatile RAM
6	Non-Volatile RAM
7	Expansion RAM

**BITE Status Word - Second Byte**

Bit	Signal Description 0=PASS, 1=FAIL
0	Floating Point Math
1	A/D Voltages
2	A/D Conversion
3	Critical Parameter
4	Stack Overflow
5	Reserved (Always Zero)
6	Unused (Always Zero)
7	Unused (Always Zero)

The analog words are based on 0 to 5 volts represented by 0 to 4095 counts. The old CWS measured the sensor voltages from 0 to 5 volts. The current CWS takes the 0 to 5 volts readings from the sensors and converts them to 0 to 10 volts. Then in classic mode, the 0 to 10 volts is converted to 0 to 5 volts in counts. This demonstrates some of the differences between the old daemon and the new daemon.

The message numbers downlinked on byte 48 do not match the message titles for the old CWS. This means that when using classic mode the message number on the MCC data pages will be correct, but the message title will be incorrect. This does not effect the DCM display or how the messages are displayed to the crewmember.

## **REFERENCES**

Based on System Version: eCWS Ver: 18.6; 26 May 2006

Software Requirements Specification for EMU Enhanced Caution and Warning System (SVHSER21080)

Enhanced Caution and Warning System (ECWS) Serial Interface Definition for the Extravehicular Mobility Unit (EMU) Interface Control Document (ICD-4-1004-0C-0)

## 2.1 CWS CALCULATIONS AND DETERMINATION OF LIMITING CONSUMABLE

### PURPOSE

This section describes the method that the CWS uses to calculate EMU consumables. To supplement this information, a worksheet that EVA flight controllers can use to calculate consumables by hand is included. Reference Appendix F for the user's guide for the consumables spreadsheet application.

### DESCRIPTION

During an EVA, the CWS calculates

- Primary oxygen use rate
- Time left on primary oxygen
- % oxygen left
- Secondary oxygen use rate
- SOP time left
- Battery power left
- % battery power left
- Time left on battery
- Time left on water (when RESRV H2O ON message is present)

During an EVA, the CWS monitors O<sub>2</sub> and power use to determine which one is the limiting consumable and then displays it in the limiting consumable slot in the status list. Reference Section 1.3, Volume 4, CWS Status List and Messages, for status list information. Determining the limiting consumable is based on consumption rate and the total amount of consumable left. There are four resources that may be the limiting consumable per CWS calculations:

- Primary oxygen
- Secondary oxygen
- Battery charge
- Water

If the SOP is on, it is the limiting consumable. Otherwise, the limiting consumable is the one with the least amount of time remaining. The following data describe how the CWS calculates the limiting consumable. Reference Software Requirements Specification for the EMU Enhanced Caution and Warning System (SVHSER21080) for more information on CWS calculated parameters.

All analog signals are sampled at a minimum rate of once every 200 milliseconds. All analog signals (sensor outputs converted to counts) go through the following linear filter:

$$filtered\_value = integer\left\{\frac{(9 * filtered\_value) + (1 * new\_value)}{10} + \frac{1}{2}\right\}$$

The DCM display and the 50-baud serial data for the battery volts and amps go through the same linear filter, but with a heavier weight given to the filtered value to produce a steady value to the crewmember (4800 baud data and CWS calculations use the 9:1 weighting described above):

$$filtered\_value = integer\left\{\frac{(30 * filtered\_value) + (1 * new\_value)}{31} + \frac{1}{2}\right\}$$

These filtered values are considered to be the instantaneous values by the CWS, and is the 50 baud data that is received by MCC.

## PRIMARY O<sub>2</sub>

The CWS calculates two O<sub>2</sub> use rates.

- Instantaneous O<sub>2</sub> use rate (R1) - calculated by change in O<sub>2</sub> tank pressure in the past minute. This is recalculated every 6 seconds, unless the O<sub>2</sub> use rate is >10 psi/min. In this situation the rate is calculated every second. It will continue to be calculated every second until the use rate drops below 3 psi/min. The average primary oxygen use rate (R1<sub>filt</sub>) is calculated by passing R1 through the standard analog signal linear filter described above.
- Filtered O<sub>2</sub> use rate (R2) - smoothes the instantaneous rate by reducing the effects of transients and momentarily high or low use rates. The filtered rate is updated whenever the instantaneous rate is updated, and is used in calculating the time left on the primary O<sub>2</sub>. The filtered rate is calculated with the following algorithm.

$$R2_{new} = \frac{15}{16} R2_{old} + \frac{1}{16} R1$$

R2 - Filtered O<sub>2</sub> rate  
R1<sub>filt</sub> - Filtered - Instantaneous O<sub>2</sub> rate

The CWS will use either the filtered O<sub>2</sub> use rate, or 1.5 psi/min to determine the time left on primary O<sub>2</sub>. The CWS assumes an O<sub>2</sub> use rate of 1.5 psi/min in the following situations:

1. The SCU is connected
2. For 90 seconds after the SCU is disconnected and the instantaneous O2 use rate is <10 psi/min
3. The primary O2 pressure drop over the last minute is less than 1.5 psi/min during non-EVA times (x=1,2,3,4,5,6,8) or during the first 10 minutes of an EVA (x=7 and SCU disconnected)

The CWS assumes that the SCU is connected when vehicle volts are sensed, and assumes that the SCU is disconnected when vehicle volts are not sensed.

The time left on primary O2 is calculated using the filtered O2 use rate. If the filtered O2 use rate is less than 0.3 psi/min then 0.3 is used when calculating the primary O2 time left. Also when calculating the primary O2 time left, it is assumed that the last 75 psi in the primary tanks is not usable, so this is subtracted.

If the filtered O2 use rate is calculated every minute, the time left is calculated every 6 seconds. If the average use rate is calculated every second, the time left is calculated every second.

Time left in minutes is calculated as:

$$TIME \quad LF = \frac{(PO_2 - 75)}{R2}$$

Percent O<sub>2</sub> left is also calculated for the status list.

$$\% O_2 \quad LF = 100 \frac{(PO_2 - 75)}{775}$$

PO<sub>2</sub> - Current primary O<sub>2</sub> tank pressure

75 is minimum usable primary tank pressure

850 is nominal full primary O<sub>2</sub> pressure

775 is nominal usable range: 850 - 75

## SECONDARY O<sub>2</sub>

The initial SOP pressure is read at EMU powerup and stored in nonvolatile RAM. The fault message "SOP P LOW/ SOP P XXX0/ SOP RATE XXX" is displayed:

- when SOP pressure drops more than 600 psi from the initial value  
or
- if the SOP pressure is < 4500 psi:

The SOP rate is based solely on SOP pressure readings stored every 6 seconds. Eleven readings are stored to calculate an unfiltered SOP rate every minute.



The SOP TIME LF is based on the sum of mass quantities available from both the SOP and primary O<sub>2</sub> tanks. The total mass available is divided by the mass flow rate to determine time available.

$$SOP \ TIME \ LF = \frac{primary \ O_2 \ mass + SOP \ mass}{total \ mass \ flowrate}$$

Calculation of these mass values is an iterative numerical solution process and makes use of the Beattie-Bridgeman equation of state. For details on the calculations refer to the Software Requirements Specification for the EMU Enhanced Caution and Warning System (SVHSER21080).

If the SOP is on, the SOP TIME LF is calculated every 15 seconds.

The CWS determines that the SOP is on if the following conditions exist:

1. the O<sub>2</sub> Actuator is in the EVA position and
2. Either
  - (a) The suit pressure is less than 3.10 psig (reset condition is 3.20 psig) or
  - (b) The suit pressure is less than 4.05 psig (reset condition is 4.10 psig) and the SOP pressure is falling at a rate greater than 36 psi/min (reset condition is 24 psi/min)

#### BATTERY POWER

The CWS assumes a total initial battery capacity of 32 amp-hours. This initial capacity can be changed by the crewmember prior to the EVA to match the actual capacity of the battery being used for the EVA (see Appendix F for information on when the capacity should be changed by the crewmember in the CWS).

The CWS determines time left on battery using the following logic:

battery amp seconds used = the running total (sum) of the amps measured each second

battery amp seconds left = initial capacity selected - battery amp seconds used

$$BATT \ TIME \ LF(sec) = \frac{battery \ amp \ sec \ left}{I_{filtered}}$$

Where  $I_{filtered}$  is the filtered battery amps.  $I_{measured}$  is the instantaneous current run through the 9:1 weight filter that is used for all of the analog signals, described at the beginning of this section. The calculation for  $I_{filtered}$  is described below:

$$I_{NewFiltered} = \frac{15}{16} I_{oldFiltered} + \frac{1}{16} I_{measured}$$

If the EMU power selector switch is in SCU instead of BATT, then  $I_{filtered}$  is assumed to be 3.8 amps in order to calculate the battery time left.

Percent power left is calculated as follows:

$$\% PWR \quad LF = 100 \frac{\text{battery amp sec left}}{\text{Initial capacity selected} * 3600 \text{sec/hr}}$$

## WATER

The CWS monitors the amount of water left indirectly by monitoring the H2O gas pressure and the H2O water pressure. If the H2O gas pressure minus the H2O water pressure is greater than 2.1 psi, a 30-minute countdown timer is started. TIME LF starts at 30 minutes and decreases at 1-minute intervals. The 30-minute timer does not reflect the actual time left, but is a projected time, based on water usage at 1000 Btu/hr metabolic rate.

## CCC (LiOH and Metox)

CCC is not calculated as a limiting consumable by the CWS. However, the CWS monitors CO2 concentration. Whenever the CWS detects a CO2 concentration of greater than 8.0 mmHg (pressure compensated) in the ventilation loop, a warning message is issued, alerting a crewmember of an impending CCC breakthrough. The EVA flight controller can calculate time left on CCC. Refer to the EMU Calculations Worksheet below and Appendix F for the EMU consumables user's guide.

## CO2 PRESSURE COMPENSATION

The CWS uses the suit pressure and airlock pressure in order to pressure compensate the raw CO2 sensor value. The crew will see the compensated value on their DCM display, but the ground will be able to see both the raw and compensated values in the downlinked data. The CWS daemon on the ground calculates the compensated value based on the downlinked raw CO2 value, Suit Pressure, and Airlock Pressure/X-State.

In order for the CWS to be able to pressure compensate the CO2 raw value, it requires the absolute suit pressure, so it needs the Suit Pressure sensor (Item 114) and the Feedwater Pressure sensor (Item 138) be operational. The CWS assumes that the Suit Pressure sensor output is invalid if message 156 "RLF VLV FAIL" is active, message 154 "SUIT P EMERG" is active, or the sensor value is negative. The CWS determines that the Feedwater Pressure sensor output is invalid if it is >15.5 psia.

If the Suit Pressure sensor output is valid but the Feedwater Pressure sensor output is invalid, then pressure compensation will only happen during XSTATE 7. During XSTATE 7 the ambient pressure is assumed to be zero.

If pressure compensation is not possible due to the sensors described above being lost, then the CWS will default back to using the raw sensor values along with the warning message limits associated with them.

The CWS uses linear interpolation to convert counts to ppCO<sub>2</sub>, and to correlate absolute suit pressures to their corresponding correction factor. Reference the Software Requirements Specification for the EMU Enhanced Caution and Warning System (SVHSER21080) for the tables that the CWS uses for linear interpolation.

- To convert between counts and ppCO<sub>2</sub>:
- Theoretical CO<sub>2</sub> Sensor Counts =  $(4095/5v) * (2.0185 * (\log_{10}(\text{ppCO}_2) + 1))$
- To calculate the correction factor:
- Theoretical Correction Factor =  $0.2196 * \text{Absolute Suit Pressure} ^{0.7221}$
- To calculate the corrected ppCO<sub>2</sub>:
- $\text{ppCO}_{2\text{corrected}} = \text{CO}_2 / \text{correction factor}$

#### FLIGHT SPECIFIC VALUES

Constants used by the CWS are based on design requirements. Actual times and percentages can be calculated using information provided in the USA Flight Data Book and the flight controller consumable calculation program or the EMU Calculation Worksheet shown on the following page.

**EMU Calculation Worksheet**

TOTAL TIME EV (MIN)	_____	= total time on battery = (hr x 60) + min
DELTA TIME EV (MIN)	_____	= time since last status check = current time EV - previous time EV = ((hr <sub>2</sub> x 60) + min <sub>2</sub> ) - ((hr <sub>1</sub> x 60) + min <sub>1</sub> )
O2 PRESSURE (psi)	_____	= (775/100) x (% O2 LF) + 75
O2 USE RATE (psi/min)	_____	= (previous O2 P - current O2 P) / DELTA TIME EV
AVG O2 USE RATE (psi/min)	_____	= (initial O2 - current O2) / TOTAL TIME EV
METABOLIC RATE (BTU/hr)	_____	= 581 x O2 USE RATE
AVG MET RATE (BTU/hr)	_____	= 581 x AVG O2 USE RATE
O2 TIME LEFT (min)	_____	= (current O2 P - 150) / O2 USE RATE
AMP MIN USED	_____	= Initial Ahr (1 - % PWR LF / 100) x 60
AMPS AVG	_____	= AMP MIN USED / TOTAL TIME EV
PWR TIME LF <u>CWS</u> (min)	_____	= ((Initial Ahr x 60 min/hr) - AMP MIN USED) / AMPS AVG
PWR TIME LF <u>ACTUAL</u> (min)	_____	= (ACTUAL - AMP MIN USED) / AMPS AVG
% PWR LF <u>CWS</u>	_____	= ((Initial Ahr x 60 min/hr) - AMPS x Total TIME EV) x (100 / (Initial Ahr x 60 min/hr))
% PWR LF <u>ACTUAL</u>	_____	= (ACTUAL - AMPS x Total TIME EV) x 100 / ACTUAL
APPROX. WATER USAGE	_____	= TIME EV x 0.8 lb/hr
LIOH EV TIME LF (hr)	_____	= [ACTUAL BTUs - 1500 - ((P/B time + Depress time (hr)) x 400 BTU/hr) - (AVG MET RATE x EV Time)] / AVG MET RATE
Metox EV TIME LF (hr)	_____	= [7400 BTUs - ((P/B time + Depress time (hr)) x 400 BTU/hr) - (AVG MET RATE x EV Time)] / AVG MET RATE
BATTERY RECHARGE TIME	_____	= TIME EV x (AMPS AVG / 1.55)

NOTE: 150 = Required O2 P remaining at SCU connection  
850 = 100% O2 P  
775 = (850 - 75)  
ACTUAL = actual amp-hr from the Boeing Flight Data Book (x 60 to give minutes)  
ACTUAL BTUs = actual BTUs from the Boeing Flight Data Book  
400 = typical metabolic rate for pre and post EVA activities  
1.55 = ALPS recharge current  
Initial Ahr = Initial battery capacity entered into the CWS by the crewmember

This worksheet can be completed given the TIME EV, TIME LF, %O2 LF, and % PWR LF.

## **REFERENCES**

Based on System Version: eCWS Ver: 18.6; 26 May 2006

## 2.2 EMU PURGE DATA

### PURPOSE

This section provides purge times and flowrates for nominal and off-nominal EMU purges, including EMU nitrogen purge and EVA initiated purges. Use of either purge valve during an EVA will require immediate consideration to EVA Termination, due to the significant reduction to the O<sub>2</sub> consumable time left (including both primary and secondary oxygen).

### DESCRIPTION

The EMU provides purge capability via two purge valves, the DCM purge valve and the helmet purge valve (also known as the combination purge valve (CPV)). The EMU purge valves are used for nominal and off-nominal conditions. The DCM purge valve is used nominally for purging nitrogen from the EMU prior to prebreathe. The DCM purge valve and the helmet purge valve can be used for loss of cooling and the helmet purge valve can be used for loss of ventilation, contamination control, and dehumidification.

### EMU NITROGEN PURGE

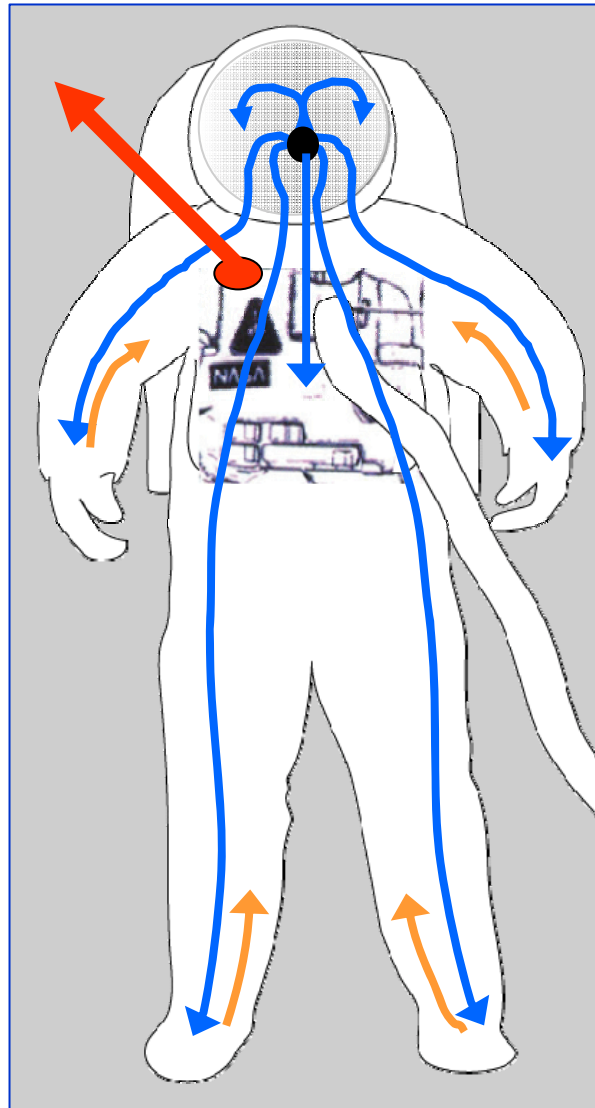
EMU nitrogen purge and prebreathe are performed to lessen the chances of developing decompression sickness (DCS). Refer to Section 3.1 for information on DCS, and Section 3.3 for information on prebreathe. EMU nitrogen purge is conducted to reduce the mass of nitrogen trapped in the EMU during donning. The trapped nitrogen is replaced by 100 percent O<sub>2</sub>. Nominally, EMU nitrogen purge is accomplished by using the DCM purge valve. The purge may also be conducted using the helmet purge valve; however, the purge time would require extension to account for the lower flowrate and would have to be coordinated with the MER for further analysis.

As designed, neither the EMUs nor the vehicles contain flow meters for indicating real-time O<sub>2</sub> flow rates through each EMU; therefore, confirming a proper N<sub>2</sub> purge is based on indirect pressure indications.

The same EMU purge procedure will be used for both ISS Stage EVA and ISS Docked EVA to ensure the proper pressure limits are monitored and reached; however, there are different considerations when using the Shuttle transfer oxygen to support the purge. This information will be covered later in this section. The EMU purge procedure for Shuttle EVAs will be covered following all ISS EVA considerations.

Analysis has shown that 9.7 ft<sup>3</sup> of gas volume must be purged through the suit to reduce the ppN<sub>2</sub> to 3 percent of total pressure. The goal of 97% oxygen is conservative and exceeds the 95% O<sub>2</sub> requirement (per SVHS 7800). The time to move 9.7 ft<sup>3</sup> of volume through the suit depends on the interaction of gas dynamics and hardware dynamics of the EMU/vehicle oxygen systems.

Refer to figure 2.2-1 to follow the flow of gas through the suit during a purge using the DCM purge valve.



**Figure 2.2-1. Flow path during Nitrogen Purge using DCM Purge Valve**

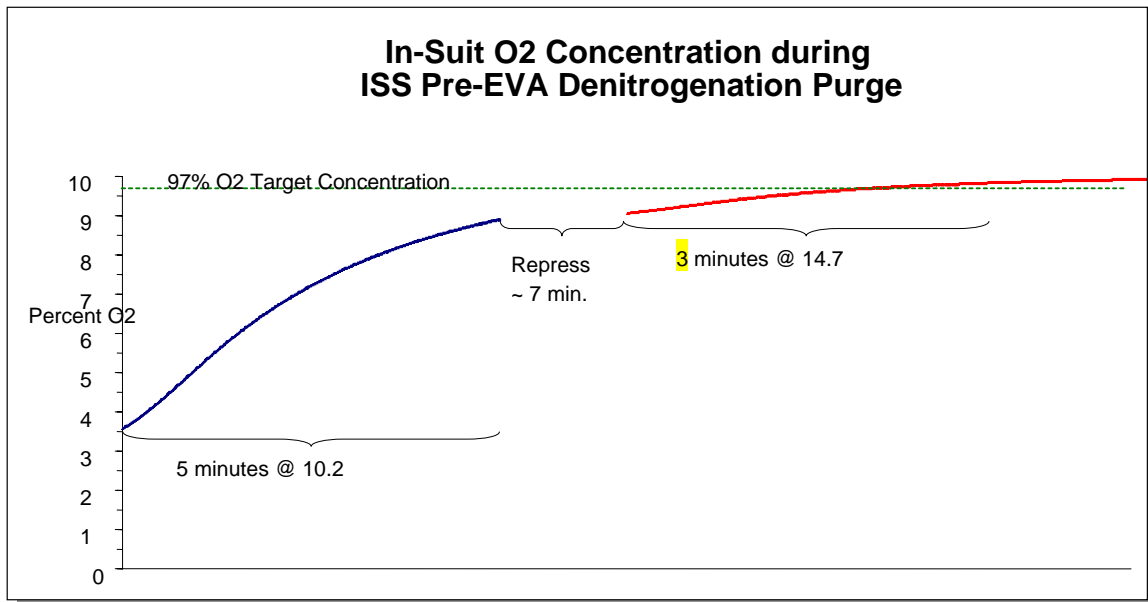
#### EMU Nitrogen Purge – ISS EVA

##### EMU Nitrogen Purge Sequence of Events

1. Suit is Donned - Cabin air is trapped in the suit; PPN2: 80%; PPO2: 20%
2. FAN ON – internal circulation - Air enters SSA at helmet vent port; Air exits SSA through LCVG vent ducts at the arms and boots; FAN flow mixes with oxygen prior to entering Helmet
3. Suit PRESS to 4.3 - Suit is pressurized to 4.3 psig with O<sub>2</sub> to perform EMU leak check; 56% N<sub>2</sub> at 10.2 psia ambient; 62% at 14.7 psia ambient
4. DCM Purge for 5 minutes - Suit P and O<sub>2</sub> P decrease and stabilize

5. Purge paused and ISS A/L repress initiated - EMU DCM purge valve is closed; EMU gas volume is about 10% N2 prior to repress.
6. During repress, O2 system recovers - EMU tank O2 P increases to near source pressure again by the end of repress; 92% at 14.7 psia
7. Purge completed – post repress purge of 3 minutes giving a total purge time of 8 minutes; recovered O2 P gives faster purge out to final N2 (down to 3% N2 conservative vs. 5% required).

Total purge sequence takes 15 minutes and is reflected in Figure 2.2-2



**Figure 2.2-2. ISS O2 Concentration during EMU Purge**

EMU Purge prior to ISS EVA begins at 10.2 psia for 5 minutes until the airlock is repressed to 14.7 psia. The repress is conducted 5 minutes following start of purge to prevent the oxygen levels in the airlock from exceeding flight rule limits. The 5 minutes was a compromise between the ECLSS requirements to avoid exceeding fire hazard limits and the Flight Surgeon requirements to bring the suit to at least 50% oxygen prior to introducing a higher nitrogen pressure environment (14.7 psia). The only way that the 14.7 psia gas could leak into the suit is via negative pressure at the suit seals. Pockets of negative pressure could occur while purging during repress if the suit pressure falls to below ambient pressure. Maintaining a suit pressure greater than 0.25 psig protects against the potential for negative flow and is achievable with an oxygen pressure of 600 psia as indicated by a Primary O2 Pressure transducer (575 psia actual at the item 113A flow restrictor.)

The EMU Purge procedure (1.220 EMU PURGE (ISS EVA SYS/7A - ALL/FIN 7)) was designed to be conservative in getting the N2 below 5%, with the following assumptions used in the analysis:



1. The minimum EMU Primary Tank Pressure (O2 P) of 725 psia indicated (actual 700psia) achieves 97% oxygen in-suit concentration in 8 minutes total purge time. This correlates to a minimum O2 flow rate of 4.5 lbm / hour into the EMU volume.

Note: The 8-minute purge time is calculated to remove the equivalent mass of 1 free suit volume (2.9 cubic feet) considering the possibility that some crewmembers may be required to use an EMU larger than nominal. In order to remove the N2 mass of 1 suit volume out of the EMU, more than that volume must be purged out of the suit. This is due to the limits in mixing efficiency, i.e., some of what is being purged out is actually the fresh O2 coming into the suit leaving a significant amount of N2 after one suit volume. This is the reason for purging 9.7 cubic feet.

2. A Maximum EMU free volume of 3 ft<sup>3</sup> when donned is assumed. This allows for crewmembers that are required to “size up” one EMU HUT size; nominal suit free volumes are generally about 1.5 ft<sup>3</sup> or about half the assumed value.
3. No credit is taken for the increased flow rate out of the EMU during the first minute of purge, while the EMU Suit Pressure is purged down from ~4.1psid to the equilibrium purge pressure.
4. The Item 113B flow restrictor is assumed to be sized to minimum flow specification i.e. minimum effective area.
5. EMU Fan is ON and good ventilation flow is indicated to ensure significant O2 mixing with the initial ventilation gases (providing a 72.6% mixing efficiency.)

#### EMU NITROGEN PURGE EXTENSION - ISS EVA

If supply pressures drop too low, the EMU Purge procedure lists impacts of EMU O2 pressure ranges below 725 psia indicated. Since lower pressures will lower the oxygen flowrate to the EMU, more purge time will be required to remove the 9.7 cu. ft<sup>3</sup> of gas (97% oxygen) in preparation for EVA. Table 2.2-1 lists the purge time extension required for a particular EMU pressure range below 700 psia actual.

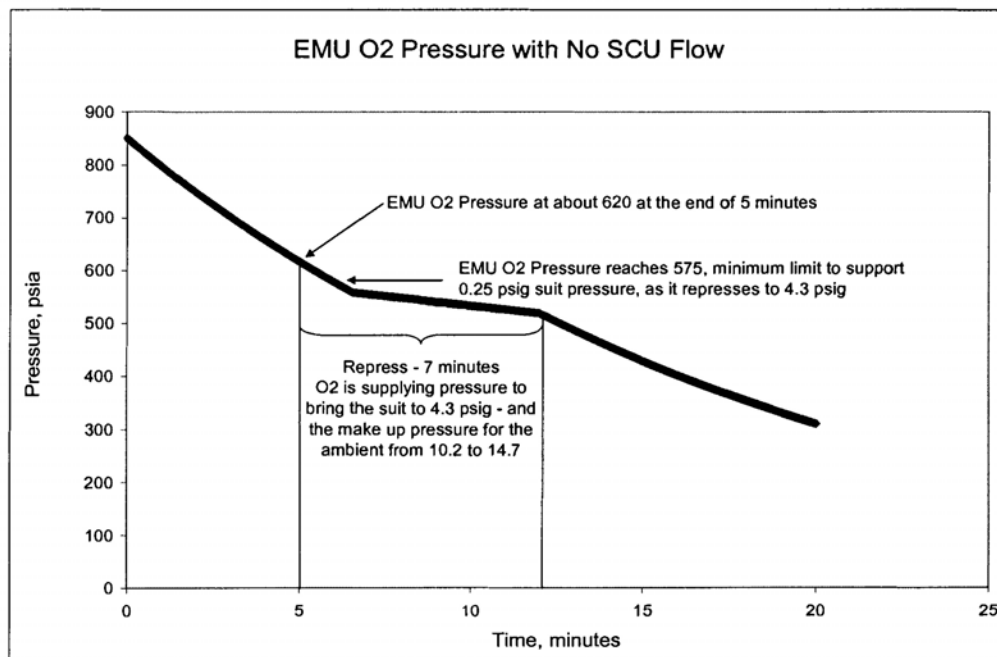
**Table 2.2-1. Purge Time Extension Requirements at 10.2 psia**

Purge Time Extension (min)	Total Purge Time (including extension time) (min)	EMU O2 Pressure Range* (psia)
1	9	655 - 700
2	10	610 - 655
3	11	575 - 610

\* O2 sensor error is not included and must be accounted for that particular sensor calibrated with the error recorded in the Flight Hardware Handbook for a specific flight.

This table is a simplification, as the actual time spent within these pressure ranges would also affect the required extension time. Operationally, even the granularity of this table is not required since extending the purge to the maximum of 3 minutes is not a significant hit to a timeline or to consumable margins.

Exceedingly low pressure, below 600 psi indicated (575 actual), will not hold EMU suit pressure high enough to ensure proper mixing. The nominal supply pressure of 850 psia in the Primary O2 Tanks, should maintain the EMU O2 Pressure above 600 psia indicated during the first 5 minutes of purge. If the pressure approaches this value, there may be no or low flow conditions through the umbilical. This can be verified with the EMU purge valve closed; the EMU O2 pressure will increase as the pressure in the tanks equalizes with the vehicle supply pressure. If no rise in pressure is detected, the O2 supply may be out of configuration and may require switching over to the ISS Oxygen tank supply. An EMU pressure below 600 psia will not be sufficient to finish the last 3 minutes of purge (refer to Figure 2.2-3).



**Figure 2.2-3. EMU O2 Pressure without SCU Flow**

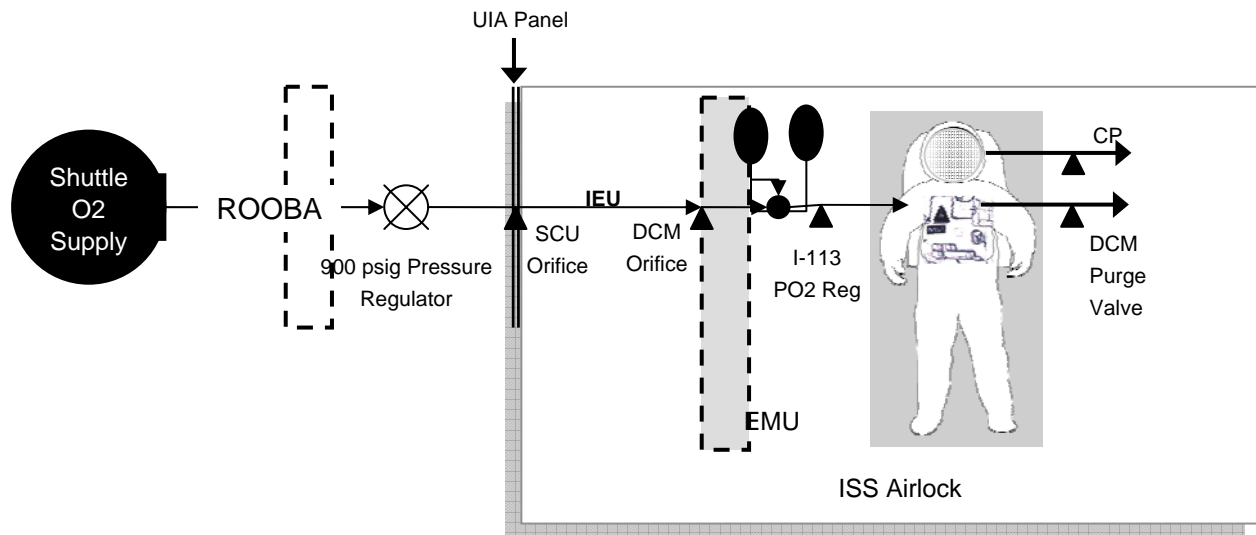
In order to avoid this condition, the purge valve is now closed during the actual repress to avoid the decreasing suit pressure from introducing unwanted nitrogen into the suit volume. In the past, the EMU Purge was required to be 12 minutes long to maintain conservatism since the end of the purge was accomplished at 14.7 psia. Historically, on Shuttle flights, the purge time at 14.7 psia was 12 minutes. The latest procedure reduces actual purge time to 8 minutes but is more conservative due to breathing

increased oxygen concentration in the suit while waiting for repress. The overall time for the EMU Purge procedure is a few minutes longer, but the actual purge clock has been reduced.

Figure 2.2-3 also demonstrates that EMU Purge can not be completed within requirements without SCU oxygen flow. In case of SCU oxygen failure, several workarounds may be considered: serial purging (one crewmember at a time), initial purge prior to repress may be completed on O2 tanks and then SCUs swapped to finish the purge and if the team decides to waive off the EVA for the day, the spare SCU may be installed.

#### EMU Nitrogen Purge – ISS Docked EVA

The purge configuration for EVAs from the ISS Airlock is more complicated due to the line loss and instrumentation inherent in the transfer system. The O2 supply circuit from the Shuttle was designed to reduce ISS O2 transfer requirements and Oxygen Recharge Compressor Assembly (ORCA) operations, and allows support of EVA prebreathe directly from the Shuttle O2 source. The recharge oxygen orifice bypass assembly (ROOBA) was designed and instated as an addition to the existing ISS O2 system to provide adequate flow for EVA purge and prebreathe. ROOBA bypasses the 16 lbm/hr flow restrictor, which was initially installed to prevent condensation during equalization\blowdown\recharge and to provide the required flowrates for ECLSS systems. This flow restrictor inhibited adequate flowrates for EVA operations necessitating ROOBA hardware. ROOBA provides a path for the transfer oxygen to supply the proper flowrates through the ISS SCU (figure 2.2-4). Refer to Volume 3, Section 4.1 ECLSS systems for more information on ROOBA (section currently TBD).



**Figure 2.2-4. Functional EMU Purge Schematic – Shuttle O2 Source**

As mentioned before, the minimum EMU O2 pressure is 700 psia to achieve 97% oxygen in the suit within the 8-minute purge time. There should be very few cases

where this requirement cannot be met, as the worst case shuttle supply pressure is no less than 790 psia. The lowest oxygen pressure seen during EMU operations was seen on STS-109 EVA#5; however, pressures seen during the 8 minute purge range between 826 and 857 psia on average. The pressure losses through the oxygen circuit from the docked Shuttle to the ISS Airlock, including the ROOBA hardware and through the ISS SCU, still provide enough pressure to give an EMU O<sub>2</sub> Pressure of at least 740 psia: this pressure exceeds the minimum EMU O<sub>2</sub> Pressure needed to support an 8 minute purge and is therefore an acceptable purge time. This purge procedure maintains conservatism to ensure denitrogenation and prevention of decompression sickness.

Data from the first use of this procedure (STS-121) and the following flight (STS-115) suggests that occasionally the purge may need to be extended. During STS-115, one EMU fell slightly below the limit, with only a slight improvement from one umbilical to the other. The purge was extended to 11 minutes total, and EVA preparations continued.

#### EMU Nitrogen Purge – Shuttle EVA

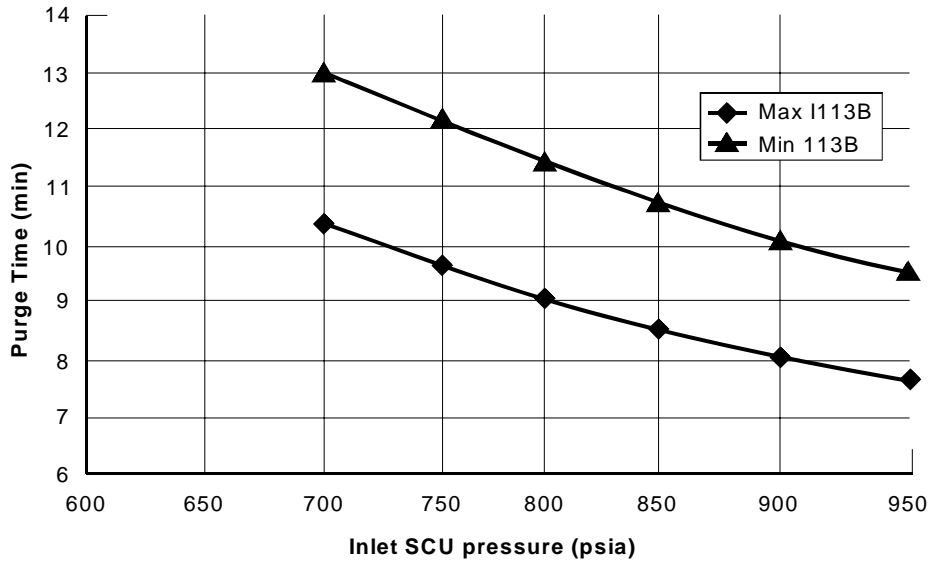
The Shuttle EMU Purge procedure remains a constant 8 minute purge at 10.2 psia and a 12 minute purge at 14.7 psia.

#### Purge Gas Dynamics

The primary gas dynamics associated with EMU purge are the O<sub>2</sub> pressure at the SCU inlet and the pressure drop through the SCU. The O<sub>2</sub> pressure at the SCU inlet is defined as 900 ± 50 psia. The pressure drop through the SCU is defined as 45 psid maximum and 25 psid minimum. The primary hardware dynamic is the item 113B flow restrictor. The item 113B flow restrictor has a variable orifice set to flow with a minimum and maximum flowrate band. The item 113B is set preflight by USA FCE. The flow requirements for the 113B are 5.5 to 7.1 lb O<sub>2</sub>/hr at 900 ± 50 psia with a maximum flowrate of 7.49 lb O<sub>2</sub>/hr at 1050 psia. A minimum flow of the 113B is defined as the design point of 5.5 lb O<sub>2</sub>/hr at 900 psia, and the maximum flow of the 113B is defined as 7.1 lb O<sub>2</sub>/hr at 900 psia.

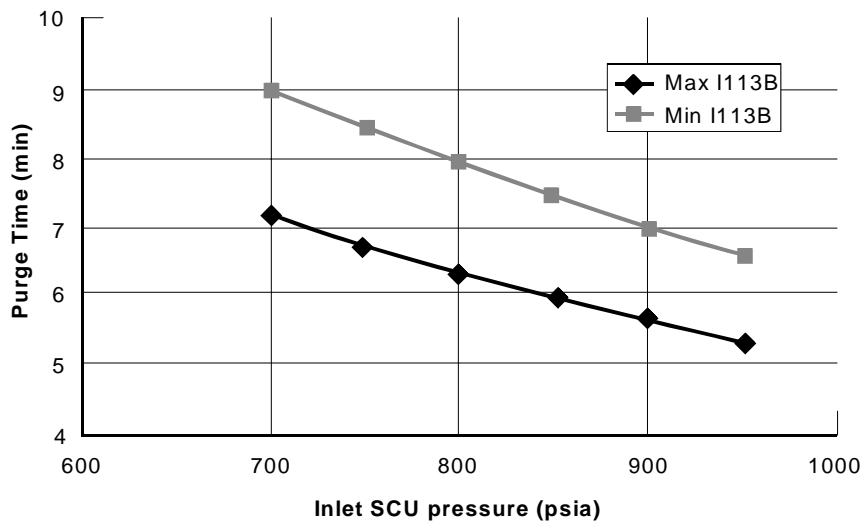
2.2-5 is a graphical representation of the nitrogen purge data for both 14.7 psia and 10.2 psia.

Note: The item 113B flow restrictor is the limiting factor for the flowrates because of the low downstream suit pressures (~1.0 psid) that cause the item 113D regulator to operate full open.



(a) Purge times for 14.7 psia airlock

j\_20597\_164a.cv5

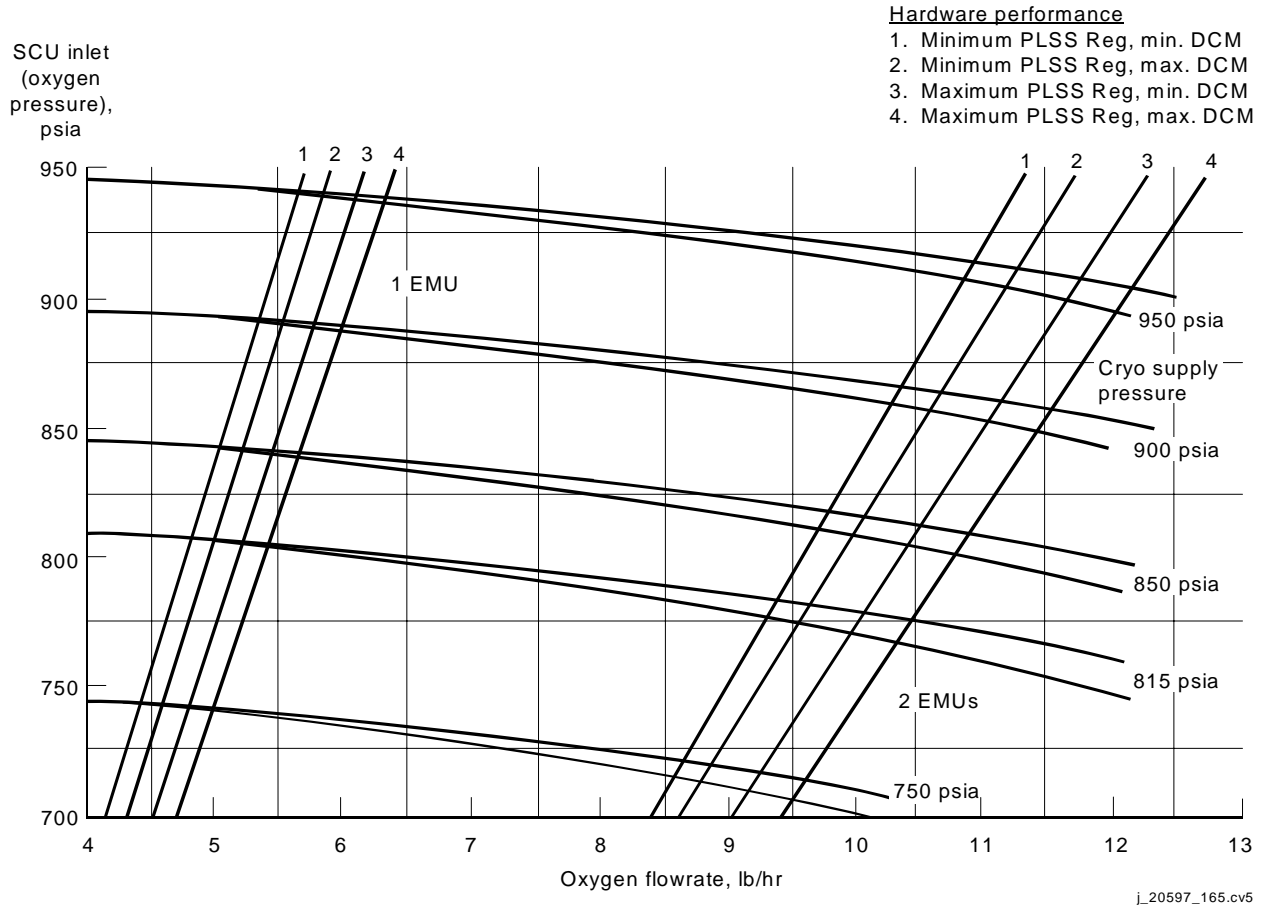


(b) Purge times for 10.2 psia airlock

j\_20597\_164b.cv5

**Figure 2.2-5. EMU nitrogen purge times - DCM purge valve**

See Figure 2.2-6 for the relationship between SCU inlet pressure and O<sub>2</sub> mass flowrates during N<sub>2</sub> purge, as influenced by EMU hardware characteristics. This figure can be used to determine the individual or combined oxygen flowrates expected during EMU N<sub>2</sub> purge, based on EMU hardware performance and SCU supply pressure. Assuming two EMUs are purging the EMU hardware with maximum flow at a SCU supply pressure of 850 psia, the resultant oxygen flowrate is approximately 10.8 lb/hr. Refer to SSSH drawing 6.1, sheet 2 of 2 for information regarding the orbiter's pressure control system and oxygen flowrates.



EVA-INITIATED PURGES – FAILURE RESPONSE

The helmet purge valve is the primary purge mode for two reasons:

- For loss of CO<sub>2</sub> control (LiOH failure or expenditure), the close proximity of the valve to the crewmember’s face ensures adequate CO<sub>2</sub> removal
- The helmet purge valve is sized to be approximately half the size of the DCM purge valve, which means a longer period of purge time available due to the smaller mass flowrate

The DCM purge valve is used as a backup for crewmember-initiated purge. This mode has the advantage of providing some crewmember cooling in the event of a cooling system failure.

There are several disadvantages of using the DCM purge valve.

- The location of the DCM purge valve (on top of the DCM) is a considerable distance from the crewmember's face, reducing the efficiency of CO<sub>2</sub> washout.
- For all practical purposes, the purge time is restricted to the 30-minute limit of the SOP tanks.

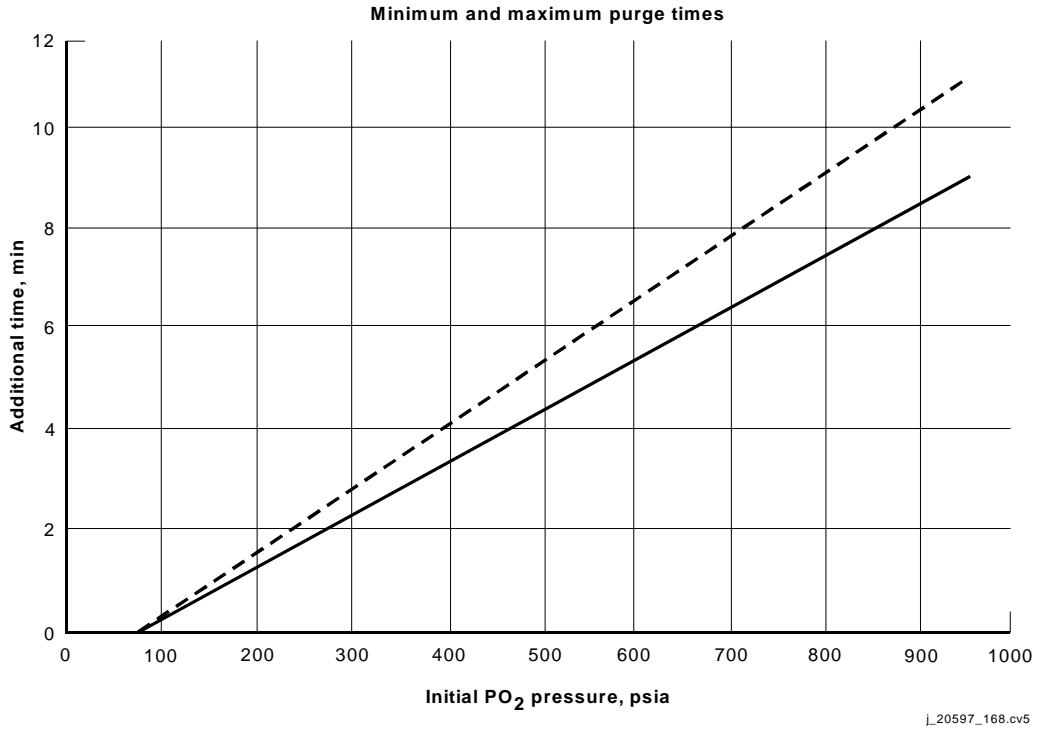
An EVA-initiated purge is defined as opening either the DCM purge valve or helmet purge valve in response to a failure. These failures include loss of cooling, loss of ventilation, LiOH expenditure/breakthrough, airflow contamination, and fogging.

The time available for purge depends on different variables, including primary oxygen pressure, secondary oxygen pressure, EMU hardware characteristics, and ambient pressure. The following data and trends assume the purge is initiated at vacuum conditions. EMU hardware considerations include the orifice size of the DCM and helmet purge valves and the oxygen flow restrictors.

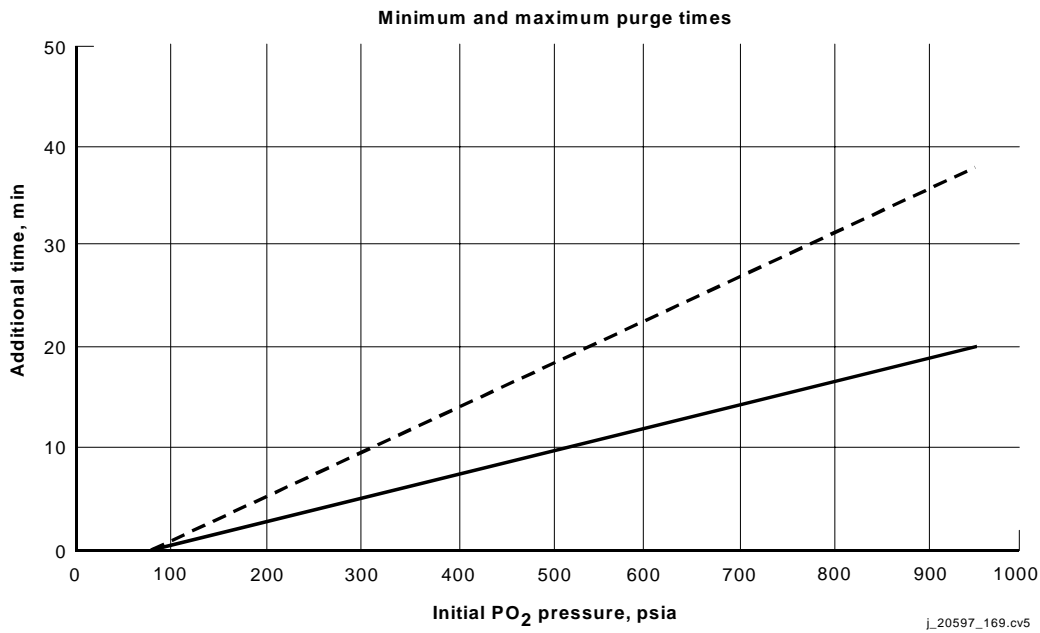
Purge analysis was performed by Hamilton Standard, based on test data (EMUM-1388, Appendix E). The results of this analysis are presented in the following graphs. The minimum time shown for a purge is defined by maximizing the flow through the valve (shown as a solid line), and the maximum time for a purge is defined by minimizing the flow through the valve (shown as a dashed line).

#### Purge Time Available - Primary Oxygen

The following curves may be used to determine how much time is available before the SOP comes on line. Figure 2.2-7 and Figure 2.2-8 show additional purge times from the primary O<sub>2</sub> tanks for the DCM purge valve and the CPV, respectively. Starting with a primary O<sub>2</sub> tank pressure of 700 psi at the beginning of the purge, the DCM purge time available from the primary system is approximately 6 to 8 minutes. Similarly, if the primary O<sub>2</sub> tank pressure is 700 psi at the onset of purge, the CPV purge time available from the primary system is approximately 14 to 28 minutes.



**Figure 2.2-7. Additional DCM purge time from primary O<sub>2</sub> tanks**



**Figure 2.2-8. Additional CPV purge time from primary O<sub>2</sub> tanks**

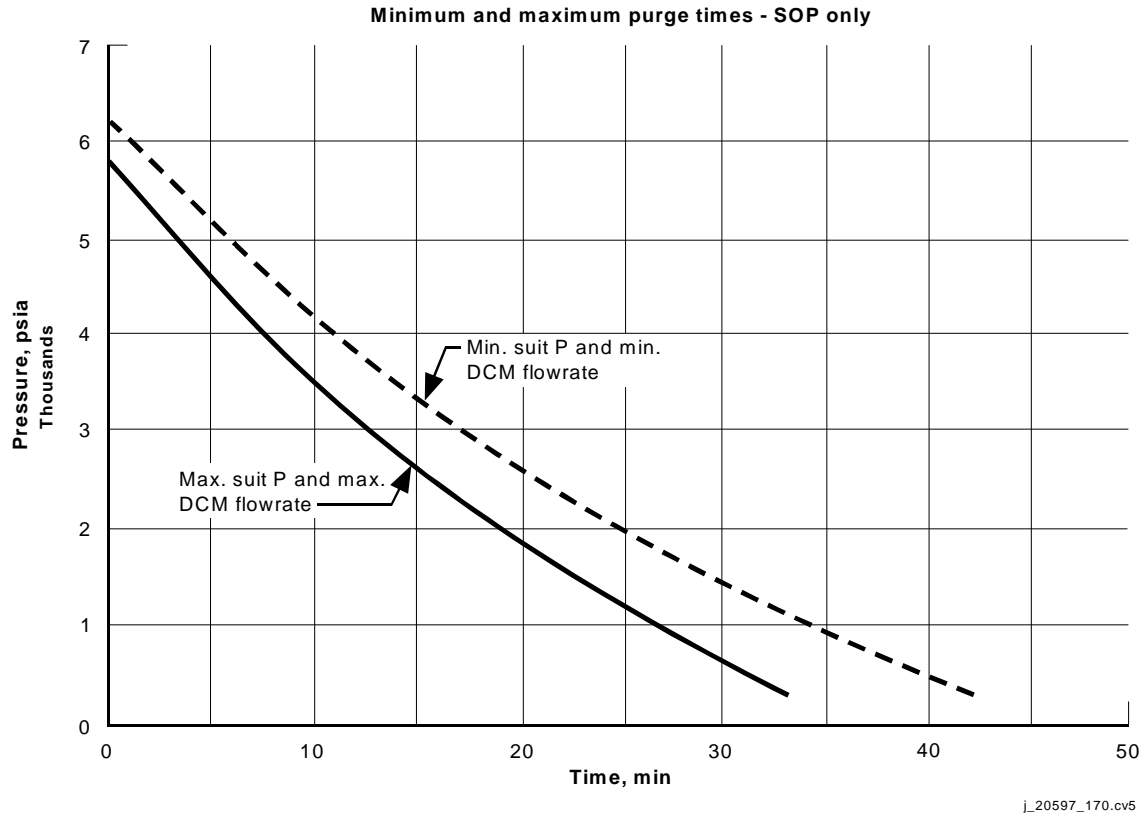


### Purge Time Available - SOP

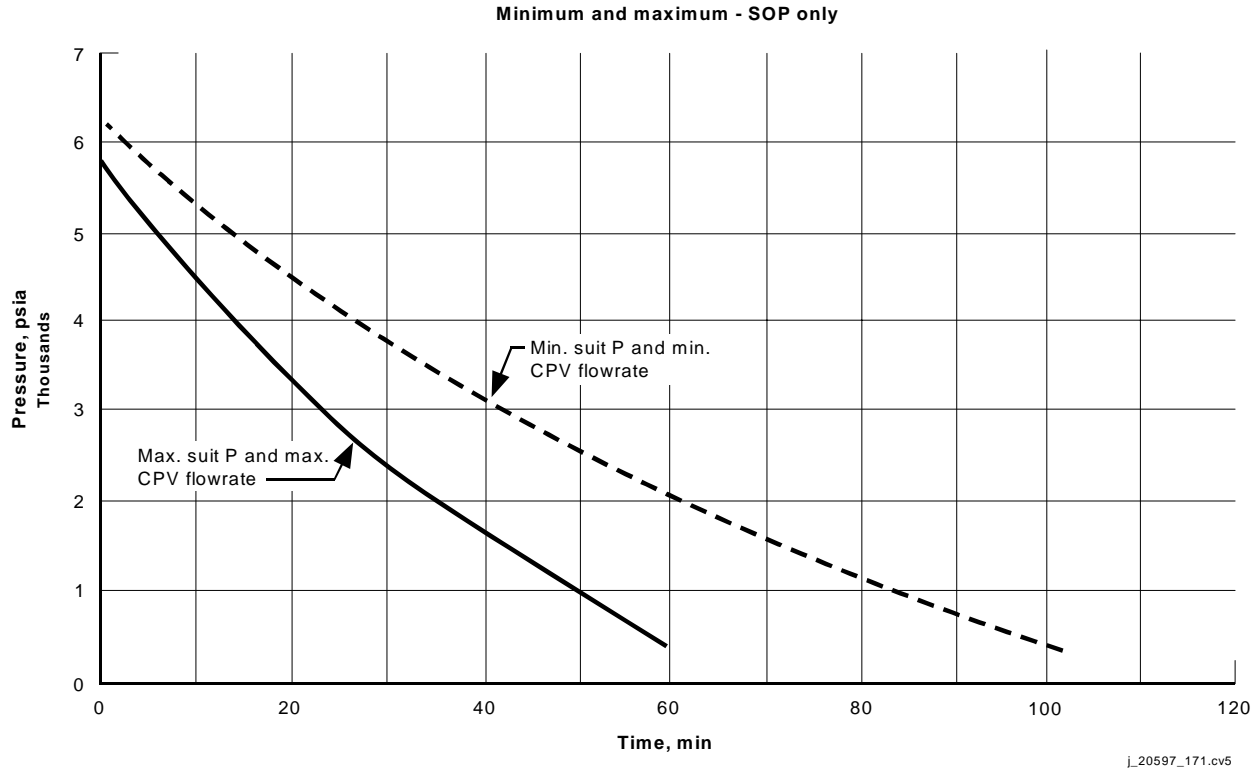
Note: the new No-Go limit for the SOP as defined by Flight Rules is 5410 psia as opposed to the 5800 psia assumed for the purposes of this data.

It is necessary to determine the time available on the SOP when an EVA-initiated purge is required. These curves do not take into account the available O<sub>2</sub> from the primary oxygen system. Figure 2.2-9 and Figure 2.2-10 illustrate the maximum and minimum purge times available for a DCM purge and a CPV purge as a function of SOP tank pressure, respectively. Assuming a maximum SOP pressure of 6200, the purge time available with the DCM purge valve is approximately 42 minutes. Assuming a minimum SOP pressure of 5800, the purge time is approximately 33 minutes. Similarly, at 6200, the purge time with the CPV is approximately 102 minutes and at 5800, the purge time is approximately 60 minutes. The minimum purge times come from the maximum regulated suit pressure of 3.7 psia and 3.9 psia for the DCM and helmet purge valves (CPV), respectively, and its maximum flow condition. Likewise, the maximum purge times come from the minimum regulated suit pressure of 3.33 psia for both the DCM and helmet purge valves and their minimum flow conditions.

Another application of Figure 2.2-9 and Figure 2.2-10 is to determine the amount of SOP used, given a specific purge time. For example, if the DCM purge valve was open for 10 minutes, the SOP pressure would drop from 6200 to 4200 or 5800 to 3500, depending on SOP initial pressure and flow conditions. Similarly, if the helmet purge valve was open for 10 minutes, the SOP pressure would drop from 6200 to 5400 or 5800 to 4500, depending on SOP initial pressure and flow conditions.



**Figure 2.2-9. SOP tank pressure profile for DCM purge**



**Figure 2.2-10. SOP pressure profile for CPV purge**

Total Purge Time Available - Primary Oxygen and SOP

Total purge time available can be estimated by combining the time available on the SOP with the time available on the primary oxygen system. Using the DCM purge valve, the time on the SOP is 33 to 42 minutes and the time on the primary system (700 psi) is 6 to 8 minutes; therefore, the total purge time is 39 to 50 minutes. Using the CPV, the time on the SOP is 60 to 102 minutes and the time on the primary system (700 psi) is 14 to 28; therefore, the total purge time is 74 to 130 minutes.

The total purge times may also be estimated from Figure 2.2-11 and Figure 2.2-12. Choose an initial primary oxygen pressure to estimate total purge time available. The available purge time for the DCM purge valve is shown in Figure 2.2-11. Given a primary pressure of 600 psi, the total purge time available is 38 to 57 minutes. The available purge time for the CPV is shown in Figure 2.2-12. Given a primary pressure of 600 psi, the total purge time is 72 to 125 minutes.

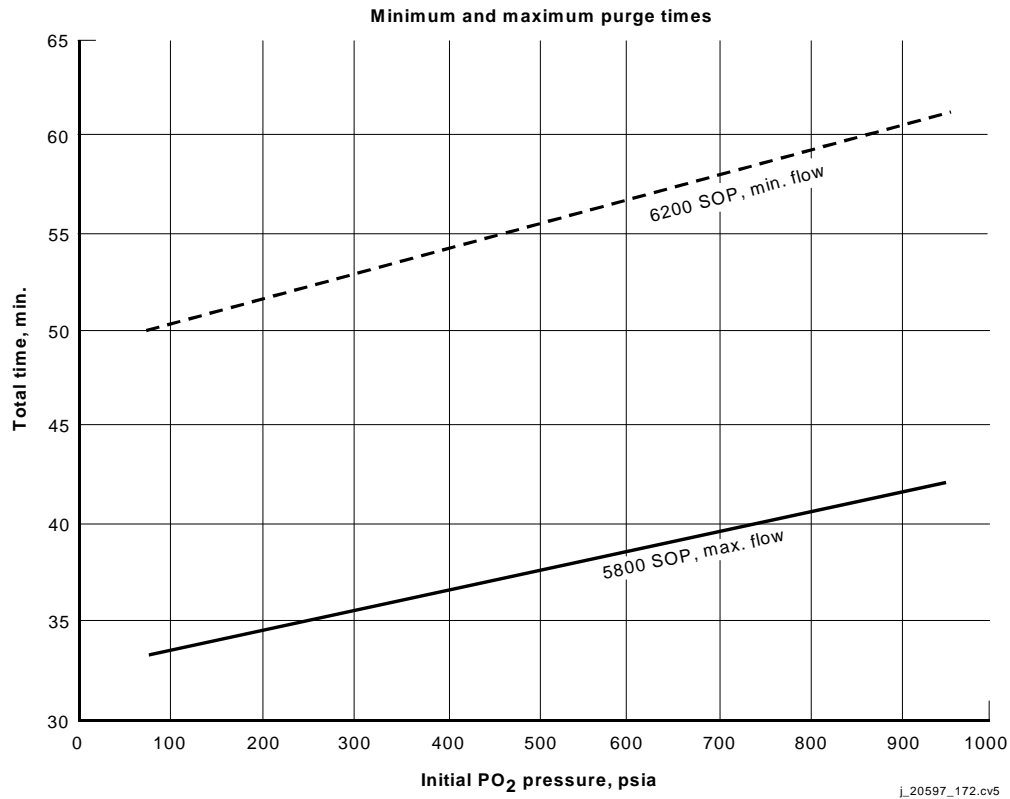


Figure 2.2-11. Available purge time for DCM purge

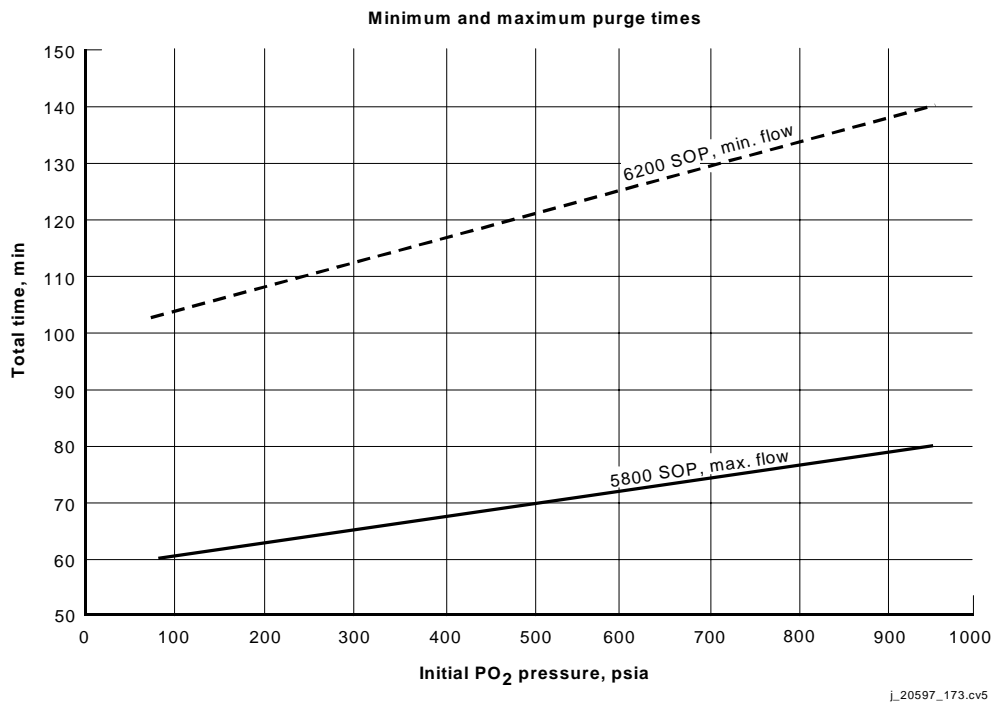


Figure 2.2-12. Available purge time for CPV purge

## Purge Profiles

The remainder of the curves, giving the overall purge profile, show the suit pressure and primary tank and secondary tank pressure profiles for both the DCM purge valve and the CPV. These curves may be used to determine when the SOP will come on line and when the suit pressure will drop off once a purge is initiated.

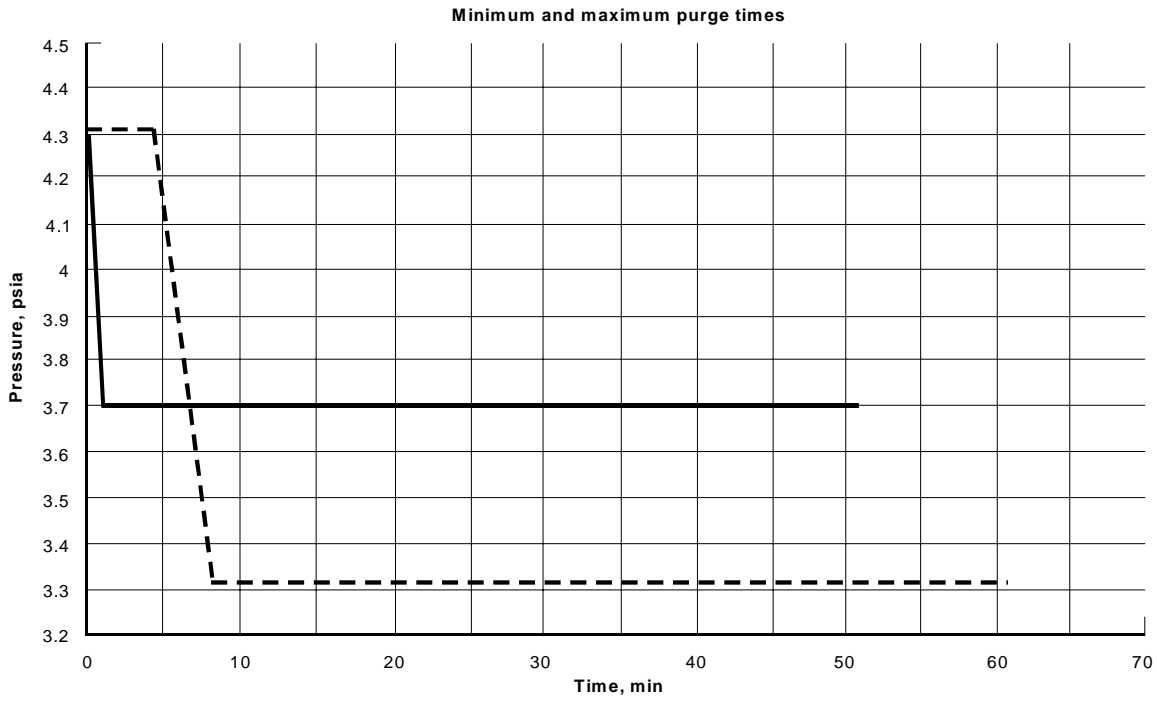
Figure 2.2-13, Figure 2.2-14, and Figure 2.2-15 show the suit pressure, primary O<sub>2</sub> tank pressure, and SOP pressure, respectively, for a DCM purge. If the purge is initiated with a full primary tank pressure of 950 psia, suit pressure can be maintained at 4.3 psia for 4 minutes before the item 113 cannot provide enough flow to compensate for the flow through the DCM purge valve. The suit pressure then decreases to 3.7 psia or 3.33 psia for either a minimum or a maximum flow case. The pressure decay takes 2 to 4 minutes before the SOP comes on. The total purge time available ranges from 51 to 61 minutes.

Figure 2.2-16, Figure 2.2-17, and Figure 2.2-18 show the suit pressure, primary O<sub>2</sub> tank pressure, and SOP pressure, respectively, for a CPV purge. If the purge is initiated with a full primary O<sub>2</sub> tank pressure of 950 psia, suit pressure is maintained at 4.3 psia for approximately 12 to 25 minutes before the item 113 cannot provide enough flow to compensate for the flow through the CPV. The suit pressure then decreases to 3.9 psia or 3.33 psia for the minimum or maximum flow case. The pressure decay takes 2 to 5 minutes before the SOP comes on. The total available purge time ranges from 85 to 140 minutes.

In simpler terms, Figure 2.2-14 illustrates the maximum and minimum purge times available for a DCM purge as a function of initial O<sub>2</sub> tank pressure. At a full tank pressure of 950 psia, the maximum purge time is 42 minutes and the minimum purge time is 35 minutes using primary oxygen. The curve depicts extended purge time because of SOP operation at the point where the curve levels out. Figure 2.2-17 shows the maximum and minimum purge times available for a helmet purge. At a full tank of 950 psia, the maximum purge time is approximately 50 minutes and the minimum purge time is approximately 48 minutes using primary oxygen. The curve depicts extended purge time because of SOP operation at the point where the curve levels out.

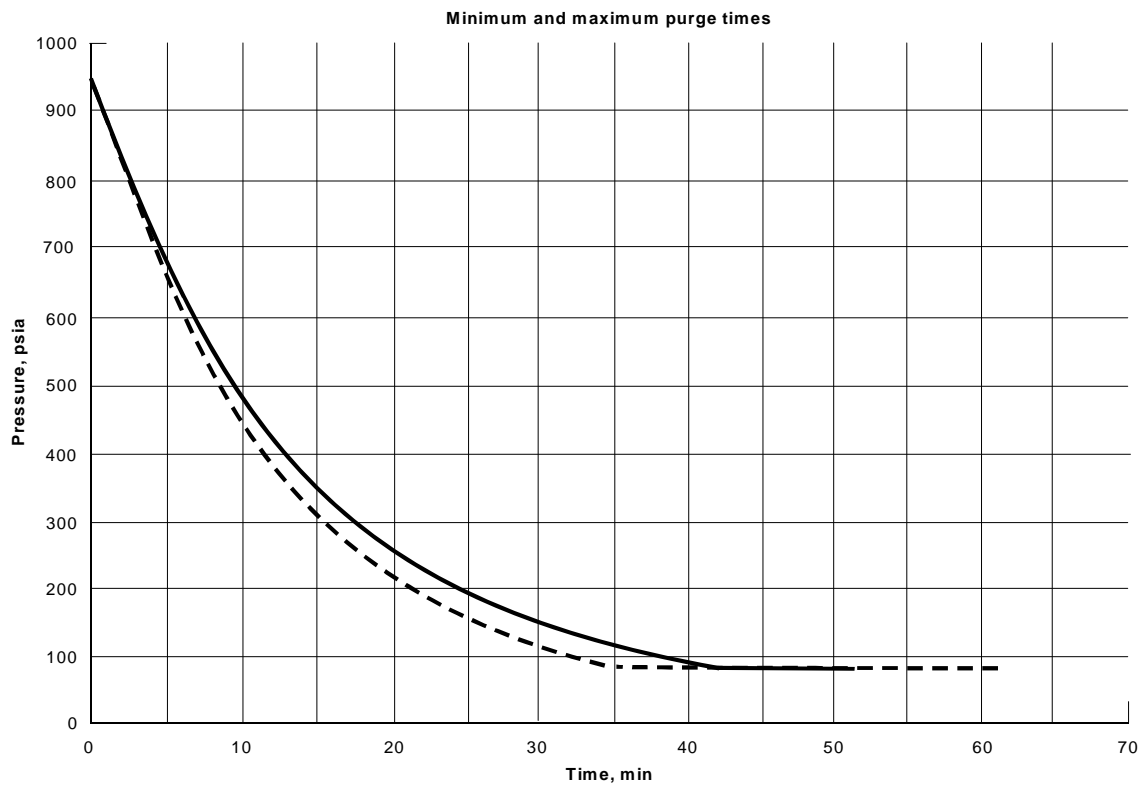
The range of primary O<sub>2</sub> tank pressures that will preclude SOP initiation for a DCM purge is approximately 550 to 850 psia, as shown in Figure 2.2-13 and Figure 2.2-14. The range of primary O<sub>2</sub> tank pressures that will preclude SOP initiation for the CPV is approximately 200 to 550 psia, as shown in Figure 2.2-16 and Figure 2.2-17.

For reference, the general equation for flow through an orifice is located at the end of this section.



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**Figure 2.2-13. Suit pressure profile for DCM purge**



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**Figure 2.2-14. Primary O<sub>2</sub> tank pressure profile for DCM purge**

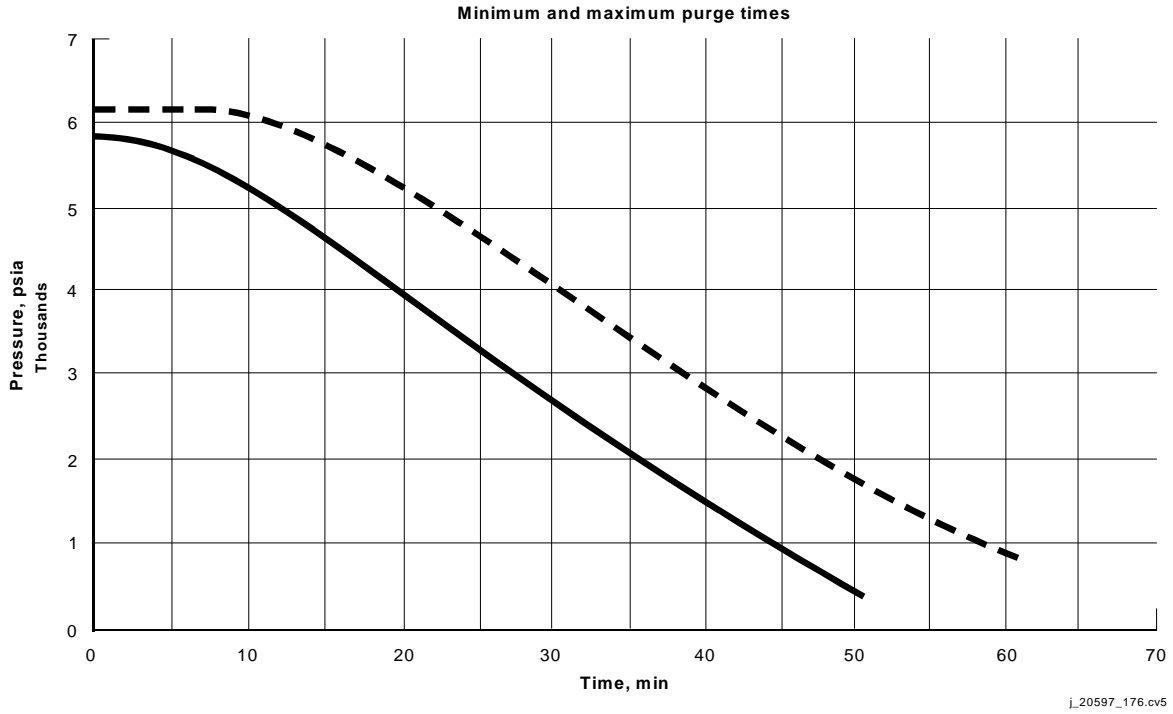


Figure 2.2-15. SOP tank pressure profile for DCM purge

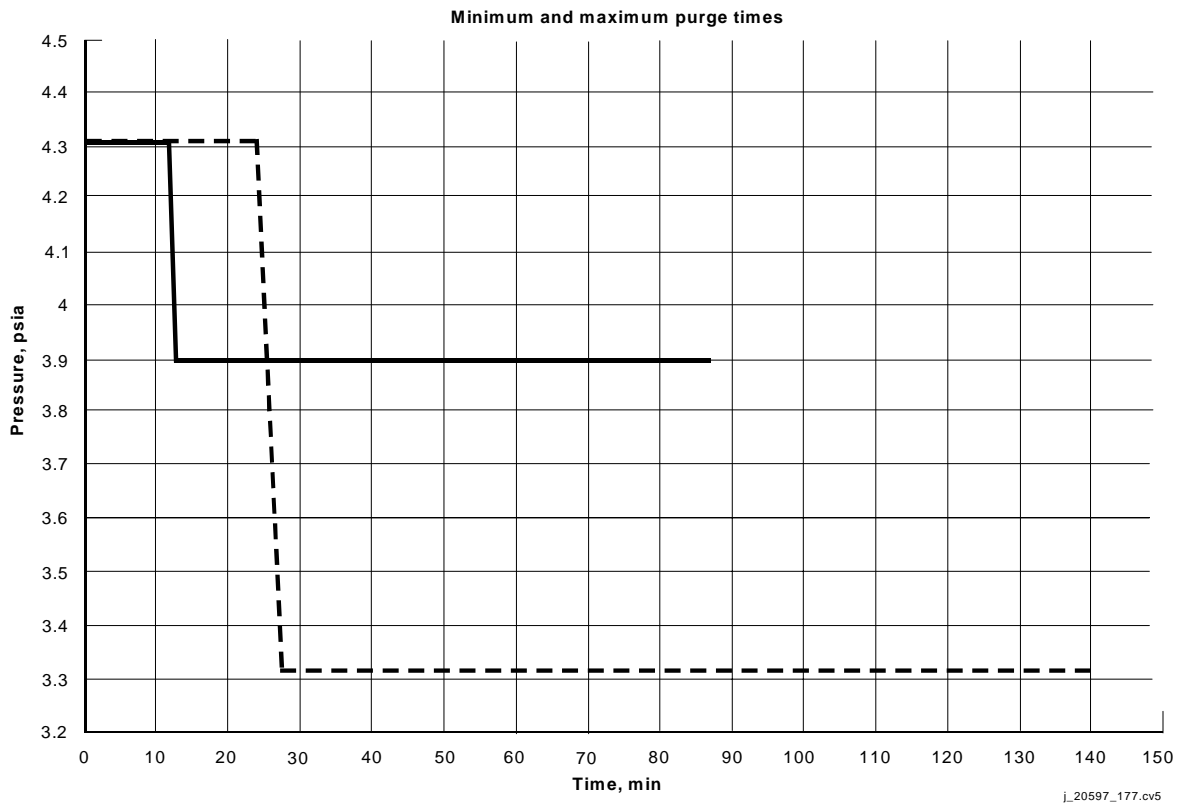


Figure 2.2-16. Suit pressure profile for CPV purge

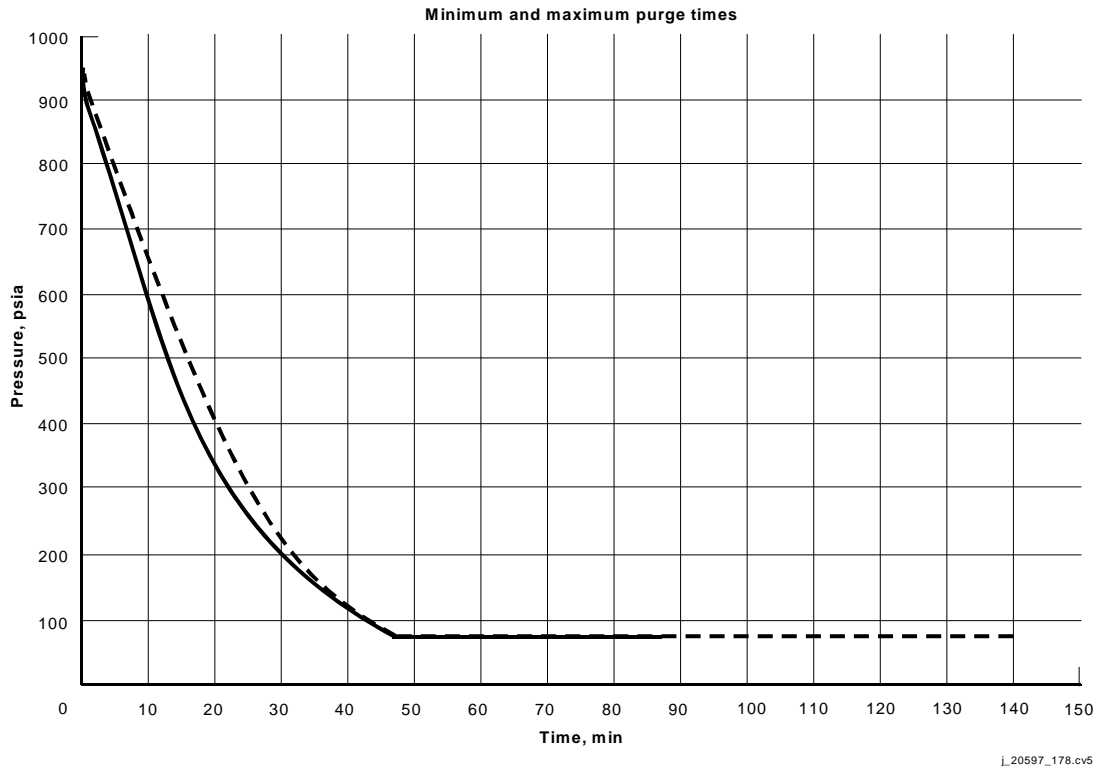


Figure 2.2-17. Primary O<sub>2</sub> tank pressure profile for CPV purge

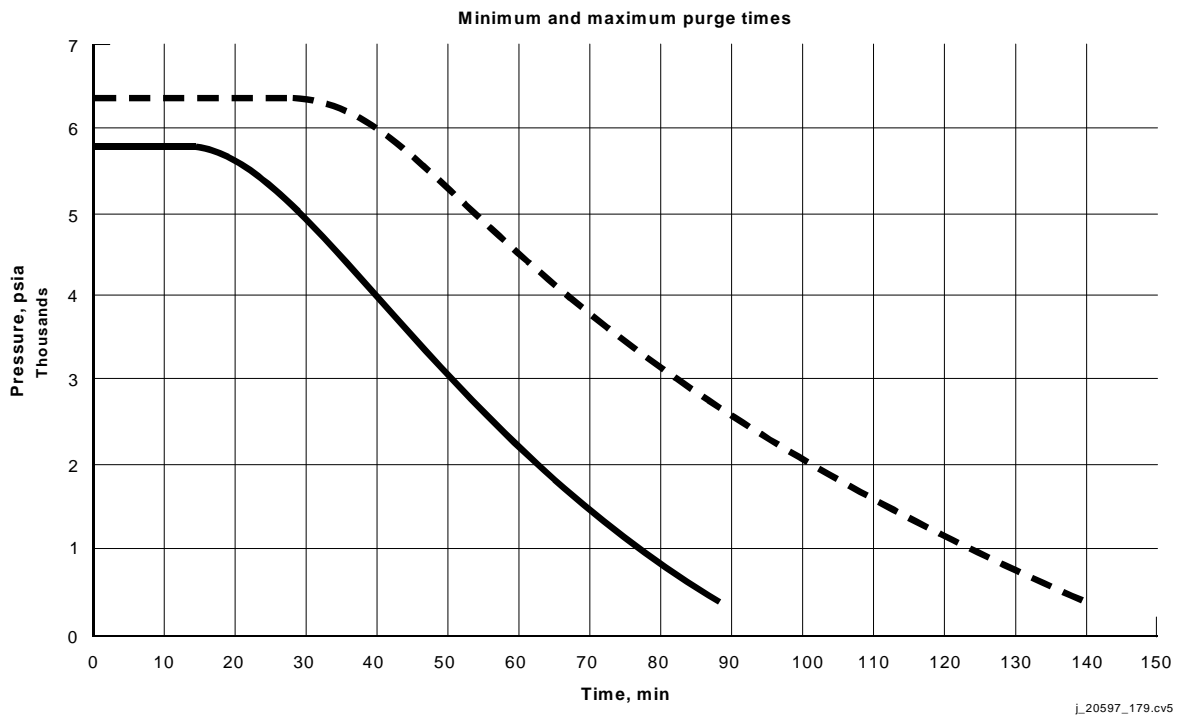


Figure 2.2-18. SOP tank pressure profile for CPV purge



### GENERAL EQUATION - FLOW THROUGH AN ORIFICE

There are many variables that determine the flowrate through the DCM purge valve and the helmet purge valve. The general equation for flow through an orifice is shown below. Assume one-dimensional compressible flow through the orifice. Equations are derived from EMUM 1388.

$$m = \sqrt{\frac{K}{R}} \frac{P_1}{\sqrt{T}} A C_d \frac{M}{\left(1 + \frac{K-1}{2} M^2\right)^{\frac{K+1}{2(K-1)}}} (144)(3600)\sqrt{g}$$

$$M = \sqrt{\frac{\left(\frac{P_1}{P_2}\right)^{\frac{K-1}{K}} - 1}{\left(\frac{K-1}{2}\right)}}$$

For  $M < 1$ , unchoked flow:  $P_2 > \frac{1}{2} P_1$  (i.e., when downstream pressure is greater than one-half of upstream pressure).

$$m = \frac{A C_d P_1}{\sqrt{TR}} \left( 2g \frac{K}{K-1} \left[ \left(\frac{P_2}{P_1}\right)^{\frac{2}{K}} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}} \right] \right)^{\frac{1}{2}} (3600)$$

For  $M > 1$ , choked flow:  $P_2 < \frac{1}{2} P_1$  (i.e., when downstream pressure is less than one-half of upstream pressure).

$$m = \frac{A C_d P_1}{\sqrt{RT}} \left[ gK \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}} \right]^{\frac{1}{2}} (3600)$$

Where,

- m = mass flow (lb<sub>m</sub>/hr)
- A = area (in<sup>2</sup>)
  - A<sub>DPV</sub> - area of DCM purge valve = 0.018077
  - A<sub>HPV</sub> - area of helmet purge valve = 0.0112
- C<sub>d</sub> = discharge coefficient\*
- P<sub>1</sub> = upstream pressure (absolute suit pressure); P<sub>suit</sub> + P<sub>amb</sub>
- P<sub>2</sub> = downstream pressure (absolute ambient pressure); P<sub>amb</sub>
- T = absolute temperature (R): °R = °F + 459.7
- R = individual gas constant (48.28 ft-lb<sub>f</sub>/lb<sub>m</sub>-R for O<sub>2</sub>)
- K = ratio of specific heats: C<sub>P</sub> ratio (1.39 for O<sub>2</sub>)
- g = gravity (32.174 ft/s<sup>2</sup>)

$$*C_d = 0.0401 \left( \frac{P_2}{P_1} \right)^5 + 0.1359 \left( \frac{P_2}{P_1} \right)^4 - 0.3401 \left( \frac{P_2}{P_1} \right)^3 + 0.1092 \left( \frac{P_2}{P_1} \right)^2 - 0.0166 \left( \frac{P_2}{P_1} \right) - 0.9066$$

(To calculate discharge coefficient,  $C_d$ , use a 5<sup>th</sup> order polynomial curve fit - reference Hamilton Standard Engineering TS 0660, 3/92, p.6 of 24.)

## REFERENCES

1. Analysis 2006 – 034 EMU: STS- 12 1 EMU Denitrogenation Purge Requirements  
Sub-references
  - (a) SV799IOOI2, Subsystem; Life Support, Primary (PLSS) (CEI 1 OO), Rev BM
  - (b) SV79229412, Display and Control Module (DCM) (CEI 300), Rev BB
  - (c) HS Systems Analysis 77-1 94, Nitrogen Purge Analysis, E. Tepper
  - (d) HS Systems Analysis 89-648, Evaluation of Nitrogen Purge of the Suit with Shortened EMU LCVG *Arm* Ducts for Worst Case Conditions
2. SVHS 7800 - Space Vehicle Hamilton Sundstrand

## 2.3 PRIMARY OXYGEN SYSTEM

### PURPOSE

This section describes the EMU primary oxygen system. Operational data on the primary oxygen system is presented for use in predicting its performance during on-orbit conditions.

### DESCRIPTION

The primary oxygen system of the EMU is designed to provide a source for suit pressurization, feedwater pressurization, and breathing oxygen. This system was designed to provide sufficient oxygen for a 6-hour EVA, 15-minute egress, 15-minute ingress, and 30-minute reserve for a total of 7 hours of operation. This system has the additional capability of being recharged during on-orbit operations by the orbiter cryogenic oxygen supply system.

### OXYGEN STORAGE

The EMU contains two cryogenically formed stainless steel oxygen bottles that are classified as critical pressure vessels, meaning that they are designed to leak before bursting (i.e., any undetected defect will propagate such that a leak will occur before the bottle loses its structural integrity and bursts).

The bottles have the following requirements:

- Normal operating pressure is  $900 \pm 50$  psia
- Maximum operating pressure is 1050 psia
- Volume per bottle is 240 in<sup>3</sup> (1.217 lb of usable oxygen for two bottles at 850 psia and 90° F)
- Proof pressure is 1575 psia
- Burst pressure is 2100 psia
- Minimum operating pressure is 75 psia

The normal operating pressure is supplied by the orbiter cryogenic oxygen supply system. The maximum operating temperature is based on filling the bottles to the maximum pressure (950 psia) at the coldest temperature (65° F) and then raising the temperature to the hottest storage temperature (120° F), which results in the maximum pressure of 1050 psia. The usable oxygen of the tank is primarily based upon an EVA duration of 7 hours, assuming the crewmember is working at a rate below 1000 Btu/hr with a suit leak rate of 30 scc/min. The proof pressure is 1.5 times the maximum operating pressure, while the burst pressure is 2 times the maximum operating pressure. The proof pressure is the amount of pressure the bottles can hold without causing structural deformation, and burst pressure is when the bottle deforms and loses its structural integrity. The minimum operating pressure is the lowest pressure at which the dual mode regulator (item 113D) can control pressure and meet flow requirements into the suit, based on a maximum metabolic rate of 2000 Btu/hr.

## SUIT PRESSURIZATION

The suit pressure (dual mode) regulator, item 113D, provides 100 percent oxygen from the primary oxygen system to the EMU at two regulation pressures. During suit donning and prebreathe operations, the EMU is pressurized to  $0.9 \pm 0.5$  psid with the O<sub>2</sub> actuator in the IV position. During depress, repress, and EVA conditions, the EMU is pressurized to  $4.3 \pm 0.1$  psid when the O<sub>2</sub> actuator is in the PRESS or EVA position. The only difference between these positions is that in the EVA position, the SOP is enabled, whereas in the PRESS position, the SOP is unable to come on line. The OFF position of the O<sub>2</sub> actuator closes a shut-off valve upstream of the suit pressure regulator, which stops all oxygen flow into the suit.

The mass of oxygen in the suit can be estimated from the ideal gas law.

Assumptions/givens:

- T = O<sub>2</sub> temp = 70° F = 530° R
- P = Suit pressure = 4.3 lb/in<sup>2</sup>
- V = Maximum estimated suit free volume = 3.0 ft<sup>3</sup>
- M = Molecular weight of O<sub>2</sub> = 32 lb/lb•mol
- R<sub>u</sub> = Universal gas constant = 1545 ft•lb/lb•mol °R
- R = R<sub>u</sub>/M = gas constant for O<sub>2</sub> = 48.28 ft•lb/lb °R

The ideal gas law is as follows:

$$PV = NR_uT \text{ or } PV = mRT$$

$$m = \frac{PV}{RT} = \frac{(4.3 \text{ lb/in}^2)(3 \text{ ft}^3)(144 \text{ in}^2/\text{ft}^2)}{(48.28 \text{ ft}\cdot\text{lb}/\text{lb}\cdot\text{°R})(530 \text{ °R})}$$

$$m = 0.072 \text{ lb}$$

## FEEDWATER PRESSURIZATION

The primary O<sub>2</sub> system via the water pressure regulator (item 113E) is used to pressurize the EMU feedwater system to 14.6 - 15.7 psid anytime the O<sub>2</sub> actuator is not in the OFF position. The pressure for the feedwater system was chosen to ensure that any gas dissolved in the water remains in solution.

Figure 2.3.1 shows the EMU pressure profile for Carl Walz's ETA chamber run performed on June 21, 1996 (SEMU 3014/PLSS 1014). This figure demonstrates the relationship between airlock pressure, feedwater pressure (gas and water), and suit pressure (on an absolute pressure scale). The chamber run used a 14.7 psi prebreathe protocol, which required a 4-hour in-suit prebreathe.

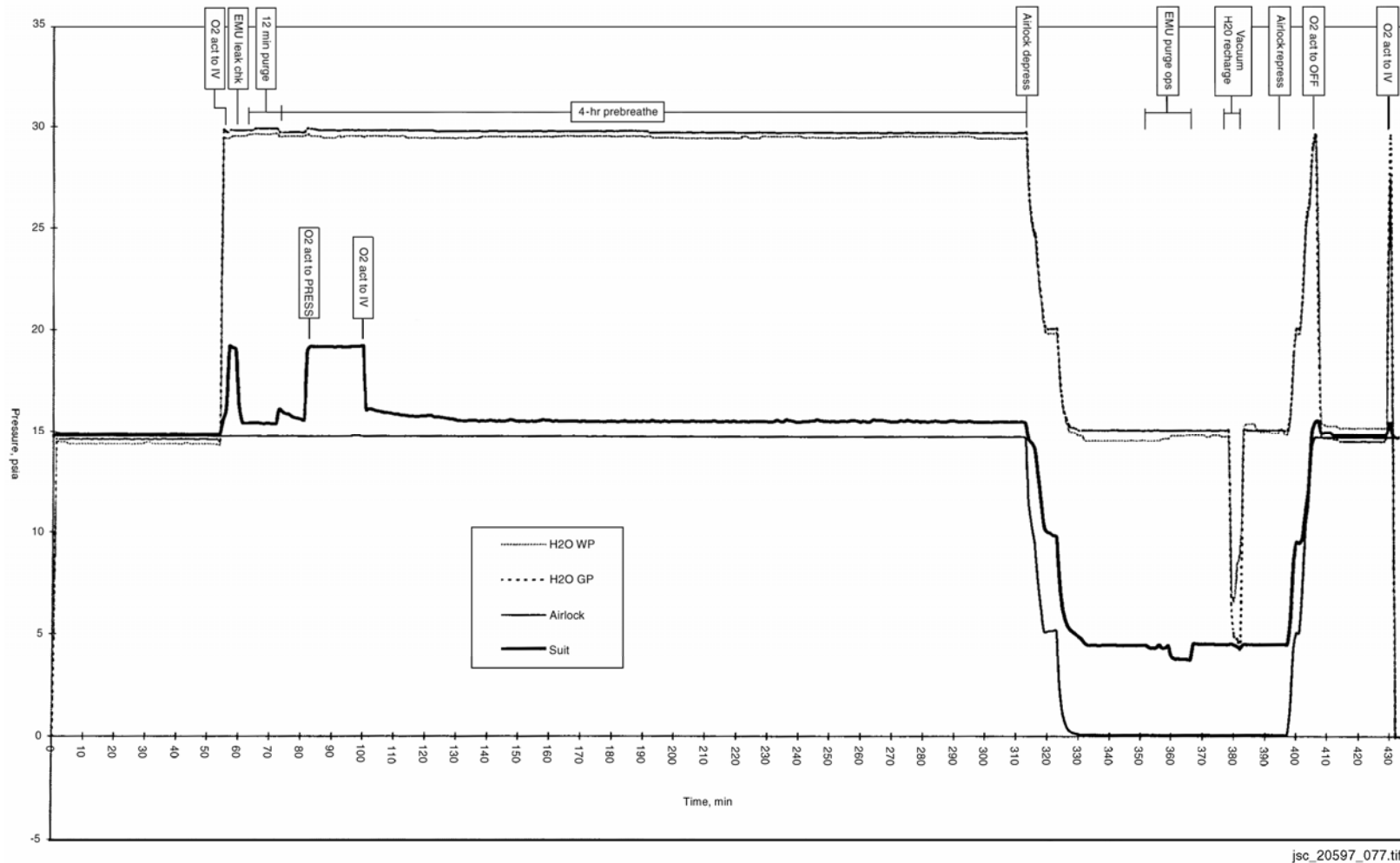


Figure 2.3-1. EMU pressure profile

Figure 2.3.1 includes a 20-minute block of time about 25 minutes into the prebreathe where the O<sub>2</sub> actuator is taken to the PRESS position to pressurize the suit to 4.3 psid. This block of time at the higher pressure was used to evaluate crew mobility, adjustable thermal mitten application, mini-workstation configuration, and tether evaluations. This graph also shows the effect of a vacuum water recharge, as well as opening the helmet purge valve and DCM purge valve at vacuum (labeled on the graph as EMU purge ops.).

## BREATHING OXYGEN

The primary oxygen system provides the only source of breathing oxygen during a nominal EVA (SOP is used only during contingency/emergency operations). The nominal oxygen consumption rate is considered to be 1.8 psi/min for the primary O<sub>2</sub> tanks; however, this rate will change, depending on the size of the crewmember, temperature of the environment, work rate, and crewmember metabolic rate.

The linear relationship between primary O<sub>2</sub> pressure and EVA time remaining for various values of crewmember consumption can be seen in Figure 2.3.2. The nominal use rate in this figure (1.8 psi/min) is based on the usage at a metabolic rate of 1000 Btu/hr.

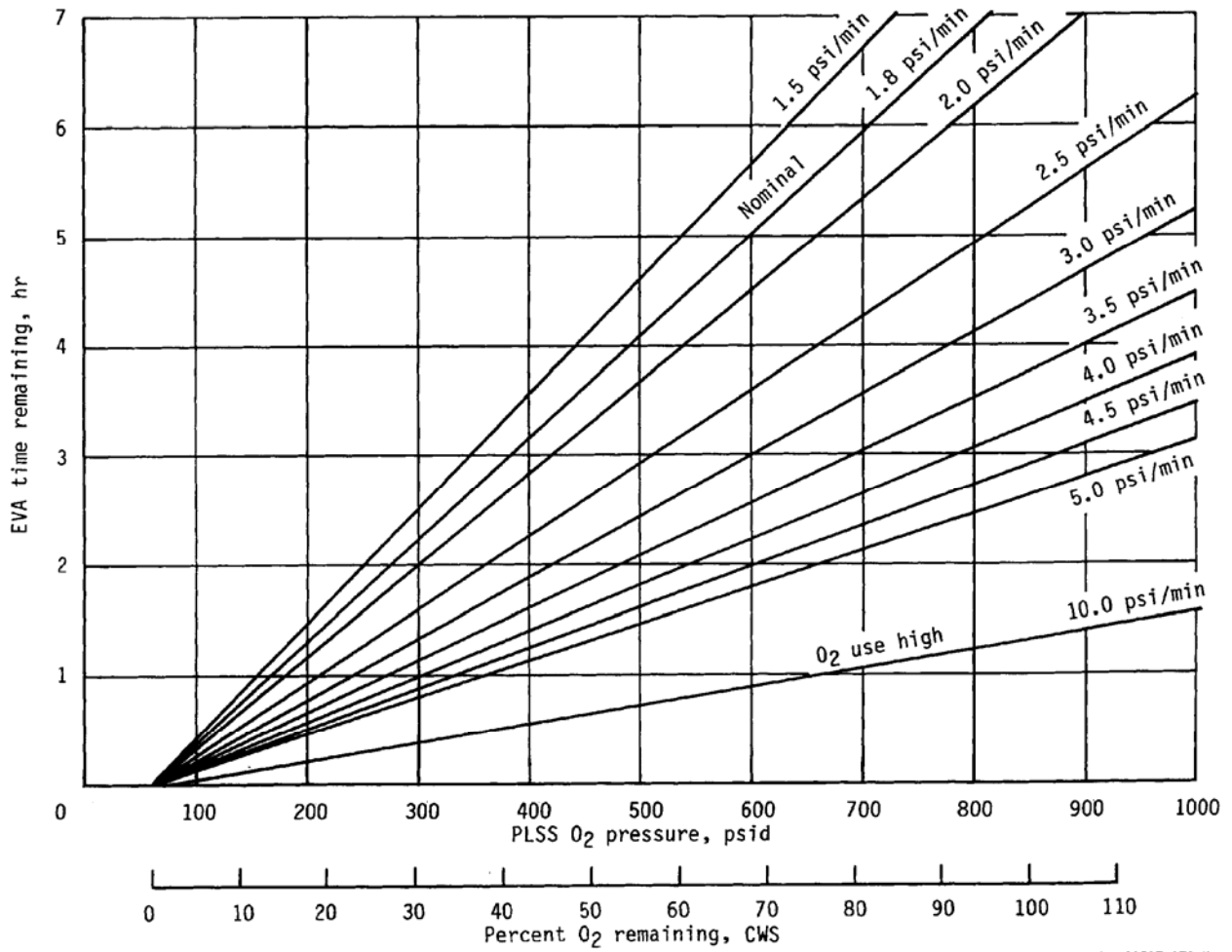


Figure 2.3-2. EVA time remaining

The approximate metabolic work rate of a crewmember can also be extracted from the O<sub>2</sub> consumption rate because the two parameters are directly proportional (assuming no suit pressure integrity failures). Figure 2.3-3 can be used as a guideline in helping to approximate crewmember metabolic rate (tu/hr).

To use this graph,

1. Find the appropriate primary O<sub>2</sub> ΔP (psi) curve on the graph right-hand scale, which runs from the right side to the top of the graph. The ΔP is the difference in primary oxygen tank pressure over a delta time period (Δt). Example: The primary tank dropped 60 psia (ΔP) in 26 minutes (Δt).
2. Locate the correct delta time (Δt in minutes) from which step 1 primary O<sub>2</sub> ΔP reading was taken (left scale). Example: 26 minutes (Δt).
3. Move horizontally along the Δt line until intersection with the primary O<sub>2</sub> ΔP curve.
4. Move vertically down to the bottom scale to get the O<sub>2</sub> use rate in psi/min for the given ΔP and Δt. Moving vertically to the top scale gives the approximate work rate in Btu/hr for the same ΔP and Δt. Example: O<sub>2</sub> use rate is 2.3 psi/min, and the work rate is approximately 1300 Btu/hr.

Metabolic rate (MR) in Btu/hr can also be calculated in the following manner:

$$MR = 581 \times R, \text{ where } R = \text{O}_2 \text{ use rate (psi/min)}$$

Refer to Section 2.1 for more information on calculating metabolic rate.



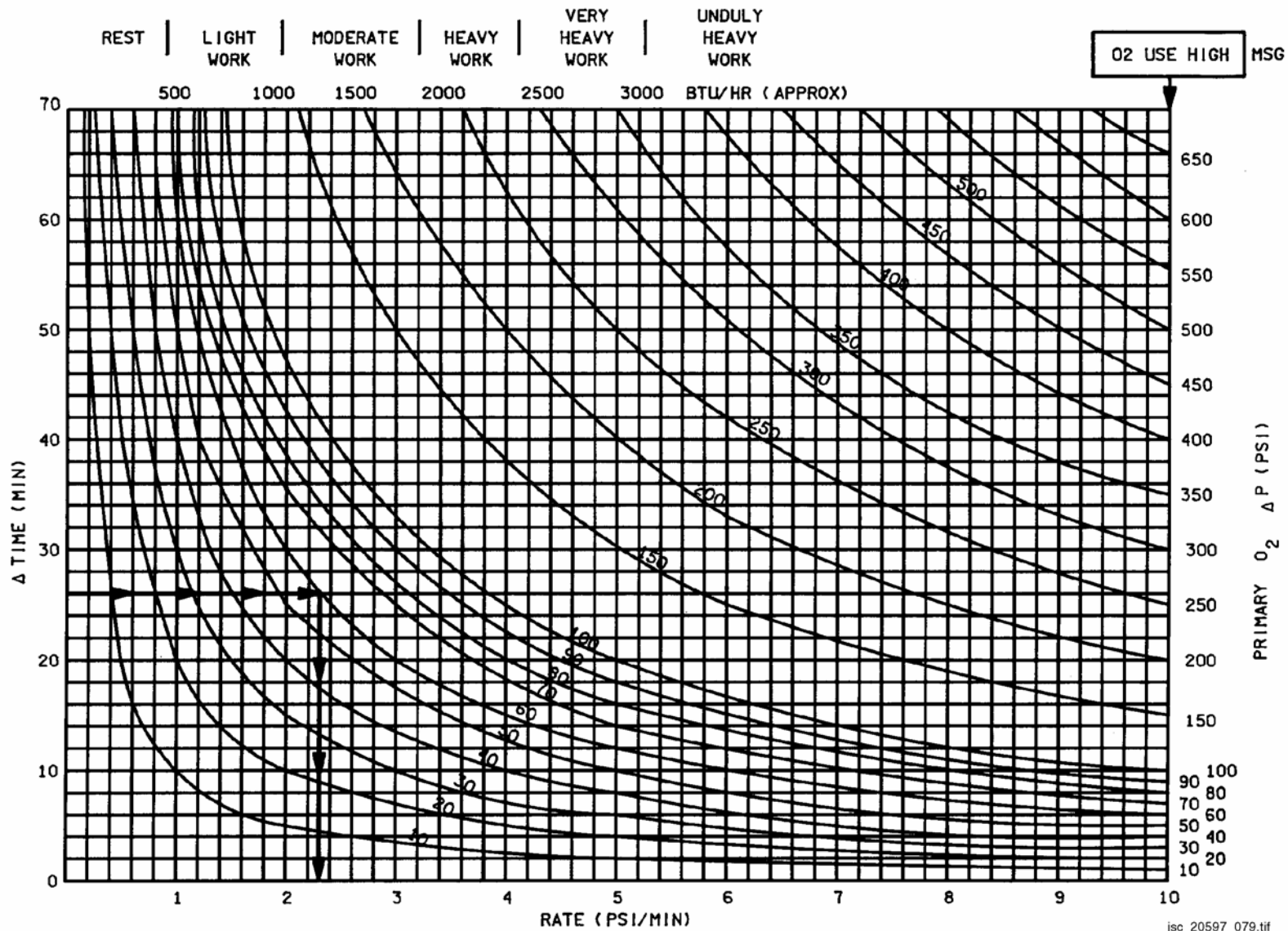


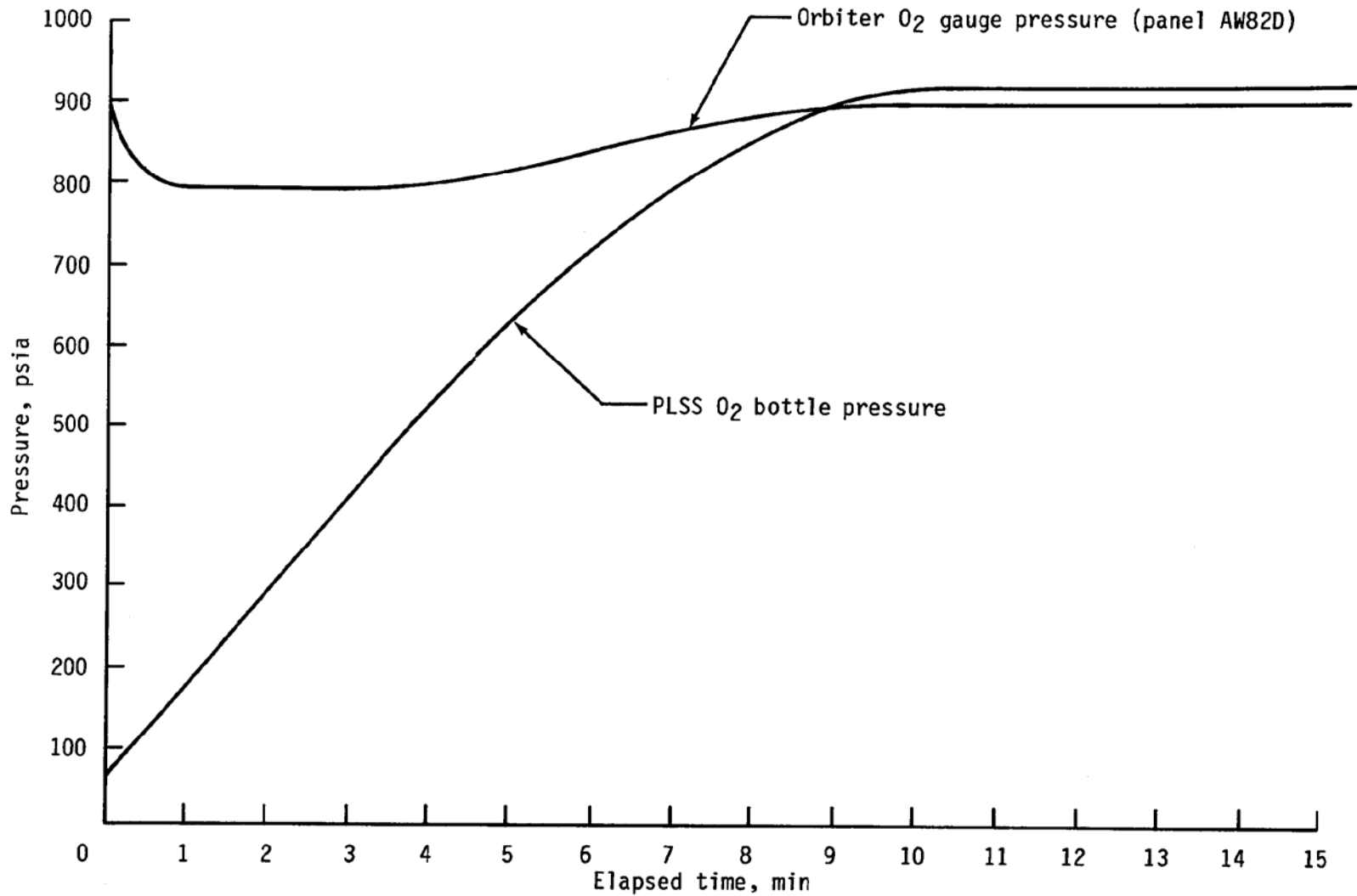
Figure 2.3-3. Work rate determination

## PRIMARY OXYGEN RECHARGE

The EMU primary oxygen system is rechargeable from the orbiter cryogenic oxygen system to a pressure of 850 - 950 psia. It shows the relationship between primary oxygen bottle pressure and the time required to charge the tanks from a depleted condition of 75 psia, which is the minimum usable tank pressure. A primary tank pressure of 850 psia is considered to be a full charge. The elapsed time to reach a complete recharge from a fully depleted tank (75 psia) is 8 minutes, based on Figure 2.3-4. To obtain the time to recharge a partially depleted tank, find the elapsed time at the initial EMU primary tank pressure and subtract this time from a fully recharged time of 8 minutes (850 psia). For reference, the orbiter oxygen source gauge pressure reading on panel AW18D is also shown.

Example: EMU 1 has a partially depleted primary oxygen supply that reads 500 psia.  
How long will it take to recharge the primary O<sub>2</sub> system to 850 psia?

Solution: At 850 psia, elapsed time = 8.00  
At 500 psia, elapsed time = 3.75  
 $\Delta t = 4.25$  minutes



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Figure 2.3-4. Primary oxygen recharge performance

## FAILED HARDWARE

This subsection deals with the two most likely failures that would cause the EMU positive pressure relief valve (PPRV) to open and purge excess suit pressure overboard. The two failures are:

- Failed-open primary O<sub>2</sub> suit regulator
- Failed-open SOP second stage regulator

The analyses in this discussion try to establish how much time the crewmember would have to rectify either situation before the EMU oxygen supply was depleted.

### Failed-Open Primary Regulator

1. In the event an EMU incurs a failed-open primary suit regulator, how long would it take the SOP to come on line?

Example: With an initial primary O<sub>2</sub> tank pressure of 950 psi, how long would it take to bleed the tank down to 30 psi (minimum usable pressure for failed-open regulator)?

The following equation comes from actual bleed-down data:

$$\ln\left(\frac{P}{P_0}\right) = -0.076t_0$$

where,

P = pressure (psi)

P<sub>0</sub> = initial pressure (psi)

t<sub>0</sub> = time (min)

$\bar{R}$  = universal gas constant (psi - ft<sup>3</sup>/ lb mole - °R)

For  $\ln\left(\frac{30}{950}\right) = -0.076t_0$ ;  $t_0 = 45.46$  min

The following is the amount of time it takes to deplete the usable oxygen left in the suit and tanks:

Suit leak: 50 sccm = 1.77 x 10<sup>-3</sup> scfm

$$PV = nRT$$

$$\frac{V}{n} = \frac{RT}{P} = \frac{(10.73)(520)}{14.7} = 379.6 \text{ ft}^3/\text{lb-mole} = 11.86 \text{ ft}^3/\text{lb O}_2$$

$$\frac{1.77 \times 10^{-3} \text{ scfm}}{11.86 \text{ ft}^3 / \text{lb O}_2} = 1.49 \times 10^{-4} \text{ lb / min } \textit{suit leak}$$

Metabolic: (assuming 1000 Btu/hr, RQ = 0.9)

$$\left( \frac{1000 \text{ Btu}}{\text{hr}} \right) \left( \frac{1.625 \times 10^{-4} \text{ lb}}{\text{Btu}} \right) \left( \frac{\text{hr}}{60 \text{ min}} \right)$$

$$= 2.71 \times 10^{-3} \text{ lb/min } \textit{metabolic flowrate}$$

$$\text{Total: } 1.49 \times 10^{-4} + 2.71 \times 10^{-3}$$

$$= 2.86 \times 10^{-3} \text{ lb/min}$$

Usable mass in bottles (0.278 ft<sup>3</sup>) from 30 psi to 4.5 psi (PPRV reseal pressure). The PPRV would open with a failed-open primary oxygen regulator.

$$n = \frac{PV}{RT} = \frac{(30 - 4.5)(0.278)}{(10.73)(520)} = 1.27 \times 10^{-3} \text{ lb - moles} = 4.065 \times 10^{-2} \text{ lbO}_2$$

Usable mass in bottles and suit (0.278 ft<sup>3</sup> + 2 ft<sup>3</sup>) from 4.5 to 3.5 psi (SOP actuation pressure).

$$\frac{(4.5 - 3.5)(2.278)}{(10.73)(520)} = 1.306 \times 10^{-2} \text{ lb O}_2$$

$$\text{Total usable mass} = (4.065 + 1.306) \times 10^{-2} = 5.371 \times 10^{-2} \text{ lb O}_2$$

Time to breatherdown:

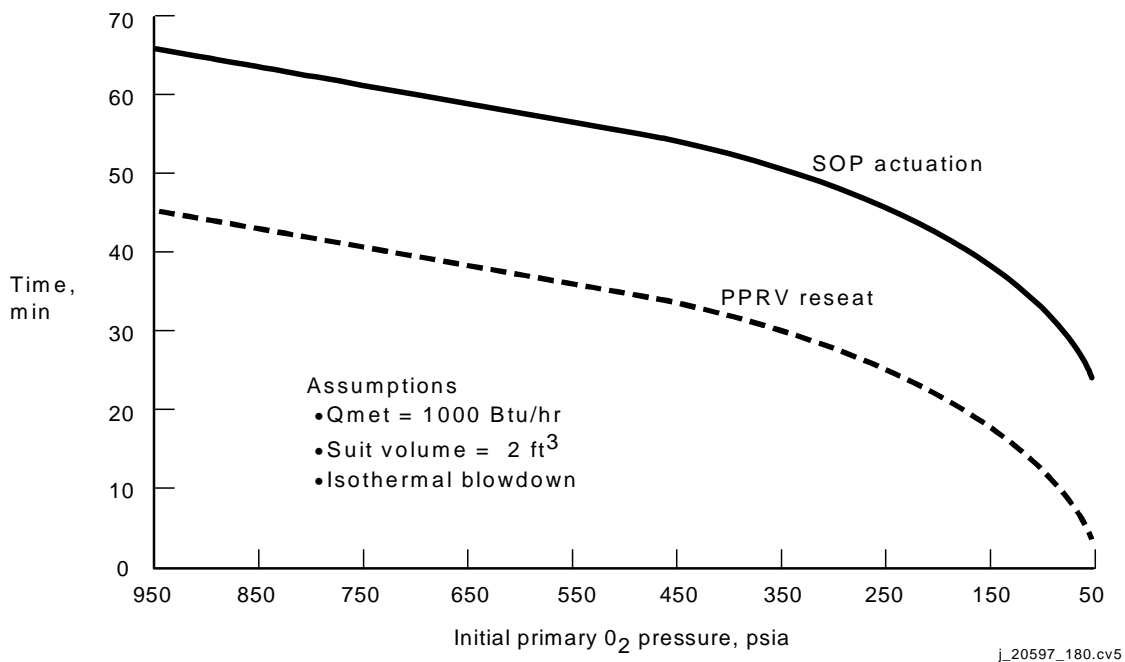
$$\frac{5.371 \times 10^{-2}}{2.86 \times 10^{-3}} = 18.78 \text{ min}$$

$$\text{Total} = 45.56 + 18.78 = 64.34 \text{ min}$$

Figure 7.3-5 is a plot of time versus initial bottle pressure, according to the following equation:

$$t = \ln \frac{(P_{\text{O}_2 \text{initial}}) - 3.4}{0.076} + 18.78 \text{ (breatherdown time)}$$

The dotted line represents the above equation minus 18.78 min; after the “useful” bottle pressure (~30 psi) had been used, the crewmember would open the purge valve.



2. Once the primary oxygen bottles are empty, how long can the SOP go on makeup mode?

Assuming average net metabolic rate	= 1000 Btu/hr
Suit Leakage	= 50 sccm $O_2$ = 0.0087 lb/hr $O_2$ maximum
Metabolic consumption	= 0.0001625 (1000) = 0.1625 lb/hr $O_2$
Total oxygen consumption	= 0.1712 lb/hr $O_2$

Minimum useful  $O_2$  from SOP (assume maximum SOP leakage and five SOP checks) =  $2.714 - 0.131 = 2.583 \text{ lbm } O_2$

Minimum makeup mode time =  $2.583/0.1712 = 15.1 \text{ hr}$

It should be noted, however, that the EMU will lose the ability to degas the coolant loop after the primary bottle blowdown. The feedwater bladders will no longer be pressurized. Therefore, the crewmember may lose cooling soon after primary bottle blowdown from an airbound pump.

SOP Second-Stage Regulator Failed Open

If the SOP second-stage regulator fails open, how long will the purge flow last?

Known: Interstage pressure will be regulated by the first stage until bottle pressure drops to approximately 300 psia. Therefore, flow is constant for the majority of the blowdown.

The maximum failed-open flow spec = 7.49 lb/hr O<sub>2</sub>

Regulator data shows a unit at maximum flow

Time at constant flow: Maximum charge density = 32.7 lbm/ft<sup>3</sup>

Minimum charge density = 31.0 lbm/ft<sup>3</sup>

Residual density at 365 psia, 180° F = 4.8 lbm/ft<sup>3</sup>

Minimum bottle volume = 179.011 in<sup>3</sup>

Maximum bottle volume = 184.821 in<sup>3</sup>

$$\text{Minimum useful O}_2 = (31.0 - 4.8) \frac{179.01}{1728} = 2.714 \text{ lbm O}_2$$

$$\text{Minimum constant purge time} = \frac{2.714}{7.49} (60) = 21.7 \text{ min}$$

If residual was expended at same rate = 25.7 min

$$\text{Maximum constant purge time} = \frac{2.98}{7.49} (60) = 23.9 \text{ min}$$

If residual was expended at same rate = 28 min

## 2.4 EMU BREATHEDOWN

### PURPOSE

During EVA operations when the oxygen supply to the suit is off, the crewmember will breathedown the pressure of the EMU. This section presents data that will help determine the length of time for the suit pressure to decay, based on metabolic rate and free suit volume.

### DESCRIPTION

When the O<sub>2</sub> actuator is placed in the OFF position, the EMU oxygen shutoff valve (item 113C) is closed to prevent oxygen from the EMU primary tanks or the orbiter supply from entering the suit. With oxygen no longer flowing into the EMU, the crewmember will breathedown the pressure of the suit. Vacuum water recharge, BTA, and cold restart are three operations where a crewmember would be in the suit with the O<sub>2</sub> actuator in the OFF position. A failed closed oxygen shutoff valve (item 113C) or suit pressure regulator (item 113D) would also cause a breathedown situation.

### SUIT BREATHEDOWN RATES

A technique used for predicting suit pressure decay rates follows. The respiration quotient (RQ) is the ratio of the moles of CO<sub>2</sub> produced to O<sub>2</sub> consumed as a result of tissue metabolism. RQ is a function of diet, with a value of 0.9 used for EMU applications (per SVHS 7800 EMU System Level Specification). A carbohydrate diet yields a higher RQ = 1.0, while a fat diet yields RQ = 0.7.

Assumptions:

- O<sub>2</sub> temp 70° F
- Ideal gas
- RQ = 0.9
- Approximate free suit volume between 1.5 and 3.0 ft<sup>3</sup>
- Suit leakage at vacuum 0.0087 lb/hr

Equations:

MR = metabolic rate in Btu/hr

$$\text{lb O}_2 / \text{Btu} = (1.708 \times 10^{-4} - (\text{RQ} - 0.707) \times (1.23 \times 10^{-5} / 0.293)) = 0.000162697$$

$$\text{O}_2 \text{ consumption in lb O}_2/\text{hr} = (\text{MR} \times 1.62697 \times 10^{-4} \text{ lb O}_2 / \text{Btu})$$



The ideal gas law is as follows:

$$P = \frac{mRT}{V}$$

Where:

m = mass

V = volume

R = gas constant for oxygen 48.291 ft-lbf/lbm °R

T = 70° + 460° = 530° R

V = 1.5 ft<sup>3</sup>, 2.0 ft<sup>3</sup>, or 3.0 ft<sup>3</sup>

$$\frac{\Delta P}{\Delta t} = \frac{\Delta m}{\Delta t} \frac{RT}{V} \quad \frac{\Delta m}{\Delta t} = (M \cdot R \cdot \uparrow + 0.0087) \text{ lb / hr}$$

$\uparrow$                        $\uparrow$   
 O<sub>2</sub> consumption      leakage

Example for MR = 800 Btu/hr and V = 3.0 ft<sup>3</sup>

$$\frac{\Delta P}{\Delta t} = \frac{[(800)(1.62697 \cdot 10^{-4}) + 0.0087] \frac{\text{lb} (48.291 \text{ft} - \text{lb})(530^\circ \text{R})}{\text{hr} \quad \text{lb} \cdot ^\circ \text{R}} \frac{\text{hr}}{60 \text{min}}}{3.0 \text{ft}^3}$$

$$\frac{\Delta P}{\Delta t} = 19.744 \frac{\text{lb}}{\text{ft}^2 \text{min}} \cdot \frac{\text{ft}^2}{144 \text{in}^2}$$

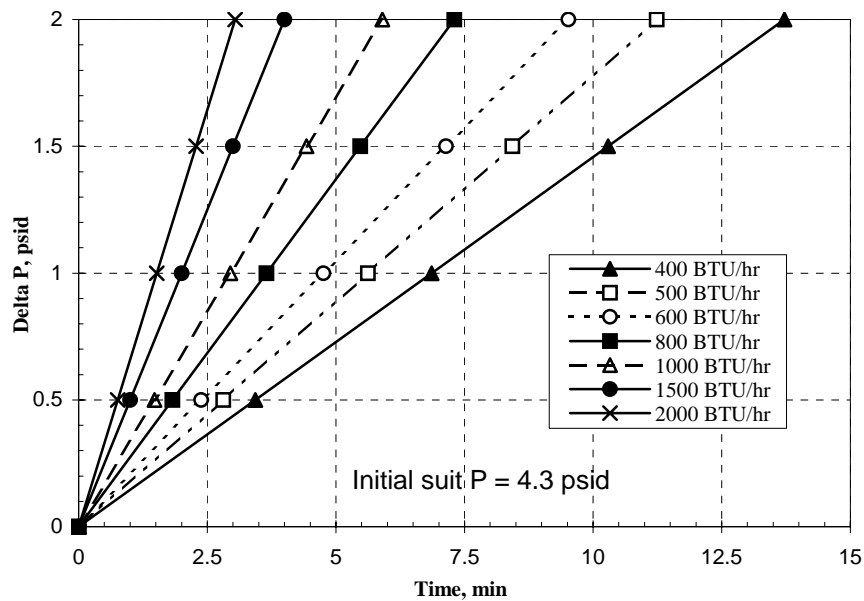
$$\frac{\Delta P}{\Delta t} = 0.137 \frac{\text{lb}}{\text{in}^2 \cdot \text{min}}$$

$$\frac{\Delta P}{\Delta t} = 0.137 \text{ psi / min or } 7.29 \text{ min / psi}$$

Table 3.4-1 lists theoretical suit pressure decay rates for various crewmember metabolic rates and free suit volumes. The free suit volume of the crewmember in a small, pivoted hard upper torso (HUT) is 1.5 ft<sup>3</sup>, assuming that this crewmember is the largest possible size that can still fit in a small HUT. A medium pivoted or planar HUT has a free volume of 2.0 ft<sup>3</sup>, based upon an average size person in that HUT. The free suit volume of the smallest possible person who still needs a large pivoted, large planar or an X-large pivoted HUT is 3.0 ft<sup>3</sup>. The breathedown rates in Table 2.4-1 are conservative because of leakage dropoff with suit pressure decay and relief of O<sub>2</sub> from water bladders into the suit volume. The three accompanying graphs (Figure 2.4-1) plot the data recorded in the table.

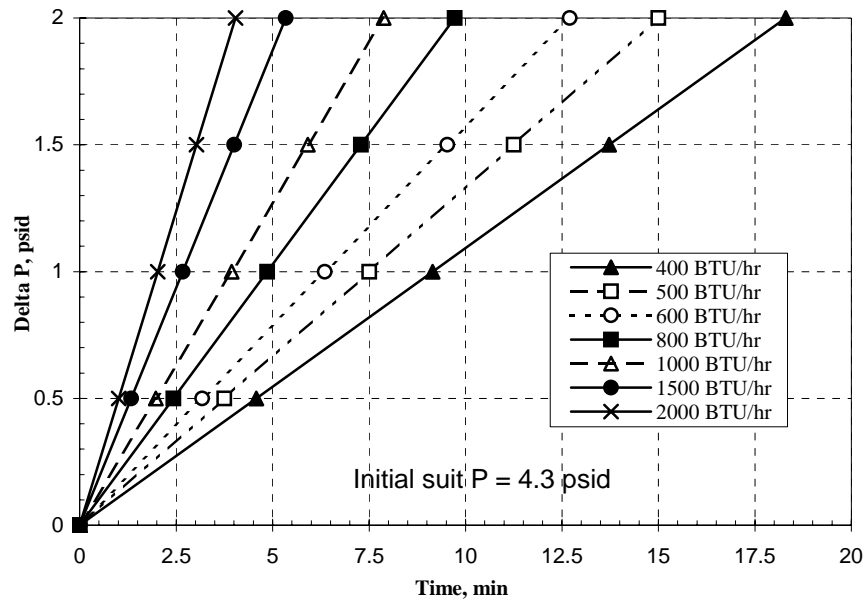
**Table 2.4-1. Suit breathedown rates**

Metabolic rate	1.5 ft <sup>3</sup>		2.0 ft <sup>3</sup>		3.0 ft <sup>3</sup>	
	psi/min	min/psi	psi/min	min/psi	psi/min	min/psi
400	0.146	6.86	0.109	9.15	0.073	13.73
500	0.178	5.62	0.133	7.50	0.089	11.25
600	0.210	4.76	0.157	6.35	0.105	9.53
800	0.274	3.65	0.206	4.87	0.137	7.29
1000	0.338	2.95	0.254	3.94	0.169	5.91
1500	0.499	2.00	0.374	2.67	0.250	4.01
2000	0.660	1.52	0.495	2.02	0.330	3.03

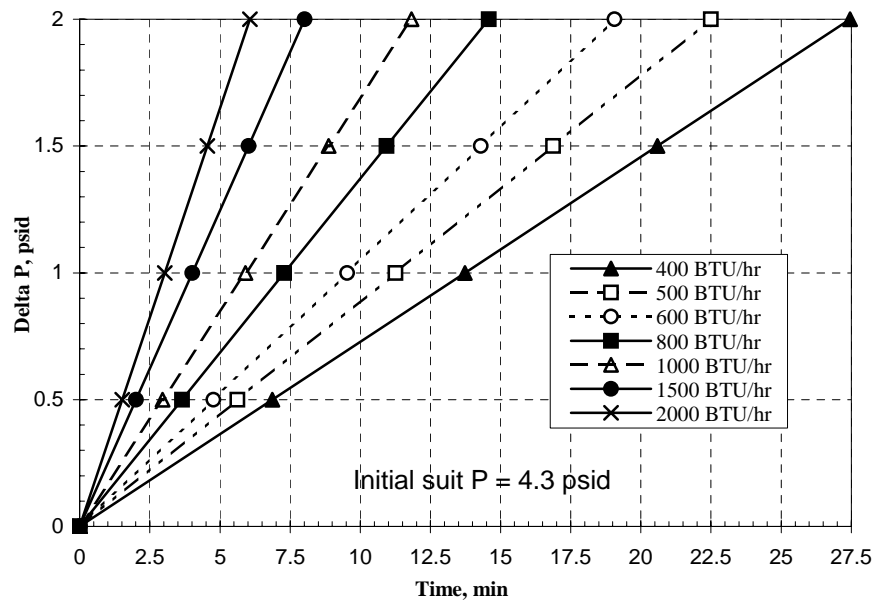


(a) Suit volume = 1.5 ft<sup>3</sup>

**Figure 2.4-1. Suit breathedown rates**



(b) Suit volume = 2.0 ft<sup>3</sup>



(c) Suit volume = 3.0 ft<sup>3</sup>

Figure 2.4-1. Concluded

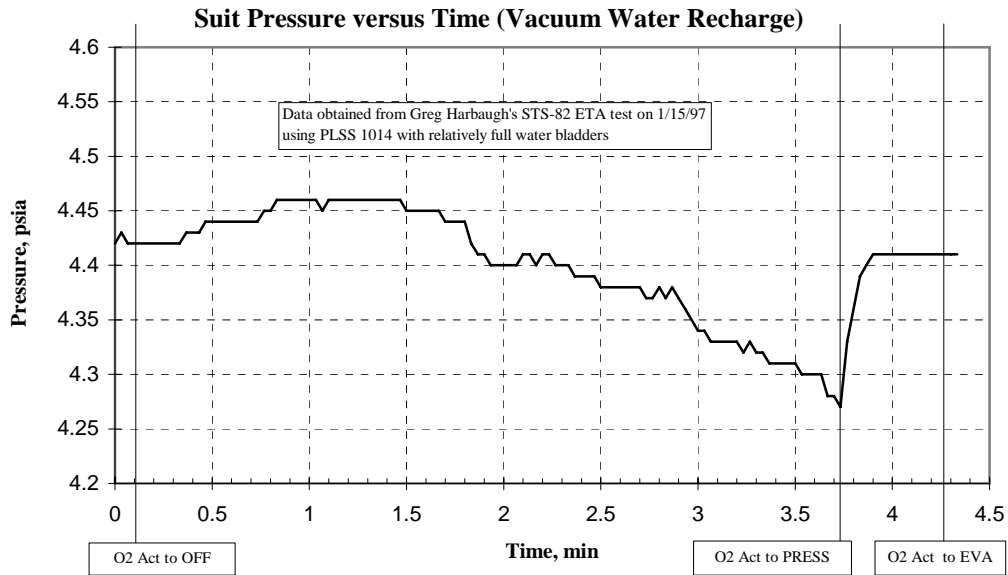
## VACUUM WATER RECHARGE – SHUTTLE ONLY

During an EVA, the most prominent procedure that would involve placing the O<sub>2</sub> actuator in the OFF position is a vacuum water recharge. If the water in the EMU feedwater bladders has expired or leaked, a water recharge of the bladders at vacuum conditions may be needed. During this time, the O<sub>2</sub> actuator will be placed in the OFF position to relieve the pressure on the back side of the bladders and allow the bladders to refill with water supplied by the SCU. When the O<sub>2</sub> actuator is in the OFF position, the pressure of the suit will be breathed down by the crewmember.

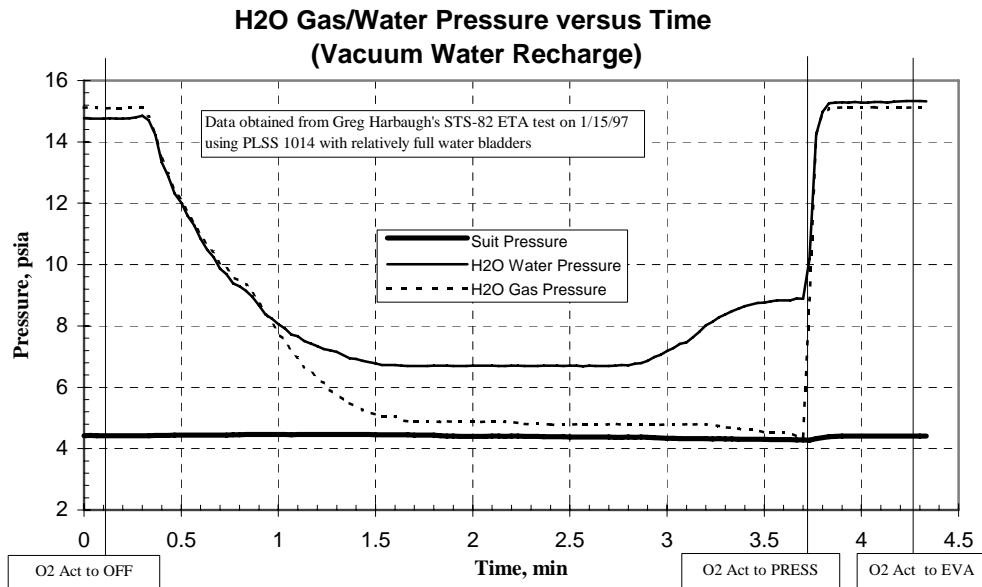
The time required to perform a vacuum water recharge is a function of the suit pressure, H<sub>2</sub>O water pressure, and H<sub>2</sub>O gas pressure, as shown in Figure 2.4-2 and Figure 2.4-2. This data was taken from Greg Harbaugh's ETA chamber run on January 15, 1997. His HUT was a pivoted large and his free suit volume can be assumed to be 3.0 ft<sup>3</sup> (PLSS 1014 suit pressure regulates high toward 4.4 psid).

Figure 2.4-2 shows the slight increase in suit pressure (approximately 0.04 psid) due to the low mode relief valve (item 120B) opening and dumping the O<sub>2</sub> on the back side of the water bladders into the volume of the suit through the T11 port. This graph also shows the suit pressure breathed down until moving the O<sub>2</sub> actuator to PRESS during a vacuum water recharge.

Figure 2.4-3 demonstrates the relationship between the EMU water bladders H<sub>2</sub>O gas pressure (H<sub>2</sub>O GP) side and water pressure (H<sub>2</sub>O WP) side during a vacuum water recharge at an ETA chamber run. After the O<sub>2</sub> actuator is taken to the OFF position and the H<sub>2</sub>O GP is relieved into the volume of the suit (leveling off slightly greater than suit pressure), the H<sub>2</sub>O WP decreases to around 6.5 psid where the bladders are in the process of being filled. After the bladders fill up, the H<sub>2</sub>O WP increases to about 8.6 psid, and after 30 seconds in this stable condition, the water bladders are considered full. The O<sub>2</sub> actuator is moved into the PRESS position to pressurize the back side of the bladders to around 15 psid, which in turn pressurizes the water side.



**Figure 2.4-2. Suit pressure versus time (vacuum recharge)**

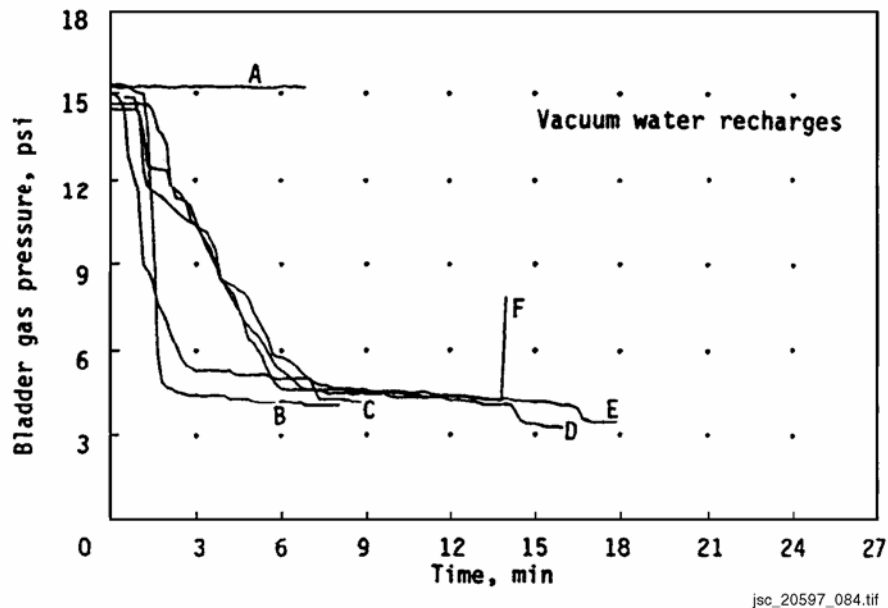


**Figure 2.4-3. H<sub>2</sub>O pressure versus time (vacuum recharge)**

Figure 2.4-4 shows actual data taken during several EMU vacuum water recharge cycles, with varying amounts of water in the bladders to be filled. Figure 2.4-4 (a) plots six curves, A through F, depicting the gas pressure on the back of the feedwater bladders during vacuum water recharge. The disparity in the rates reflects that various amounts of water were contained in the bladders at the beginning of recharge. Curves B and C reflect relatively full feedwater tanks, whereas curves D, E, and F reflect relatively empty bladders. The main conclusion from this graph is that the H<sub>2</sub>O GP bleeds down faster (under 3 minutes) if the bladders are relatively full, as opposed to empty bladders (about 6 minutes). Curve A is a calibration curve that shows no gas pressure decay.

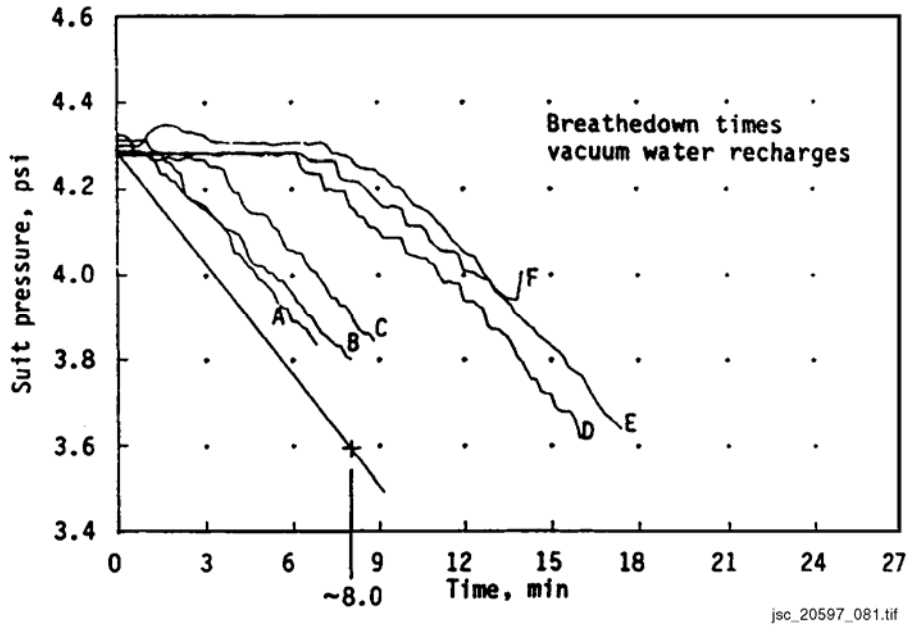
Figure 2.4-4 (b) plots the complementary curves to Figure 2.4.4 (a) for the suit breatherdown rates. Each curve, A through F, correlates with the feedwater gas bladder curves A through F. The obvious conclusion from the graph is that higher gas volumes on the back of the feedwater tanks (D, E, and F because they are relatively empty bladders) yield extended times (approximately 6 minutes) before the suit pressure drops off because of the additional O<sub>2</sub> introduced into the suit from the back side of the water bladders via the low mode relief valve (item 120B). These curves reflect the worse case scenario for suit pressure breatherdown (i.e., no gas leakage from the suit).

A good approximation for the worst case suit breatherdown scenario, meaning initial suit pressure 4.3 psi and no oxygen leakage into the suit from the feedwater tanks, is represented by the straight line curve in Figure 2.4-4 (b). The lowest allowable suit pressure is defined to be 3.6 psi. From the graph, it can be seen that the minimum time for suit breatherdown to 3.6 psi during water recharge is approximately 8 minutes.



(a) Bladder gas pressure versus time

**Figure 2.4-4. Vacuum water recharges**



(b) Suit pressure versus time

**Figure 2.4-4. Concluded**

## 2.5 CONTAMINANT CONTROL CARTRIDGE

### PURPOSE

This section describes the specifications and operating characteristics for the EMU's two Contaminant Control Cartridges (CCCs), the LiOH and the Metox cartridge.

### Background

The shuttle Extravehicular Mobility Unit (EMU) uses Lithium Hydroxide (LiOH) in the CCC to remove CO<sub>2</sub> during Extravehicular Activity (EVA). Although the LiOH must be replaced after each EVA, it is not considered a major logistics penalty due to the relative short on-orbit stay of the shuttle (7 to 14 days) and the low number of EVAs per mission (3 to 8 planned and/or contingency).

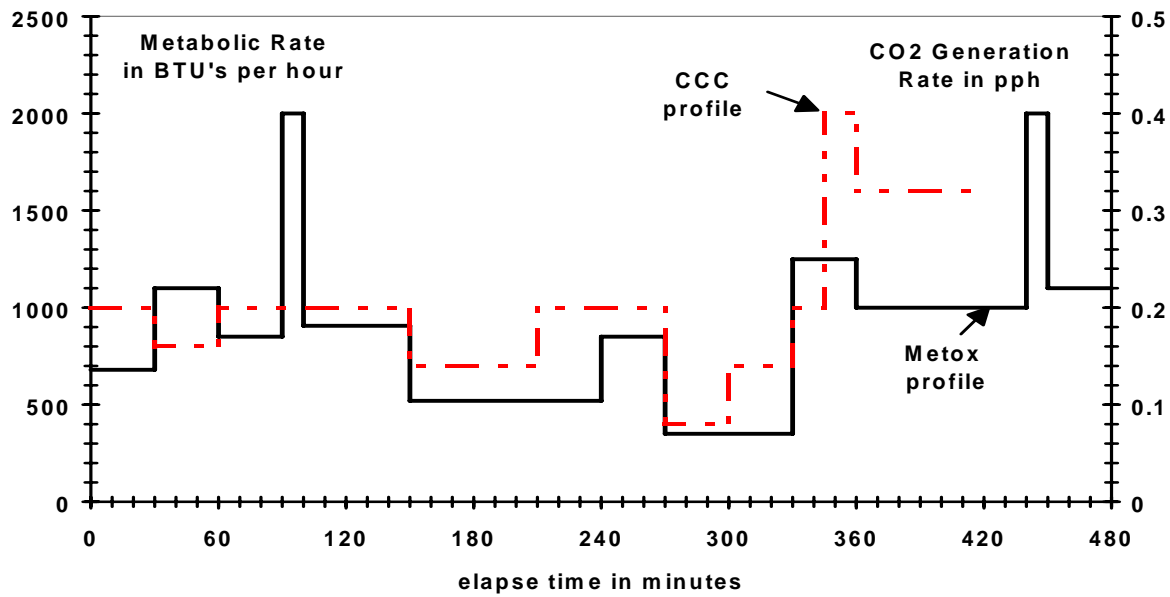
However, with the arrival of the permanent International Space Station (ISS), a significant reduction in EVA logistic costs can be realized by incorporating a regenerable CO<sub>2</sub> removal system into the EMU.

To achieve this goal, Hamilton Sundstrand Space Systems International (HSSSI), and the National Aeronautics and Space Administration (NASA) Johnson Space Center's (JSC) Crew and Thermal Systems Division (CTSD) began developing a regenerable metal oxide based CO<sub>2</sub> removal system in the mid 1980's. By 1989, this effort had resulted in the development of the flat sheet sorbent assembly configuration.

The design and development of the current flight system was begun in 1996. The system, nicknamed "Metox" to reflect its use of *metal-oxide* as the CO<sub>2</sub>sorbent material, consists of two (2) assemblies, a metal oxide sorbent canister assembly (Figure 2.5-1) and a regeneration assembly (Figure 2.5-2). The canister is interchangeable with the EMU's CCC. The regenerator assembly is designed to restore the canister by removing the absorbed CO<sub>2</sub> and trace contaminants.

Metabolic Requirements - The total designed CO<sub>2</sub> removal capacity for EMU ISS operation is 1.48 pounds. This is based on the required capacity to support an 8-hour EVA at an average metabolic rate of 850 BTUs per hour (equivalent to a CO<sub>2</sub> generation rate of 0.17 pph). This represents a slight change from the shuttle-based CCC requirement of 7 hours at 1000 BTUs per hour (0.2 pph). Figure 8 presents the CCC and Metox SOW metabolic profiles and the equivalent CO<sub>2</sub> generation rates during EVA. Operation at both profiles was verified during qualification testing.





**Figure 2.5-1 - Metabolic profile comparison: LiOH and Metox**

## 2.5.1 LIOH CCC

### 2.5.1.1 Description

The EMU LiOH CCC contains LiOH to remove CO<sub>2</sub> and charcoal to remove trace contaminants and odors.

The LiOH CCC uses three chemical reactions to remove CO<sub>2</sub>

1.  $\text{LiOH}_{(s)} + \text{CO}_{2(g)} \rightarrow \text{Li}_2\text{CO}_{3(s)} + \text{H}_2\text{O}_{(g)} + 40,562 \text{ BTU/lb}\cdot\text{mole CO}_2$
2.  $\text{LiOH}_{(s)} + \text{H}_2\text{O}_{(g)} \rightarrow \text{LiOH}\cdot\text{H}_2\text{O}_{(s)} + 26,340 \text{ BTU/lb}\cdot\text{mole H}_2\text{O}$
3.  $\text{LiOH}\cdot\text{H}_2\text{O}_{(s)} + \text{CO}_{2(g)} \rightarrow \text{Li}_2\text{CO}_{3(s)} + 3 \text{ H}_2\text{O}_{(g)} - 12,118 \text{ BTU/lb}\cdot\text{mole CO}_2$

Even though the direct absorption of CO<sub>2</sub> by the dry LiOH dust is captured in reaction 1., it contributes little to the overall sorption process. Reaction 1 is about 1/10 that of reactions 2 and 3, collectively. Obtaining the highest conversion of LiOH to Lithium Carbonate (Li<sub>2</sub>CO<sub>3</sub>) requires water absorption to form Lithium Hydroxide Monohydrate (LiOH·H<sub>2</sub>O) in reaction 2, followed by CO<sub>2</sub> absorption by the monohydrate that forms the final carbonate and releases the H<sub>2</sub>O from the previous reactions (refer to reaction 3).

The CCC contains sufficient LiOH to remove 1.48 lb of CO<sub>2</sub> while maintaining ppCO<sub>2</sub> less than 7.6 mmHg for metabolic rates up to 1600 BTU/hr (for a period of 1 hour) and less than 15 mmHg for metabolic rates of up to 2000 BTU/hr (for a period of 15 minutes). The cartridge also contains a filter to trap and limit particulates in the ventilation flow stream to 0.1 mg/m<sup>3</sup> as well as charcoal to absorb trace contaminants.

A list of the trace contaminants and the removal capability of the CCC can be found in the S/AD (SV79200/2). The CCC provides a minimum CO<sub>2</sub> absorption of 1.48 lb of CO<sub>2</sub> which is equivalent to a workload of 7000 BTUs. The LiOH cartridges provided for flight typically are capable of absorbing 1.9 to 2.1 lb of CO<sub>2</sub> (9500 to 10,500 BTUs). The capacity of each flight CCC can be found in the Boeing Flight Data Book. The used LiOH cartridges are repacked on the ground for future use. Specifications for the CCC are given in Table 2.5-1.

**Table 2.5-1. CCC specifications**

Source: SV792600/2 S/AD Cartridge, Contamination Control (CEI #480)

Description	Specification
Maximum operating pressure <sup>1</sup>	6.7 psig
Leakage <sup>2</sup>	10 cc/hr (max) at 6.5 psig
CO <sub>2</sub> removal	1.48 lb (min)
ppCO <sub>2</sub> limits <sup>3</sup>	<7.6 mmHg for 1 hr @ 1600 BTU <15 mmHg for 15 min at 2000 BTU workload
Capacity (certified minimum)	7000 BTU
Capacity (nominal) <sup>4</sup>	9000 BTU
Total cartridge weight	6.4 lb maximum
LiOH weight	2.45 lb minimum
Charcoal weight	0.121-0.286 lb

- <sup>1</sup>. BTA operation at 8.45 psig is acceptable because CCC proof pressure is 10.05 psig.
- <sup>2</sup>. Refers to overboard leakage through the inlet/outlet ports.
- <sup>3</sup>. Refers to CO<sub>2</sub> limits in helmet area.
- <sup>4</sup>. Actual capacity is referenced in the Boeing Flight Data Book.

The CCC is charged with a minimum of 2.45 lb of LiOH. The CO<sub>2</sub> removal capacity of the LiOH is a function of the environment. The capacity of the LiOH is 85 percent in a warm-to-neutral environment and can be as low as 70 percent in a cold environment. A cold environment is defined as -75° F or colder. If the orbiter is in a cold attitude, this temperature may be encountered during the EVA.

The CCC is certified for a 7-hour EVA, assuming a 4-hour prebreathe and a neutral/hot environment, as shown in Table 2.5-2.

**Table 2.5-2. CCC certification matrix**

Source: EMUM 1388

Prebreathe time	Environment		
	Cold	Neutral	Hot
20 to 40 minutes	X	X	X
3.5 to 4.0 hours	*	X	X

X - The CCC is qualified to meet the 7-hour (7000 BTU) EVA requirement.

\* - For a cold environment, the CCC is qualified to meet a 4.8-hour EVA.

While the EMU is donned, the CCC provides CO<sub>2</sub> removal prior to the EVA, during the EVA, and following the EVA until EMU doffing. A typical crewmember metabolic rate during an EVA is approximately 850 BTU/hr. In contrast, the typical crewmember metabolic rate prior to and following the EVA is approximately 500 BTU/hr.

Effective CO<sub>2</sub> removal requires water to complete the reaction. If the CCC is not preconditioned, the initial CO<sub>2</sub> absorption will be slow as the sorbent absorbs moisture from the inlet airstream; therefore, water is added to the sorbent in the manufacturing process to avoid this phenomenon.

The LiOH remaining is calculated by determining the original capacity, then subtracting the amount consumed before the EVA and the amount consumed during the EVA. Refer to Section 2.1, CWS Calculations/Limiting Consumable, for information on LiOH consumable calculations. The original capacity is calculated as follows:

$$\text{Original capacity} = \text{Max capacity} * \text{EnvFactor}$$

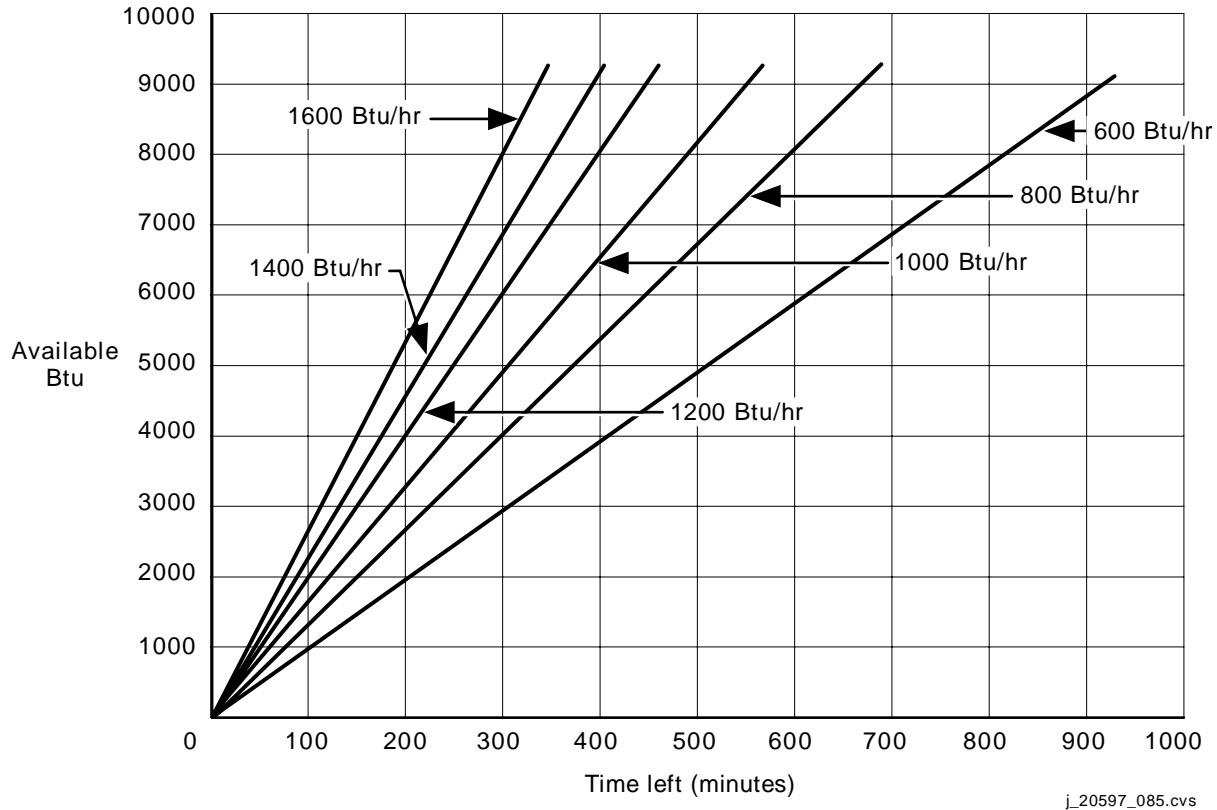
where, neutral/hot EnvFactor = .85 and cold EnvFactor = .70

The maximum capacity is the capacity of the LiOH before taking into account the efficiency of it. The Boeing Flight Data Book provides the 85 percent capacity number for BTUs, which is the capacity in a neutral/hot environment; therefore, the efficiency of the LiOH in a cold environment is determined by taking the capacity given in the Boeing Flight Data Book and dividing by 0.85, then multiplying by the cold EnvFactor of 0.70.

Figure 2.5-2 can be used to determine the EVA time left, based on LiOH consumption. This graph shows the time left as a function of metabolic rate and capacity remaining. Determine the time left on LiOH by using the average metabolic rate and available LiOH capacity to find where the curve for that particular metabolic rate intersects the available BTUs on the Y-axis and the time left on the X-axis. For example, assume that your average metabolic rate is 1000 BTU/hr and current LiOH capacity is 7500 BTUs. Figure 2.5-2 shows that the time left is approximately 450 minutes (7.5 hours). Refer to Section 2.3, Primary Oxygen System, for information on metabolic rate as a function of O<sub>2</sub> consumption rate.

The CCC capacity listed in the Boeing Flight Data Book is sufficient to maintain CO<sub>2</sub> levels in the EMU below 8.0 mmHg. Assuming an average metabolic rate of 1000

BTU/hr, the MONITOR CO<sub>2</sub> message will be annunciated 1 hour before consuming the full capacity. For consumables tracking, subtract 1 hour from the estimated time to consume full capacity to determine when the first CWS message can be expected.

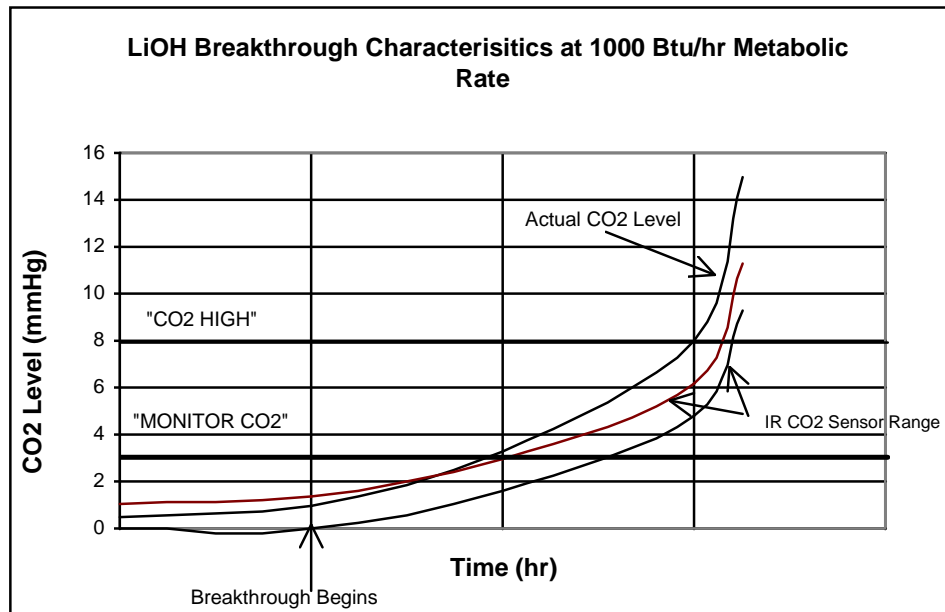


**Figure 2.5-2 Predicted CCC usage**

Source: EMUM 1388

Figure 2.5-2 shows the LiOH breakthrough characteristics at 1000 BTU/hr. It indicates the CWS messages associated with an increase in CO<sub>2</sub> in the suit. MONITOR CO<sub>2</sub> is issued when the sensor reads greater than 8 mmHg and CO<sub>2</sub> HIGH is issued when the sensor reads greater than 12.4 mmHg when the CO<sub>2</sub> sensor is able to compensate the reading using absolute suit pressure. This allows for more accurate CO<sub>2</sub> readings. Absolute suit pressure is the result of suit pressure and AL pressure. If either of these cannot be determined, the CWS reverts to the noncompensated threshold of MONITOR CO<sub>2</sub> at 3mmHg and CO<sub>2</sub> High at 8mmHg. The suit pressure will be invalid; hence pressure compensation will not be possible, when the relief valve fail or the suit P emergency messages are active. This figure reflects the actual CO<sub>2</sub> level expected in the event of a LiOH breakthrough and its associated IR CO<sub>2</sub> sensor range. The actual CO<sub>2</sub> levels are at the LiOH CCC outlet. According to this figure, it takes about an hour for the actual CO<sub>2</sub> to climb from 0.3 mmHg to 3 mmHg in the event of breakthrough at 1000 BTU/hr, at which point the MONITOR CO<sub>2</sub> message is issued. Similarly, it takes 1 hour for the actual CO<sub>2</sub> to climb from 3 mmHg to 8 mmHg; therefore, there is

approximately 1 hour between CWS warnings. Refer to Section 3.5 for more information on CO<sub>2</sub> considerations and information on the IR CO<sub>2</sub> sensor.



**Figure 2.5-3. CCC performance and breakthrough**

Source: Canman Multimission & 7 hour Cold Case LiOH Evaluation  
Post Test Summary Report, 9/4/85

Historical Information

Following the first EVA on STS 51-I, the CCC for EV 1 was inadvertently reused for the second EVA. Approximately 4 hours 15 minutes into the second EVA, EV 1 reported a "MONITOR CO<sub>2</sub>" message on his DCM. The ppCO<sub>2</sub> level in his suit was slowly increasing. The total time that this CCC was used was over 14 hours.

On the third EVA of STS-49, a record was set for the longest EVA, 8 hours 29 min. At the end of the EVA, EV 2's ppCO<sub>2</sub> sensor reading began to climb. The time on this CCC included an airlock fitcheck with three suited crewmembers the day before, an extended prebreathe due to a rendezvous burn waveoff, and the 8 hour 29 minute EVA. The total time was over 12 hours.

### 2.5.1.2 References

1. SV792600/2 S/AD Cartridge, Contamination Control (CEI #480)
2. EMUM 1388
3. EMU Requirements Evolution
4. Maria Keilich, Hamilton Standard

### 2.5.2 Metal Oxide (Metox) Canister

Quick Look Reference Data

#### 2.5.2.1 Operational Specifications

Description	Specification
Maximum operating pressure <sup>1</sup>	6.7 psig
Leakage <sup>2</sup>	10 cc/hr (max) at 6.5 psig
CO <sub>2</sub> removal	1.48 lb (min) = 8 hr EVA @ 850 BTUs
ppCO <sub>2</sub> limits <sup>3</sup>	<7.6 mmHg for 1 hr @ 1600 BTU <15 mmHg for 15 min at 2000 BTU workload
Capacity (certified minimum)	7000 BTU
Capacity (nominal) <sup>4</sup>	9000 BTU
Total cartridge weight	6.4 lb maximum
Metal Oxide weight	2.45 lb minimum
Charcoal weight	0.121-0.286 lb

1. BTA operation at 8.45 psig is acceptable because CCC proof pressure is 10.05 psig.

2. Refers to overboard leakage through the inlet/outlet ports.

3. Refers to CO<sub>2</sub> limits in helmet area.

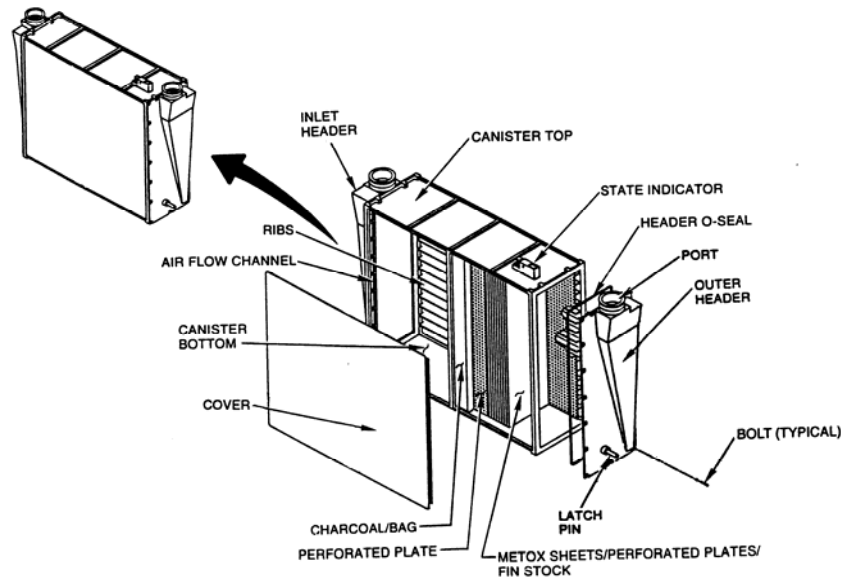
4. Actual capacity is referenced in the Boeing Flight Data Book.

#### 2.5.2.2 Canister Description

The metal oxide canister consists of metal oxide sheet assemblies, a charcoal bag containing activated charcoal and a container and cover panel with cast headers that are fastened to the container. The metal oxide sheet assembly is shown in Figure 2.5-4 and consists of an encapsulated metal oxide sorbent sheet, perforated plates, and air passage fins. There are approximately 45 metal oxide sheets loaded into each side of the canister. After this is completed, a perforated plate is installed to separate the metal oxide from the charcoal. A charcoal bag is placed in the remaining volume in the canister and charcoal is loaded into the bag. Although dimensionally different, the charcoal and bag construction are the same as that used in the LiOH CCC. A wave spring is placed between the loaded charcoal bag and the headers. Similarly, a silicone compression pad is placed between the metal oxide and the header and is fastened to the container housing.

The canister removes metabolically produced CO<sub>2</sub> in the EMU during EVA and in the ISS Joint Airlock during prebreathe activities. It also contains charcoal to remove trace contaminants from the EMU vent loop. After the EVA, the canister is removed from the EMU and placed in the Metox Regenerator. Regeneration is accomplished by flowing heated cabin air through the canister. The canister can then be reused in either the EMU or in the ISS Joint Airlock CO<sub>2</sub> removal subsystem for EVA prep and post activities. The canister can be installed in the EMU and the regenerator by a single crewmember in less than 3 minutes without the use of tools. The state indicator and labels prevent the canister from being installed into the EMU or regenerator in the incorrect orientation.

### 2.5.2.3 Assembly



**Figure 2.5-4. Canister assembly EXPLODED VIEW**

The canister assembly (Figure 2.5-4) consists of stainless-steel housing, approximately 90 metal oxide sheet assemblies, a quarter (1/4) pound activated charcoal bed, a 150 mesh particulate filter and a state or status indicator.

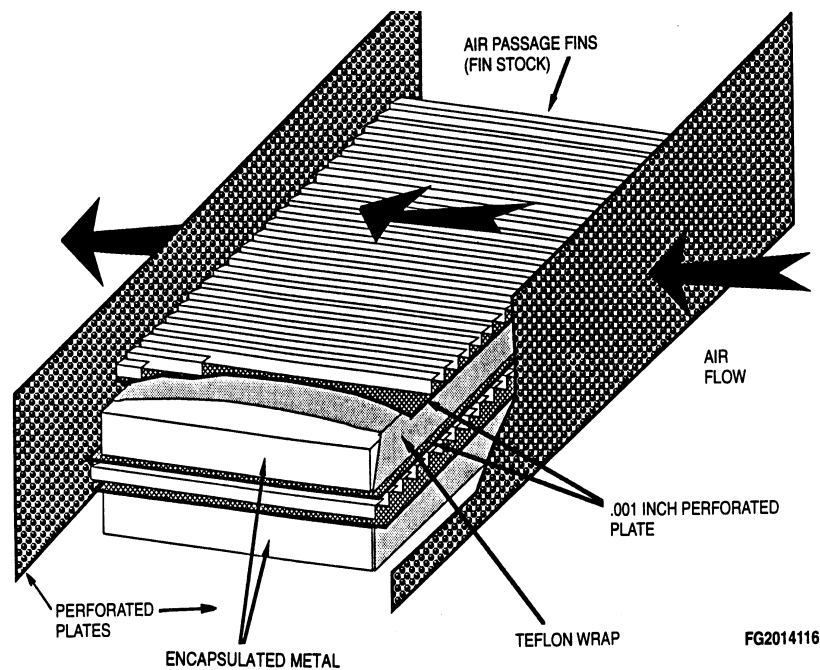
### 2.5.2.4 Housing

The six sided stainless steel housing is fabricated from four major parts, a three-sided base (top, front and bottom) machined from a single billet, a cover plate (back) and two cast headers (sides). The cover plate is welded and the headers are screwed to the base plate. Both the front and back walls have ribs machined into their internal faces. The ribs provide both structural strength and distribute or collect the flow between the beds and headers. Perforated plates are brazed to both sets of ribs to separate the beds from the flow distribution channels. A center support is also welded between the

front and back walls to provide additional structural support. This support divides the internal cavity into two equal volumes.

### 2.5.2.5 Sheet Assemblies

Each metal oxide sheet assembly consists of sorbent wrapped in porous Teflon and sandwiched between two thin perforated plates for support (Figure 2.5-5). Between adjacent sheet assemblies are 0.020-inch high stainless steel heat exchanger fin stock sheets. These provide the air flow passages through the bed.



**Figure 2.5-5 Metal oxide sheet assembly**

### 2.5.2.6 Fabrication

Prior to attaching the headers, approximately 45 metal oxide sheet assemblies are loaded into each of the two volumes. After the sheets are installed, two Nomex bags filled with activated charcoal are placed in the approximately 1/4 inch space between the metal oxide sheets and the back wall, (one bag for each side). The charcoal and bag constructions are similar to those used in the EMU LiOH canister. Two perforated plates, similar to the ones brazed to the ribs, are installed between the sheets and the charcoal bag (one sheet per side). The headers are then fastened to the base plate. A face seal o-ring is used to provide environmental leakage protection.

### 2.5.2.7 Headers

The headers are machined from a common casting mold. The 150 mesh particulate filter is welded into the right side header (header closest to the state indicator). A slight difference between the left and right header bolt patterns prevents the headers from



being installed incorrectly. A radial o-ring seal is used on both header ports for sealing with the EMU or regenerator assembly.

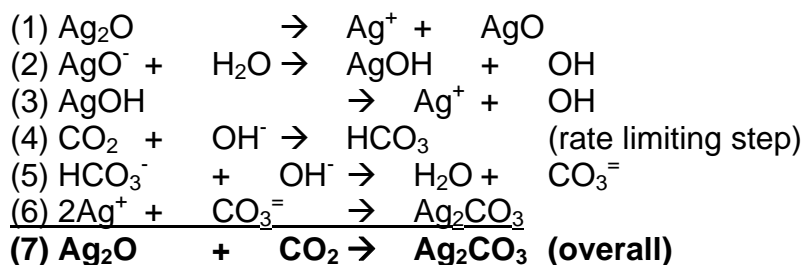
### 2.5.2.8 State Indicator

A state indicator is attached to the housing to indicate whether the canister has been regenerated or is expended. An interference bracket is built into the oven and contacts the state indicator to prevent the canister from being installed backwards in the oven.

Operationally, the state indicator is not used for two reasons. A tolerance stack-up will allow some canisters to complete a regeneration cycle and stay sufficiently clear of the solenoid which actuates the state indicator to the "regenerated" position. In addition, this indicator is easily bumped by the crew. As a result, serial and barcode numbers are used to track the status of a canister as regenerated or expended.

### 2.5.3 Metal Oxide Chemistry

Experimentally it has been shown that CO<sub>2</sub> will not react directly with metal oxides. A reaction takes place only if there is enough moisture available to react with the oxide to form a hydroxide. The proposed mechanism for the reaction of CO<sub>2</sub> with silver oxide to form silver carbonate is shown below.



It should be noted that the water is not consumed in the overall reaction, but acts as a catalyst for the reaction by combining with the silver oxide to maintain a supply of hydroxide ions for the rate limiting reaction in step 4, and silver ions for equation step 6.

### 2.5.4 Canister Operation

During usage, between 6 and 7 CFM of moist, CO<sub>2</sub> laden oxygen (o2) or air is passed through the canister. Testing has demonstrated flows of between 6 and 9 CFM at inlet temperatures of between 55 and 95° F, dew point temperatures of between 27 and 73° F and total pressures of between 3.33 and 23.6 psia. During cabin usage the ambient temperature (heat sink) ranges from 65 to 80° F. The EMU ambient temperature range increases from (minus) -167° to (plus) +220° F during vacuum (space) operation. Based on computer simulations (Figure 2.5-6), the range in vacuum ambient temperature is expected to result in a 36 to 81° F internal PLSS (heat sink) temperature. During testing heat sink temperatures of between 38 and 93° F were demonstrated.

During operation, gas enters the left header and is distributed across the back cover plate. It first passes through the charcoal bed, where metabolically produced trace contaminants are removed. It then passes through the metal oxide bed, where CO<sub>2</sub> and some water (H<sub>2</sub>O) vapor are removed. The refreshed O<sub>2</sub> is then collected along the front wall and directed to the right header where it passes through the 150-micron particulate filter before exiting the canister and entering the EMU Ventilation Loop.

#### **2.5.4.1 Regeneration**

Canister flow direction during the heating mode of the regeneration cycle is opposite the usage flow direction (i.e., the flow enters the right header, is distributed across the front wall, passes through the metal oxide and charcoal beds, is collected on the back wall and exits through the left header). Metal oxide is regenerated by flowing approximately 7.5 CFM of 200 to 400° F air through the canister for a duration of approximately 10 hours. This is followed by a 4-hour cool down period to return the canisters and oven to a safe touch temperature. During cooling mode, all flow internal to the canister is stopped and cool air is directed over the outside canister surface. This is done to prevent cabin CO<sub>2</sub> from being re-absorbed by the canister.

Regeneration is accomplished by increasing the temperature to between 300 and 400 degrees Fahrenheit (° F). At this temperature the silver carbonate decomposes directly to silver oxide and CO<sub>2</sub>. Water is not required for regeneration and in fact has to be completely driven from the bed before the temperature can be raised above the boiling point (212° F).

#### **2.5.4.2 Canister performance**

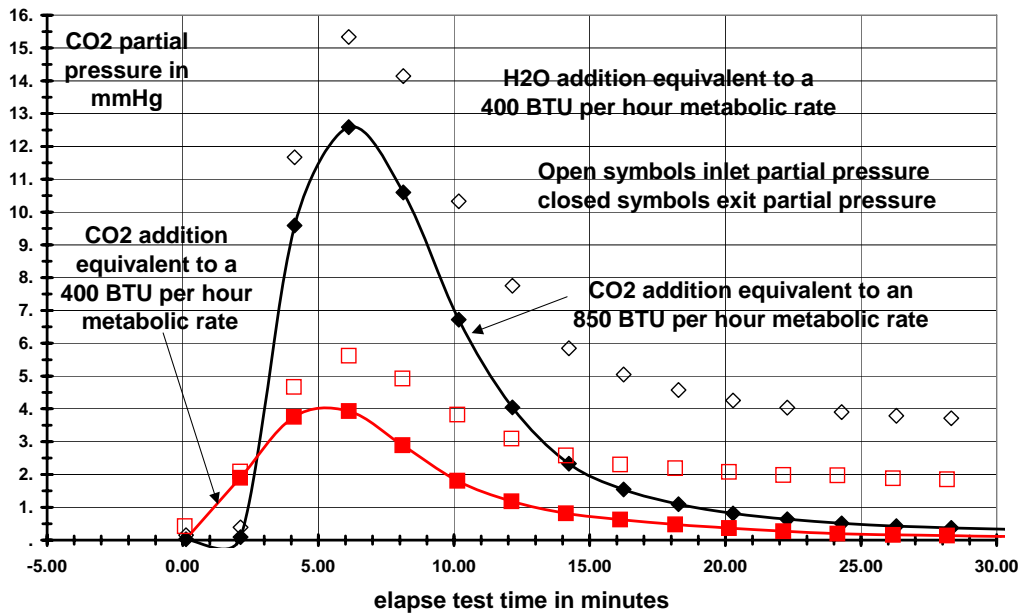
##### **Performance Requirements**

During pre-EVA camp-out operation, the canister is required to remove 0.1 pph CO<sub>2</sub> for 12 hours (1.2 pounds total). The total required CO<sub>2</sub> removal capacity for EMU operation is 1.48 pounds. As part of that capacity, the canister is required to support an 8-hour EVA at an average metabolic rate of 850 BTU/hr (equivalent to CO<sub>2</sub> generation rate of 0.17 pph). This represents a slight change from the LiOH CCC requirement of 7 hours at 1000 BTU/hr. The change in EVA requirements is the result of shuttle EVA experience. For IVA, the canister is required to maintain the Joint Airlock CO<sub>2</sub> partial pressure at less than 7.6 mmHg. For EVA, the requirement is for a crewmember's inspired CO<sub>2</sub> partial pressure to be less than 7.6 mmHg for metabolic rates up to 1600 BTU/hr and below 15 mmHg for metabolic rates between 1600 and 2000 BTU/hr. The Beginning-Of-Life (BOL) and End-Of-Life (EOL) pressure drop requirements are 0.67 and 0.9 inches of water, respectively, at 7.2 CFM of O<sub>2</sub>, 4.1 psia and 72F (EVA conditions).

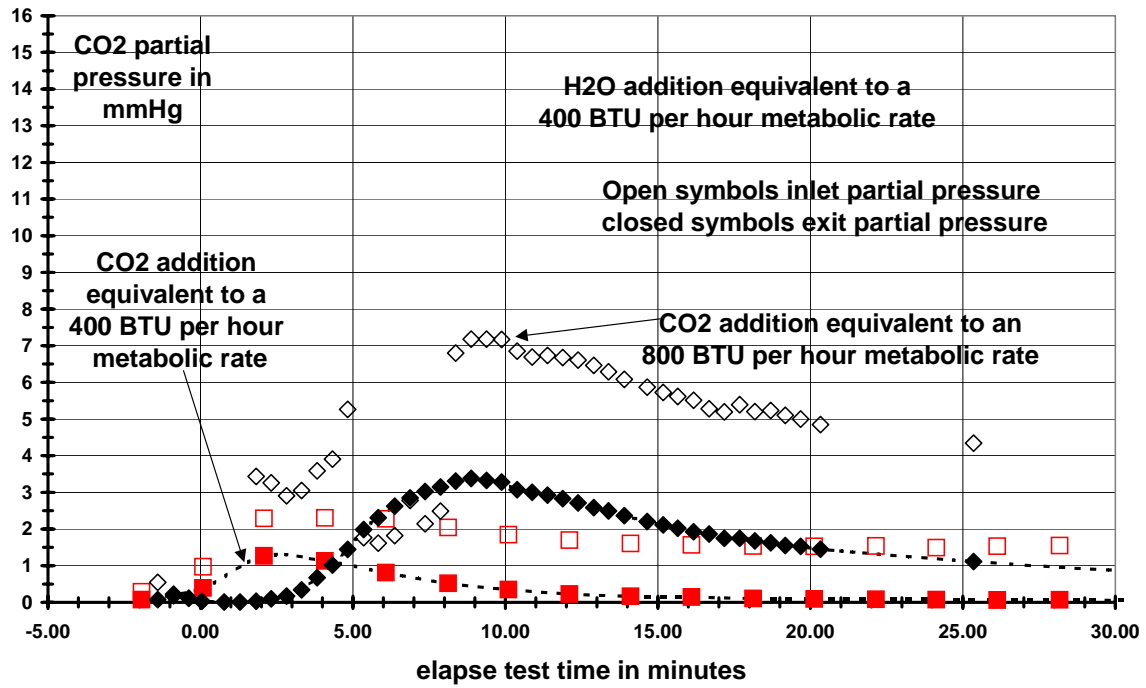
The canister operates for a minimum of 55 absorption/regeneration cycles.

### Start-up

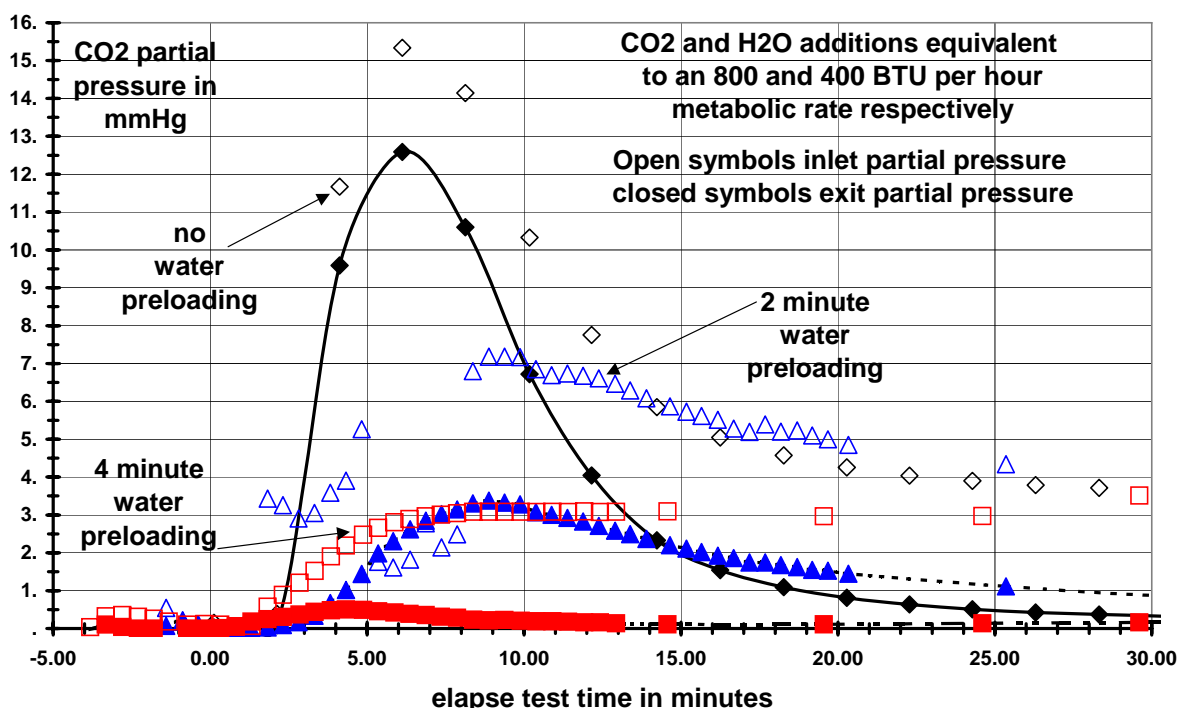
As indicated in the previous discussion, water is required for the reaction. Figure 2.5-6 shows the impact of water loading on initial CO<sub>2</sub> removal capability. The test utilized a full regenerated canister in a closed loop flow configuration. In all tests, water was added to the flow at a metabolic rate equivalent to approximately 400 BTU per hour. Tests were conducted at two CO<sub>2</sub> addition rates, approximately 400 and 800 BTUs per hour. In the tests, both the CO<sub>2</sub> and H<sub>2</sub>O additions were begun at zero elapsed minutes. The results indicate that during the first 4 to 6 minutes of operation the metal oxide was not able to remove the CO<sub>2</sub> as fast as it is being added. This results in an increase in the CO<sub>2</sub> partial pressure. This is an impact to a manned Metox change-out. The crew should be notified that the CO<sub>2</sub> level will spike upon initial insertion of the replacement canister until enough moisture is available (< 10 min). Performing a delta-purge at this time will help the situation, but probably not eliminate the spike given that purging via the DCM purge valve diverts a portion of the moisture-rich recirculation flow from the crewmember overboard. The CO<sub>2</sub> levels return to nominal within a few minutes after enough moisture is available in the canister to perform the reaction effectively.



**Figure 2.5-6. CO<sub>2</sub> Start-up sensitivity to H<sub>2</sub>O loading no preload**



**Figure 2.5-7 CO<sub>2</sub> Start-up sensitivity to H<sub>2</sub>O loading  
2 minute preload**



**Figure 2.5-8. CO<sub>2</sub> Start-up sensitivity to H<sub>2</sub>O loading various preloads**

In the tests presented on Figure 2.5-9, H<sub>2</sub>O addition was begun at 2 minutes before CO<sub>2</sub> flow was initiated. Although a build up in the CO<sub>2</sub> partial pressure was still observed, the maximum level was significantly reduced (12 down to less than 4 mmHg at the 800 BTU rate and 4 down to less than 1.5 mmHg at the 400 BTU rate). Figure 2.5-10 compares 0, 2 and 4 minute water preloads. The results indicate that with a 4-minute water preload there was virtually no CO<sub>2</sub> build-up.

During actual usage no CO<sub>2</sub> build up is anticipated, since nominally the fan is started before donning the helmet and includes an 8 to 12 minute purge shortly after locking the helmet. This allows some water pre-loading of the metal oxide. However, as mentioned above, during the period shortly following a manned Metox replacement, the CO<sub>2</sub> levels may increase slightly because the new canister has not been pre-conditioned.

### 2.5.4.3 Water Loading

The amount of water that the metal oxide absorbs is primarily a function of relative humidity. As shown in Figure 2.5-9, the relative humidity is defined as the inlet water partial pressure divide by the saturation pressure at the gas outlet temperature. The outlet temperature is controlled by the heat generation rate (metabolic rate), the mass flow (air flow rate and total pressure) and heat loss. The bed is a superior desiccant and will absorb all the water available in the air stream until it reaches its saturation point. This is shown in Figure 2.5-10.

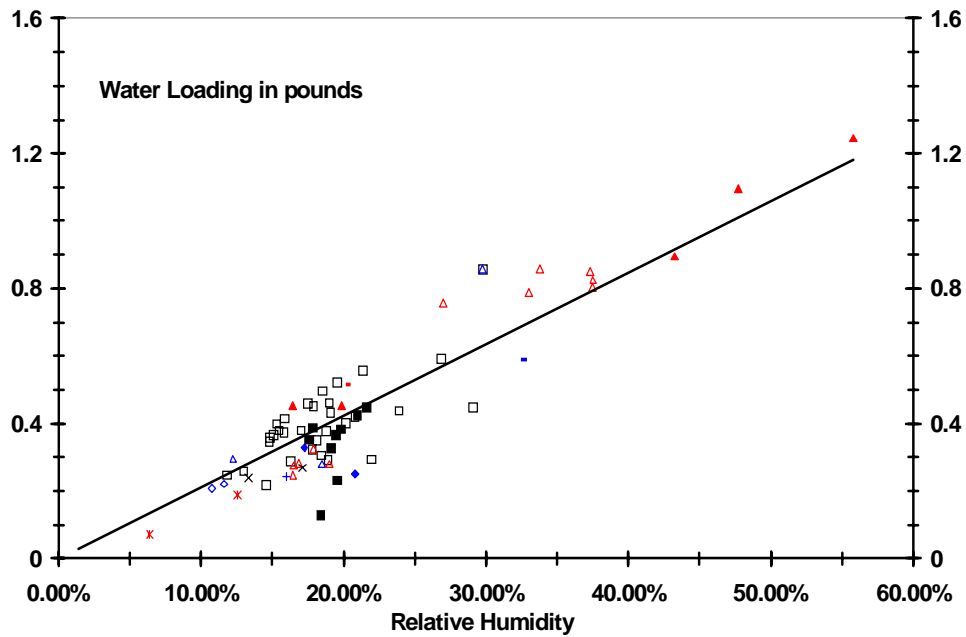


Figure 2.5-9. H<sub>2</sub>O loading

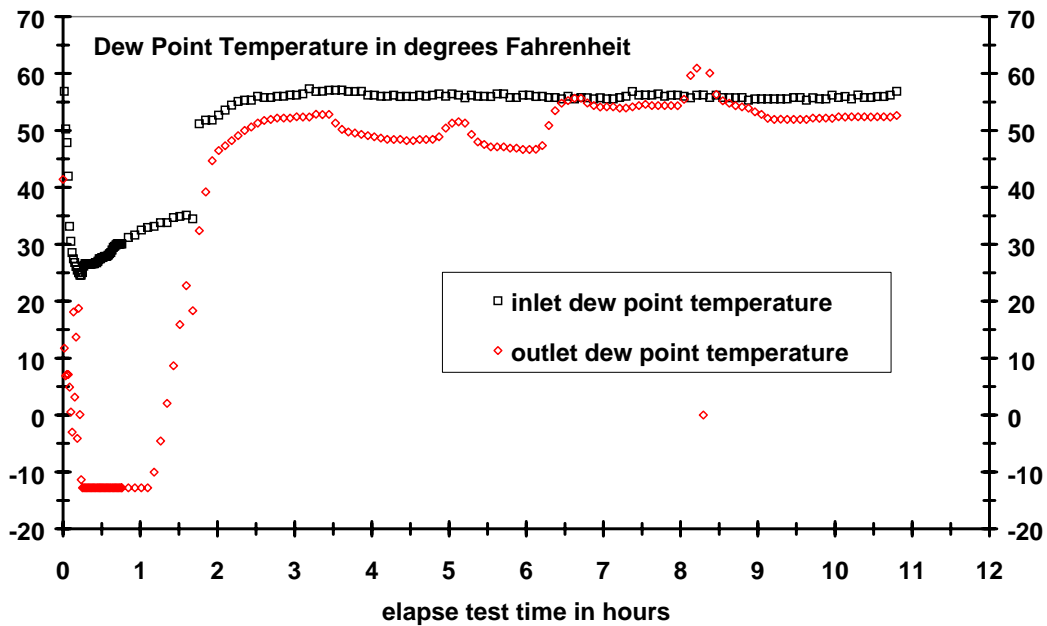


Figure 2.5-10. H<sub>2</sub>O absorption

Figure 2.5-11 shows the canister inlet and outlet dew point temperatures. The initial (minus) -12° F canister outlet dew point temperature represents the minimum range of the instrumentation. The 30° F inlet dew point temperature is approximately equivalent

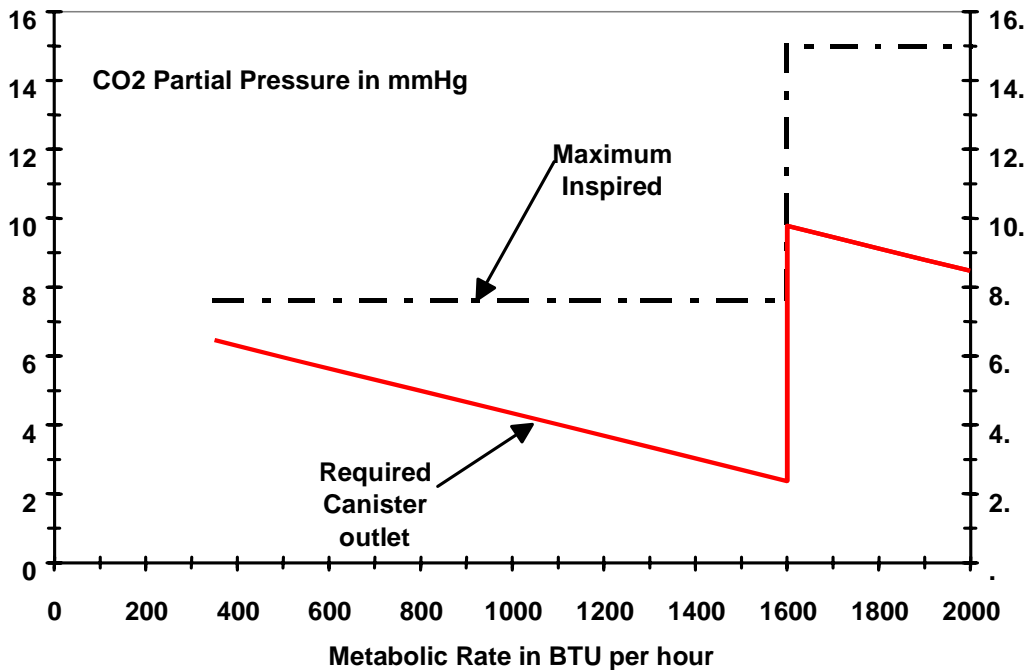
to the humidity level that would be reached at a 400 BTU per hour metabolic rate when starting with bone-dry air. The figure shows that initially the canister absorbs all the entering water. After approximately one hour, the outlet dew point temperature begins to rapidly rise as the bed removal rate decreases. At an outlet dew point temperature of 25° F, the inlet dew point temperature was increase to 55+/-2° F for the remainder of the test. This represents the anticipated inlet dew point after the bed has become saturated and the Sublimator begins to control the helmet inlet dew point. The increase in outlet dew point temperature between 6 and 9 hours is the result of the higher CO<sub>2</sub> removal rates. This increased the canister temperature, which further decreases the water removal rate. During the 2000 BTU per hour test point at 8 hours, water is actually evaporated from the bed as the bed temperature reaches a maximum average of 115° F.

#### **2.5.4.4 Metabolic Requirements**

The total designed CO<sub>2</sub> capacity for EMU ISS operation is 1.48 pounds. This is based on the required capacity to support an 8-hour EVA at an average metabolic rate of 850 BTU per hour (equivalent to a CO<sub>2</sub> generation rate of 0.17 pph). This represents a slight change from the shuttle-based CCC requirement of 7 hours at 1000 BTU per hour (0.2 pph).

#### **2.5.4.5 CO<sub>2</sub> Partial Pressure Requirement**

For 10.2 ops, the canister is required to maintain the cabin inspired CO<sub>2</sub> partial pressure to be less than 7.6 mmHg. For EVA, the requirement is for a crewmember's inspired CO<sub>2</sub> partial pressure to be less than 7.6 mmHg for metabolic rates up to 1600 BTU per hour and below 15 mmHg for metabolic rates between 1600 and 2000 BTU per hour. Because the inspired level of Co<sub>2</sub> partial pressure is a mixture of the canister's refreshed air and the crew person's expired air (i.e., helmet wash out efficiency), the inspired requirements were translated into the maximum allowable canister CO<sub>2</sub> outlet pressure, Figure presents the maximum allowable canister outlet CO<sub>2</sub> partial pressure versus metabolic rate. The figure show that as the metabolic rate increase, the required canister outlet CO<sub>2</sub> partial pressure decreases to a minimum of 2.37 mmHg at a metabolic rate of 1600 BTU per hour. Based on this, a CO<sub>2</sub> partial pressure of 2.37 mmHg was established as the maximum allowable CO<sub>2</sub> partial pressure.



**Figure 2.5-11. Required CO<sub>2</sub> partial pressure**

### 2.5.4.6 CO<sub>2</sub> Capacity

The CO<sub>2</sub> capacity of the metal oxide is primarily a function of water loading and metabolic rate. Water loading determines how much material is active and metabolic rate determines how much material is required to maintain CO<sub>2</sub> pp below 2.37. Figure presents the CO<sub>2</sub> loading versus H<sub>2</sub>O loading and Figure 2.5-13 presents the CO<sub>2</sub> and H<sub>2</sub>O loading versus the metabolic rate.



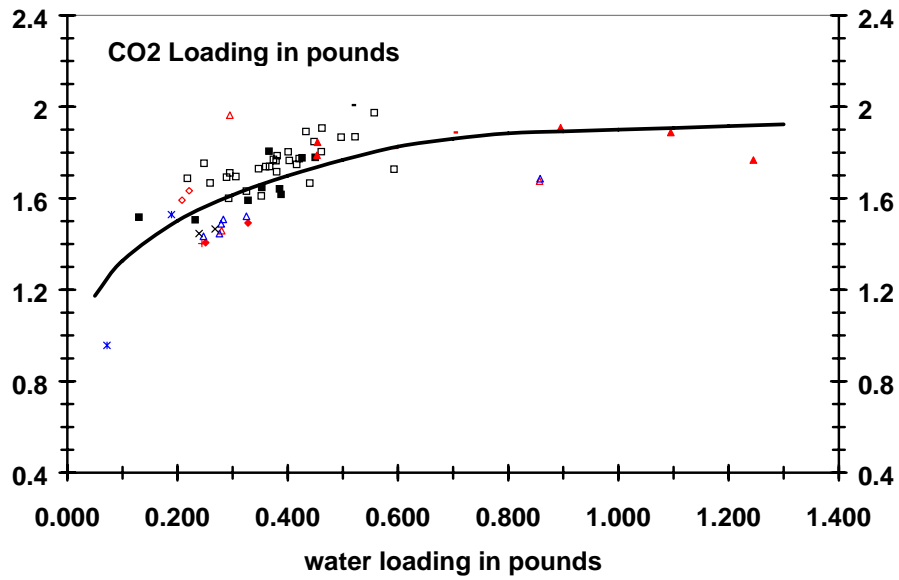


Figure 2.5-12. CO<sub>2</sub> vs. H<sub>2</sub>O loading

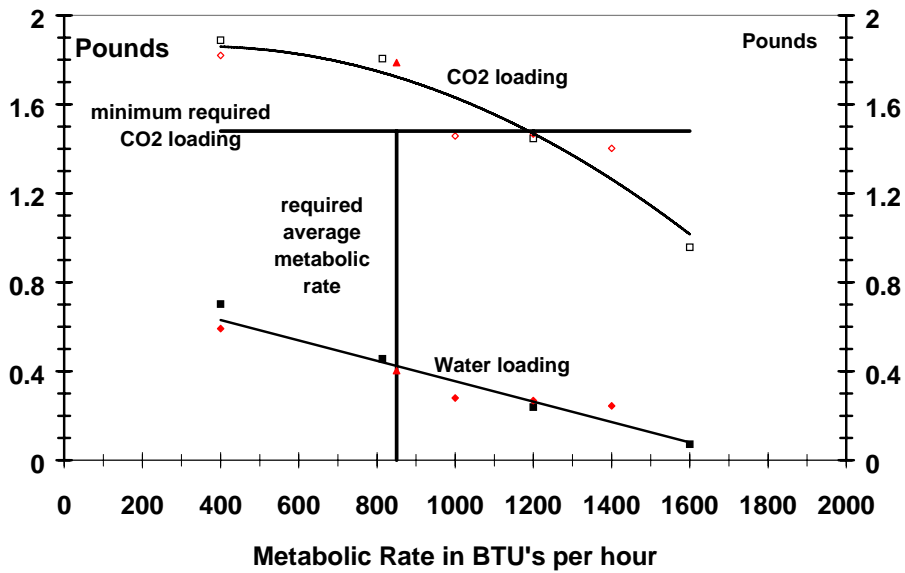
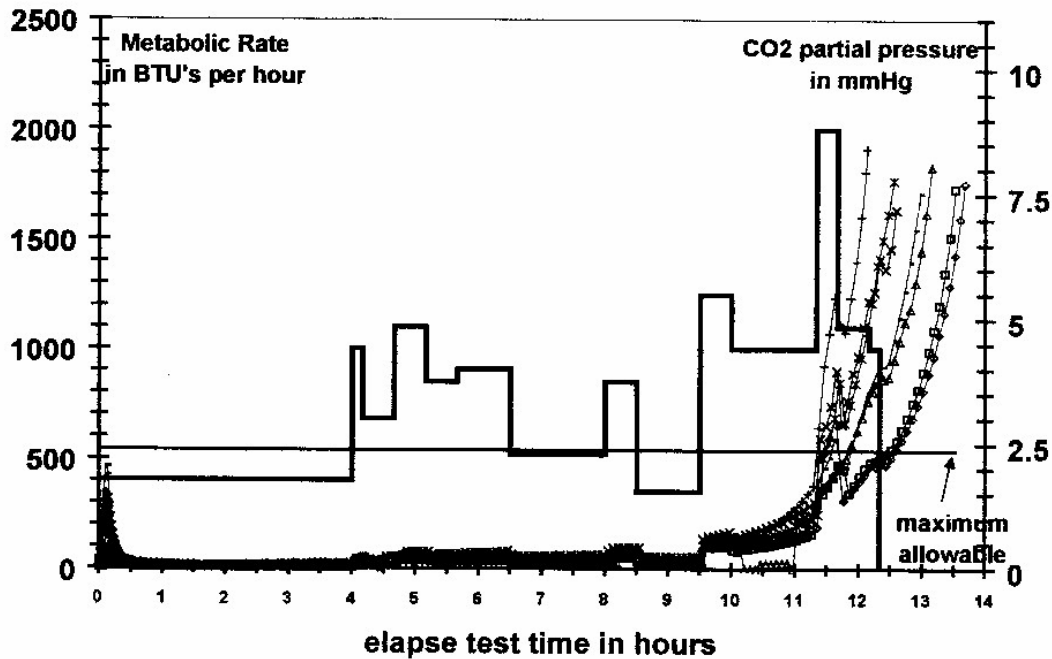


Figure 2.5-13. CO<sub>2</sub> and H<sub>2</sub>O vs. metabolic rate



**Figure 2.5-14. CO<sub>2</sub> partial pressure vs. time (for 4-hour prebreathe)**

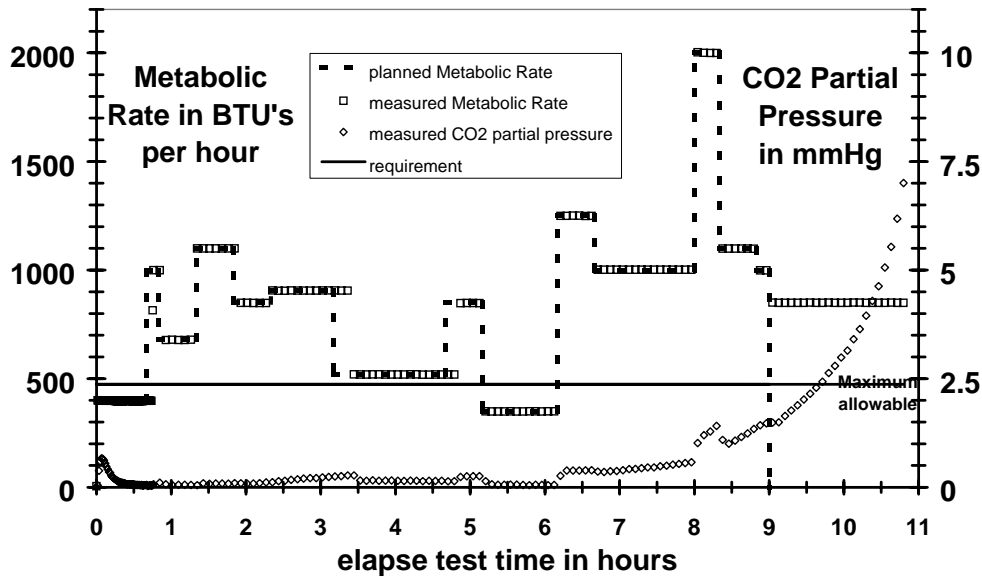
#### 2.5.4.7 Operation Life

The canister must be capable of meeting the operating requirements for a minimum of fifty-five (55) absorption/regeneration cycles. The CO<sub>2</sub> capacity at nominal conditions and the pressure drop are presented on Figure 2.5-14.

#### 2.5.5 Metabolic Data

##### 2.5.5.1 Metox Metabolic Profile

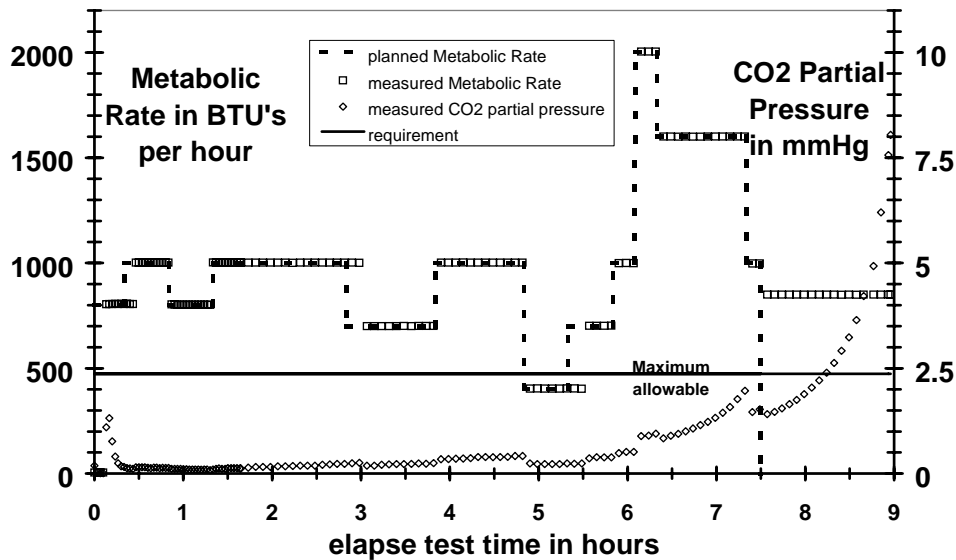
Figure presents the metabolic profile utilized during a nominal test and the resulting typical canister CO<sub>2</sub> outlet partial pressure. The metabolic profile represents a slight modification to the previous presented metal oxide SOW profile (Figure 2.5-15). The modification included combining the two 10 minute, 2000 BTU per hour metabolic rate periods into one period of 20 minutes. It also added the 40-minute prebreathe at 400 BTU per hour, the 10-minute egress and ingress activities at 1000 BTU per hour and final 850 BTU per hour period. The 850 BTU per hour period was run until the outlet partial pressure reached 7.6 mmHg. The entire test was run with the canister in a room temperature vacuum ambient at an average heat sink temperature of 52° F, a 65° F inlet temperature, 55° F dew point temperature, 4.3 psia inlet pressure and a 6.5 CFM gas flow. These conditions are representative of a cool (-30° F) ambient and were repeated periodically throughout the testing (baseline conditions) to evaluate performance with usage.



**Figure 2.5-15. CO<sub>2</sub> partial pressure vs. time at the nominal ISS metabolic profile**

**2.5.6 CCC Metabolic Profile**

Figures present the metabolic profile based on the alternate CCC profile and the typical resulting canister CO<sub>2</sub> outlet partial pressure. This metabolic profile is the result of adding a 20-minute prebreathe at 800 BTU per hour, a 10-minute ingress at 1000 BTU per hour, and, as above, an 850 BTU per hour period to the previously presented "CCC" metabolic profile. The test was run with the canister in a room temperature vacuum ambient at an average heat sink temperature of 70° F, a 78° F inlet temperature, 49° F dew point temperature, 4.4 psia inlet pressure and a 6.4 CFM gas flow. These conditions are representative of a warm to hot (125° F) ambient. Again, the results show that the CO<sub>2</sub> outlet partial pressure is below the maximum allowable level of 2.37 mmHg for the entire 7 ½ -hour (1.48 pound) profile. The figure also shows a CO<sub>2</sub> outlet pressure transient during the initial pre-breathe period.



**Figure 2.5-16. CO<sub>2</sub> partial pressure vs. time at the nominal CCC metabolic profile**

**2.5.7 Extended Prebreathe Metabolic Profile**

The Metox SOW metabolic profile translates into a total CO<sub>2</sub> generation of 1.36 pounds at a respiratory quotient of 0.9. Subtracting this from the total required capacity of 1.48 pounds leaves a balance of 0.12 pounds. This is generally allocated among the following three (3) activities:

1. Forty minutes at 400 BTU per hour for EMU donning and checkout (or 20 minutes at 800 BTU per hour).
2. Ten minutes at 1000 BTU per hour for airlock egress.
3. And 10 minutes at 1000 BTU per hour for airlock ingress.

Forty (40) minutes is considered the minimum pure O<sub>2</sub> "prebreathe" time required to avoid the "Bends" during EVAs that start from a cabin pressure of 10.2 psia. When the EVA starts from a cabin pressure of 14.7 psia, the minimum "prebreathe" time increases to four hours. For an eight hour average EVA, this increase the total CO<sub>2</sub> generation by approximately 20 percent (1.48 to 1.75 pounds). Figure 2.5-16 presents the results of several tests utilizing a 4 hour prebreathe. Based on this testing the Metox is not certified for a 4-hour prebreathe combined with an 8-hour EVA.

## **2.5.8 On-Orbit History**

### **2.5.8.1 02/20/2002: Metox Caused Odor in Equipment Lock**

Several canisters have been successfully regenerated on ISS using the Common Cabin Air Assembly (CCAA). On February 20<sup>th</sup>, regeneration of two Metox canisters (S/Ns 0009 & 0010) was initiated. Approximately 2.5 hours after the initiation of regeneration, a strong odor (described as a sweet smell, like paint drying) was reported by the Expedition 4 crew. Two and ¾ hours after initiation, regeneration was aborted manually. At this point in canister regeneration, its internal temperature would be 250° F. This particular canister had been expended during an EVA over 6 months prior (July 2001), at which time regeneration was attempted, but aborted after 50 minutes due to unrelated CCAA problems. The CCAA had been repaired well before this second regeneration attempt of these canisters.

It was later discovered that shortly after the first regeneration attempt, the Expedition 2 crew opened the regenerator door past 90 degrees, which changed the position of the diverter valve in the Metox Regenerator to the Heating mode flow position (see regenerator system brief for details of this valve). Opening this valve to a slight, passive flow of cabin air, over the course of 6 months, allowed trace contaminants, which are nominally in the ISS air volume, to build up in the charcoal bed filter of the Metox canister. The sudden release of these contaminants back into the station volume is the leading suspect of the anomalous odor.

Since this anomaly, the Russians have taken a keen interest in Metox operations. Immediately after the odor was detected, since the cause was unknown at the time, the crew was confined to the Russian segment for almost 24 hours while the U.S. segment was scrubbed clean of the odor. After weeks of investigation and continuing discussions between the Russian and American materials, safety, medical, and ECLSS communities, regeneration was allowed to occur. Certain preventative measures were taken on the first few attempts to regenerate canisters after the anomaly.

### **2.5.8.2 Metox Logistics Plan**

The plan to launch and return Metox canisters must be planned well in advance to account for manifesting issues with weight and on-orbit usage. Canisters are stored regenerated (dry), and weigh significantly more than most shuttle payloads.

## **2.5.9 Malfunction Procedure References**

Metox CANISTER O-RING CHANGEOUT

Metox REPLACEMENT (MANNED)

## **2.5.10 Analysis/Test References**

SV792600/2 S/AD Cartridge, Contamination Control (CEI #480)

### **2.5.11 More References**

EMU Mini Data Book, Rev J

Metox CO2 Removal System Training Pitch, Hamilton Sunstrand, 12/12/2000

## 2.6 EMU BATTERY

### PURPOSE

This section provides information on the operational and recharge characteristics of the EMU battery.

### DESCRIPTION

During EVA tasks, the EMU battery supplies all internal power to the PLSS. Physically, the battery consists of 11 silver-zinc cells, connected in series that can furnish a minimum of 26.6 amp-hr of power over a 7-hr EVA. The battery specification calls for a nominal battery voltage of 16.5 to 16.8 V dc, with an average current draw during EVA of between 3.5 to 3.8 amps. However, EVA flight data shows a typical battery range from 17.1 V dc at 2.9 amps (in bypass mode) down to 16.9 V dc at 3.5 amps (non-bypass mode). Each of the 11 cells produces approximately 1.5 volts. Battery specifications (item 490) are shown in Table 2.6-1.

**Table 2.6-1. EMU battery specifications**

Source: SV792600/2 S/AD Battery (CEI no. 490)

Description	Specifications
Power <sup>1</sup>	26.6 amp-hr
Rechargeable	Six on-orbit cycles <sup>2</sup>
Output voltage (nominal)	16.8 volts
Discharge profile	3.8 amps for 7 hr
Weight	9.9 lb
Wet life <sup>3</sup>	170 days
Relief valve	16-40 psid

<sup>1</sup>Actual capacity is referenced in the Boeing Flight Data Book.

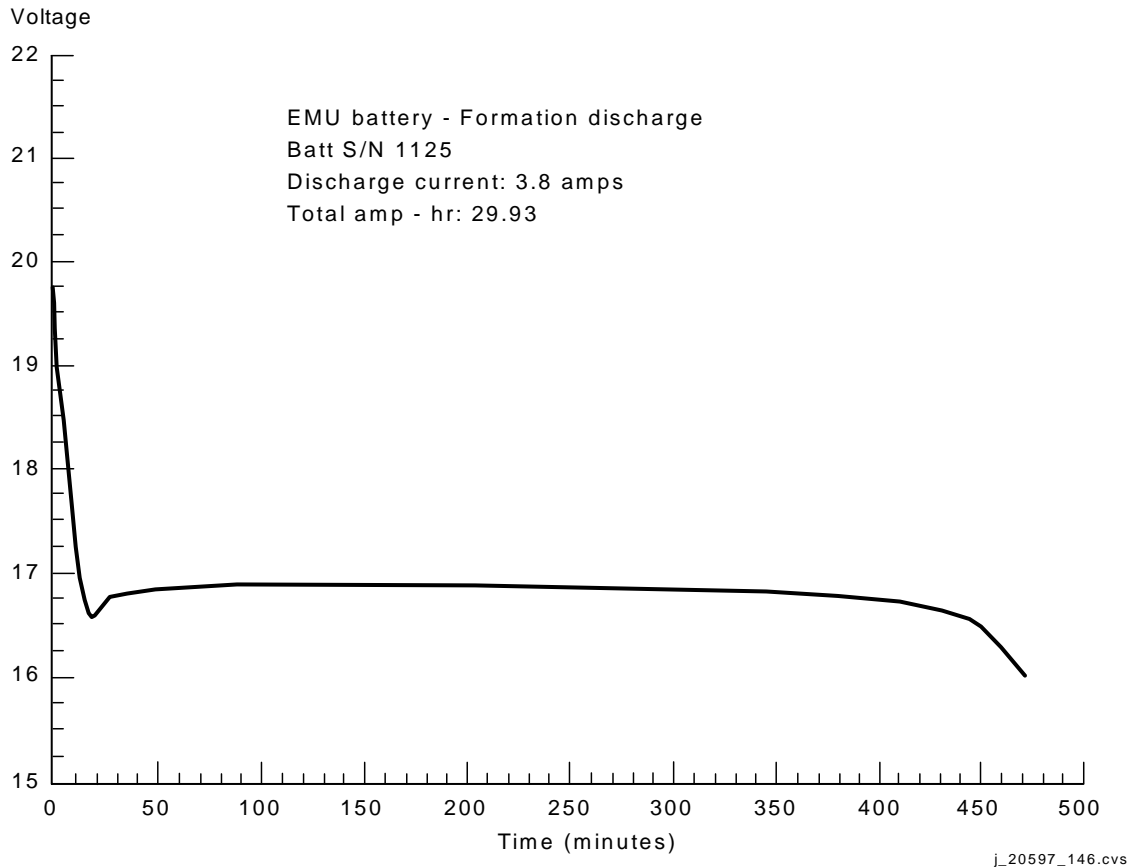
<sup>2</sup>This does not include preflight charge/discharge formulation cycles during processing.

<sup>3</sup>A waiver may be written to extend wet life in special circumstances (EMUM-1051, EMUM-0028).

EMU batteries that have been provided for flight typically can provide between 30 and 32 amp-hr during their first service cycle. The battery must start out at this higher capacity so that it can still provide the required minimum 26.6 amp-hr during the sixth service cycle. The first two cycles on the battery, performed on the ground, are referred to as formation cycles. The on-orbit cycles, also called service cycles, start with the third one. The specific capacity for each battery flown is listed in the Boeing Flight Data Book.

The battery has a wet life of 170 days. Wet life is defined as the period that the battery is activated with potassium hydroxide (KOH) electrolyte. During this time, typically the battery goes through two formation cycles and then can be charged/discharged six times. A charge/discharge cycle is defined as 26.6 amp-hr.

Figure 2.6-1 shows the characteristic discharge curve for an EMU battery. Note the very flat and stable voltage over a 7-hr EVA. A fully charged battery supplies an open circuit voltage of about 20 V dc. When connected to the EMU, the voltage drops quickly to the normal range of 16.5 - 16.8 V dc. This voltage remains relatively constant until approaching the end of the 7-hr capacity, when the voltage drops to approximately 16 V dc. At this point, the battery is considered fully discharged.



**Figure 2.6-1. EMU battery discharge characteristics**

Post-EVA, the battery can be recharged with the airlock power supply (ALPS). The ALPS is configured for battery recharge with controls located on panel AW18H. When the discharged battery is connected to the ALPS via the SCU, the open circuit voltage is 18.0 - 18.5 volts. The battery is then recharged using a constant current of approximately 1.55 amps. When the battery reaches a terminal voltage of 21.8 V dc, the power supply begins a gradual tapering of the charge current. Therefore, the ALPS will provide a regulated 1.55 amps to the battery until the charge approaches completion, and at that point the current will gradually drop below 1 amp. Figure 2.6-2 illustrates the estimated battery recharge time versus EVA time.



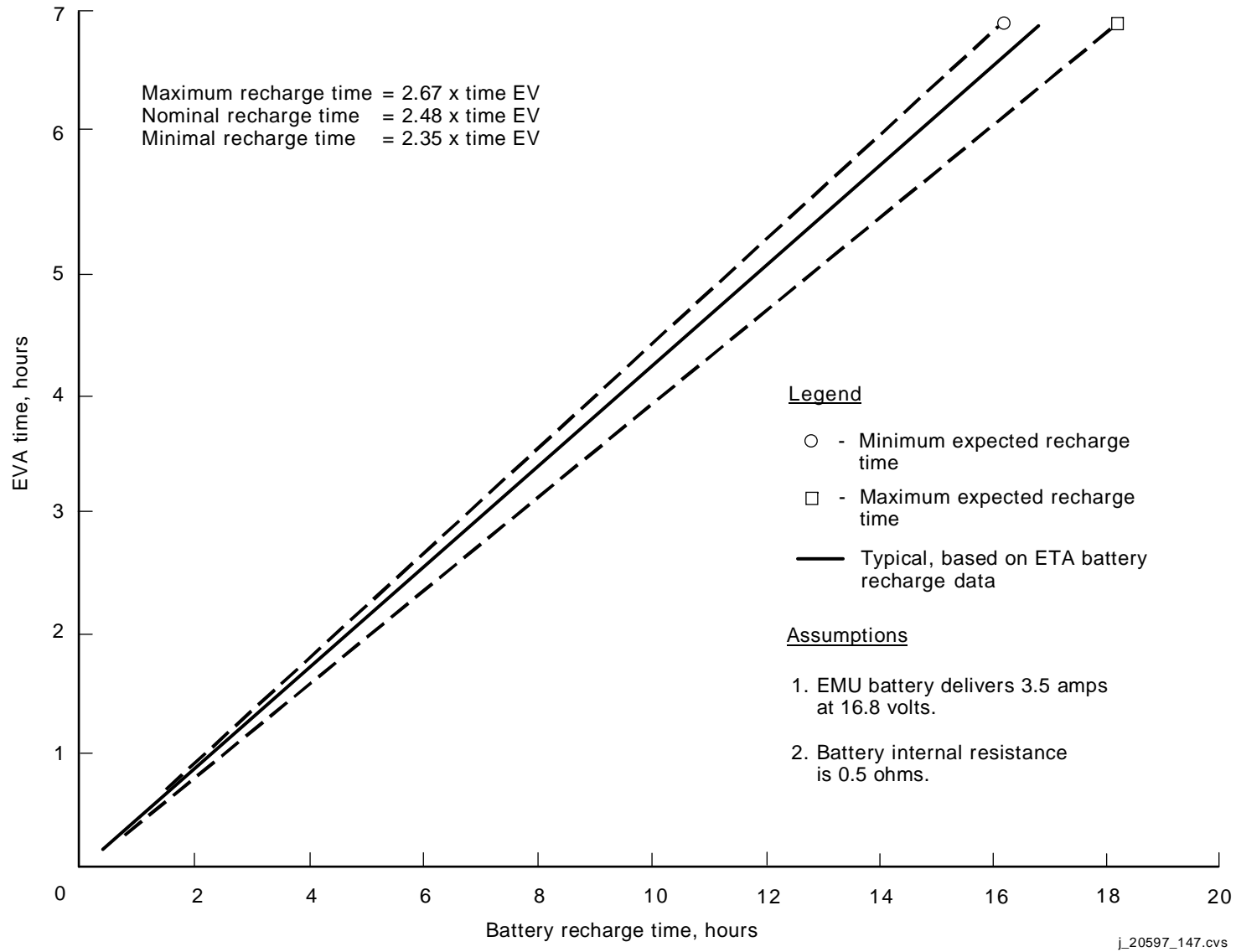
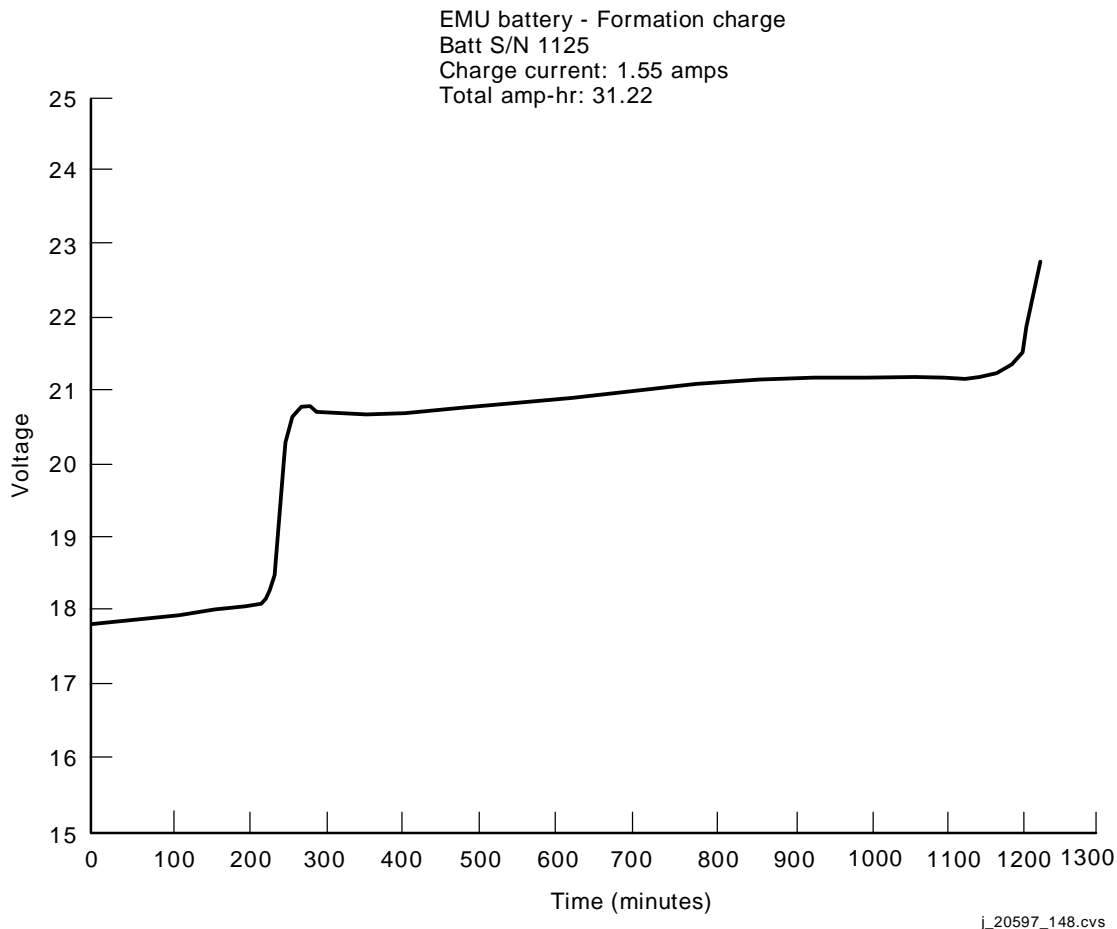


Figure 2.6-2. Estimate of battery recharge time versus EVA time

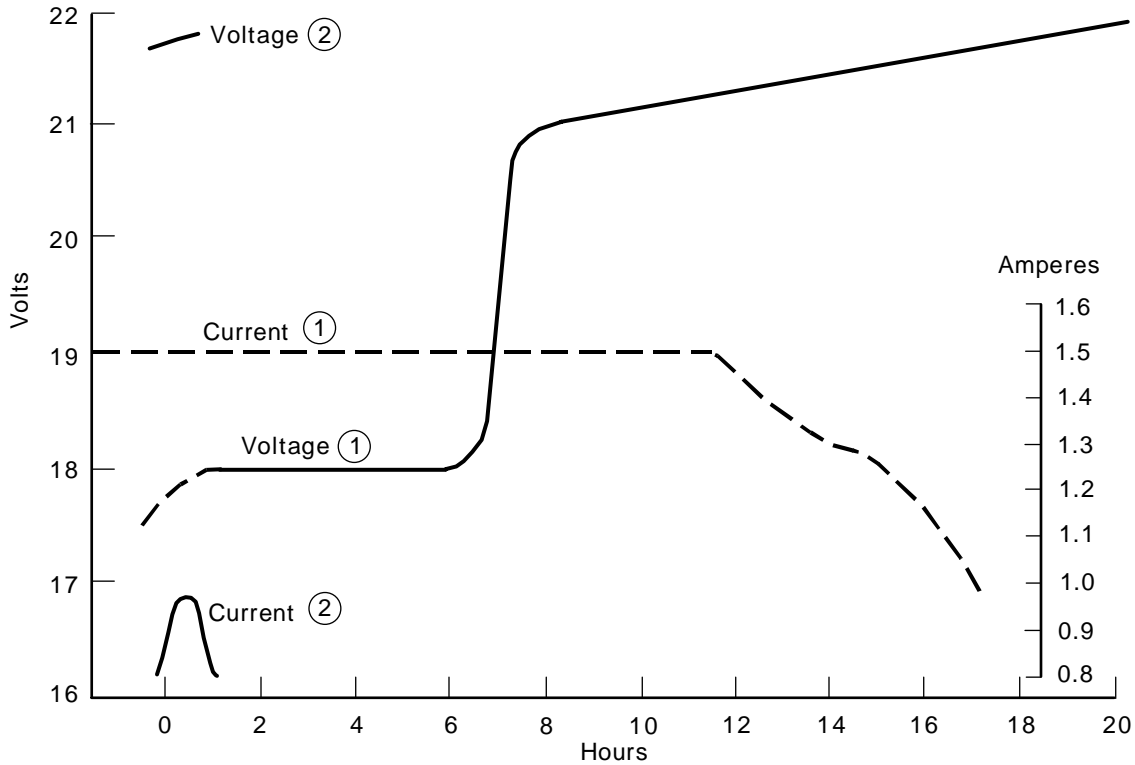
Following the charge, an open circuit battery voltage will gradually drop to a stable value of approximately 1.86 volts per cell ( $11 \times 1.86 = 20.45 \text{ V dc}$ ), indicating a fully charged battery. Figure 2.6-3 shows the characteristic charge curve for an EMU battery. The battery voltage increases from 17.5 V dc to approximately 21.2 V dc over a short period of time. However, the time required to charge a completely depleted battery can take as long as 20 hr. Figure 2.6-4 graphically shows the recharge characteristics both for a fully depleted battery and for the topoff of an unused battery.

A good rule of thumb to determine battery recharge time is to multiply the battery use time (TIME EV) by a factor of 2.25 (3.5 amps/1.55 amps). For a more accurate estimate of recharge time, determine the actual amps drawn during the EVA and divide that number by 1.55.

The second on-orbit recharge (service cycle) of a battery is characterized by what is referred to as the “sophomore slump.” The battery does not recharge to the full potential. For this reason, it is important to track the recharge history on a particular battery. On the third recharge, the battery will increase in amp-hr as compared to the previous recharge.



**Figure 2.6-3. Battery charge characteristics**



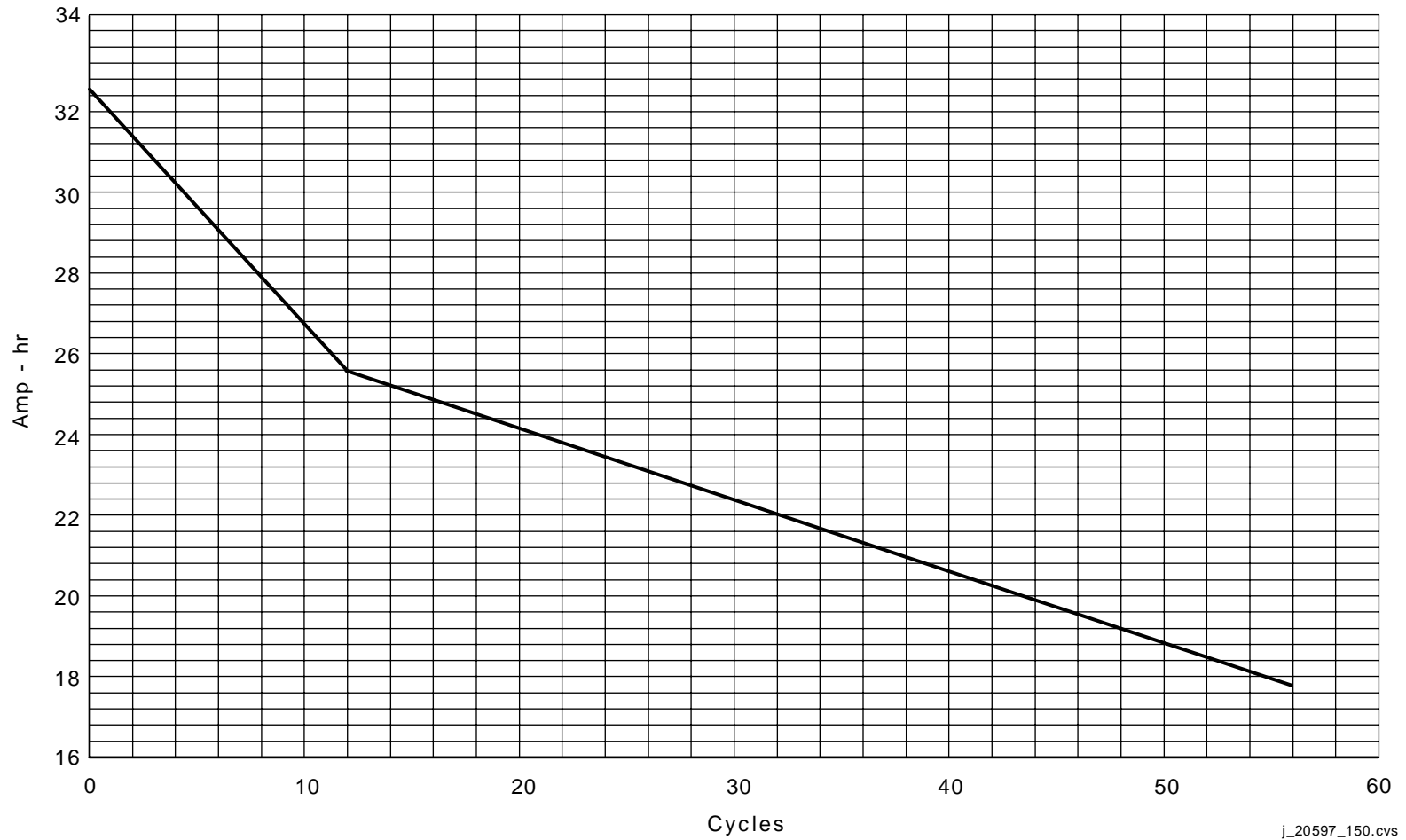
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<sup>1</sup>Recharge characteristics for a fully depleted battery.

<sup>2</sup>Battery topoff for an unused battery.

**Figure 2.6-4. Battery recharge characteristics**

The available power of the EMU battery decreases with each charge/discharge cycle. This decrease is due to changes in the crystal structure of the electrodes (initially the silver and then the zinc) in each battery cell. Figure 2.6-5 depicts the typical performance from a battery starting out at about 32.5 amp-hr capacity. This chart is an example of how cycles influence the remaining battery capacity. For example, at six cycles, the capacity has decreased to 29 amp-hr, which equates to an approximate 0.5 amp-hr decrease per cycle. In general, the battery capacity degrades 1.875 percent after each recharge, which is approximately 0.5 amp-hr. To account for this degradation, 0.5 amp-hr should be subtracted from the actual battery capacity. The sophomore slump poses problems with calculating actual battery power left on the ground.



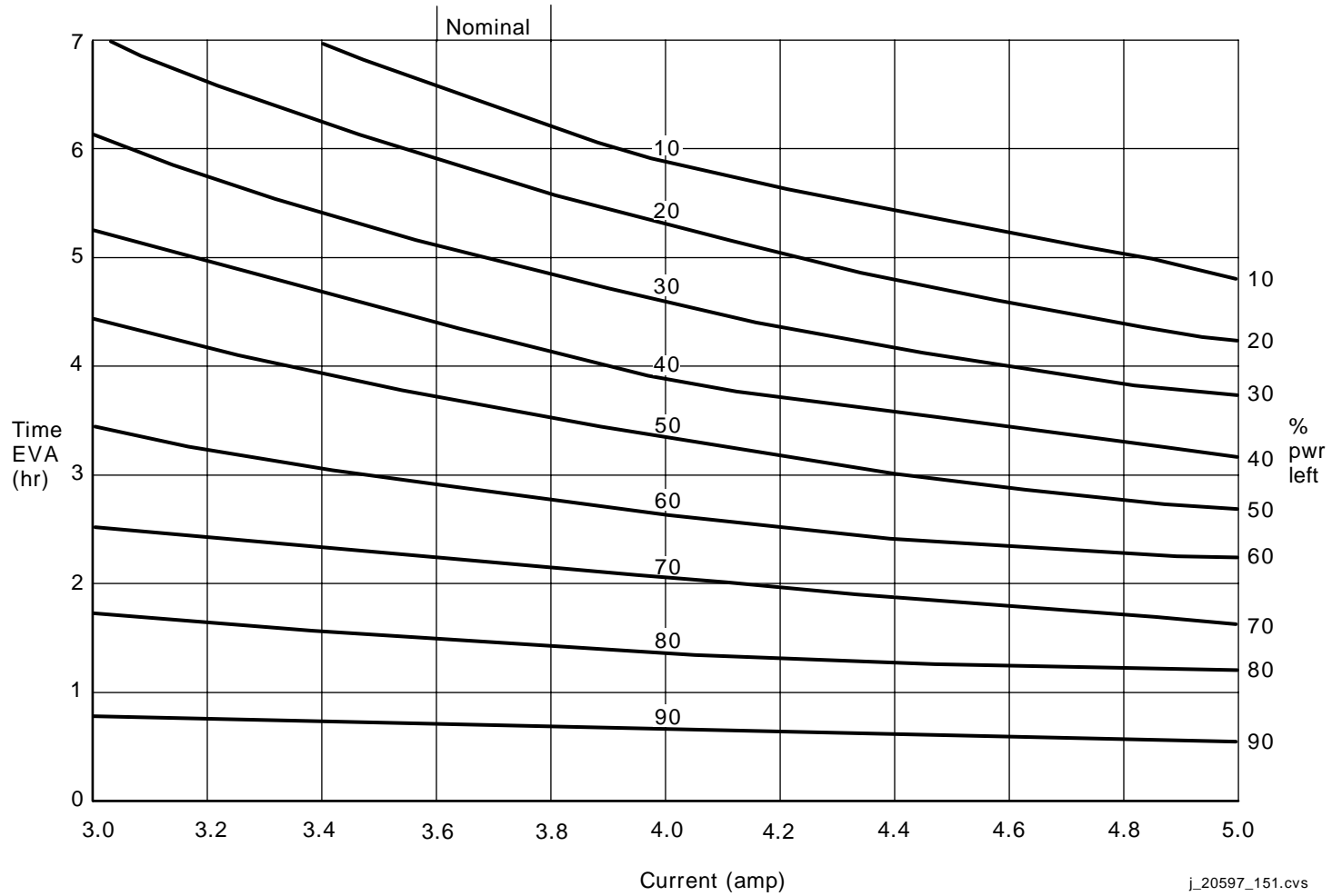
**Figure 2.6-5. Amp-hr versus cycle number**

Battery charge/discharge curves are included in the Boeing Flight Data Book for each battery. Typically, discharge curves show that the batteries start at approximately 19-20 volts, drop off quickly to approximately 16.8 - 17 volts and stabilize for a few hours, and then drop off again. The curves do not show battery discharge characteristics beyond 16 volts, because at 16 volts a battery is considered used. However, once the voltage has decayed to about 16 volts, a continuous dropoff below 16 volts is rapid; i.e., a matter of minutes. When the battery voltage drops below 15.7 volts, the CWS will issue a "BATT VDC LOW" message. The CWS limit was set at 15.7 volts to take into account line voltage loss; therefore, a battery at 16.0 volts may read 15.7 volts at the voltage sensor. There are many indications of low battery voltage: the communications start to get scratchy, the fan degrades, and the solenoid valves and DCM electronics lose function. There will be a total loss of comm at 15 to 15.5 volts. Below 14.7 volts, the fan will degrade. At around 13 volts, the solenoid valves are no longer operational. The specification for a loss of DCM electronics is at 13.5 volts; however, data has shown that the DCM electronics did not drop out until 11 volts.

Battery performance can be checked by referring to the TIME EV and % PWR parameters tabulated in the status list and Figure 2.6-6. To use this graph, locate the TIME EV on the left scale and move horizontally across graph to intersect the appropriate % PWR curve. Then move vertically down to the bottom scale to determine the EMU current draw. Refer to Section 2.1 for battery consumable calculations.

#### MIDDECK BATTERY CHARGER

A discharged EMU battery may also be charged on orbit using the middeck battery charger (MBC), if it is manifested. The MBC is used on flights where consecutive (back-to-back) EVAs will preclude the use of the ALPS. The MBC is plugged into an assigned middeck 28 V dc power supply and the EMU battery is attached to one of two output leads. When the power supply is turned on, the MBC goes through a startup sequence that lasts 5 seconds and is indicated by both red "charging" LED and green "ready" LED being illuminated. After the startup sequence, the red LED indicates to the crew that the charging is proceeding nominally at 1.55 amps. The green LED indicates that the battery has reached 21.8 V dc and the MBC has automatically terminated the charging process.



**Figure 2.6-6. Battery performance**

There is no telemetry to MCC as to the status of EMU battery charging using the MBC. The crew is able to detect an anomaly with battery charging if neither the red nor green LEDs are illuminated when a battery is connected and power is supplied. The charger detects the following failures:

- Overvoltage (input or output)
- Overcurrent (output)
- Open circuit (no battery connected) at power on reset
- Overtime for charge (charge terminated after 24 hr caused by a failed EMU battery cell)

The crewmember, however, does not have insight into which failure has occurred. EMU battery charging using the MBC follows the same characteristics shown in Figure 2.6-3 and Figure 2.6-4, except that it shuts down at the end of charging rather than providing a continuous trickle charge.

## REFERENCES

SV792600/2 S/AD Battery (CEI no. 490)

Vicki Margiott, Hamilton Standard Windsor Locks

EMU Requirements Evolution

EMUM-1051

EMUM-0028

EMUM-1213

## 2.7 EMU FEEDWATER AND COOLING

### PURPOSE

This section describes the feedwater and cooling systems of the EMU, including feedwater usage and the operational characteristics of the sublimator and the LCVG bypass.

### DESCRIPTION

The EMU feedwater system contains three water tanks, two primary and one reserve. The three tanks hold 9.1 lb of water and can be recharged from the orbiter supply water system. The primary function of the feedwater system is to deliver water to the sublimator for EMU heat load rejection. It also provides makeup feedwater for cooling loop operation.

The amount of feedwater used during an EVA is nearly impossible to calculate. It is based on makeup water to the LCVG and heat load on the sublimator. Many factors affect the heat load on the sublimator, including environmental conditions such as orbiter attitude, altitude, and elevation as well as crewmember workload, personal thermal comfort, temperature control valve (TCV) settings, and EMU electronics. Most of these factors change constantly during an EVA.

For consumables calculation, a conservative feedwater usage of 0.8 lb of water per hour may be used. As a historical point of reference, STS-61 flew at an altitude of 320 n. mi., an elevation of 28.5°, and the payload bay pointed towards the Earth. The average feedwater used per crewmember per EVA was 0.72 lb per hr. Refer to Section 2.1 for further information regarding water usage.

### SUBLIMATOR HEAT LOAD

Total heat load on the sublimator is a function of the sublimator UA (overall heat transfer or conductance) and the position of the DCM TCV that allows water from the LCVG cooling loop to flow through the sublimator. UA is the thermal performance of the heat exchanger (sublimator). The units are Btu per hour per square foot of surface per degree Fahrenheit. The UA requirement is 120. Problems associated with contamination led to the introduction of the supplemental sublimator. The supplemental sublimator adds surface area to the sublimator; this addition increases the performance to 150 Btu/hr/ft<sup>2</sup>/°F, which surpasses the design specification. The increase in UA allows for increased cooling capacity in hot environments. Because of the incorporation of Flourel bladders in the water tanks and ethyl vinyl acetate tubing on the LCVG, contamination is no longer a problem. Sublimator UA is calculated by the following equation:

$$UA = -W_x \ln \left( \frac{1 - \Delta T_{sub}}{T_{in} - 32} \right) \left( 1 + \left[ 0.9x \frac{Q_{vent}}{Q_{water}} \right] \right)$$

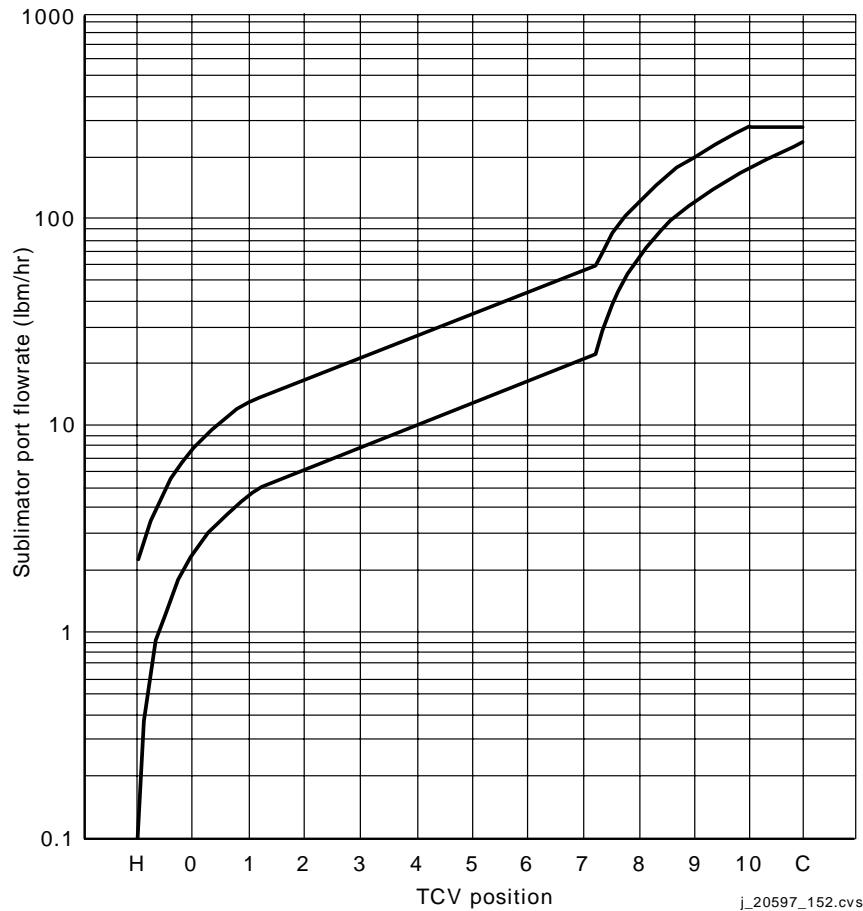


Where:

- W = mass flowrate of LCVG water passing through the sublimator
- $Q_{\text{water}} = mC_p\Delta T$  (heat load on sublimator in maximum cold)
- $r = m(T_{\text{pump in}} - T_{\text{sub out}})$
- $Q_{\text{vent}} = Q_{\text{met}}/3 = (P*587)/3$
- P = primary O<sub>2</sub> usage (psi/min)

The EMU flight controller has no way of obtaining the numbers for the temperature of the water entering the pump ( $Q_{\text{water}}$ ) or the delta temperature ( $\Delta T$ ) across the sublimator; therefore, there is no way of calculating the UA of the sublimator real time.

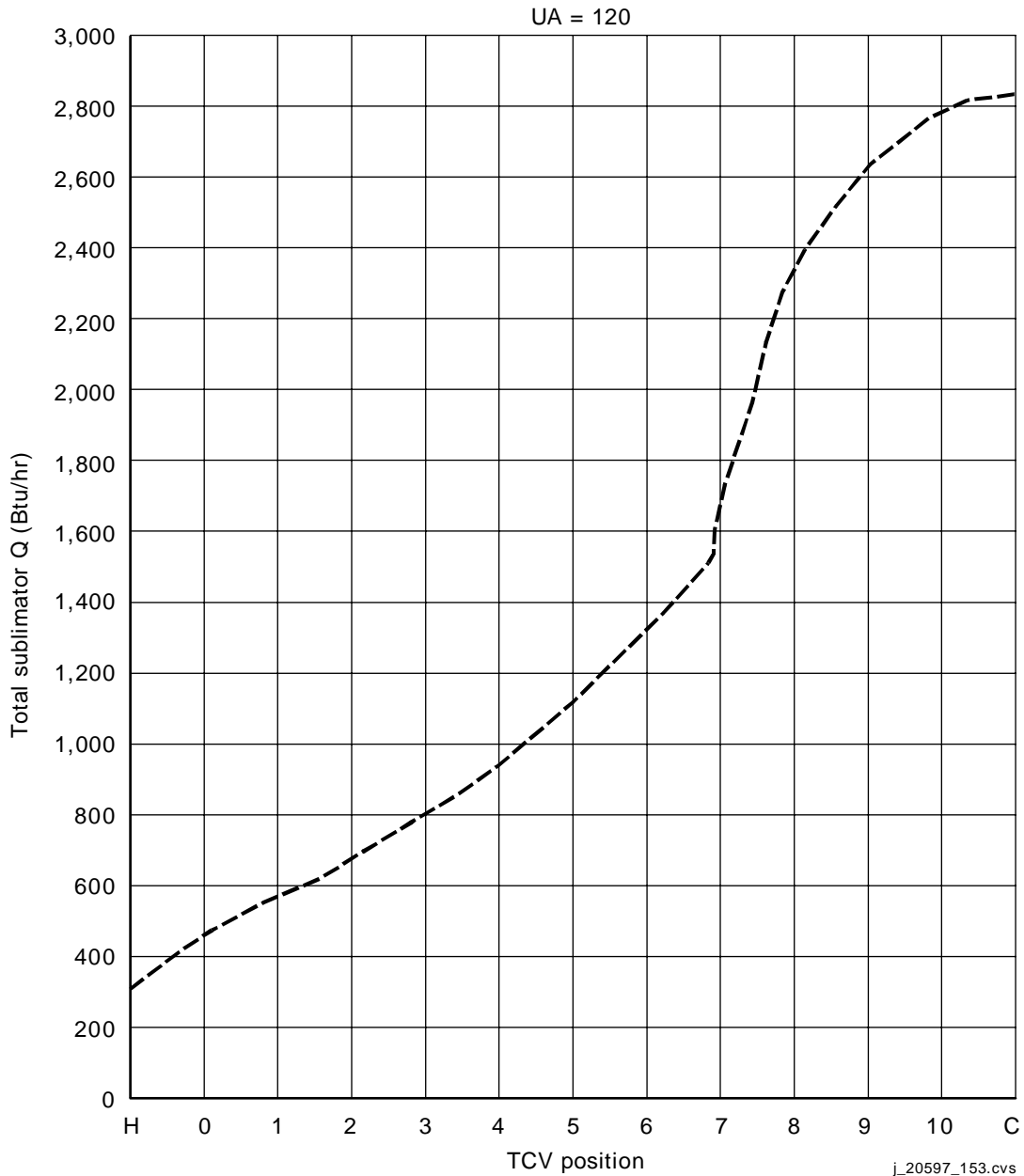
However, we can determine the amount of LCVG water flowing through the sublimator if we know the TCV position. Figure 2.7-1 plots data showing the mass flowrate of LCVG water through the sublimator as a function of TCV position. This figure demonstrates the flowrates for the original TCV (not LCVG bypass). The two curves represent the minimum and maximum range of values for flowrate versus TCV position.



**Figure 2.7-1. Mass flowrate for original TCV**

TCV range from 1 to 7 appears to be linear, whereas the range from 7 to C appears to be exponential. Therefore, the TCV is more sensitive in the range from 1 to 7.

The current EMU sublimators have a target UA of 120 Btu/hr/ft<sup>2</sup>/°F; however, this number will fluctuate from sublimator to sublimator. Figure 2.7-2 depicts the sublimator heat load as a function of TCV position at the target UA.



**Figure 2.7-2. Total sublimator heat load versus TCV position**

Figure 2.7-3 is a complementary family of plots that uses the mass flowrate of water through the sublimator as a parameter in the place of TCV position. Sublimator heat load can be determined from this graph for any given flowrate. For example, at a flowrate of 220 lb/hr through the sublimator, the heat load is 2750 Btu/hr for a UA of 120. For a UA of 80, at the same flowrate, the heat load is only 2350 Btu/hr. Therefore, the overall heat transfer capability is lower at lower UAs.

The CWS issues a "SUBLM P X.X, SET H2O OFF" message when the sublimator pressure reads <1.5 psi or >5.3 psi. Conditions that can cause these pressure extremes include feedwater pressure regulator failure (shift low, high, open, closed), blockage in the line, and high heat load.

The primary failure mode of the sublimator is referred to as sublimator breakthrough. Sublimator breakthrough is defined as the uncontrolled water flow through the porous plate. It is caused by a blockage in the steam flowpath, an increase in sublimator pressure, or high heat flux. Sublimator breakthrough may be recoverable by turning off the water, placing the TCV in the maximum hot position to reform the ice pack, and turning the water back on.

#### LCVG BYPASS

The LCVG bypass is installed to alleviate crew thermal comfort problems. The PLSS becomes coldsoaked during low metabolic rate periods. The previous PLSS design exposed crewmembers to the chilled water flowing through the coldsoaked PLSS during these periods. The cold environment associated with certain locations and attitudes also caused crewmembers to experience thermal problems. The LCVG bypass thermally isolates the cold PLSS from the LCVG and, therefore, isolates the crewmember.

The bypass consists of two modifications to the EMU system, a modified TCV that shuts off the flow of water to the LCVG and a plate containing a bypass line between the SCU-to-sublimator inlet line and the LCVG-to-pump line that is installed between the HUT and the PLSS at the fluid interface plate. The bypass allows complete blockage of the flow to the sublimator and the LCVG, causing the water in these lines to become stagnant and the only flow in the system to be between the pump and the DCM. The bypass line allows flow for cooling the fan/pump/separator and the DCM electronics and contains an orifice that limits the flow through the bypass line to 15 lb/hr. A filter is installed upstream to prevent blockage and contamination of the orifice. The EMU front-to-back dimension is increased by 0.3 inches.

The flowrate in bypass mode, TCV positions H through 3, is 15 lb/hr. The flowrate with the bypass for TCV positions 3 through C is 225 lb/hr; however, the flowrate developed at the outlet of the pump is 240 lb/hr.

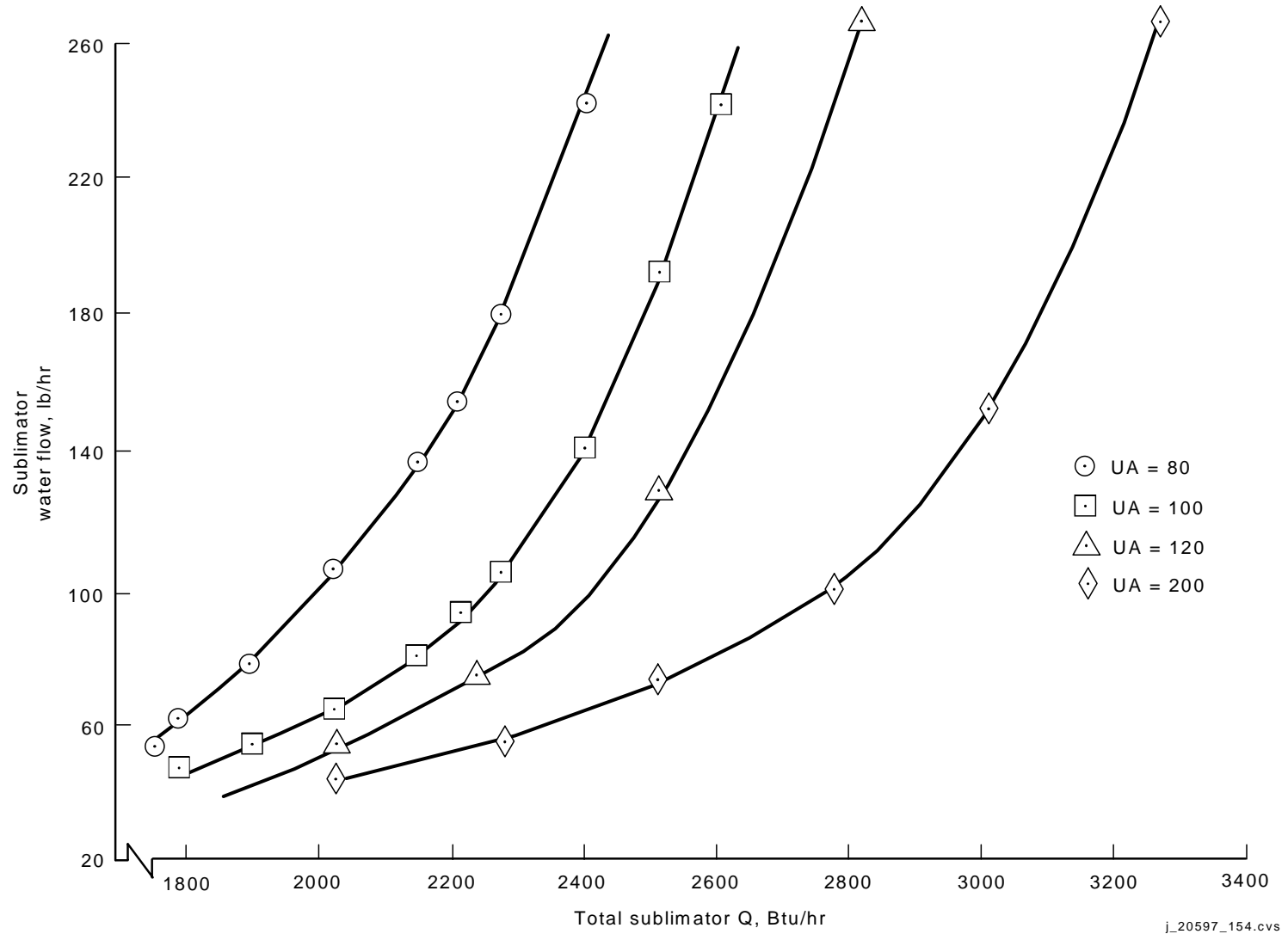
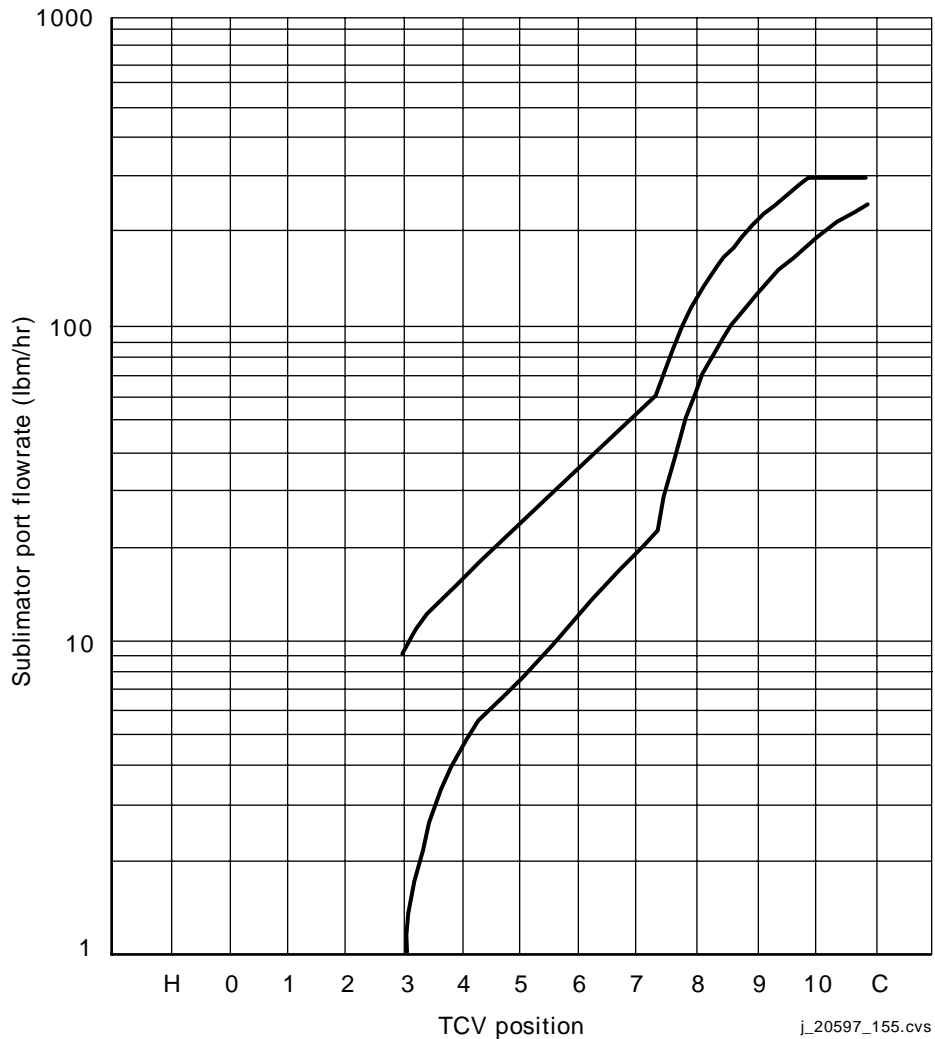


Figure 2.7-3. Total sublimator heat load

Figure 2.7-4 plots data showing the mass flowrate of LCVG water through the sublimator as a function of TCV position for the modified TCV that is used with the LCVG bypass. The two curves represent the minimum and maximum range of values for flowrate versus TCV position. Note that there is no flow through the sublimator until the TCV is in position 3, illustrating the bypass characteristic.



**Figure 2.7-4. Mass flowrate for LCVG bypass**

## 2.8 FAN DATA

### PURPOSE

This section provides information on the performance of the EMU fan/separator/pump assembly (item 123).

### DESCRIPTION

The centrifugal fan (item 123A) is driven by a motor that circulates the O<sub>2</sub> within the EMU. The O<sub>2</sub> is supplied by the oxygen systems (primary, secondary) and scrubbed, using the CCC (item 480), which removes the crewmember's exhaled carbon dioxide (CO<sub>2</sub>). The fan, running at a nominal speed of 18-20k rpm during EVA, delivers a minimum of 6.0 acfm (actual cubic feet per minute) ventilation flow to the helmet inlet to ensure adequate CO<sub>2</sub> washout for the crewmember. As a flight controller, the insight into the fan operation includes the fan rpm's, SCU/battery current, and SCU/battery voltage. The fan rpm can also be used to determine the vent flowrate and the status of the vent flow sensor/check valve (item 121).

### NOMINAL OPERATING PARAMETERS

During suit operations, the fan functions in two distinct modes: 1) non-speed control during IV operations when absolute suit pressures are high and 2) speed control during EVA operations when the absolute suit pressure is relatively low or whenever the vent loop is blocked (SOP checkout).

The only insight the flight controller has into proper fan operation is fan rpm and, to a lesser extent, the volts and amperage values supplied by the EMU battery or the orbiter via the SCU. The amperage will vary, depending on the absolute air pressure at the fan inlet. If the EMU is operating at low absolute pressures, the speed control function will initiate. Speed control lowers the amperage drawn by the suit by pulsing the current to maintain nominal rpm's of 18-20k. At low absolute pressures, the fan does not have to work as hard to achieve nominal rpm's because of the lower density of the O<sub>2</sub>. Table 2.8-1 lists expected EMU power data with the fan operating under a variety of pressure profiles. The EMU power data with the fan not operating is shown in Table 2.8-2. These tables assume that power is provided to the EVC and the DCM system electronics.

During SOP checkout, the fan runs while the vent flow duct (located at the neck ring) is blocked by the SCOF to verify the suit pressure supplied by the SOP second-stage pressure regulator. In this condition, the airflow circulation is deadheaded, which forces the fan into speed control, even at high absolute pressures (15.8 psia). The power data for the SOP checkout condition is displayed in Table 2.8-3 with power supplied to the EVC and the DCM system electronics.

**Table 2.8-1 Nominal EMU power data with FAN - ON**

Power source	O <sub>2</sub> actuator position	Ambient pressure (psi)	Absolute suit pressure (psi)	EMU amps	EMU volts	Fan rpm (k)
Batt	PRESS/EVA	14.7	19.0	2.4 - 5.0	16.5 - 21	16 - 20
SCU	PRESS/EVA	14.7	19.0	1.5 - 5.0	18.5 ± 4	16 - 20
Batt	IV	14.7	15.6	2.4 - 4.0	16.5 - 21	19 - 20
SCU	IV	14.7	15.6	1.5 - 5.0	18.5 ± 4	17 - 20
Batt	OFF	14.7	14.7	2.4 - 4.0	16.5 - 21	19 - 20
SCU	OFF	14.7	14.7	1.5 - 5.0	18.5 ± 4	17 - 20
Batt	PRESS/EVA	10.2	14.5	2.3 - 3.9	16.5 - 21	19 - 20
SCU	PRESS/EVA	10.2	14.5	1.5 - 4.7	18.5 ± 4	17 - 20
Batt	IV	10.2	11.1	2.3 - 3.9	16.5 - 21	19 - 20
SCU	IV	10.2	11.1	1.5 - 4.7	18.5 ± 4	17 - 20
Batt	OFF	10.2	10.2	2.3 - 3.9	16.5 - 21	19 - 20
SCU	OFF	10.2	10.2	1.5 - 4.7	18.5 ± 4	17 - 20
Batt	PRESS/EVA	0.0	4.3	3.5 ± 0.5	16.5 - 21	19.3 ± 0.5
SCU	PRESS/EVA	0.0	4.3	3.5 ± 0.5	18.5 ± 4	17 - 20

**Table 2.8-2. Nominal EMU power data with FAN - OFF**

Power source	O <sub>2</sub> actuator position	Ambient pressure (psi)	Absolute suit pressure (psi)	EMU amps	EMU volts
Batt	IV/OFF/PRESS/EVA	14.7 to 0.0	19.0 to 4.3	0.8 - 1.3	16.5 - 21
SCU	IV/OFF/PRESS/EVA	14.7 to 0.0	19.0 to 4.3	0.8 - 1.3	18 - 20

**Table 2.8-3. Nominal EMU power data with FAN - ON and vent flow blocked by SCOF**

Power source	O <sub>2</sub> actuator position	Ambient pressure (psi)	EMU amps	EMU volts	Fan rpm (k)
Batt	IV	14.7	2.6 - 3.2	17.0 - 21.0	19.0 - 19.6
SCU	IV	14.7	2.8 - 3.5	17.0 - 21.0	18.3 - 19.6
Batt	IV	10.2	2.6 - 3.2	17.0 - 21.0	19.0 - 19.6
SCU	IV	10.2	2.8 - 3.5	17.0 - 21.0	18.3 - 19.6

## FAN MODES

### Non-Speed Control

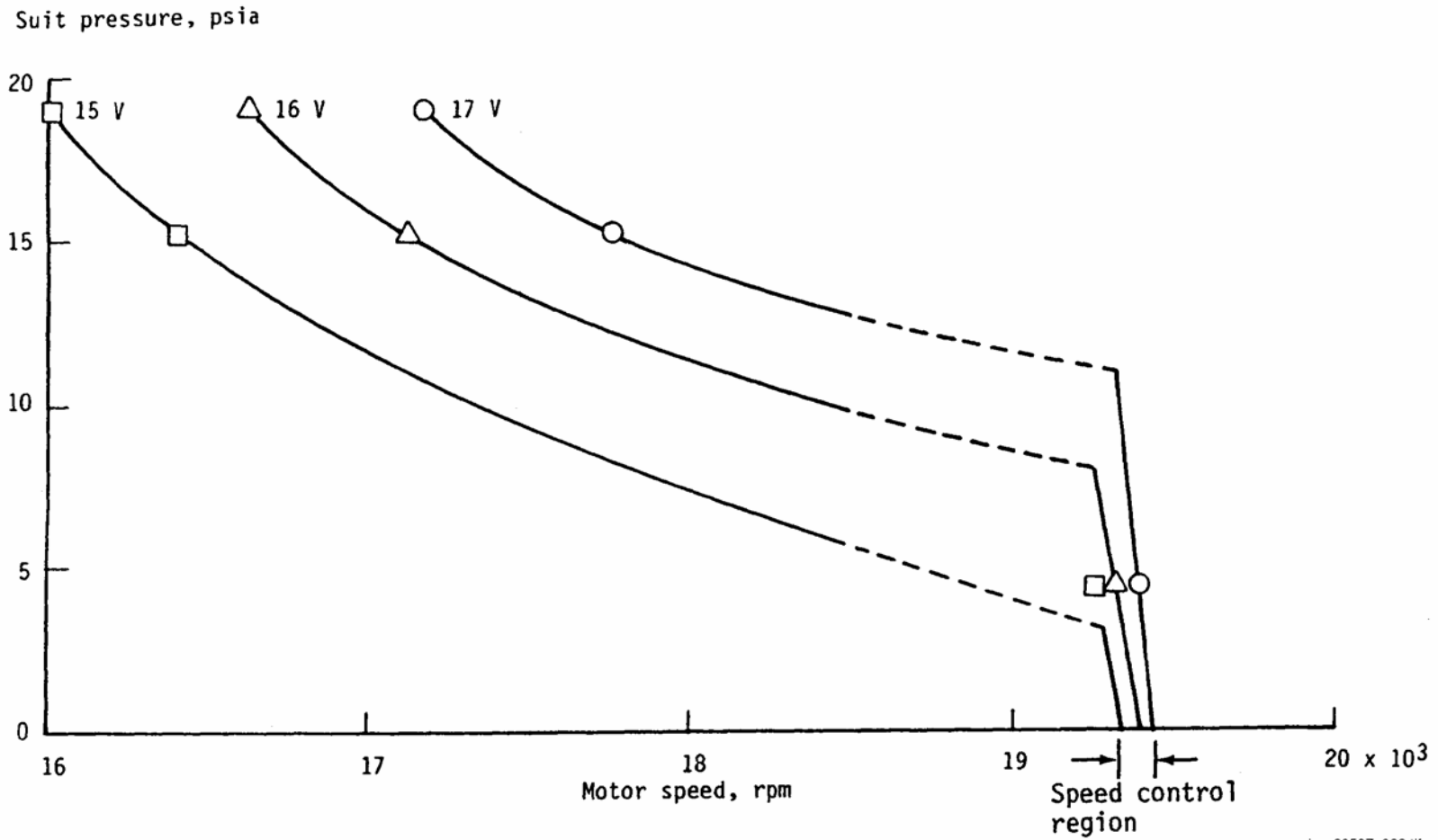
At elevated absolute suit pressures, the fan operates without speed control, depending on the voltage of the fan motor. The fan motor rpm is inversely proportional to the absolute suit pressure; i.e., as absolute suit pressure decreases, the fan rpm increases. Figure 2.8-1 graphically illustrates the fan operation as a function of absolute suit pressure and voltage of the fan motor. The fan motor voltage is approximately 1 volt less than the DCM status list value for battery volts because of line loss through the DCM switches (fan and power) and the electrical harness (Item 151). The fan current is approximately 0.9 amps less than the status list value for battery amps because of the current draw by the DCM electronics and EVC.

If the fan speed does not reach 13k rpm within 5 seconds after initial startup or the speed drops below 13k rpm during operation, the fan is automatically shut down by the motor electronics.

### Speed Control

The EMU fan speed control is enabled when the fan rpm reaches a preset level (approximately 19,300 rpm). Speed control effectively removes power from the motor windings when necessary (windings are not pulsed every revolution) and keeps the fan rpm's constant. Under lower pressures, the fan does not need as much current to keep the fan rpm's constant because of the lower resistance experienced by the fan. Motor current is minimum when speed control is working. The motor current is directly proportional to the absolute suit pressure; i.e., as absolute pressure decreases, fan rpm increases and fan current decreases. From Figure 2.8-1, it can be seen that initiation of speed control is a function of the absolute suit pressure and the voltage at the fan motor. With speed control, the fan speed is maintained at approximately  $19.5k \pm 1k$  rpm by the fan electronics.





jsc\_20597\_082.tif

Figure 2.8-1. Motor speed versus suit pressure as a function of voltage

Figure 2.8-2 is a graph showing the relationship between fan rpm, voltage at the fan motor, fan current, and motor torque. Although the motor torque parameter is not an extremely useful parameter in flight control, the other three parameters - fan rpm, motor voltage, and fan current - are helpful in determining the health status of the fan.

#### Example

What is the fan current if the status list reads 19k rpm and the battery volts read 17.0?

1. Assume that the voltage at the fan is 1 volt less than the DCM status list reading (line and switch loss); therefore, motor voltage is 16.0 volts.
2. Start at the left of the graph at 19k rpm, move horizontally to the intersection with the 16.0-volt battery load line (~1.6 in-oz torque). The battery load lines are decreasing diagonal lines running from left to right on the chart.
3. Move vertically down to the intersection of the fan current load line at 16.0 volts. The fan current load lines at different voltages are increasing diagonal lines running from left to right on the chart.
4. Move horizontally to the right to the fan amps scale and take a reading. Fan amps = 3.25

Therefore, the EMU current should be  $\sim 3.25 + 0.9$  amps = 4.15 amps.

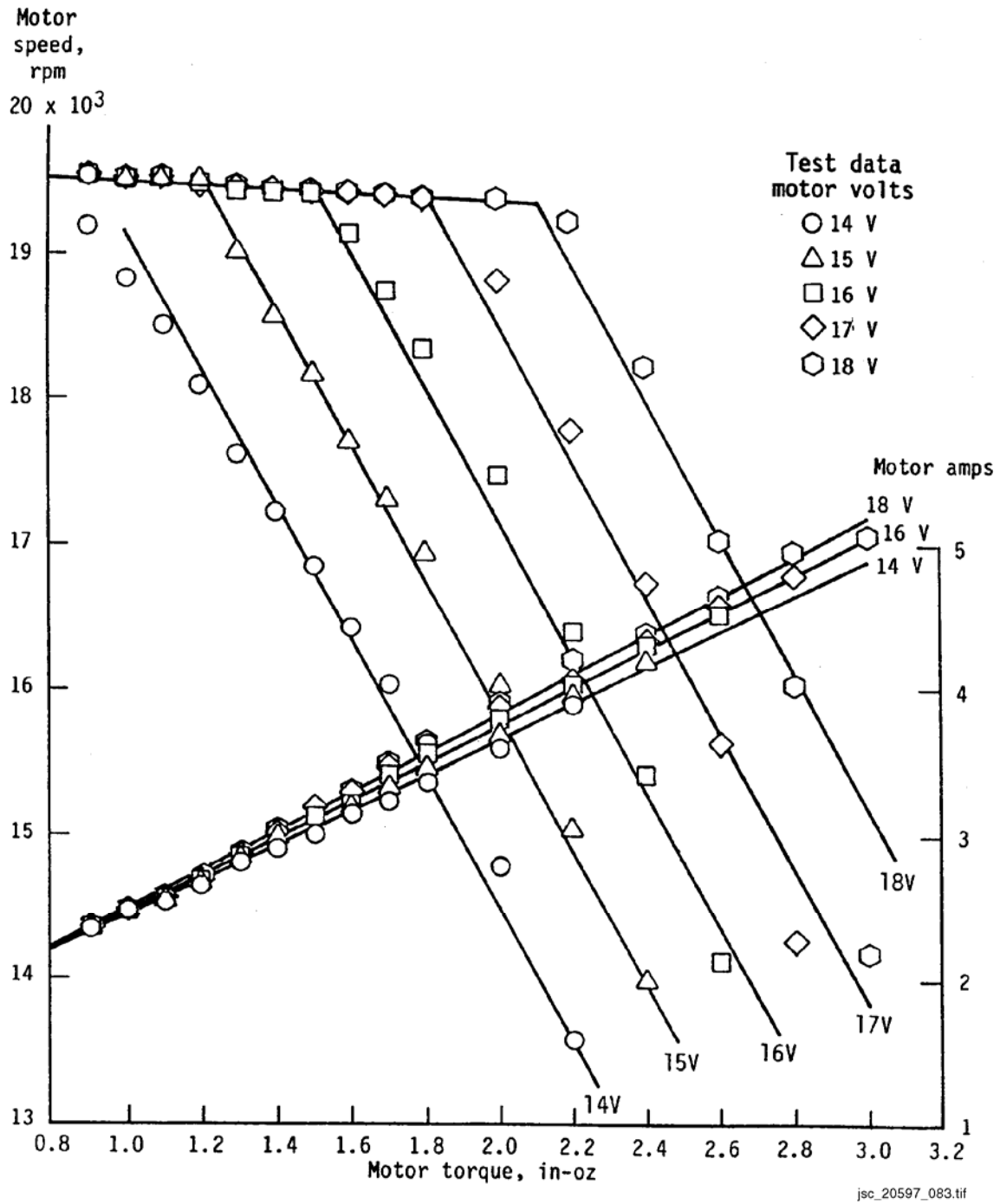
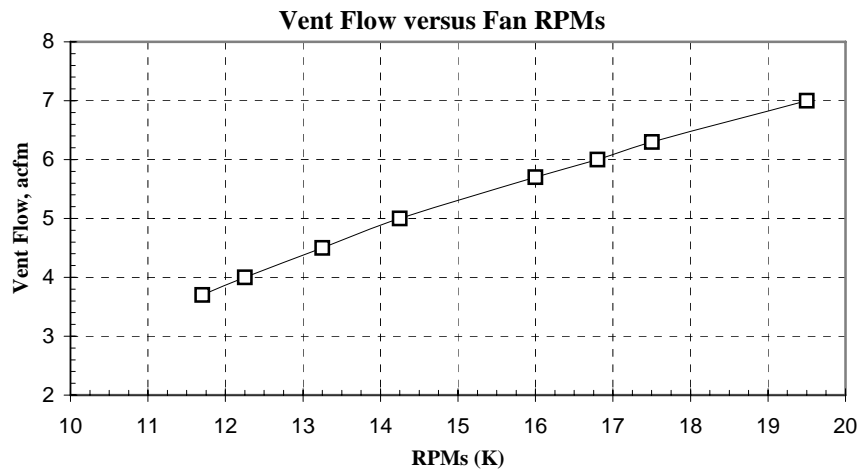


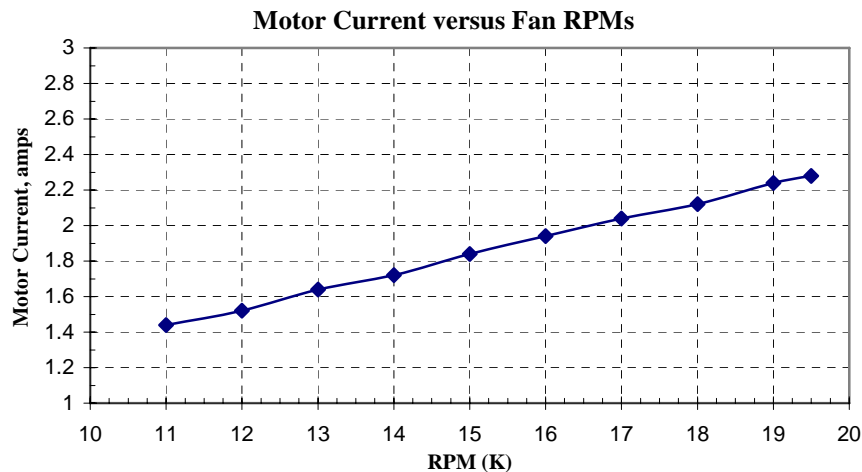
Figure 2.8-2. Fan motor performance

### Vent Flow Data

The vent flow sensor/check valve (item 121) is used to determine the health and status of the fan by measuring its output O<sub>2</sub> flow. The fan must run at 18-20k rpm to deliver a minimum of 6.0 acfm O<sub>2</sub> flow to the helmet to ensure adequate CO<sub>2</sub> washout for the crewmember. If the vent flow drops to 3.7 acfm due to degraded fan or vent flow blockage, CO<sub>2</sub> washout cannot be maintained effectively, and the partial pressure of CO<sub>2</sub> will increase in the helmet. At a vent flow of 3.7 acfm, the EMU CWS issues a NO VENT FLOW message on the DCM display. Figure 2.8-3 illustrates the characteristics between the fan speed and the vent flow at item 121, assuming the fan becomes degraded during operation. The motor current and fan speed relationship with degraded fan operation are shown in Figure 2.8-4. (The theoretical data for these figures was obtained from PLSS, item 123 - Effects of Drift of Motor Speed Control, F. Sribnik, Hamilton Standard Analysis 82-62, February 12, 1982.)



**Figure 2.8-3. Vent flow and fan rpm characteristics**



**Figure 2.8-4. Fan rpm's and motor current performance**

## 2.9 EMU CONSUMABLES MODEL

### PURPOSE

This section describes the results of a computer model designed to output EMU performance as a function of crewmember size and temperature environments.

### DESCRIPTION

Three crewmember sizes, 5 percentile female (103 lb), 50 percentile male (154 lb), and 95 percentile male (215 lb), were modeled against the general hot, neutral, and cold flight temperature environments. The temperature environments are defined as follows:

1. Hot flight environment: 100 n. mi. altitude, 78°  $\beta$  angle orbit, an 8.5-ft empty cargo bay, cargo bay to the Sun, crewmember facing cargo bay 2 ft from liner, dirty suit, dirty liner.
2. Cold flight environment: 100 n. mi. altitude, 90°  $\beta$  angle orbit, a 20.29-ft empty cargo bay, cargo bay facing away from the Sun, crewmember facing cargo bay 2 ft from liner, dirty suit, dirty liner.
3. Neutral environment: 100 n. mi. altitude, 60°  $\beta$  angle orbit, an 8.5-ft empty cargo bay, cargo bay to Earth, crewmember facing cargo bay 2 ft from liner, dirty suit, dirty liner.

The metabolic rate at which the crewmember performs an activity is defined as the activity rate. To help present the comparison of accumulated results, the computer model uses the concept of equivalent activity rate (EAR). The EAR is a technique used to normalize the 5 percentile female and the 95 percentile male to the 50 percentile male when performing an equivalent task.

The standard levels of activity for a 50 percentile male are 400, 800, 1200, 1600, and 2000 Btu/hr. For the 5 percentile female and the 95 percentile male, the corresponding metabolic rate at the standard 50 percentile male activity level is calculated by the following equation:

$$MR_S = MR_A(WT_S / WT_A)^{0.75}$$

Where:  $MR_S$  = Metabolic rate of selected subject  
 $MR_A$  = Metabolic rate of 50 percentile male for equivalent task  
 $WT_S$  = Weight of selected subject  
 $WT_A$  = Weight of 50 percentile male

For example: When a 50 percentile male uses 800 Btu/hr for an activity, a 95 percentile male would use 1027 Btu/hr for the same task. The 95 percentile male would be assigned an EAR of 800 Btu/hr.

The baseline consumable quantities used for the computer model are

1. Oxygen - 1.217 lb usable (does not include SOP oxygen)
2. Feedwater - 9.25 lb usable (includes primary and reserve tanks)
3. LiOH - 1.48 lb (started LiOH cartridge)

**Table 2.9-1. EMU consumables lifetime values**

Environment	Metabolic rate	EAR	Consumables lifetimes, hr		
			O <sub>2</sub>	Feedwater	LiOH
Body size: 5 percentile female (103 lb)					
Hot	289	400	21.73	9.20	28.94
	578	800	11.82	6.85	14.17
	868	1200	8.11	5.71	8.64
	1157	1600	6.18	4.87	5.76
	1447	2000	4.99	4.23	3.98
	2000	N/A	3.66	3.36	1.99
Neutral	289	400	21.73	25.19	32.90
	578	800	11.82	13.07	15.96
	868	1200	8.11	9.61	9.64
	1157	1600	6.18	7.60	6.36
	1447	2000	4.99	6.13	4.33
	2000	N/A	3.66	4.42	2.19
Cold	289	400	21.73	44.38	33.16
	578	800	11.82	26.27	16.30
	868	1200	8.11	14.89	9.98
	1157	1600	6.18	10.47	6.70
	1447	2000	4.99	7.98	4.67
	2000	N/A	3.66	5.07	2.37
Body size: 50 percentile male (154 lb)					
Hot	400	400	16.45	7.41	21.59
	800	800	8.76	5.86	9.95
	1200	1200	5.97	4.68	5.98
	1600	1600	4.54	3.85	3.46
	2000	2000	3.66	3.27	2.09
Neutral	400	400	16.45	18.59	22.88
	800	800	8.76	10.61	10.09
	1200	1200	5.97	7.73	6.08
	1600	1600	4.54	5.85	3.56
	2000	2000	3.66	4.55	2.11
Cold	400	400	16.45	41.63	24.17
	800	800	8.76	22.83	11.0
	1200	1200	5.97	11.53	6.15
	1600	1600	4.54	7.44	3.65
	2000	2000	3.66	5.35	2.13

**Table 2.9-1. Consumables lifetime values (concluded)**

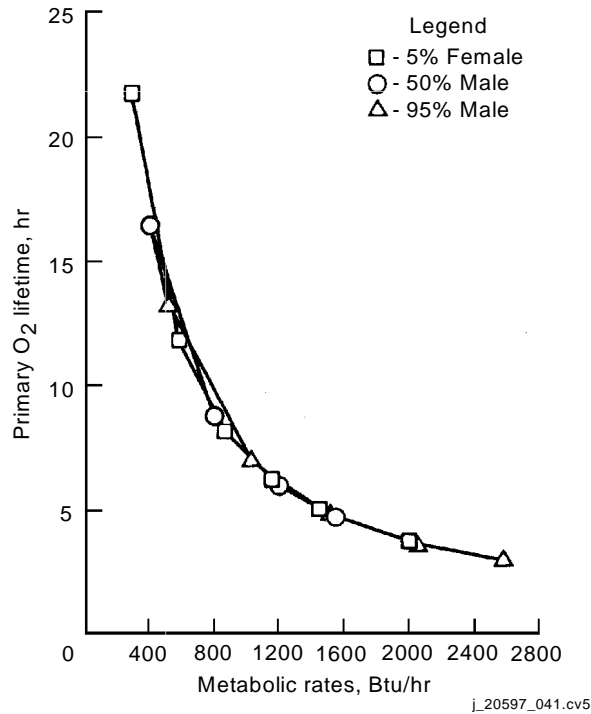
Environment	Metabolic rate	EAR	Consumables lifetimes, hr		
			O <sub>2</sub>	Feedwater	LiOH
Body size: 95 percentile male (215 lb)					
Hot	400	N/A	16.45	8.19	21.80
	514	400	13.23	7.08	17.05
	1027	800	6.95	5.12	7.43
	1541	1200	4.70	3.92	3.99
	2055	1600	3.56	3.12	2.24
	2569	2000	2.86	2.74	1.17
Neutral	400	N/A	16.45	20.30	23.28
	514	400	13.23	15.67	17.94
	1027	800	6.95	9.40	7.83
	1541	1200	4.70	6.24	4.21
	2055	1600	3.56	4.42	2.37
	2569	2000	2.86	3.42	1.24
Cold	400	N/A	16.45	43.15	24.26
	514	400	13.23	40.90	18.83
	1027	800	6.95	17.16	8.21
	1541	1200	4.70	8.28	4.42
	2055	1600	3.56	5.30	2.49
	2569	2000	2.86	3.90	1.31

**RESULTS**

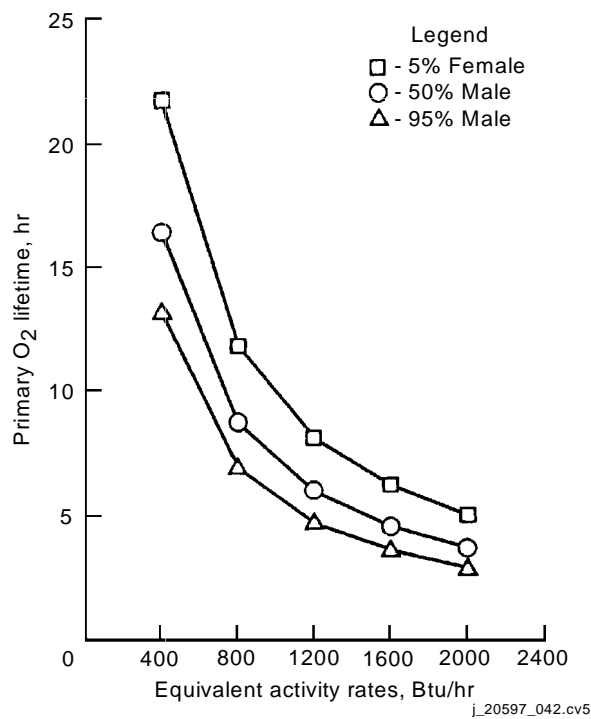
Figures 2.9-1 through 2.9-19 show the results of the consumables study. Graphs of consumables lifetimes are included for oxygen, feedwater, and LiOH. Usage lifetimes are plotted against metabolic rates or EARs for different body sizes and different temperature environments.

**OXYGEN**

The lifetime of oxygen in the EMU is solely a function of metabolic rate. Therefore, graphs for different temperature environments are not necessary. Figure 2.9-1 (a) shows that oxygen lifetime is independent of body size at a given metabolic rate. Since metabolic rates are different for the three body sizes at a given activity level, Figure 2.9-1 (b) shows three curves for oxygen lifetime vs. EAR. This figure shows, as expected, that the lifetime of oxygen decreases as body size increases at a constant activity level. The range of oxygen lifetime is 21.7 hours (5 percentile female at an EAR of 400 Btu/hr) down to 2.9 hours (95 percentile male at an EAR of 2000 Btu/hr).



(a) Metabolic rates



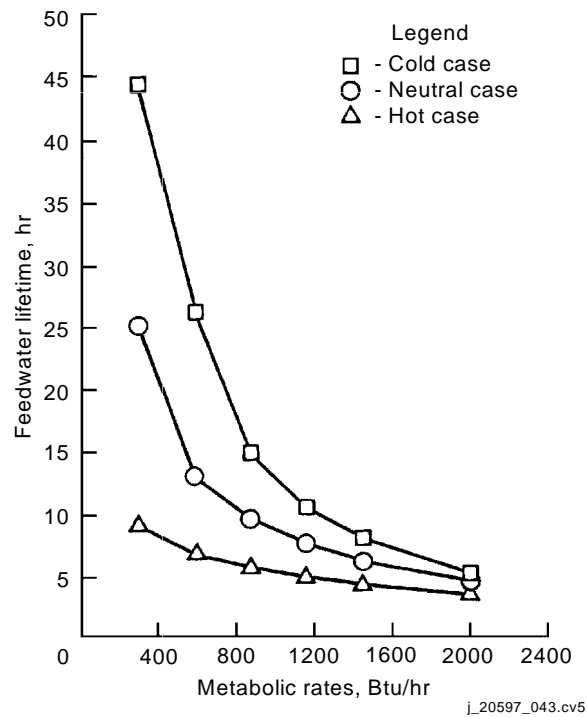
(b) EARs

Figure 2.9-1. Primary oxygen lifetime

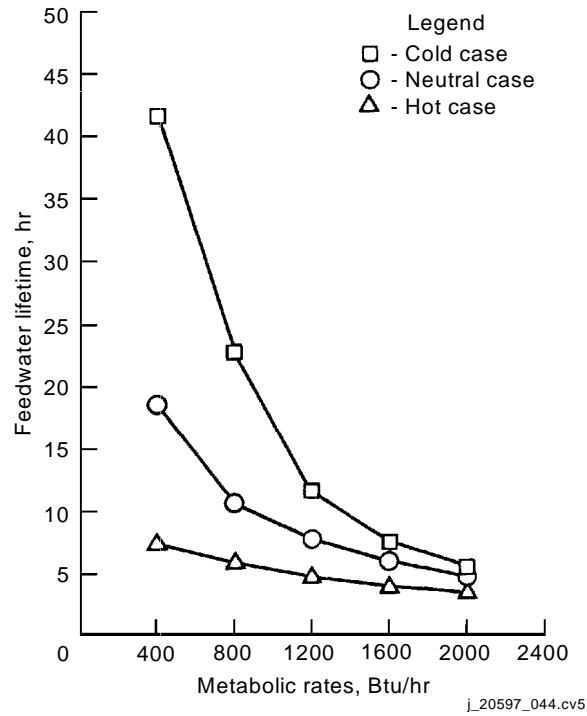


## FEEDWATER

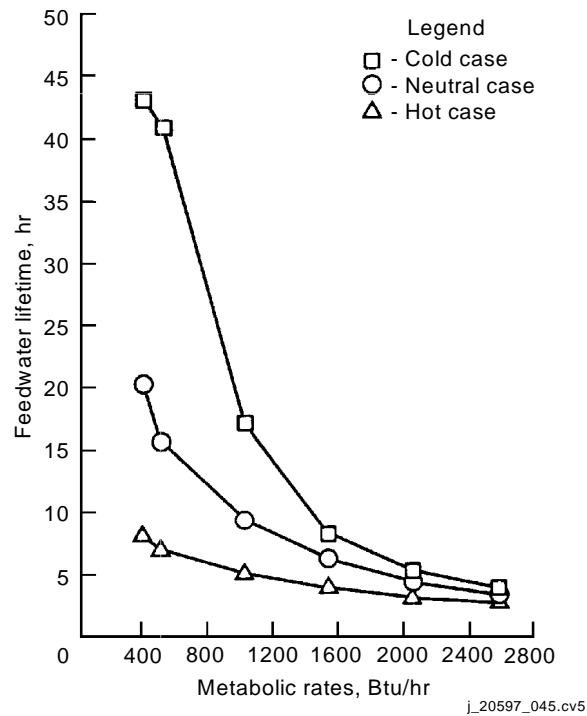
The constant body size graphs (Figures 2.9-2 through 2.9-4) show that feedwater lifetime declines as metabolic rate increases, as expected. They also show that at low metabolic rates, environmental changes have a major impact on feedwater lifetime. The heat flow into the EMU is a large portion of the total heat load of the feedwater system at low metabolic rates. As metabolic rates increase, the heat flow into the EMU remains practically constant and becomes a smaller percentage of the total heat load. The range of feedwater lifetime is 44.4 hours (5 percentile female, cold case at 289 Btu/hr) down to 3.9 hours (95 percentile male, hot case at 2569 Btu/hr = 2000 Btu/hr equivalent metabolic rate).



**Figure 2.9-2. Feedwater lifetime - 5 percentile female**

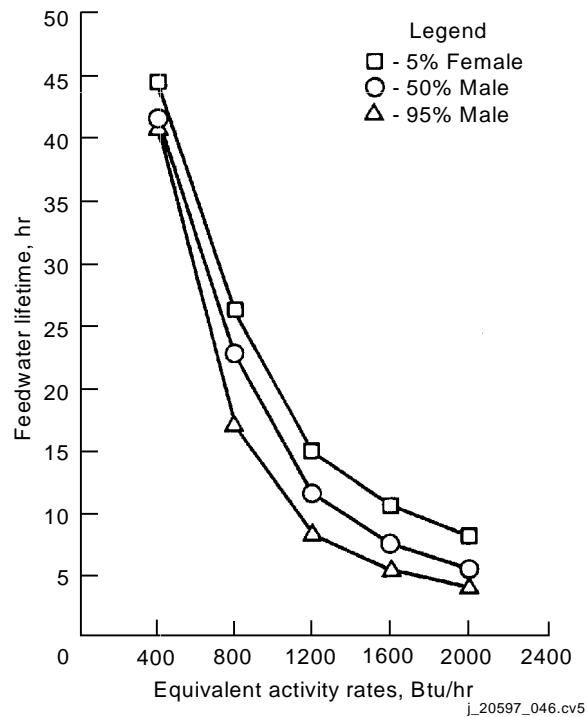


**Figure 2.9-3. Feedwater lifetime - 50 percentile male**



**Figure 2.9-4. Feedwater lifetime - 95 percentile male**

Figures 2.9-5 through 2.9-7 show feedwater lifetimes vs. EARs at constant environmental conditions. The separation of the curves is more constant in Figures 2.9-5 through 2.9-7 than in Figures 2.9-2 through 2.9-4. The graphs show that as the activity levels increase, changes in body size have a larger (percentage) effect on feedwater lifetime. Differences in heat loads due to body size changes are not constant with changes in activity level, as are the heat leaks of environmental changes.



**Figure 2.9-5. Feedwater lifetime vs. EARs - cold case**

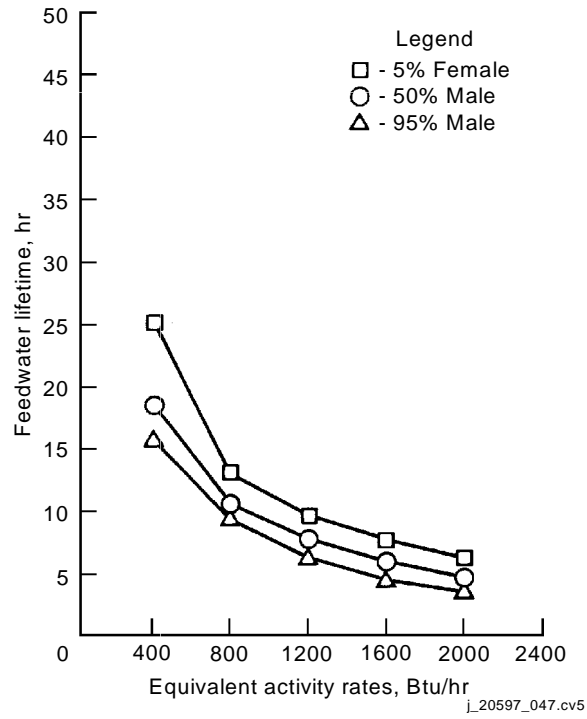


Figure 2.9-6. Feedwater lifetime vs. EARs - neutral case

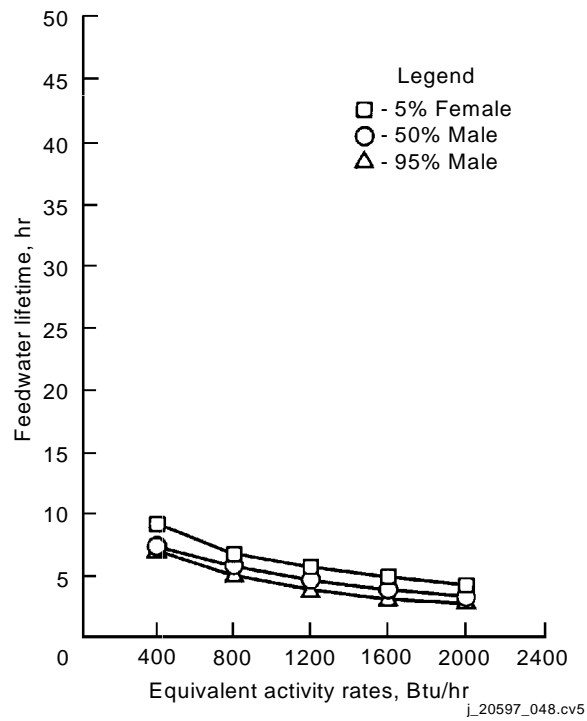
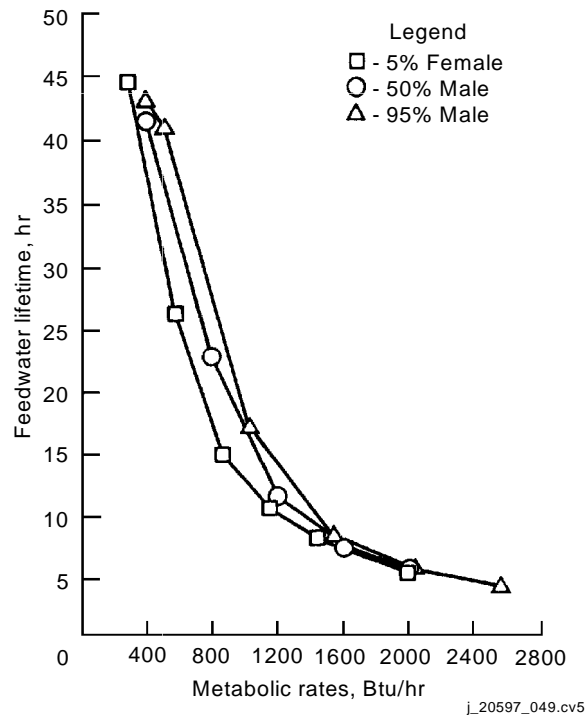


Figure 2.9-7. Feedwater lifetime vs. EARs - hot case

Figures 2.9-8 through 2.9-10 show feedwater lifetimes vs. metabolic rates in constant environmental conditions. For the cold case (Figure 2.9-8), the feedwater lifetime shows a dependency on body size. Feedwater lifetime is longer for the larger body size in Figure 2.9-8. A major factor in this dependency is the increased surface area of the larger body size. In the cold case, heat is leaking out of the EMU suit. With the larger surface area of a larger body size, more heat leaking to the environment leaves less of a heat load on the feedwater system.

For the neutral (Figure 2.9-9) and hot (Figure 2.9-10) cases, the feedwater lifetime is relatively independent of body size. In the neutral case, there is practically no heat leak from the suit to the environment. Therefore, body size changes do not affect feedwater lifetime. In the hot case analysis, it was found that increased perspiration rates in the larger body size tended to increase feedwater lifetime. This increase offsets the expected decrease in feedwater lifetime due to increased heat leakage in the larger body sizes.



**Figure 2.9-8. Feedwater lifetime vs. metabolic rates - cold case**

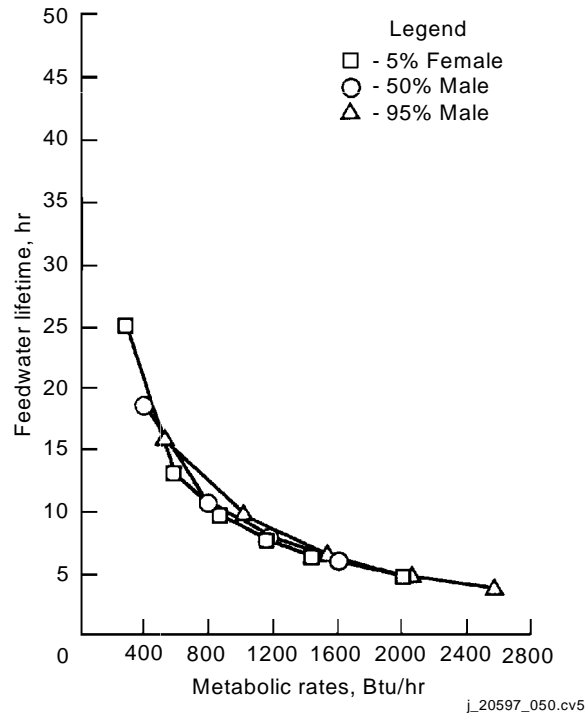


Figure 2.9-9. Feedwater lifetime vs. metabolic rates - neutral case

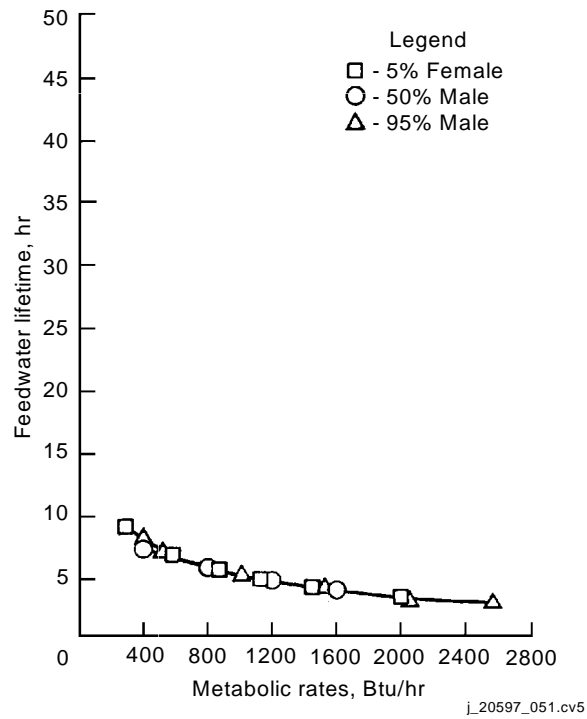


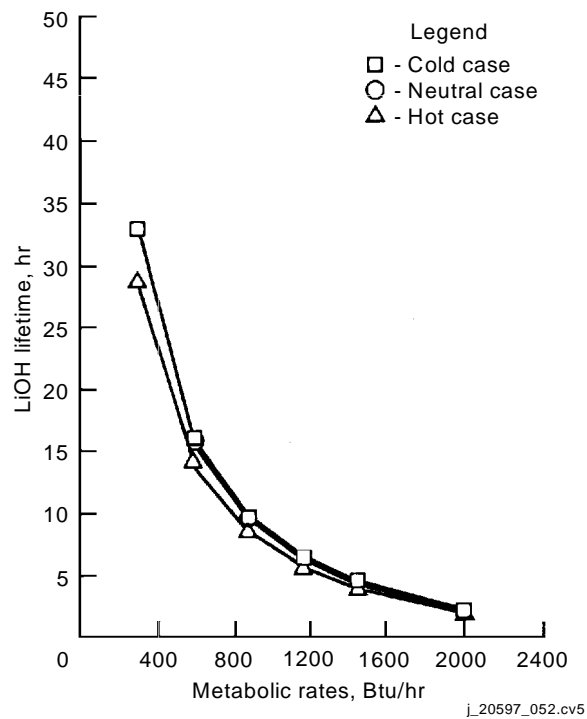
Figure 2.9-10. Feedwater lifetime vs. metabolic rates - hot case

## LiOH

Figures 2.9-11 through 2.9-19 show the results of the LiOH lifetime study. Similar to the feedwater graphs, the first three graphs (Figures 2.9-11 through 2.9-13) are constant body size graphs; the second three (Figures 2.9-14 through 2.9-16) are constant environmental condition graphs using EARs; and Figures 2.9-17 through 2.9-19 are constant environmental condition graphs using metabolic rates.

Figures 2.9-11 through 2.9-13 show that changes in environmental conditions have very little effect on LiOH lifetimes. The graphs do not show that as environmental conditions become better, the LiOH lifetimes become slightly shorter. It has been determined that humidity has a much greater effect on the LiOH reaction than do environmental conditions. The range of LiOH lifetimes is 33.2 hours (5 percentile female, cold case at 289 Btu/hr) down to 1.2 hours (95 percentile male, hot case at 2569 Btu/hr).

Figures 2.9-14 through 2.9-16 show relationships between LiOH lifetimes and EARs very similar to those of oxygen. Figures 2.9-17 through 2.9-19 show that the LiOH lifetimes are practically independent of body size for constant metabolic rates (as are oxygen lifetimes).



**Figure 2.9-11. LiOH lifetime - 5 percentile female**

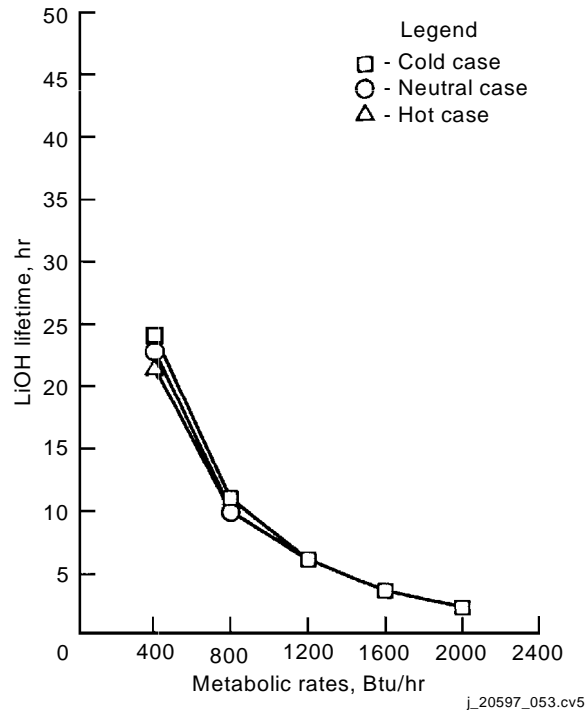


Figure 2.9-12. LiOH lifetime - 50 percentile male

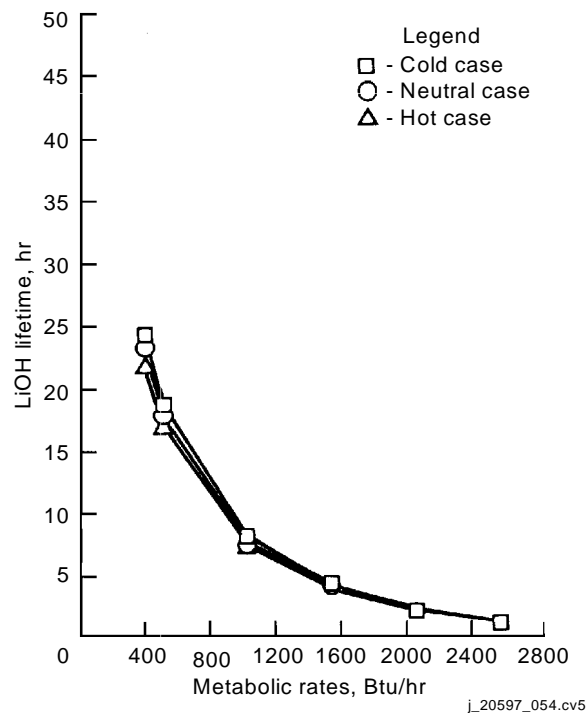


Figure 2.9-13. LiOH lifetime - 95 percentile male



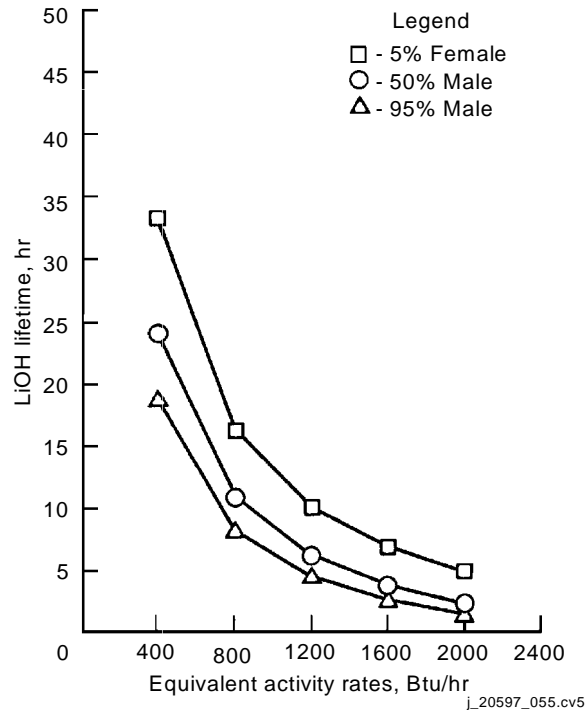


Figure 2.9-14. LiOH lifetime vs. EARs - cold case

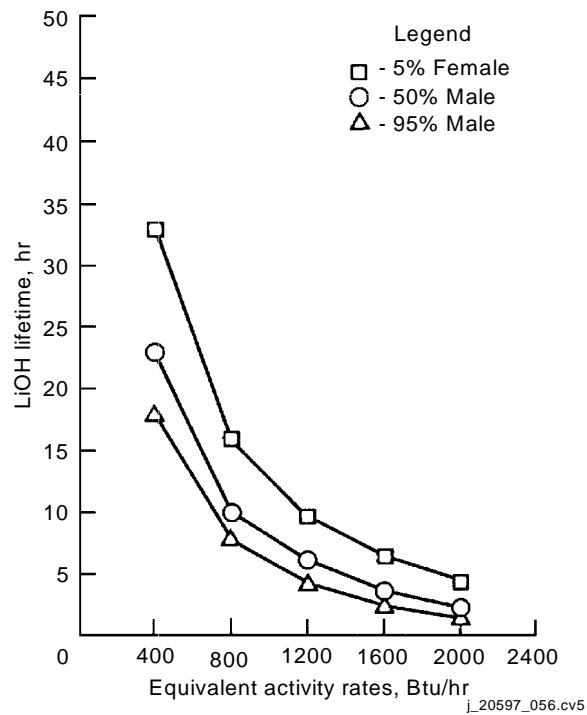


Figure 2.9-15. LiOH lifetime vs. EARs - neutral case

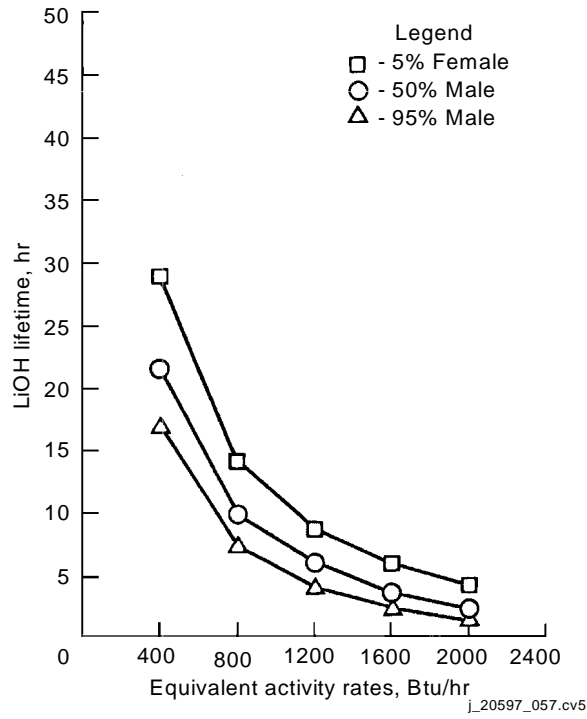


Figure 2.9-16. LiOH lifetime vs. EARs - hot case

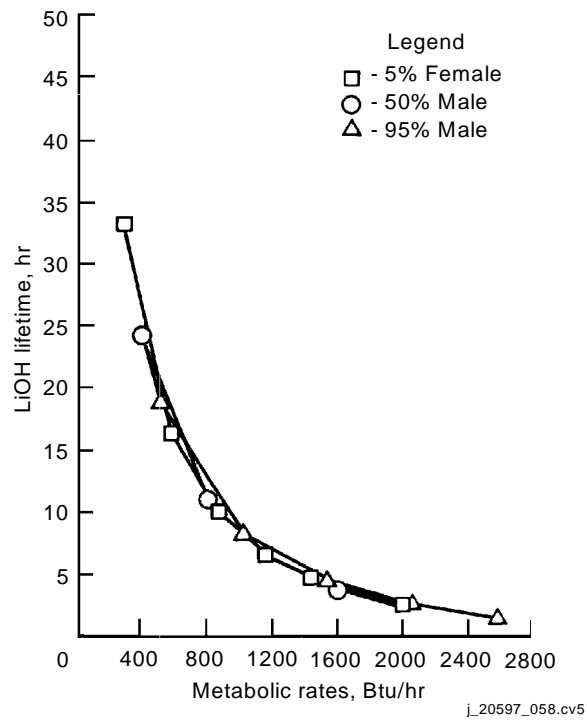


Figure 2.9-17. LiOH lifetime vs. metabolic rates - cold case

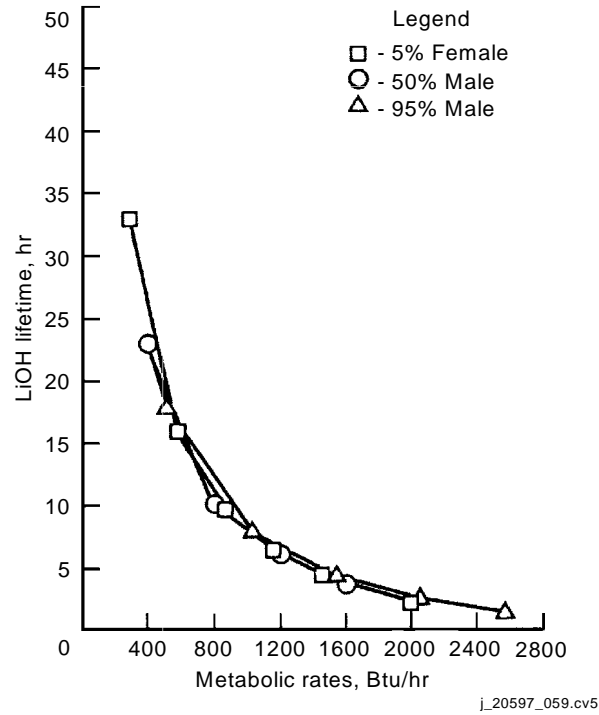


Figure 2.9-18. LiOH lifetime vs. metabolic rates - neutral case

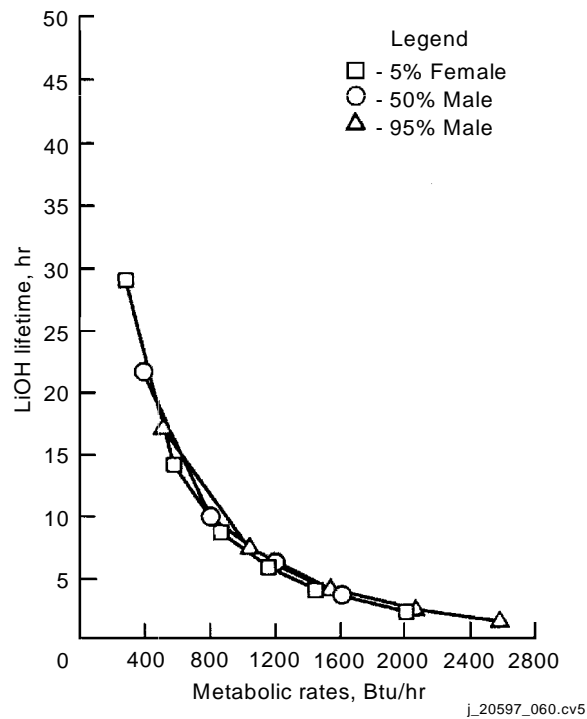


Figure 2.9-19. LiOH lifetime vs. metabolic rates - hot case

### 3.1 DECOMPRESSION SICKNESS

#### PURPOSE

This section describes the theory, symptoms, susceptibility, prevention, and treatment of decompression sickness (DCS) as it relates to manned spaceflight.

#### DESCRIPTION

Decompression sickness is caused by a reduction in atmospheric pressure. DCS results when the pressure of dissolved gases in the tissues is greater than the ambient pressure, allowing inert gases, namely nitrogen, to evolve out of solution and form bubbles in the blood and tissues. These bubbles form microbubbles, which already exist throughout the body. Microbubbles can develop only in areas with pressures much lower than their surroundings, such as turbulent blood flow at points of vessel constriction or branching and muscles where shear forces are prevalent. Other low pressure areas may occur along the surfaces of cells or blood vessels where water does not adhere.

#### THEORY

The governing equation for DCS is Boyle's law, which states that a volume of gas will increase as ambient pressure is decreased. Boyle's law is the inverse relationship between pressure and volume. The law is commonly written:

$$P_1V_1 = P_2V_2$$

The formation of gas bubbles is dependent on the amount of gas permitted to diffuse into the bloodstream. Gas tends to diffuse from areas of high partial pressures to areas of low partial pressures. Normally, inert gases diffuse from the tissues into the blood and then to the lungs, where they are exhaled. Henry's law, which governs these actions, states that the amount of gas dissolved in a liquid is proportional to the pressure exerted on the liquid (i.e., as pressure decreases, solubility decreases).

When ambient pressure is reduced, there is a period of time in which internal pressures have not equalized and are high enough to permit a greater amount of dissolved gas than usual. Supersaturation occurs when decompression is so rapid that excess internal gas is not removed and builds up beyond normal levels. A certain amount of supersaturation can be tolerated by the body before the inert gas will come out of solution and form bubbles. Once a critical supersaturation level is reached, bubbles can form and DCS may soon follow. The Haldane ratio (R) is an estimate of this critical saturation level. J. S. Haldane first described this concept in 1906, and his studies showed that DCS will not occur in humans if the ratio of initial exposure to final decompression pressure is not greater than two to one (i.e., a human is safe from DCS if he/she is not exposed to less than one-half, or 50 percent, of his/her equilibrium pressure). Because nitrogen (N<sub>2</sub>) has been found to be the primary gas involved in bubble formation, the Haldane ratio, or tissue ratio (R), is defined as the ratio of the tissue nitrogen (ppN<sub>2</sub>) prior to decompression to the final ambient pressure. N<sub>2</sub> is

present as 79 percent of our atmosphere at sea level; therefore, R can be converted from 2:1 to 1.58:1. This new ratio states that critical supersaturation will occur when the decompression pressure is 1/1.58, or 63.3 percent, of the initial ppN<sub>2</sub>. Data from chamber tests has shown that an R of 1.65 imparts a 5% risk of DCS. This is considered an acceptable risk and serves as a basis for the present prebreathe protocols.

Some tissues release gases more rapidly than others. Bubbles will first evolve out of the blood, where they are either carried to the lungs for release or become obstructions to flow. The brain and muscle tissue are known as fast tissues and are next to allow gases to diffuse out. The bones and joints are slow tissues because they retain gases longer and may cause recurring DCS effects.

Bubble formation can obstruct blood vessels and distort and rupture tissues. A number of reactions occur at the interface of the bubbles with the blood. Activity at this contact surface indirectly causes the release of bound lipids into the blood, activation of enzymes, and alteration of proteins. This, in turn, promotes the clumping of red blood cells and platelets around the bubbles, further obstructing flow through the blood vessels. As the blood becomes more viscous, capillary pressure rises and promotes loss of fluid into the surrounding tissues. This fluid loss reduces the flow, because the ratio of red blood cells to plasma is increased and the fibrinogen concentration is increased (i.e., increased coagulation). This is the rationale for taking aspirin before an EVA. The aspirin is an anticoagulant that makes the blood less viscous.

## **SYMPTOMS**

There are two categories of DCS recognized by the medical community, type I and type II.

### *Type I - Joint pain*

These symptoms are exhibited in roughly 90 percent of all DCS cases. In type I DCS, an abnormal sensation may be felt first in the arms and legs, followed by dull or throbbing pain in the joints, muscles, and bones. Type I DCS is commonly referred to as the "bends." Symptoms of type I DCS include joint pain, tingling, numbness, skin itching, and swelling. Pain may be made worse by physical activity. Joint pain may be relieved by applying direct pressure to the joint (as with a blood pressure cuff) or by raising the surrounding pressure, such as in a hyperbaric chamber.

### *Type II - Peripheral or central nervous system (CNS)*

Incidents of type II DCS occur much less frequently than those of type I.

- **CNS**

Symptoms exhibited by aviators are usually traced to brain involvement. Divers tend to exhibit symptoms of spinal cord involvement.

Brain involvement includes convulsive seizures, unconsciousness, stupor, collapse, nausea, vomiting, vertigo, headache, restlessness, speech impediments (aphasia), confusion, and personality changes.

Spinal cord involvement includes paraplegia, monoplegia, muscular weakness, paralysis, muscle spasms, loss of bladder and rectal control, and altered reflexes.

- Chokes

Symptoms can develop during exposure or several hours after. Symptoms are caused by a progressive obstruction of pulmonary capillaries by N<sub>2</sub> bubbles carried to the lungs and result in reduced gas exchange and blood flow. They manifest as a dry nonproductive cough, labored shallow breathing, and chest pain upon inhalation. Chokes can lead to cyanosis, loss of consciousness, circulatory collapse, and even death.

NASA has adopted a new approach to assess and manage EVA DCS risk. This new approach entails a new classification system for symptoms of DCS and a detailed treatment philosophy. The symptoms are documented in the EVA cuff checklist and the treatment philosophy is captured in a detailed treatment procedure located in the EVA Checklist. Type I symptoms are divided into cuff 1, cuff 2 and cuff 3 and type II symptoms are classified as cuff 4. The following is a description of the 4 cuff classifications and the associated actions as described in the cuff checklist:

*Cuff 1 – Mild joint pain that is difficult to distinguish from suit pressure points*

Cuff 1 symptoms include mild pain at single or multiple sites and/or single site parathesia (pins and needles). Cuff 1 symptoms are mild enough not to impact performance and are not confirmed symptoms of DCS; therefore, the EVA is continued and the symptoms are reported post EVA in a PMC. However, if the symptoms resolve upon repress, the symptoms were caused by DCS and should be treated as cuff 2 symptoms. Suit pressure points and other EVA related pains will not magically disappear upon repress; therefore, if the symptoms clear, it is confirmed DCS and must be treated accordingly.

*Cuff 2 – Moderate joint pain*

Cuff 2 symptoms are moderate cuff 1 symptoms that do interfere with performance. The affected crewmember will terminate the EVA. The unaffected crewmember will complete worksite cleanup and payload bay safing. The affected crewmember can assist with worksite cleanup if it does not aggravate his symptoms. The crewmembers will repress together as soon as cleanup and safing is complete.

*Cuff 3 – Severe joint pain or multiple site parathesia*

Cuff 3 symptoms are severe cuff 1 symptoms or migratory, trunkal or multiple site parathesia (pins and needles), or severe or unusual headache. Cuff 3 is more severe than cuff 2 and could potentially develop into cuff 4 (or type II) DCS if not treated immediately. The unaffected crewmember will assist the affected crewmember to the

airlock and then perform payload bay safing. The EVA is terminated for both crewmembers and the airlock is repressed as soon as possible.

*Cuff 4 – Central neurological or cardiopulmonary (type II symptoms)*

Cuff 4 symptoms should be treated as a medical emergency. The crewmember could be unconscious or incapacitated. Cuff 4 requires that the affected crewmember abort the EVA. The unaffected crewmember will assist the affected crewmember to the airlock and the affected crewmember will be repressed immediately. The unaffected crewmember will repress with the affected crewmember if no safing is required or safing is complete; however, the more likely scenario is the affected crewmember will repress solo in order to expedite treatment. The payload bay must be safed because an emergency de-orbit may be required to treat the affected crewmember if symptoms do not resolve with cabin repress and oxygen treatment.

Refer to Aeromedical Flight Rules A13.1.2 – 26 and A13.1.2 – 27 regarding DCS symptoms, response, treatment and crew disposition.

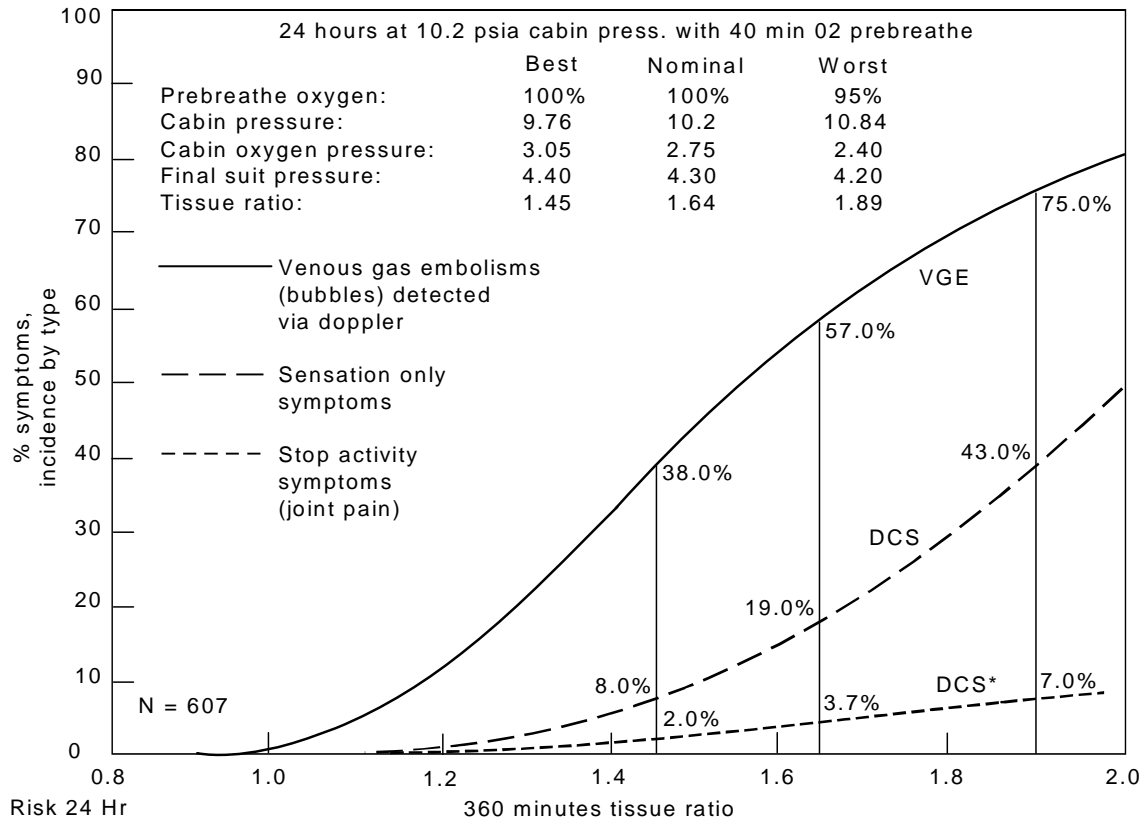
### SUSCEPTIBILITY

Many variables enter into whether an individual is more or less susceptible to DCS. A few of the possible contributing factors include the following:

- Percent body fat: Fatty tissues take on larger amounts of N<sub>2</sub> than other tissue types. Susceptibility increases with high levels of body fat.
- Circulatory system: Individuals with poor circulation are more susceptible.
- Dehydration: Inadequate hydration increases the viscosity of the blood.
- Gravity gradient: Zero-g exposure may alter N<sub>2</sub> washout in the body through its impact on gas diffusion and fluid shifts.
- Exercise: Exercise enhances bubble formation and aggravates any symptoms.
- Age: Younger individuals seem less susceptible to DCS.
- Exposure duration: Incidence of contracting DCS increases as the duration of exposure to reduced pressure is increased.
- Tissue ratio (TR): This ratio measures the risk of DCS, also known as the Haldane ratio:  
$$TR = \frac{ppN_2}{P_f}$$
where ppN<sub>2</sub> refers to the ppN<sub>2</sub> after completion of prebreathe and P<sub>f</sub> is the final decompression pressure.

Figure 3.1-1 plots the incidence of bubbles detected going through the pulmonary artery (venous gas embolisms (VGEs)) and the incidence of two levels of symptoms of DCS

against the R value (level of protection provided by a given prebreathe procedure). This figure is a representation of 607 vacuum chamber exposures under test conditions designed to replicate EVA conditions. Test subjects were selected to be representative of the astronaut population in percent body fat, age, and physical condition, all of which are measures that have been related to incidence of DCS. A half time of 360 min was chosen to represent the rate of nitrogen loss from those tissues likely to cause DCS. A half time is the time after which half of the original N<sub>2</sub> content, or partial pressure, would be replaced with O<sub>2</sub>.



DCS\* = Symptoms resulting in test termination or delayed symptoms

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**Figure 3.1-1. Combined decompression data versus tissue ratio**

Source: NASA technical memorandum "Empirical models for use in designing procedures for space operations," JSC no. 100456



## PREVENTION

The most successful method of preventing an occurrence of DCS has been found to be breathing pure oxygen (O<sub>2</sub>) for a period of time prior to decompression. A prebreathe of pure oxygen is implemented to denitrogenate the tissues and minimize the chance of DCS during EVA. Several hours of breathing 100 percent O<sub>2</sub> will wash out a majority of the inert gases in the body. Refer to Section 3.3 for details on Shuttle prebreathe.

Aspirin has also been used to help prevent DCS by reducing platelet aggregation in the blood, which aids circulation and reduces blood flow obstruction.

Periodic exercise during prebreathe periods is recommended to help eliminate trapped N<sub>2</sub> in the body tissues. Periodic body movement and avoiding overcooling result in higher blood flow in the arms and legs, which will increase N<sub>2</sub> loss and reduce the risk of DCS.

Drinking fluids may help compensate for increasing blood viscosity due to microbubble formation, platelet aggregation, and red cell clumping.

## TREATMENT

Recompression in a hyperbaric chamber is widely accepted as the primary treatment for DCS. It is used to decrease the size of evolved bubbles and provides relief from any related pain symptoms. In most cases, recompression to sea level is sufficient to alleviate the symptoms. The philosophy of DCS treatment is to maximize pressure, time and oxygen. The DCS treatment procedure is located in section 20 of the EVA Checklist. The procedure guides the crewmembers through a treatment path according to cuff classification. Detailed procedures are given to ensure that the affected crewmember is treated promptly. The bends treatment adapter (BTA) is not used for initial DCS treatment as the suit has to be depressurized for installation. DCS treatment for late or recurring DCS is located in the Medical Checklist. The following is a summary of the DCS treatment malfunction procedure:

Cuff 1: Continue the EVA and report DCS symptoms in Post EVA PMC.

Cuff 2 and 3: Terminate the EVA and repress the airlock to cabin pressure. The affected crewmember will remain in PRESS mode to maximize total pressure (total P = 4.3 + 10.2 = 14.5 psi). A medical exam is done after 20 minutes at 10.2 psi to check if the symptoms are resolving. If the symptoms resolve, the crewmember will remain in the EMU for an additional 160 minutes to complete treatment. If the symptoms do not resolve, the cabin pressure will be raised to 14.7 (total pressure = 19 psi) and in-suit treatment will continue for 190 minutes with periodic medical exams. If symptoms still do not resolve, then the cabin pressure is raised to 15.56 psi (total pressure = 19.86). The cabin pressure can not be taken higher than 15.56 without cracking the Orbiter's positive pressure relief valve. If symptoms still do not resolve, the crewmember will remain in the EMU and the Surgeon will consider administering fluids or pharmaceuticals. If still no joy, the Surgeon will dictate further action. Surgeon will

consider the use of the BTA and whether an early de-orbit is required. Refer to Section 3.2 of this handbook for more information on the BTA.

**Cuff 4:** Abort the EVA. The affected crewmember may have to repress solo. The unaffected crewmember will repress once payload bay safing is complete. Subsequent depress/repress of the unaffected crewmember should be done as quickly as possible because the affected crewmember will be disconnected from the SCU during this time (no cooling or consumable resupply). A quick test is given to the affected crewmember to determine his level of consciousness. If the crewmember is conscious and breathing adequately, crewmember will remain in the EMU in the PRESS mode and the cabin pressure will be raised to 15.56 psi. An exam will be conducted after 15 minutes. If symptoms are resolving, the crewmember will remain in the EMU in the PRESS mode for an additional 150 minutes. If the symptoms are not resolving, the crewmember will remain in the EMU and the Surgeon will consider administering fluids or pharmaceuticals. If still no joy, MCC will consider emergency deorbit to a site with hyperbaric facilities. If the crewmember is unconscious and not breathing, a medical procedure for resuscitation/CPR will be administered once the EMU is doffed. The cabin pressure will be immediately increased to 15.56 psi. MCC will prepare for an emergency de-orbit to a landing site with a hyperbaric facility.

Note that O<sub>2</sub> toxicity must be recognized as a possibility with the use of this procedure. Oxygen toxicity becomes a hazard after 6 hours on 100 percent O<sub>2</sub> at sea level.

After treatment complete and symptoms resolved, the crewmember doffs the EMU and breathes on the QDM for 2 hours. The Surgeon will be consulted for further DCS treatment. Surgeon will determine return to IV and EV duty based on JPG 1800.3 Decompression Sickness Procedures and Guidelines.

## **OTHER PRESSURE-RELATED AILMENTS**

Another decompression problem similar to the bends, known as an aneurysm, is caused by the expansion of trapped gas in body cavities during a reduction in ambient pressure (such as depress or a loss of cabin pressure). The following symptoms are typical:

- Abdominal distension or bloating
- Ear pain, inability to clear ears, loss of hearing acuity
- Sinus pain
- Toothache, jaw pain

Treatment calls for a repress if the pain becomes progressive.

Another pressure-related ailment, known as compression sickness, may occur upon exposure to increasing ambient pressure (such as during repress). This illness is caused by an imbalance of high external pressure on the eardrum with low internal

pressure on the middle ear if the Eustachian tube is closed. Typical symptoms of compression sickness include:

- Ear pain, inability to clear the middle ear, loss of hearing
- Sinus and facial pain

Treatment involves stopping the repress and performing the Valsalva maneuver to equalize the pressure on the middle ear. If the problem persists, the airlock will be depressed until the symptoms are relieved. At this time, the repress can proceed slowly while noting any recurrence. Optimally, the crewmember will control the repress rate to avoid compression problems. If an emergency repress is required, it will probably result in compression symptoms of some kind.

These pressure-related ailments are directly related to Boyle's law.

## 3.2 BENDS TREATMENT ADAPTER

### PURPOSE

To define the history, operation, and method of treatment associated with the BTA.

### DESCRIPTION

The BTA is a device that allows the EMU to be pressurized to 8.0 psi over ambient cabin pressure for the treatment of DCS. The BTA is used to treat DCS in the event that repressurization to sea level does not clear symptoms.

### HISTORY

The bends recovery adapter (BRA) was used before the BTA and was flown only on scheduled EVA flights. The outmoded BRA was essentially an independent external system for pressurizing the EMU. The BRA used a special helmet fitted with an O<sub>2</sub> hose connection and an 8.5-psi relief valve. O<sub>2</sub> regulated to 8 psid was supplied to the EMU via a portable oxygen system (POS) connection on the ECLSS panel. The EMU PPRV was capped off for BRA regulation pressure. The BTA has flown on every shuttle flight since STS-34 (1989). The BTA has the advantage of decreased mass and volume and, therefore, has little impact on orbiter stowage.

### OPERATION

The BTA (item 491) consists of an 8-psid relief valve (item 493) and a 15-psid pressure gauge (item 492), shown in Figure 3.2-1. A poppet keeper screw and a 3/8-inch box-end wrench are used in conjunction with the BTA to configure the EMU for bends treatment. The wrench is stowed with the BTA, usually in a middeck locker. One poppet keeper screw is stowed on the BTA prior to use, and its placement precludes the installation of the BTA on the PPRV without first removing it. A spare poppet keeper screw is stowed in the Maintenance Kit. Functionally, the BTA replaces the PPRV for protection against overpressurizing the suit. The BTA acts as a higher pressure PPRV, relieving at 8 psid in lieu of 4.7 psid (PPRV relief pressure). A cutaway of the BTA relief valve is shown in Figure 3.2-2. A poppet keeper screw forces the PPRV open so that the two valves will not be additive.

If the poppet keeper screw is not used, the PPRV and BTA are additive, as shown in Figure 3.2-2. Figure 3.2-3, part a, shows the BTA and PPRV configuration with the suit in the PRESS position. The suit and the PPRV are at 19.0 psia ( $4.3 + 14.7 = 19.0$ ). Figure 3.2-3, part b, demonstrates that the PPRV opens at 19.4 psia ( $4.7 + 14.7 = 19.4$ ). Once the PPRV opens, lines A and B are now pressurized to 19.4 psia. However, the BTA relief valve does not open until there is a delta pressure of 8 psi. Figure 3.2-3, part c, shows that if the suit pressure is cycled again, the PPRV would not open until 24.1 psia ( $4.7 + 19.4 = 24.1$ ), but the BTA relief valve will open at 22.7 psia ( $8 + 14.7 = 22.7$ ), and line B will stabilize to 22.7 psia. If the suit pressure was cycled once more, the PPRV would not open until the suit pressure reached 27.4 psia ( $12.7 + 14.7 = 27.4$ ).

If the poppet keeper screw is not installed, the final relief pressure would be 12.7 psid. Structurally, the suit cannot withstand this amount of pressure.

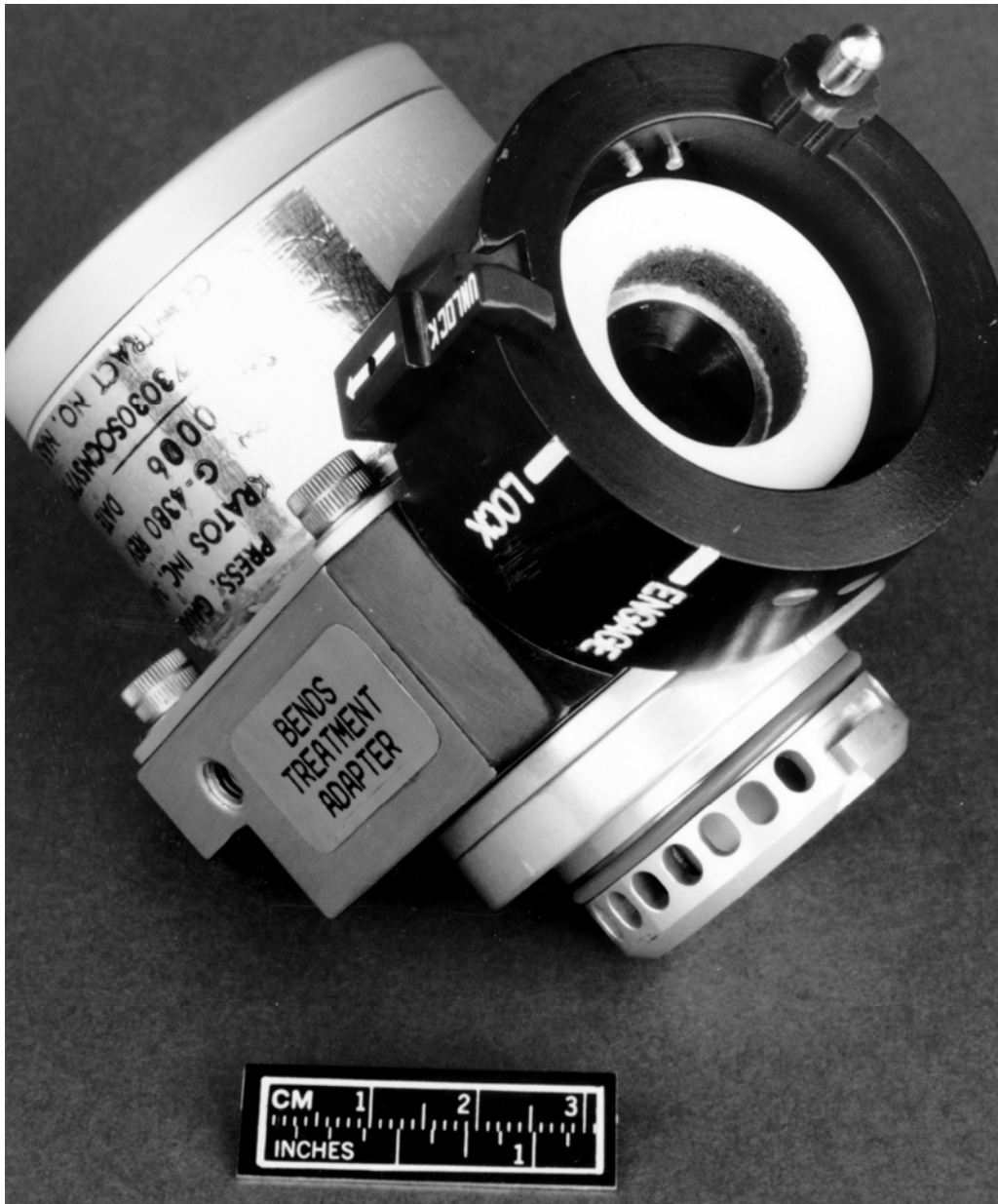
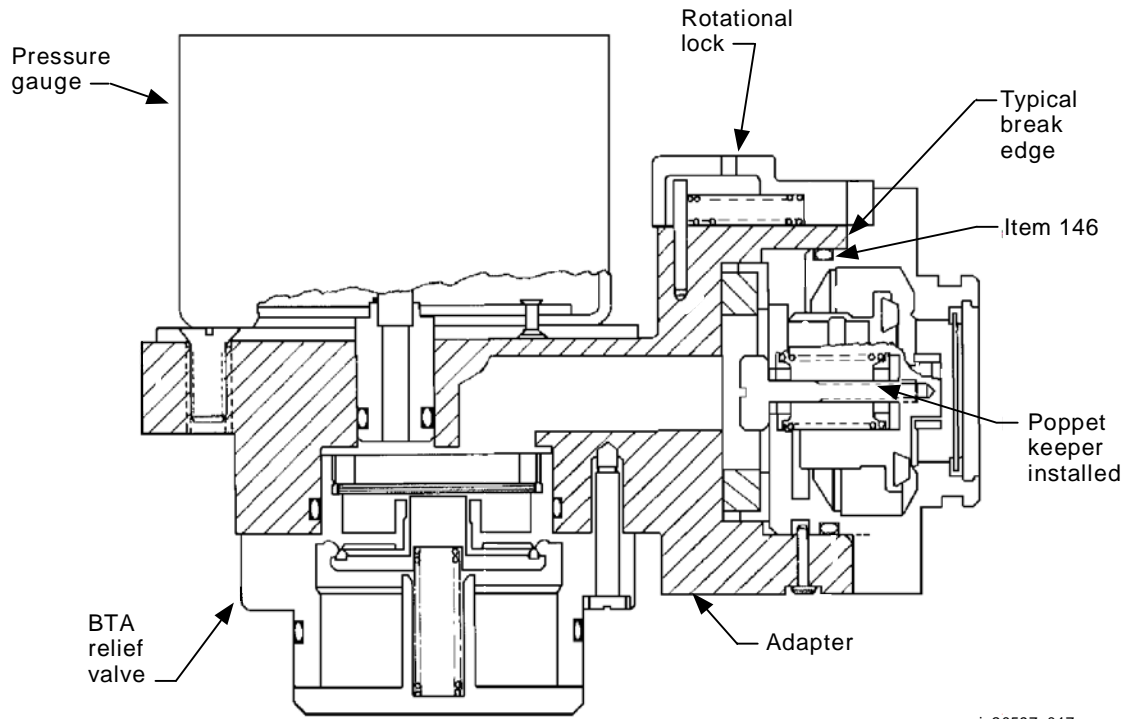
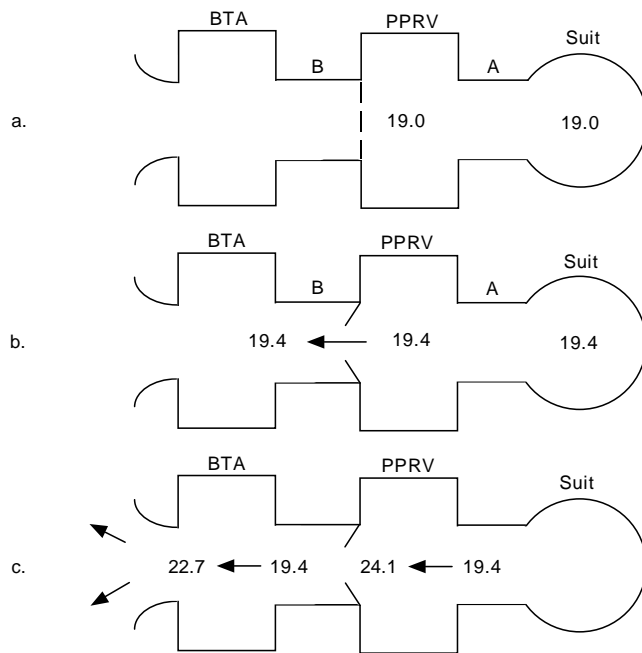


Figure 3.2-1. BTA



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**Figure 3.2-2. BTA cutaway**



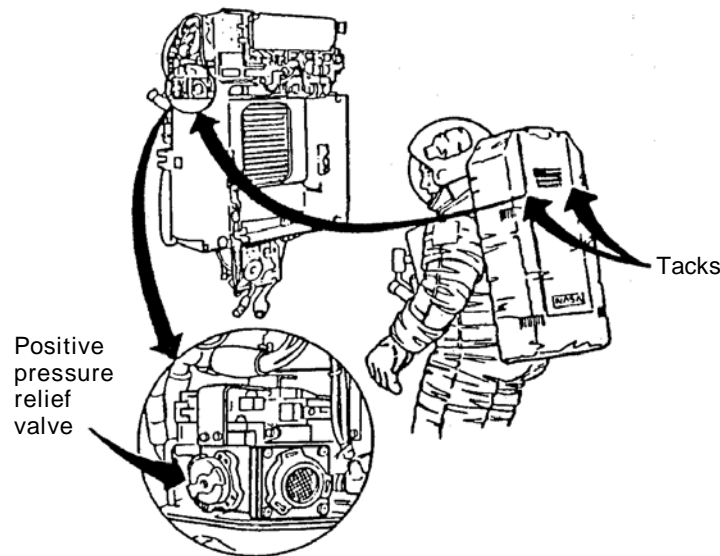
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**Figure 3.2-3. BTA operation - without poppet keeper installed**

## TREATMENT

If DCS occurs, the EV crewmembers would return to the airlock and connect to their SCUs for repress. After equalizing the airlock with cabin pressure, symptoms are evaluated by the affected crewmember and the surgeon. If symptoms persist and cabin pressure is below 14.7 psi, the entire cabin is pressurized to 14.7 psi. In most cases, the symptoms go away at 14.7 psi. If symptoms are still present, bends treatment is continued with the BTA. Detailed BTA procedures are located in the Medical Checklist of Flight Data File in the section titled Bends Treatment W/Bends Treatment Apparatus (BTA). Section 3.1 of this handbook contains more information on the bends treatment protocol.

Treatment with the BTA requires access to the PPRV, which is located on the upper left side of the portable life support system (PLSS). To access the PPRV, the PLSS thermal micrometeoroid garment (TMG) is unzipped and the impact shield is removed (Figure 3.2-2). The BTA is unstowed and the poppet keeper screw is removed from the housing and threaded into the PPRV (Figure 3.2-5). This action overrides the PPRV and the BTA is ready for installation. The BTA has labels indicating the ENGAGE, LOCKED, and UNLOCK positions, and the housing above the PPRV has an alignment mark for correct positioning of the BTA. The BTA is installed by aligning the ENGAGE mark on the BTA with the mark above the PPRV and rotating clockwise to the locked position (Figure 3.2-6). In the LOCKED position, the BTA still remains somewhat loose on the PPRV.



**Figure 3.2-4. PPRV location**

The test port F sealing plug, located on the secondary oxygen pack (SOP), must be removed to provide orifice flow for BTA operations. Due to the position of test port F on the SOP, the lower torso assembly (LTA) must be disconnected to access it. The location of test port F on the SOP is shown in Figure 3.2-7. The test port F sealing plug

(BTA orifice - item120D) is removed by using the 3/8-in. end of the BTA wrench. It requires four to six counterclockwise turns to remove the sealing plug. Test port F and the sealing plug are shown in Figure 3.2-8. The plug is not tethered, but the BTA has a threaded stowage point for the plug. The plug should be stowed on the BTA directly after removal.

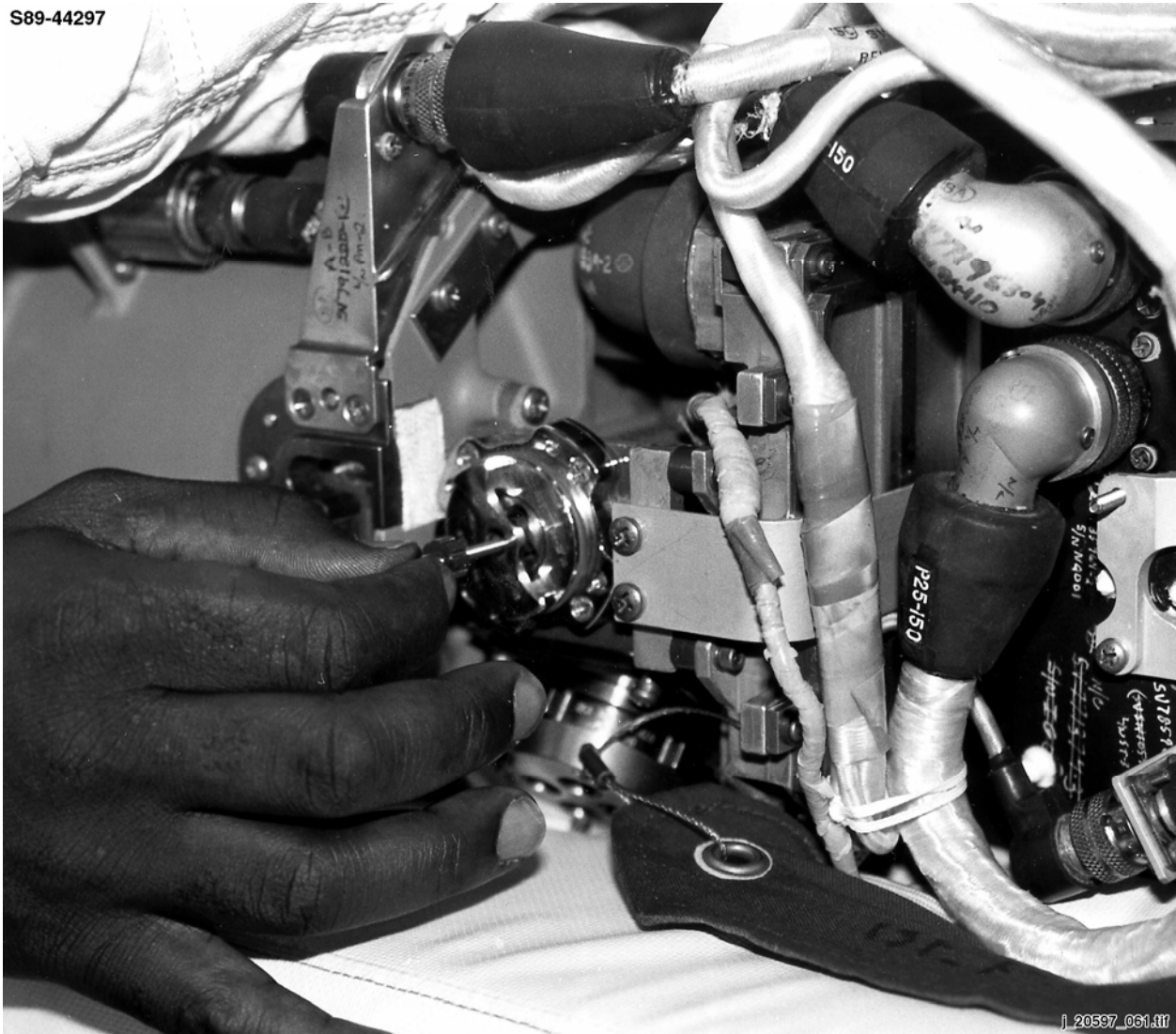
A detailed discussion of the BTA procedure requires reference to a basic EMU schematic shown in Figure 3.2-9. The BTA uses the internal systems of the EMU. The EMU water tanks are dumped to provide more free volume for oxygen storage, allowing faster pressurization of the suit during BTA operations. With the water tanks empty, the BTA installed, and test port F removed, the pressurization process can begin. Placing the O<sub>2</sub> actuator in the PRESS position opens the O<sub>2</sub> shutoff valve, pressurizes the suit to 4.3 psid, and allows the water pressure regulator to flow 15 psi O<sub>2</sub> into the water tank volume. The O<sub>2</sub> actuator is then moved to the OFF position. The low mode relief valve opens after being triggered by a pressure drop upstream of the check valve provided by the BTA orifice (test port F). The flowrate of this orifice is 1400 ± 300 sccm O<sub>2</sub> (source: EMU Requirements Evolution, p. 174). Once the low mode relief valve opens, it dumps the O<sub>2</sub> pressure in the water tanks through the T-II port into the suit. Each cycle of the O<sub>2</sub> actuator from PRESS to OFF increases the suit pressure approximately 0.5 psi. This is repeated until the suit pressure is 8 psid (total P = 14.7 + 8 = 22.7 psi). The BTA gauge is used to monitor suit pressure during BTA operations and bends treatment, because the limit of the suit pressure transducer is 6 psid and the limit of the suit gauge is 5.5 psid.

The CWS will issue a SUIT P HIGH/ O2 RATE/ SOP RATE message when the suit pressure is > 4.55 psid followed by a RLF V FAIL/STOP DEPRESS message when the suit pressure is > 5.7 psid. These CWS messages should be ignored during BTA operations.

Suit pressure must be maintained at 8 psid; therefore, once the crewmember breathes down the pressure by 0.5 psid, the O<sub>2</sub> actuator should be cycled from PRESS to OFF to bring the suit pressure back up to 8 psid. Bends treatment will continue for approximately 2 hours, according to the surgeon's direction.



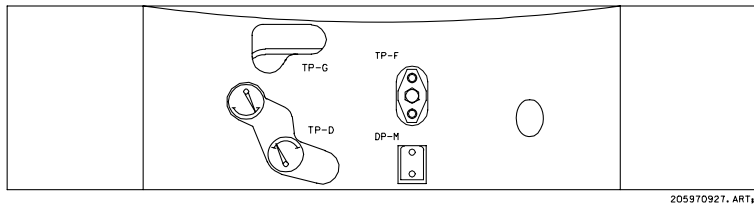
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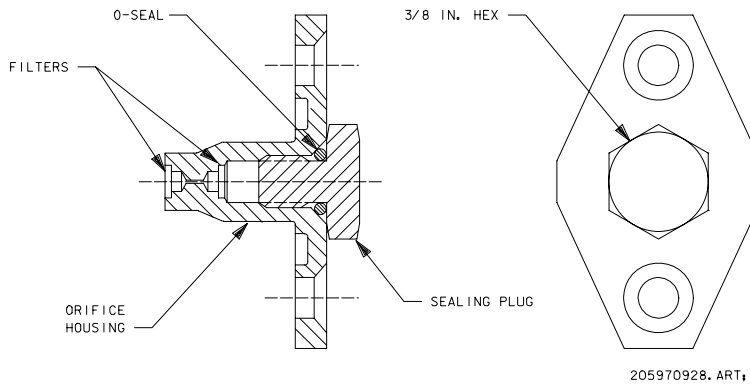
**Figure 3.2-5. Poppet keeper screw installation**



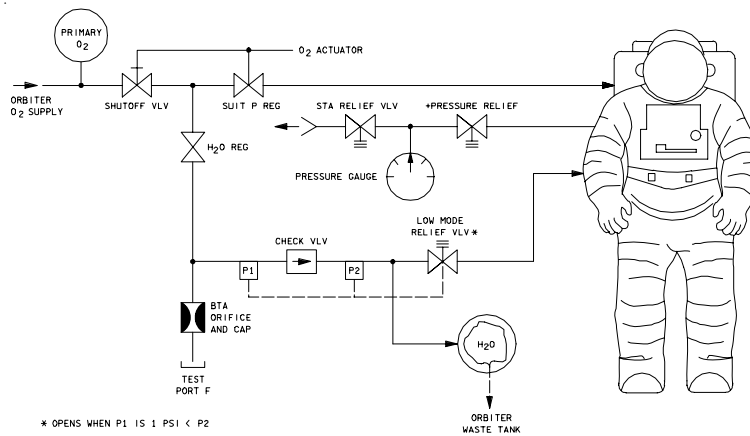
**Figure 3.2-6. BTA installation on PPRV**



**Figure 3.2-7. Test port F location**



**Figure 3.2-8. Test port F and sealing plug**



**Figure 3.2-9. Basic EMU schematic**

### **3.3 PREBREATHE**

#### **PURPOSE**

This section provides information on both ISS and Shuttle prebreathe protocols.

#### **DESCRIPTION**

Decompression sickness (DCS) is minimized by breathing pure oxygen for a period of time prior to reducing the ambient pressure. The purpose of this prebreathe time is to wash out inert gases, namely nitrogen, from the blood and tissues. This prevents nitrogen gas from coming out of solution at reduced ambient pressures and causing DCS.

The prebreathe protocol before EVA involves breathing 100 percent O<sub>2</sub> for different durations and levels of intensity, depending on the protocol selected. The duration of prebreathe depends on oxygen flow, level of activity and cabin pressure.

#### **ISS Prebreathe Protocols**

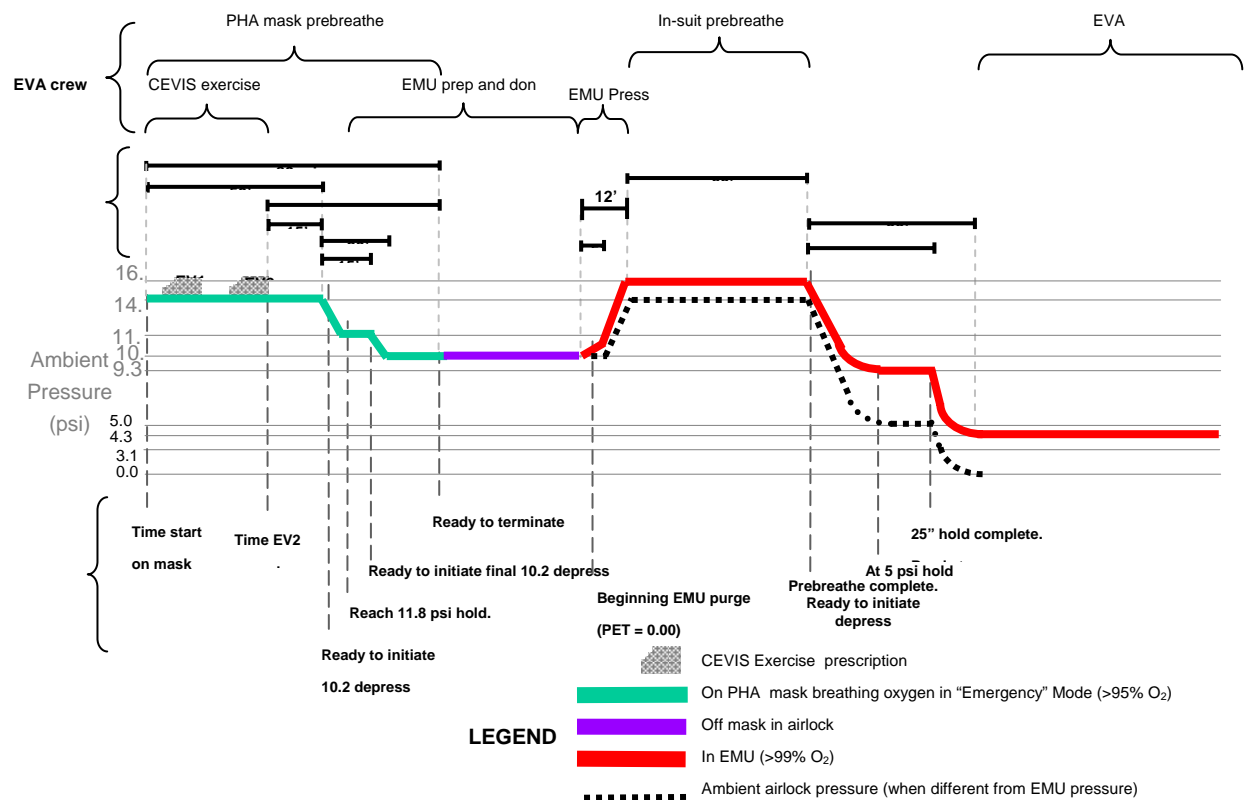
There are three prebreathe protocols currently available for ISS EVA: exercise, campout and 4-hr in-suit. The protocol is selected based on DCS risk, mission objectives, operational complexity, crew training, consumables, timeline and the timeframe required for critical EVA tasks. Flight team desires will have to be weighed against general risk and program-level issues. It is also important to consider crew day length violations when mission planners are making these decisions. Integrated decisions are typically made first at the flight JOP followed by the SSPCB.

Exercise Prebreathe has the lowest predicted risk of DCS (reference NASA DCS Risk Definition & Contingency Plan, 1998). Exercise prebreathe has the most laboratory testing and on-orbit experience. The campout protocol was designed to be more conservative than the currently published Shuttle 10.2 prebreathe protocol; however, it has not been directly laboratory or vacuum chamber tested. Thus far, several EVA teams have performed the campout protocol as dictated by flight specific requirements. The 4-hr in-suit prebreathe has been used in over 300 vacuum chamber events but has not been thoroughly laboratory tested and incurs a slightly higher predicted risk.

#### **Exercise Prebreathe**

The exercise prebreathe protocol was designed to incorporate the latest research in decompression sickness prevention. The constraints associated with campout namely crew isolation, oxygen usage and waste management, provided the initial driver for developing the exercise prebreathe protocol. Prebreathe exercise reduces the risk of DCS. The idea was to take advantage of the benefit of exercise in off-gassing nitrogen (i.e. nitrogen washout) and uptake of oxygen. Increased nitrogen washout reduces overall time it takes to achieve the proper nitrogen ratio within the tissues. Exercise also increases cardiac output causing faster nitrogen elimination even after exercise. The purpose was to incorporate the latest research while reducing overall crew time.

The prebreathe reduction program (PRP) was developed to design and test the best protocol possible to mimic actual conditions in spaceflight. There has been no reported incidence of decompression sickness in the space program; however, in the armed forces and other high altitude experiences the incidence of decompression sickness under similar circumstances was much higher. The experts surmise that the difference may be due to many factors but most apparent is the non-ambulatory (non-walking) effect of being weightless. This is also referred to as adynamia. Adynamia produces less nuclei than a walking subject which is believed to have an affect on incidence of DCS. Therefore, the testing of this new protocol included subjects being required to be non-ambulatory at the various phases of the protocol. This allowed a more accurate account of the actual conditions on-orbit. Refer to the end of this SCP for more information on the testing protocol.



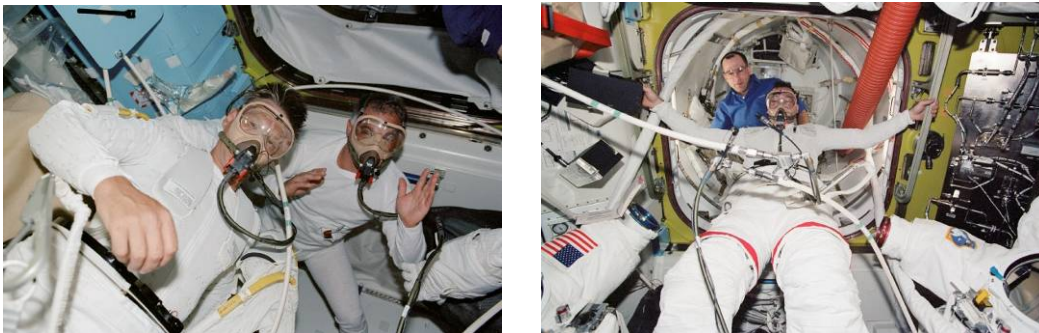
**Figure 3.3-1. Exercise Prebreathe Pressure Profile**

The exercise prebreathe protocol is performed the morning of the EVA and includes an initial mask prebreathe that is performed while exercising on the CEVIS ergometer. The exercise portion of this protocol is an individual prescription based on the aerobic capacity of the crewmember and designed to maximize denitrogenation. The mask prebreathe is 80 minutes including the initial 45 minutes prior to depressurization to 10.2 psi. The first crewmember begins exercise for a total of 10 minutes remaining on

the mask and then the second crewmember performs the exercise. There must be 15 minutes post exercise and before depress to 10.2 psi to match the ground-tested protocol. If EV1 begins exercise within 10 minutes after prebreathe initiate and EV2 starts exercise within 25 minutes after prebreathe initiate, the requirement of maintaining 45 minutes of mask time after exercise will be satisfied.

- EV crewmembers don O2 masks the morning of the EVA. This initial 80-minute mask prebreathe must be unbroken and no less than 45 minutes must be completed prior to depressing below 11.8 psi.
- Each crewmember serially performs 10 min of exercise on the ergometer
- The first 3 minutes is ramping up from 25 to 75% VO2 max with the remaining 7 minutes at 75% VO2 max
- The crew remains on the mask and performs part of EVA PREP
- The airlock is depressed to 10.2 in no less than 20 minutes and must not be initiated prior to ensuring that 15 minutes has elapsed following exercise for both crewmembers. This is to meet the requirement of both crewmembers having at least 45 minute of oxygen following exercise and allows for the time that may be needed to meet the control zone and terminate the mask prebreathe.
- The crew doffs the mask at the end of depress and 80 minutes of mask time
- The crew dons the EMU performing an additional in-suit prebreathe of 60 min. Repress to 14.7 may be accomplished following 5 minutes of EMU purge. The total oxygen prebreathe including mask and in-suit must be no less than 140 minutes.
- The final depress from 14.7 to vacuum must be no less than 30 minutes in order to meet the ground tested criteria (25 minutes between 14.7 and 3.1 psi.).

The prebreathe cue card and procedures contain callouts to record the times at each prebreathe milestone. Note that this protocol was designed to allow the most time following exercise and final depressurization to allow the nuclei produced by exercise to dissolve.



**Figure 3.3-2 Mask Prebreathe**

Using exercise prebreathe resulted in being ahead on the EVA Prep timeline for 9 of the 11 EVAs from flight 7A to 11A. It is difficult to attribute this only to the protocol as there are many reasons that a crew can get ahead on the EVA prep schedule, including waking up early, expedited suit donning, efficiency from training and on-orbit experience. Some factors that could cause a crew to fall behind the timeline include hardware failures, suit problems, prebreathe interruptions, and delays in EVA sync points such as payload constraints, MT translation, or robotic arm movement. Selection of exercise prebreathe as the protocol of choice must be weighed against program risks and hardware limitations. The infrastructure of this protocol is more complicated and the timing more critical than other protocols but the overall DCS risk is lower and well documented.

### *ISS Prebreathe Configuration*

Exercise prebreathe and campout prebreathe for assembly flights nominally use Shuttle-supplied oxygen that is plumbed through the ISS and ROOBA to the PHA ports in the ISS Joint Airlock. Refer to Volume 3, Section 4.1 ECLSS for more information on oxygen circuitry and ROOBA (section currently TBD). Each PHA is attached at the PHA ports for the duration of the prebreathe. For stage EVAs, exercise and campout prebreathe must use HPGT oxygen plumbed directly to the PHA ports as the Shuttle is not present to conserve oxygen.

### *Alternate Exercise Prebreathe Configuration*

For Assembly flights, if the ISS oxygen circuit or transfer circuit is not working properly, the Shuttle oxygen ports can be used as a backup for exercise prebreathe. This would require 90ft of PHA hose attached to the Shuttle LEH port and 2-60 ft hoses attached either at the PHA ports or PBA ports in the ISS Joint Airlock. This configuration further complicates the protocol but has been used several times on-orbit prior to the installation of the ROOBA hardware. The flow rate through the LEH ports is adequate to support exercise as long as the PHA hose length provides enough volume to act as an accumulator. This hose length was determined to be 90-ft per ground testing and analysis.

### *Prebreathe Interruption*

Interruptions in exercise are accommodated up to 2 minutes of interruption by extending the exercise time at 75% max VO<sub>2</sub> for the time of the interruption. Interruptions in oxygen prebreathe are accommodated by a buy-back ratio dependent on the atmospheric pressure and period of time elapsed since exercise. Higher pressure and the increased cardiac output require a longer buy-back. If there is a planned interruption during the in-suit prebreathe, the team should consider depressing back to 10.2 psi to protect the prebreathe. Refer to Flight Rule B13-107 for a detailed matrix of interruption responses.

*Hardware Failure Response*

The exercise prebreathe protocol has many time critical components and requires a quick response to operational and hardware failures. Table 3.3-1 lists the failure response for the hardware involved in the exercise prebreathe protocol (reference Flight Rule B13-107 and B15-55 for additional detail and rationale). For each hardware failure, contact ISS BME for hardware status, location and operational feasibility. Hardware failures are, in most cases, followed by a break in prebreathe that will cost valuable time; therefore, an expedited response is very important to stay on track for the EVA.

**Table 3.3-1 Exercise Prebreathe Protocol Failure Response Matrix**

<b>Hardware</b>	<b>Failure Response</b>
<b>Oxygen supply</b>	<p>UIA pressure and O2 HI P supply must be greater than 1431 kPa to support mask prebreathe. If high pressure oxygen is still available, in-suit prebreathe is a permissible backup. If both ROOBA supply and direct ISS O2 tank supply are insufficient, Shuttle LEH ports may be used, if Shuttle is present and equivalent pressures are adequate to support flowrates.</p> <p>Note: O2 supply pressure greater than 1431 kPa is based on the maximum outlet pressure of the PHA regulator (150 ± 5 psia) plus pressure sensor accuracy (range 0 - 3500 psia ± 1.5%).</p>
<b>CEVIS (including ancillary hardware)</b>	<p>Prescribed workload can be controlled with the CEVIS Contingency Controller or with the PCMCIA card and the nominal CEVIS controller.</p> <p>If vibration isolation system is not useable, CEVIS can be used in hard mounted configuration with restrictions on max speed (70 rpm setting and peaks no greater than 80 rpm).</p> <p>Cycling shoes are interchangeable.</p> <p>IFM power supply can be used for workload control in the event of a control box failure.</p> <p>Shuttle ergometer may be a permissible backup (if available). However, due to current hardware certification limitations, MCC-H may have to grant a waiver to use as backup.</p>
<b>Heart Rate Monitor</b>	<p>Use alternate ISS CheCS heart rate monitoring equipment (heart rate watch or pulse oximeter).</p>
<b>Theraband Exercise Tubing</b>	<p>A backup piece of tubing is nominally installed. If both bands fail, retrieve spare tubing on ISS.</p>



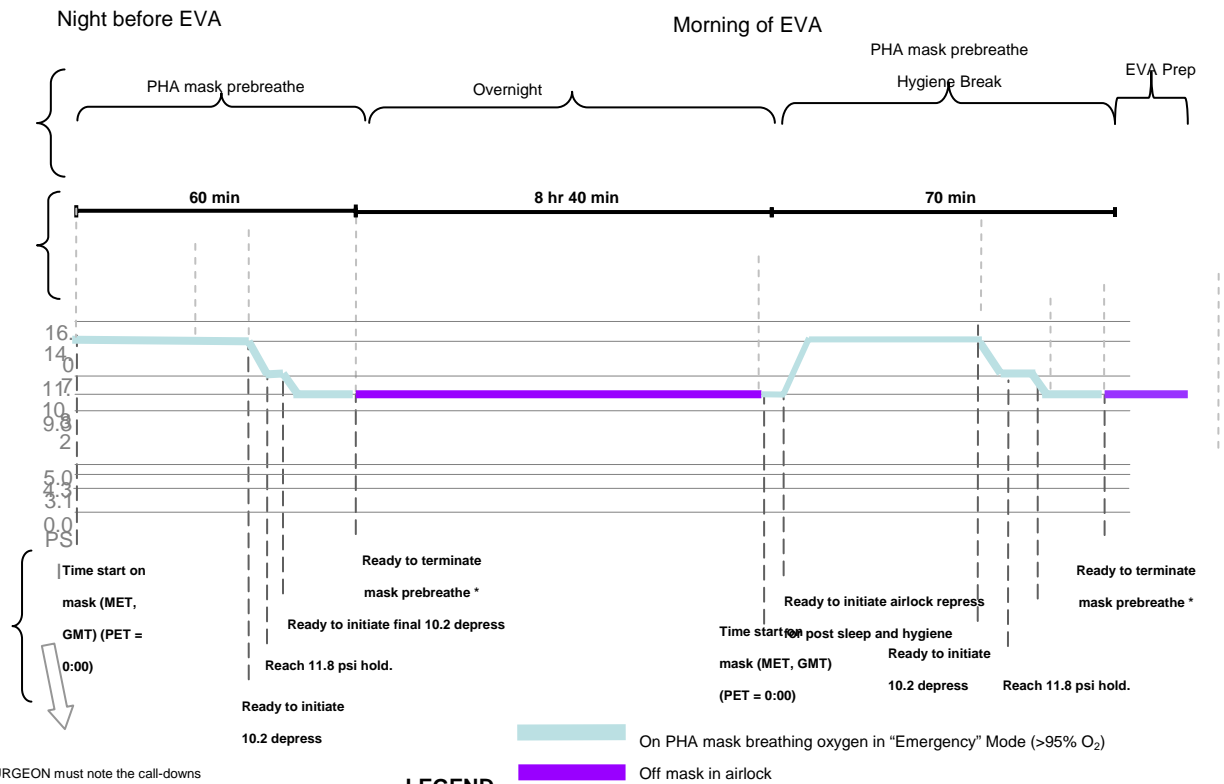
<b>Prebreathe Hose Assembly Kits</b>	There is a spare kit which provides single fault tolerance for failure of any one item. The kit includes one 30ft spare segment of hose and 1 each of the valves and mask. Quick don masks (QDMs) can be swapped out with ISS inventory in the event of several failures. Qualitative mask flow must be acceptable per crewmember to verify adequate flow through the hose and entire system. A relief valve is required at the source.
<b>ISS Major Constituents Analyzer (MCA) for 10.2 Ops</b>	Used to monitor airlock atmosphere while isolated (i.e.: O2, CO2, N2). If failed, 2 CSA-O2s are required to continue prebreathe protocol.
<b>CHeCS CSA-O2 for 10.2 Ops</b>	Two oxygen monitors are required during isolated operations to protect for potential sensor drift. If the MCA is down, 2 units are required. Otherwise, 1 unit is acceptable. CSA-O2% is known to drift low at lower pressures. Therefore, at 10.2 psi, the delta between the MCA and CSA-O2 readings will be further apart than they were at nominal pressure.
<b>CCAA</b>	A portable fan assembly (PFA) and LiOH may be used for CO2 removal for 1 hour. There is not a backup for cooling or humidity control.
<b>CO2 Removal receptacle</b>	Can use Metox or LiOH. If CCCs are unavailable, prebreathe can continue as long as CO2 limits remain within ppCO2 constraints listed in Flight Rule B13-53. In the event of a CO2 Removal Box failure, a PFA may be used with LiOH for up to one hour.
<b>IMV</b>	One Node 1 IMV valve is required for contingency repress. There is a fwd and aft valve. Oxygen released by masks must be mixed with cabin air to minimize risk of fire. This can be achieved by IMV, cabin fan/CCAA or portable fan.
<b>PCS</b>	If all crewmembers are isolated, two PCSs are required for caution and warning; otherwise only 1. There is at least one PCS onboard ISS to use as a spare.
<b>ATUs</b>	At least one airlock ATU must be useable. There are three in the airlock. These are ORUs. In the event all 3 are lost, the crewmembers can communicate UHF via the EMUs provided there is a non-isolated crewmember to communicate with.
<b>Emergency Equipment</b>	One Fire extinguisher and one PBA (per isolated crewmember) are required. Spare hardware can be borrowed from other modules.

<b>Pressure Control Equipment</b>	Airlock PCA, Crewlock Cabin Pressure Sensor, as well as the I-138 Feedwater Pressure Sensor on each EMU can serve as cabin total pressure sensors. However, the Airlock PCA provides rapid depress detection and automatic software response. Oxygen introduction can also be accomplished with the PHAs.
<b>Smoke detection</b>	If all crewmembers isolated, must have smoke detection in all other modules.
<b>Depress Pump</b>	If depress pump fails, PCA VRIV can be used.

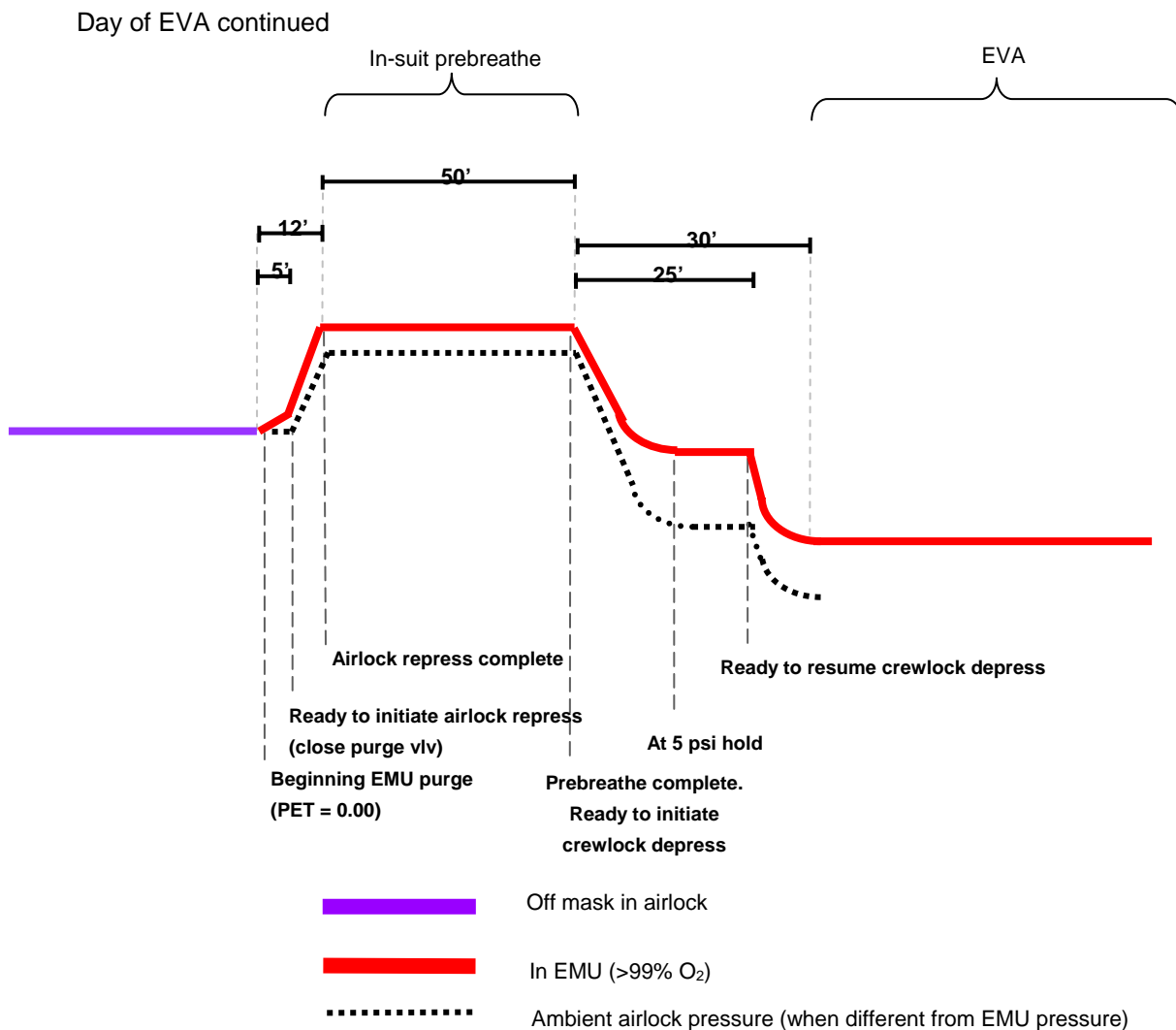
\*For specifics on additional hardware and detection requirements, refer to Flight Rule B15-55

### Campout Protocol

The campout protocol was originally intended to mimic the Shuttle 10.2 psi protocol. The idea is to provide denitrogenation through staged decompression and oxygen prebreathe. There is an initial 60 minute mask prebreathe upon initial depress to 10.2 for overnight campout in the airlock. The crew remains in the airlock for 8 hours, 40 minutes minimum. The next morning, the crew performs another mask prebreathe, represses the airlock, performs hygiene break, retrieves breakfast and returns to the airlock for depress back down to 10.2. The minimum time on the mask for both cycles is 130 minutes. This protocol is delineated below:



SURGEON must note the call-downs and insure that prebreathe constraints are being followed, and should voice concurrence to FLIGHT



**Figure 3.3-3 Campout Prebreathe Pressure Profile**

ISS campout prebreathe protocol was reviewed by an independent review team to ensure that the assumptions and data used in the analysis would provide an appropriate level of protection. The analysis demonstrated it to be an acceptable protocol but with limited experience as compared with the exercise prebreathe protocol. The protocol was designed to be more conservative than its shuttle predecessor but incurs a slight increase in risk due to lack of direct ground testing and limited experience. However, on-orbit experience will increase with time and thus far, it has proven to be a viable option. In order to satisfy the accept criteria for ISS EVA protocols, an additional 10 minutes of in-suit prebreathe was added to the campout protocol making the total in-suit EMU prebreathe for campout 50 minutes. This additional time achieves calculated risk of Grade IV VGE of less than 20 percent for the upper 95 percent confidence level moving this protocol into the NASA DCS risk acceptance limits. The decision to use the

campout protocol must include a review of its limitations as compared to other protocols and weighed against risk and program requirements. Even though campout is an acceptable option, it requires more time on the mask, more isolation time, more cycles on the depress pump and the CCAA and more consumables (oxygen, power, and Metox) than the exercise prebreathe protocol. Campout is also not recommended for back-to-back EVAs due to an oversubscribed timeline.

**Table 3.3-2 Campout Protocol Failure Response Matrix**

*Includes only the deltas to the Exercise Prebreathe Failure Response Matrix*

Hardware	Failure Response
<b>ISS Major Constituents Analyzer (MCA) for Overnight Campout</b>	Used to monitor airlock atmosphere while isolated (i.e.: O2, CO2, N2). The MCA is highly desired since the CSA-O2 requires manual readings. If the MCA fails, the CO2 levels are controlled via the CCAA and CO2 removal box. There will be no insight into the effectiveness of CO2 removal in the airlock and will be assumed to be lost. Analysis has been done to prove that the CO2 levels will not violate limits in this 9 hour time period with expected metabolic activity. The airlock PCA will be used to identify a leak which could cause O2 limit violations but this risk has been accepted per Flight Rule B 15-55 Go/No-Go Criteria for EVA Prebreathe.
<b>CHeCS CSA-O2 for 10.2 Ops</b>	Used for portable O2 monitoring while isolated in the Airlock. If the MCA is down on the day of EVA, 2 units required. Otherwise, 1 unit is acceptable. The units must pass pressure verification prior to isolated crewmember sleep. CSA-O2% is known to drift low at lower pressures. Therefore, at 10.2 psi, the delta between the MCA and CSA-O2 readings will be further apart than they were at nominal pressure.
<b>CCAA (crew sleep)</b>	If the CCAA fails during sleep, crew must remain awake until CCAA restart. The PFA cannot be used as a backup because it is limited to 1 hour of continuous use.
<b>CCAA (Crew awake)</b>	The PFA and LiOH may be used for CO2 removal for 1 hour. There is not a backup for cooling or humidity control.

\* Use Exercise Prebreathe Matrix for hardware impacts not listed here.

Four-Hour In-suit Prebreathe

The 4-hour In-Suit Prebreathe Protocol is tested on the ground each time a vacuum chamber test is performed and therefore is validated more than the other protocols. However, the risk is higher than exercise prebreathe protocol due to duration and intensity of denitrogenation. The acceptable risk established from testing is

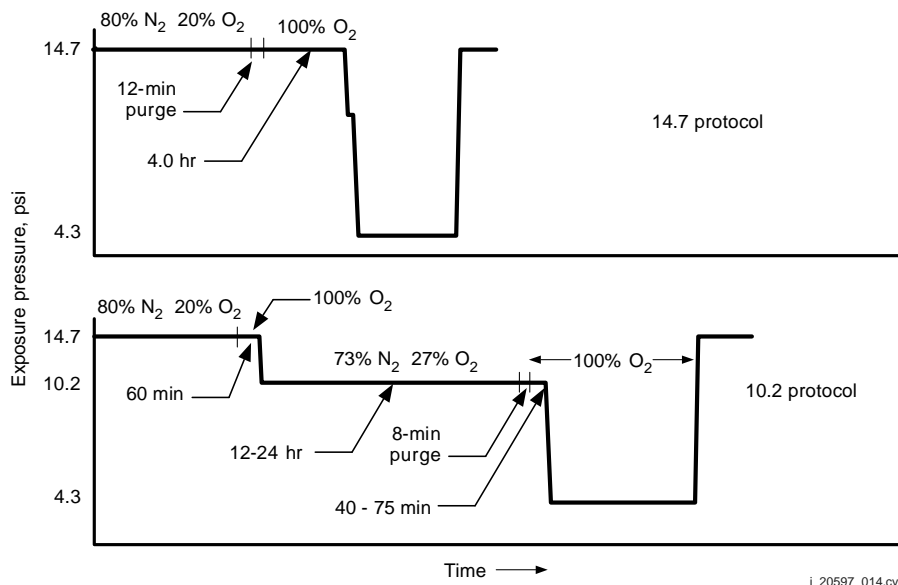
< 1.5 percent total DCS with no incidence of the more severe type II cases. It is possible to perform METOX Change-Out (manned) to allow for maximum EVA capability. Provided that Crew Day Length violations can be approved, we could support a 6:30 EVA PET.

Contingency EVA

Contingency EVAs are those required to affect the safety of the vehicle and crew. The nominal prebreathe protocols will be used if the criticality and time allows. If minimizing EVA preparation time is more critical to crew safety, then a minimum of 2.5 hours of unbroken prebreathe with > 95% O<sub>2</sub> is recommended at a vehicle pressure above 12.5 psi/646 mmHg. A minimum prebreathe of 2.5 hours would reduce the estimated risk of incapacitating bends to <50% for an EVA up to 6 hours in duration. This recommended time is very approximate and should be extended if possible. Preparations for decompression treatment should be conducted as early as possible in case of an incident. The Flight Surgeon will be consulted for a recommended prebreathe protocol for any contingency EVA.

**Shuttle Prebreathe Protocols**

There are currently two approved prebreathe protocols for the shuttle program. One is performed at 10.2 psia and the other at 14.7 psia. Figure 3.3-4 illustrates how each protocol varies with exposure pressure and O<sub>2</sub> usage. Testing at JSC has verified that each protocol is equally effective in preventing DCS. Each protocol results in less than 5 percent N<sub>2</sub> in volume after purge and less than 8 percent N<sub>2</sub> after in-suit prebreathe.



**Figure 3.3-4. Shuttle Prebreathe protocols (NASA Technical Memorandum 58259)**

The upper plot of Figure 3.3-4 shows the 14.7 psia protocol. This protocol uses a 12-minute purge that occurs immediately after the EMU is donned. Purge time consists

of flowing pressurized O<sub>2</sub> into the suit to remove any trapped N<sub>2</sub>. After nitrogen purge, 4 hours are spent in the suit prebreathing to wash out internal N<sub>2</sub> from the blood and tissues. The N<sub>2</sub> level of the body drops considerably after breathing pure O<sub>2</sub> for 4 hours. The ppN<sub>2</sub> starts at 11.6 psi (79 percent of 14.7 psi) and drops to approximately 7.1 psi. Following depress to vacuum, with the suit pressure at 4.3 psi, the Haldane ratio (R) is 1.65, which is low enough that DCS is unlikely to occur.

The lower plot of Figure 3.3-4 illustrates the 10.2 psi prebreathe protocol. It begins with an initial 1-hour mask prebreathe of 100 percent O<sub>2</sub> using the QDMs. The first 45 minutes of this prebreathe is done prior to depressing below 12.5 psi, and the remaining 15 minutes is performed during depress to 10.2 psi total pressure. The initial prebreathe is not considered complete until the crewmember(s) has breathed pure O<sub>2</sub> for 1 hour and the cabin pressure is at 10.2 psi. Once initial prebreathe is complete, the EV crew remains in the 10.2 psi atmosphere from 12 to 36 hours, depending on the mission plan. If the crew remains at 10.2 for 36 hours, the initial 1-hour mask prebreathe may be deleted. If the crewmembers are at 10.2 from 12 to 24 hours, the in-suit prebreathe, ranges from 40 to 75 minutes, respectively.

If initial mask prebreathe or in-suit prebreathe is interrupted and cabin air is breathed for a short period of time, a 2:1 payback rule is necessary to eliminate the N<sub>2</sub> that was introduced. This rule has been tested and approved only for a short break in prebreathe. The value for R at the end of this procedure is equivalent to that obtained from the 4-hour in-suit prebreathe at 14.7 psi cabin pressure (R = 1.65). The nitrogen level in the body drops from 11.6 psi during initial mask prebreathe, further decreases during 10.2 psi cabin pressure maintenance, and finally reaches a safe level during in-suit prebreathe.

The 10.2 psi prebreathe protocol is preferred by the EV crewmembers because of the reduced time of in-suit prebreathe (40 to 75 minutes as opposed to 4 hours). This reduced prebreathe time means that the EV crew can contribute more productive time toward mission activities. The 14.7 psi prebreathe protocol was used for the first space shuttle-era EVA during STS-6. It was later replaced by the 10.2 psi protocol and is retained for use on Spacelab missions or contingency EVAs. Most Spacelab experiments require a 14.7 psi cabin pressure. However, if Spacelab is deactivated, the 10.2 psi protocol may be used. This condition could occur in the event that a manual PLBD closure or RMS stow is required.

Research at JSC has shown that EVAs may be performed on consecutive days (back-to-back) without altering the chances of incurring DCS symptoms. Testing proved that 17 hours between two EVAs should be sufficient to preclude the occurrence of any symptoms.

## Theory

Denitrogenation is effective because gases tend to diffuse from high concentration areas to low concentration areas. Eliminating all inhaled N<sub>2</sub> allows the internal N<sub>2</sub> pressure to seek the external atmosphere and consequently travel to the lungs for exhalation and elimination. For all protocols, the risk of developing DCS is roughly

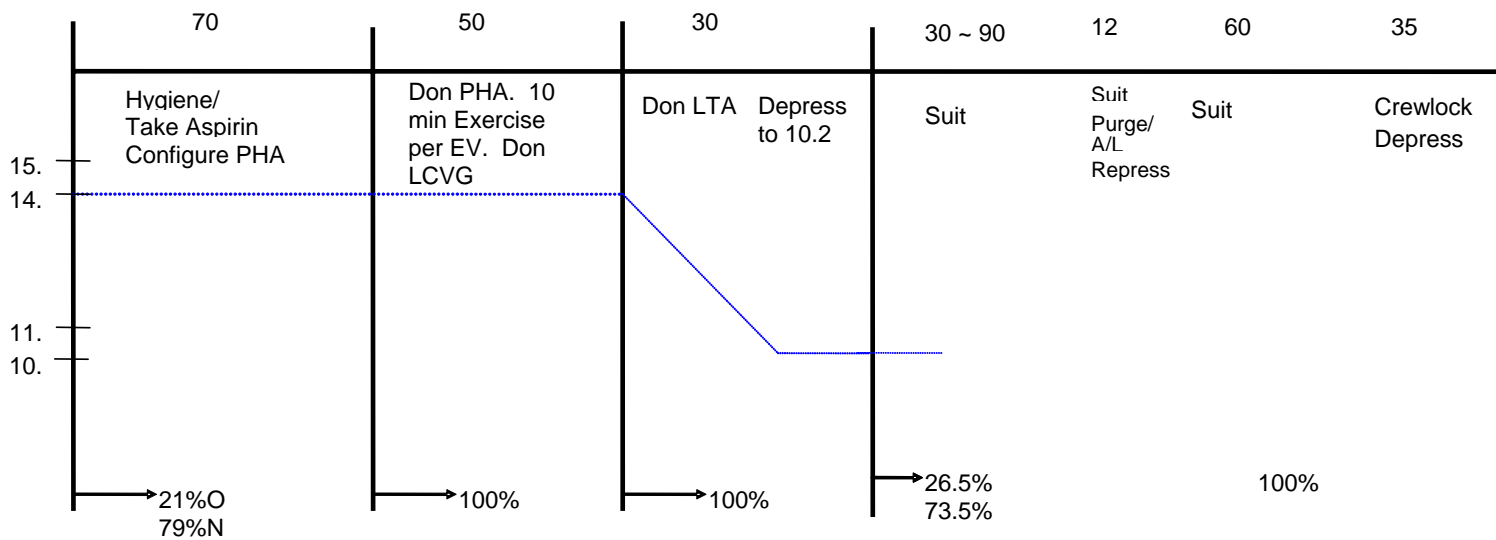
approximated using the Haldane equation to calculate the Haldane ratio, R.  
R values between 1.65 and 1.68 are associated with reduced risk of developing DCS.

$$R = \frac{ppN_2}{P_f}$$

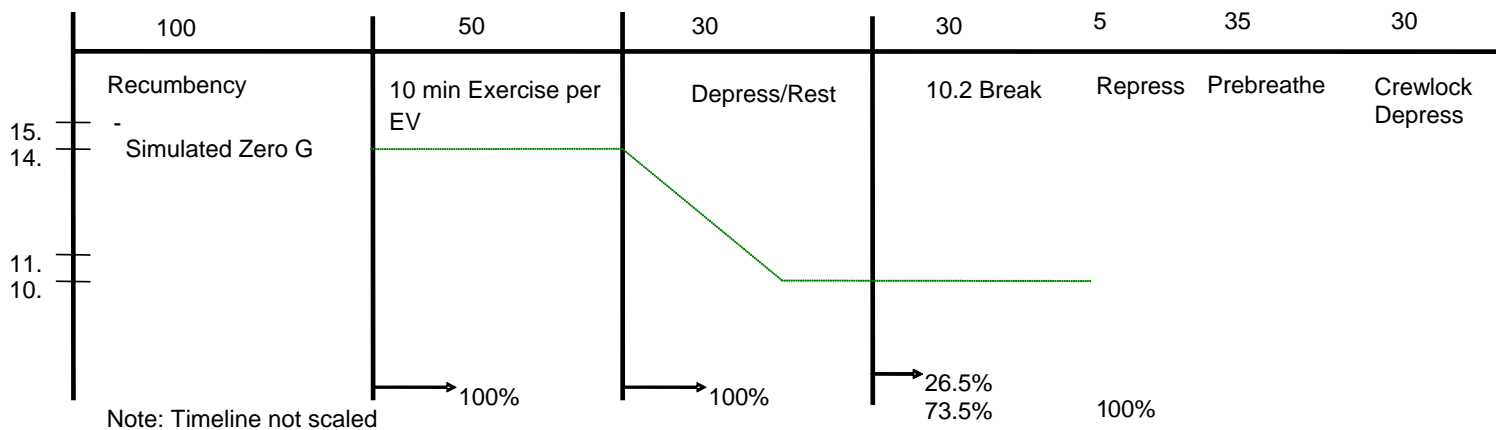
ppN<sub>2</sub> - Partial pressure of N<sub>2</sub> after completion of prebreathe  
P<sub>f</sub> - Final ambient pressure

**Testing (ISS Exercise Prebreathe)**

**STATION TIMELINE  
PRESSURE**



**TEST TIMELINE  
PRESSURE**



**Figure 3.3-5 Prebreathe Timeline a) Prescribed Protocol, b) Tested Protocol**



Refer to Figure 3.3-5 for a comparison of the prescribed exercise prebreathe protocol and the laboratory tested protocol. The prescribed protocol is conservative when compared to the tested protocol and many of the operational constraints found in the documented protocol are derived from the tested protocol. Originally the in-suit prebreathe duration was 40 minutes; however, the in-suit Doppler (ISD) program was cancelled removing Venous Gas Emboli (VGE) detection capability. The removal of the ISD program resulted in an extension of the in-suit prebreathe time to 60 minutes.

**References:**

Flight Rule B13-107

Flight Rule B15-55 Airlock Go/No-Go for Prebreathe

Flight Rule A13-103

Prebreathe Discussions: DX35 and JOP

SSPCB Presentation: Campout vs. Exercise; Moore, Laura, March 2004.

### 3.4 HYPOXIA

#### PURPOSE

This section provides general information on hypoxia as it relates to EVA, including the different types, symptoms, and treatment of hypoxia.

#### DESCRIPTION

Hypoxia is caused by a deficiency of oxygen in the body tissues. Anoxia is the complete lack of O<sub>2</sub>; if not treated, death can occur in 5-7 minutes. Dalton's law states that the total pressure of a mixture of gases is equal to the sum of the partial pressures (pp) of each gas in the mixture:

$$P_{\text{total}} = pp_1 + pp_2 + pp_3 + \dots$$

A minimum partial pressure of O<sub>2</sub> (ppO<sub>2</sub>) must be maintained to provide an adequate pressure gradient from the lungs to the tissues. Partial pressure is used for establishing oxygen requirements in manned environments. The total pressure of the breathing medium has no effect. The ppO<sub>2</sub> at sea level is 3.06 psi. According to Aeromed flight rule A13.1.2-5A, the minimum ppO<sub>2</sub> at 14.7 psi and 10.2 psi cabin pressure is 2.29 psi and 2.35 psi, respectively. These limits ensure adequate delivery of oxygen to the alveoli and represent the O<sub>2</sub> pressure equivalent to breathing air at 8000 ft altitude. If the ppO<sub>2</sub> drops below these limits, the crew must put on the quick don masks (QDMs) or launch and entry helmets (LEHs) for supplemental O<sub>2</sub>. At 8000 ft, the body uses mechanisms to compensate for the drop in oxygen pressure by increasing heart rate and increasing cardiac output and hyperventilation. These signs are not pathological manifestations, but physiological adjustments. Symptoms occur when the physiological adjustments are not enough to compensate and usually occur at higher altitudes.

The lower limit to sustain life for an extended period of time is 2.9 psi (38,000 ft), assuming a breathing source of pure oxygen with RQ assumed to be 1. A more conservative physiological limit is found in Aeromed flight rule A13.1.2-5B, which states that an EVA must be terminated if the suit falls below 3.25 psi. This limit is based on achieving an alveolar O<sub>2</sub> pressure that is equivalent to a person breathing air at 8000 ft.

Mean alveolar oxygen pressure is calculated as follows:

$$P_{\text{AO}_2} = (P_{\text{B}} - P_{\text{H}_2\text{O}}) F_{\text{IO}_2} - P_{\text{ACO}_2} (F_{\text{IO}_2} + ((1 - F_{\text{IO}_2}) / RQ))$$

where,

$P_{\text{B}}$  = ambient barometric pressure

$P_{\text{H}_2\text{O}}$  = water vapor at body temperature (47 mmHg at 37° C)

$F_{\text{IO}_2}$  = fraction of inspired oxygen (1.0 for 100% O<sub>2</sub>, 0.21 for air)

$P_{\text{ACO}_2}$  = mean alveolar carbon dioxide pressure (40 mmHg at sea level)

RQ = respiratory quotient (assumed to be 1.0 for 100% O<sub>2</sub>)

Assuming a PACO<sub>2</sub> of 36 mmHg (0.7 psi), a water vapor pressure of 47 mmHg (0.91 psi) in the lungs, a respiratory quotient (RQ) of 0.88, a PAO<sub>2</sub> of 70 mmHg (1.35 psi), and a breathing source of 92% oxygen (assuming 8% N<sub>2</sub> in the suit), the total pressure is 163 mmHg (3.15 psi). The alveolar oxygen pressure (PAO<sub>2</sub>) is 70 mmHg (1.35 psi) at 8000 ft.

$$P_{AO_2} = (163 - 47) 0.92 - 36 (0.92 + ((1 - 0.92) / 0.88)) = 70 \text{ mmHg}$$

The minimum pressure that protects a crewmember from hypoxia in the EMU is 3.15 psia, given the worst case situation of 8% N<sub>2</sub> in the suit. Because of the accuracy of the suit pressure sensor, the displayed suit pressure may indicate 3.30 psia, while the body could actually be at 3.15 psia.

Note that PACO<sub>2</sub> is really the pressure that defines where the body is in terms of hypoxia and not so much the ambient PPO<sub>2</sub>. However, the flight rules are written in terms of PPO<sub>2</sub> to accommodate the sensor readings.

Table 3.4-1 lists the alveolar O<sub>2</sub> pressure, alveolar CO<sub>2</sub> pressure, and the water vapor pressure at various altitudes and pressures.

**Table 3.4-1. Respiratory gas pressures**

Source: Fundamentals of Aerospace Medicine, 2<sup>nd</sup> edition,  
Roy L. Dehart, M.D., M.P.H., 1996

Altitude (m)	Altitude (ft)	Pressure (psia)	Pressure (mmHg)	P <sub>AO2</sub> (mmHg)	P <sub>ACO2</sub> (mmHg)	P <sub>H2O</sub> (mmHg)
Breathing Air						
0	0	14.69	759.97	103	40	47
305	1000	14.17	733.04	98.2	39.4	47
610	2000	13.66	706.63	93.8	39.0	47
914	3000	13.17	681.23	89.5	38.4	47
1219	4000	12.69	656.34	85.1	38	47
1524	5000	12.23	632.46	81	37.4	47
1829	6000	11.77	609.09	76.8	37	47
2134	7000	11.34	586.49	72.8	36.4	47
2438	8000	10.91	564.64	68.9	36.0	47
2743	9000	10.50	543.31	65	35.4	47
3048	10,000	10.10	522.73	61.2	35	47
3353	11,000	9.72	502.92	57.8	34.4	47
3658	12,000	9.34	483.36	54.3	33.8	47
3962	13,000	8.99	464.82	51	33.2	47
4267	14,000	8.63	446.53	47.9	32.6	47
4572	15,000	8.29	429.01	45	32	47
4877	16,000	7.96	411.99	42	31.4	47

**Table 3.4-1. Respiratory gas pressures (concluded)**

Altitude		Pressure		P <sub>AO2</sub>	P <sub>ACO2</sub>	P <sub>H2O</sub>
(m)	(ft)	(psia)	(mmHg)	(mmHg)	(mmHg)	(mmHg)
5182	17,000	7.65	395.73	40	31	47
5486	18,000	7.34	379.73	37.8	30.4	47
5791	19,000	7.05	364.49	35.9	30	47
6096	20,000	6.76	349.5	34.3	29.4	47
6401	21,000	6.48	335.28	33.5	29	47
6706	22,000	6.21	321.31	32.8	28.4	47
7010	23,000	5.95	307.85	32	28	47
7315	24,000	5.7	294.89	31.2	27.4	47
7620	25,000	5.46	282.45	30.4	27	47
Breathing 100% Oxygen						
10,058	33,000	3.81	197.10	109	40	47
10,973	36,000	3.30	170.94	85	38	47
11,887	39,000	2.86	148.08	64	36	47
12,802	42,000	2.48	128.27	48	33	47
13,716	45,000	2.15	111.25	34	30	47
14,021	46,000	2.05	105.92	30	29	47

Table 3.4-2 shows the relationship between pressure (psi) and O<sub>2</sub> saturation, depending on the breathing source.

**Table 3.4-2. Pressure versus arterial O<sub>2</sub> saturation**

Source: Textbook of Medical Physiology, Guyton. 1981.

Altitude (ft)	Pressure (psi)	Breathing pure O <sub>2</sub> arterial O <sub>2</sub> saturation (%)	Breathing air arterial O <sub>2</sub> saturation (%)
Sea level	14.7	100	97
10,000	10.11	100	90
20,000	6.76	100	70
30,000	4.37	99	20
40,000	2.73	87	5
50,000	1.69	15	1

When breathing 100% O<sub>2</sub> at sea level, the body is 100% saturated with O<sub>2</sub> (arterial saturation). At sea level and 60% O<sub>2</sub> saturation, death will occur due to hypoxia. The ppO<sub>2</sub> in a space vehicle should be maintained ideally to provide 95% blood saturation to ensure optimum performance. At a nominal EMU pressure of 4.3 psi and 100% O<sub>2</sub>, there is 99% O<sub>2</sub> saturation, which is nearly equivalent to breathing at sea level.

When O<sub>2</sub> saturation declines to 87%, the symptoms of hypoxia become apparent. O<sub>2</sub> saturation below 65% is considered critical because the symptoms of hypoxia become severe and time of consciousness is brief.

Table 3.4-3 shows the different stages of hypoxia relative to altitude and oxygen saturation of blood.

**Table 3.4-3. Stages of hypoxia**

Source: Fundamentals of Aerospace Medicine, 2<sup>nd</sup> edition,  
Roy L. Dehart, M.D., M.P.H., 1996

Stage	Altitude breathing air		Altitude breathing 100% O <sub>2</sub>		Arterial O <sub>2</sub> saturation
	(m)	(ft)	(m)	(ft)	
Indifferent	0-3000	0-10,000	10,400-11,900	34,000-39,000	98-87
Compensatory	3000-4600	10,000-15,000	11,900-13,000	39,000-42,500	87-80
Disturbance	4600-6100	15,000-20,000	13,000-13,700	42,500-44,800	80-65
Critical	6100-7000	20,000-23,000	13,700-13,900	44,800-45,500	65-60

At the indifferent stage, adaptation to the dark is affected at altitudes as low as 1500 m (5000 ft), where visual acuity at night is reduced by approximately 10 percent. Impaired performance of new tasks and a slight increase in heart rate and ventilation rate occurs at this stage.

At the compensatory stage, cardiovascular and respiratory responses provide some protection against hypoxia. These responses may include increases in respiratory minute volume, cardiac output, heart rate, and blood pressure. After a short period of time, hypoxic responses at this altitude include drowsiness, impaired judgement, and difficulty with mental and motor tasks.

At the disturbance stage, the physiological compensatory mechanisms are no longer capable of adequately oxygenating the tissues, leading to more severe symptoms of hypoxia that include headache, dizziness, air hunger, euphoria, fatigue, faulty memory, severely impaired judgement and motor performance, and tunnel vision.

Finally, at the critical stage, mental performance deteriorates and mental confusion and dizziness occur within minutes and total loss of consciousness follows with little or no warning.

After exposure to reduced O<sub>2</sub> levels, there is a certain amount of time before unconsciousness results. This is called the time of useful consciousness (TUC). Table 3.4-4 shows the TUC at different altitudes, assuming the breathing source is air. For example, if cabin pressure is lost suddenly in an airplane flying above 16,000 m (52,500 ft), the sudden drop in the inspired PO<sub>2</sub> to less than 0.39 psi (20 mmHg) would cause loss of consciousness in 20 seconds and death in 4 to 5 minutes.

**Table 3.4-4. TUC after acute exposure to reduced oxygen levels**

Source: The Physiological Basis For Spacecraft Environmental Limits, NASA publication 1045, Nov. 1979.

Total pressure (psi)	Altitude (ft)	TUC (sec), moderate activity	TUC (sec), sitting quietly
6.20	22,000	300	600
5.45	25,000	120	180
4.77	28,000	60	90
4.36	30,000	45	75
3.46	35,000	30	45
2.72	40,000	18	30
0.82	65,000	12	12

**TYPES**

There are several different types of hypoxia. Each affects the body at a different level. Table 3.4-5 gives a general idea of the source and cause of the different types of hypoxia.

**Table 3.4-5. Types of hypoxia**

Source: AFVA 160-6.

Type	Level	Examples of causes
Hypoxic hypoxia	Lung	<ul style="list-style-type: none"> <li>• Child holding breath</li> <li>• Drowning</li> <li>• Pneumonia</li> <li>• Low ppO<sub>2</sub></li> </ul>
Hypemic hypoxia	Blood	<ul style="list-style-type: none"> <li>• Maybe enough O<sub>2</sub>, but not enough red blood cells</li> <li>• Loss of blood</li> </ul>
Histotoxic hypoxia	Tissue	<ul style="list-style-type: none"> <li>• Cyanide poisoning</li> <li>• Carbon monoxide poisoning</li> <li>• Alcohol level</li> </ul>
Stagnant hypoxia	Circulation	<ul style="list-style-type: none"> <li>• Blood not flowing (poor circulation)</li> <li>• Blood pools due to G forces</li> <li>• Person in shock</li> <li>• Warm climate, blood cells become dilated</li> <li>• Clots</li> </ul>

Low partial pressures of oxygen at high altitudes, reduction in ppO<sub>2</sub>, and reduction in lung capacity can cause hypoxic hypoxia. Hypemic hypoxia is related to the ability of

blood to accept O<sub>2</sub>. Histotoxic hypoxia is caused by the inability of a cell to make use of O<sub>2</sub>. A cell may already be saturated with poison or toxin. Stagnant hypoxia is caused by reduced blood flow, such as when the heart stops or from heart attack, shock, pooling of blood, embolism, extreme temperatures, exhaustion, weightlessness, tourniquets, and hyperventilation.

## SYMPTOMS

Hypoxia affects individuals differently. Visual, myocardial, and nervous tissues require the highest levels of oxygen and, therefore, are more readily affected than other tissues. There are many signs and symptoms of hypoxia associated with altitude.

### Subjective symptoms:

- Air hunger
- Apprehension
- Tingly feeling
- Euphoric attitude
- Belligerence
- Fatigue
- Nausea
- Light headedness
- Dizziness
- Headache
- Hot/cold flashes
- Tunnel vision
- Blurred vision
- Numbness

### Objective signs:

- Increased rate and depth of breathing
- Cyanosis
- Poor judgement
- Muscle incoordination
- Mental confusion
- Unconsciousness

Several factors affect the severity of signs and symptoms, including altitude, time spent at altitude, rapid rate of ascent, physical exertion, temperature extremes, fatigue, alcohol, medications, and poor nutrition.

## TREATMENT

The treatment for hypoxia as it relates to the shuttle program is to breathe 100% O<sub>2</sub> and descend to a safe altitude. The flight surgeon is responsible for the treatment and diagnosis of hypoxia. The treatment for hypoxia as it relates to the EMU is to abort the EVA and perform an emergency repress of the airlock.

## REFERENCES

NASA SP-118 Space-Cabin Atmospheres

Textbook of Medical Physiology, Guyton

The Physiological Basis for Spacecraft Environmental Limits, NASA Publication 1045

NSTS-12820, Space Shuttle Operational Flight Rules

Fundamentals of Aerospace Medicine, 2<sup>nd</sup> edition, Roy L. Dehard, M.D., M.P.H., 1996

Review of Medical Physiology, William F. Ganong, M.D.



### 3.5 CO<sub>2</sub> CONSIDERATIONS

#### PURPOSE

This section describes the CO<sub>2</sub> considerations related to EVA, including background information, physiological limits, and EMU design considerations.

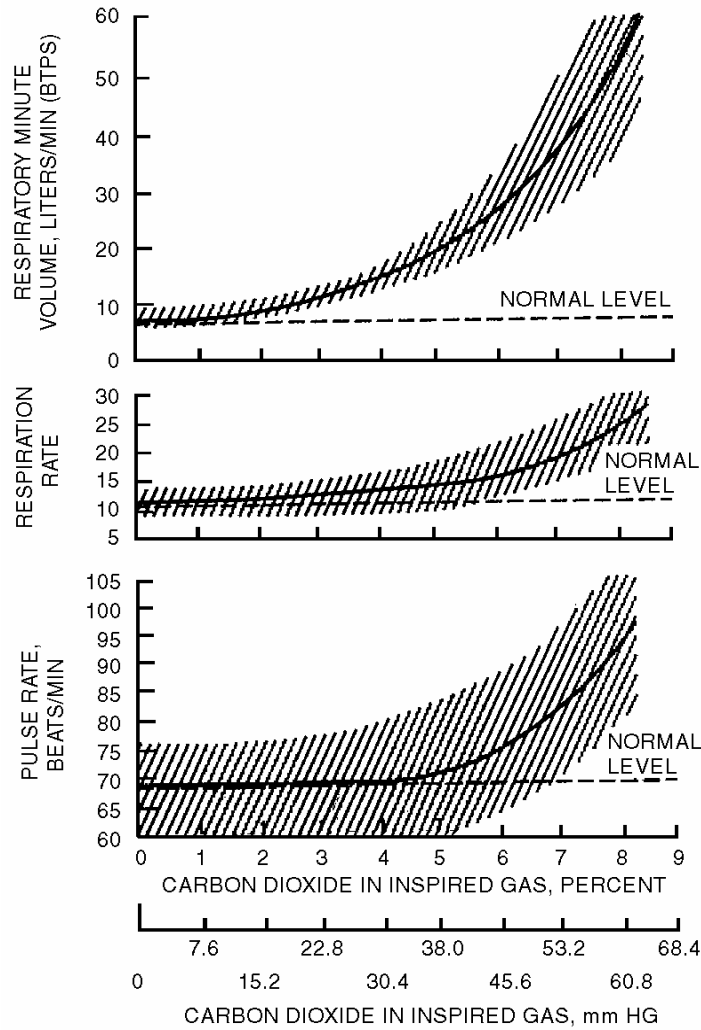
#### DESCRIPTION

CO<sub>2</sub> is a product of respiration. The concentration of CO<sub>2</sub> increases in closed environments that are crowded or poorly ventilated.

The effects of increased levels of CO<sub>2</sub> depend on concentration and the time of exposure. The body responds to a buildup of CO<sub>2</sub> by increasing the depth of breathing, respiration rate, and heart rate. Other symptoms may include headaches, dizziness, drowsiness, or muscular weakness.

Chronic exposure to CO<sub>2</sub> disrupts the acid-base balance of the body. Production of the acid and base occurs as part of the normal metabolic processing of CO<sub>2</sub>. Normally, CO<sub>2</sub> is expelled from each cell of the body tissues as a waste byproduct of metabolic reactions. The bloodstream picks up the dissolved CO<sub>2</sub> and eventually carries it to the lungs, where it is exchanged for O<sub>2</sub>. The entire pH balancing process can be upset if the ambient partial pressure of CO<sub>2</sub> (ppCO<sub>2</sub>) is increased above normal concentrations. A higher external ppCO<sub>2</sub> makes removal of CO<sub>2</sub> from the lungs more difficult and allows CO<sub>2</sub> to build up in the bloodstream. The central nervous system recognizes the increased CO<sub>2</sub> in the blood when more acid is produced and the pH of the bloodstream is lowered. The central nervous system next commands the body to overcome this buildup of excess CO<sub>2</sub> by increasing the depth of breathing, the breath rate, and the heart rate. The most common symptom of CO<sub>2</sub> toxicity is increased breathing rate, which usually occurs at 1 to 2 percent (7.6 to 15 mmHg). The pulse begins to increase at 3 to 5 percent (22 to 38 mmHg).

Figure 3.5-1 shows the immediate effects of increased CO<sub>2</sub> on pulse rate, respiration rate, and respiratory minute volume (BTPS = body temperature and pressure, saturated with water) for subjects at rest.



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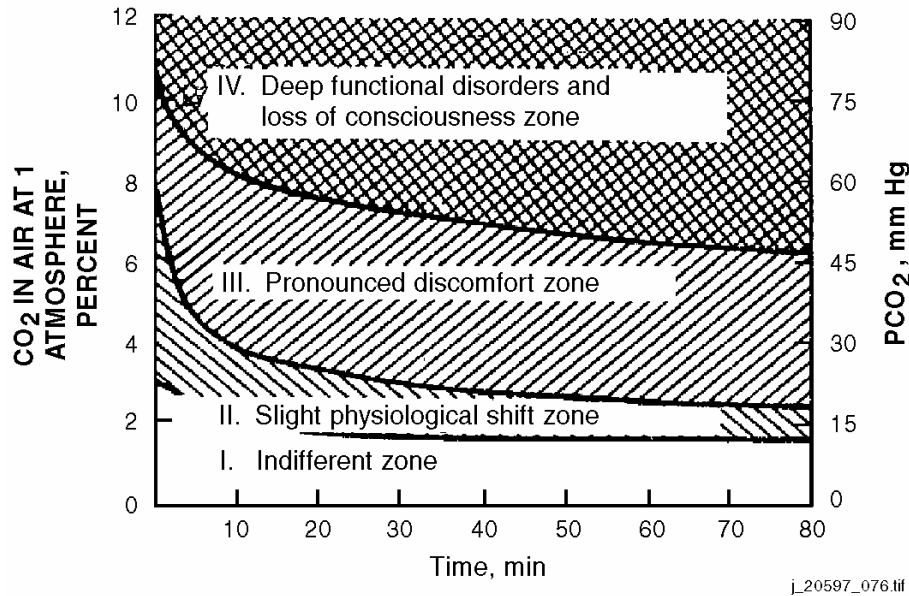
**Figure 3.5-1. Immediate effects of increased CO<sub>2</sub>**

Source: Space Physiology and Medicine, 2<sup>nd</sup> edition, 1989

The hatched areas represent one standard deviation on each side of the mean. To convert percentage CO<sub>2</sub> to partial pressure, multiply percent value by 1.013 for kilonewtons per square meter or by 7.6 for mmHg (ref. NASA publication 1045, p. 10). For comparison, standard air volume at sea level is composed of 0.03 percent CO<sub>2</sub>, which corresponds to 0.23 mmHg CO<sub>2</sub>. Given a CO<sub>2</sub> level of 15 mmHg (2 percent), the respiratory minute volume increases from 8 L/min to approximately 10 L/min, and the respiration rate increases from 12 to 13 breaths per minute. The pulse rate remains relatively constant until the level of CO<sub>2</sub> reaches 31 mmHg (4 percent), at which time it rapidly increases.

The duration of exposure to increased ppCO<sub>2</sub> also affects the body's response to CO<sub>2</sub> toxicity. With the increase in ppCO<sub>2</sub> in the alveolar areas of the lungs, the alveolar ppO<sub>2</sub> must decrease to keep the total alveolar pressure constant. The combination of

decreased alveolar ppO<sub>2</sub> and increased ppCO<sub>2</sub> acts to magnify the body's response with time. Serious physical disorders occur sooner with increased ppCO<sub>2</sub> and will worsen as exposure time extends. Figure 3.5-2 shows symptoms common to most subjects exposed for various times to CO<sub>2</sub> air mixtures at 1 atmosphere (14.7 psi).



**Figure 3.5-2. General symptoms resulting from duration exposure of CO<sub>2</sub>**

Source: The Physiological Basis for Spacecraft Environmental Limits, NASA publication 1045.

In zone I, no performance degradation or any other effect is noted. In zone II, small threshold hearing losses have been found and there is a noticeable increase in depth of respiration. In zone III, judgement errors, mental depression, headache, dizziness, nausea, air hunger, and decreased visual acuity have been found. In zone IV, there is marked mental deterioration, dizziness, stupor, and eventually unconsciousness.

As a side note, recent evidence has indicated that CO<sub>2</sub> may be involved in contributing to the formation of bubbles during the onset of decompression sickness. This occurrence may be due to the high solubility and rate of diffusion of CO<sub>2</sub>, which is 20 times that of O<sub>2</sub> (ref. NASA publication 1045).

### PHYSIOLOGICAL LIMITS

Based on available data, the limiting physiological ppCO<sub>2</sub> values for the shuttle cabin have been set as shown in Table 3.5-1. There seems to be no minimum ppCO<sub>2</sub> required for normal physiological functions; therefore, any value from 0 to 3.8 mmHg is acceptable for unlimited long-term exposure. The range of 3.8 to 7.6 mmHg is permissible for a limited-duration exposure. The maximum level that can be tolerated by crewmembers over long periods of time is 7.6 mmHg. According to Aeromed Flight Rule A13.1.2-4 A., if the ppCO<sub>2</sub> levels in the cabin are between 7.6 and 15 mmHg, the

surgeon will evaluate all crew activities. Levels from 7.6 to 15 mmHg require that physical activity be restricted and possibly that the mission be aborted. Any true ppCO<sub>2</sub> values greater than 15 mmHg call for an immediate mission abort. According to Aeromed Flight Rule A13.1.2-4 A., if the CO<sub>2</sub> removal system is unable to maintain ppCO<sub>2</sub> levels in the cabin below 15 mmHg, the crew will don the QDMs, and the mission will be terminated. Symptoms of CO<sub>2</sub> toxicity will be alleviated by using the QDMs and breathing 100 percent O<sub>2</sub>.

**Table 3.5-1. Limiting physiological ppCO<sub>2</sub> values and actions**

Source: The Physiological Basis for Spacecraft Environmental Limits, NASA publication 1045; also dictated by Aeromed Flight Rules.

ppCO <sub>2</sub> physiological limits Percent mmHg		Recommended action
<0.5	<3.8	Nominal, indefinite exposure
0.5 - 1.0	3.8 - 7.6	Nominal, for mission limited duration
1.0 - 2.0	7.6 - 15	Restriction on activity, possible mission abort
>0	>5	If correction unsuccessful, take immediate action to don QDM and terminate the mission

## EMU DESIGN

The above CO<sub>2</sub> limitations have been incorporated into the EMU design through a CCC, CWS limits, and a CO<sub>2</sub> sensor. The EMU requirements allow a maximum inspired CO<sub>2</sub> of 7.6 mmHg for 1 hour at metabolic rates of 1600 Btu/hr and below and 15 mmHg for 15 min at rates up to 2000 Btu/hr. Refer to Section 2.5 for more information on CCC specifications and operational characteristics.

The EMU provides ventilation flow to remove metabolically produced CO<sub>2</sub> from the suit environment. The flowrate requirement for the EMU is 6 acfm at helmet inlet flow, which translates into a fan requirement of 7.2-7.5 acfm (ref. EMU Requirements Evolution).

The EMU CO<sub>2</sub> upper limits stored in memory of the CWS are based on the physiological limits given previously. Exceeding the limits shown in Table 3.5-2 will generate a fault message that will be displayed on the DCM, accompanied by a warning tone. Diagnosis of a real failure or a CO<sub>2</sub> sensor malfunction will follow per the EVA Cuff Checklist. If a valid message occurs, the EVA should be terminated. If it is only a sensor failure, the EVA may be continued. During EVA, pressure compensated CO<sub>2</sub> limits will nominally be annunciated, however the CWS will default to uncompensated CO<sub>2</sub> limits in the event of a failed suit pressure sensor. To maintain pressure compensation for IV operations, the airlock pressure sensor (feedwater pressure sensor) is required to measure absolute suit pressure.

**Table 3.5-2. EMU CWS ppCO<sub>2</sub> limits and actions**

Pressure Compensated CWS CO <sub>2</sub> limits / (Uncompensated CWS CO <sub>2</sub> limits)	CWS message	Recommended action
<8.0mmHg / (<3.0 mmHg)	None	Nominal indefinite exposure
8.0 – 12.4 mmHg (3.0 - 8.0 mmHg)	"MONITOR CO <sub>2</sub> , CO <sub>2</sub> XX.X MM"	<ul style="list-style-type: none"> <li>• Minimize physical activity</li> <li>• Assess physiological symptoms</li> <li>• Troubleshoot for a sensor failure using the helmet purge valve</li> <li>• If symptoms are noted, terminate EVA</li> <li>• If no symptoms noted, continue EVA and monitor physiological condition</li> </ul>
>12.4 mmHg (>8.0 mmHg)	"CO <sub>2</sub> HIGH, OPEN PURGE V"	<ul style="list-style-type: none"> <li>• Assess physiological symptoms</li> <li>• Troubleshoot for a sensor failure using the helmet purge valve</li> <li>• If symptoms are noted, terminate EVA</li> <li>• If no symptoms noted, continue EVA and monitor physiological condition</li> </ul>

According to Aeromed Flight Rule A13-107, ppCO<sub>2</sub> Constraints (One Gas), the EVA will be terminated if the CO<sub>2</sub> levels are between 8.0 and 12.4 mmHg (or between 3 and 8 mmHg uncompensated) with symptoms of CO<sub>2</sub> toxicity, or if the CO<sub>2</sub> levels are greater than 12.4 (8 mmHg uncompensated) without confirmation of a sensor failure. Determining if there is a sensor failure is necessary to avoid unnecessary termination of the EVA. "CO<sub>2</sub> SNSR BAD" message is an indication of a failed high or low CO<sub>2</sub> sensor. If this message is not enunciated, the crewmember will determine if the sensor is failed by opening the helmet purge valve and assessing subjectively if a difference is noted. If a difference is noted, it suggests that high levels of CO<sub>2</sub> were present. If no difference is noted, it suggests a failed sensor; therefore, the EVA will continue while physiological condition is monitored. The Flight Controllers can also monitor trends in downlinked data to determine if the sensor is failed. In the event of a sensor failure, the Flight Surgeon may request to periodically evaluate the crewmember for symptoms of hypercapnia. If symptoms are present, the EVA will be terminated.

The CO<sub>2</sub> sensor is located downstream of the LiOH or METOX canister (CCC) in the ventilation supply line to the helmet. It functions via a supply line containing <1 percent of the normal vent flow. The readings from the sensor will indicate high CO<sub>2</sub> only if the CCC no longer scrubs out CO<sub>2</sub> (breakthrough of CCC) or if the sensor fails high. For METOX, the ppCO<sub>2</sub> will fluctuate more than it does with LiOH. Higher ppCO<sub>2</sub> values are expected with METOX.

The infrared (IR) sensor emits a wavelength band, of which CO<sub>2</sub> absorbs a certain wavelength in that band. The CO<sub>2</sub> and reference filters look at a certain wavelength. Thermopiles convert the resultant wavelength to a voltage and send it to the electronics module for comparison with a precalculated value, and outputs 0 to 5 V dc to the CWS. The output of the CO<sub>2</sub> sensor is logarithmic. Refer to Section 2.1 for information on the CO<sub>2</sub> calculation. The lowest uncompensated value from the sensor is ~0.18 mmHg, and the highest uncompensated value is 30 mmHg. The CO<sub>2</sub> sensor specifications are shown in Table 3.5-3.

**Table 3.5-3. IR CO<sub>2</sub> transducer specifications**

Sources: SVHS13024, Hamilton Standard and NASA EMU LSS and SSA Data Book

Description	Specification
Input voltage	±13.5 V dc
Output	0-5 V dc, corresponding to 0.1-30 mmHg pCO <sub>2</sub>
Error band	±1 mmHg from 0-10 mmHg CO <sub>2</sub> , a linear rise to ± 2 mmHg at 20 mmHg, and remains at ±2 mmHg from 20-30 mmHg CO <sub>2</sub>
Response time (at 75° F)	10 seconds max. to reach 90% output with step change in CO <sub>2</sub>
Test interfaces: Inputs  Outputs	TEST: TTL logic level, active low, used in ground test mode RX: TTL level serial input to reprogram calibration levels  BITFLG: TTL logic level, indicates failure, active low TX: TTL logic level serial output used to display operational parameters and self-health status; operates at 9600 baud

There are various failure and recovery methods associated with the CO<sub>2</sub> sensor. The sensor is designed to fail off-scale high to 30 mmHg if the sensor fails the self-test. If the sensor fails, cycling the power may recover it. The sensor also fails off-scale high if water enters the sensor cavity. A hydrophobic sleeve (Zytex) was incorporated to protect the sensor from water damage. The sleeve precludes water from entering the sense cell cavity. Note that due to the quick response time of the sensor, small changes in CO<sub>2</sub> may be seen with changes in metabolic rate.

## REFERENCES

Space Physiology and Medicine, 2<sup>nd</sup> Edition

The Physiological Basis for Spacecraft Environmental Limits, NASA publication 1045

NSTS-12820, Space Shuttle Operational Flight Rules

NASA SP-118, Space-Cabin Atmospheres

EMU Requirements Evolution

Specification no. SVHS13024, Hamilton Standard

NASA EMU LSS and SSA Data Book

SVHSER21080 Software Requirements Specification for the EMU Enhanced Caution and Warning System, Rev. GE, 31 March 0512 November 03.

System Version: eCWS Ver: 18.6; 26 May 2006

## 3.6 SPACE RADIATION

### PURPOSE

To provide an overview of radiation concerns for EVA crewmembers.

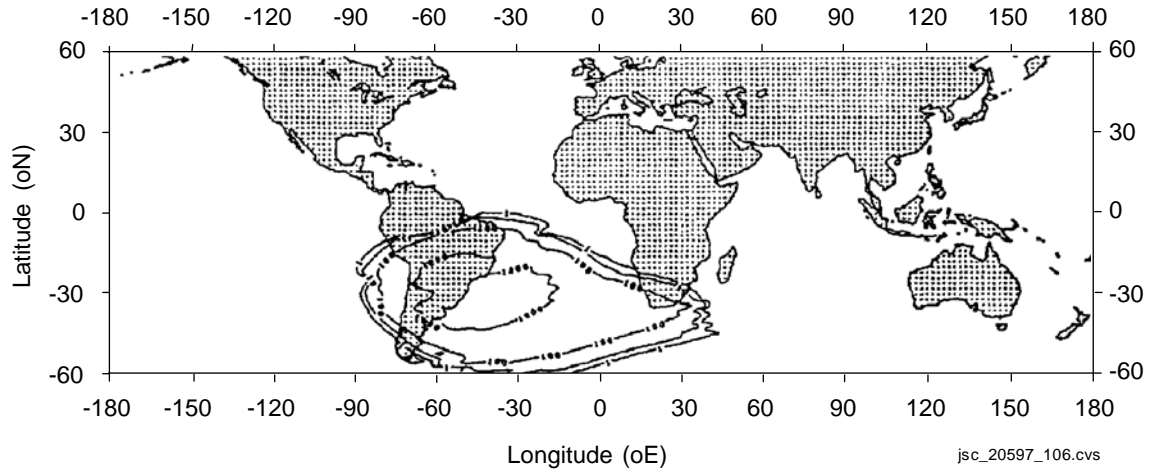
### DESCRIPTION

A major concern for space travel is the level of ionizing radiation exposure incurred by crewmembers. The level of radiation experienced during space flight has been characterized as “the primary source of hazard for orbital and interplanetary space flight” (ref. 1). In general, radiation levels during space flight have been low, even on the Mir. However, with the advent of Space Station, individuals will begin spending more time in space, and the problem of providing adequate radiation protection will expand. The question of space radiation may be even more crucial for EVA crewmembers who are not significantly protected by the extravehicular mobility unit (EMU) and who may not be shielded by the vehicle during their EVAs. Therefore, it is extremely important to consider anticipated radiation levels when planning for EVA.

The ionizing radiation experienced in space can be attributed to three major sources: (1) primary galactic cosmic radiation, (2) geomagnetically trapped radiation, and (3) solar flares/solar particle events. Galactic cosmic radiation (GCR) originates outside our solar system in galactic space. It consists of ionized atomic nuclei that are accelerated via magnetic fields to high energy levels. About 85 percent of GCR is composed of hydrogen nuclei (protons), about 13 percent is helium nuclei (alpha particles), with the remainder composed of heavier nuclei. Radiation dose attributable to the GCR is a function of spacecraft altitude and inclination (ref. 2).

Trapped radiation exists at the two Van Allen belts, of which the South Atlantic anomaly (SAA) is a portion. The location of the SAA is depicted in Figure 3.6-1 (ref. 2). The Van Allen belts are made up of several discrete belts, including two large electron belts, a high-energy proton belt, and three low-energy proton belts (ref. 3). The innermost portion of the Van Allen belts is composed of protons dipping down as low as 200 km above the Earth’s surface. This is the location of the SAA (ref. 4). For planning purposes, the SAA is the primary source of radiation in low-Earth orbit. At trajectories greater than a 30° inclination, there will be approximately five passages through the SAA in a given day, and most of the accumulated radiation is attributable to the SAA (ref. 4). Although the radiation intensity of the SAA is stronger at higher inclinations, the actual amount of time spent in the SAA may be short and the resulting dosage lower than a low inclination traverse that requires a longer transit time. In addition, the total accumulated dose will be related to the solar cycle (ref. 2). Radiation doses from trapped radiation will decrease during solar maximum due to proton loss as the increased solar activity causes atmospheric expansion. Conversely, these doses will increase during periods of solar minimum.





**Figure 3.6-1. Location of radiation belts in the SAA (from ref. 1)**

For higher altitudes or inclinations, solar flare activity becomes increasingly important. Solar flare activity is somewhat predictable, occurring in 11-year cycles. During a solar flare, protons are emitted along with radio frequency waves, X-rays, electrons, alpha particles, and ionized gas and light, both visible and ultraviolet (ref. 3). These particles may continue to reach the Earth or a spacecraft in low Earth orbit for several days after the flare itself has ceased. Dosages are difficult to predict because of the high variability of each event. If a solar burst were to occur during a space flight, it might be necessary to return the crew to Earth as quickly as possible (ref. 1). The types of radiation and their sources are presented in Table 3.6-1.

**Table 3.6-1. Types of radiation (ref. 2)**

Name	Nature of radiation	Source
X-ray	Electro-magnetic	Primary: Solar corona, stars galaxies, terrestrial atmosphere in auroral zone Secondary: Spacecraft structure in some parts of the radiation belts, in the auroral zone, and in interplanetary space following some solar flares
Gamma ray	Electro-magnetic	Stars, galaxies, unknown sporadic sources, and spacecraft atmosphere
Electron	Particle	Radiation belts and auroral regions
Proton	Particle	Galactic cosmic rays, radiation belts, and solar flares
Neutron	Particle	Primary: Galactic cosmic rays Secondary: Galactic cosmic ray interaction with spacecraft
Alpha particle (helium nucleus)	Particle	Galactic and solar
HZE particle (heavy primary nuclei)	Particle	Galactic and solar

## RADIATION MEASUREMENT AND RISKS

Radiation cannot be measured directly. Instead, the amount of resultant ionization is used to define radiation levels and subsequent biological effects. There are several interrelated units used to express radiation measurements. These are presented in Table 3.6-2 (ref. 2).

**Table 3.6-2. Radiation terminology (ref. 2)**

<ul style="list-style-type: none"> <li>Absorbed Dose (D): Ionizing radiation energy absorbed per unit mass of a given material (NASA measure in radiation absorbed doses (RADs)) equivalent to <math>10^{-5}</math> joules of energy per gram of tissue</li> </ul>
<ul style="list-style-type: none"> <li>Dose Equivalent (H): The product of "D" with a quality factor (Q), which relates dose to actual biological effect</li> </ul>
<ul style="list-style-type: none"> <li>Quality Factor (Q): A dimensionless multiplier used to correlate absorbed dose (H) to cancer risk. The Q value for each type of radiation is assigned by the International Committee on Radiation Protection</li> </ul>

There are two types of radiation risk that are of concern, stochastic and deterministic. For stochastic risk, the probability of an effect is a function of received dose, but there is some uncertainty with regard to actual occurrences. Genetic defects in offspring, cancer, and leukemia are examples of stochastic risks. Alternatively, deterministic risks and severity of effects are directly related to dose. These include sterility, radiation-induced nausea, and skin reddening (ref. 2). Table 3.6-3 provides a comparison of radiation dose and the probable effects accompanying these exposure levels.

**Table 3.6-3. Expected early effects of acute whole body radiation on Earth (ref. 2)**

Dose (RADs)	Probable effects
0-50	No obvious effect, except possible anorexia and minor blood changes
50-100	Vomiting, nausea within 1 day (10-20%); fatigue
100-200	Vomiting, nausea, followed by other symptoms of radiation sickness (up to 50%); <5% deaths expected
200-350	Vomiting, nausea (50-90%), followed by other symptoms such as loss of appetite, diarrhea, minor bleeding; 5-90 % deaths within 2-6 weeks
350-550	Vomiting, nausea in most people on first day, followed by other symptoms of radiation sickness such as fever, hemorrhage, diarrhea, emaciation; >90% deaths within 1 month
550-750	Vomiting, nausea; nausea onset within 4 hours (100%), followed by severe symptoms of radiation sickness; up to 100 % deaths
1000	Vomiting, nausea within 1-2 hours (100%); probably no survivors
5000	Immediate incapacitation; 100% fatalities within 1 week

Table 3.6-4 shows the radiation dose associated with various activities on Earth. Table 1.9-5 presents radiation limits for the public (OSHA-determined) vs. NASA - imposed limits for crewmembers. Table 3.6-4 and Table 3.6-5 show the radiation dose as applied to human tissue and is expressed in units of roentgen (radiation) equivalent man (rem).

**Table 3.6-4. Radiation exposure (ref. 3)**

Exposure type	Effective dose equivalent
Gas range	0.02 mrem/yr
Tobacco	~2 mrem/cigarette
Chest X-ray	10 mrem/X-ray
Houston background	100 mrem/yr
Kerala, India background	1300 mrem/yr

**Table 3.6-5. Dose limits (ref. 3)**

Target population	Dose equivalent
Public at large	0.1 rem/yr
Occupational dose limits	5.0 rem/yr
NASA - blood forming organs (BFOs)	50 rem/yr
NASA - eye	200 rem/yr
NASA - skin	300 rem/yr
NASA (30-day max.)	
BFO	25 rem
Eye	100 rem
Skin	150 rem
NASA (career max.)	
Eye	400 rem
Skin	600 rem

Note that NASA limits are applicable to specific organs, whereas the OSHA limits are applied to whole body dose. There is a differential sensitivity of certain organs and tissues to radiation effects, and NASA recognizes this distinction when determining crewmember limits. In general, radiation exposure is more detrimental to dividing tissues, such as bone marrow, than to slowly growing tissues, such as those found in the central nervous system. Therefore, the damage incurred by a given exposure level will be more significant in the rapidly dividing, highly sensitive tissues than in the low to moderately sensitive tissue. Table 3.6-6 delineates some of the tissue sensitivities found in the human body.

**Table 3.6-6. Differential radiosensitivity of human tissue (ref. 1)**

Sensitivity level	Tissue
High	Lymphatics/lymphoid tissue, bone marrow, gastrointestinal epithelium, gonads, embryonic tissues
Moderate	Skin, vascular epithelium, lung, kidney, liver, lens of eye
Low	Central nervous system, endocrine glands (except gonads), muscle, bone/cartilage, connective tissue

**EVA RADIATION CONSIDERATIONS**

The following rules from the U.S. Federal Register, Vol. 52, No. 17, must be followed when developing timelines for EVAs that may lead to higher than necessary radiation levels:

- There should be no occupational exposure to radiation without the expectation of overall benefit from the activity causing the exposure.
- No exposure is acceptable without first examining the justifications behind it.
- Sustained effort must be made to ensure that doses are maintained as low as reasonably achievable (ALARA).

In simple terms, it is very important to minimize radiation exposure of crewmembers to keep their equivalent doses low and limit the potential risks associated with radiation. Each EVA should be evaluated, case-by-case, to justify the risk-to-benefit ratio of the specific radiation exposure. Although it is difficult to accurately predict certain radiative events, avoidance of obvious dangers, such as the SAA, through careful planning is critical. Delays of one or two orbits could have a fourfold alteration in the radiation dose reaching an EVA crewmember.

Prior to a flight, the timing of an EVA can be worked with the Timeliners, who should have accurate knowledge of passages through the SAA and predicted radiation events. In addition, the Flight Surgeons and the Space Radiation Group (SRAG—on BME loop) can be contacted real time to evaluate the potential impacts of EVA replanning on projected radiation exposure.

**SUMMARY**

In summary, radiation is a concern to all space travelers and especially to EVA crewmembers, who may experience a greater exposure risk than their IVA counterparts. The effects of radiation exposure may be acute or long term and may even be passed on to offspring in the form of genetic alterations. Some types of radiation are predictable (SAA) and should be avoided whenever possible. Other types of radiation (solar effects) are less predictable and may require real-time decisions regarding benefit/risk of performing EVAs or even continuing a flight. The FAO and the FAO support room track passes through the SAA and should be consulted when planning or

replanning EVA timelines. Likewise, the Flight Surgeon and the surgeon support room are integral in this planning process. A full evaluation of risk vs. benefit must be performed to ensure that the EVA crewmembers are able to fulfill their mission objectives with as little exposure as possible.

## REFERENCES

Space Physiology and Medicine, NASA SP-447, chapter 20

Manned Systems Integration Standards, NASA-STD-3000/Vol. 1/Rev. B, pp. 5-83 through 5-106

SN3/M. Golightly, Presentation to DF42, 2/98

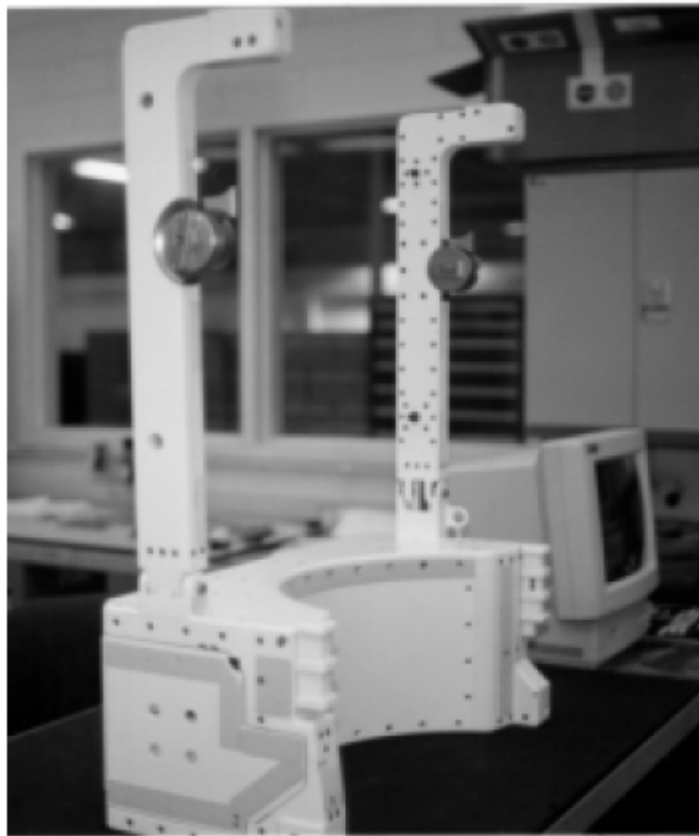
Brown, Nelson E., Dashner, Thomas, and Hayes, Benita, NASA CR-2160, Extravehicular Activities Guidelines and Design Criteria, URS/METRIX Co., Huntsville AL 35805, 1973, pp. 1-4, 1-5, 5-44 through 5-55

## 4.1 SIMPLIFIED AID FOR EVA RESCUE

### 4.1.1 INTRODUCTION

The Simplified Aid for EVA Rescue (SAFER) is a small, self-contained, propulsive backpack system used to provide free-flying mobility for an Extravehicular (EV) crewmember. Figure 4.1-1 shows SAFER without the Thermal Micrometeoroid Garment (TMG). SAFER is a single string system for contingency use only.

SAFER is designed to be used as a self-rescue device for a separated EV Crewmember. If a functional SAFER is available, each EV crewmember must wear one. If not, a two fault tolerant tether protocol is required.

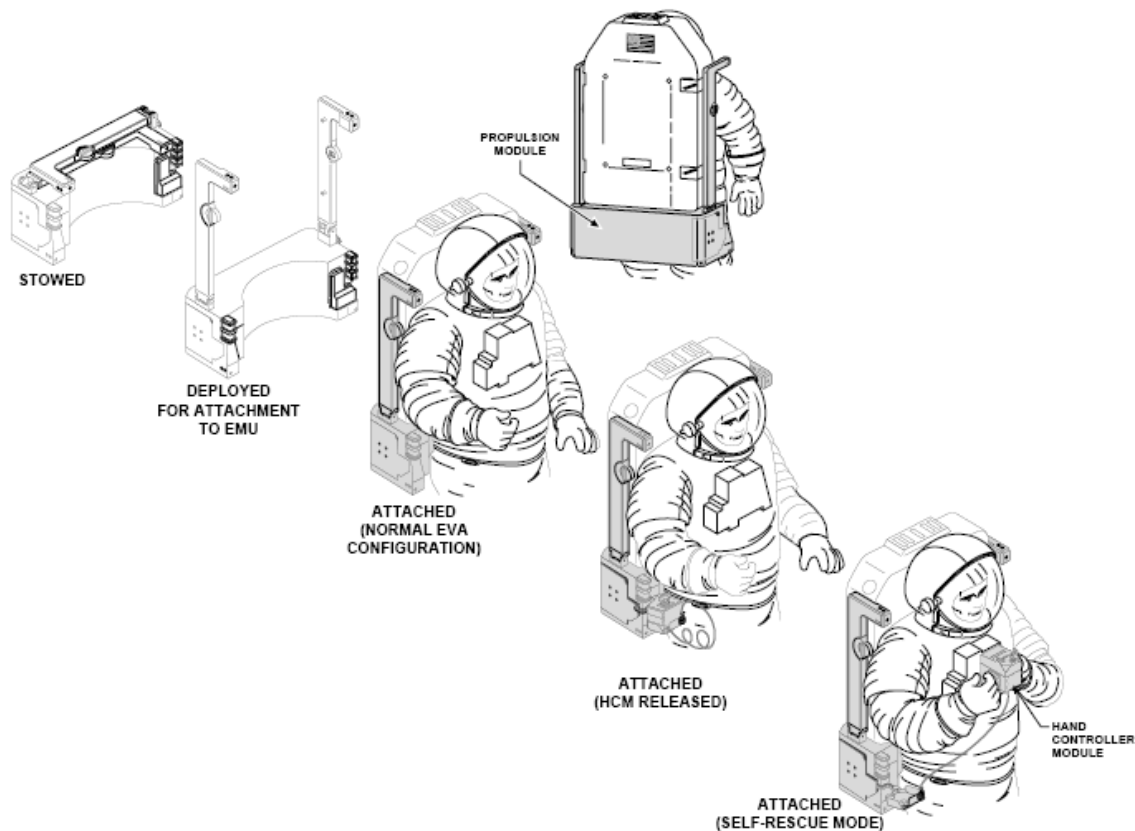


**Figure 4.1-1. SAFER**

SAFER has adequate propellant and control authority to stabilize and return a tumbling/separating crewmember.

SAFER fits around the Extravehicular Mobility Unit (EMU) Primary Life Support Subsystem (PLSS) without limiting suit mobility (Figure 4.1-2). SAFER utilizes 24 gaseous-nitrogen (GN<sub>2</sub>) thrusters to provide six degrees-of-freedom maneuvering control. SAFER is controlled by a Hand Controller Module (HCM) which provides the controls and displays for the EV crewmember to operate SAFER and to monitor its

status. The HCM deployment mechanism will be covered in detail in Section 5.1.2.2. The SAFER propulsion system provides a total delta velocity of at least 10 ft/sec. An Intravehicular (IV) replaceable battery provides a minimum of 13 minutes of power when activated (sufficient to accomplish a worst-case rescue scenario). The battery also provides sufficient power for up to 52 one-minute checkouts of SAFER during a 1 year on-orbit lifetime.

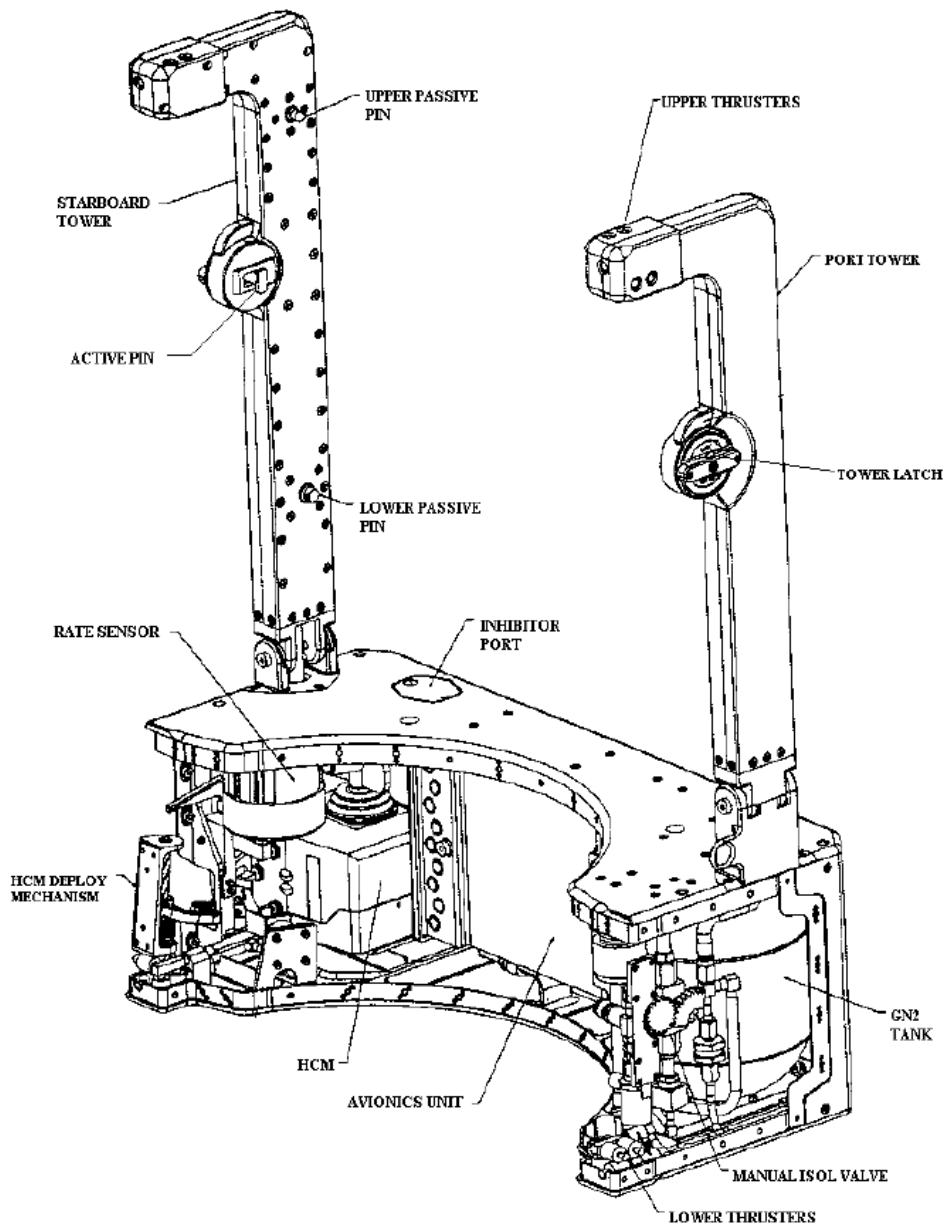


**Figure 4.1-2. Attachment of SAFER to EMU**

The SAFER flight unit weighs approximately 76 lbs. The towers fold for launch, landing, and on-orbit stowage in a stowage bag. The stowage configuration will be covered in greater detail in Section 5.1.3.

### Structures and Mechanisms

The SAFER propulsion module consists of a main frame structure, two towers, and an avionics unit, as shown in Figure 4.1-3. All propulsion module components are mounted to this structure. The structure is designed so that the SAFER flight unit can withstand a 300 lb (1 ft/sec) impact load and remain fully functional. In addition, the structure is designed to allow SAFER to withstand a 600 lb (2 ft/sec) impact load and maintain EMU/crewmember safety.



**Figure 4.1-3. SAFER propulsion module and mechanisms**

The main frame structure consists of a lightweight painted aluminum alloy frame for housing SAFER components. With the exception of the upper thrusters which are mounted to the towers, all of the SAFER propulsion system components are contained in the main frame.

### Manual Isolation Valve

Attached to the forward port side of the main frame is the actuator for the manual isolation valve. This handle provides a large grip for the crewmember to open or close the manual isolation valve. When the handle is pulled upward, a bracket attached to the



slider mechanism actuates the lever of the isolation valve to the closed position. Pushing downward on the handle will open the valve.

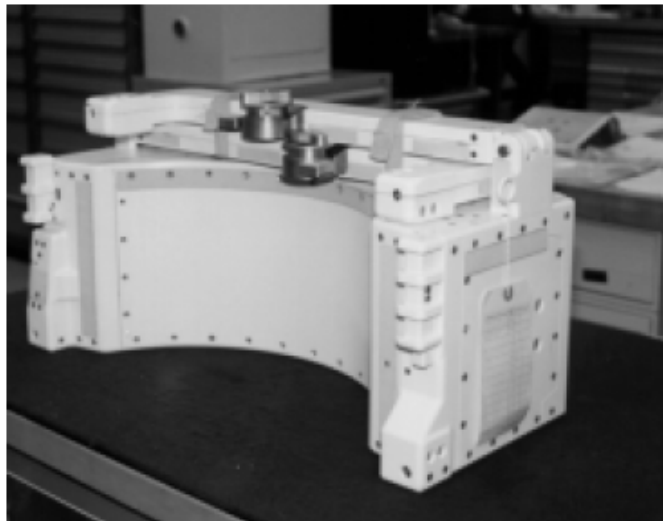
## Handles

The main frame structure has two strap type handles on the back of SAFER that are used for IV handling on orbit. The TMG prevents the handles from becoming a snag point when not in use. A tether point is provided at the base of the port tower on the front side as a temporary restraint during donning/doffing and transfer of SAFER.

## Towers

The port and starboard towers are constructed of lightweight machined aluminum. The towers provide the means to mount the SAFER to the EMU PLSS interfaces.

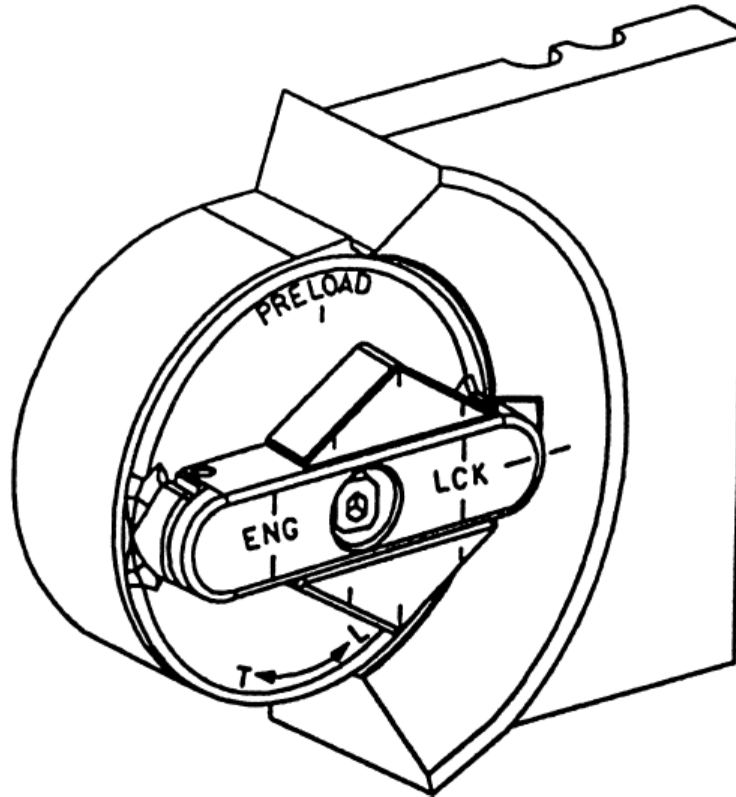
The towers have hinge joints which allow them to be folded for SAFER stowage. The hinge joints are designed with provisions for GN2, electrical power, and signal routing to the thrusters. In addition, the hinge joints are designed to prevent pinching of an EMU glove. Two Velcro straps are used to secure the towers in the folded position (Figure 4.1-4). These straps are removed prior to EVA and reinstalled after EVA for SAFER stowage. The towers are unfolded for IV or EV attachment of SAFER to the PLSS interfaces.



**Figure 4.1-4. SAFER with folded towers**

The inboard sides of the towers contain the interfaces to the EMU PLSS. The interface on each tower consists of one latch/active pin and two passive pins. The latch is a “push and turn” circular dial which attaches and locks to the MMU striker plate on the PLSS. The latch has three positions: PRELOAD, ENGAGE, and LOCK (Figure 4.1-5). The PRELOAD and ENGAGE positions allow for positioning and engaging of the active pin to the MMU striker plate. The LOCK position ensures that the active pin cannot

disengage from the MMU striker plate. Passive pins above and below the latch attach to the PLSS at the Airlock Adapter Plate (AAP) striker plates (i.e., the EMU/airlock mounting interface). These pins provide a passive contact point between SAFER and the EMU. These pins also serve as alignment guides for the latches.



*Figure 4.1-5. SAFER tower latch*

#### 4.1.2 System Description

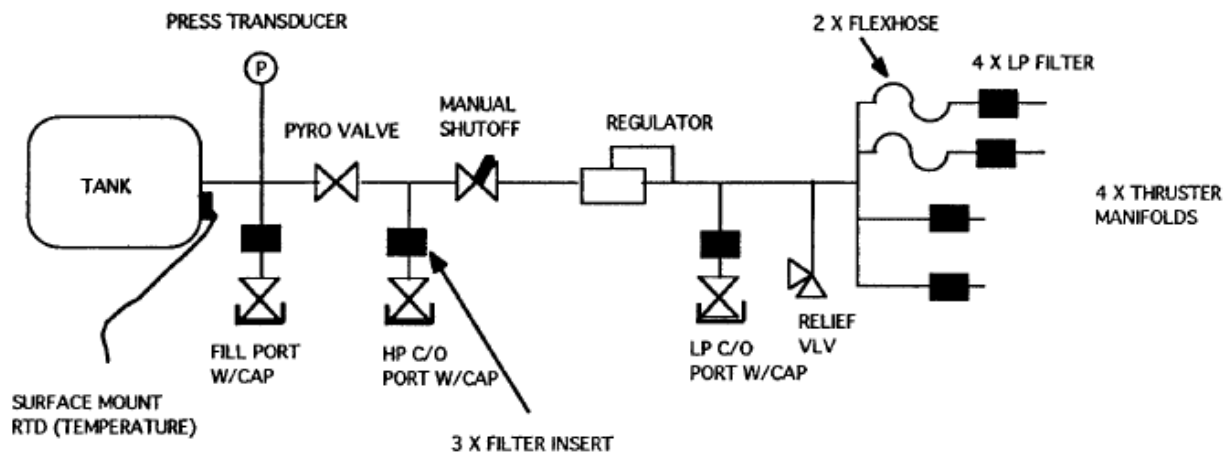
This section discusses the function and characteristics of each major assembly and system of SAFER as listed below:

- A. Propulsion System
- B. Hand Controller Module
- C. System Monitoring Software
- D. Avionics Software
- E. Battery

#### 4.1.2.1 Propulsion System

The Propulsion System contains the following components (shown schematically in Figure 4.1-6):

- A. GN2 tank
- B. Pressure Transducer
- C. Temperature Transducer
- D. Pyrotechnic Isolation Valve
- E. Manual Isolation Valve
- F. Regulator
- G. Relief Valve
- H. Thrusters

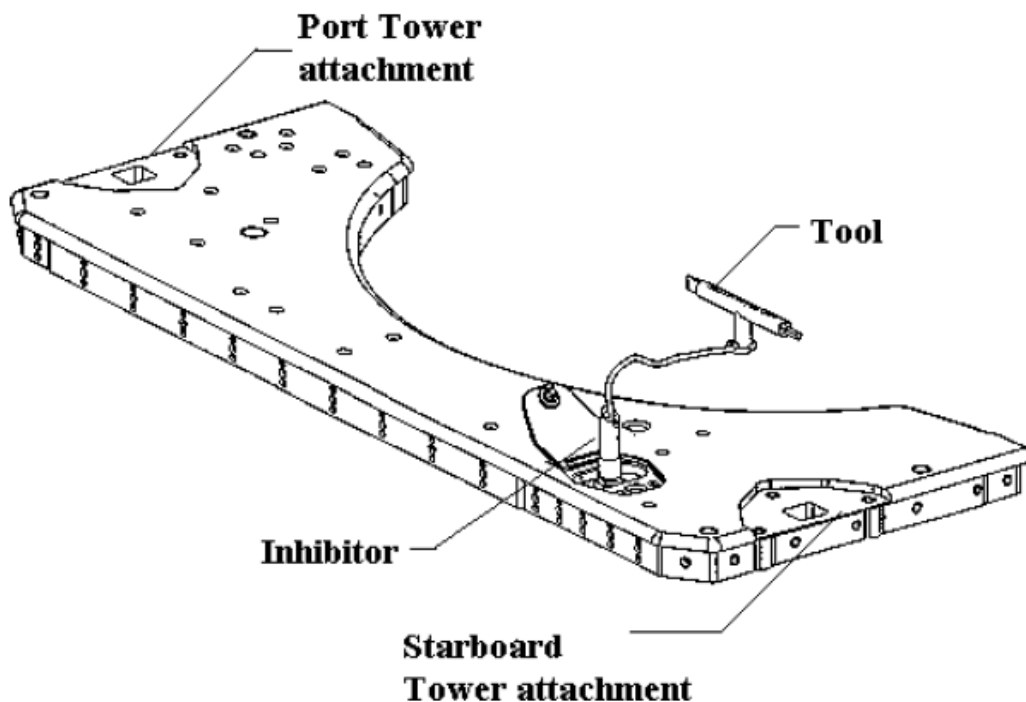


**Figure 4.1-6. SAFER propulsion system schematic**

The high pressure tank contains 2.92 lbs of GN2 that is charged to 8000 psia at 80°F prior to flight. The tank is lined Kevlar wrapped stainless-steel and is certified for 100 cycles to the maximum operating pressure of 10,000 psia. The initial charge pressure prevents the tank pressure from exceeding the 10,000 psia maximum pressure at elevated temperatures. The SAFER GN2 tank is not rechargeable on orbit.

The GN2 tank has a pressure and a temperature transducer. The pressure transducer has an operating range of 0 to 10,000 psia with an accuracy of +/- 100 psia. The temperature transducer has an operating range of -100°F to +200°F with an accuracy of +/- 2°F and is surface mounted with adhesive to the tank. These parameters are displayed on the HCM display. The pyrotechnic isolation valve (pyro valve) allows for

long term leak-free storage of the GN2 supply. This type of valve was chosen for this application because mechanical valves are prone to leakage which would result in a shorter on-orbit lifetime. This valve uses the NASA Standard Initiator (NSI) for activation. NSI is a common pyrotechnic initiator that is used to operate a normally closed pyro valve. The pressure generated by the NSI gases pushes a piston at the valve inlet allowing gas to flow from the tank through the valve and on to the pressure regulator. This is only mentioned because the failure message associated with the pyro valve uses the term NSI. This will be discussed in greater detail in Section 4.1.2.3. When SAFER is powered, the pyro valve receives a fire command to open the valve, allowing propellant to flow. In order to prevent the pyro valve from firing during IV checkout, an inhibitor is installed. The inhibitor is tethered to a combination T-handle tool. One end of the T-handle tool consists of a flat head screwdriver used to open the inhibitor port, and the other end consists of an Allen head driver used for battery changeout. This inhibitor also protects against firing from an accidental power on switch throw during IV handling and stowage. Figure 4.1-7 shows the SAFER top plate with the inhibitor installed. A power switch guard is installed for launch and entry because the inhibitor is not certified to withstand these vibrations and loads.



**Figure 4.1-7. SAFER top plate with inhibitor**

The manual isolation valve is nominally open during EVA to allow propellant flow when the pyro valve is fired. The intended purpose of the manual isolation valve is to allow the crewmember to isolate the GN2 supply from the downstream regulator and thrusters if a thruster fails on. The manual isolation valve is closed during IV operations to

prevent propellant flow in case the pyro valve is inadvertently fired. This valve is actuated by a slider mechanism located on the port side (shown in Figure 4.1-3) and is accessible by the EV crewmember.

The pressure regulator reduces the GN2 line pressure from tank pressure to a nominal thruster inlet pressure of 215 psia. The relief valve protects the region downstream of the regulator from over pressurization caused by a failed-open or leaking regulator. The relief valve cracks at 315 psia and maintains a maximum downstream pressure of 400 psia with a maximum inlet flow rate (i.e. failed open regulator). When the relief valve opens, the resulting GN2 dump is designed to be non-propulsive and is vented through the TMG.

After passing through the regulator and relief valve, GN2 is routed to four thruster manifolds. Two of the thruster manifolds are located on the starboard and port sides of the main frame and two manifolds are located in the starboard and port towers. The tower manifolds are Teflon flex-hoses with Nomex braiding to allow the towers to fold for stowage. Each of these manifolds contains a GN2 filter and a set of six electric-solenoid thruster-valves.

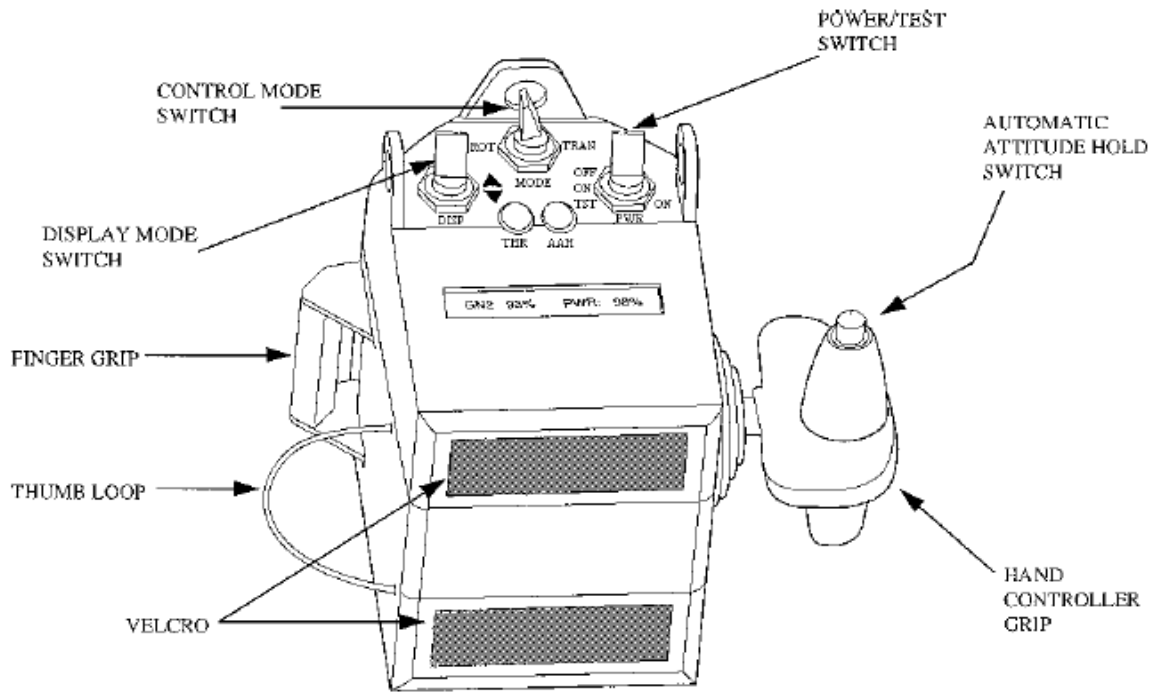
SAFER has a total of 24 thrusters; four thrusters point in each of the  $\pm X$ ,  $\pm Y$ , and  $\pm Z$  directions. The thrusters are opened with 24 V dc power at 1 amp and are kept open with a 5000 Hz pulse at 0.25 amps. Each thruster is capable of providing 0.8 +/- 0.08 lbf of thrust and a minimum specific impulse of 70 lbf-sec. When a thruster valve opens, GN2 is released and expanded through the thruster's conical nozzle to provide a propulsive force. The avionics software commands up to four thrusters at a time to provide full six degrees-of-freedom motion ( $\pm X$ ,  $\pm Y$ ,  $\pm Z$ ,  $\pm roll$ ,  $\pm pitch$ ,  $\pm yaw$ ).

All high pressure lines are made of Inconel 718, and all low pressure lines are made of stainless steel. There are 2 test ports and 1 fill port in the propulsion system that are used for ground operations only.

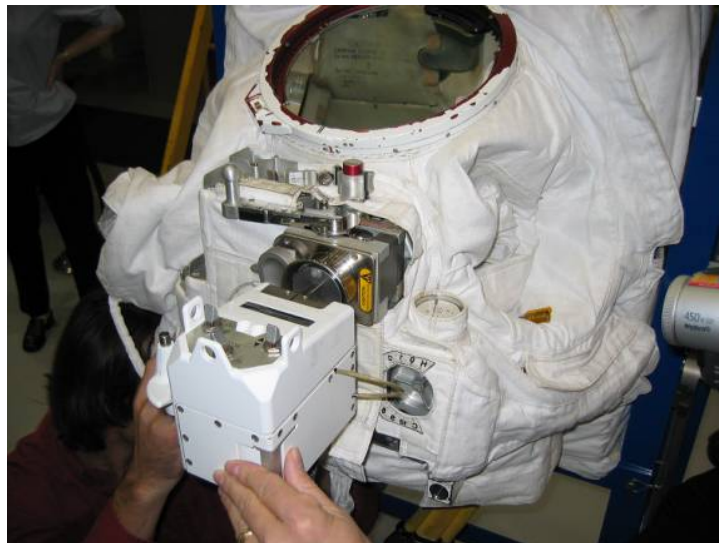
#### **4.1.2.2 Hand Controller Module**

The HCM contains the controls and displays for SAFER checkout and flight. The HCM is designed to be held by the crewmember's left hand using the thumb loop and the finger grip and operated with the right hand. For added stability, it attaches to the front of the EMU Display and Control Module (DCM) using Velcro.

For the case of TPS inspection using SAFER (for more details see Volume 5), the SAFER HCM can be hardmounted to the DCM. This is accomplished with a ball detent bracket which interfaces with a cut out on the HCM. Figure 4.1-9 shows the HCM hard mounted to the DCM.



**Figure 4.1-8. SAFER hand controller module**



**Figure 4.1-9. SAFER HCM hardmounted to DCM**

The following displays and switches are contained on the HCM, as shown in Figure 4.1-8:

- A. Liquid Crystal Display (LCD): A 16-character backlit LCD displays prompts, status information, and fault messages.
- B. Thruster cue light: A red light emitting diode (LED), labeled THR, is illuminated when a thruster “on” discrete is detected by the system software.
- C. Automatic Attitude Hold (AAH) light: A green LED, labeled AAH, is illuminated when AAH is enabled for one or more rotational axes.
- D. Power/test switch: A three-position toggle switch, labeled PWR, is used to power the ON or TST/ON modes of SAFER. The top position of the switch (oriented away from the SAFER crewmember) is the OFF position. The center position is the ON position. The bottom position is the TST/ON position. The TST/ON mode is used to activate the self-test performed checkout. The ON mode is used during SAFER flight (i.e. self-rescue).
- E. Display proceed switch: A three-position momentary toggle switch, labeled DISP, is used to control the parameters/messages displayed on the LCD. The switch springs back to the center null position when released. The top or forward switch position is labeled with an up arrow, and the bottom or aft switch position is labeled with a down arrow. When the switch is moved to the aft position (i.e., in the direction of the down arrow), the display advances to the next parameter/message. When the switch is moved to the forward position, (i.e., in the direction of the up arrow), the display moves back to the previous parameter/message. This switch is also used to proceed to the next test step in the self test if a failure is encountered by moving the switch forward or aft.
- F. Hand controller grip: The hand controller grip is a four axis mechanism with three rotary axes and one transverse axis. A command is generated by moving the hand controller from the null center position. Commands are terminated by returning the hand controller to the center position (the hand controller automatically springs back to the center position when released).
- G. Control mode switch: A two-position toggle switch, labeled MODE, is used to configure the hand controller for either rotational or translational commands. The left switch position, labeled ROT, is the rotational mode and controls roll, pitch, and yaw. The right switch position, labeled TRAN, is the translational mode.

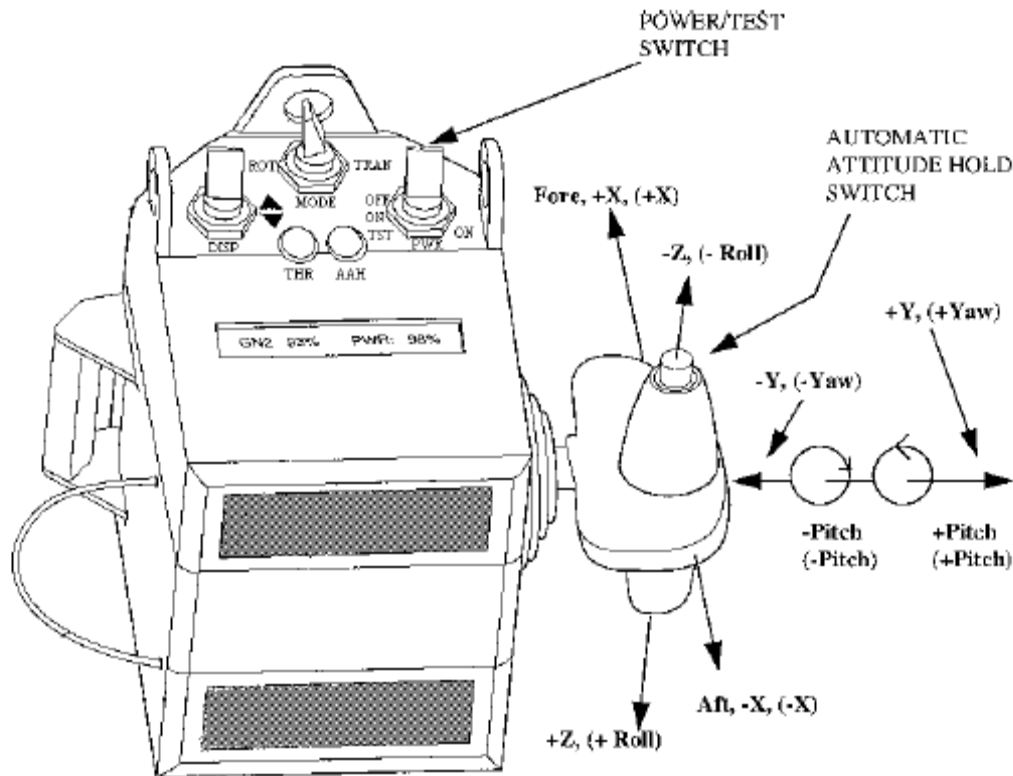
When the MODE switch is in the TRAN position,  $\pm X$ ,  $\pm Y$ ,  $\pm Z$ , and  $\pm$ pitch commands are available, as shown in Figure 4.1-9.  $\pm X$  commands are generated by rotating the hand controller forward or aft, respectively.  $\pm Y$  commands are generated by pulling the hand controller to the right or pushing it to the left, respectively.  $\pm Z$  commands are generated by rotating the hand controller down or up, respectively.  $\pm$ Pitch commands are generated by rotating the hand controller about the Y axis.

When the MODE switch is in the ROT position,  $\pm$ roll,  $\pm$ pitch,  $\pm$ yaw, and  $\pm X$  commands are available, as shown in Figure 4.1-9.  $\pm$ Roll commands are generated by rotating the hand controller down or up, respectively (same hand

controller motion as the Z commands in the TRAN mode).  $\pm$ Yaw commands are generated by pulling the hand controller to the right or pushing it to the left, respectively (same hand controller motion as the Y commands in TRAN mode). The  $\pm$ pitch and  $\pm$ X commands are generated as discussed above.

Note: The crewmember has x-translations and pitch commands in both the ROT and TRAN modes. These are the two most often used axes and allow the crewmember to use both without changing control modes.

- H. AAH (Automatic Attitude Hold) push button: The push-button switch on the top of the hand controller grip allows AAH activation and termination. The push-button switch activates AAH when depressed a single time and deactivates AAH when pushed twice within 0.5 seconds.



**Figure 4.1-10. Hand controller axes for TRAN and ROT modes**

During EVA, the HCM is located in the starboard side of the main frame and is deployed by the actuator also located on the starboard side. The HCM is deployed when the actuator is lifted upward (requires approximately 12 lbs of force), allowing the deployment arm and tray which holds the HCM to swing out (as shown in Figure 4.1-11). The crewmember grips the hand controller and pulls the HCM out of the tray (requires approximately 3.5 lbs of force) and positions it for self-rescue.



An electrical umbilical provides power and a serial data bus for data and command transmissions between the HCM and SAFER. The umbilical contains strain relief for loads up to 125 lbs. The umbilical is routed through a stand-off on the deployment tray. This stand-off aids an EV crewmember in retrieving the HCM if it is inadvertently released. The HCM umbilical is stowed by routing it through a soft loop attached on the hand controller grip side.



**Figure 4.1-11. SAFER HCM slider actuation**

#### **4.1.2.3 System Software**

The system software performs four functions:

- A. Self test
- B. Activation sequence
- C. System monitoring
- D. Ground checkout test

The fault detection system also performs the computation of parameters and construction of messages for the HCM display.

## Self Test

The self test is performed during SAFER checkout to verify proper system function. The self test is initiated by performing the following switch throws:

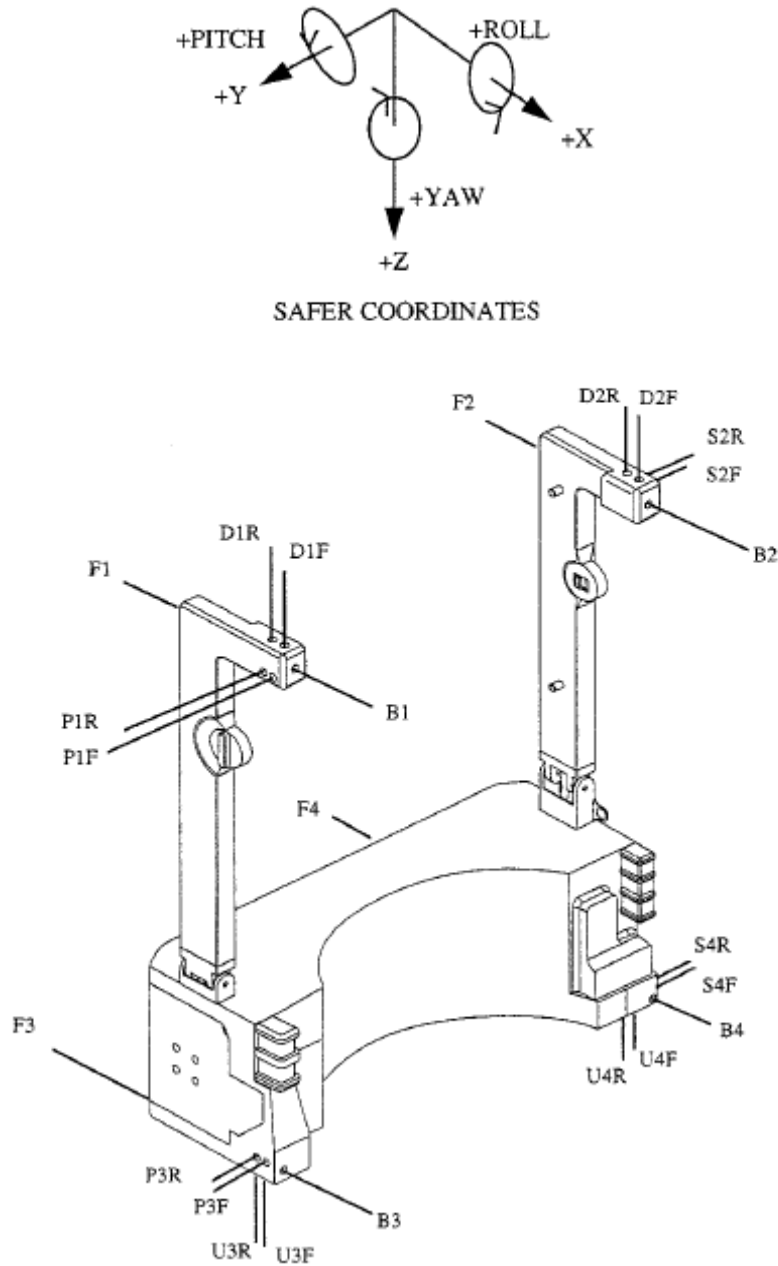
- A. PWR - TST/ON
- B. PWR - ON
- C. PWR - TST/ON

SAFER operates in the self-rescue mode with the power switch in either the ON or TST/ON positions (steps 1 and 2 above). The software must see the TST/ON command twice (step 3) before going into the self-test mode. This switch sequence prevents inadvertent activation of the self test during a rescue scenario. During the self test, the crewmember is led through a series of prompts displayed on the HCM display. When the action in each prompt has been successfully completed, the next prompt is automatically displayed. If a particular test action is unsuccessful, a failure message is displayed (these failures will be discussed later in this section). The self test can be terminated at any time by returning the power/test switch to the OFF or ON positions. In addition, if any portion of the test fails, the remaining portions of the test can be finished by depressing the display proceed switch in either direction. The self test consists of the following tests performed in the order listed below:

1. NSI checkout test: This test is performed automatically with no prompt displayed to the crewmember. The system performs a continuity check of the NSI firing circuitry. If the test fails, the failure message NSI CIRCUIT OPEN is displayed. When the sequence is completed, the NSI test is concluded and the thruster test is initiated.
2. Thruster test: The thruster test is initiated immediately after initiating the self test. Each thruster is automatically commanded on or "dry fired" for 20 msec with a 0.5 second interval between thruster firings. The thruster cue light will be illuminated when the thrusters are commanded during the test. The software recognizes that a thruster has dry fired when it receives a thruster "on" discrete (which indicates that a thruster has received an electrical command to open). When this test is initiated, the following nominal status prompt or failure message is displayed:

	<u>Nominal Prompt</u>	<u>Failure message</u>
Thruster test:	SELF TEST-WAIT	FAIL:JET XXX

The "XXX" is a two or three character thruster identifier as shown in Figure 4.1-12. The first character represents the direction that the thrust moves SAFER (e.g., F is forward, D is down, and S is starboard...). The second character is the manifold that feeds the thruster. The third character is used to designate forward or rear when there are two thrusters located on the same manifold and firing in the same direction (e.g., S2F and S2R). The thruster test will stop immediately if a failure is detected and the failure message will be displayed. The test can be resumed by depressing the display proceed switch in either direction.



**Figure 4.1-12. SAFER coordinates and thrusters**

3. Hand controller test: After the thruster test is completed, the crewmember is prompted through this test which verifies the function of each switch on the HCM and the detent positions on the hand controller. The following nominal action prompts and corresponding failure messages are displayed:

	<u>Nominal Prompt</u>	<u>Failure message</u>
AAH switch test:	DEPRESS AAH	FAIL:HC AAH
Rotation mode switch test:	MODE TO ROT	FAIL:HC ROT
Translation mode switch test:	MODE TO TRAN	FAIL:HC TRAN
Hand controller detent test:	HC TO DETENT	FAIL:HC DETENT
Hand controller +X test:	HC +X	FAIL:HC +X
Hand controller -X test:	HC -X	FAIL:HC -X
Hand controller +Y test:	HC +Y	FAIL:HC +Y
Hand controller -Y test:	HC -Y	FAIL:HC -Y
Hand controller +Z test:	HC +Z	FAIL:HC +Z
Hand controller -Z test:	HC -Z	FAIL:HC -Z
Hand controller +pitch test:	HC +P	FAIL:HC +P
Hand controller -pitch test:	HC -P	FAIL:HC -P

For the AAH and rotation/translation mode switch tests, the crewmember is expected to actuate the switch to the prompted position. For the rotation mode switch test, if the switch is already in the ROT position at the time of the test, the MODE TO ROT message will not be displayed and the test will be performed automatically.

For the hand controller tests, the crewmember is expected to move the hand controller to the prompted detent, and then release the hand controller to the center position. The software must detect the discrete signal for the switch position or hand controller detent to pass these tests. The test prompt remains displayed until the software receives the proper discrete. If the proper discrete is not received by the software (i.e., the test failed or the proper action was not performed), the message for the test will stay displayed until the display proceed switch is actuated. If the display proceed switch is actuated, the failure message will be displayed, and when actuated a second time the next test prompt is displayed. If a test passes, the next test prompt is automatically displayed.

The hand controller detent test verifies the center null position of the hand controller. This test is performed automatically (without displaying the nominal prompt listed above) provided that the hand controller is in the center position after the translation mode switch test. Because the hand controller normally springs back to the center position, it should already be in the center position at the time of the test. If it is not in the center position (e.g. due to a hand controller failure) the HC TO DETENT message will be displayed. If the hand controller is not returned to the center position and the display proceed switch is actuated, the FAIL: HC DETENT message will be displayed. When the sequence is completed, the HCM test is concluded and the rate sensor function test is initiated.

4. Rate sensor function test: The crewmember is prompted to manually rotate SAFER's mainframe to test the rate sensor's response. To pass the test, a rate change of at least 3 degree/sec must be observed in both the positive and negative direction for all three axes (roll, pitch, and yaw). The following nominal prompt or corresponding failure message is displayed:

	<u>Nominal Prompt</u>	<u>Failure message</u>
Rate test:	<input type="text" value="RATE CHECK"/>	<input type="text" value="FAIL:RATE X X X"/>

The RATE CHECK prompt will be displayed until the rate test passes in each rotational axis, in both the positive and negative axes directions. A failure in either the positive or negative direction of an axis will cause the test to fail for that axis. If the test fails in a single axis or multiple axes (i.e., due to a system failure or due to the crewmember not rotating SAFER in all axes), the failure message for the test will be displayed when the display proceed switch is actuated. Each "X" in the failure message can represent "R" for roll, "P" for pitch, and "Y" for yaw. For example, if the test fails in both axes directions for pitch and yaw, FAIL: RATE P Y will be displayed when the display proceed switch is actuated. If the display proceed switch is actuated a second time or if the rate sensor function test is passed, the next and final prompt in the self test will be displayed. The final nominal message or corresponding failure message is displayed:

	<u>Nominal Message</u>	<u>Failure message</u>
Final prompt:	<input type="text" value="GO FOR EVA"/>	<input type="text" value="FAILED TEST"/>

GO FOR EVA will be displayed if no failures occurred during the self test. FAILED TEST will be displayed if any failures occurred. This message will remain until the power/test switch is placed in either the OFF or ON positions.

### Activation Sequence

The activation sequence occurs when SAFER is powered. First, the pyrotechnic isolation valve is fired and the rate sensors are reset. Next, each thruster is fired in 20 millisecond intervals. These firings reseal the thruster valves which reduces propellant leakage. (AAH is automatically initiated upon SAFER power up.)

### System Monitoring

When SAFER is in the self-rescue mode (not self test mode), the software performs the following functions using the instrumentation electronics shown in Table 4.1-1.

- A. Leak monitor
- B. Battery capacity check
- C. Tank pressure/temperature check
- D. Battery voltage/temperature check

**Table 4.1-1. Instrumentation electronics**

SENSOR INFORMATION		
PARAMETER MEASURED	SENSOR TYPE	SENSOR RANGE
GN2 tank pressure	Pressure sensor	0 to 10,000, ±25 psia
GN2 tank temperature	Temperature sensor	-100 to +200, ±2 °F
Roll rate	Angular rate sensor	±1000 deg/sec
Pitch rate	Angular rate sensor	±1000 deg/sec
Yaw rate	Angular rate sensor	±1000 deg/sec
Battery volts	Voltage	Analog 0 - 36 Vdc
Battery temperature	Temperature sensor	-40 to +212, ±2 °F

- A. Leak monitor: During intervals without thruster firing, a leak detection algorithm runs continually. If this algorithm determines that there has been more than a 0.3 percent decrease in GN2 mass during three of the last four one second periods, an EXCESSIVE LEAK message is displayed on the HCM display. This leak rate is equivalent to the flow rate of a single failed-on thruster.
- B. Battery capacity check: The amp-hours remaining is monitored and displayed as power percent on the HCM display as a default message. If this percentage falls below 40 percent, a down arrow is displayed next to the power percentage display. Thirteen percent is the minimum power required to perform a worst case self-rescue scenario.

- C. Tank pressure/temperature check: The pressure and temperature of the GN2 tank is monitored and can be displayed on the HCM display. If the tank pressure is  $\leq 524$  psia, a down arrow is displayed next to the tank pressure display. This limit is 5 percent above the point at which degraded thruster performance is expected.

The tank GN2 mass is calculated from pressure and temperature readings and then converted into a percentage. The GN2 percent left is displayed on the HCM display as a default display. If the GN2 percent left falls below 15 percent, a down arrow is displayed next to the GN2 percent left display. This limit is based on the minimum amount of GN2 required to perform a worst case self-rescue scenario. If the temperature falls below  $-40^{\circ}$  F, a down arrow is displayed next to the temperature display. If the temperature rises above  $+140^{\circ}$  F, an up arrow is displayed next to the temperature display.

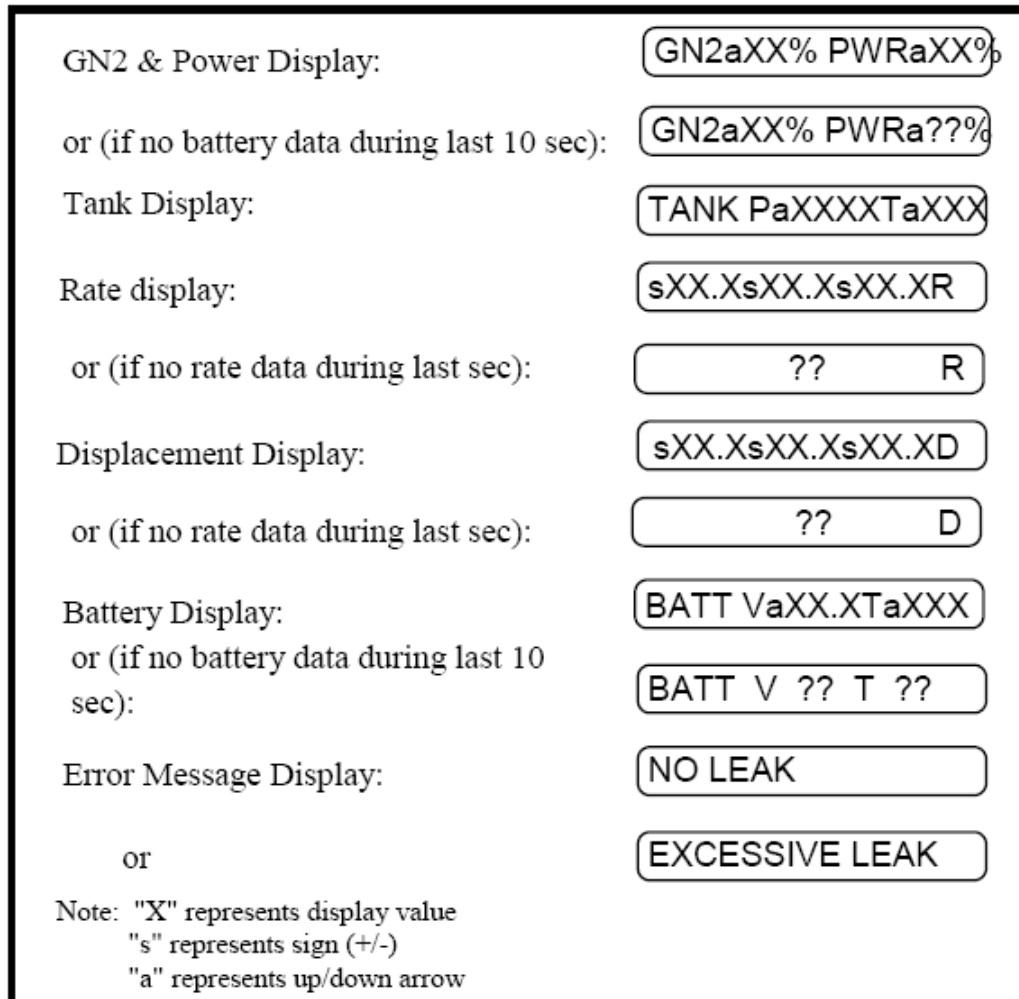
- D. Battery voltage/temperature check. The voltage and temperature of the battery is monitored and can be displayed on the HCM display. If the battery voltage falls below 35 volts, a down arrow is displayed next to the voltage display. If the temperature in the battery pack falls below 50 deg F, a down arrow is displayed next to the temperature display. If the temperature rises above  $90^{\circ}$ F, an up arrow is displayed next to the temperature display.

If any of the parameters in the above display messages becomes off nominal, the corresponding message will automatically be displayed on the HCM display and the message will flash on and off (with the exception of the EXCESSIVE LEAK message). This replaces the default display message mentioned in “GN2 and Power Display” below.

The status displays available in the self rescue mode is listed in the displayed sequence in Figure 4.1-13. When the display proceed switch is moved in the direction of the down arrow, the software will display the next status display. When the display proceed switch is moved in the direction of the up arrow, the software will display the preceding status display.

- A. GN2 and Power Display. The default display shows available GN2 and power in terms of a percentage. The maximum percentage displayed is 99 percent. A battery data failure is assumed if no battery data has been received for more than ten seconds.





**Figure 4.1-13. Self rescue mode status**

- B. Tank Display. The tank pressure and temperature are displayed together in units of psia and degrees F, respectively.
- C. Rate Display. The rate display shows angular rate in roll, pitch, and yaw (in that order) in units of degree/second. The maximum rate displayed is  $\pm 30$  degree/second. The "R" at the end of the display refers to rate. A rate sensor data failure is assumed if no valid rate sensor data has been received for more than one second.
- D. Displacement Display. The displacement display shows angular displacement in roll, pitch, and yaw (in that order) in units of degrees. The maximum displacement displayed is  $\pm 99.9^\circ$ . The "D" at the end of the display refers to displacement.
- E. Battery Display. The battery voltage and temperature is displayed in volts and degrees F, respectively. A battery data failure is assumed if no battery data has been received for more than ten seconds.

- F. Error Message Display. The avionics continuously runs a leak check of the propulsion system. If a leak is detected the crewmember receives an EXCESSIVE LEAK message. Under nominal operating conditions, a NO LEAK message is displayed.

### **Ground Checkout Test**

The fault detection system also provides for ground checkout of SAFER. This function processes commands for data requests or avionics tests from Ground Support Equipment (GSE) connected to a ground servicing serial port.

#### **4.1.2.4 Avionics System**

The SAFER avionics system consists of four Printed Circuit Boards (PCBs) and a rate sensor. The four PCBs are: the Control Electronics Assembly (CEA), the Valve Driver Assembly (VDA), the Power Supply Assembly (PSA), and the Hand Controller Electronics Assembly (HCEA). The CEA, VDA, and PSA are mounted in the avionics unit which is in the main frame. The HCEA is located inside the HCM.

The CEA processes all control commands from the hand controller and AAH and sends a command to the VDA to actuate the appropriate thruster valves. The CEA also has a serial port that provides interface for GSE. The VDA receives fire commands from the CEA and applies power to the selected thrusters. The VDA controls all 24 thrusters. The VDA uses the 24 V dc output from the PSA to fire the pyro valve during SAFER power up. When a thruster valve is commanded open, a red LED on the HCM is illuminated. Due to response time limits of the LED, short AAH controlled firings may not be seen by the SAFER crewmember.

The PSA receives power from the battery and regulates the voltages that are required for the various SAFER electrical components. The PSA also provides a single point ground for all digital and analog signal returns.

The rate sensor, a Litton LN-200 Inertial Measurement Unit, has three fiber optic gyros and rate measurement electronics that measure the angular rates in the range of  $\pm 1000$  degree/sec. A separate rate value for each angular axis (roll, pitch, and yaw) is displayed on the HCM display. When AAH is enabled, these rates are also provided to the AAH software in the CEA to determine which thrusters need to be fired. In addition, the rates are converted to angular displacements and displayed on the HCM display. The displacement angles are reset to zero in each axis when the AAH button is depressed. The rates are reset to near zero when AAH nulls them.

The HCEA controls the SAFER status displayed on the 16-character LCD.

### **Motion Control Software**

The motion control software and the CEA control SAFER's six degree-of-freedom maneuvering capability. This software commands thruster firings to provide rotational

and translational accelerations in response to HCM roll, pitch, yaw, X, Y, and Z inputs. The software only issues rotational acceleration commands for AAH.

Pilot translation commands are prioritized such that acceleration is provided along only one translational axis, with the priority being X first, Y second, and Z third. The software utilizes thruster select logic to produce on/off fire commands for each thruster such that rotational and translational accelerations are always provided in the requested direction with a maximum of four thrusters on at any time. Acceleration is provided as long as a hand controller or AAH command is present. Acceleration may be degraded below that for a single axis command when multi-axes commands are present from the HCM or the AAH. When AAH is activated and pilot translation commands are present simultaneously, translation thrusters may be modulated off to maintain attitude.

AAH can be initiated or terminated when not in the self test mode (i.e. only in the self-rescue mode). A crewmember-issued rotational acceleration command (initiated after AAH is activated) about any axis will immediately disable AAH for that axis. When an axis is terminated in this fashion, the remaining axes remain in AAH. However, any hand controller rotation command present at the time AAH is initiated will subsequently be ignored and AAH will be active in that axis. This feature is provided so that a failed-on hand controller command (in a rotational axis) will not disable AAH on that axis. When initiated, AAH provides an automatic rotational deceleration until all three axes rates are near zero. To provide this deceleration, continuous thruster firings are commanded to reduce the rotational rate for any enabled axis with a rate above 0.2 degree/sec. Once the rates for all the enabled axes are below 0.3 degree/sec, thrusters are fired automatically to maintain the attitude within approximately  $\pm 5$  degrees. Thrusters do not fire when the attitude is within a  $\pm 2$  degree deadband.

Tables 4.1-2 and 4.1-3 below show which thrusters are activated for each possible combination of commands input through the HCM. Note that there are no thrusters activated for certain input combinations in Table 4.1-3 because SAFER will process translation commands in only one axis at a time.

**Table 4.1-2. Thruster select logic for X, pitch, and yaw commands**

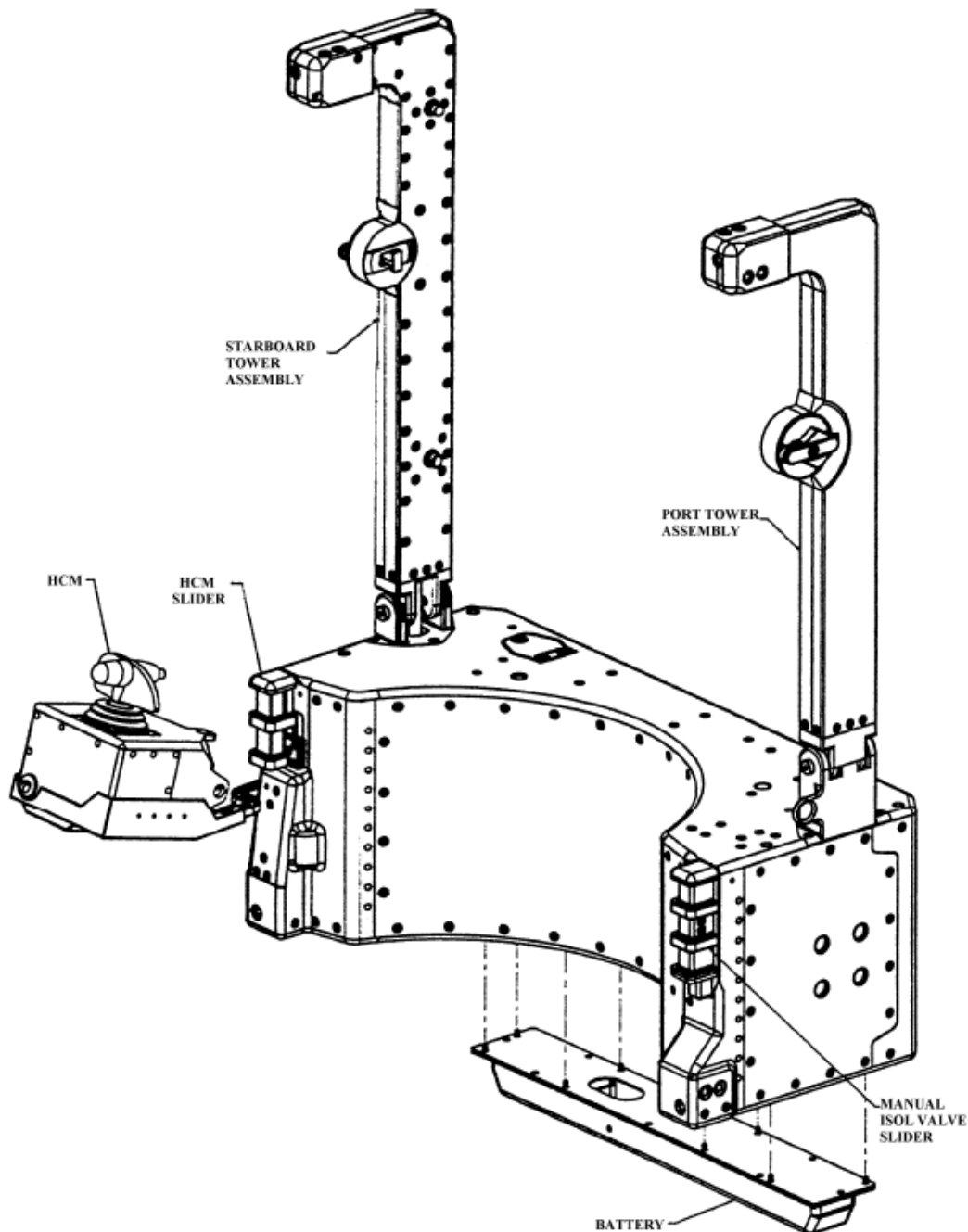
X	Pitch	Yaw	Thrusters Always Activated		Activated if No Roll	
-	-	-	B4		B2	B3
-	-		B3	B4		
-	-	+	B3		B1	B4
-		-	B2	B4		
-			B1	B4	B2	B3
-		+	B1	B3		
-	+	-	B2		B1	B4
-	+		B1	B2		
-	+	+	B1		B2	B3
	-	-	B4	F1		
	-		B4	F2		
	-	+	B3	F2		
		-	B2	F1		
		+	B3	F4		
	+	-	B2	F3		
	+		B1	F3		
	+	+	B1	F4		
+	-	-	F1		F2	F3
+	-		F1	F2		
+	-	+	F2		F1	F4
+		-	F1	F3		
+			F2	F3	F1	F4
+		+	F2	F4		
+	+	-	F3		F1	F4
+	+		F3	F4		
+	+	+	F4		F2	F3

**Table 4.1-3. Thruster select logic for Y, Z, and roll commands**

Y	Z	Roll	Thrusters Always Activated		Thrusters Activated if No Pitch or Yaw	
-	-	-				
-	-					
-	-	+				
-		-	P1R		P1F	P3F
-			P1R	P3R	P1F	P3F
-		+	P3R		P1F	P3F
-	+	-				
-	+					
-	+	+				
	-	-	U3R		U3F	U4F
	-		U3R	U4R	U3F	U4F
	-	+	U4R		U3F	U4F
		-	P1R	S4R		
		+	S2R	P3R		
	+	-	D2R		D1F	D2F
	+		D1R	D2R	D1F	D2F
	+	+	D1R		D1F	D2F
+	-	-				
+	-					
+	-	+				
+		-	S4R		S2F	S4F
+			S2R	S4R	S2F	S4F
+		+	S2R		S2F	S4F
+	+	-				
+	+					
+	+	+				

**4.1.2.5 Battery**

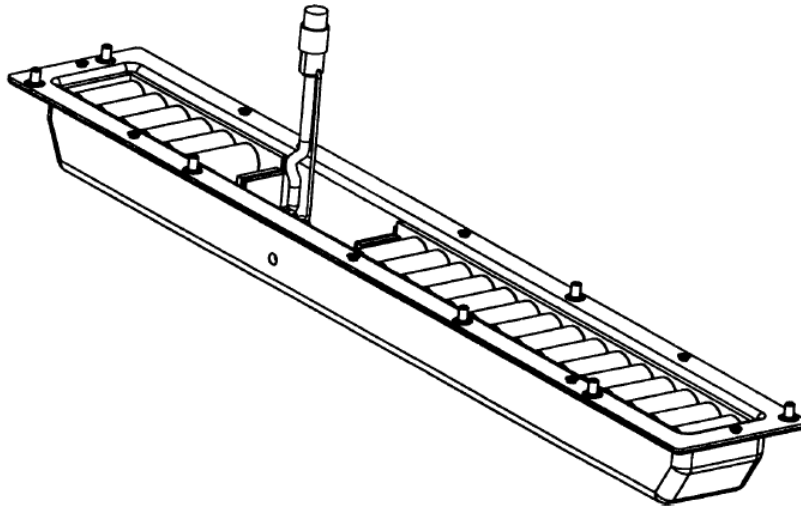
The battery provides power for all SAFER electrical components. The battery connects to the bottom of the main frame, as shown in Figure 4.1-14. The battery can be replaced if needed by an IV crewmember using the 9/64 inch hex wrench T-handle tool. SAFER is launched with the battery installed.



**Figure 4.1-14. SAFER battery attachment**

The battery consists of electrochemical cells, diodes, current limiters, and wires and is enclosed in a battery box along with a capacity gauge and a connector. The battery cells are Lithium Manganese Dioxide (LiMnO<sub>2</sub>). Figure 4.1-15 shows a drawing of the battery without the top cover plate and the TMG. This battery is the first “smart” battery used in a NASA application. It contains a capacity gauge circuit to track battery voltage, battery current, battery temperature, percent amp-hours remaining, and the battery

serial number. The battery provides sufficient power for 52 on-orbit IV checkouts (1 minute maximum duration each), and for one self-rescue scenario of 13 minutes (all during a 1 year on-orbit lifetime). A 13 minute self-rescue represents approximately 5 percent of the battery capacity.



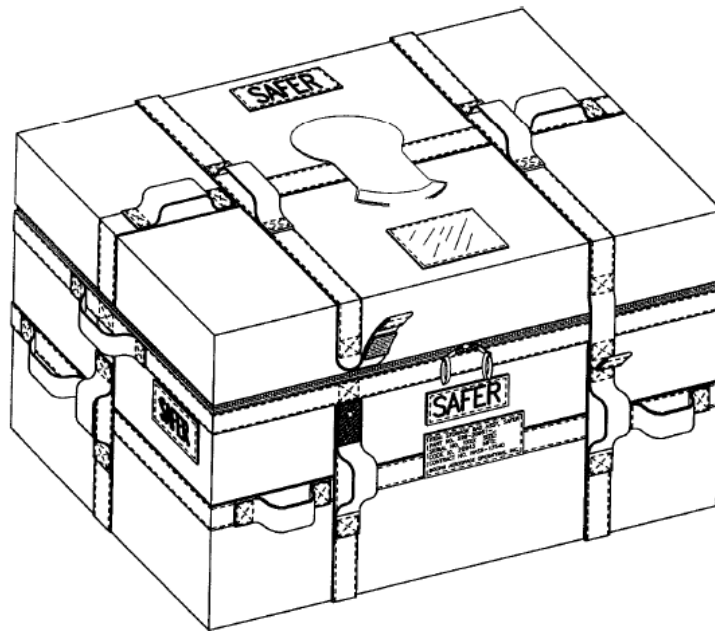
**Figure 4.1-15. SAFER battery**



**Figure 4.1-16. SAFER battery changeout**

### 4.1.3 Stowage

SAFER is designed for on-orbit stowage in a habitable environment of the Orbiter and ISS. SAFER is capable of withstanding a stowage environment of 30 F to +130\_F for up to 4 months. A minimum of 3 hours is required to return SAFER to ambient temperature. Each SAFER is stowed in an individual on-orbit stowage bag beginning with STS-88 (ISS 2A). Each stowage bag can hold SAFER, one spare battery, one inhibitor connected to the T-handle tool and one spare inhibitor. The HCM is stowed outside of the mainframe in the SAFER Stowage Bag for launch and entry; however, the deployment arm and tray are stowed in the main frame. Figure 4.1-17 shows the SAFER Stowage Bag.



**Figure 4.1-17. SAFER stowage bag**

### 4.1.4 SAFER Crew Rescue

SAFER crew rescue is performed for an untethered separation of an EVA crewmember. This procedure begins with SAFER HCM deployment and SAFER power up. AAH is activated as soon as the crewmember cycles the power switch to ON or TST/ON position. The separated crewmember begins flying back toward the nearest structure as soon as he or she reaches a stable attitude. Power and GN2 percentages needs to be monitored during the rescue flight. The IV crewmember assists in guiding the separated crewmember toward the nearest structure.

Note: If SAFER does not respond to command inputs, power must be cycled in order to reset the software. The power switch must be moved to OFF, then back to ON. Moving the power switch from TST/ON to ON then back to TST/ON will result in SAFER performing a self test and not function for self rescue.



#### **4.1.4.1 SAFER Contingency**

This section covers corrective procedures for SAFER malfunctions that could occur during SAFER flight. These types of malfunctions result in SAFER providing uncontrolled motion. These include failed-on thrusters and failed on hand controller commands. The objective of this procedure is to stop further acceleration caused by the malfunction. Depending on the malfunction, this is accomplished by one or more of the steps in the procedure, discussed below: For a single failed-on thruster, a tumble as well as a translation rate will occur. The tumble is arrested by activating AAH and the translation acceleration is terminated by closing the manual isolation valve.

For a failed-on rotation command, a pure tumble will occur with no translation. As with the previous case, the tumble is arrested by activating AAH. This is done because the avionics software will allow AAH to override the failed on rotation command. Then the isolation valve is closed to prevent the failure from reoccurring.

For a failed-on translation command, a translation will occur. This command can be cancelled by providing (and holding) a translation command in the opposite direction. This cancellation occurs because the avionics software sees a command conflict (i.e., two simultaneous hand controller commands in opposite directions in the same axis). While holding the opposite hand controller command, the isolation valve is closed so that the hand controller can be released without providing further thrust. This procedure is necessary because holding an opposite command provides a quicker way to stop the acceleration than reaching down to close the isolation valve. A quicker response is needed for this malfunction because a failed-on translation command provides full translation acceleration (whereas a single failed on thruster provides only approximately  $\frac{1}{4}$  the acceleration).

In all of the above malfunction cases assistance is required because the SAFER crewmember is unable to fly back. If possible, the other EV crewmember may provide assistance, or if needed the orbiter may have to undock to provide retrieval (if the orbiter is present).

#### **4.1.5 SAFER HCM Unintentional Deploy**

This section covers the two cases where the SAFER HCM may be unintentionally deployed with the inhibitor plug not installed and the correct actions to take. The two nominal scenarios where the inhibitor is not installed are during EVA Prep starting at SAFER donning and during EVAs.

If the HCM is unintentionally deployed at anytime during EVA Prep, we must assume that the pyro valve has blown. The worst case leak rate must then be used to calculate if the SAFER propulsion module will have enough GN<sub>2</sub> for the duration of that EVA (Refer to Fight Rule B15-107). During Post EVA a modified SAFER checkout should be performed to determine if the pyro valve did indeed fire (Refer to Section 4.1.5.1 below for the modified SAFER checkout).

If the HCM is unintentionally deployed during an EVA, the unaffected crewmember will stow the HCM being careful not to touch the power switch. The EVA will be continued nominally. During Post EVA a modified SAFER checkout should be performed to determine if the pyro valve was blown.

#### **4.1.5.1 Modified SAFER Checkout**

A modified SAFER checkout is used to determine if the pyro valve has blown. The inhibitor plug must be installed and the manual isolation valve must be in the open (down) position. The crew should deploy the HCM and power on the unit. During power on, the thrusters go through an initialization sequence.

If a dry thruster firing is heard at this time, the pyro valve is not blown. The HCM can be powered down and restowed with the manual isolation valve in the closed (up) position.

If a wet thruster firing is heard, the pyro valve was blown at some time previous and a leak check must be performed to determine the leak rate so the amount of GN2 can be calculated for subsequent EVAs.

#### **4.1.5.2 SAFER Leak Check**

To perform an accurate leak check, the GN2 temperature and pressure reading must be taken from the HCM display of the effected unit while still powered on. This should be done during Post EVA and will count as time zero (start of the leak check). The temperature and pressure readings will go to Engineering and they will calculate the starting GN2%. The SAFER can be powered off and stowed. The manual isolation valve needs to be in the open (down) position during the 24 hour leak check. This gives an accurate leak rate in the EVA configuration. After 24 hours, the SAFER will be powered back up and a second temperature and pressure reading will be taken. The manual isolation valve should be closed just prior to this power up so as not to lose GN2 during thruster initialization. Engineering will determine the GN2% again and the actual leak rate for that unit. From that leak rate, we can calculate how long that SAFER will have GN2 above the go/no-go limit. The SAFER should be powered down and stowed with the manual isolation valve in the closed (up) position.

Below is the equation Engineering uses to determine the leak rate. It is followed by an example.

**Leakrate worksheet for SAFER**

Summary:

1. Record first data set on SAFER tank; then calculate corrected pressure for nominal temperature of 80F
2. Record second data set on SAFER approximately 1 day later and correct pressure for nominal temperature of 80F
3. Calculate leak rate as “psi/hour” decay
4. Predict tank pressure (for 80F) at end of next EVA
5. Compare to GO/NO-GO requirement of 6575 psia At 80F

A. Record:

Tank Pressure, P1 = \_\_\_\_\_  
Tank Temperature, T1 = \_\_\_\_\_  
Date/time: \_\_\_\_\_  
Calculate Corrected Start Pressure:  
Delta Temp, DT1 = 80 – T1 = \_\_\_\_\_ (positive if T1 < 80)  
Delta Pressure, DP1 = 23 \* DT1 = \_\_\_\_\_  
Corrected pressure, CP1 = DP1 + P1 = \_\_\_\_\_

B. Record:

Tank Pressure, P2 = \_\_\_\_\_  
Tank Temperature, T2 = \_\_\_\_\_  
Date/time: \_\_\_\_\_  
Calculate Corrected End Pressure:  
Delta Temp, DT2 = 80 – T2 = \_\_\_\_\_ (positive if T2 < 80)  
Delta Pressure, DP2 = 23 \* DT2 = \_\_\_\_\_  
Corrected pressure, CP2 = DP2 + P2 = \_\_\_\_\_

C. Calculate Leak Rate:

Pressure Lost = CP1 – CP2 = \_\_\_\_\_  
Leak Time = # hours between data point 1 and 2 = \_\_\_\_\_  
Leak Rate = Pressure lost / leak time = \_\_\_\_\_

D. Predict Final Pressure at end of next EVA:

Number of hours till end of EVA = \_\_\_\_\_  
Delta Pressure by end of EVA = Leak Rate \* # hours = \_\_\_\_\_  
Final Pressure (at 80F) = CP2 – Delta Pressure = \_\_\_\_\_

E. GO/NO-GO Requirement is minimum 6575 psia at 80F

*EXAMPLE:*

A. Record:

Tank Pressure, P1 = 7852  
Tank Temperature, T1 = 77  
Date/time: March 26, 0800  
Calculate Corrected Start Pressure:  
Delta Temp, DT1 = 80 – T1 = 3 (positive if T1 < 80)  
Delta Pressure, DP1 = 23 \* DT1 = 69  
Corrected pressure, CP1 = DP1 + P1 = 7921

B. Record:

Tank Pressure, P2 = 7714  
Tank Temperature, T2 = 78  
Date/time: March 27, 0600  
Calculate Corrected Final Pressure:  
Delta Temp, DT2 = 80 – T2 = 2 (positive if T2 < 80)  
Delta Pressure, DP2 = 23 \* DT2 = 46  
Corrected pressure, CP2 = DP2 + P2 = 7760

C. Calculate Leak Rate:

Pressure Lost = CP1 – CP2 = 161  
Leak Time = # hours between data point 1 and 2 = 22  
Leak Rate = Pressure lost / leak time = 7.32

D. Predict Final Pressure at end of next EVA:

Number of hours till end of EVA = 12  
Delta Pressure by end of EVA = Leak Rate \* # hours = 87.8  
Final Pressure (at 80F) = CP2 – Delta Pressure = 7672

E. GO/NO-GO Requirement is minimum 6575 psia at 80F

**SAFER is GO**

**Related Documentation References**

USA Simplified Aid for EVA Rescue (SAFER) Operations Manual, JSC 26283A, March 5, 1998.

USA Simplified Aid for EVA Rescue (SAFER) Project Avionics Software Design Specifications Rev B, AR&SD -98-004, April 1999.

## 4.2 EMU HELMET LIGHTS, BATTERIES, AND CHARGER

### PURPOSE

This section provides information on the third generation EMU helmet lights (also known as EVA helmet interchangeable portable (EHIP) lights), the rechargeable nickel metal hydride (NiMH) batteries used to power them, and the helmet light battery charger that is used to recharge the NiMH batteries. These helmet lights currently are used on scheduled EVA flights and provide an EV crewmember with portable lighting during an EVA. (First generation helmet lights are used on contingency EVA flights, see Section 5.2)

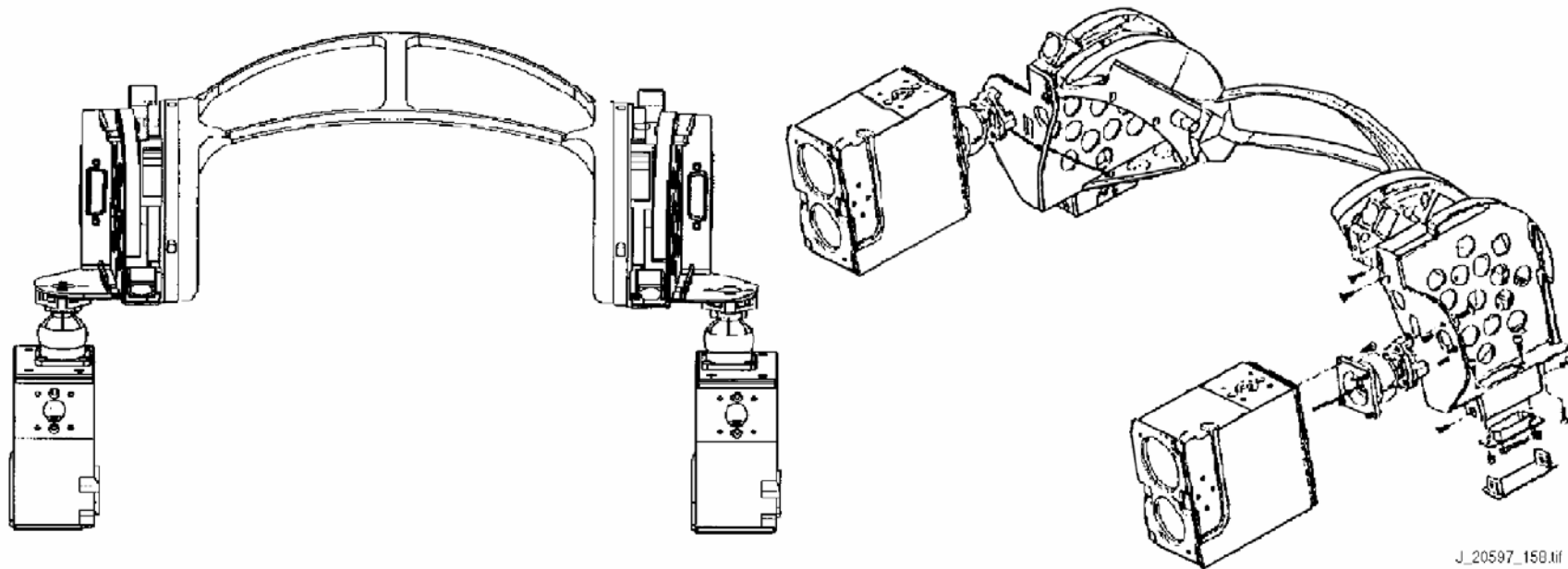
### DESCRIPTION

#### EVA HELMET INTERCHANGEABLE PORTABLE LIGHTS

The EHIP lights consist of four lamps, two battery packs, an aluminum crossmember, power control switches, polyswitches, and housings (Figure 4.2-1). The lights are capable of continuous operation for 9.5 hours. The third generation lights interface with the EMU in the same fashion as the first generation lights that use lithium bromide complex (LiBCX) batteries.

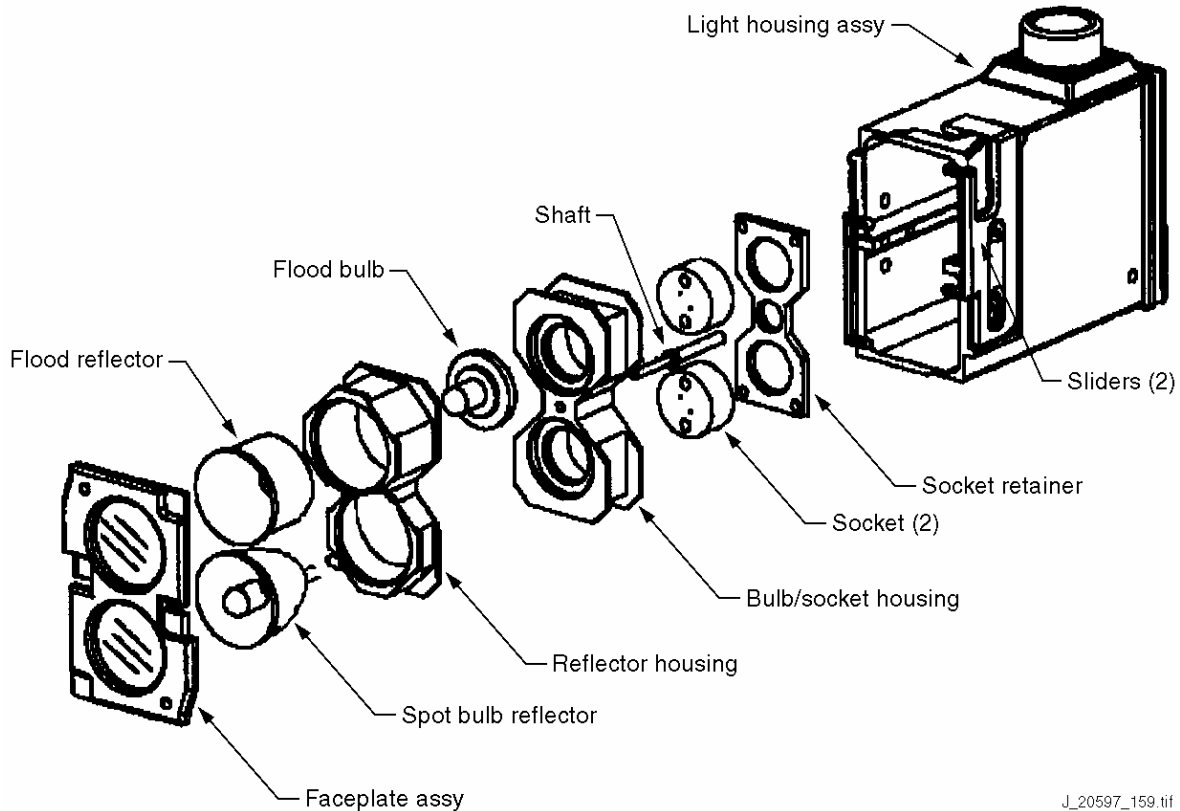
Each side of the lights contains two lamps, a floodlight (on the bottom) and a spotlight (on the top). The bulbs are 6 watt halogen bulbs. They are IV replaceable by removing the light module front cover (which is retained by spring-loaded latches) and unplugging the flood reflector and flood bulb or the spot bulb/reflector (one piece; see Figure 4.2-2 for an inverted view of the light housing assembly) and replacing the necessary component (currently spare flood reflectors are not manifested). These bulbs are required to have a minimum life of 30 hours, but the manufacturer's advertised life is 50 hours. Testing has shown life upwards of 95 hours.

The EHIP lights turn on and off by two pushbutton switches, one on each side. One push of the button turns the bottom light on (the flood), the second push turns the bottom light off and the top light on (the spot), and a third push turns the bottom light off. The force required to operate the light switches is 3.5 to 10 lb. The design precludes the possibility of having more than one light on per side at the same time. Originally, the actuation button was located on the top of the light housing assembly. To accommodate the EMU camera mounts, the light housing assembly was inverted, placing the actuation button on the bottom (Reference Section 6.3 EMU RF Camera Assembly (ERCA)).



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**Figure 4.2-1. EHIP lights**

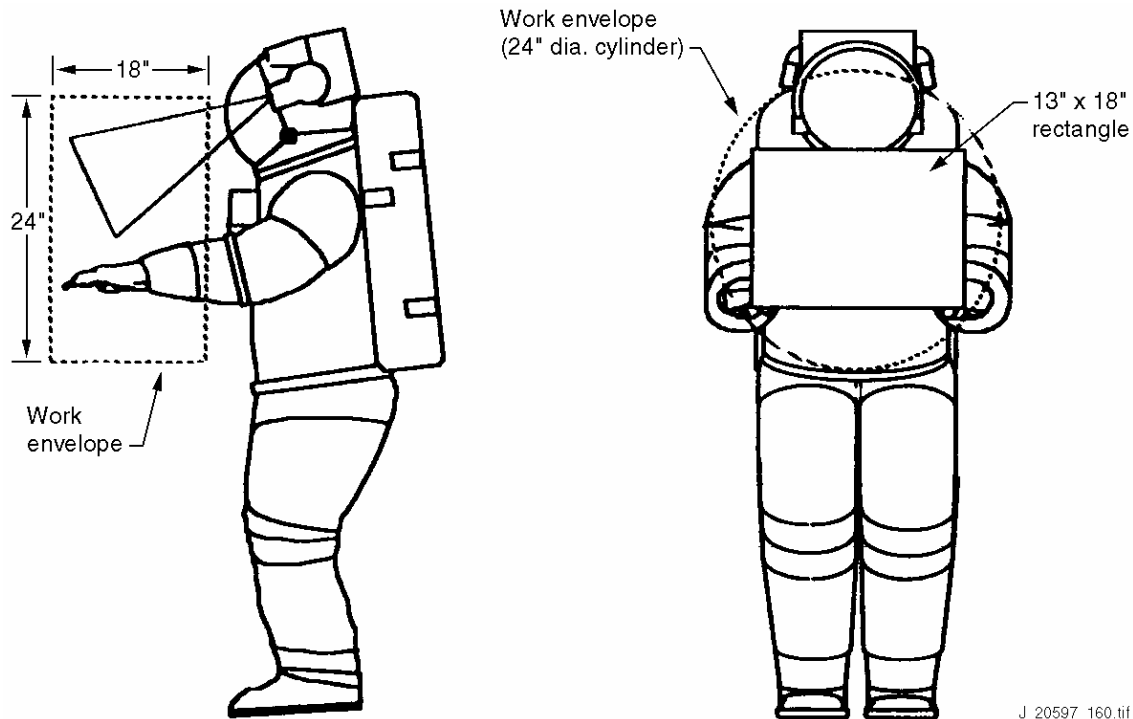


**Figure 4.2-2. EHIP light, exploded view**

The floodlights provide 10 footcandles of illumination at 2 feet from the light assembly within a rectangular worksite area of 13 inches high by 18 inches wide, with two lights on (one per side). See Figure 4.2-3. Each individual floodlight provides a maximum 3:1 illumination ratio from the center of the beam to the edges of a 24-inch-diameter circle at a distance of 2 feet from the center of the light module. There are no visual dark spots within the area of the circle.

The lights gimbal 30° up and 30° down. They also swing left and right, 13° toward the helmet and 45° away from the helmet.

The lights remain functional with an inadvertent bump load of 25 lb. The EHIP lights weigh approximately 4 lb 3 oz. (without batteries) and must be locker-stowed for launch and landing.



**Figure 4.2-3. Worksite light illumination**

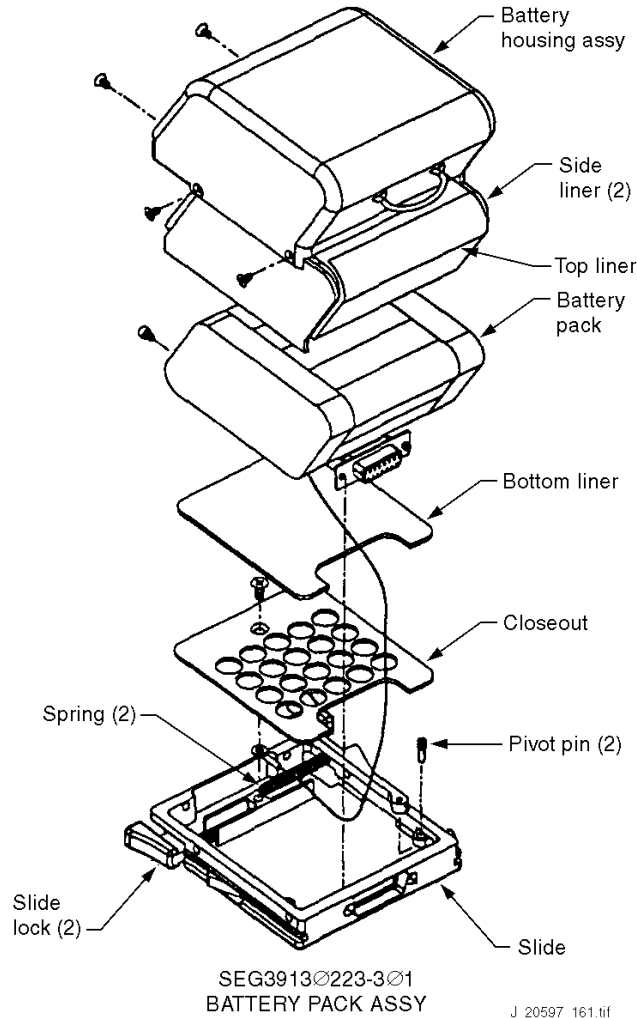
#### NICKEL METAL HYDRIDE BATTERY

Each side of the lights contains one NiMH rechargeable battery pack (Figure 4.2-4). The battery pack has 15 NiMH cells consisting of 3 parallel strings of 5 cells in series (3P-5S configuration). It has a capacity of approximately 10 Ah and draws about 1 amp. It is a 6 V battery pack that has a cycle life of >200 cycles and a wet life of

>5 years. After 200 cycles, there is very little capacity degradation. One battery pack weighs approximately 2.3 lb. There is a Velcro patch on each battery to allow for temporary stowage of the helmet lights (there is no Velcro on the helmet light housing). The battery packs may be changed during EVA (there is a small tether on each one to facilitate changeout).

Each cell string contains a polyswitch current limiter that provides thermal and overcurrent protection and a 10k ohm thermistor that provides battery temperature to the helmet light battery charger. A polyswitch can be thought of as a resettable fuse. It is a conductive polymer that has unique properties such that if more current is passed through it than what it is set for, the resistance jumps by orders of magnitude and reduces the current. The polyswitch can also be tripped by overtemperature. The polyswitch is resettable by removing the excessive current or heat that caused it to trip. The polyswitch nominally should not be used because the charging station of the charger also has overtemperature protection built into each station that trips at a lower temperature. This is discussed again in the Charger description.





**Figure 4.2-4. Battery pack**

These batteries have more capacity than the first generation LiBCX, but they also self-discharge at a maximum rate of 1 percent per day. Because of this self-discharge rate, it is necessary for the crew to “top off” the batteries with a fresh charge before using them for EVA. It is recommended that the batteries be charged within 5 days of the EVA. If this is not possible, the flight controller on console should determine the capacity of the battery, based on a maximum discharge rate of 1 percent per day. The decision then can be made if the battery has enough capacity to provide power for the helmet lights for the entire duration of the EVA. Recharging is done using the helmet light battery charger.

#### HELMET LIGHT BATTERY CHARGER

The helmet light battery charger charges four EHIP battery packs simultaneously and independently. The charger weighs approximately 4.4 lb and receives power from the orbiter power supply ( $28 \pm 4$  V) via a Y-cable. The Y-cable plugs into the Middeck Utility Panel (MUP) of the Orbiter and provides power for two helmet light battery

chargers via one 10A port. Each of the four battery packs slides into guides that align the battery pack with the mating connector on the charger. The battery installation and removal force is 3.5 to 10 lb. There are four sets of four LEDs that indicate the stage currently in progress (one set for each charging station). Once powered, the charger does not require any action other than sliding the battery pack into the charger and checking the charging station LEDs.

The four LEDs and their associated indications are as follows: STANDBY/RE-INSTALL (blue), CHARGING (yellow), MAINTENANCE (green), and TEMP FAULT (red). At least one LED for each charging station is illuminated at all times if power is applied to the charger.

The STANDBY/RE-INSTALL LED (blue) indicates that there is no battery pack connected to the station and the station is receiving power. If a battery pack has been installed and the STANDBY/RE-INSTALL LED is illuminated, the crewmember should verify that the battery pack is fully seated. When a battery pack is removed from the station, this LED will illuminate.

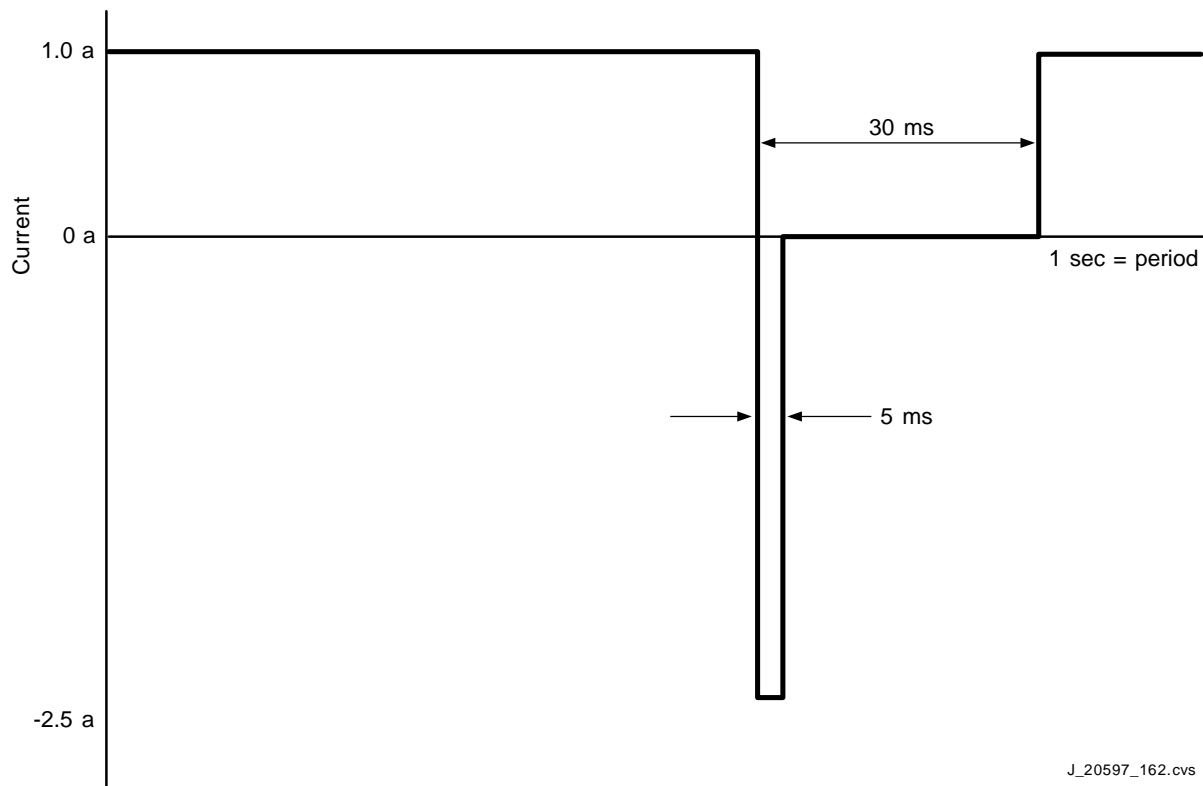
The CHARGING LED (yellow) illuminates immediately after a battery pack is installed in the charging station. This is true even for a freshly charged battery (the rationale for this is discussed below in the Charging description). The yellow LED remains on until charging is complete.

The MAINTENANCE LED (green) illuminates when the battery pack is fully charged. This LED indicates that the topping charge (or maintenance charge) stage is active. It takes approximately 5 hours to charge a depleted battery, but the battery pack can be left in the charging station indefinitely. The charger trickle charges the battery, keeping it at peak charge. The TEMP FAULT LED (red) illuminates if the internal battery skin temperature is  $\geq 131^{\circ}$  F. This equates to approximately a  $113^{\circ}$  F battery housing touch temperature. The crewmember must remove the battery pack and let it cool to room temperature. This also resets the station (as is shown by the STANDBY/RE-INSTALL LED). When the battery pack reaches room temperature, it may be reinstalled in the station for charging.

Both the MAINTENANCE LED (green) and the TEMP FAULT LED (red) illuminate if the battery is too cold ( $\leq 50^{\circ}$  F). The charger warms the battery pack at a reduced charging rate until a normal charge can be applied (this is the same level of charging that occurs during the maintenance charge). When the battery reaches the  $50^{\circ}$  F threshold, the CHARGING LED (yellow) illuminates, indicating normal charge has initiated (the other LEDs will extinguish).

The charger uses a reverse pulse (burp) charge current waveform with charge termination based on battery voltage and temperature. This technique lowers charge overvoltage and heat generation and increases battery charge acceptance. Reverse pulse charging is best illustrated by referring to Figure 4.2-5.

During charging operations, the charger connects all three of the battery strings in series to minimize the required current and ensure equal charge input to each string. Charging may be terminated by five different algorithms, but the two most common are battery voltage inflection and temperature slope algorithm. The charger primarily looks for a positive voltage inflection or a certain temperature rate of rise to trigger charge termination. Note that if a fully charged battery is installed in the charger, it may take 5- 15 minutes to receive the green LED, indicating that the charge is complete. This is because it takes some amount of time to trigger the termination algorithms that are indicative of a full charge. The battery reaches >95 percent capacity every time it is charged.



**Figure 4.2-5. Reverse pulse charge**

The battery pack is 6 V. During nominal usage, the batteries will actually start above the 6 V mark. End of life for the battery pack is considered 5 V; if the battery reaches 4 V, the voltage quickly drops to 0 V. If this occurs, the electrode structure in the cells gets torn down. Upon a subsequent charge, the cells have a high initial resistance to charging, which leads to a high initial charge voltage. Once the electrode structure is built back up, the cells drop in impedance and, thus, charge voltage drops. The voltage drop may trigger the negative voltage slope termination algorithm of the charger and

cause it to wrongly indicate that the battery is fully charged by illuminating a green LED. This false signal can occur in about 15 minutes. The operational workaround, if the battery becomes fully depleted and if the crewmember notices the false quick charge, is for the crewmember to remove the battery from the charger and reinsert it. This begins the nominal (maximum 5 hour) battery recharge. This process will not permanently damage the battery pack or its capacity.

The NiMH batteries generate heat while charging; however, the charger has a fan that will pull the heat from the battery, through vents at each station, and out of the charger. If the fan (located on the side opposite the power connector) is inoperable, the charger should not be used.

The charger and batteries must be locker-stowed for launch and landing. The batteries may not be stowed in the charger for launch and entry. Kapton tape is placed over both the charger and battery connectors for launch. The charger also has a connector cap to cover the power port on the charger when it is not in use and it is attached to the charger via a lanyard.

Because the charger draws approximately 5 amps (conservative number), the required power based on the orbiter power supply is as follows (remembering  $V = IR$ ): 24 V equates to 120 W, 28 V equates to 140 W, and 32 V equates to 160 W. The charger has an on-orbit replaceable 7.5 amp fuse (this is a common fuse flown in the fuse kit), which limits the maximum wattage of the charger to 240 W. The charger also has four Velcro squares on the bottom to restrain it during charging.

## REFERENCES

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CDR for STS-80 EHIP Lights (EC5/H. Nguyen), July 26, 1996

EHIP Lights and Battery Pack Assembly for the DTO 671 Program CARD, August 1996

EHIP Lights Battery Charger presentation (EC5/H. Nguyen), July 11, 1997

EHIP Battery Charger DTO 671 Program CARD, July 7, 1997

Safety Analysis Report (SAR) for the EHIP Lights DTO 671 Program, August 1997

SAR for the EHIP NiMH Battery Charger, August 1997

Summit Products Corporation Operating Instructions for the EHIP Battery Charger P/N QC-1001, August 6, 1997

## **4.3 PHASE VI HEATED GLOVES**

### **4.3.1 Glove Description**

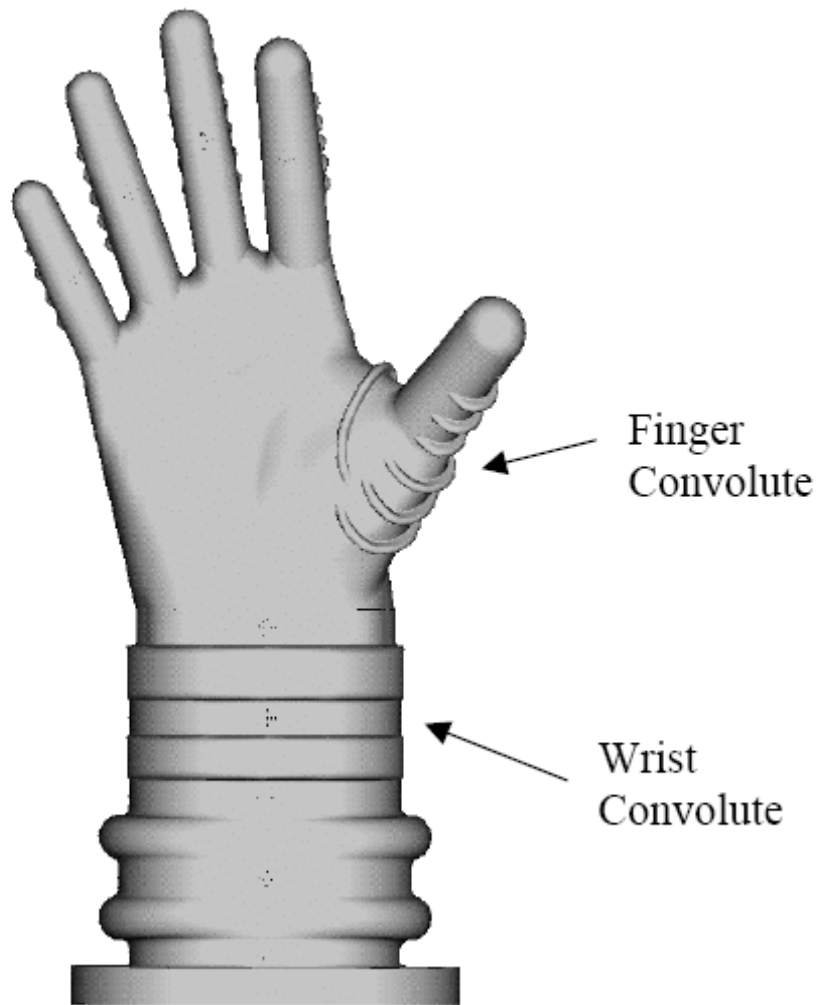
The EMU Phase VI glove is the active interface between the crew member and the work being performed. While preserving a greater degree of nude hand mobility than previous glove designs, it provides a protective barrier against the natural environment, as well as work place hazards. The glove is equipped with a low torque disconnect. The Phase VI glove is comprised of the following basic components: bladder, restraint, TMG, wrist tether strap, and wrist disconnect. The Phase VI glove build process starts with a casting of the crewperson's hands. A laserscan data file is obtained from the hand cast and is used to create the bladder dip form and restraint patterns. The end result of the process is an individualized, extremely accurate fitting glove that allows the user excellent mobility and task capability.

### **4.3.2 Bladder**

The Phase VI glove bladder is made of urethane material and is designed to maintain pressure in the glove assembly, while not exaggerating the torque or limiting the range of the finger joints and wrist gimbals. A Teflon liner (dual layer) provides abrasion protection to the bladder from the comfort glove, wristlet, or LCVG. One end of the Teflon liner is stitched to a 3/8" wide strip of urethane, which is then bonded to the bladder using urethane adhesive UR1087. The other end of the Teflon liner is sewn to a flange ring of MP1880 that is reinforced with double-coated bladder cloth. It is then attached by capturing the MP1880 flange under the clamping ring at the glove disconnect.

The Phase VI glove bladder is considered a low easement bladder and as such, it has a very conformal fit with the CM's hands. This results in significantly less folding and bunching of the bladder within the restraint, producing a more comfortable and mobile glove.

The inside of the bladder is "flocked" with small cotton fibers to reduce rucothane tack for ease of donning and doffing. The Phase VI glove bladder is shown in Figure 4.3-1.



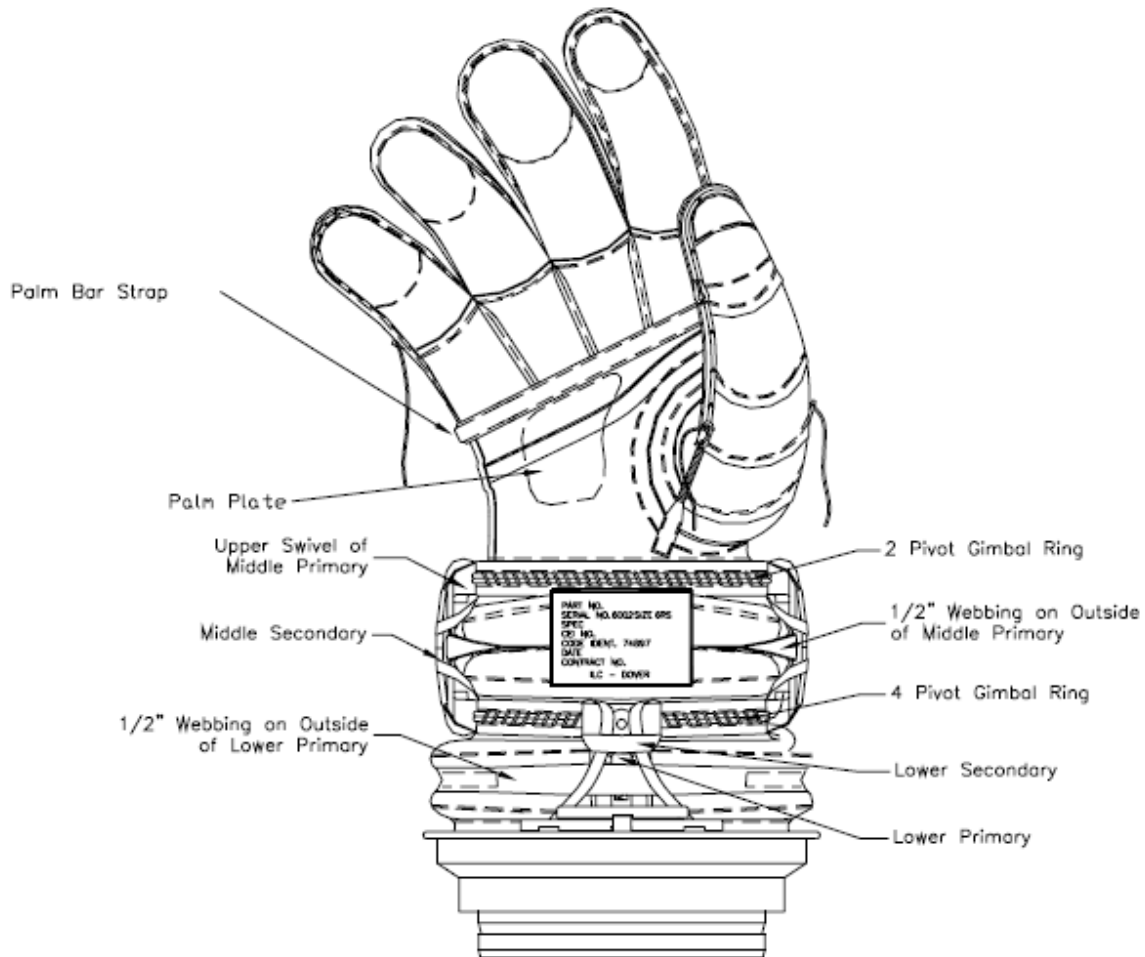
**Figure 4.3-1. Phase VI glove bladder**

### **4.3.3 Restraint**

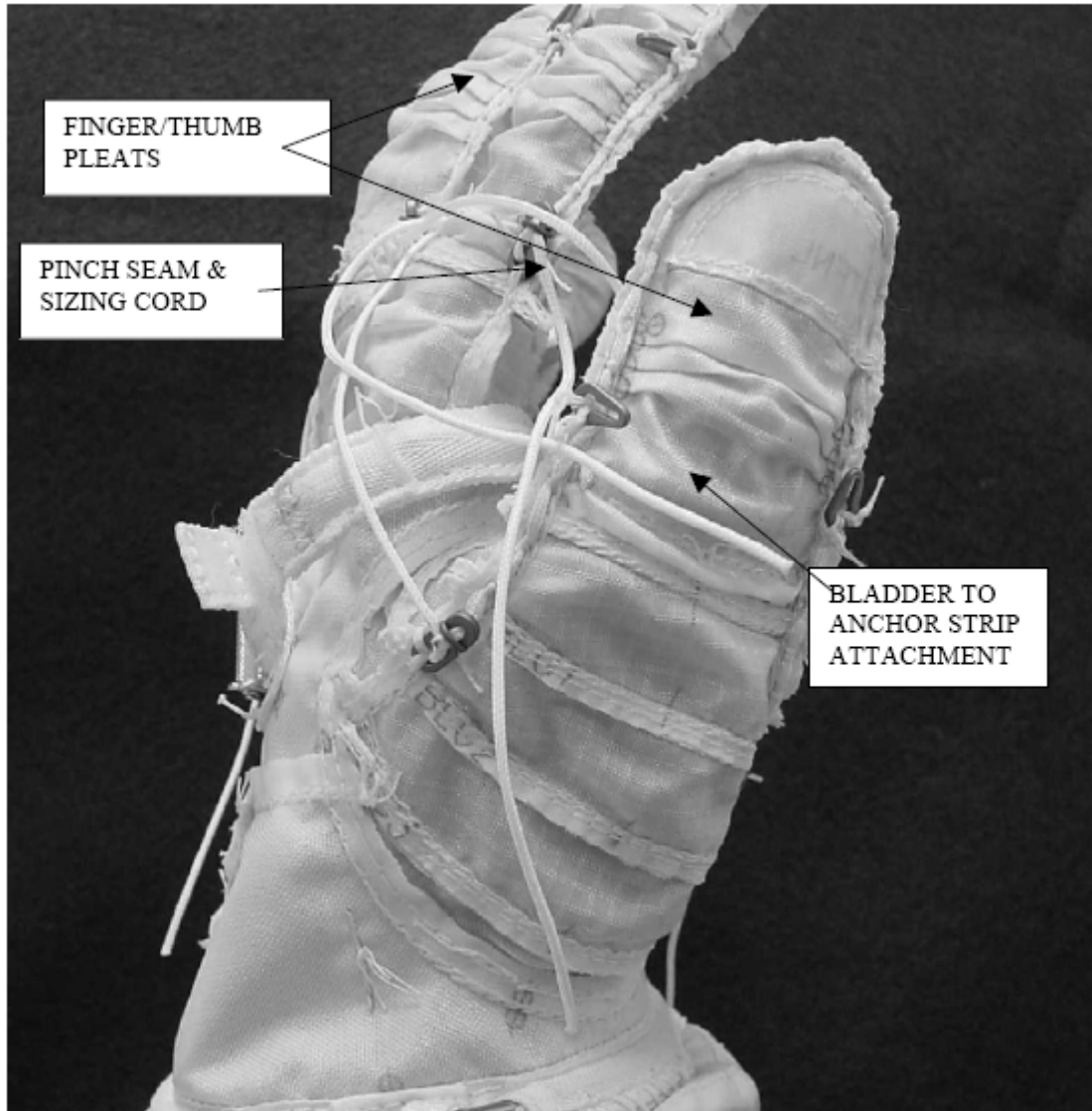
The restraint is the basic structural element of the Phase VI glove. Its purpose is to manage both pressure loads and man loads while permitting the joints to flex with low torque. The Phase VI glove restraint is designed to meet Satellite Man Load (SML) requirements and has at least a 2.0 safety factor on ultimate loads. It is made of 6 oz. Dacron fabric, 3 oz. Dacron fabric, and 3 oz. Dacron ripstop fabric. Restraint hand seams are turned to the exterior to minimize bladder abrasion (Figure 4.3-2).

The fingers are made of front and back halves which are pleated and joined together by pinch seams. The seams form the primary axial restraint of the Phase VI glove fingers. The seams form the primary axial restraint of the fingers while the pleats permit the desired range of finger flexing. Stitched to the interior of each finger are circumferential bladder anchor strips made of urethane coated fabric (Figure 4.3-3). These anchor strips are a means of semi-permanently attaching the bladder to the restraint. This

ensures proper distribution of the bladder and also prevents the bladder from shifting as the hand enters or leaves the glove. The palm and back of the restraint tie directly to the upper pivot gimbal ring. Two outboard gimbal swivels have the middle primary restraint lines attached to them. These restraints then attach to the outboard gimbal swivels of the lower gimbal ring. This section of the glove, in conjunction with the upper wrist convolutes, significantly increased wrist flexion/extension mobility over previous glove designs.



**Figure 4.3-2. Phase VI glove restraint**



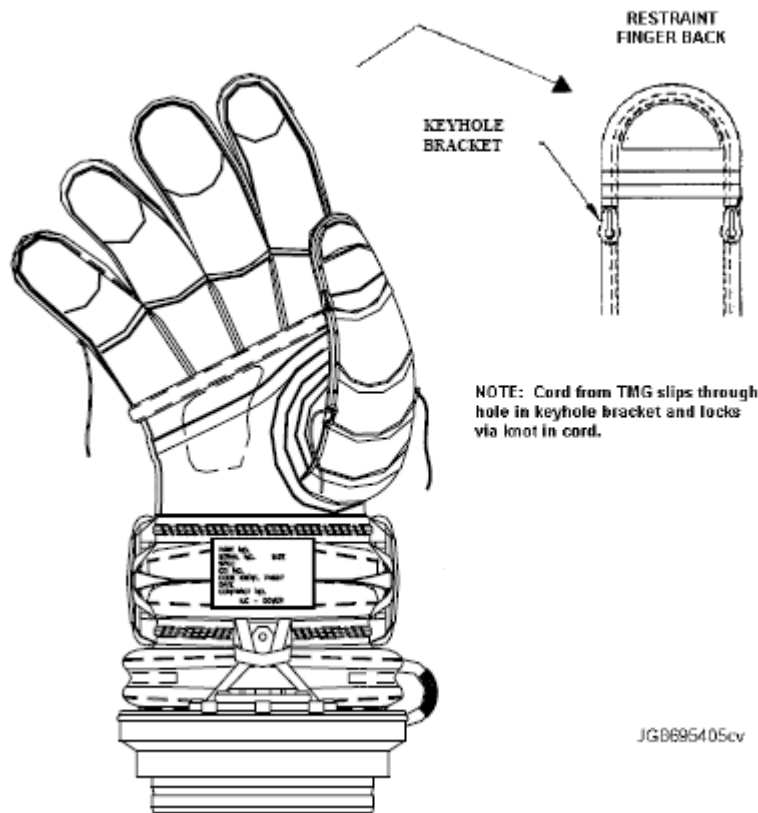
**Figure 4.3-3. Phase VI glove**

The lower pivot gimbal ring has one pivot on the palm side and one on the restraint's back side. The lower primary restraint lines attach at these locations and then terminate at the wrist disconnect. This section of the glove, in conjunction with the lower wrist convolutes, significantly increased wrist adduction/abduction mobility over previous glove designs. Webbing reinforcements called tight lines are used at the small diameter of the convolutes to minimize bladder bulging between gimbal rings and between the lower gimbal ring and the glove disconnect. Bulging here would reduce mobility and increase wrist torque.

Secondary webbing restraints are also employed between the upper and lower gimbal rings and between the lower gimbal ring and the wrist disconnect. They are unloaded, unless their associated primary restraints fail. Both the lower primary and lower secondary webbing restraints are attached to the wrist disconnect via stainless steel



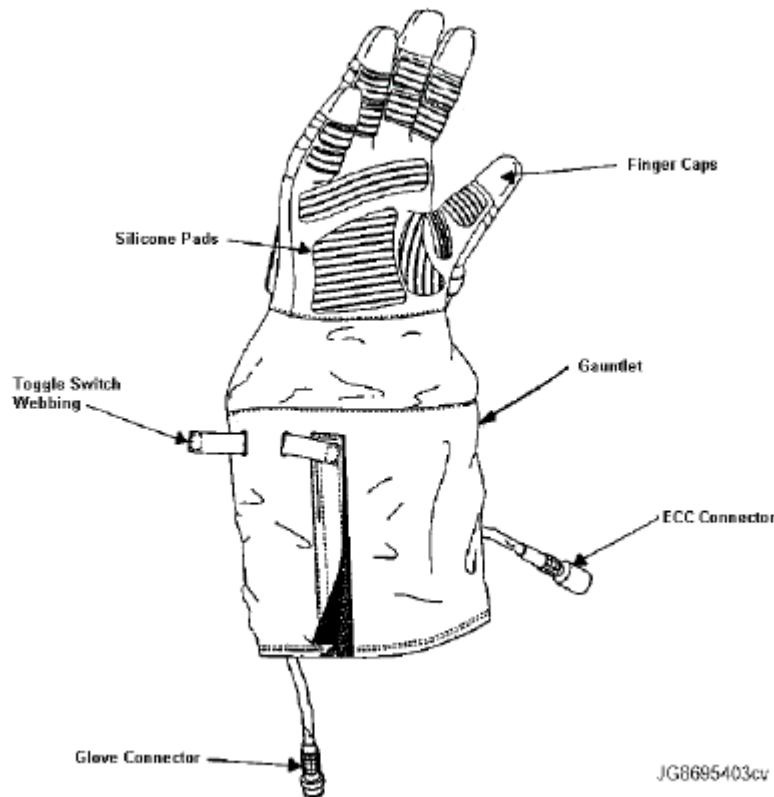
brackets. The gimbal rings, webbing restraints, and restraint brackets all provide a structural path to withstand pressure and manloads. Finger and thumb lengths are adjustable via a lacing cord/terminator bracket system (Figure 4.3-4). A fabric flange stitched to the restraint, the bladder flange, and the bladder liner flange are all bolted between a clamping ring and the wrist disconnect to provide a pressure seal.



**Figure 4.3-4. Phase VI glove less TMG**

#### 4.3.4 Thermal Micrometeoroid Garment

A glove Thermal Micrometeoroid Garment (TMG) must fulfill two near mutually exclusive requirements: allow maximum mobility and keep the crewperson's hands warm in all environments. The evolution of the Phase VI glove TMG has led to greater mobility with slightly reduced (though fully adequate) thermal protection. The Phase VI glove TMG is shown in Figure 4.3-5.



**Figure 4.3-5. Phase VI glove TMG**

The finger and thumbs of the TMG are formed of front and back halves, with the back halves being comprised of multi-layer insulation consisting of an outer layer of Teflon T-162 fabric over four layers of unreinforced aluminized Mylar, in between which is a non-woven Dacron spacer material to prevent thermal shorting of the aluminized layers. The innermost layer of the fingers is nylon chiffon, which acts as a protective buffer between the restraint and aluminized Mylar. This cross-section differs from the suit lay-up in the following aspects:

- A. Aluminized Mylar is unreinforced in fingers only.
- B. Outer shell is Teflon fabric instead of orthofabric.
- C. Inner layer or liner is chiffon instead of neoprene-coated ripstop.

These differences are all aimed at minimizing the negative effects of TMG bulk on overall glove mobility. The fingertips of the TMG are dipped in silicone rubber to aid dexterity. The fingertips of the TMG contain thermofoil heaters. These heaters are located approximately over each fingernail and provide additional thermal comfort on demand.

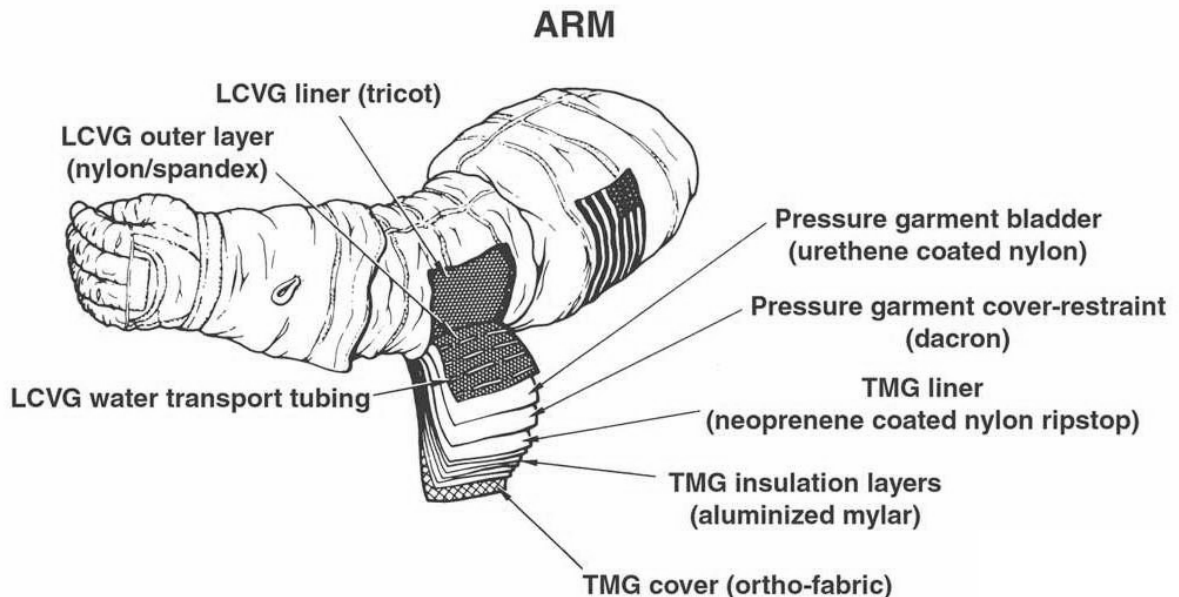
The Phase VI glove TMG is an Orbital Replacement Unit (ORU) and is expected to last six EVAs before it needs ground refurbishment. The TMG is attached to the

restraint/bladder combination via lacing cords that lock into keyhole brackets on each side of the fingers and thumb. The TMG is also attached to the restraint/bladder with Velcro hook and pile that covers the area of the palm plate. The TMG is also attached by routing the palm bar restraint strap through slots on the TMG hand back. This keeps the crew's fingertips in close proximity to the TMG finger caps. Removing the TMG is accomplished by releasing the palm bar strap and carefully demating the palm side Velcro attachment while inverting the TMG up to the keyhole brackets and pulling the TMG off of the fingertips. Installation of the TMG is the opposite.

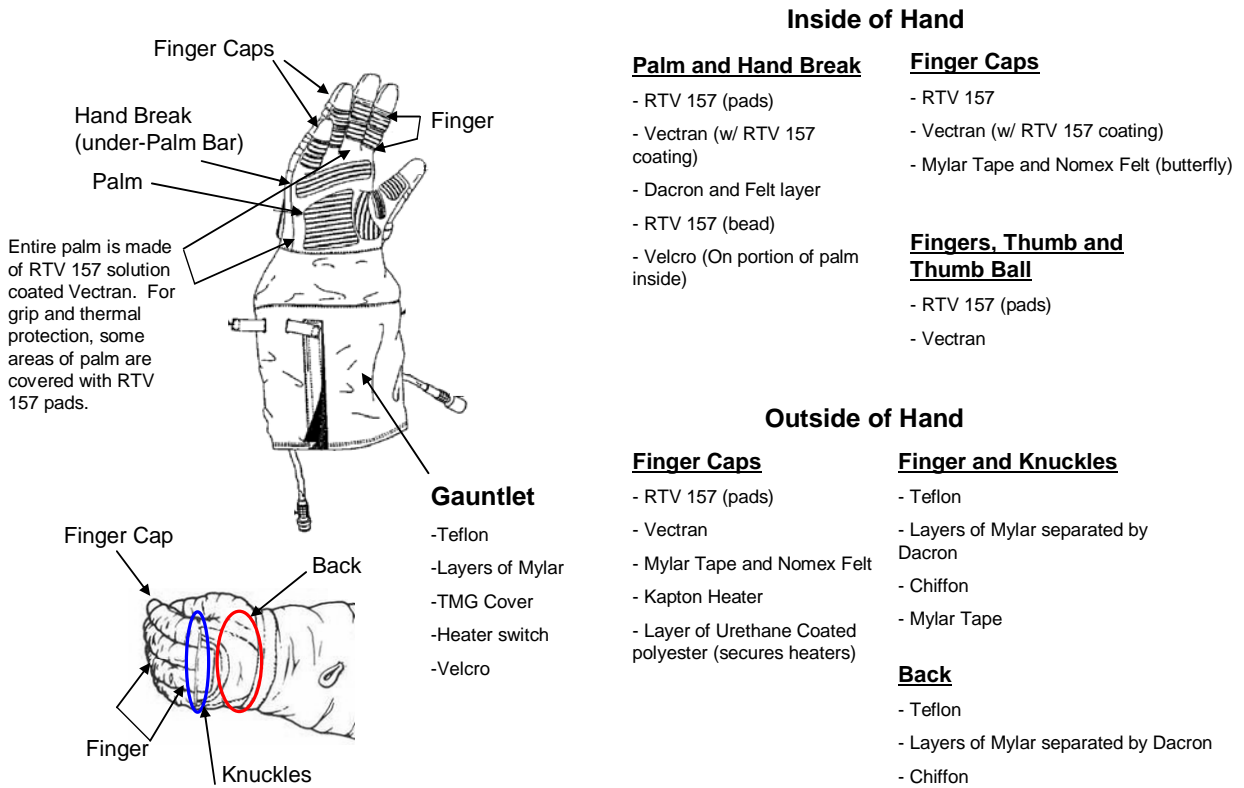
The base material for the Phase VI glove palm is a Vectran knit which is stretched and compressed into the 3-D shape of the palm which is then maintained with a thin coating of silicone. This fabrication technique eliminates seams in the TMG palm and improves mobility. The palm is then coated with RTV 157 for high cut and abrasion resistance and thermal protection. There are divisions in the silicone rubber coating to maximize mobility.

A cone shaped shroud referred to as the gauntlet is attached to the hand portion of the TMG. The gauntlet protects the wrist area of the restraint as well as the wrist disconnect from the ambient thermal environment. It also serves as a mounting location for the glove heater switch and LEMO quick disconnects for the glove heaters. The gauntlet serves as the mounting location for the EVA Cuff Checklist.

Materials details for the TMG, Restraint, and Bladder can be found in Figures 4.3.6-4.3.8.



**Figure 4.3-6. Layers in EMU Lower Arm (for comparison)**

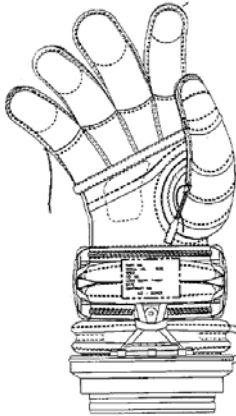


**Figure 4.3-7. Glove TMG Materials**

## Under TMG + Restraint

### Wrist

- Wrist liner - Dual Teflon Layer (3/8 inch Wide Strip Bonded to Bladder)



### Palm

- Palm Bar/Palm Bar Restraint (polyester tunnel)
- Fiberglass Plate

### Entire Glove

- Glove Bladder – Urethane; inside flocked with small cotton fibers

\*Crew Comfort Gloves-optional

**Figure 4.3-8. Layers starting below Restraint in Gloves**

### 4.3.5 Wrist Tether Strap

The Wrist Tether Strap (not shown) retains small articles used during EVA in close proximity to the hands. It is not, and should not be considered a safety tether. The wrist tether strap has a breaking force of 30-150 lb. static load to protect the crewmember and pressure suit integrity.

### 4.3.6 Glove Side Wrist Disconnect

The Phase VI glove interfaces with the Lower Arm via a stainless steel dual seal wrist disconnect (Figure 4.3-9). The flanges of both the bladder and the restraint mount under a clamping ring on top of the wrist disconnect. This disconnect is the passive half that mates with the suit side (arm) wrist disconnect element. The glove disconnect also includes a dual seal wrist bearing to provide wrist rotation.



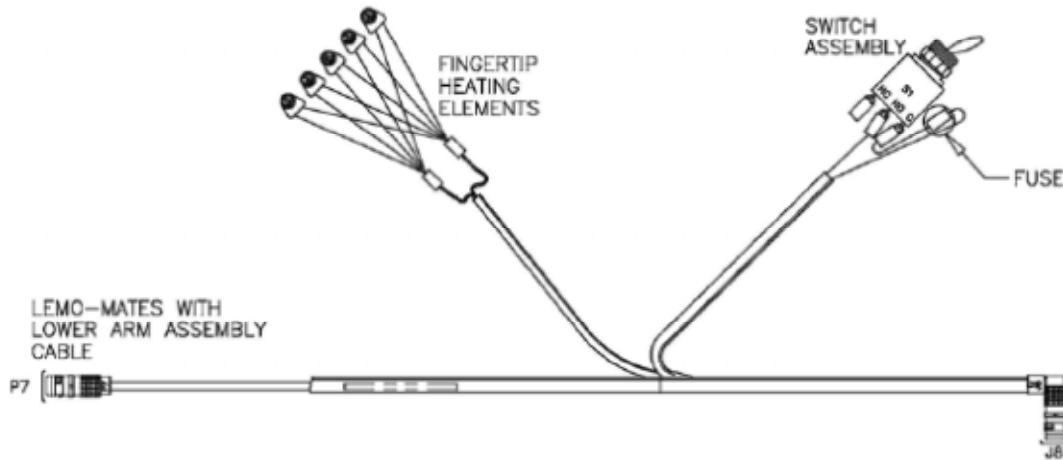
**Figure 4.3-9. Glove disconnect**

#### **4.3.7 Glove Heaters**

Thermofoil heaters are attached inside each of the fingertips of the glove TMG, located approximately over each of the crewmember's fingernails. The heaters are activated via the gauntlet mounted hermetic switches (see Figure 4.3-10).

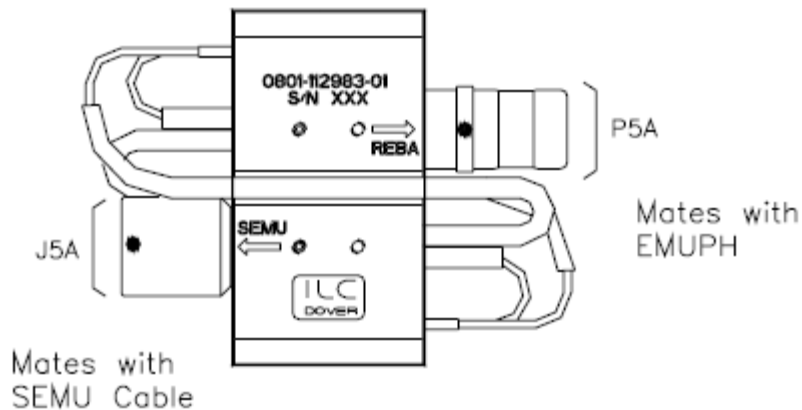
The heaters are powered by a remote battery pack, called the Rechargeable EVA Battery Assembly (REBA). Each glove heater can be activated independently of the other. Heaters are connected in parallel for system reliability.

The heaters connect to the EMU Power Harness system via a LEMO quick disconnect. The heater electrical harness also includes a scar LEMO connector, which allows for future electronics options. Figure 4.3-11 provides an overview of the system contained in the glove.



**Figure 4.3-10. Phase VI glove TMG heaters, switch and cable**

The In-line Cable Voltage Regulator (ILCVR) is module inserted at the interface between the SEMU Harness and the EMUPH that regulates the power provided to the Phase VI glove heaters. The ILCVR (Figure 4.3-11) converts the REBA output from 14.0V maximum to 9.0 +0.2/-0.5V. It is installed in the Connector Sheath with an extension (P/N 0102-812936-01) located in the ORU HUT O2 pocket.



**Figure 4.3-11. In-Line cable voltage regulator**

#### 4.3.8 Related Documentation References

EMU Mini Data Book

EMU Systems Training Workbook

EMU Requirements Evolution

## 4.4 EMU ENHANCEMENTS

### PURPOSE

This section describes enhancements to the EMU, including the planar HUT, sizing rings, and sizing cam adjustments which allow the arms and legs to be sized to the crewmember.

#### 4.4.1 Planar Hard Upper Torso

The Planar Hard Upper Torso (HUT) provides the structural mounting interface for the Primary Life Support System (PLSS), Display and Controls Module (DCM), Helmet, Arms, Lower Torso Assembly (LTA), and the EMU Electrical Harness (EEH). It also provides pressure containment for this portion of the body and fluid passages from the PLSS to the DCM and to the Liquid Cooling and Ventilation Garment (LCVG).

Many of the interfaces for the Planar HUT have been redesigned from the interfaces used with the Pivoted HUT to allow for easier changeout on orbit.

The Planar Hard Upper Torso (HUT) Assembly consists of four major subassemblies: The Hard Torso Shell (HTS), the Helmet-Suit Disconnect, the HUT-side Body Seal Closure (BSC), the Water Line and Vent Tube Assembly (WLVTA), and the HUT Thermal Micrometeoroid Garment (TMG).

The main component of the Planar HUT is the HTS. The HTS consists of a rigid fiberglass shell (Figure 4.4-1) and two fixed metal retainers that act as the HUT-Arm interface. The HTS also contains the PLSS-HUT and PLSS-DCM mounting pads and mounting brackets and the EMU electrical harness (EEH) brackets. Assembled onto this unit are the HUT-side of the Helmet-Suit Disconnect, the HUT-side of the Body Seal Closure (BSC), the Waterline and Vent Tube Assembly, the Harness Pad and the Shoulder Harness Straps.

The Helmet-Suit Disconnect consists of the disconnect itself, the Helmet Vent Pad, and the Shoulder Harness Brackets. The Helmet-Suit Disconnect is installed onto the Neck ring of the HTS with a silicone seal to retain pressure.

The HUT-side BSC is constructed of metal and is attached to the bottom flange of the HTS with screws and uses an "O" ring to act as a pressure seal. Through the BSC

Mounts, the HUT provides an interface to the Mini-Work Station and the Modified Mini-Work Station. The Water Line Vent Tube Assembly mounts to the HTS interior and interfaces with the LCVG. The WLVTA supplies cooling water to circulate through the LCVG and provides for exhaust of SSA vent air.

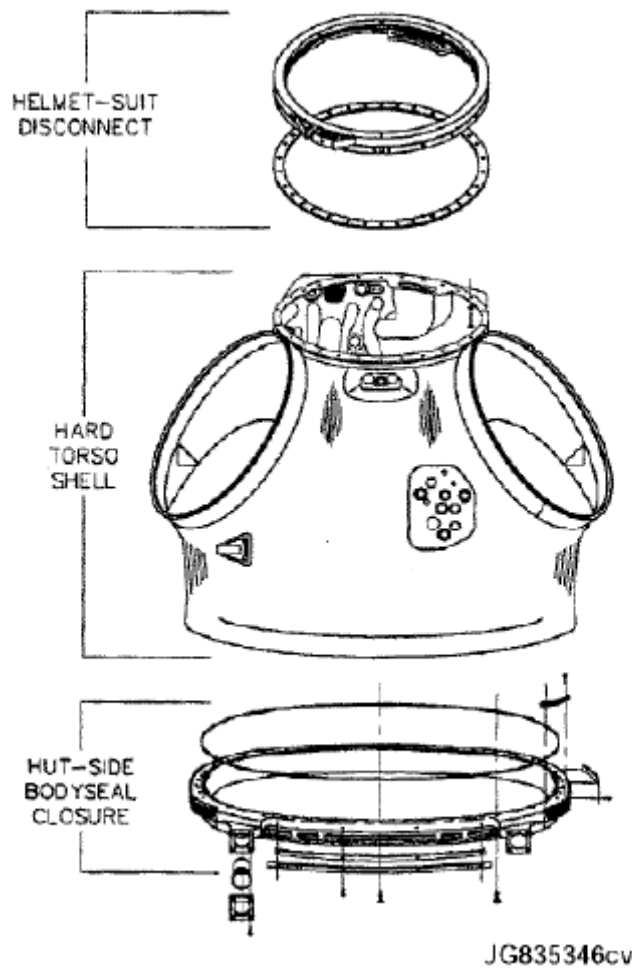
The TMG covers the outside surface of the HUT and provides thermal protection and protection from micrometeoroids. The TMG has long sleeves that also cover the upper arms. The SEMU Power Harness is routed through the sleeves and body of the TMG.



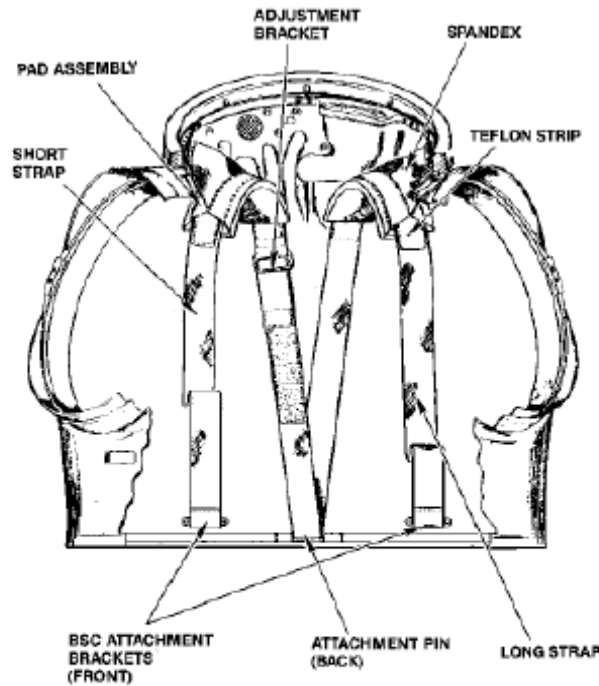
The TMG also provides for routing and coverage of the O2 line and actuator cable and the 391 and 392 electrical jumper harnesses.

A Shoulder Harness (Figure 4.4-2), much like a pair of suspenders, is a crewmember option and supports the weight of the EMU on the crewmember's shoulders during

1-G unpressurized activity and tends to stabilize the crewmember in the suit during 0-G pressurized conditions. The Shoulder Harness has two main parts: the Straps and the Pads. The straps are used to adjust and position the pads which act to distribute the load on the shoulders for optimum positioning of the HUT.



**Figure 4.4-1. Planar hard upper torso**



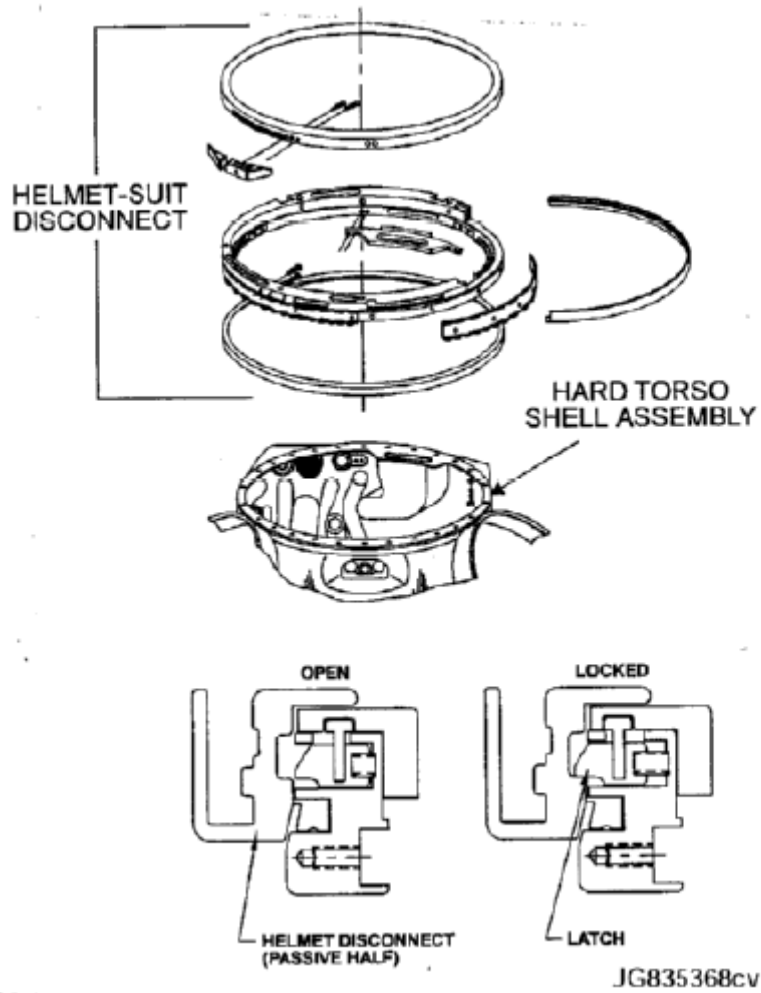
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**Figure 4.4-2. Shoulder harness**

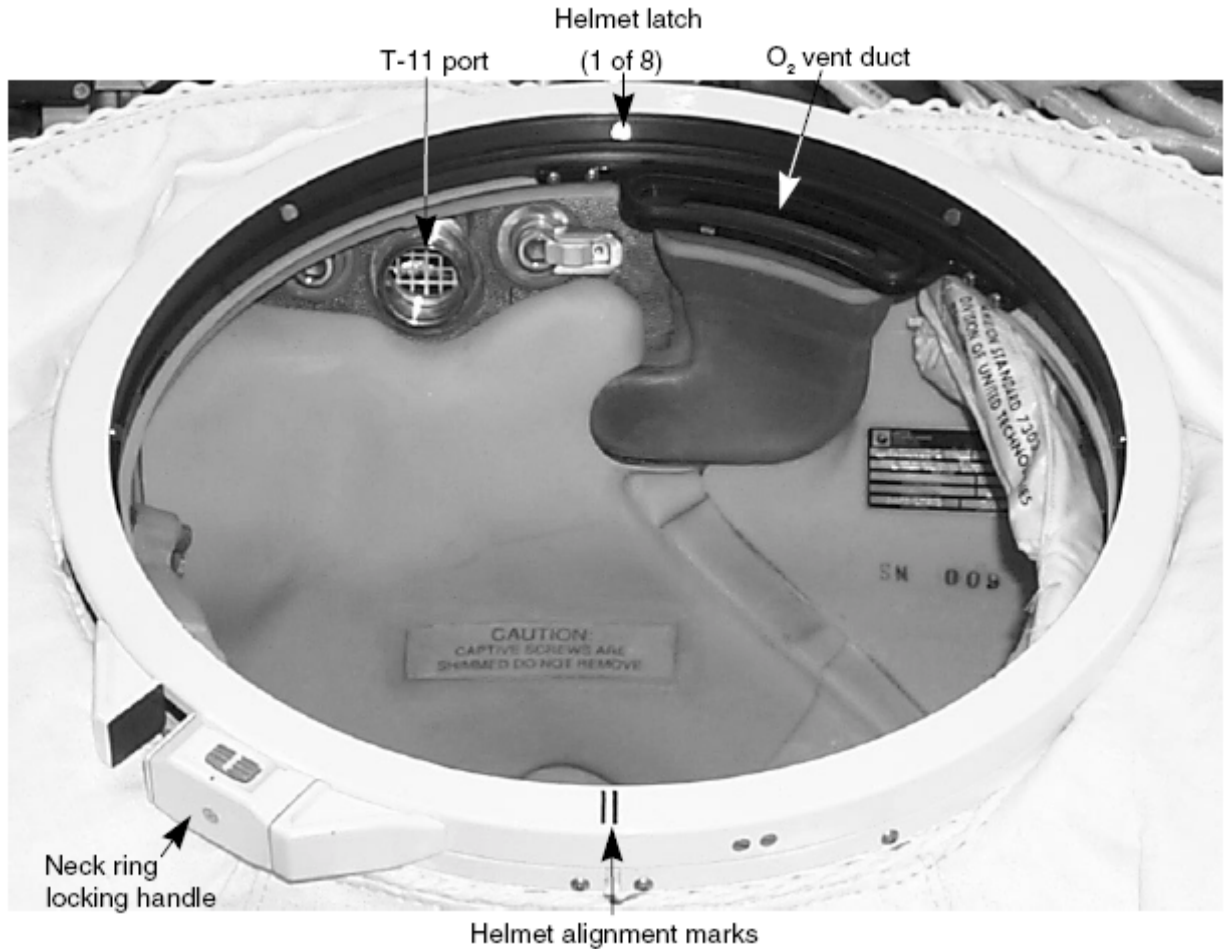
#### 4.4.1.1 Helmet to Planar HUT Interface

The connection of the Helmet to the Planar HUT is provided by a quick disconnect ring (Figure 4.4-3, Figure 4.4-4). The active half (the portion that contains the moving parts – cams, levers, pins, etc.) is attached to the HUT Neck Ring Flange. The passive half (the portion with no moving parts) is attached to the bottom of the Helmet. The operation of the active half of the quick disconnect is controlled by a locking handle that is located on the outside of the disconnect ring just right of center. The handle has three positions: Open, Engage, and Locked. These positions refer to the status of the locking ring cam, which controls the in and out position of the latching pins. Movement of the handle moves the cam and in turn, the latch pins.

The latch pins extend out of the ring in the Locked and Engage positions and are forced to retract in the Open position. A spring forces the handle to return to the Engage position when it is released from the Open position. This is a safety feature that assures that if a Helmet is properly mated to the Planar HUT it will be captured by the latch pins and will not inadvertently become detached.



**Figure 4.4-3. Helmet to planar HUT interface**



**Figure 4.4-4. HUT neck ring**

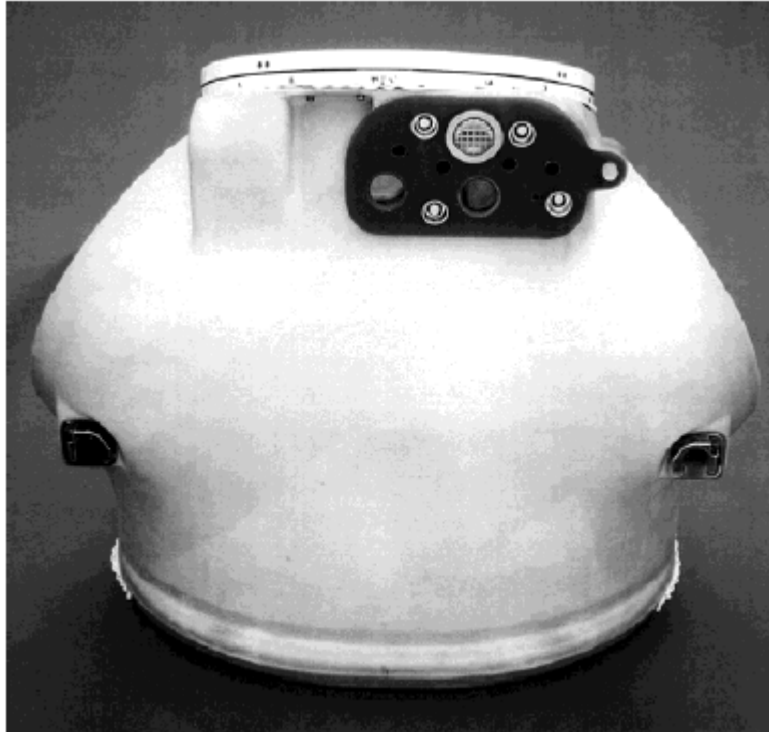
#### **4.4.1.2 PLSS To Planar HUT Interface**

The PLSS is attached to the back of the Planar HUT at three points (Figure 4.4-5 and Figure 4.4-6). There are two studs located on the lower right and left rear sides of the HTS and a PLSS/HUT interface pad at the rear of the Helmet-Suit Disconnect, right of center. To attach a Planar HUT and PLSS, the PLSS is laid on its back and the HUT is lowered onto the PLSS while aligning the two studs with their respective slots in the PLSS and sliding the HUT until the four bypass plate alignment features mate with their respective HUT pad counterbores. The rear vent pad screws are installed from the inside of the HUT. These screws are torqued in sequence to assure the “O” rings in the PLSS seal properly against the flat surface of the HUT pad.

#### **4.4.1.3 DCM To Planar HUT Interface**

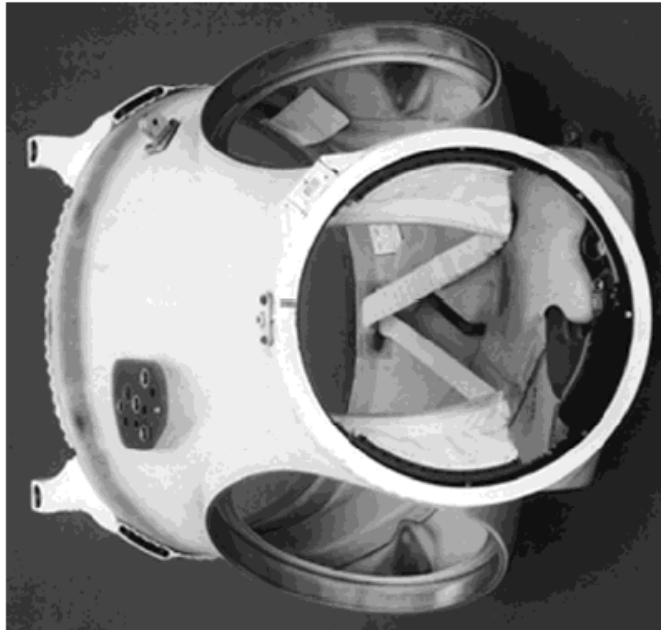
Three points, the DCM pad, the upper DCM mounting boss, and the lower DCM mounting boss, provide the attachment feature for the DCM to the HUT (Figure 4.4-7).

Two alignment pins protruding from the DCM pad on the HUT mate with holes in the DCM when the two are properly mated to assure alignment of the pneumatic and hydraulic tubes and ducts. Screws are installed from inside the HUT and are tightened in a cross torque pattern to assure "O" rings in the DCM will seal against the flat face of the DCM pad on the HUT.



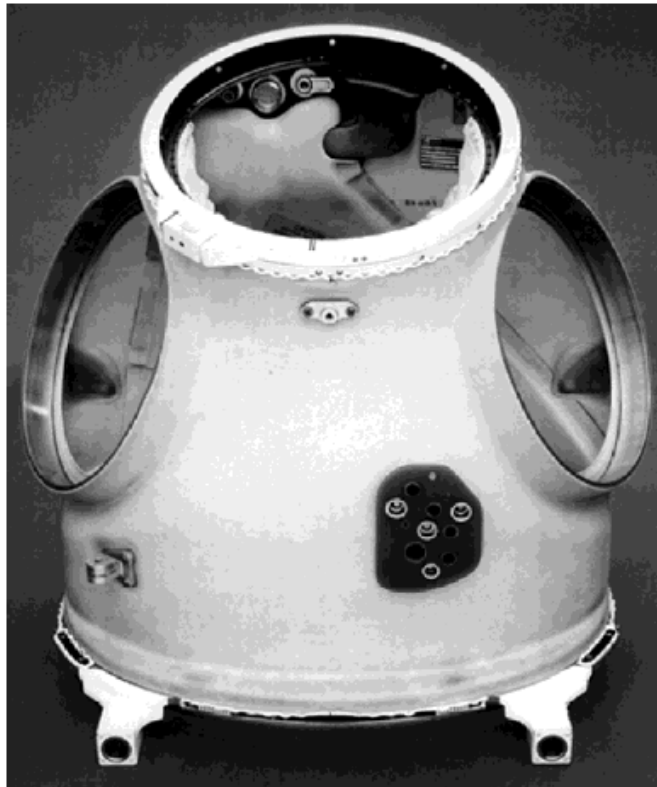
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***Figure 4.4-5. PLSS to planar HUT interface***



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**Figure 4.4-6. PLSS to planar HUT interface**



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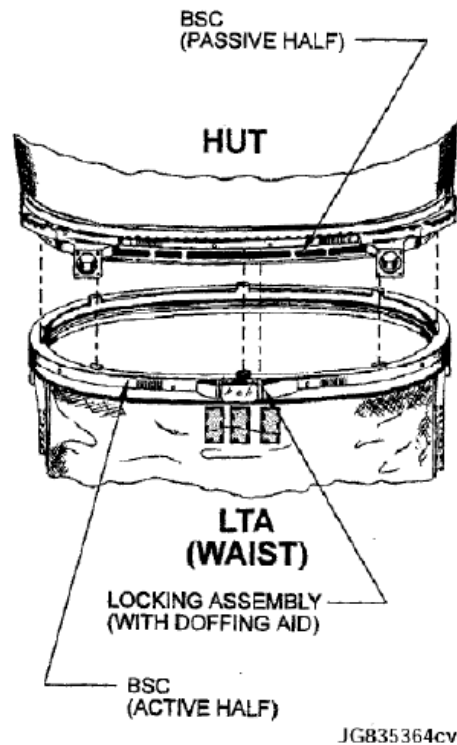
**Figure 4.4-7. DCM to planar HUT interface**

#### 4.4.1.4 EMU Electrical Harness to Planar HUT Interface

A hole in the fiberglass shell located over and to the rear of the left shoulder is provided to allow installation of the EMU Electrical Harness (EEH) connector. The bulk-head type connector is installed from inside the HUT by aligning the flat on the connector with the flat on the "D" hole and pushing the connector through. A flange with an "O" ring at the base of the thread seals against the fiberglass shell as the lock washer and attachment nut are installed. The electrical Harness coming from the EEH connector is routed over the left Scye Bearing opening under the shoulder Harness webbing and over to the front center of the HUT. The harness is secured to the fiberglass shell by tying it to harness clips with lacing cord.

#### 4.4.1.5 Enhanced Lower Torso Assembly (LTA) To Planar HUT Interface

The LTA to HUT interface is accomplished using the body Seal Closure (BSC) as shown in Figure 4.4-8. The BSC is a two-part quick disconnect similar to the Helmet to HUT Disconnect. The passive portion is attached to the Waist flange of the HUT fiberglass shell and the active portion is attached to the LTA using the LTA Donning Handles. Capture of the BSC halves is obtained by latch pins that are controlled by cams operated by a locking handle. The locking handle is located on the front middle part of the LTA half of the Disconnect and has three positions: Lock, Engage and Open. The operation of the locking handle is similar to the Helmet Disconnect except unlocking is aided by a retractable doffing aid lever.



**Figure 4.4-8. Lower torso assembly to HUT interface**

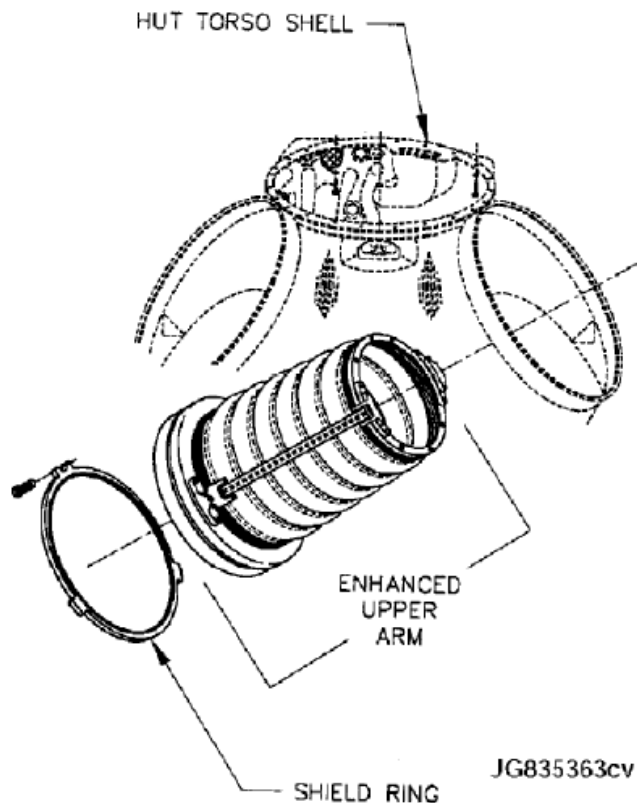
#### 4.4.1.6 Enhanced Arm to Planar HUT Interface

This interface is accomplished by inserting the Arm through a fixed metal retainer in the HUT (Figure 4.4-9). The insertion is made from inside the HUT such that the Arms are drawn through the arm openings extending to the outside of the HUT. In this manner, plug and manloads tend to hold the arms in place without the need for heavy structural attachment hardware.

A Dual Seal Scye Bearing is used in the Arm Assembly. The Scye Bearing mounts to the soft goods flange of the Upper Arm (Figure 4.4-10). The arm is secured to the

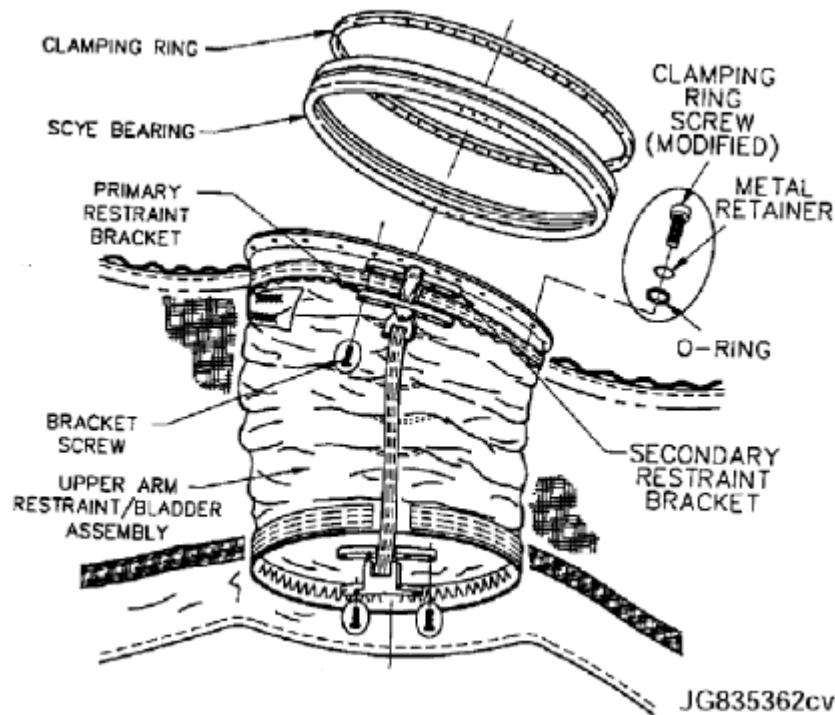
HUT by insertion of the Scye Bearing into the HUT retainer. The Scye Bearing sets against a lip on the inside surface of the metal retainer.

A retention ring retains the Scye bearing assembly in the HUT by overlapping three lips on the retention ring with matching lips on the HUT side retainer. This is accomplished by twisting the retention ring open into position such that the lip on one end of the ring overlaps the locking lip on the HUT side retainer. With the retention ring seated in this manner, the ring is secured by a cap screw.



**Figure 4.4-9. Enhanced upper arm assembly**





**Figure 4.4-10. Scye bearing installation**

#### 4.4.2 Enhanced SSA Leg and Torso Sizing

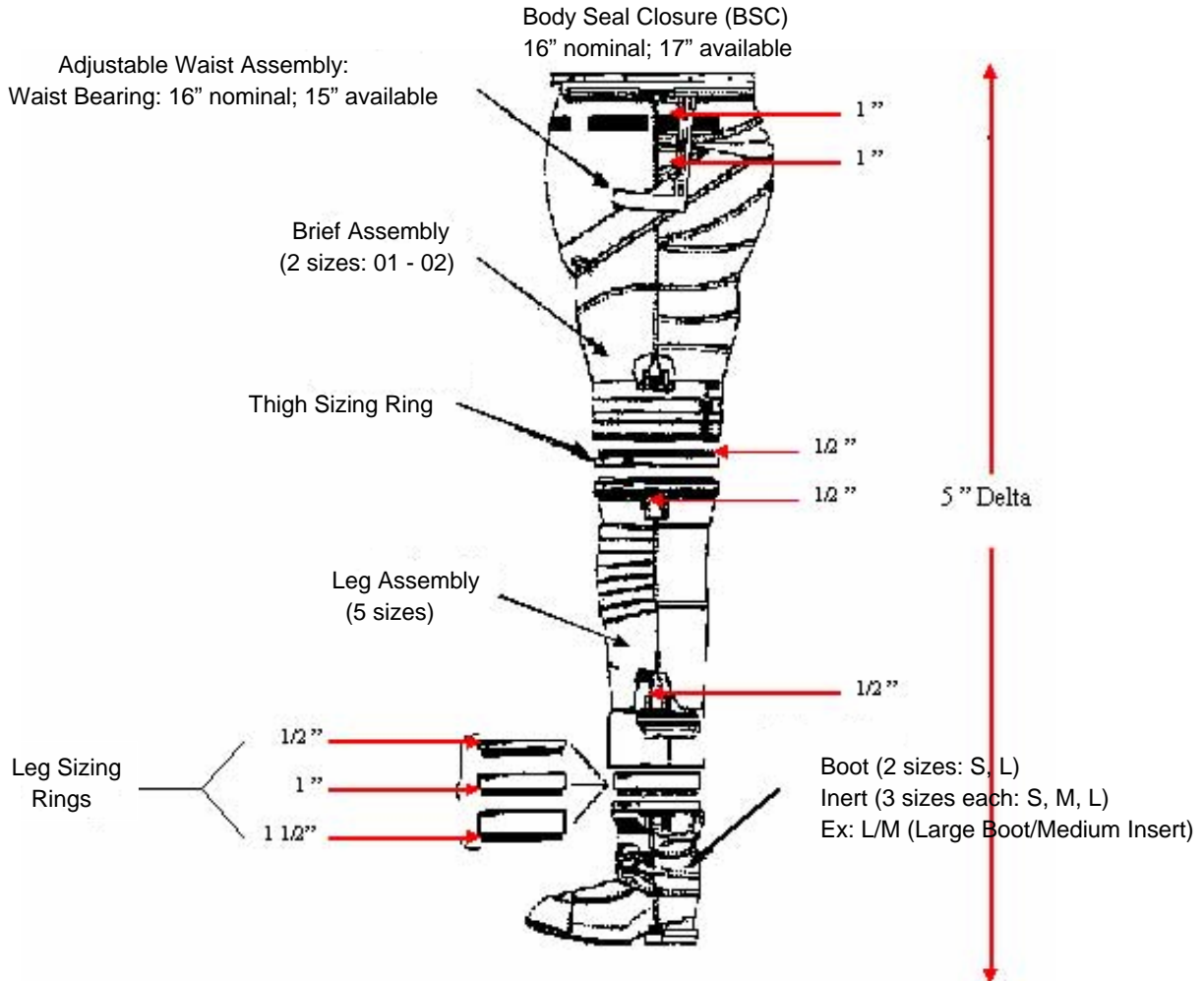
The Enhanced Lower Torso Assembly (Figure 4.4-11) consists of five major subassemblies: the Brief-Waist Assembly, the Leg Assembly, the Boot Assembly, the Thigh Sizing Ring, and the Leg Sizing Rings. The Enhanced LTA configuration includes adjustable leg restraint brackets incorporating 0.5 in. of length adjustment; a 0.5 in. thigh sizing ring, 0.5, 1.0, and 1.5 in. leg sizing rings that provide overall length adjustment by as much as 5.0 in. Resizing and change-out of the enhanced components can be performed on-orbit.

The fabric elements are joined by flange attachment to hardware, and in all cases, except at the BSC and the waist bearing, the attachment between elements is by a threaded metal quick disconnect which allows components to be interchanged easily. The LTA interfaces the Hard Upper Torso (HUT) via the BSC.

LTA thermal protection is provided by a Thermal Micrometeoroid Garment (TMG). The TMG sections fit over the waist, brief, leg and boot assemblies. They are secured to the LTA through the use of lacing cord/looptape attachments, zippers, and Velcro hook and pile.

The Brief-Waist Assembly consists of the Body Seal Closure (BSC), adjustable Waist Restraint/Bladder Assembly, a Dual Seal Waist Bearing, Brief Restraint/Bladder Assembly, and the Waist and Brief TMG Assemblies. The Brief-Waist Assembly includes the waist and hip joint and thigh fabric attachment rings.

The leg assembly consists of the Leg Restraint/Bladder Assembly and the TMG Assembly. The Leg Assembly includes an upper and lower Fabric Attachment Ring, adjustable leg restraint brackets incorporating 0.5 inch of length adjustment and primary/secondary axial restraint webbings. The Leg Assembly includes a knee joint.



**Figure 4.4-11. Enhanced lower torso assembly**

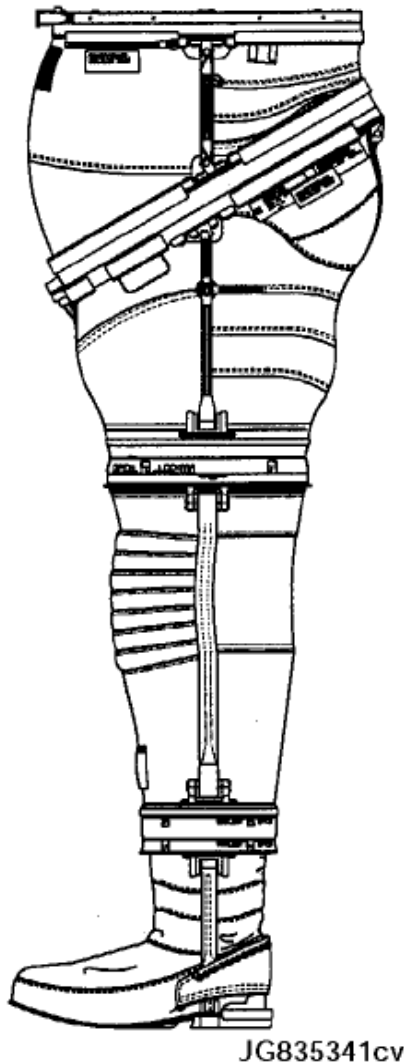
The Boot Assembly consists of the Boot Restraint/Bladder Assembly, the Boot Sole Stiffener, the Boot Heel Assembly, the Boot TMG Assembly, and the Boot Fabric Attachment Ring. The Boot Assembly contains the ankle joint.

#### 4.4.2.1 Bladder Assembly

Pressure integrity of the Enhanced Lower Torso Assembly is maintained via seals at all component disconnects and component bladder assemblies i.e. adjustable waist, brief, leg, and boot.

#### 4.4.2.2 Restraint Assembly

The LTA Restraint Assembly (Figure 4.4-12) serves to manage the circumferential loads of the LTA during normal suit operation. The restraint is constructed from polyester fabric. The Axial Restraint Webbing on the Enhanced LTA are constructed from a new, high strength, low elongation webbing. This webbing greatly reduces the amount of stretch or “growth” that occurs when the article is pressurized. The exception is the Boot Assembly, which uses polyester for Axial Restraint Webbing. The axial restraint loads are transferred in a contiguous loop from one side of the BSC to the other through the Waist, Brief, Leg, and Boot axial restraint lines. Redundancy is incorporated in the axial restraints by the use of both primary and secondary restraints. The primary restraint brackets, except for the crotch buckle and the brief-waist bearing interface, may be removed for inspection or replacement of Enhanced LTA components.

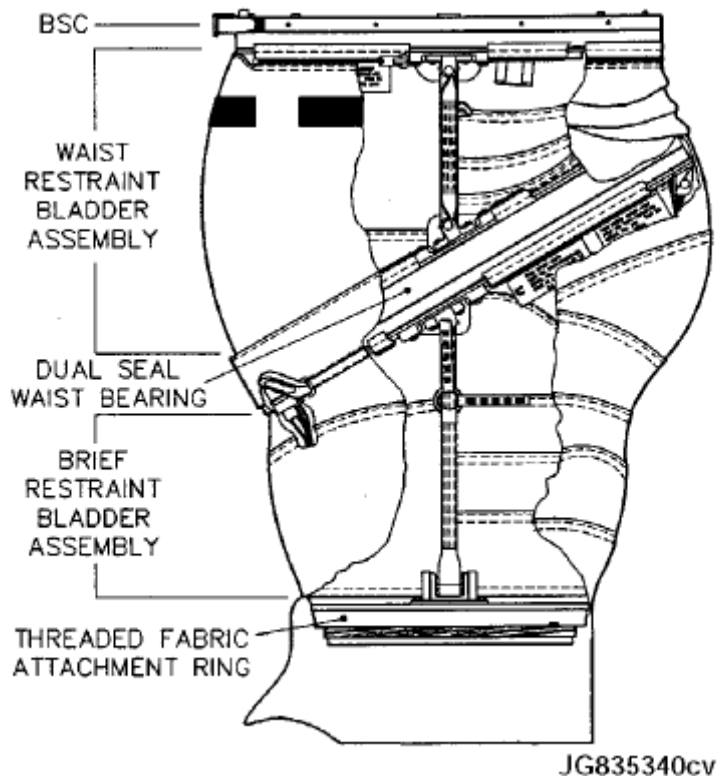


**Figure 4.4-12. Enhanced lower torso restraint assembly**

#### 4.4.2.3 Brief-Waist Assembly

The Brief-Waist Assembly (Figure 4.4-13) consists of a Body Seal Closure (LTA-half), fabric waist joint, dual seal waist bearing, thigh fabric joints, threaded fabric attachment rings at the thigh openings of the Brief, and Brief and Waist TMG assemblies. The Brief-Waist Assembly is the transition from the HUT to the Leg portion of the LTA. The Brief-Waist Assembly is the longest component of the LTA. There is 2.0 in. of adjustment available in one inch increments in the waist by removing the upper and/or lower primary restraint pins, repositioning the primary webbing and replacing the pin.

There are two sizes of Waist Bearings that join the Brief- Waist Assembly. A 16.0 in. Waist Bearing is used on the Large Brief Assembly. An appropriately sized Waist Assembly is attached to the other side of either Waist Bearing.

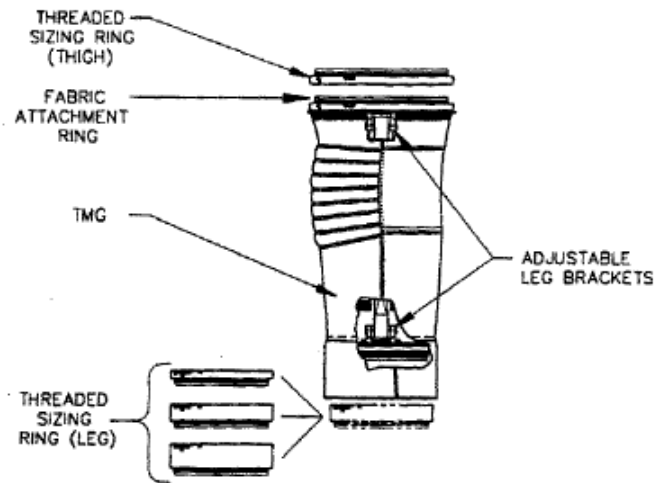


**Figure 4.4-13. Enhanced LTA brief waist assembly**

#### 4.4.2.4 Leg Assembly

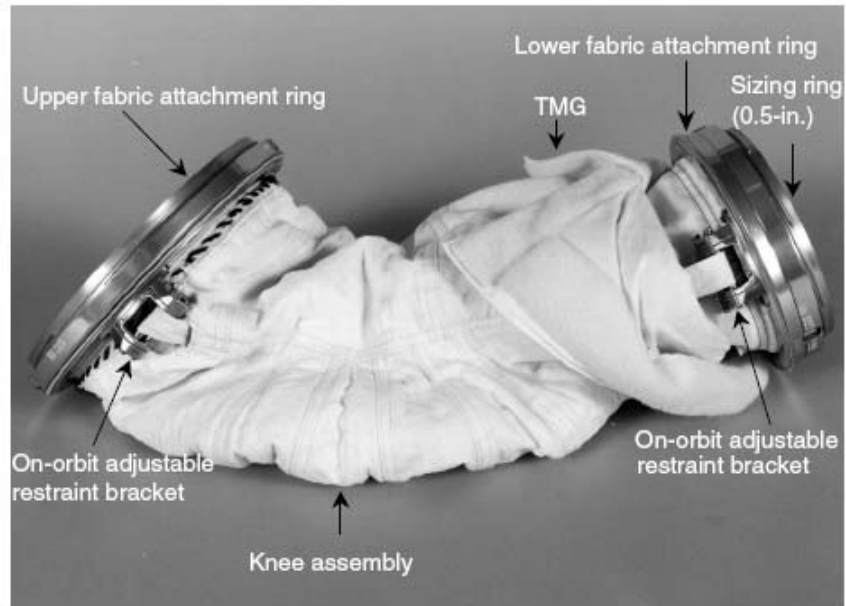
The Leg Assembly (Figure 4.4-14 and Figure 4.4-15) consists of a single-axis unidirectional fabric joint, upper and lower threaded fabric attachment rings, adjustable leg brackets, and a TMG. The Leg Assembly provides for flexure of the knee joint while maintaining SSA pressure integrity and joint shape.

Several sizes of Leg Assemblies allow for rapid resizing of the LTA. The Leg Assemblies come in five different lengths and are removed from the Brief Waist Assembly via the use of threaded Fabric Attachment Rings. The Leg Assemblies also incorporate metal Thigh and Leg Sizing Rings to achieve proper knee/convolute position. The possibilities include a 0.5 in. Thigh Sizing Ring and/or 0.5 in., 1.0 in., and 1.5 in. Leg Sizing Rings (sizes may not be combined).



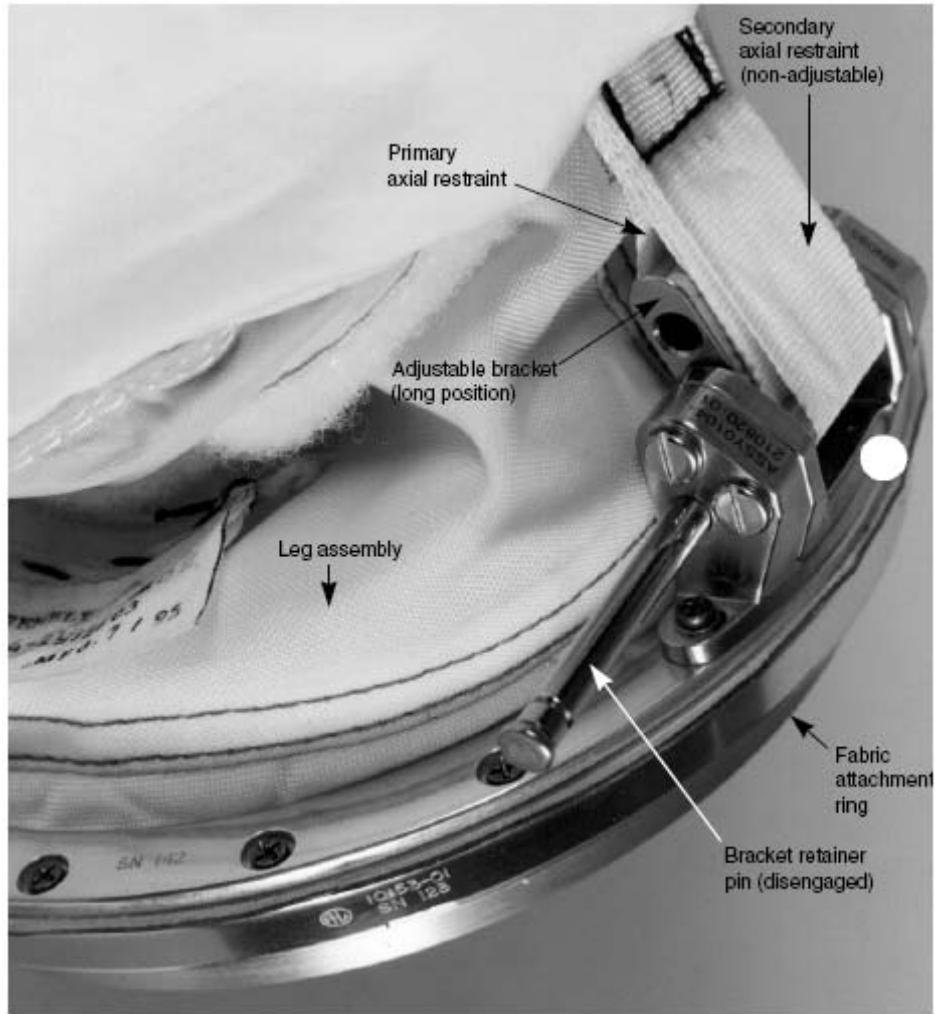
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**Figure 4.4-14. Enhanced LTA leg assembly**

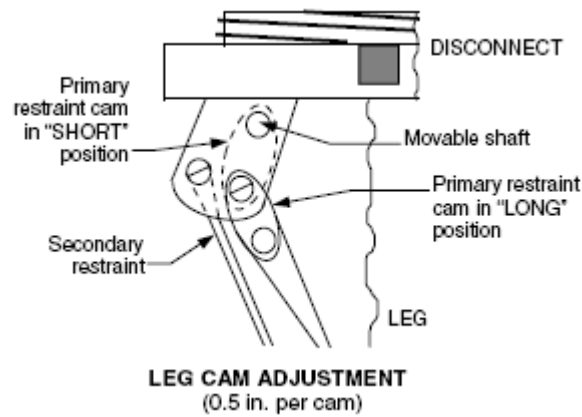


**Figure 4.4-15. Enhanced leg assembly**

The Leg Assembly also has adjustable leg restraint brackets. These allow the length of the Leg Assembly to be changed on orbit by up to 1.0 inch by adjusting each of the leg brackets by 1/2 inch per cam loop position and replacing the pin (Figure 4.4-16 and Figure 4.4-17).



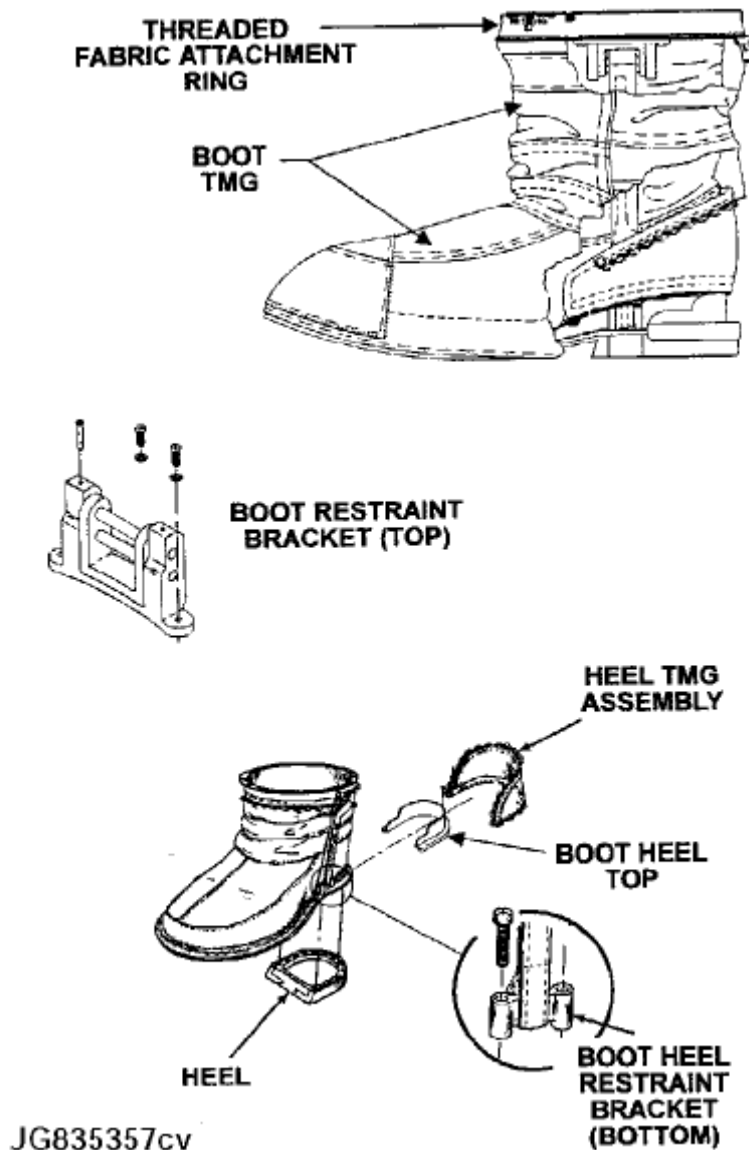
**Figure 4.4-16. Adjustable restraint bracket with pin disengaged**



**Figure 4.4-17. Leg cam adjustment drawing**

#### 4.4.2.5 Boot Assembly

The Enhanced Boot (Figure 4.4-18) consists of a fabric ankle joint, fabric foot envelope, fiberglass sole stiffener, removable heel, threaded fabric attachment ring, and a TMG. The Boot Assembly provides for flexion and extension of the ankle joint while maintaining SSA pressure integrity and joint shape. Two sizes of boots and three sizes of Boot Sizing Inserts for each of them, allow for sizing adaptation to different sizes of crew foot size. The boot top fabric attachment ring is threaded to allow insertion of sizing rings between the Leg and the Boot.



**Figure 4.4-18. Enhanced LTA boot assembly**

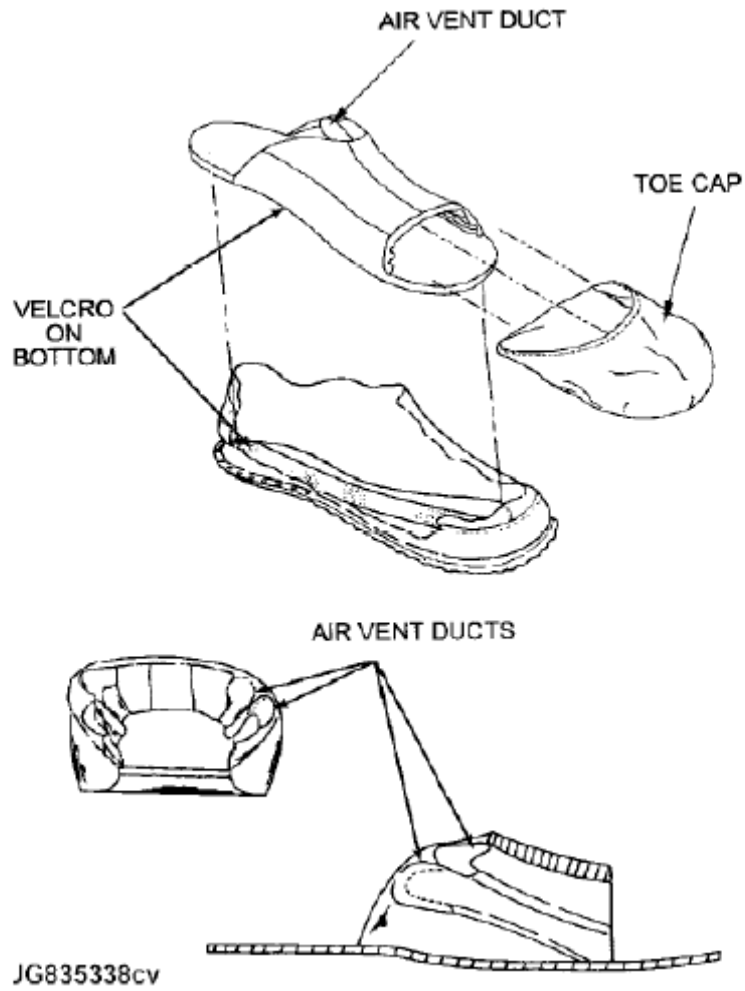


#### **4.4.2.6 Boot Sizing Inserts and Thermal Slippers**

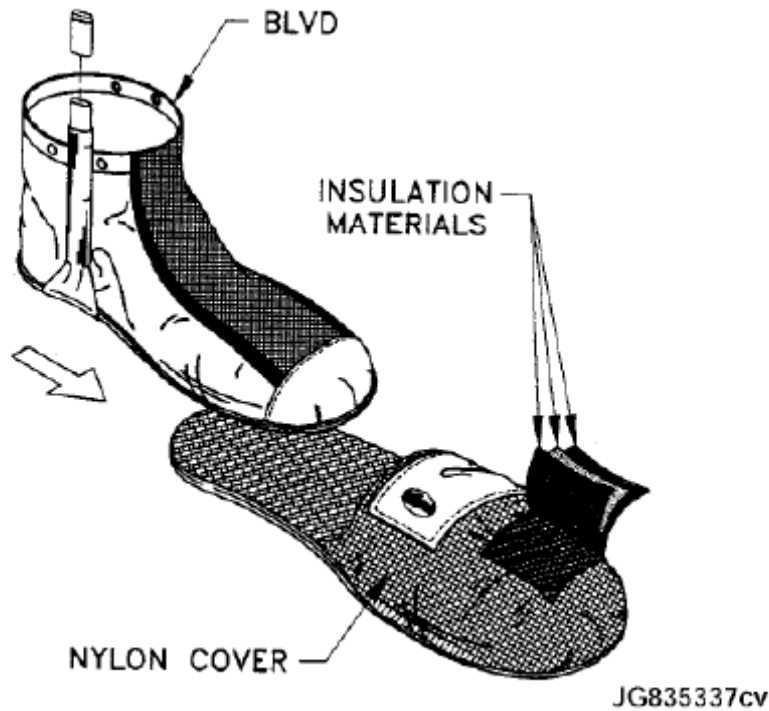
The Boot Sizing Insert (BSI) allows for sizing adaptation to different sizes of crew foot size. The BSI is installed into the Boot Assembly. The BSI is constructed from foam rubber and urethane coated nylon fabric. There are three sizes of foam Boot Sizing Inserts (BSI) available for the large and small boots. The available sizes are: Small/Small, Small/Medium, and Small/Large for Small boots, and Large/Small, Large/Medium, Large/Large for Large boots (Figure 4.4-19). In the event that a crewmember does not find the fit with a Boot Sizing Insert acceptable, the thermal slipper may be chosen (Figure 4.4-20). The thermal slipper provides for additional foot volume while maintaining thermal comfort in place of the Boot Sizing Insert.

#### **4.4.2.7 Toe Caps**

The Toe Cap was created to enclose the open, toe end of the BSI for enhanced thermal comfort. The toe cap is constructed from Rip-stop nylon polyester/nylon insulation and reinforced aluminized Mylar (Figure 4.4-19).



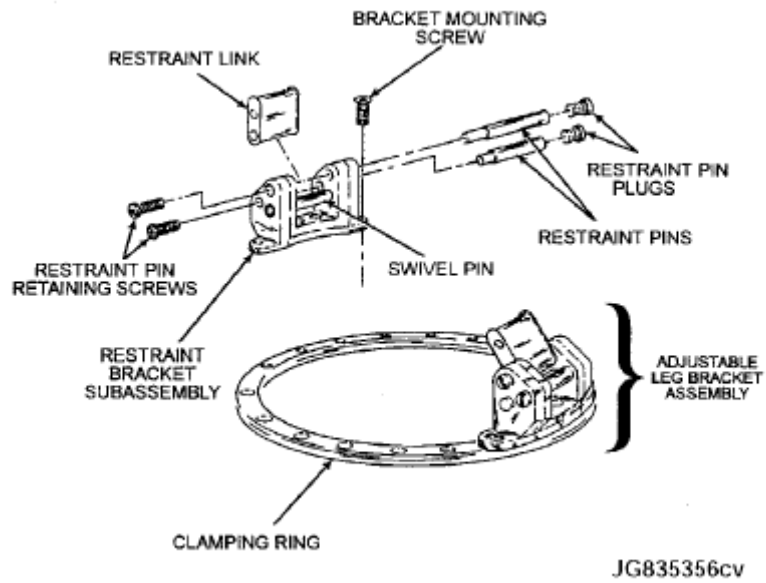
**Figure 4.4-19. Boot sizing inserts**



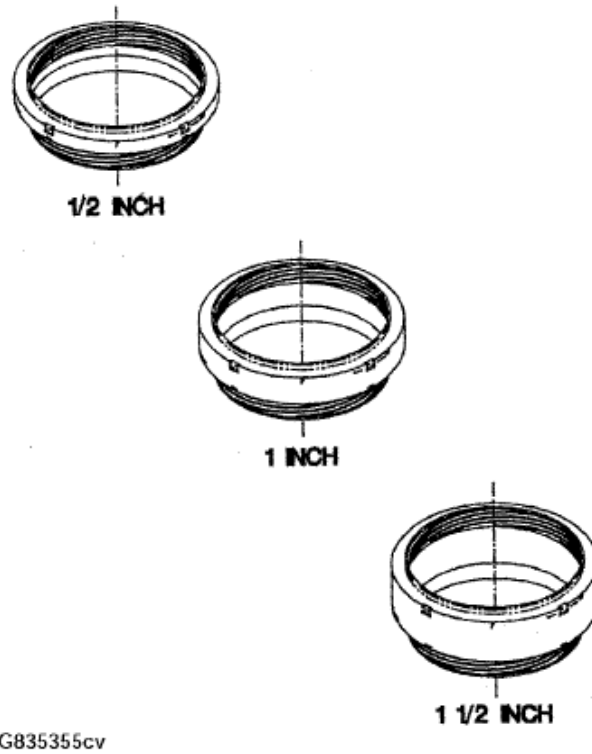
**Figure 4.4-20. EMU thermal slipper assembly**

#### **4.4.2.8 Sizing the Enhanced Lower Torso Assembly**

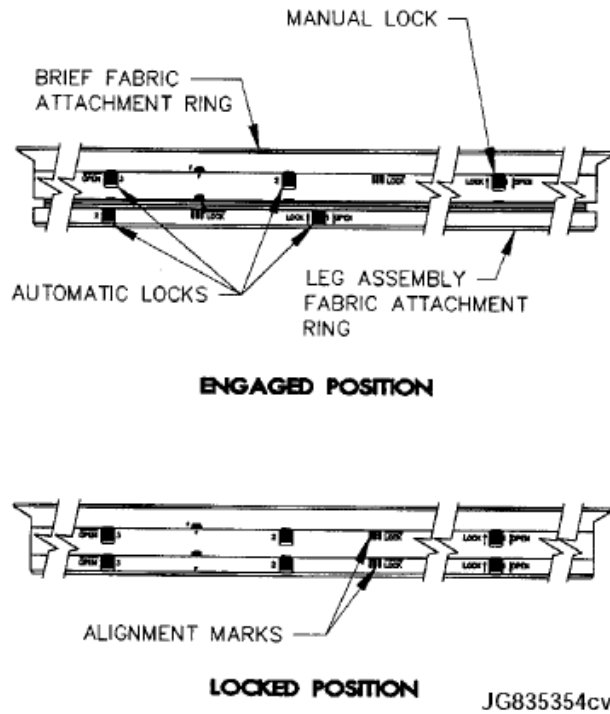
The LTA can be sized with adjustable leg brackets and sizing rings (Figure 4.4-21, Figure 4.4-22, Figure 4.4-23, and Figure 4.4-24). The leg assemblies contain brackets that can be adjusted in 0.5 in increments for a total of 1.0 in. Crewmembers with long legs can be accommodated by adding a 0.5 in. Thigh Sizing Ring. The distance between the knee and the foot can also be adjusted with Leg Sizing Rings in 0.5 in. increments from 0.5 in., 1.0 in., and 1.5 in. rings. Using the Enhanced LTA sizing provisions (five lengths of Legs, 0.5 in. Adjustable Leg brackets, Thigh and Leg Sizing Rings) allows for optimum sizing of crewmembers and assures correct knee position within the knee joint.



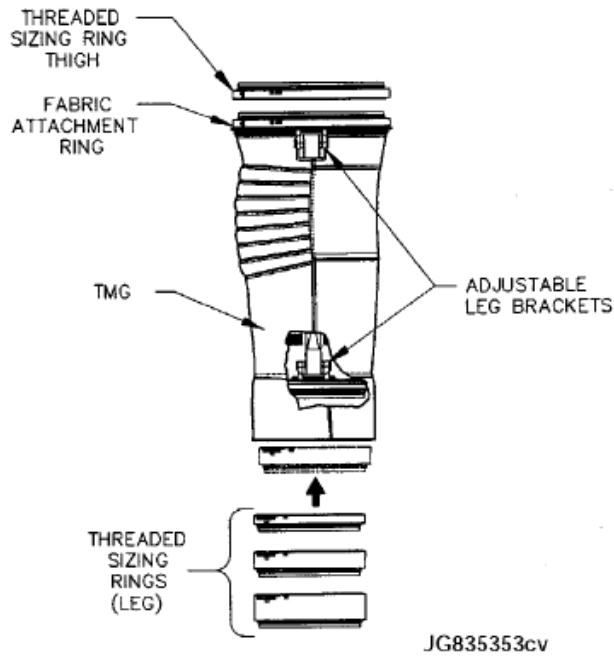
**Figure 4.4-21. Enhanced LTA adjustable leg bracket assembly**



**Figure 4.4-22. Enhanced LTA leg sizing rings**



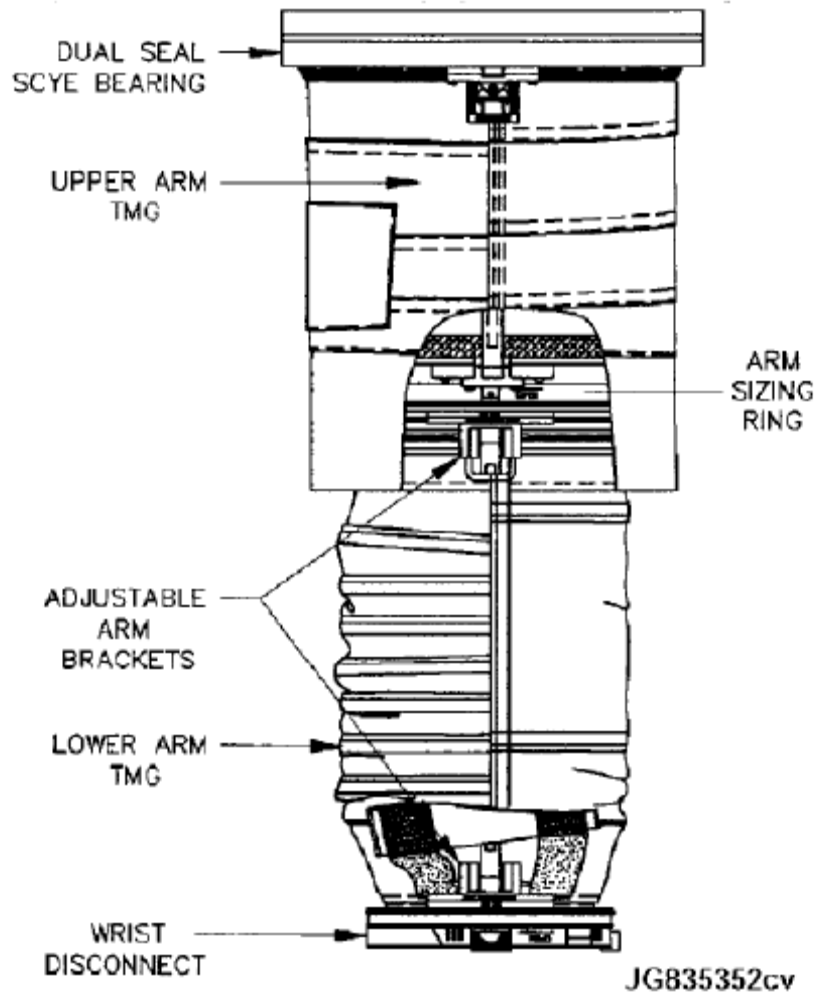
**Figure 4.4-23. Enhanced LTA fabric attachment ring/sizing interface**



**Figure 4.4-24. Enhanced LTA thigh/leg sizing provisions**

### 4.4.3 Enhanced SSA Arm Sizing

The RPHG Arm Assembly (Figure 4.4-25) consists of three (3) major components; the Upper Arm Assembly, the Sizing Ring, and the Lower Arm Assembly. The RPHG Arm Assembly incorporates in-flight sizing provisions and a power harness.



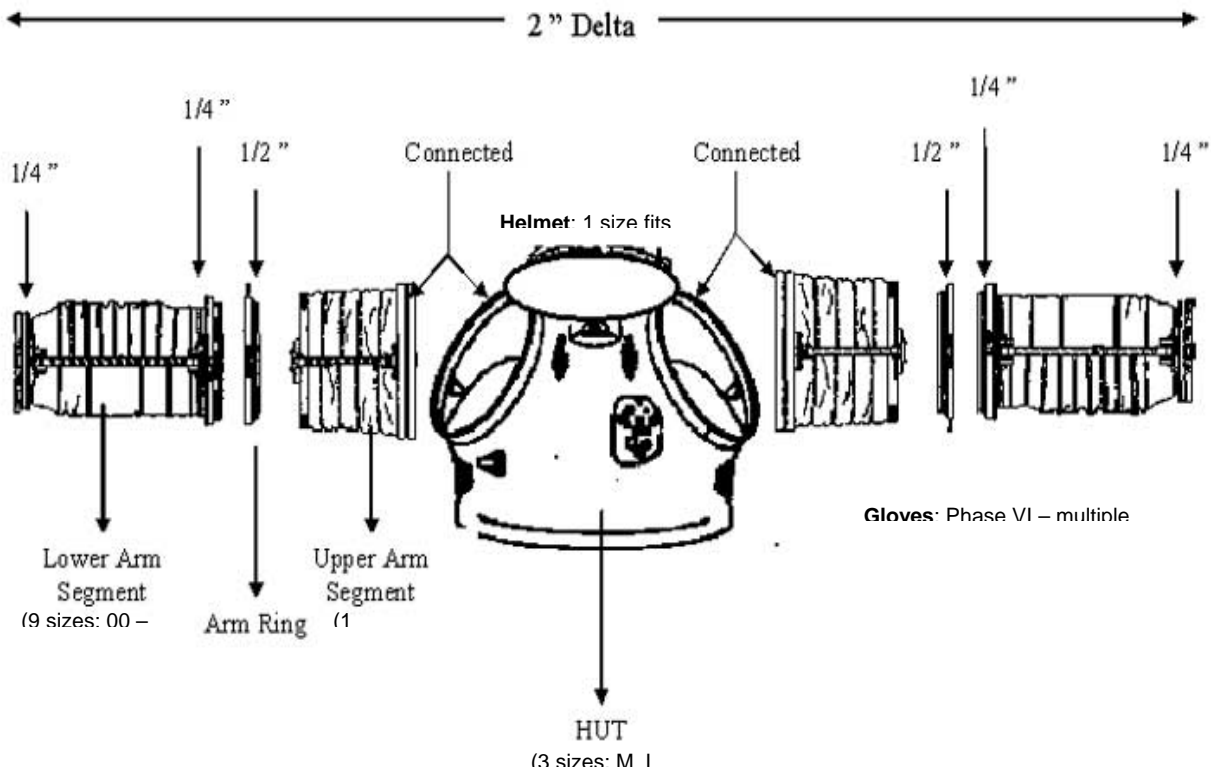
**Figure 4.4-25. RPHG arm assembly**

The RPHG Upper Arm consists of an Upper Arm Restraint/Bladder Assembly, a Dual Seal Scye Bearing, and a Dual Seal Arm Bearing with disconnect capabilities. The RPHG Upper Arm Assembly allows shoulder rotation and mobility.

The Sizing Ring provides for a 0.5-inch arm length adjustment and inserts between the Upper Arm Assembly and the Lower Arm Assembly. The Sizing Ring incorporates quick disconnect capabilities.

The RPHG Lower Arm consists of a Lower Arm Restraint/Bladder Assembly, an Arm Fabric Attachment Ring, an EMU Power Harness, and a Lower Arm TMG. The Lower

Arm Assembly allows elbow flexion and rotation. The suit side wrist disconnect is attached to the lower arm. Figure 4.4-26 shows the adjustments possible in arm length.



**Figure 4.4-26. Arm length adjustments**

The Upper and Lower Arms are joined by the Dual Seal Arm Bearing, which features a threaded metal quick disconnect and enables the upper and lower arms to be separated by crewmembers. The entire Arm Assembly interfaces with the HUT at the Scye opening.

The Thermal Micrometeoroid Garment (TMG) provides thermal protection. The Upper Arm TMG, an integral part of the HUT TMG incorporates a portion of the EMU Power Harness Assembly. The Lower Arm TMG allows access to the adjustable Lower Arm Brackets and thermally protects the Lower Arm portion of the EMU Power Harness. Attachment of the Lower Arm TMG is accomplished with looptape/lacing cord at the fabric attachment ring and Velcro hook/pile at the wrist disconnect.

The EMU Power Harness provides power to heaters in the glove to ensure crewmember finger/hand comfort. Sections of the EMU Power Harness are connected via 'plug in' connectors located at each end of the Lower Arm.

#### **4.4.3.1 Bladder Assembly**

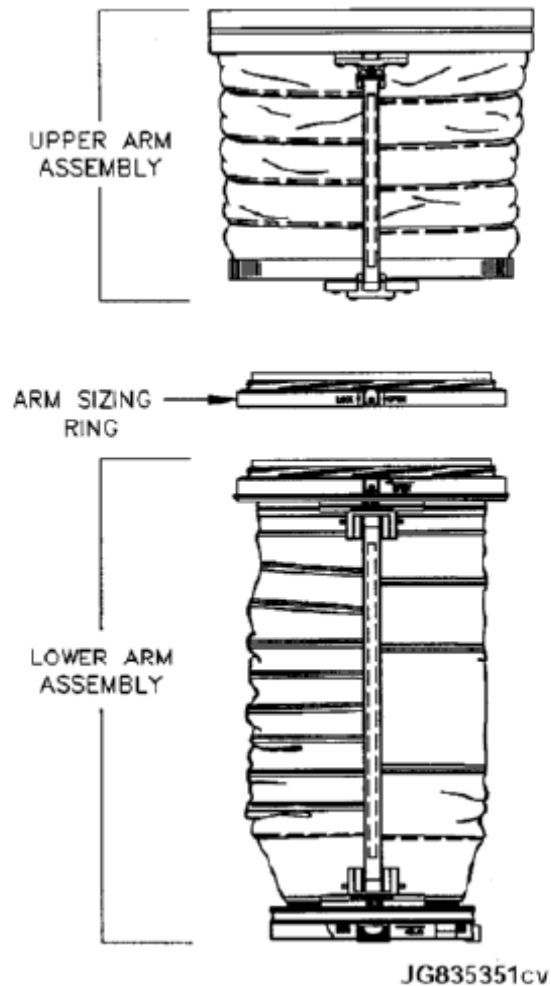
The pressure integrity of the RPHG Arm Assembly is maintained by the Bladder Assembly. The bladder Assembly on the RPHG Arm was redesigned to reduce torque and "bunching" in the convolutes.

#### **4.4.3.2 Restraint Assembly**

The Arm Restraint Assembly (Figure 4.4-27) serves to manage the pressure loads on the Arm Bladder during suit operation. The restraint is constructed from a plain weavopolyester fabric. The axial restraint webbings are constructed from a high strength, low elongation material in order to reduce the amount of stretch or "growth" that occurs when the article is pressurized.

Circumferential loads are held by the restraint fabric. Axial loads are managed by the Axial Restraint Webbings. Redundancy is incorporated in the axial restraints by the use of both a primary and secondary restraint webbing. The secondary is capable of assuming the total axial load in the event the primary was to fail.



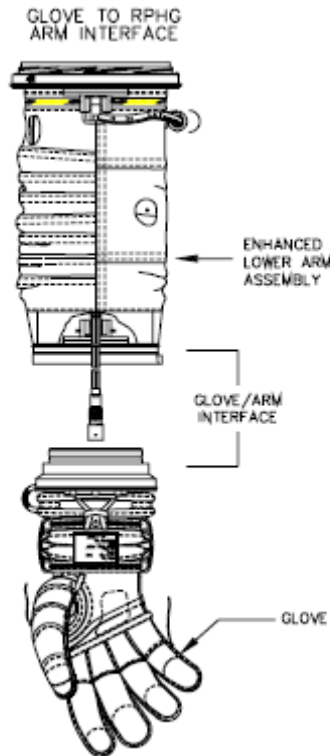


**Figure 4.4-27. RPHG arm restraint assembly**

#### 4.4.3.3 Glove to RPHG Arm Interface

Interface of the Glove to the Arm is accomplished via Wrist Disconnects (Figure 4.4-28). These are metal couplings attached to both the wrist flange of the Arm and the Glove which serve to mechanically couple and lock the two together. The Glove side of the Dual Seal Wrist Disconnect uses an "O" ring at the flange to provide a pressure seal. The suit-side of the Wrist disconnect also uses an "O" ring at the flange mount, but also incorporates a static lip seal in the hardware to ensure suit pressure integrity. Dual and redundant locks, installed on the suit-side disconnect, serve to lock the Glove to the Arm and prevent inadvertent disengagement. The outer rim of the disconnect locking ring is marked to show OPEN and LOCK positions and rotates to engage one or the other. Arrows are also engraved below the labeling to indicate direction of actuation.

Operation of the disconnect/connect mechanism consists of depressing the locking button, raising the redundant latches and rotating the locking ring to engage or disengage the Glove.

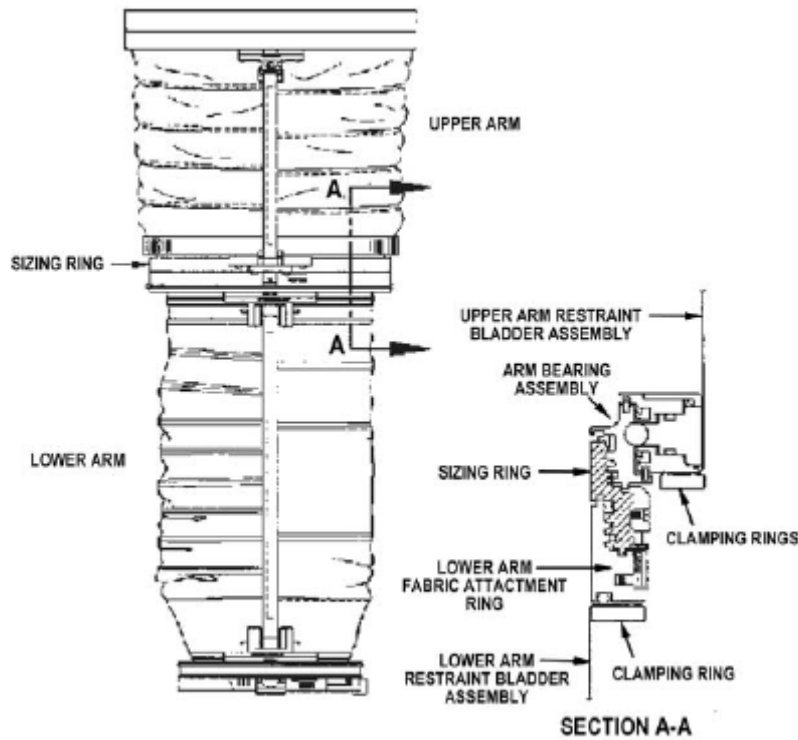


**Figure 4.4-28. Glove to RPHG arm interface**

#### **4.4.3.4 LOWER Arm to Upper Arm**

The interface of the Lower Arm Assembly and Upper Arm Assembly is accomplished via the arm bearing (Figure 4.4-29). Pressure is maintained in the bearing with two lip seals to offer redundancy. Torque has been reduced both by the use of composite spacers between the steel balls in the bearing and by the use of a light weight lubricant. The Lower Arm is attached to the arm bearing by a threaded Fabric Attachment Ring or Sizing Ring.

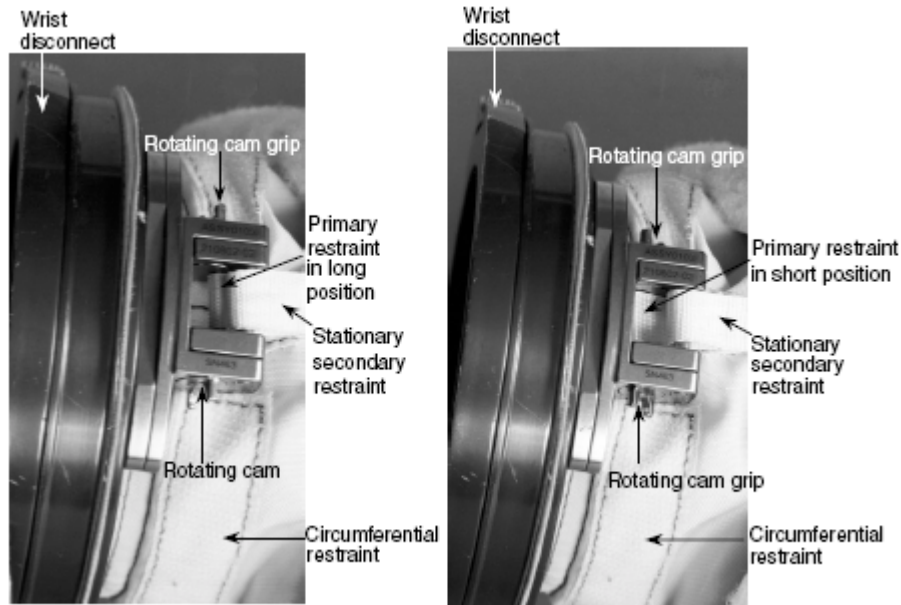
The Fabric Attachment Ring attaches to the Lower Arm through the use of a clamping ring and screws. The arm bearing end of the Upper Arm Assembly is unique in that the flange extends around the exterior of the arm bearing before turning inward to mate with the arm bearing clamping ring. Upper Arm axial restraint brackets are attached to the arm bearing via clamping ring screws. The Lower arm axial restraint brackets are attached directly to the Fabric Attachment Ring which in turn threads onto the arm bearing inner race.



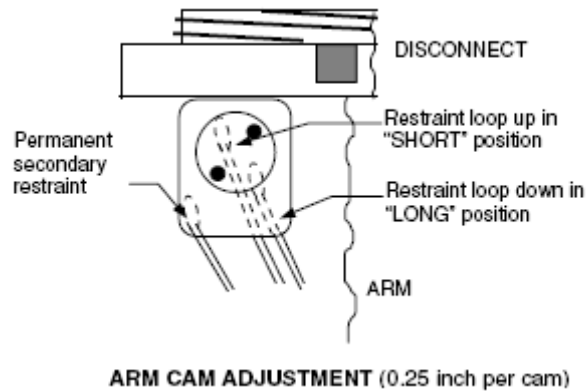
**Figure 4.4-29. Enhanced lower arm to upper arm**

#### 4.4.3.5 Sizing the RPHG Lower Arm Assembly

The RPHG Lower Arm Assembly uses adjustable arm brackets as well as a metal Arm Sizing Ring for sizing. These items are designed to allow crewmembers to perform sizing tasks on-orbit. There are four adjustable arm brackets, one at each end of both axial restraint lines. Each cam can adjust 0.25 in. for a total of 0.5 in. Figure 4.4-30 and Figure 4.4-31 show the sizing cams.

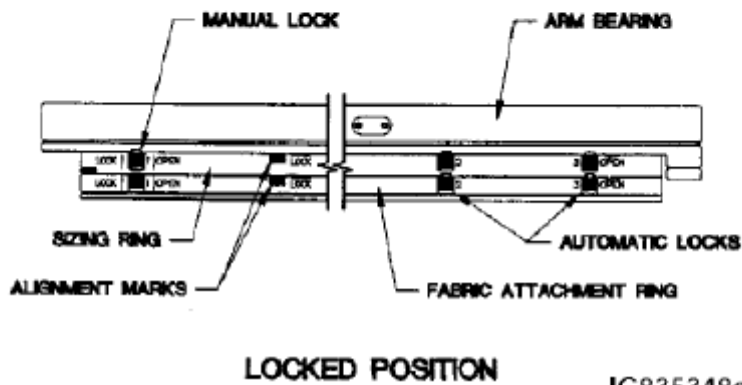
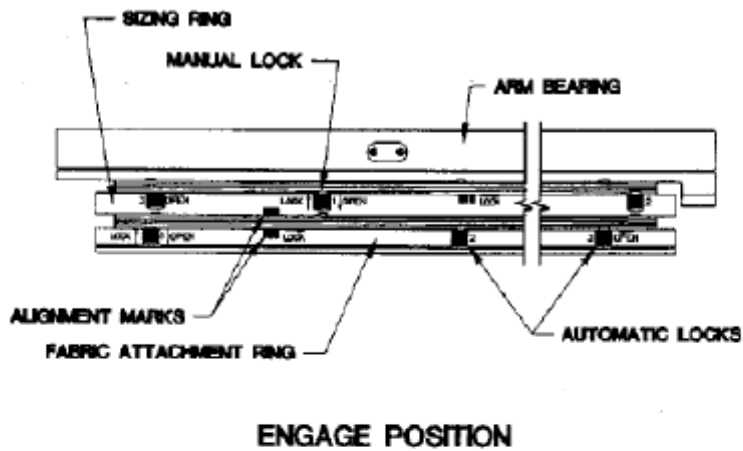


**Figure 4.4-30. Arm cam in long position (left) and short position (right)**



**Figure 4.4-31. Arm cam drawing**

The Arm Sizing ring adds an additional 0.5 in. of length to the lower arm (Figure 4.4-32). The Arm Sizing Ring threads onto and locks to the Fabric Attachment Ring, which is then threaded onto the Dual Seal Arm Bearing.



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*Figure 4.4-32. RPHG arm fabric attachment ring/sizing ring interface*

### References

EMU Mini-Data Book

EMU Systems Workbook

EMU Requirements Evolution

## **4.5 EMU RF CAMERA ASSEMBLY**

### **PURPOSE**

This section describes the features and operation of the EMU camera.

### **DESCRIPTION**

TBD

## 5.1 EVA COMMUNICATIONS SYSTEM

### PURPOSE

This section provides an overview of the EVA communications using the Space-to-Space Extravehicular Mobility Unit Radio (SSER). Functional, operational, and technical information is presented.

### DESCRIPTION

The EVA communications system provides two-way voice with the EV crew, and IV crew on the International Space Station (ISS) and orbiter. The IV crew on ISS and orbiter use the Space-to-Space Station Radio (SSSR) and Space-to-Space Orbiter Radio (SSOR), respectively, to maintain contact with the EV crew. EVA voice is nominally tied to Space-to-Ground (S/G) and Air-to-Ground (A/G), for communications with MCC-H. In addition, biomed data and EMU instrumentation is also received on ISS and orbiter for inclusion in the operational telemetry downlink.

### FUNCTION AND OPERATION

#### A. EVA Communications System Overview

The Space-to-Space Communications System (SSCS) use digital technology to share a single frequency for duplex comm. The SSER, SSSR, and SSOR comprise the family of SSCS radios. The SSCS is usually configured in low frequency (414.2 MHz) for EVA communications, but the high frequency (417.1 MHz) secondary allocation can be used when necessary. The SSCS uses a digital protocol called Time-Division-Multiple Access (TDMA) to connect each SSCS radio in a network of up to five users (radios). Each SSCS radio has full redundancy (two strings) so that loss of one receiver and/or transmitter can be resolved by switching to the alternate or backup string. Suit data and biomed telemetry to MCC-H is limited to two EMUs on the orbiter, because only two MDM channels are allocated for this purpose. On the orbiter, biomed/EMU telemetry channelization is based on SSER ID. Therefore, the SSER transmitting the lowest ID will get BIO Channel 1 and the next lowest gets Channel 2. Only audio would be available for more than two SSERs on the orbiter. On ISS, however, telemetry for up to four EMUs can be transmitted to MCC-H.

#### B. SSER Configuration and Operation

Four controls on the DCM interface with the SSER, permitting the EVA crewmembers to set up the EMUs for hardline or RF operations. The COMM mode rotary switch has four positions: HL, PRI, ALT, and OFF. The HL (hardline) position enables hardline communication when the EMU is connected to the SCU. The PRI and ALT positions power the primary and alternate transceivers, respectively. In the OFF position, all power to the SSER is removed. The Comm FREQ switch (or frequency selector) allows the SSER to operate in LOW or HIGH frequency. LOW frequency (414.2 MHz) is nominally used for EVA, but HIGH

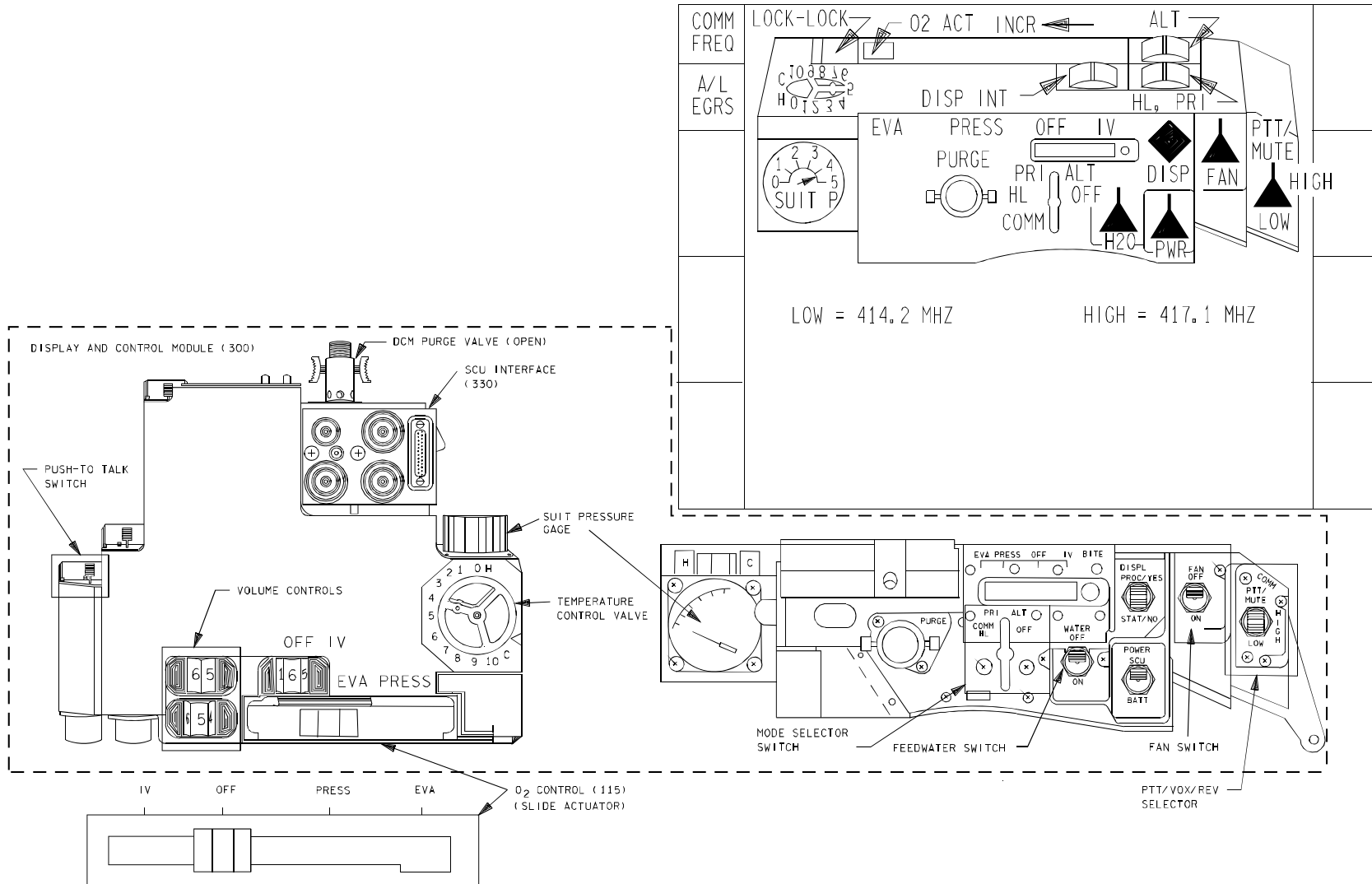
(417.1) could be used in case 414.2 MHz is noisy. The PTT/MUTE switch position is a momentary contact. The PTT function applies only to HL mode, and would work according to the EMU Audio Control Panel (EACP) or Audio Terminal Unit (ATU) configuration. In PRI or ALT (RF mode) the switch position has a MUTE function, replacing the microphone audio with a quiet pattern. In addition to the two comm switches, there are two volume controls which also interface with the SSER. The upper volume control adjusts the audio loudness for HL and PRI settings, while the lower control is for ALT audio only. A summary of the DCM controls for EVA communications, along with a description of their functions, is shown in Table 5.1-1. Figure 5.1-1 shows the DCM and position of the communication controls.

**Table 5.1-1. Summary of DCM controls for EVA comm**

Switch Name	Control type	Functions
COMM mode selector	rotary switch	HL, PRI, ALT, OFF
Comm FREQ selector	3-position toggle switch (with PTT/MUTE momentary contact)	LOW, HIGH, PTT/MUTE
Upper volume control	rotary potentiometer	HL and PRI audio level
Lower volume control	rotary potentiometer	ALT audio level

COMM mode	Used to select one of four possible configurations for the SSER electronics: HL (hardline), PRI (primary transceiver), ALT (alternate transceiver), OFF.
HL (hardline)	Only a subset of SSER audio components are powered in this setting to support hardline communications via ATU.
PRI (primary)	The SSER is configured in RF mode, with the primary (string 1) transmitter/receiver circuits selected.
ALT (alternate)	The SSER is configured in RF mode, with the alternate (string 2) transmitter/receiver circuits selected.
OFF	All power to the SSER electronics is removed. This configuration avoids mating/demating the Communication Carrier Assembly (CCA) to a “hot” EMU electrical harness (EEH), when the EMU is powered on.
Comm FREQ	In RF mode (PRI or ALT), switch is used to select transmit frequency and mute audio input to the microphone. In HL mode, the momentary position can be used as PTT key.
Upper volume	Adjusts the audio level going to the earphones, in HL and PRI modes
Lower volume	Adjusts the audio level going to the earphones in ALT mode





205975813, PNL 3

Figure 5.1-1. DCM and position of communications controls

## TECHNICAL INFORMATION

### A. Applicable Documents and References

JSC 18611 INCO Systems Briefs, Rev. G March 2006

JSC 26789 Specification, SSER, Rev. F Nov. 2003

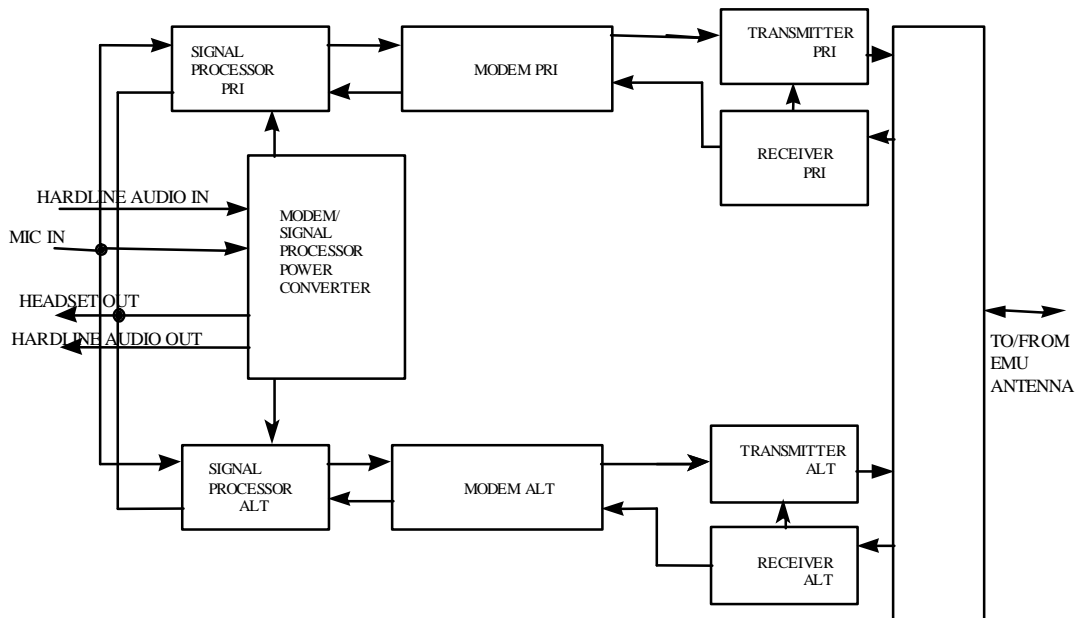
### B. System Specifications

The SSER is part of the SSCS which is a time division multiple access (TDMA) voice and data communications system. The system includes the SSOR, SSSR, and various antennas. The SSER is mounted on the EMU, and it provides a voice and data link between an EMU astronaut and the orbiter or ISS. The SSER fits in the space previously occupied by the Extravehicular Communicator (EVC) and uses the same power and control interfaces as the EVC, although some control functions have changed. The SSER will support a TDMA voice and data communications network of up to 5 SSCS users. The SSER consists of two separate strings of hardware (except front end radio frequency components) within a single enclosure for Primary (PRI) and Alternate (ALT) modes. A block diagram of the SSER is shown in Figure 5.1-2.

### C. Operational Configuration

#### 1. Activation:

The SSER is activated when power is supplied to the PRI, ALT, or HL circuits.



**Figure 5.1-2. Block diagram of SSER**

2. Deactivation

The SSER is deactivated when in OFF, or when there is no power supplied by the EMU.

3. Modes

The SSER is capable of operating in the following three modes for EVA operations:

4. PRI

When operating in PRI mode, the SSER transmits and receives at 414.2 MHz or 417.1 MHz. The SSER transmits 64 kbps audio and 4 kbps of digitized electrocardiogram (ECG) or EMU status data.

5. ALT

When operating in ALT mode, the SSER transmits and receives at 414.2 MHz or 417.1 MHz. The SSER transmits 64 kbps audio and 4 kbps of digitized electrocardiogram (ECG) or EMU status data.

6. HL

In hardline mode, the EMU can communicate in either the orbiter or ISS airlock via an umbilical. There are no RF transmissions in HL mode. The SSER accepts microphone voice signals and drives the Service and Cooling Umbilical (SCU) audio hardlines. Simultaneously, the SSER accepts audio input signals from the SCU and drive the earphone output. In HL, sidetones are provided by the orbiter or ISS ATU. The SSER provides push-to-talk (PTT) key signals and control of audio volume, in response to the EMU remote controls. When operating in any other SSER mode, the audio and PTT interfaces to the SCU are inhibited. The caution and warning tones operate nominally.

D. Electrical Characteristics and Performance

1. Power Input

The SSER is designed to operate from the following power source on primary or secondary lines:

Current	0.725 amps maximum at 17.0 V dc 0.200 amps maximum, HARDLINE mode
Voltage	15.0 to 22.5 V dc 17.0 V dc nominal

The maximum power required by the SSER with a voltage input from 15.0 to 22.5 V dc is 12.33 Watts.

2. Earphone/Microphone Interface

a. Earphone, Audio Output

The following signals are summed and drive an earphone with 600 +/- 10 percent ohms impedance:

Signal	Frequency range (Hz)	Output level
Received voice	300 to 3000	23 dBm +/- 3.0 dB (21.9 to 43.7 Vp-p across 600 ohms) (volume control set to max)
Side Tone	300 to 3000	10 +/- 2 dB below received voice
Caution Tone	1500 +/- 75 HZ	-3 dBm +/- 3 dB (1.1 to 2.2 Vp-p across 600 ohms)
Warning Tone	1500 +/- 75 Hz w/ 15 +/- 5 Hz pulse modulation & 50 +/- 15% duty cycle	-3 dBm +/- 3 dB (1.1 to 2.2 Vp-p across 600 ohms)

Caution and warning tones are provided in PRI, ALT, and HL modes. Sidetone will not be provided by the SSER in HL mode (sidestone are generated by the ATU).

b. Microphone Power Output

The SSER provides two DC power lines for microphone power with the following characteristics:

Voltage                    12.0 to 22.5 V dc  
 Current                    Current limit each circuit with a 120 ohm resistor in series with a diode

c. Microphone Input, Voice

The microphone input has the following characteristics:

Frequency                300 - 5000 Hz  
 Level                      -17 to +13 dBm, 0 dBm nominal (0.3 to 9.8 Vp-p across 600 ohms)  
 Impedence                600 +/- 10 percent ohms balanced

E. Hardline Interface

1. Audio Output - SCU

The SSER distributes voice signals from the microphone to the SCU in the HL mode. No signal processing (VOX, AGC, clipping, filtering, sidetone) will be performed on the signals. The signals provided to the SCU interface have the following characteristics:

Frequency	300 - 5000 Hz
Signal Level	-2 +/-3 dBm (1.2 to 2.5 Vp-p across 600 ohms) for nominal microphone input of 0 dBm
Impedence	600 ohms +/-10 percent, balanced and DC isolated

## 2. Audio Input - SCU

The audio input from the SCU is DC isolated in the SSER. The audio input from the SCU has the following characteristics:

Frequency	300 - 3000 Hz
Level	+27 +/-3 dBm (34.7 to 69.3 Vp-p across 600 ohms)
Impedence	600 ohms +/- 10 percent, balanced and dc isolated

With an audio input from the SCU of +27 dBm (49.0 Vp-p across 600 ohms), the audio output to the earphone is +23 dBm, +/- 3.0 dB (21.9 to 43.7 Vp-p) into a 600 ohm balanced load at maximum volume control.

## 3. PTT Key - Hardline

When the PTT switch is activated in HL mode, the SSER provides a key signal closure to a two-wire interface with the SCU having the following characteristics:

Voltage	14 V dc maximum, open circuit
Current	10 mA maximum, short circuit
DC Isolation	2 M ohms minimum, SSER to SCU interface

## 4. Activation - HARDLINE

Upon application of power to the SSER in HL mode, the SSER performs all the HL functions.

## 5. ALT/PRI Interface

### a. Audio Output Frequency Response

The audio frequency response is within +/-3.0 dB of the response at 1 kHz between 300 Hz and 3000 Hz. The response above 3.0 kHz has a negative slope.

b. RF Interface

The SSER supports the following RF inputs and outputs in the PRI and ALT modes.

c. RF Input

Center Frequency	414.2 MHz or 417.1 MHz
Level	-80.5 dBm minimum 0 dBm maximum

Damage may occur to the SSER with RF inputs above +24 dBm.

d. RF Output

Center Frequency	414.2 MHz or 417.1 MHz
Level	+18 dBm minimum, into 50 +/-2 ohm load (modulated with a data input of all '0's) +27 dBm Maximum

F. Transmission Characteristics (PRI/ALT)

1. Power Output

The SSER will continue to function with degraded performance, allowing for a VSWR greater than 2.5 to 1, and specified performance will be achieved after removal of the mismatch. The SSER will not be damaged by a short circuit or open circuit (across the antenna output) for a period up to four hours.

2. Modulation

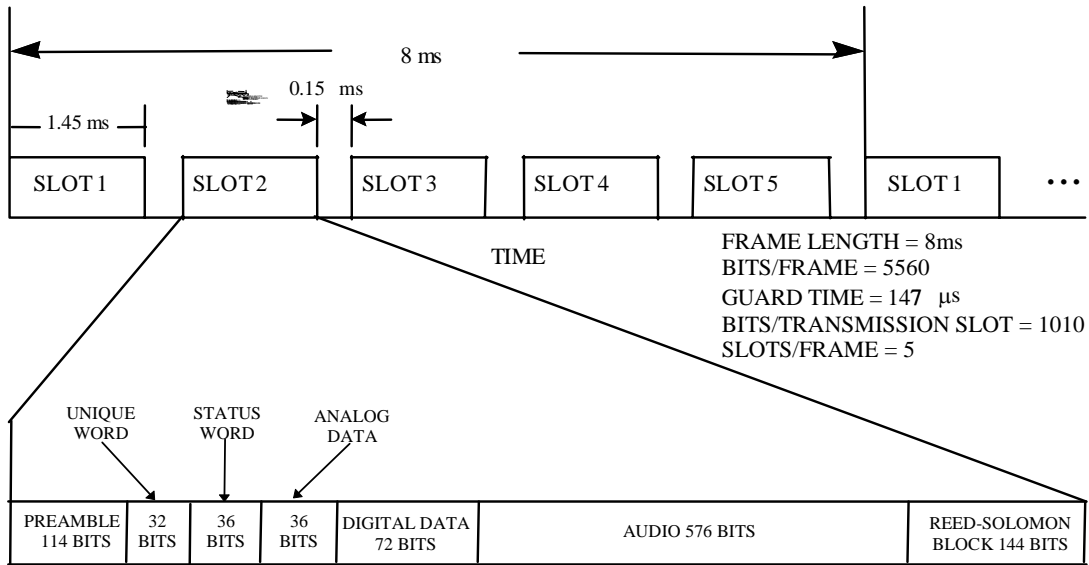
The SSER provides Frequency Shift Keying modulation for RF transmissions with the following characteristics:

Burst Rate	695 kbps
Deviation	486.5 kHz
Filtering	3 dB bandwidth of 1.04 MHz +/-52 kHz 35 dB attenuation minimum at all frequencies greater than 1.7 MHz from the carrier.

G. Signal Processing

1. Time Division Multiplexing

The SSER supports the time division multiple access scheme of the SSCS. The frame pattern of the SSCS is shown in Figure 5.1-3.



**Figure 5.1-3. Frame pattern for SSCS**

The SSER selects any open slot shown in Figure 5.1-3 for transmission. The SSER selects a transmit slot based on the information received in the status word. The audio and data is time division multiplexed as shown in Figure 5.1-3 for transmission. Each SSER transmission consists of a packet of data transmitted in the order shown below:\

1	PREAMBLE	114 bits, 10101010...
2	UNIQUE WORD	32 bits, 10101010111000000111111000000111 (AAE07E07, hex)
3	STATUS WORD	36 bits, encoded (32 bits unencoded)
4	DIGITIZED ANALOG DATA	36 bits, encoded (32 bits unencoded)
5	NOT USED	72 bits, encoded (64 bits unencoded)
6	DIGITAL AUDIO	576 bits, encoded (512 bits unencoded)
7	REED-SOLOMON BLOCK	144 bits, encoded

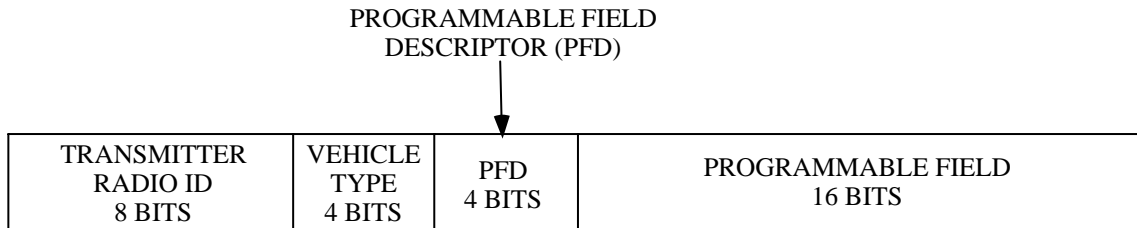
Transmissions occurs once every 8 ms +/- 20 μs, while frame synchronization is acquired. Transmissions last 1.4532 ms +/- 20 μs.

## 2. Data Encoding

The status word, digitized analog data, and digitized audio is encoded with Reed-Solomon transmission encoding, a 8/9 (0,4) Run Length Limited (RLL) translation code, and non-return to zero inverse (NRZI) encoding. The maximum zero or one run length of data following encoding is 5. The unique word is not encoded, and has a zero run length of at least 6. The preamble is also unencoded.

3. Status Word

The SSER transmits a status word which is 32 bits in length before 8/9 encoding. The format of the status word is as shown below, in Figure 5.1-4.



**Figure 5.1-4. Status word format**

4. Identification Field

The first field of the status word contains a unique 8-bit identification code. Each SSER has two identification codes (PRI and ALT). The identification codes 00h and FFh is not be used by the SSER.

5. Vehicle Type Field

The second field of the status word contains a four bit vehicle type field. The SSER vehicle type field is 3h.

6. Programmable Field

The fourth field of the SSER status word contains 16 bits, which are programmable. When the PFD field of the SSER status word is 0h, 1h, 8h, 9h, Ah, Bh, Ch, or Dh, the programmable field is not used, and the field will contain all 0's.

7. Slot Reacquisition List

When the PFD field is 2h, the first 10 bits of the programmable field are 0's. The next six bits of the programmable field contain two three bit slot numbers from 0h to 4h.

8. Network Tracking Data

When the SSER PFD field is 3h, 4h, 5h, 6h, or 7h, the programmable field contained a 16 bit two's complement integer indicating the network tracking phase error.



9. Slot Image Data

When the PFD field is Eh, the programmable field indicated the transmitter slot number in the first three bits. The next three bits, called the slot image, of the programmable field indicates the slot number of one SSCS user present. The next two bits of the programmable field indicate the number of paths (relays), up to 3, between the SSER and the SSCS user indicated by the slot image. If the number of paths is greater than 3, it is represented as 3 paths. The last eight bits of the programmable field contains the identification number of the SSCS user indicated by the slot image.

10. Information Age Counter Data

When the PFD field is Fh, the programmable field contains a 16 bit integer indicating the age of network data.

11. Time Division Demultiplexing

Each SSER receives audio transmissions from all of the slots shown in Figure 5.1-5, except the slot in which it is transmitting. Received digital or analog data from other EMU's, orbiter, or ISS does not interfere with received audio from any user.

12. Bit Synchronization

When receiving transmissions from other SSCS users at levels of -80 dBm or greater, the SSER achieves bit synchronization in less than 132  $\mu$ seconds.

13. Frame Synchronization

The SSER establishes frame synchronization by recognizing the Unique Word and identifying all SSCS users present through interpretation of the status words. Acquisition of frame synchronization is identified by a high logic level on connector J4, pin 10 in PRI mode and J4, pin 13 in ALT mode.

14. Unique Word

The Unique Word of the SSER is AAE07E07h. The SSER allows one error in the received Unique Word for acquisition purposes. The unique can be detected without decoding.

15. Frame Tracking

Once frame synchronization has occurred, if an SSER loses frame synchronization due to interference, RF blockage or deactivation for 15 seconds or less, it acquires the same transmission slot it occupied prior to the loss of synchronization if all other SSCS users remain activated. If any other SSCS user is deactivated or loses frame synchronization due to RF blockage or interference, the SSER does not select the slot for transmission

for at least 15 seconds after the user is deactivated. Once an SSCS user drops off the network, the SSER clears that slot in its local network image within 30 seconds.

#### 16. Acquisition

Upon initial activation of the SSER or loss of signal due to blockage, frame synchronization is acquired in less than 10 seconds if a signal greater than -80 dBm from the SSOR, the SSSR, or another SSER is present. The SSER is capable of recognizing and correcting conflicting slot assignments within 10 seconds. When the SSER is in acquisition, it has a random timeout period in which it does not transmit. The timeout period lasts between 0.53 seconds and 1.02 seconds, followed by TDMA transmission periods which last between 1.0 and 2.0 seconds.

Upon initial activation of the SSER or loss of signal due to blockage, frame synchronization is acquired in less than 30 seconds if a signal greater than -80.5 dBm from the SSOR, the SSSR, or another SSER is present.

#### 17. Automatic Slot Assignment

The SSER automatically selects one of the slots shown in Figure 5.1-5 prior to establishing frame synchronization. If the SSER chooses a time slot occupied by another SSCS user, an error condition is indicated in the slot reacquisition list of the status word, and the condition is resolved in less than 10 seconds. If all of the SSCS slots are occupied when the SSER is activated, the SSER will not transmit.

#### 18. Audio Digitizing

In ALT and PRI, the input analog audio is digitized and converted to 64 kbps companded audio. Audio from the four received channels is summed digitally before conversion to an analog signal. 12 bit analog to digital and digital to analog conversion will be used on the audio.

Audio latency of the SSER is less than 250 msec.

#### 19. Analog Data (EMU Status and Biomed) Digitizing

The SSER accepts analog data from the EMU which will consist of ECG and EMU Status data time division multiplexed. Input analog data signals of up to +/-20 volts does not damage the SSER. 8-bit analog to digital conversion is used on the analog data. The analog data is sampled at a rate of 500 samples per second, resulting in a data rate of 4 kbps. The simple harmonic distortion of the transmit analog data does not exceed 10 percent in the frequency range from 0 to 80 Hz.

20. ECG Data

The ECG data has the following characteristics:

Frequency	DC to 80 Hz
Voltage	0 to 5 V

21. EMU Status Data

The EMU Status Data has the following characteristics:

Data Rate	50 bps
Voltage	logic 1 4.2 to 4.8 V
	logic 0 0.8 to 1.2 V

22. Sidetone

The SSER provides a sidetone at the receiver audio output in PRI and ALT modes. The sidetone is 10 dB +/- 2 dB below the level of the received voice over the full range of the remote volume control when the RF input level of the receiver is -80 dBm.

23. VOX

The SSER incorporates a vox function in PRI and ALT modes which mutes input signals below -14 dBm +/- 3 dB (0.3 to 0.6 Vp-p across 600 ohms). When input audio signals are below -14 dBm +/-3dB, a quiet pattern is sent by the mu-law compander. The muting function is deactivated in less than 10 milliseconds. The muting function is activated when the signal drops below -14 dBm +/- 3dB for greater than 2 seconds.

24. AVC

The SSER provides an automatic volume control (AVC) function in PRI and ALT modes which controls transmit audio signals between -18 and +13 dBm (0.3 to 9.8 Vp-p across 600 ohms) to +/-2 dBm (1.7 to 2.8 Vp-p across 600 ohms). The AVC attack time is less than 10 msec. The AVC release time is 2 seconds.

25. Transmit Mute Function

When the SSER is in ALT or PRI modes, and the EMU FREQ switch is in the PTT position, all transmit audio is muted (audio is replaced by a quiet pattern).

H. Caution and Warning Tones

The SSER provides Caution and Warning (CWS) tones when the tone control inputs are activated in PRI, ALT, and HL modes.

1. Caution Tone

The SSER provides a caution tone with the characteristics listed below. The caution tone generator output signal is summed with the received audio after the volume control and distributed to the earphone output. No external or internal controls are incorporated for the adjustment of frequency.

Frequency	1.5 kHz +/- 75 Hz
Level	-3 dBm +/- 3 dB (1.1 to 2.2 Vp-p across 600 ohms)

2. Warning Tone

The SSER provides a warning tone with the characteristics listed below. No external or internal controls are incorporated for adjustment of frequency. The warning tone generator output signal is summed with the received audio after the volume control and distributed to the earphone output. The warning tone has precedence over the caution tone.

Frequency	1.5 kHz +/- 75 Hz
Modulation	Pulse Modulation with a 15 Hz +/- 5 Hz square wave, 50 +/- 15 percent duty cycle
Level	-3 dBm +/- 3 dB (1.1 to 2.2 Vp-p across 600 ohms)

3. Transmit Frequency - LO/HIGH

When the SSER is in PRI or ALT, the remote VOX/PTT key control acts as a frequency select switch between the LOW (414.2 Mhz) and HIGH (417.1 MHz) frequencies. When pins 13 (PTT or Audio Mute key) and 27 (Receive Only or High Freq.) on connector J3 (see Figure 5.1-5 for location of J3 connector on SSER housing) are both open, characterized by an impedance greater than 100k ohms, the SSER transmits and receives on 414.2 MHz. When pin 27 on connector J3 is closed to common, characterized by an impedance less than 100 ohms, the SSER transmits and receives on 417.1 MHz. When pin 13 on connector J3 is a closed to common, the transmit voice is muted and the frequency of the SSER will not be changed. When pin 13 on connector J3 is closed to common, it pin 27 is checked at least every 5 seconds to see which frequency position is selected after release of the PTT switch.

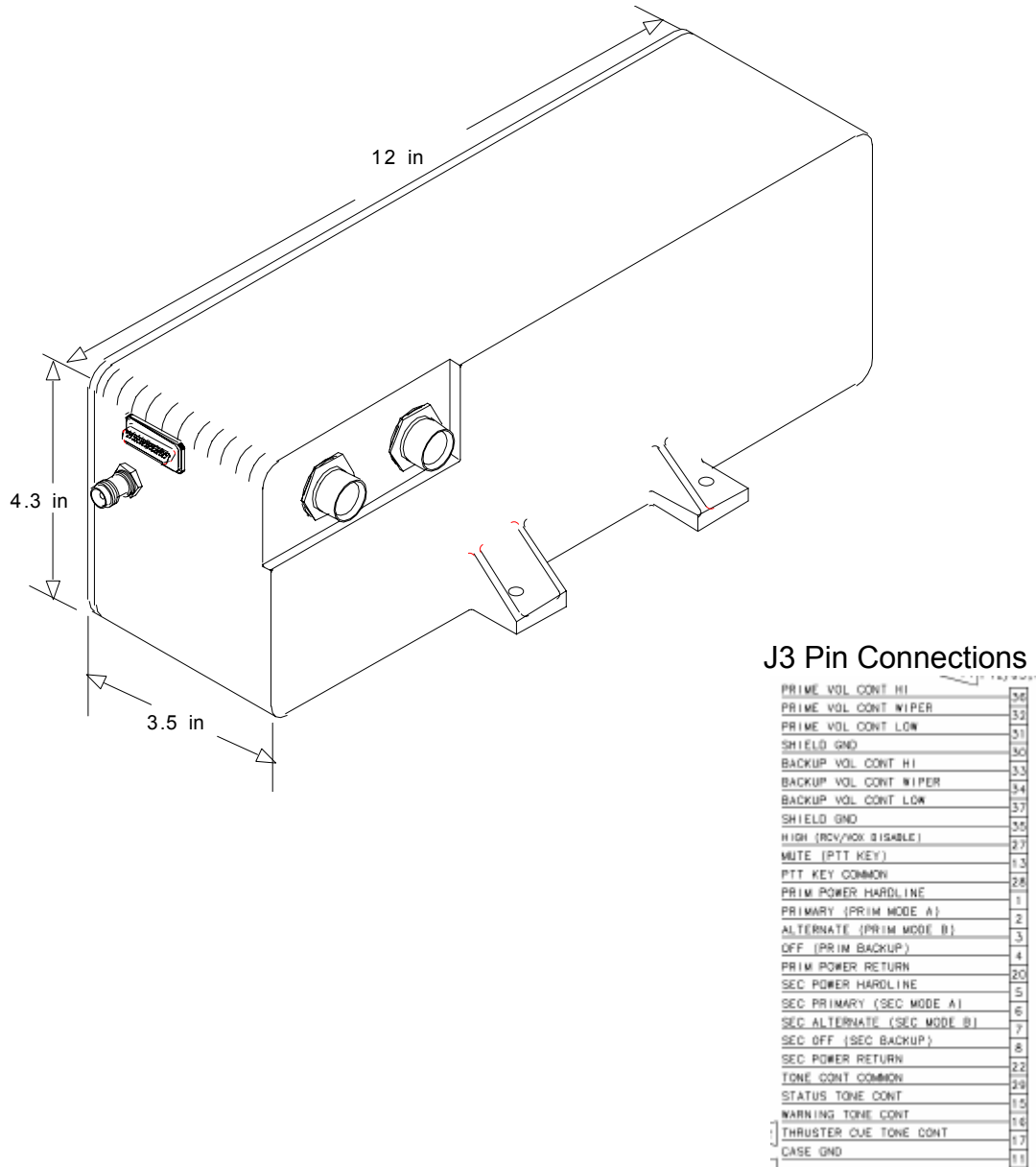
4. VOX/PTT Key Control - Hardline Mode

When the SSER is in HL mode, the remote PTT key control on pin 13 of connector J3 provides the PTT key function.

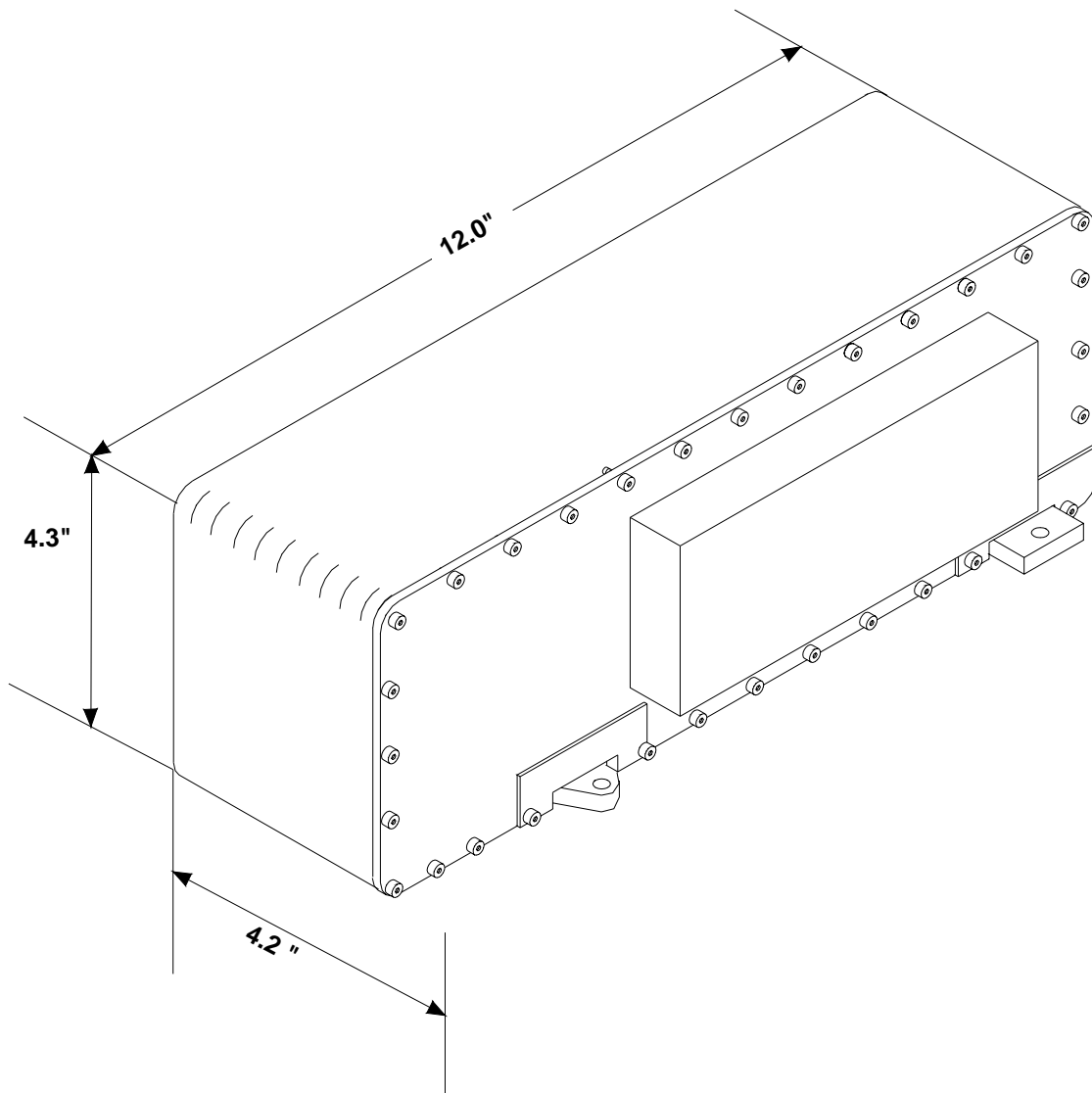
I. Physical Configuration

The SSER physical configuration is as shown in Figure 5.1-5 (the dimensions shown are nominal values). The SSER physically conform to the ICD HSC-3-0065-OP.

The weight of the SSER is approximately 10 pounds.



**Figure 5.1-5. Mechanical Outline of SSER – front view**



**Figure 5.1-6. Mechanical outline of SSER – back view**

J. Operability and Maintainability Requirements

1. Lifetime

The SSER is designed to operate for 50 missions. For design purposes, a mission consists of 55 hours of operation, including ground testing and flight operation. The SSER has a 10 year useful life.

APPENDIX A EMU PHOTO DOCUMENTATION

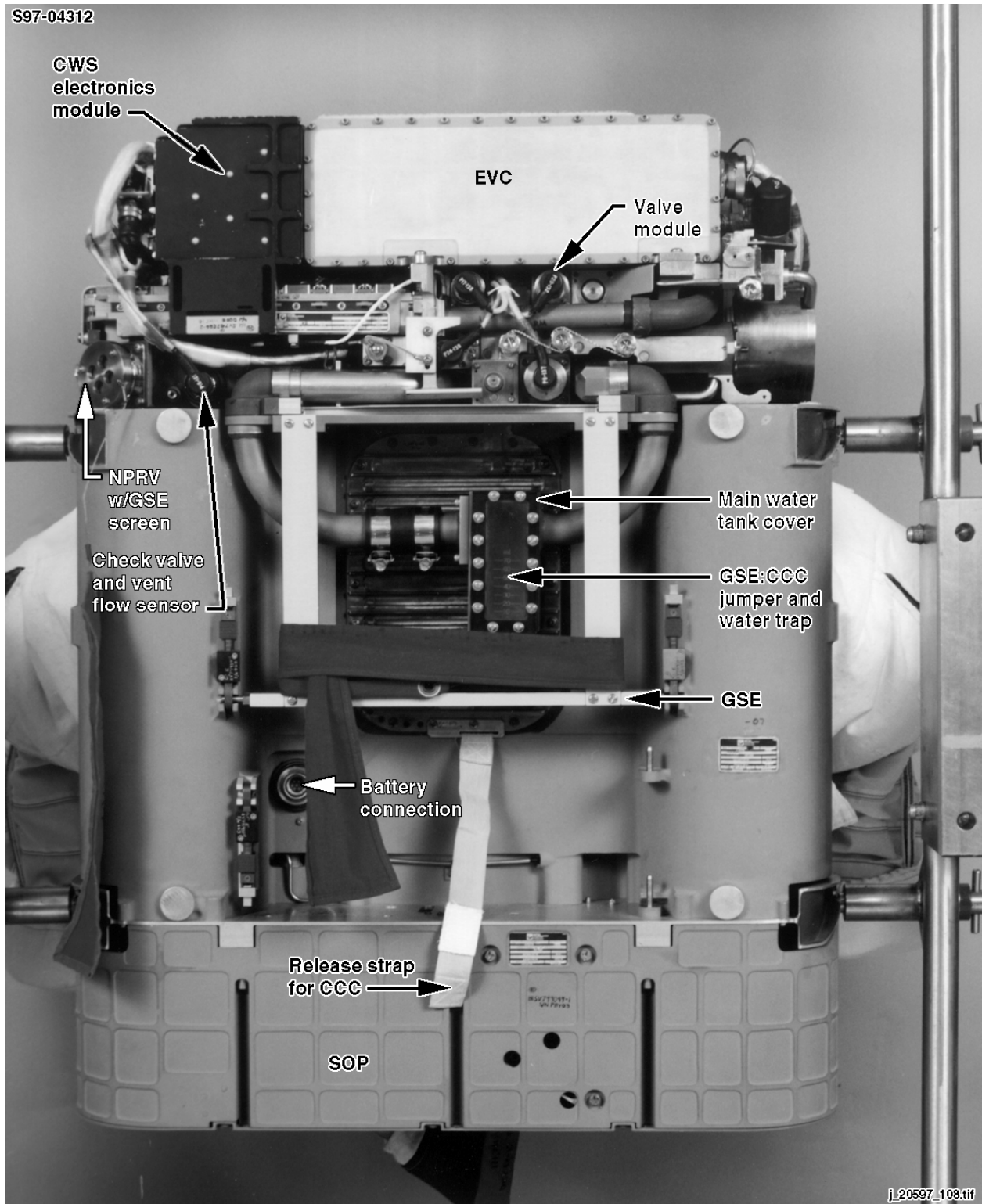


Figure A-1. PLSS with SOP - back view

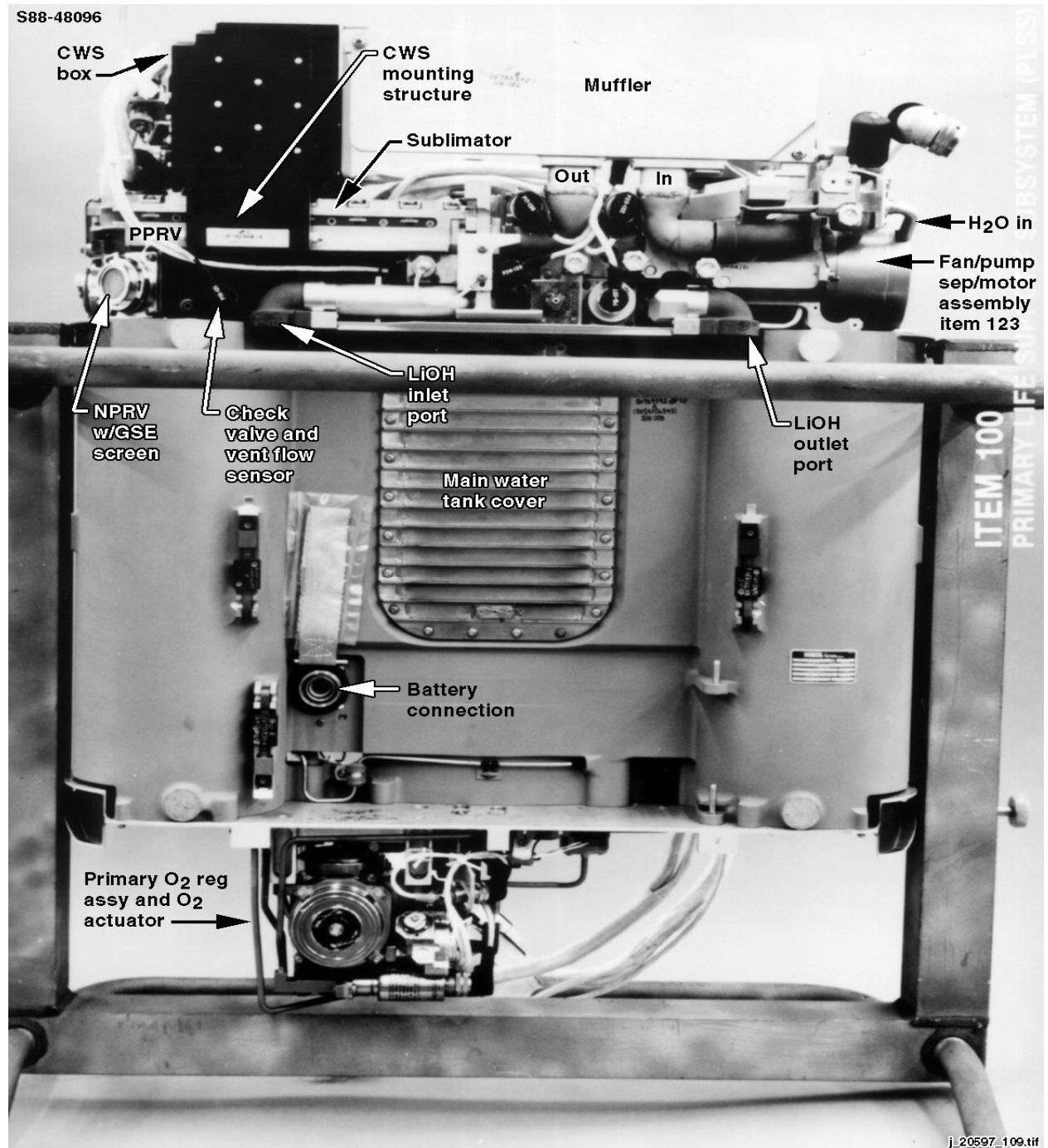


Figure A-2. PLSS without SOP - back view



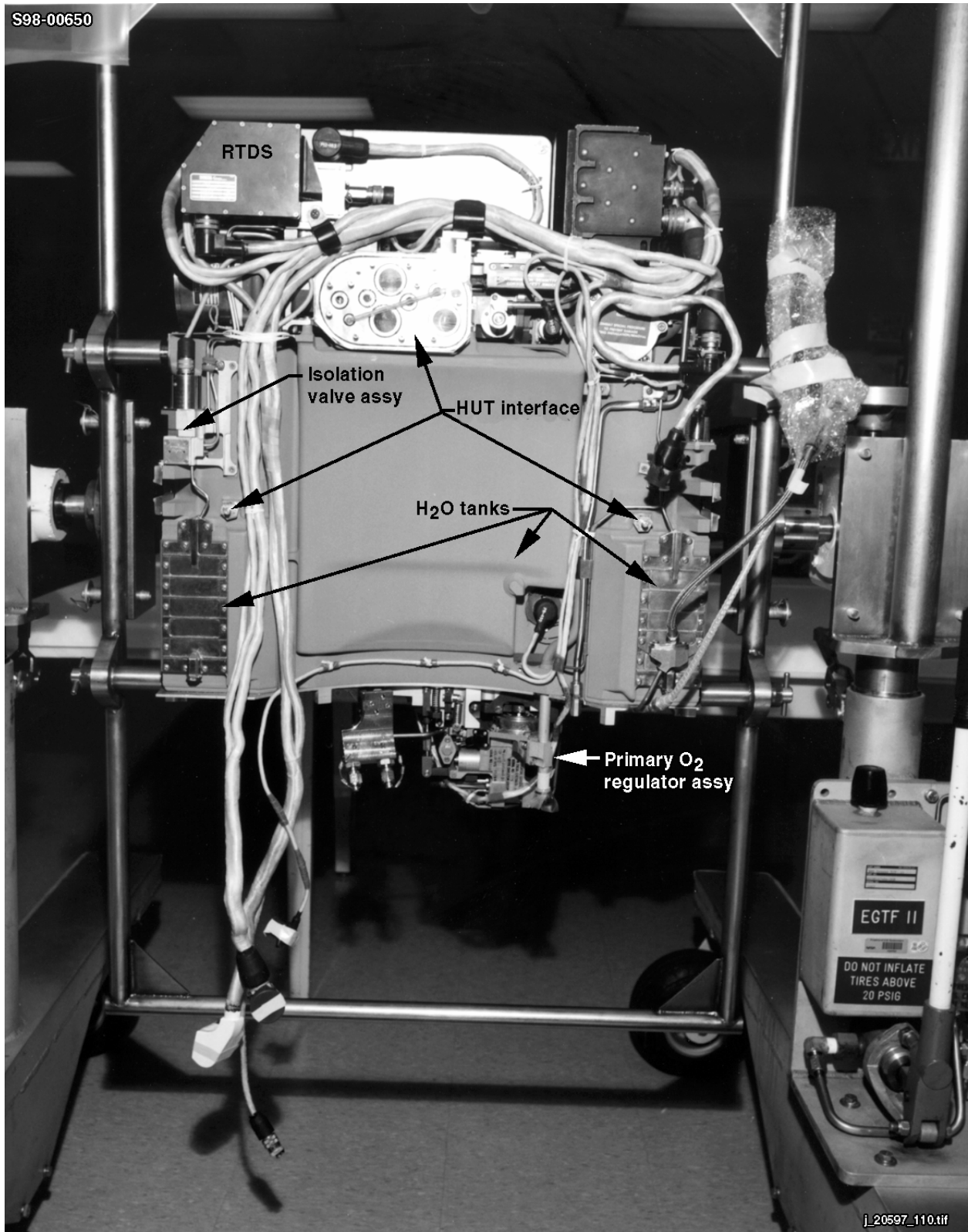


Figure A-3. PLSS without SOP - front view

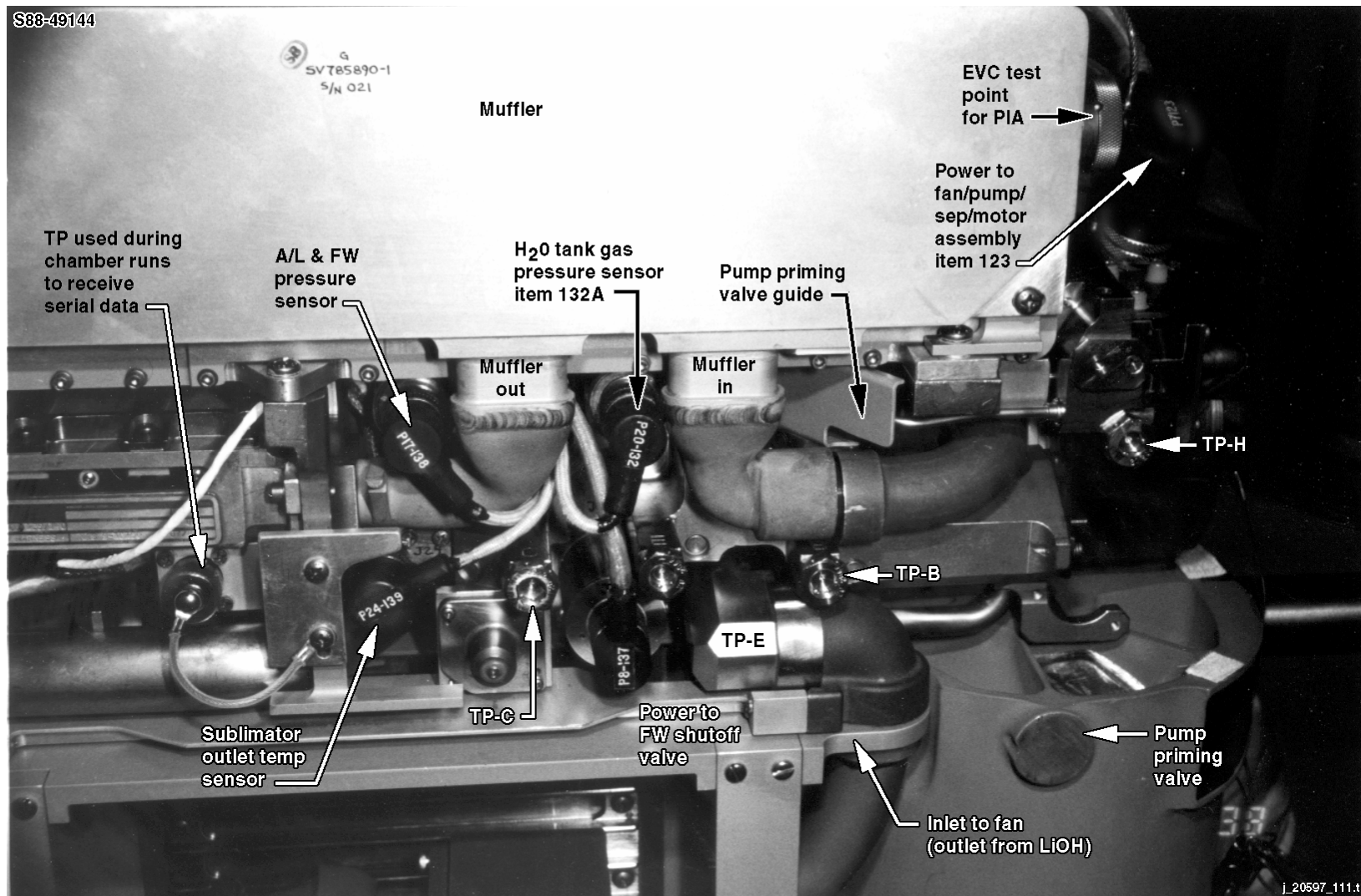


Figure A-4. Valve module

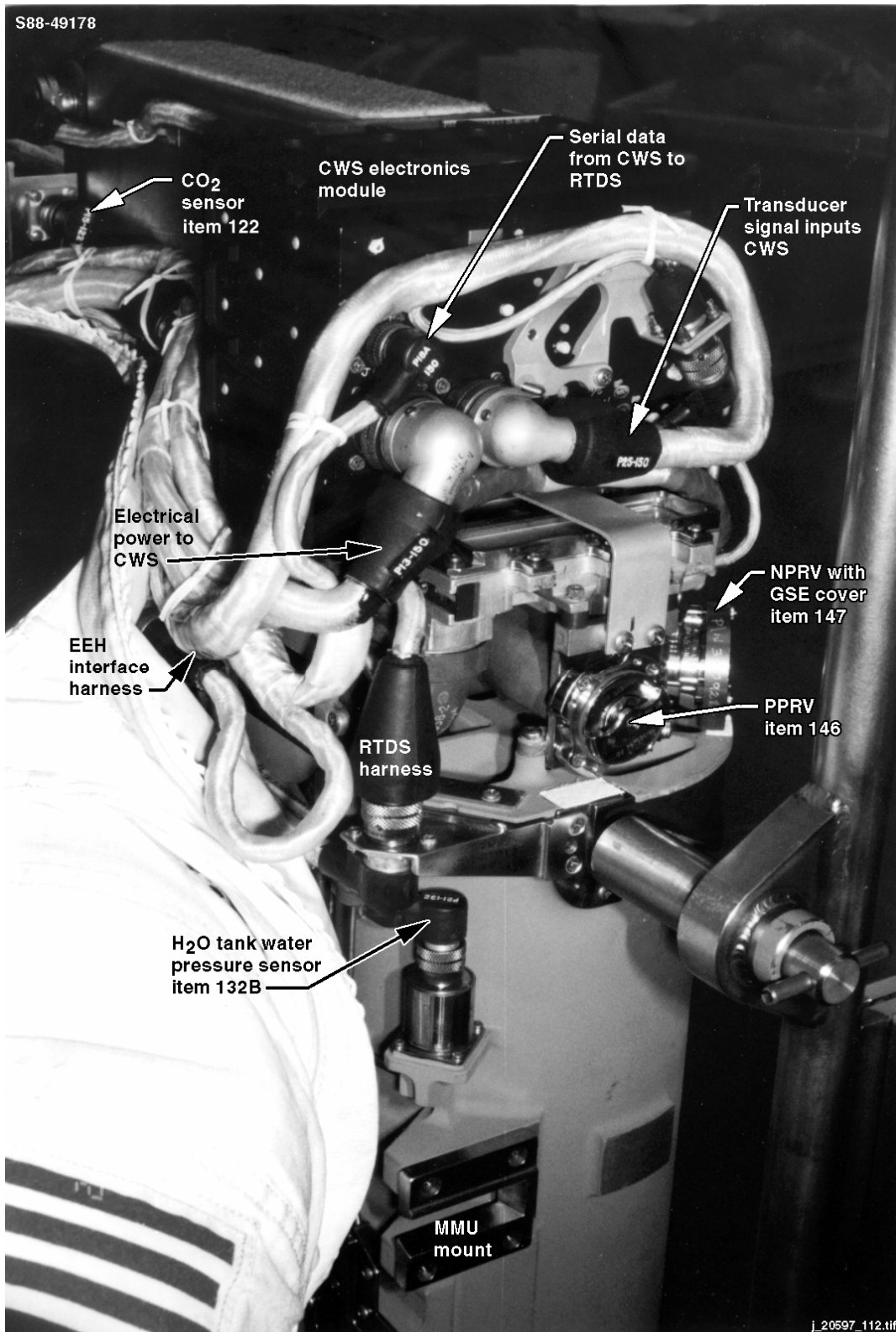
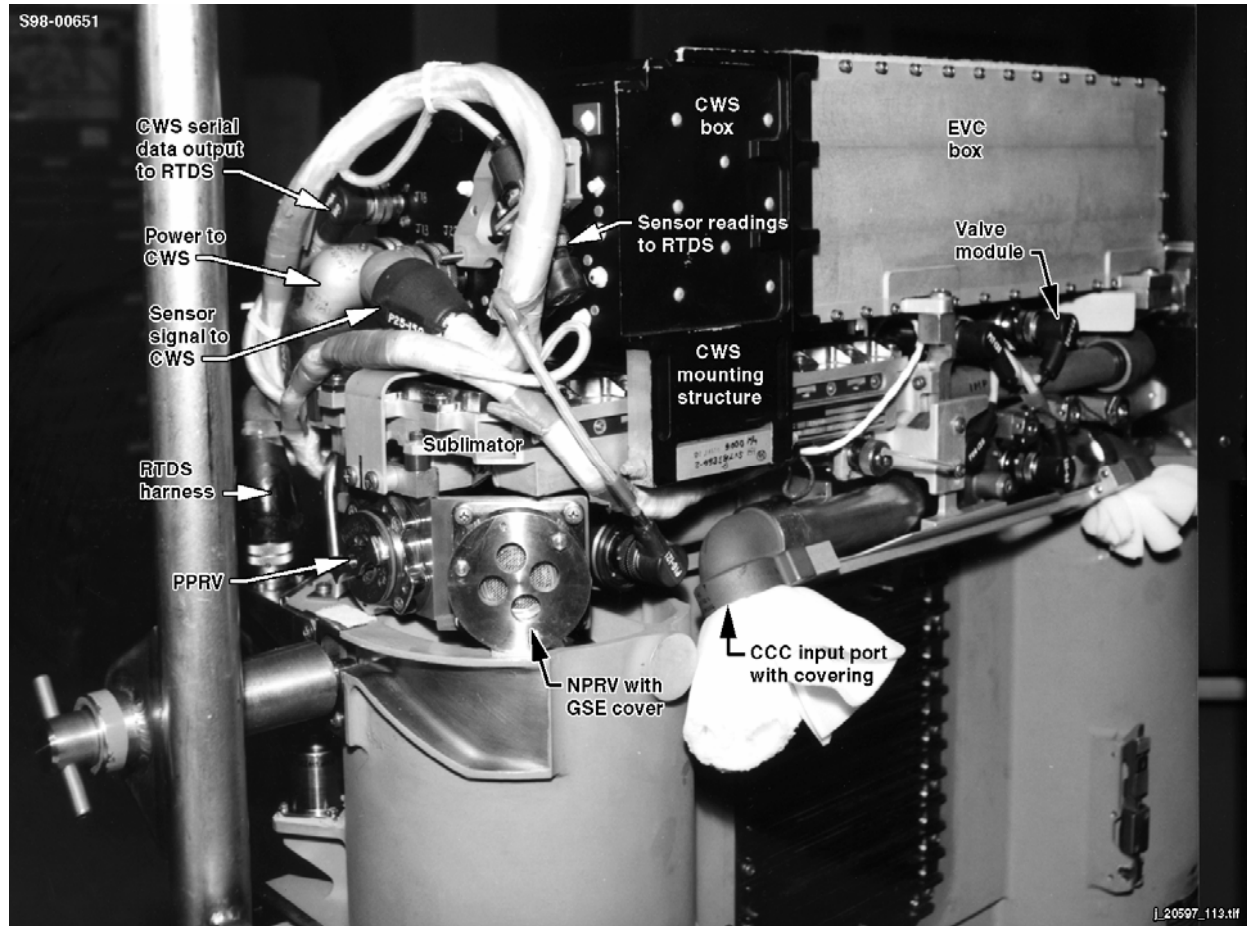
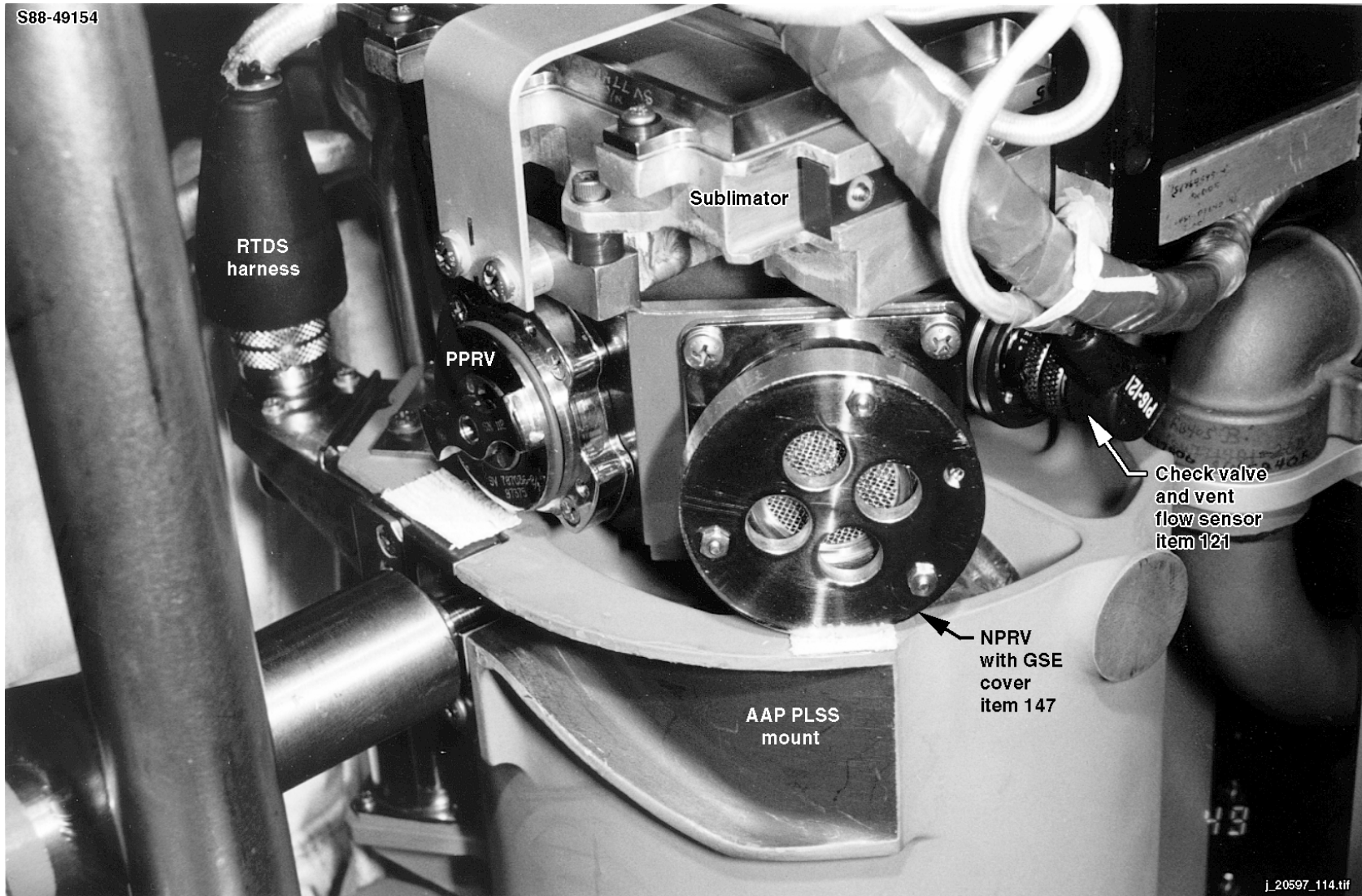


Figure A-5. CWS/PPRV/NPRV area view (1)



**Figure A-6. CWS/PPRV/NPRV**



**Figure A-7. PPRV/MPRV and sublimator**

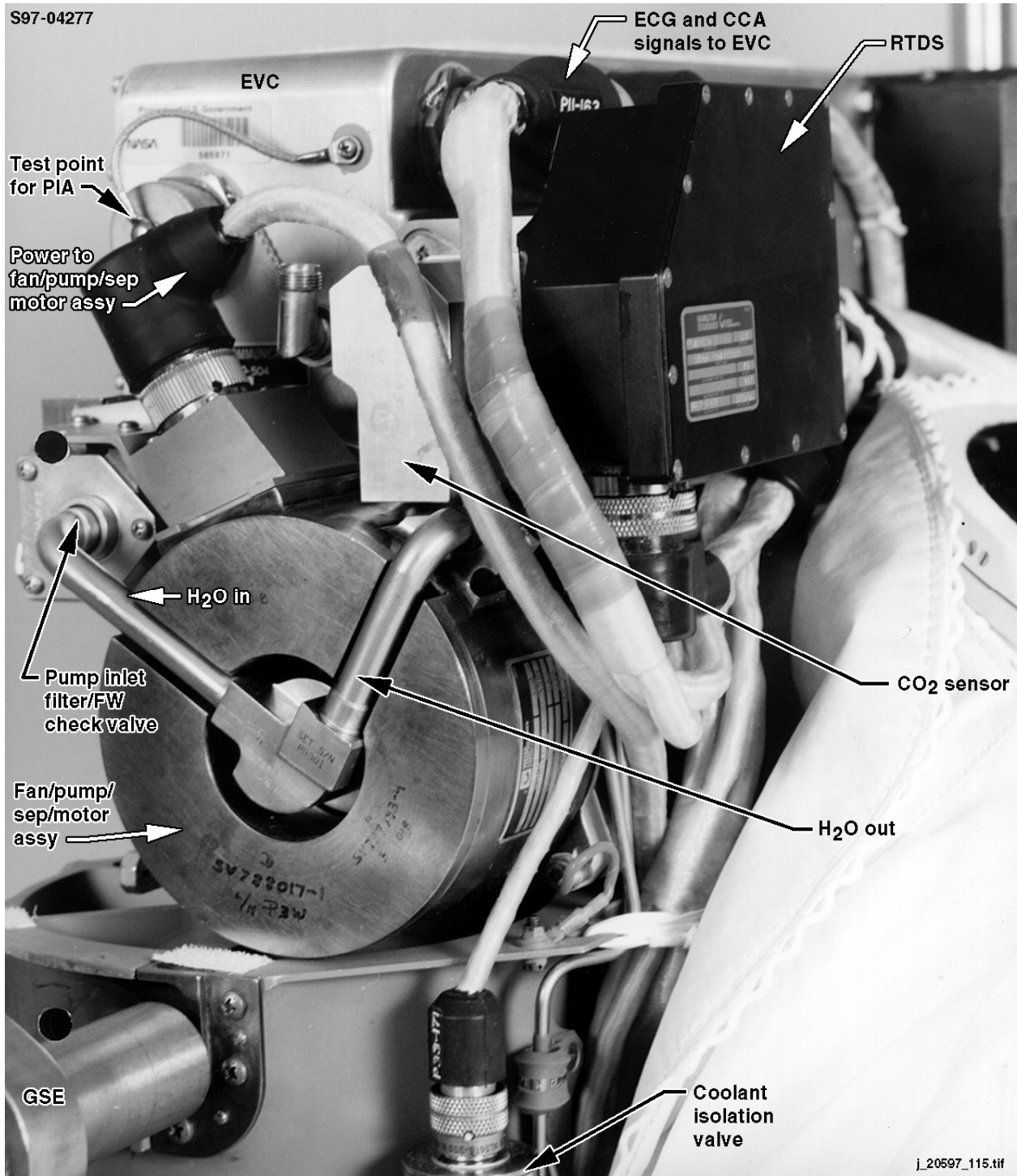


Figure A-8. Fan/pump and RTDS - area view

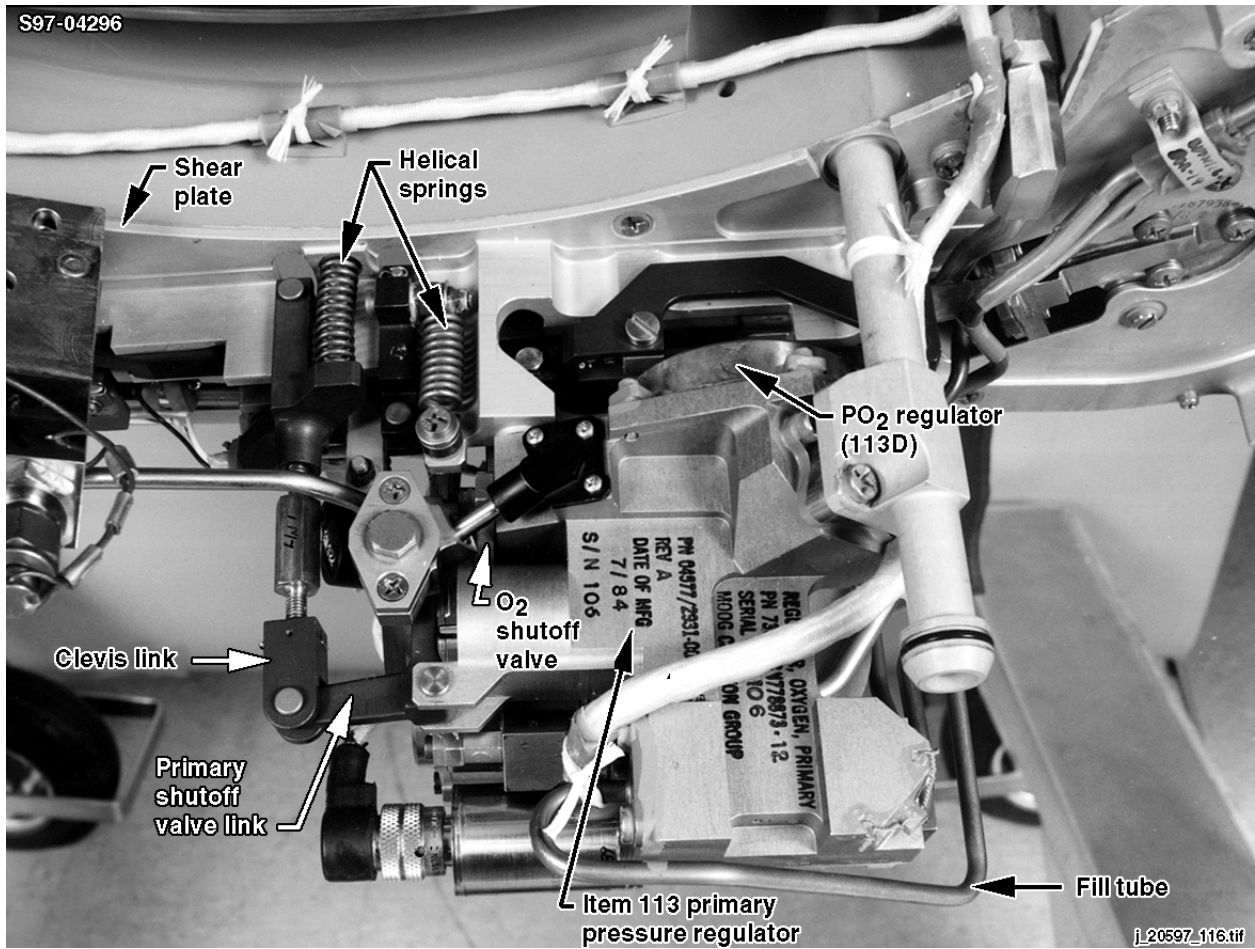
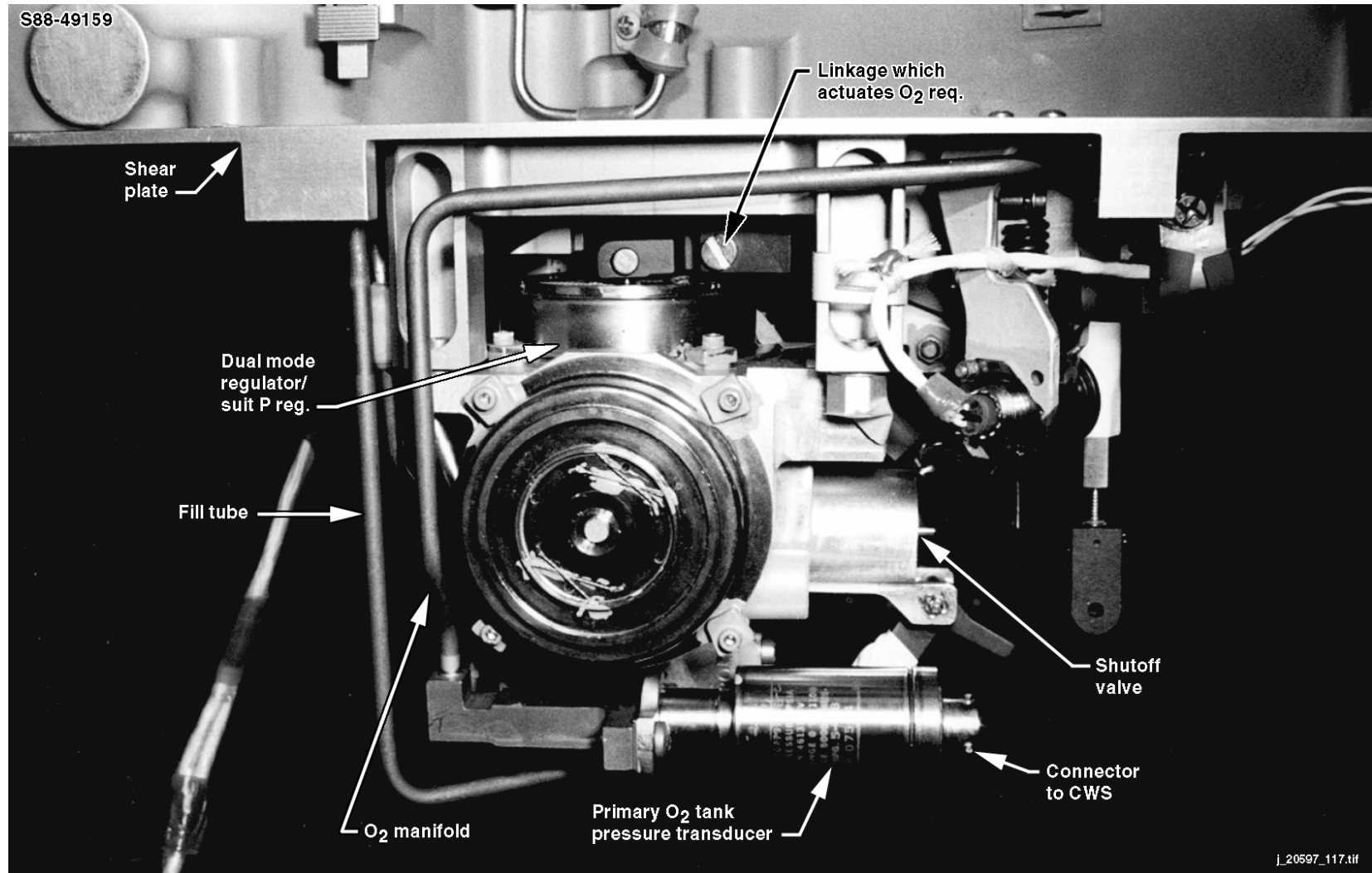


Figure A-9. O<sub>2</sub> regulator - front view



**Figure A-10. O<sub>2</sub> regulator – back view**



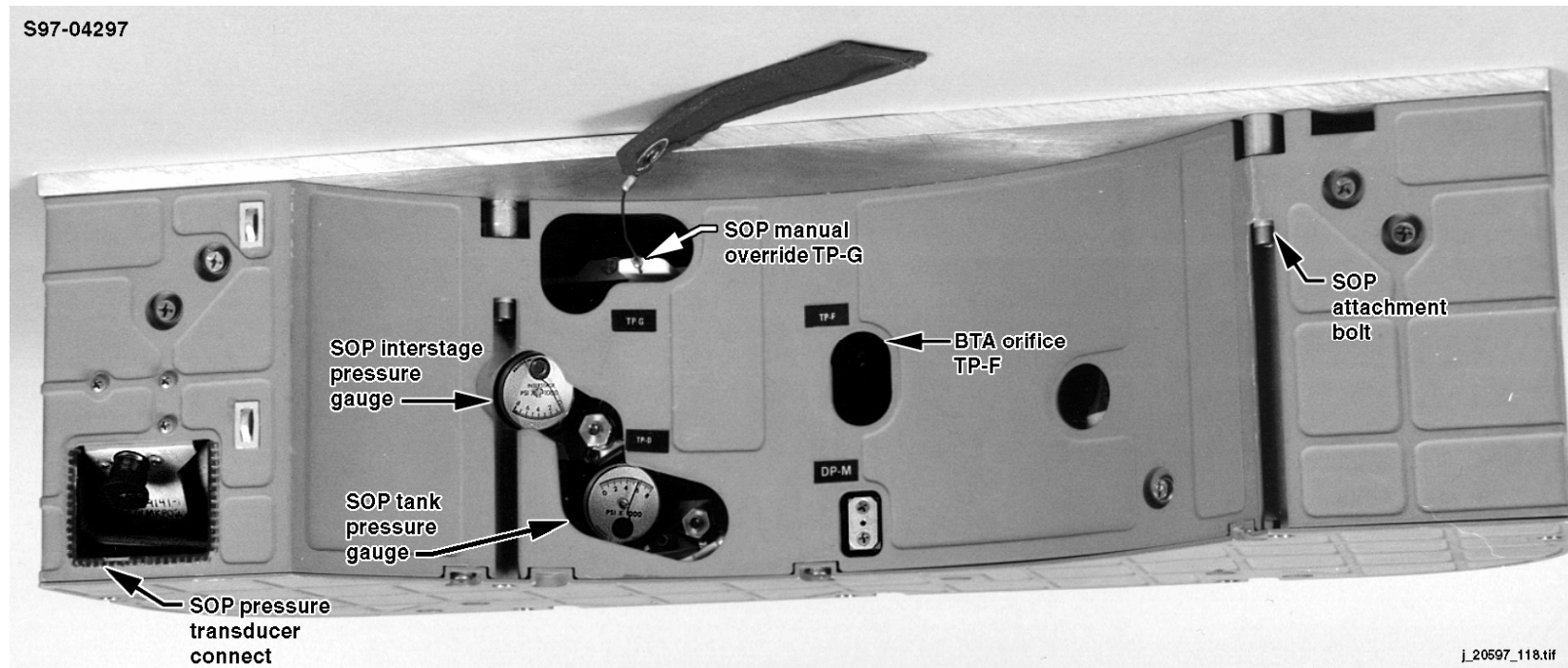


Figure A-11. SOP – front view

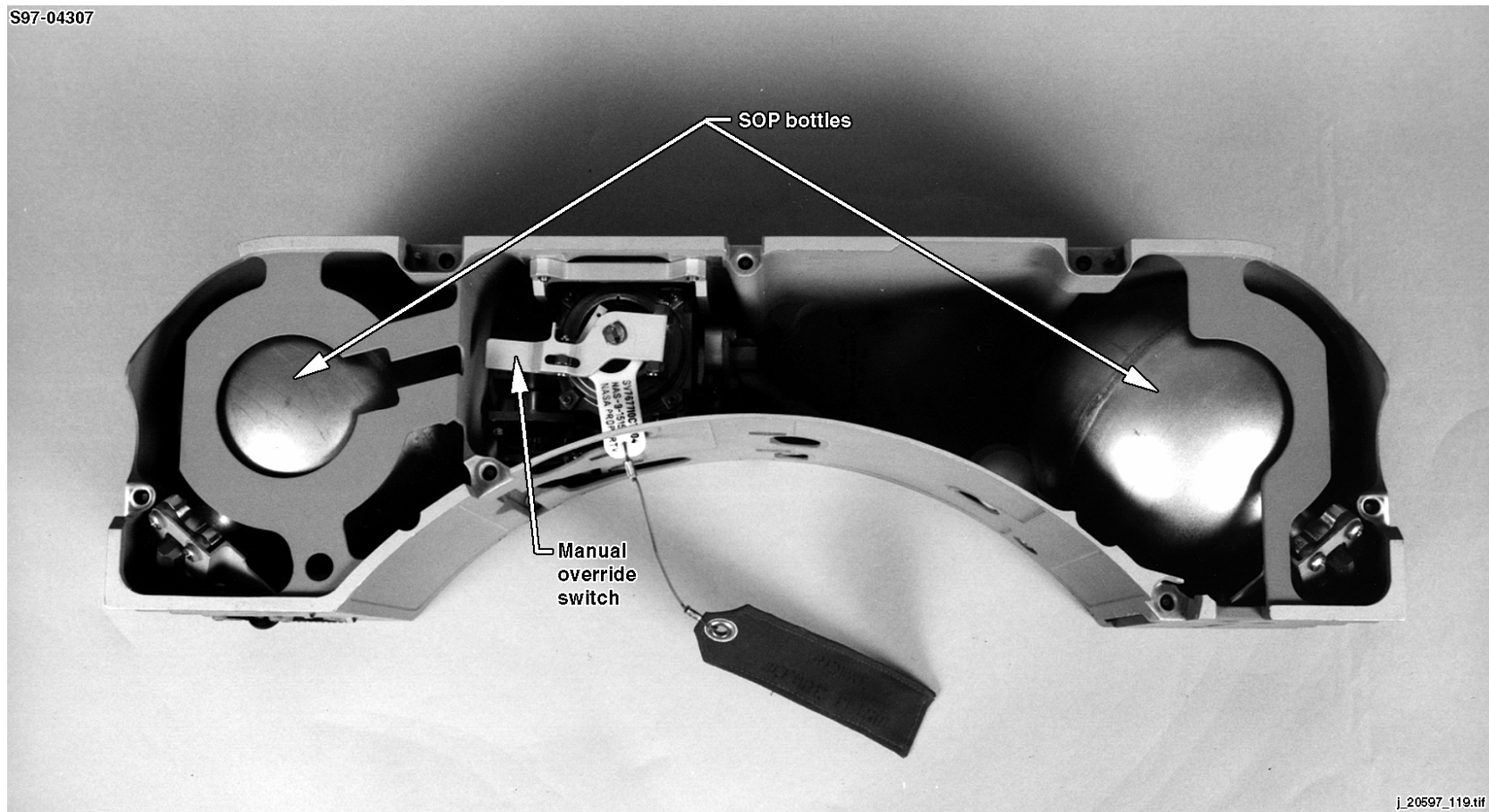


Figure A-12. SOP – top view

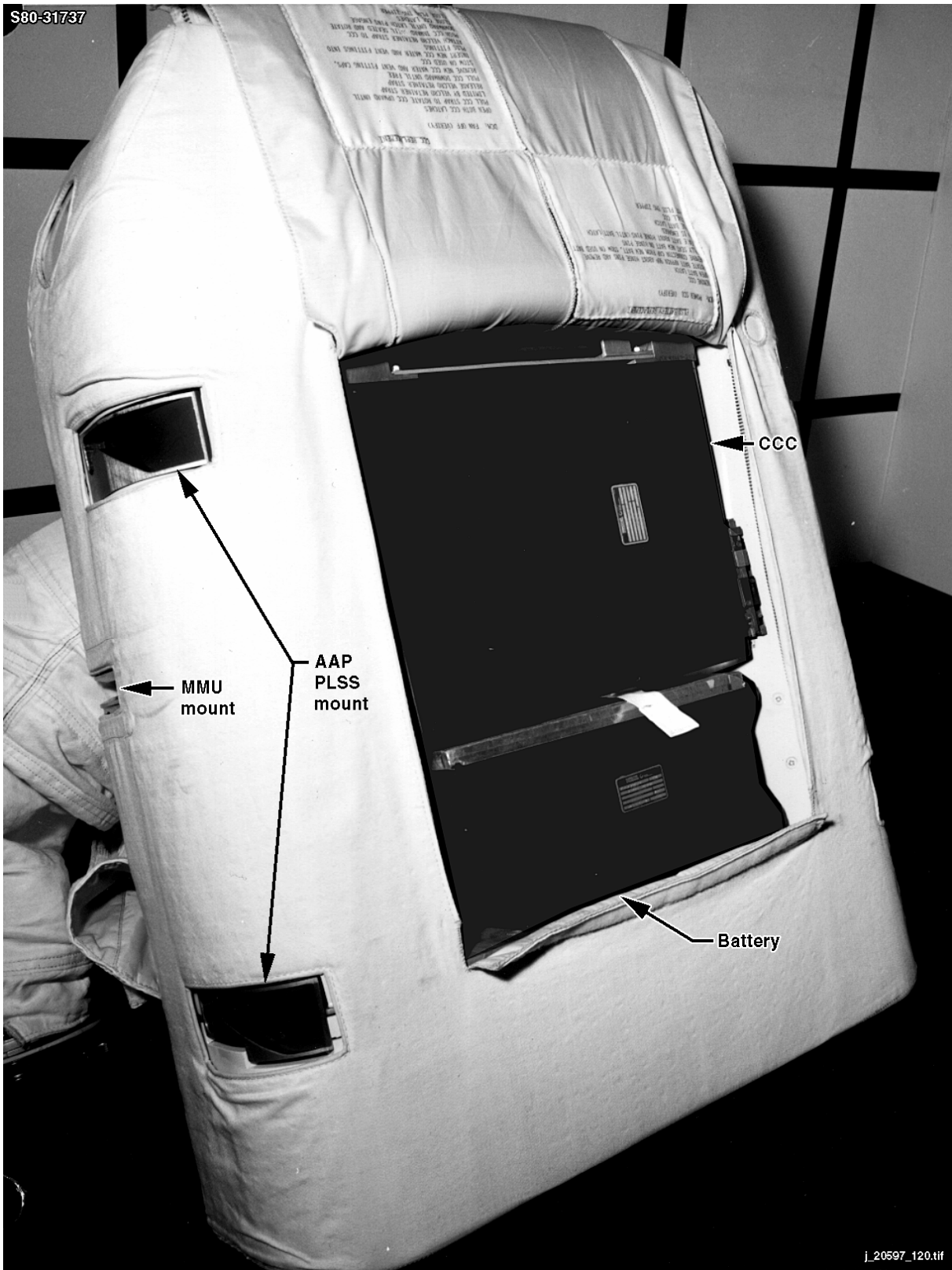


Figure A-13. PLSS with TMG - back view/CCC/battery

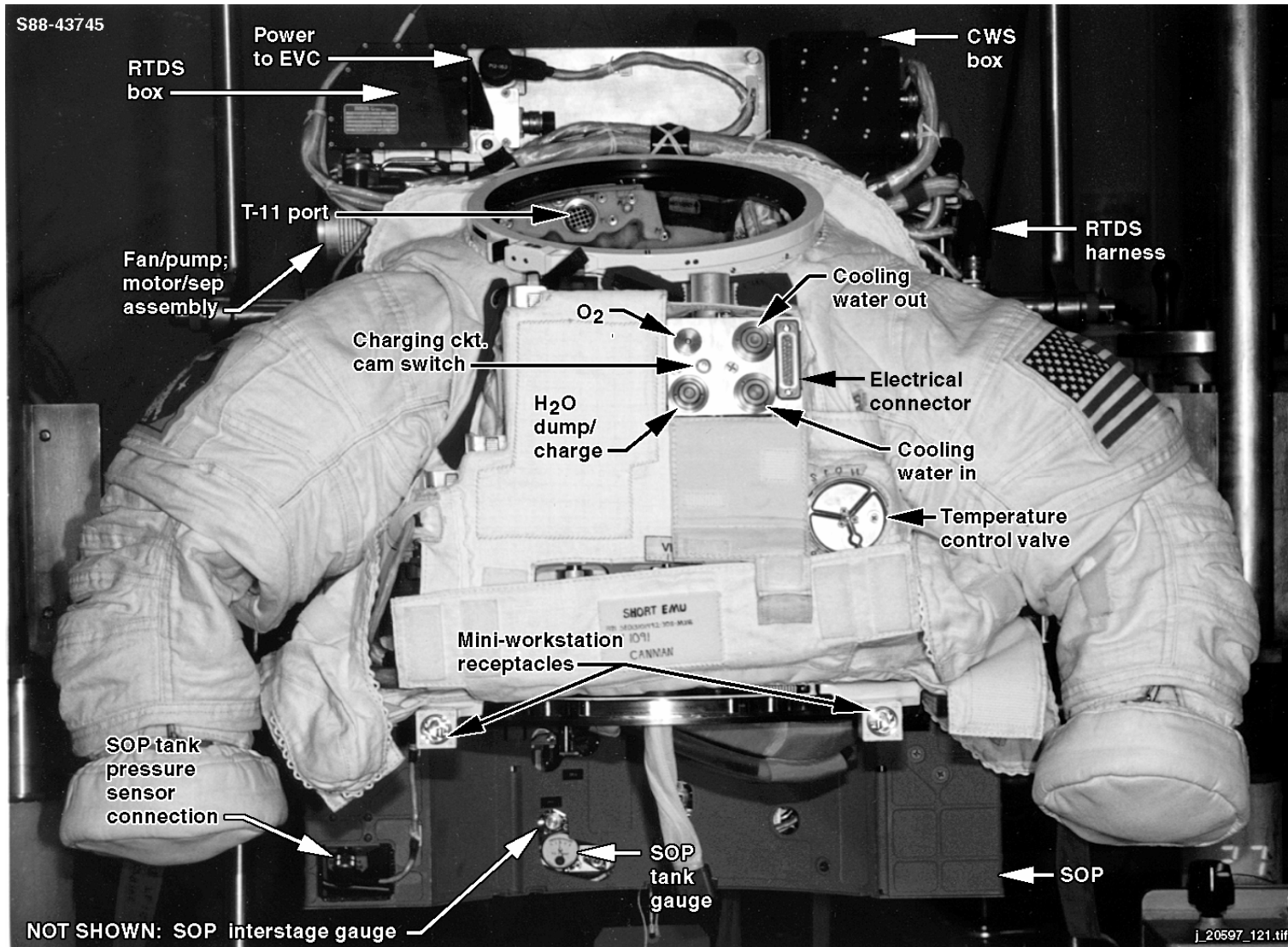
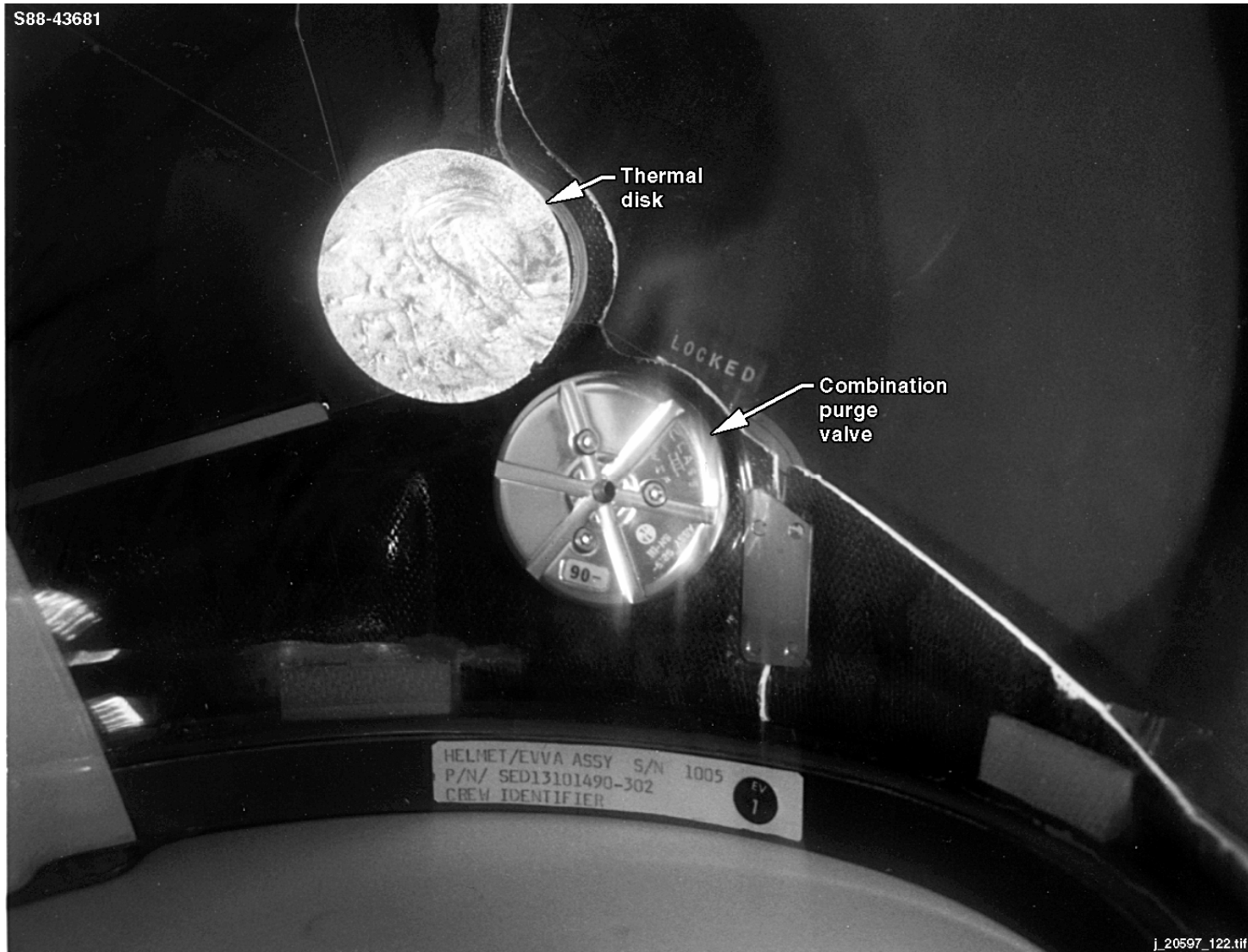
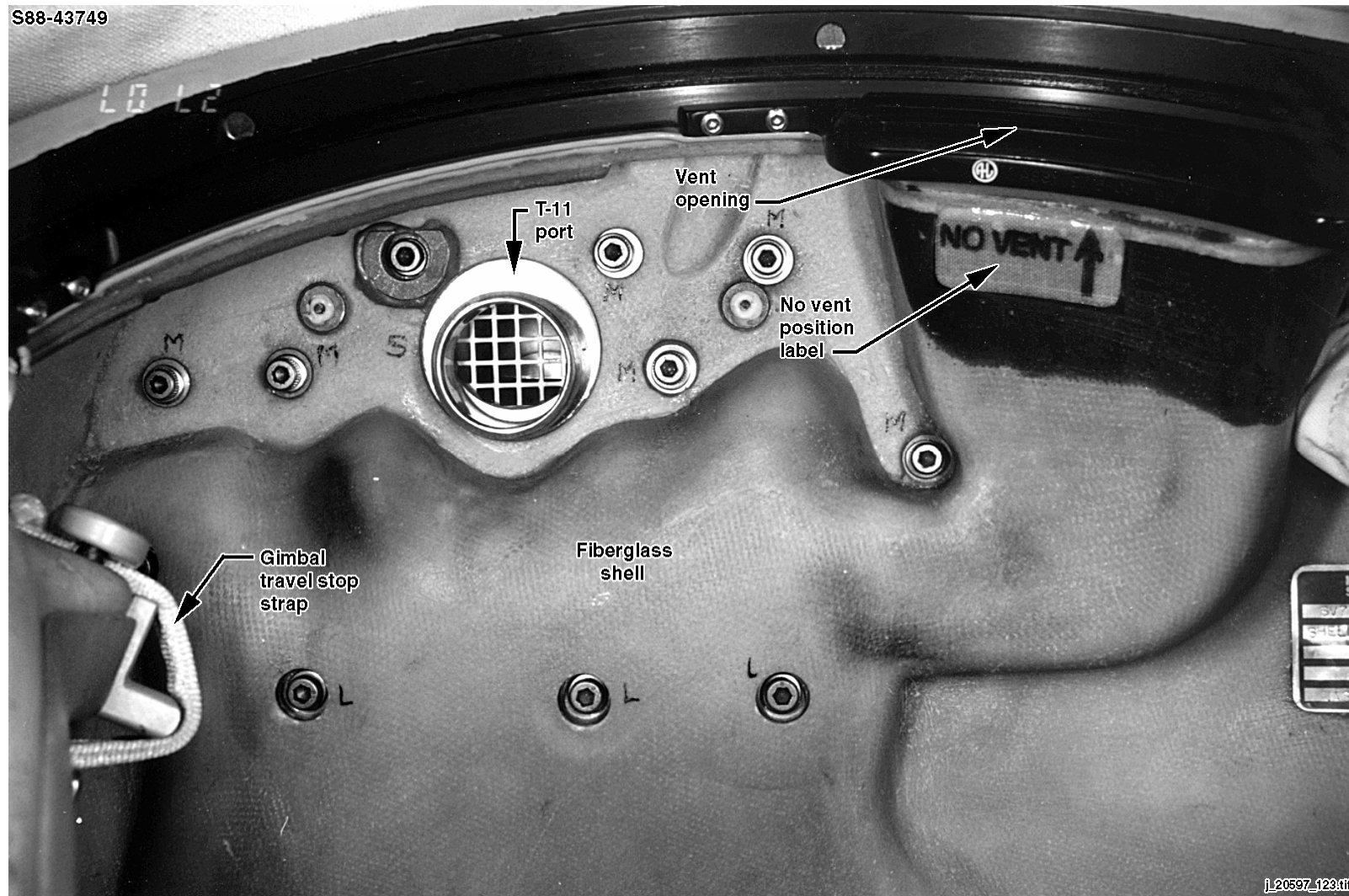


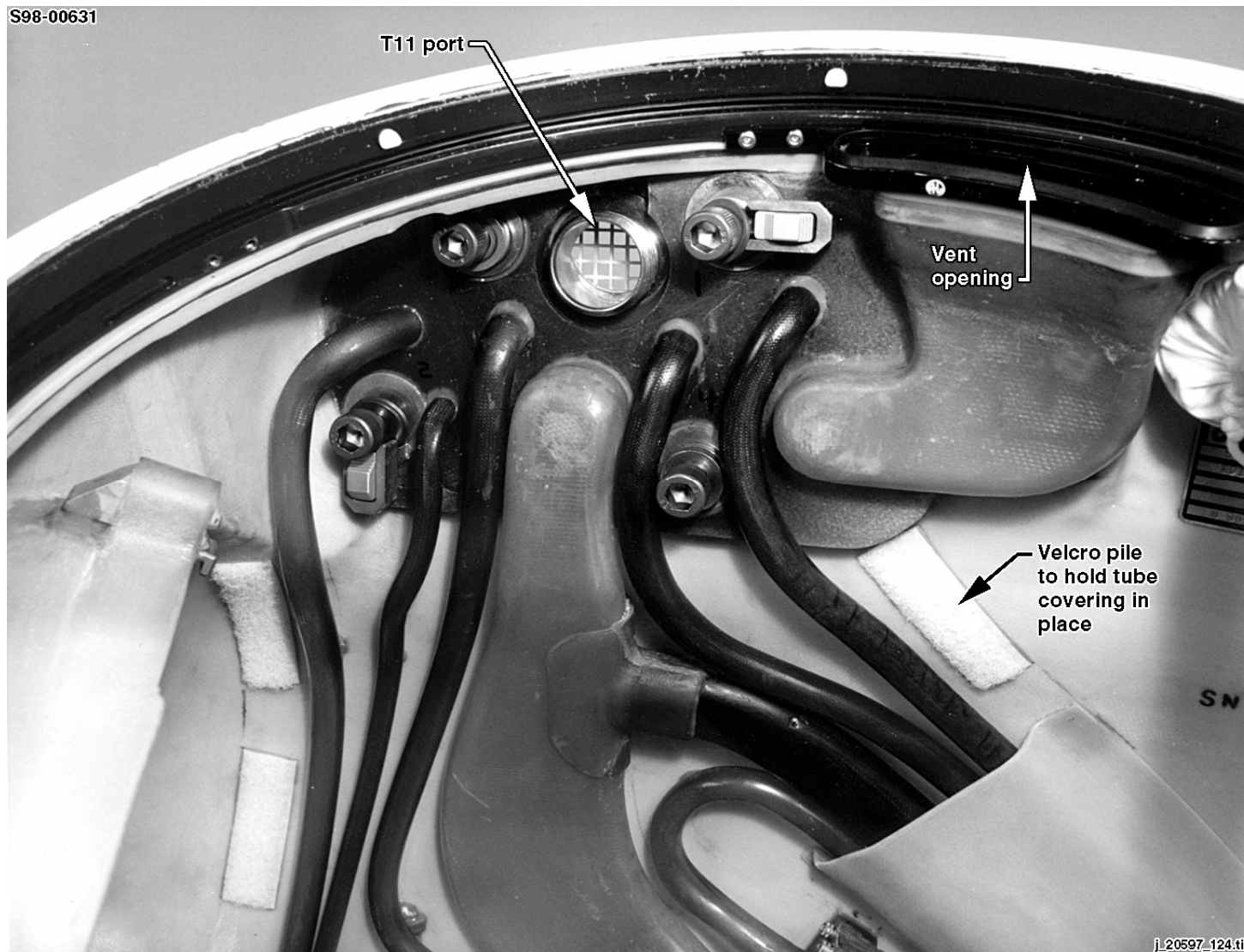
Figure A-14. Upper torso with DCM



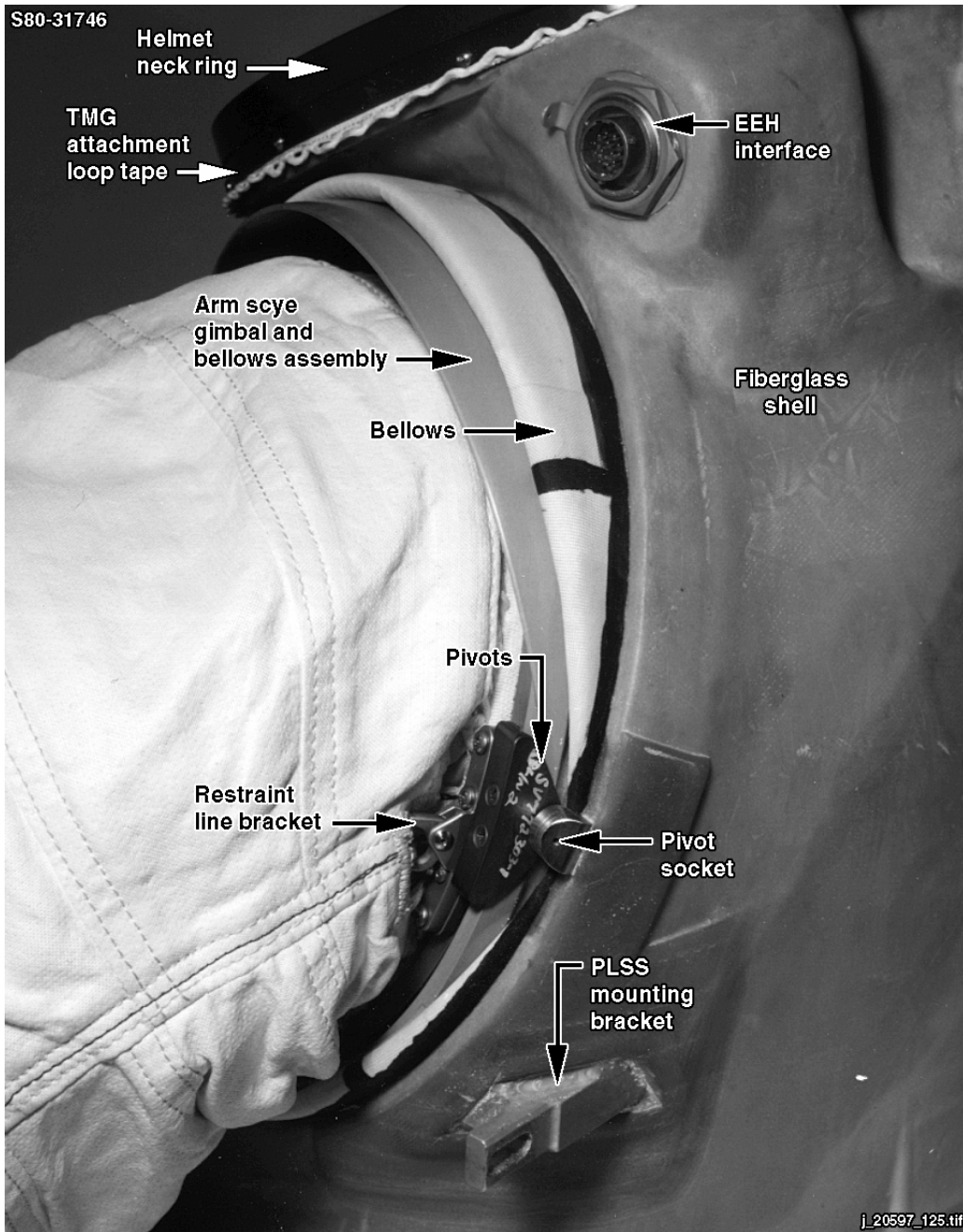
**Figure A-15. Helmet – inside, looking out**



**Figure A-16. Vent opening/inner HUT – pivoted**



**Figure A-17. Vent opening/inner HUT - planar**



**Figure A-18. HUT without TMG**



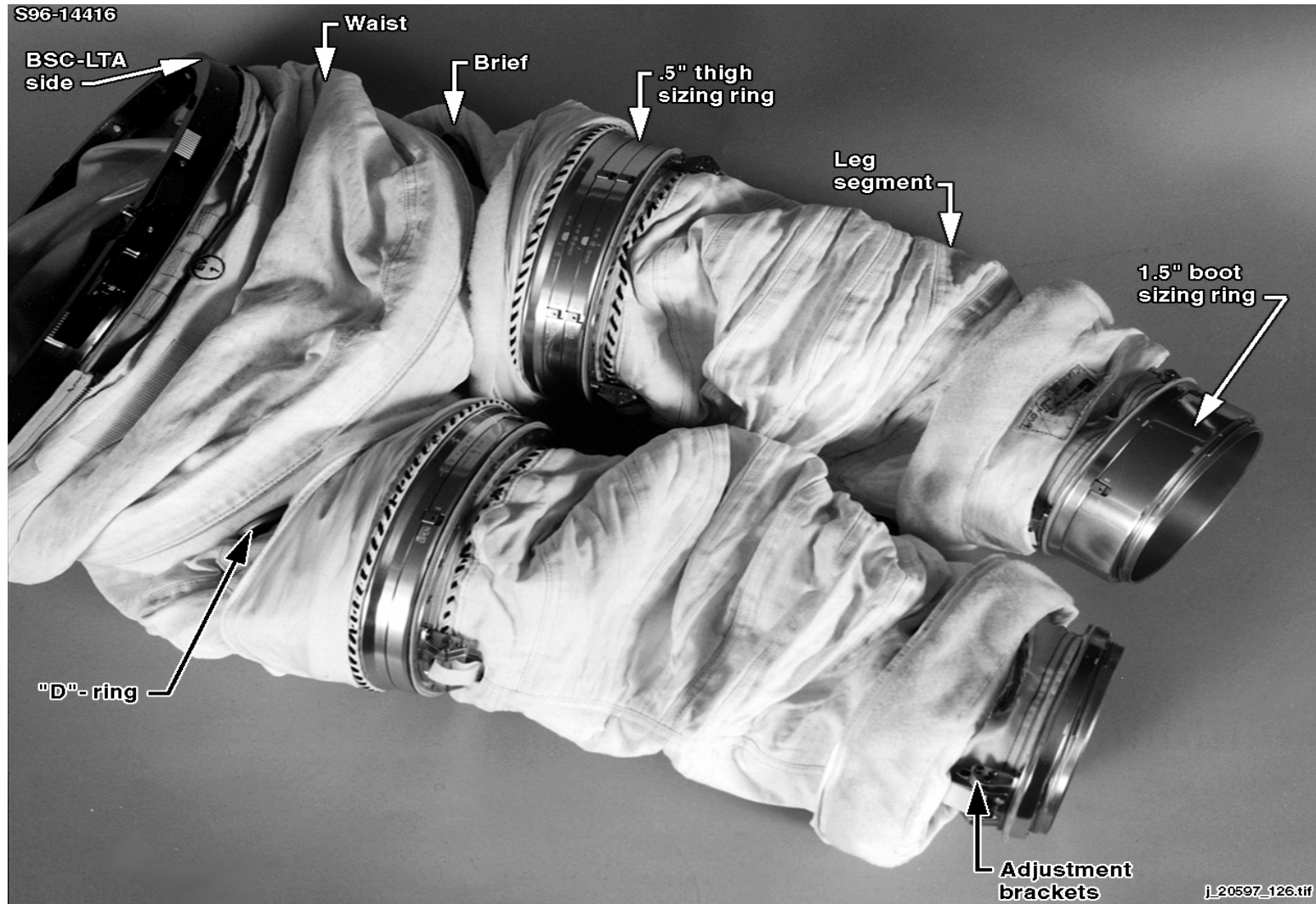
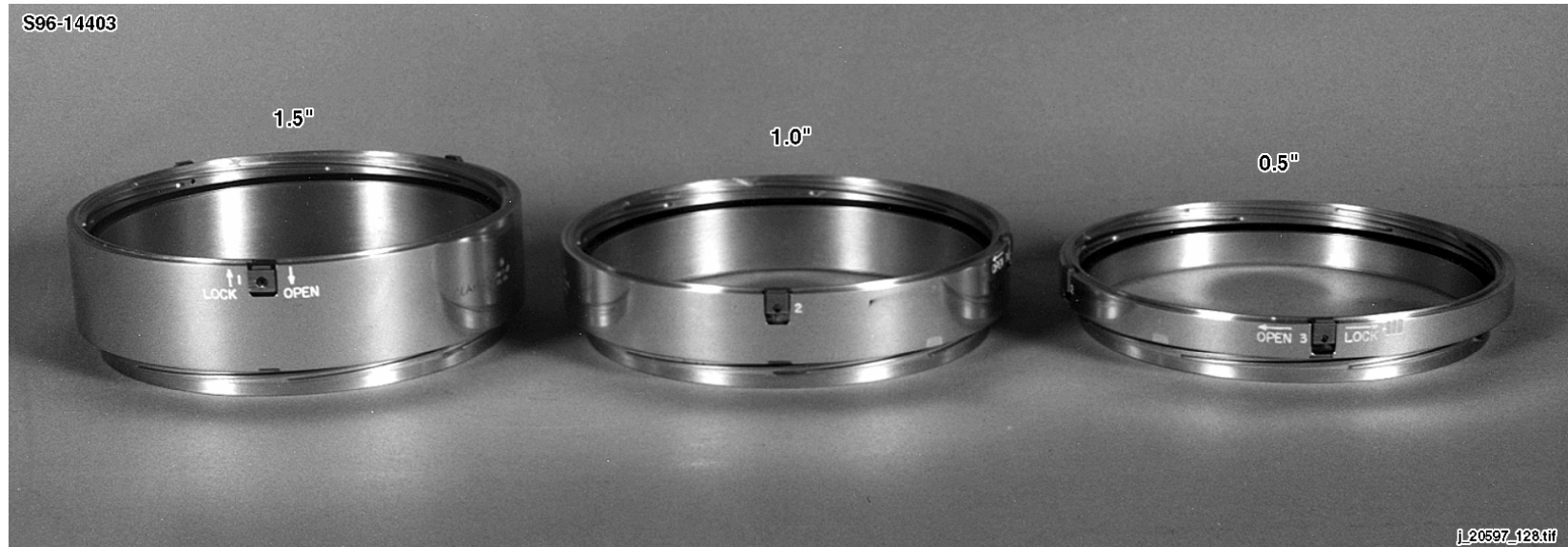


Figure A-19. Enhanced LTA

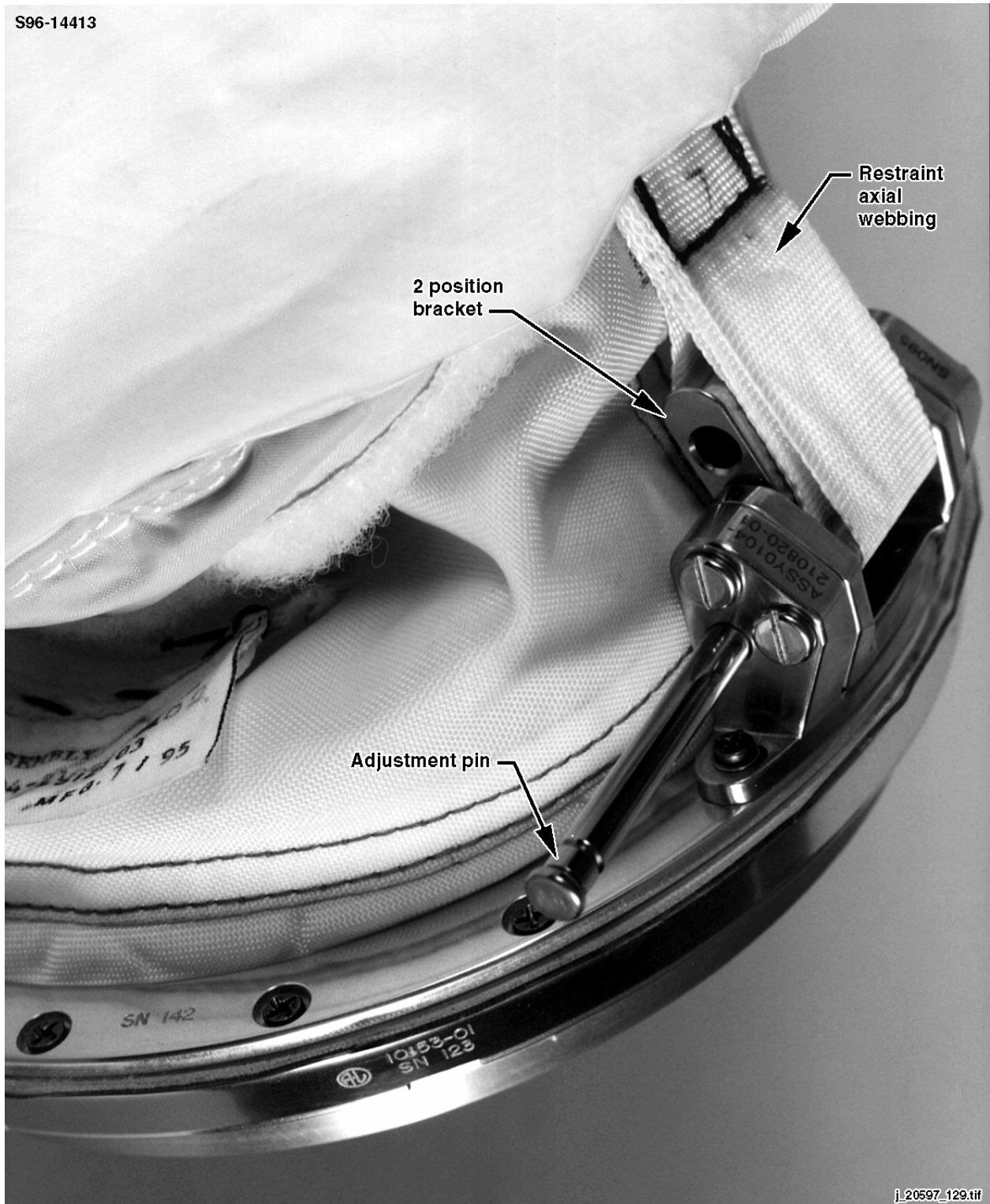
S96-14405



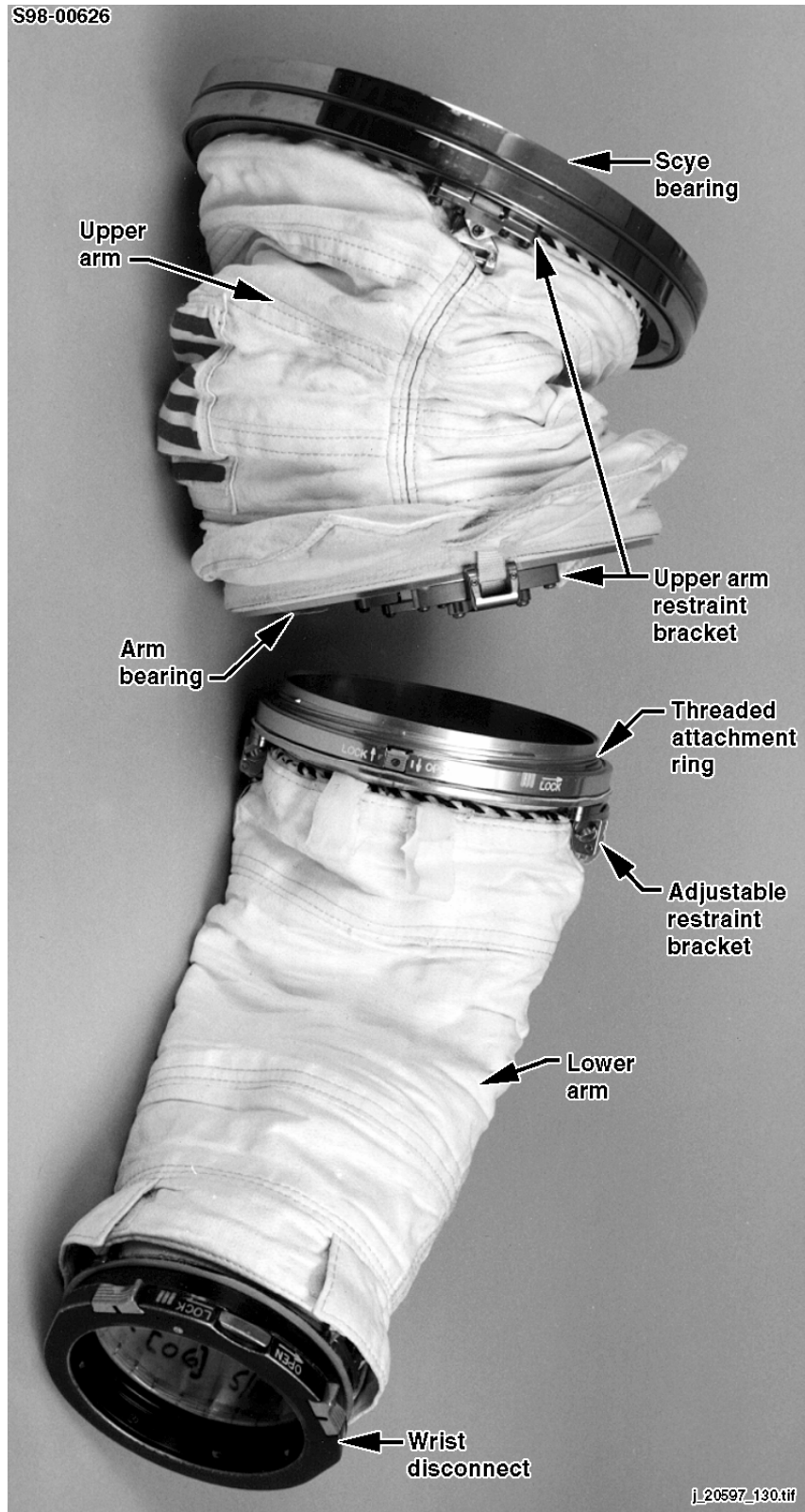
**Figure A-20. One-half-inch thigh sizing ring**



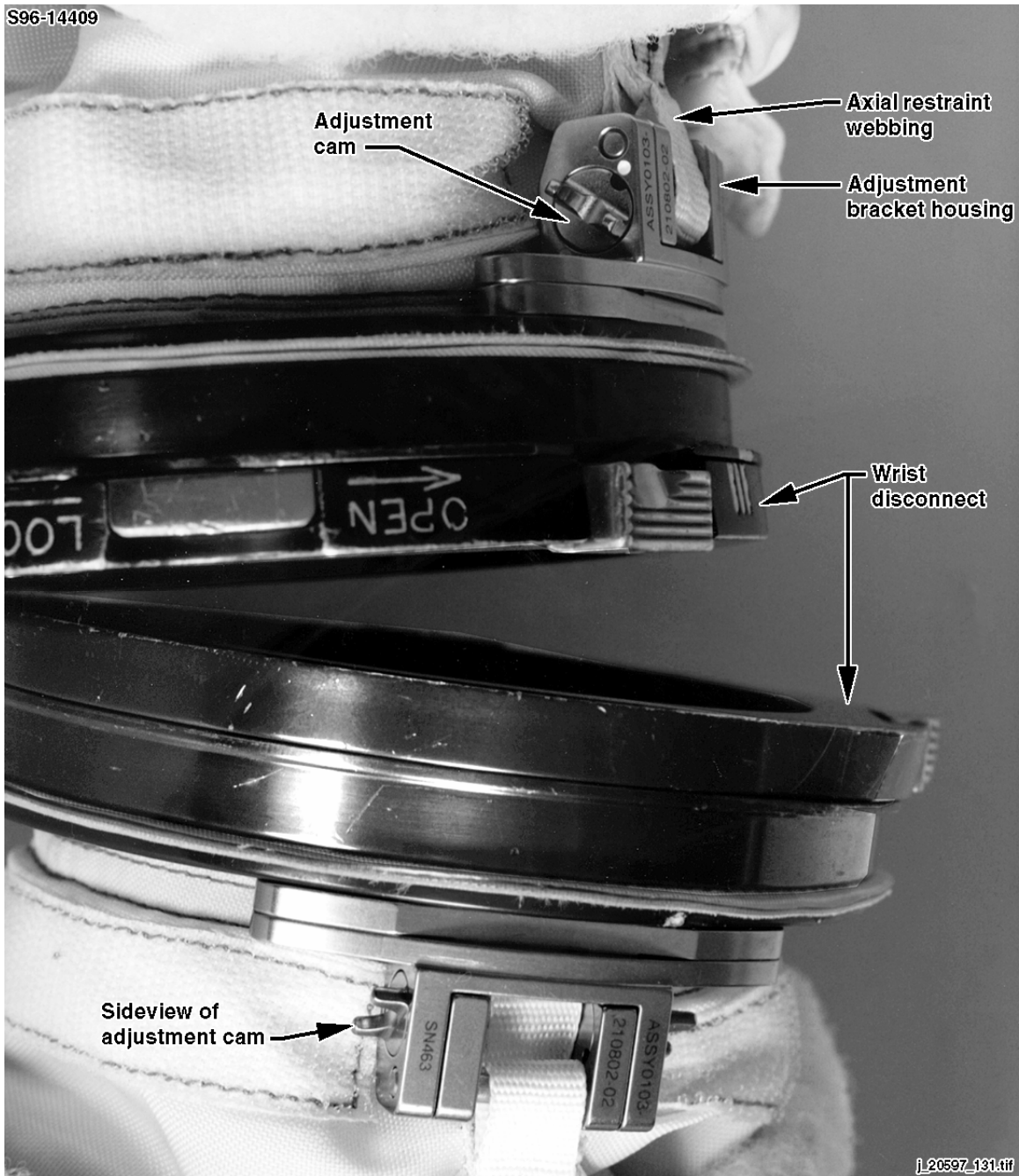
**Figure A-21. Leg sizing rings**



**Figure A-22. Leg cam adjusting bracket**

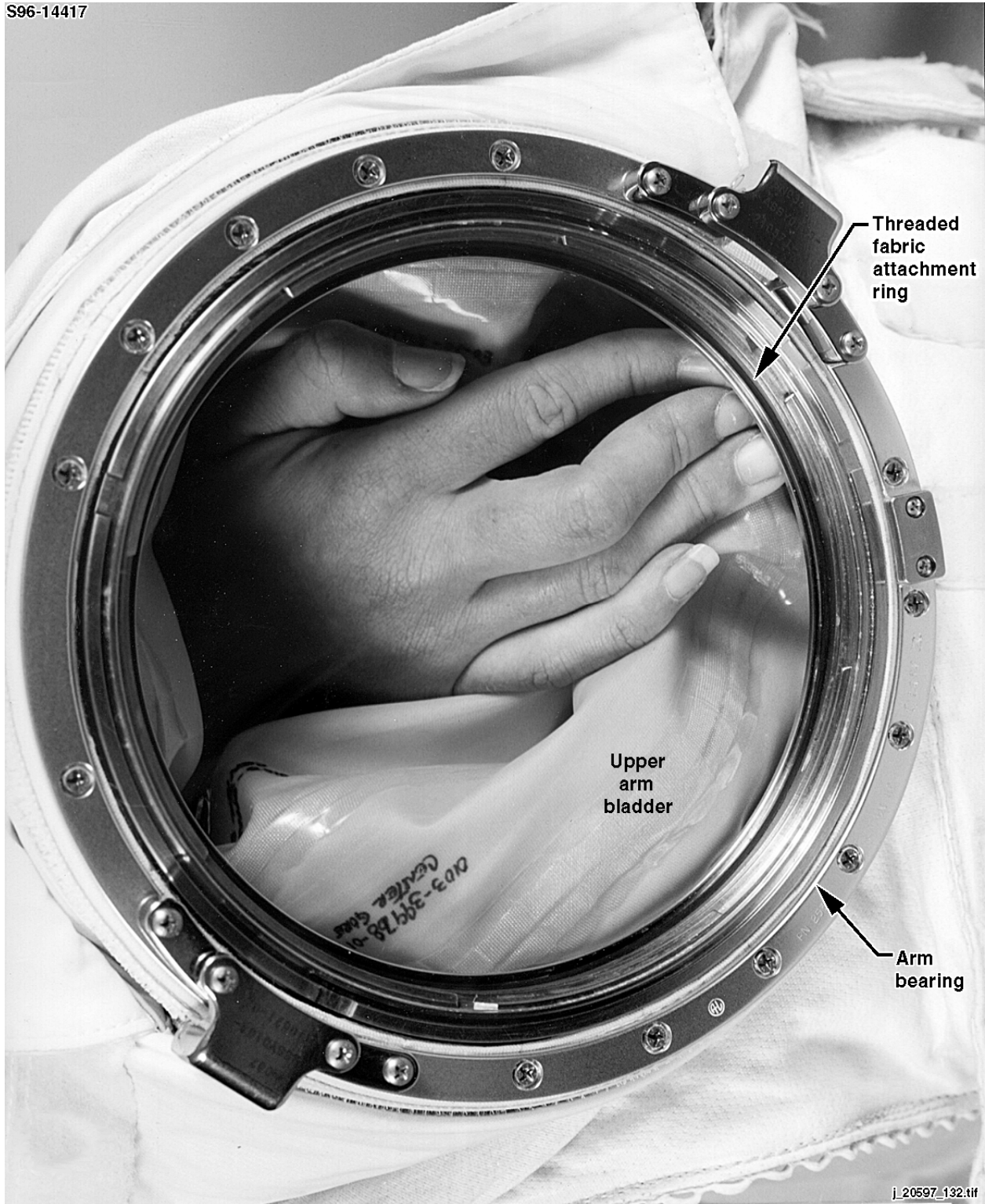


**Figure A-23. Enhanced arm assembly**



**Figure A-24. Lower arm cam adjustment brackets**

S96-14417



**Figure A-25. Upper arm fabric attachment ring**

S96-14404



**Figure A-26. One-half-inch arm sizing ring**





**Figure A-27. Heated glove attachment**



**Figure A-28. SSA power harness/battery pouch**

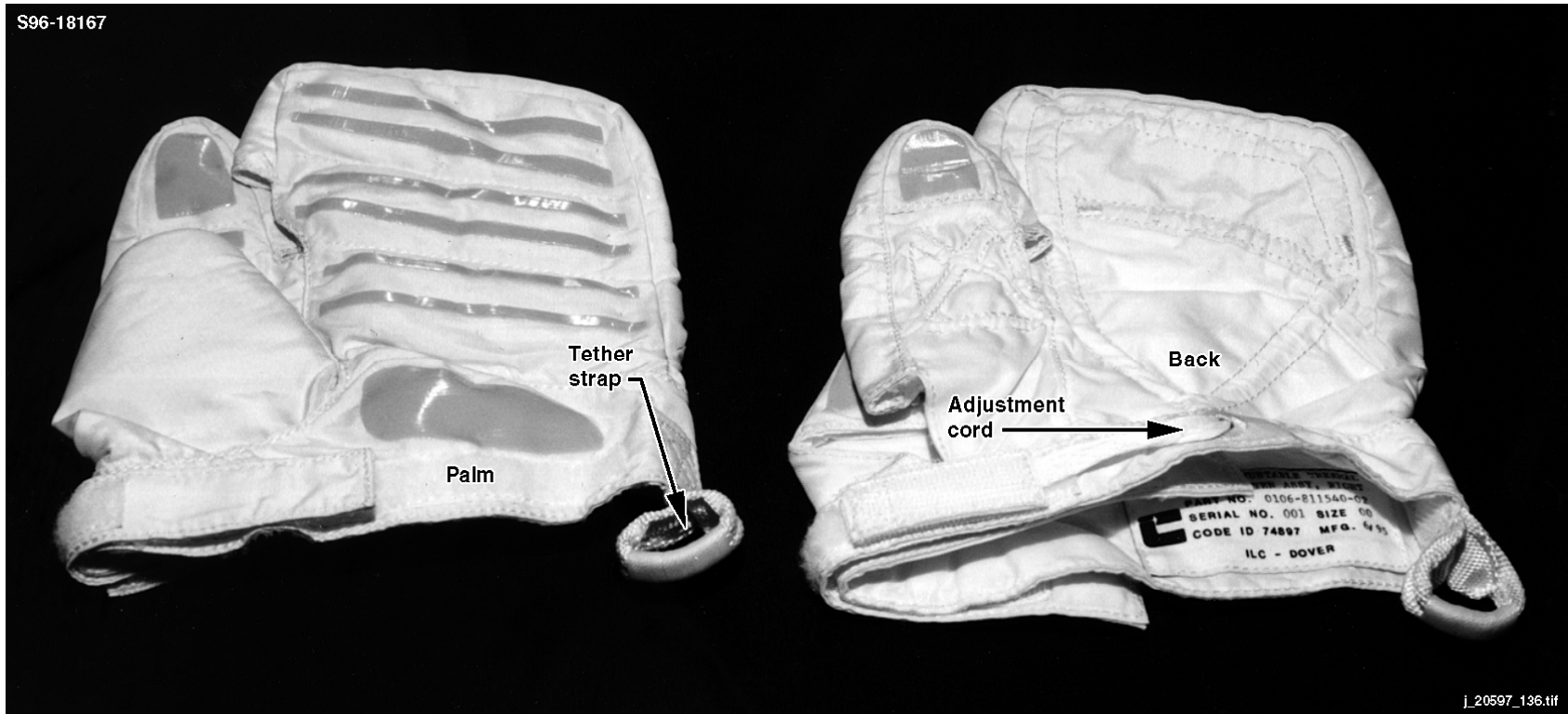
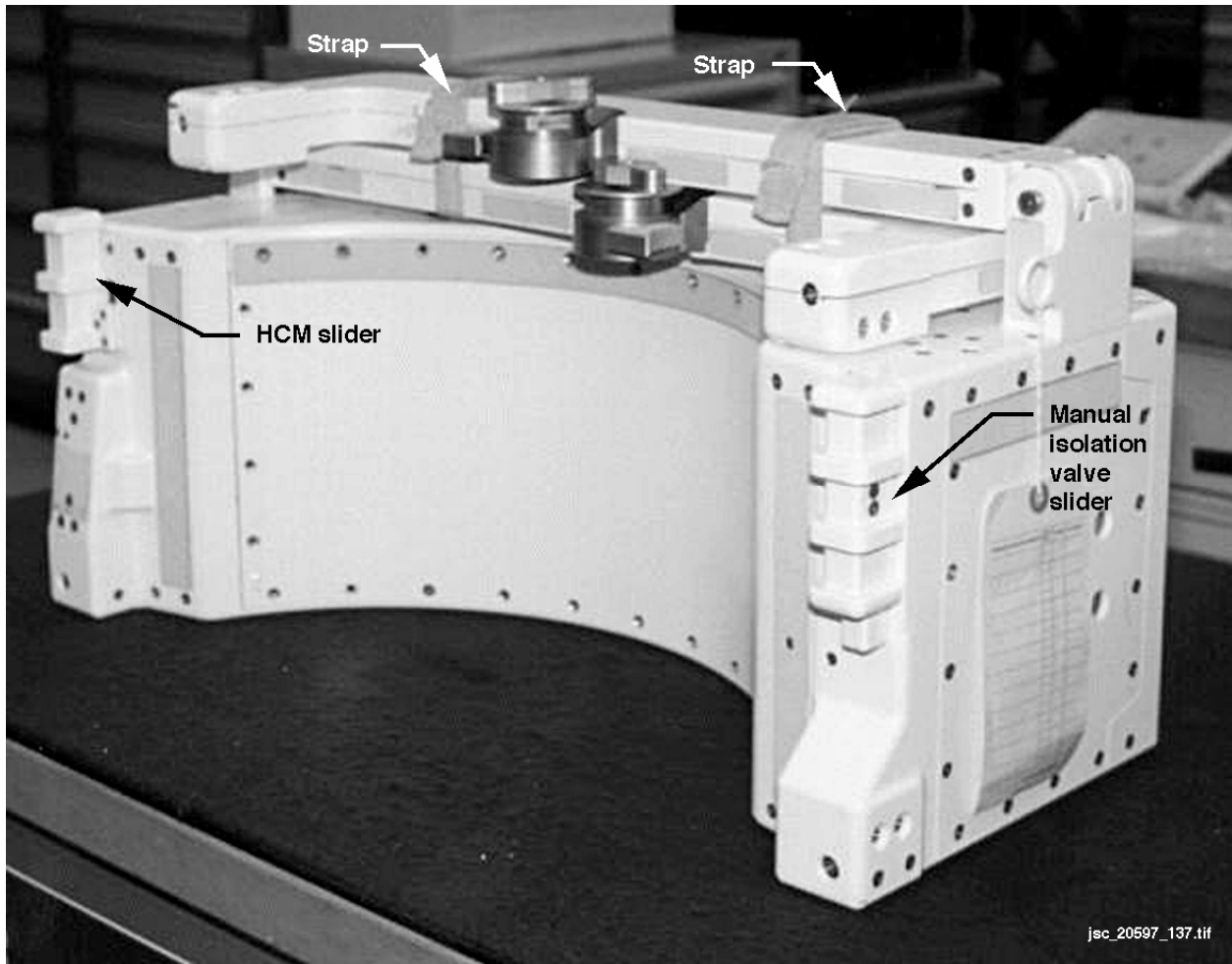
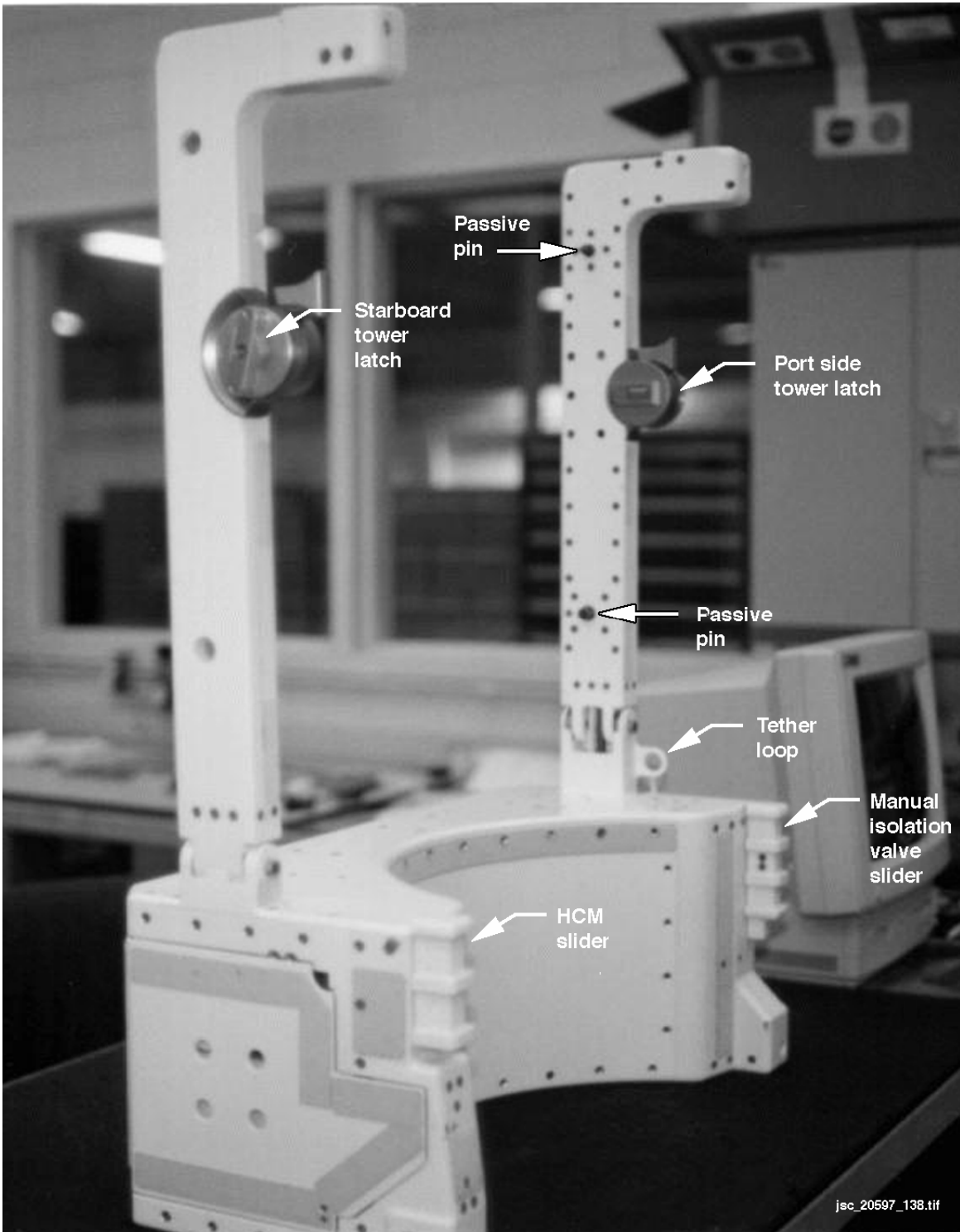


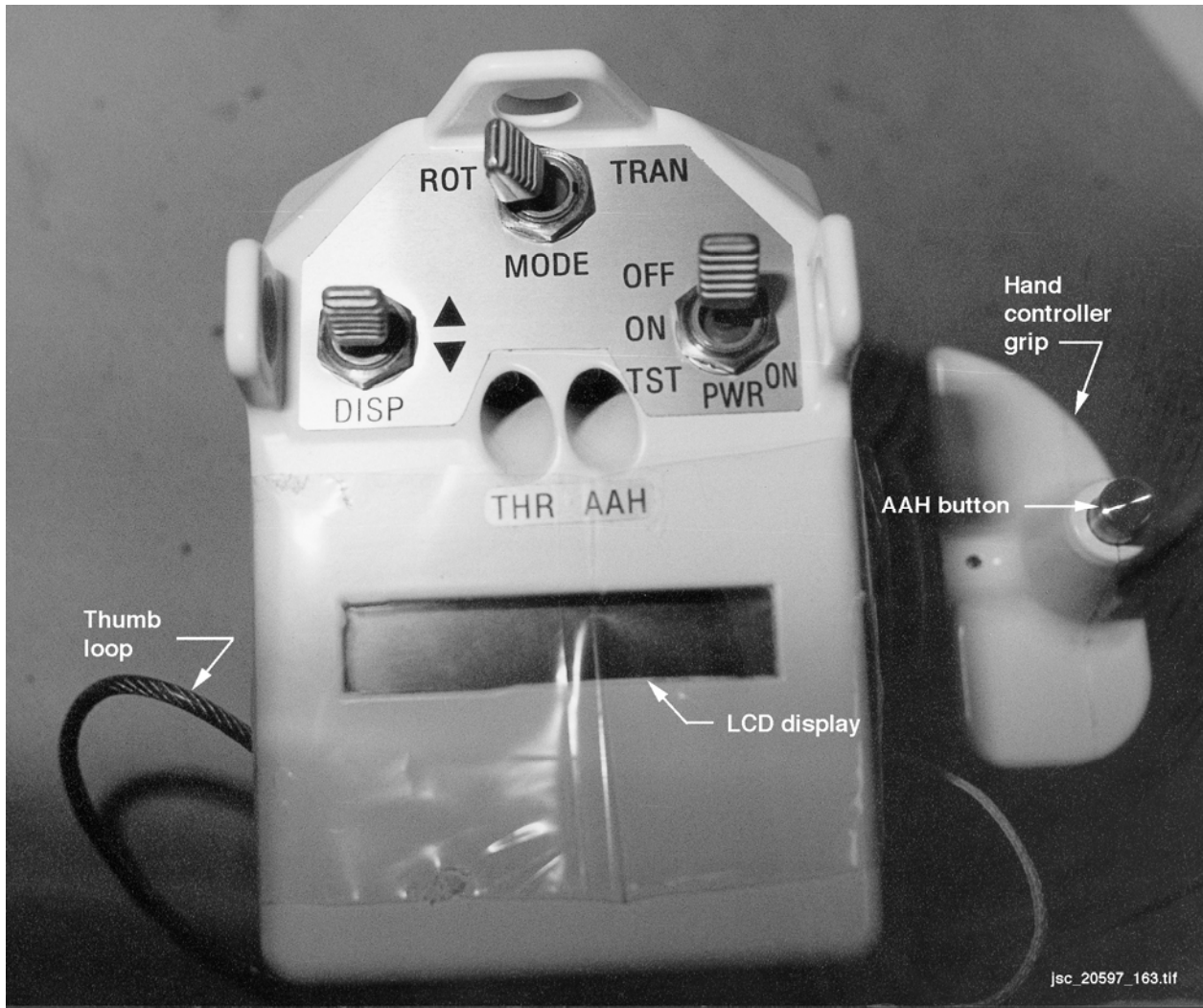
Figure A-29. Adjustable thermal mittens



**Figure A-30. SAFER with folded towers without TMG**

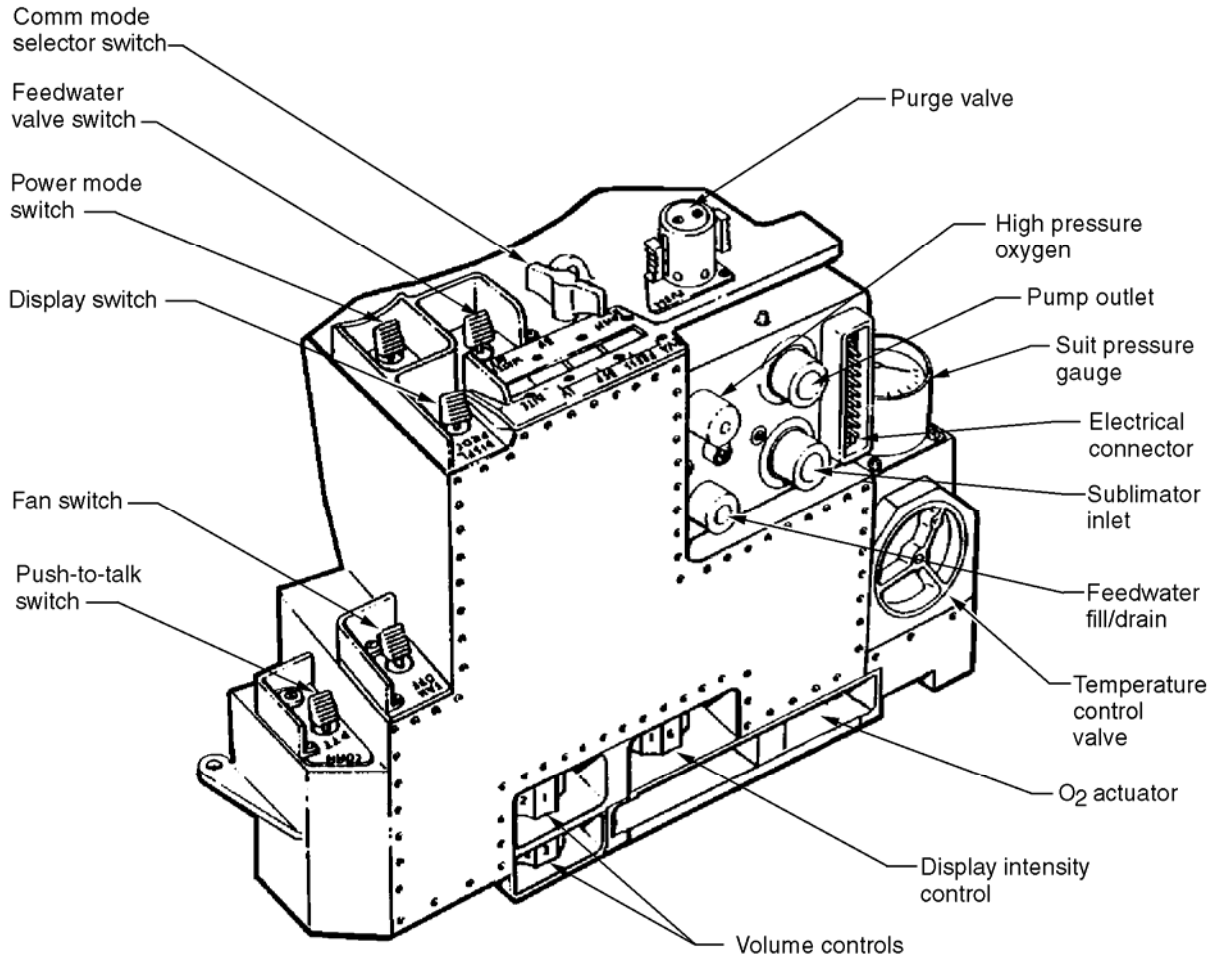


**Figure A-31. SAFER without TMG**



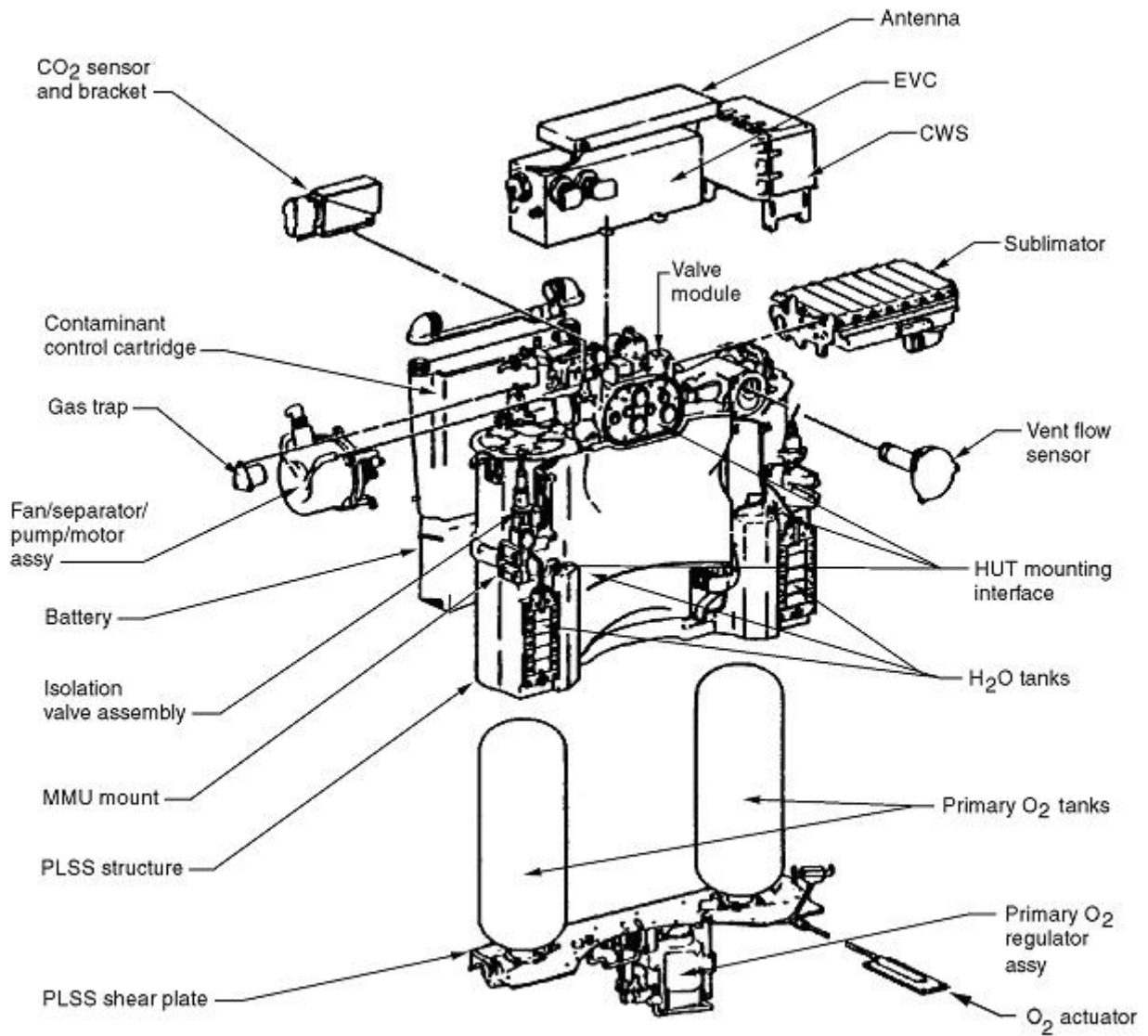
**Figure A-32. SAFER hand controller**

APPENDIX B LINE DRAWINGS



j\_20957\_139.tif

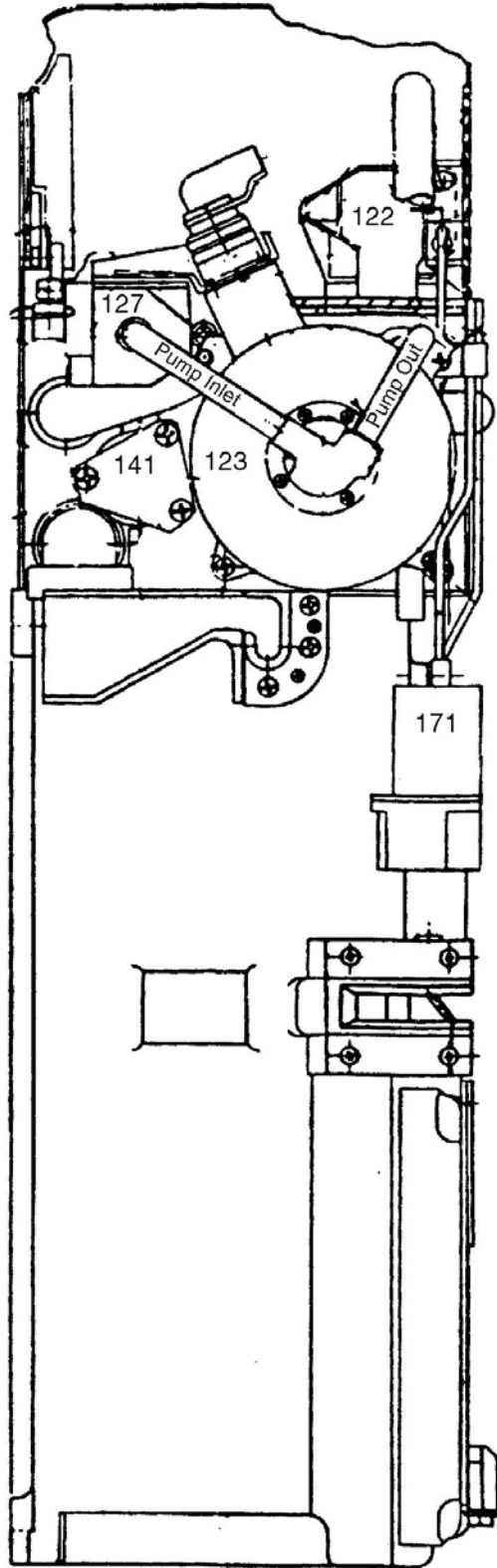
Figure B-1. DCM front view



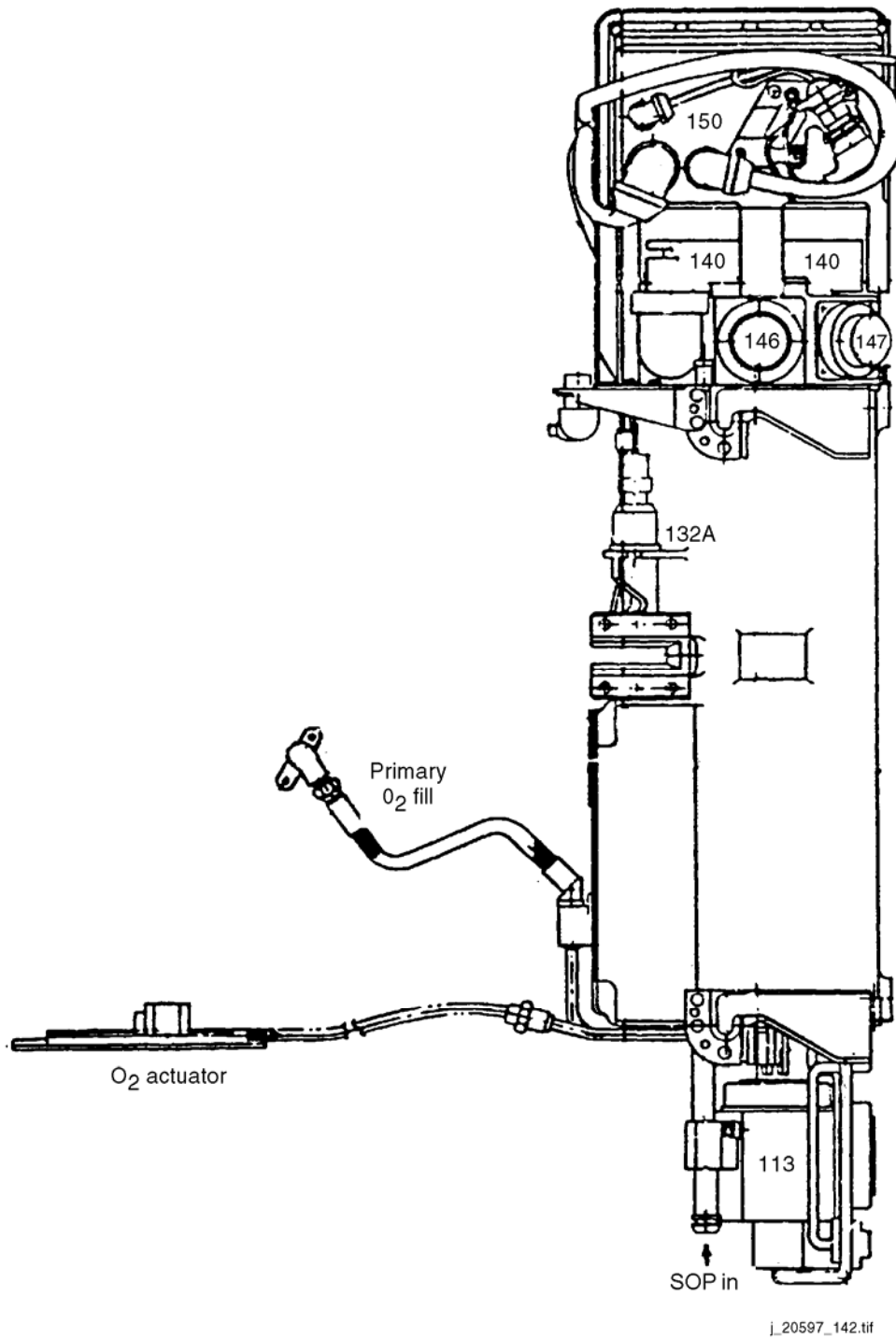
I\_20597\_140.tif

**Figure B-2. PLSS exploded view**





*Figure B-3. PLSS right side view*



**Figure B-4. PLSS left side view**

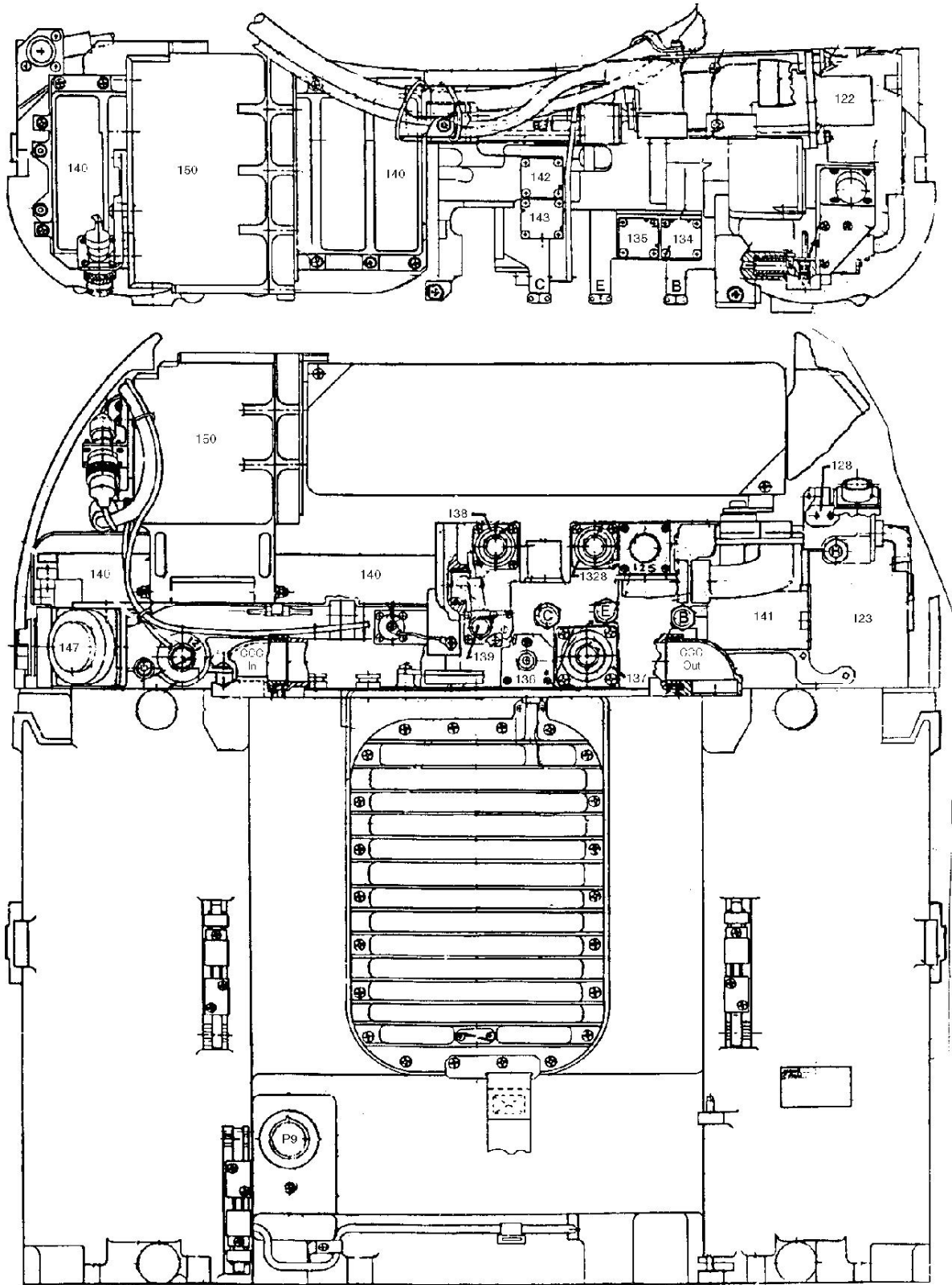
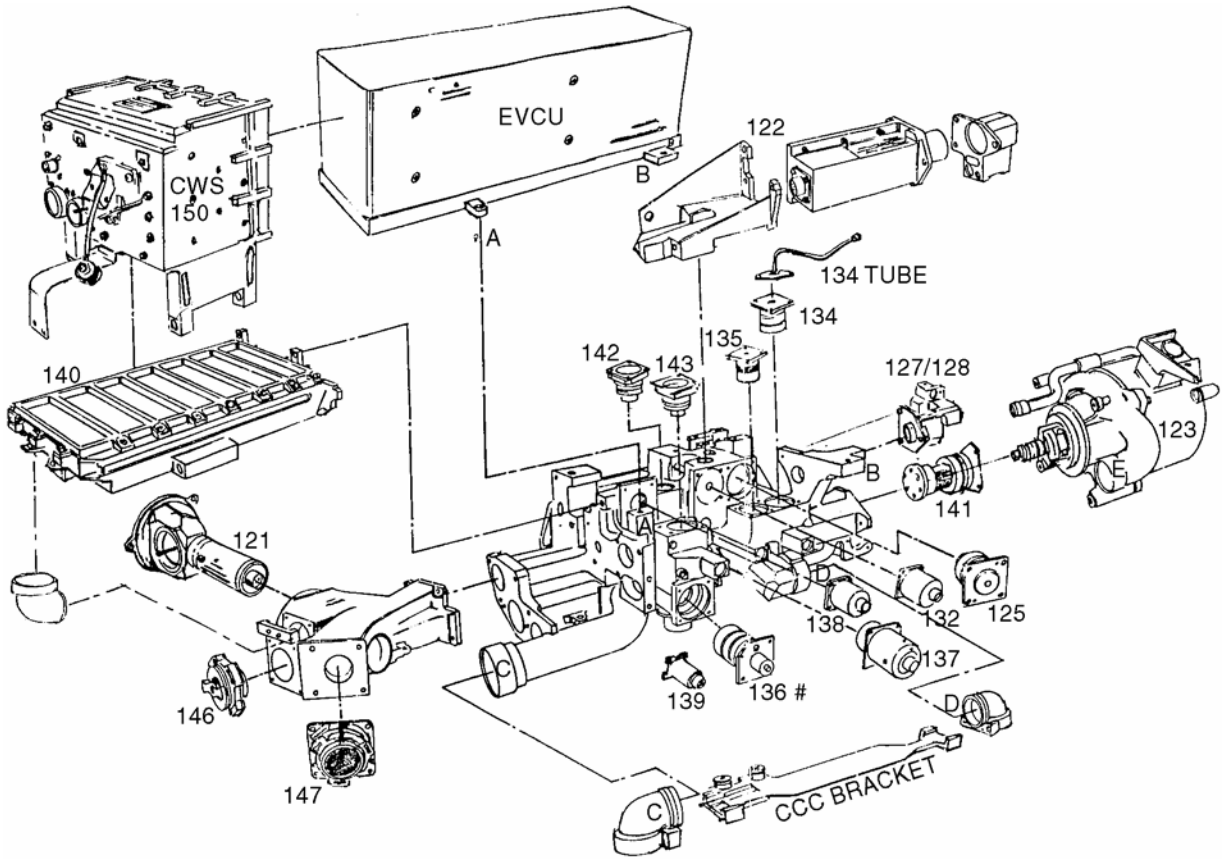
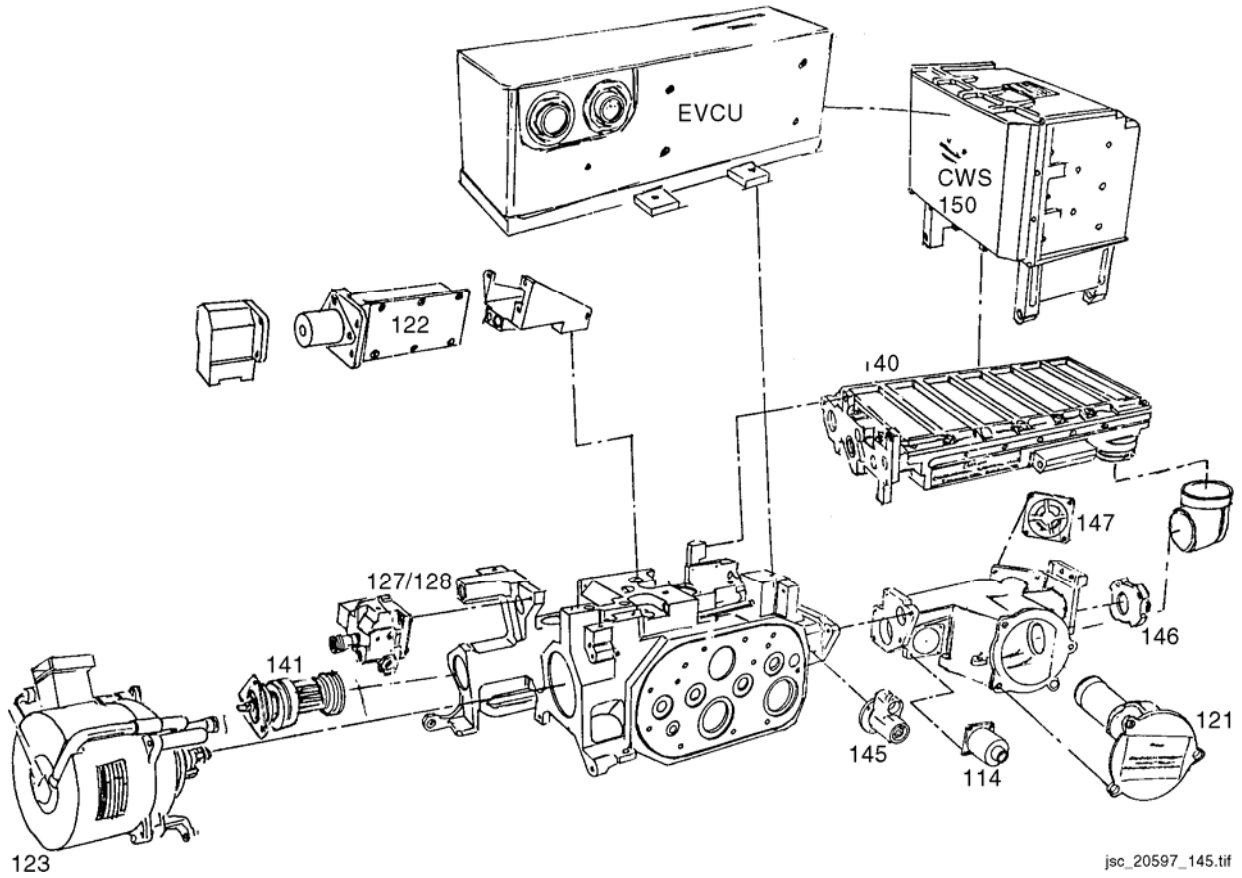


Figure B-5. PLSS back side view



jsc\_20597\_144.tif

**Figure B-6. PLSS valve module, view from rear**



**Figure B-7. PLSS valve module, view from HUT interface**

### EMU COMPONENT LIST

100	PLSS
111	Primary oxygen bottles
112	Primary oxygen pressure sensor
113	Primary pressure control module
113 A	Check valve
113 B	Variable orifice
113 C	Oxygen shut-off valve
113 D	Dual mode regulator
113 E	Water pressure regulator
114	Suit pressure sensor
115	Shear plate assembly
116	EVA microswitch
120	Dual mode relief valve
120 A	Bleed orifice
120 B	Dual mode relief valve
120 C	Check valve
121	Check valve & vent flow sensor
122	CO <sub>2</sub> sensor
123	Fan/pump/separator
125	Pitot actuated valve
126	CO <sub>2</sub> filter and orifice
127	Pump inlet filter
128	Pump check valve
131	Primary H <sub>2</sub> O tank (also item 162)
132	Feedwater supply pressure sensor (132 A & B)
134	Condensate H <sub>2</sub> O relief valve
135	Feedwater relief valve
136	Feedwater pressure regulator
137	Feedwater shutoff valve
138	Feedwater pressure sensor
139	Sublimator outlet temperature sensor
140	Sublimator
141	Gas trap
142	Water relief valve
143	Water check valve
145	Relief/valve and orifice (secondary oxygen package relief valve)
146	Positive pressure relief valve
147	Negative pressure relief valve
148	Reserve H <sub>2</sub> O tank
150	CWS
151	Electrical power harness
152	Electrical signal harness
153	C & W harness
156	RTDS harness
171	Coolant isolation valve
172	Coolant relief valve
200	SOP
210	SOP oxygen bottle

213	SOP pressure control module
213 B	SOP oxygen pressure regulator
213 D	SOP second stage regulator
213 E	SOP pressure gauge
213 F	SOP fill valve assembly
213 G	SOP interstage gauge
215	SOP pressure transducer
300	DCM
311	Suit pressure gauge
314	DCM purge valve
321	Temperature control valve
330	Common multiple connector
350	Electronics assembly
360	Volume control
361	Display intensity control
491	Bends treatment adapter (BTA)
492	BTA pressure gauge
493	BTA pressure relief valve

**APPENDIX C    EMU CONSUMABLES APPLICATION USER'S GUIDE**  
**APPLICATION CALCULATIONS – PC VERSION**  
**USERS GUIDE & REQUIREMENTS**

Current Versions:

RTDS Version 6.0	3/06/2001
STAT Version 3.0	9/29/1997
Consumables (Dec Alpha Xess app)	3/15/2005
Automated Consumables (Dec Alpha app)	TBS

The official EMU PC Consumable Application files (2 files and User's Guide) are located on the MOD server at:

S:\Divisions\DX\Eva\System\EMU Consumable Applications\PC Version

The EMU Consumables application is resident on the MCC-H workstations, accessible from the EVA DNAV menu.



**APPLICATION CHANGE RECORD**

**EMU Consumables Applications – PC VERSION**

Any changes to these files must be coordinated with DX35/P. Boehm

DATE	VERSION AFFECTED	AUTHOR	DETAILED CHANGE	FLIGHT EFFECTIVITY
02/08/97	RTDSver2.xls STATver1.xls	P. Boehm	Baseline Spreadsheets	STS-82 and subs
09/19/97	RTDSver3.xls STATver2.xls	P. Boehm	1) Changed calculation of Power per update instead of average amps 2) Updated/Added LiOH calculations based on O2 Tank Pressure 3) Updated User's Guide file	STS-86 and subs
09/29/97	RTDSver4.xls STATver3.xls	P. Boehm	Added ability for holding on SCU during EVA 1) Changed Time EV calculation on Details page to be delta time from PWR-SCU while holding 2) Updated User's Guide file	STS-87 and subs
4/18/00	RTDS Version 5.0	P. Boehm	➤ Incorporated changes per Hamilton Sundstrand EMUM 0404 "Consumable Tracking During EVA" 3/15/00 <ul style="list-style-type: none"> <li>➤ RQ value standard at 0.87</li> <li>➤ O2 Tank temp standard at 60 F</li> <li>➤ Created Initial Battery Capacity Calculations for multiple EVAs</li> <li>➤ Created CCC Btus 30 minute reserve cut-off (2700 Btus)</li> <li>➤ Set P/B met rate to standard 400 Btu/hr</li> <li>➤ Created Latest EVA PET redline times for start of EVA Clean-up</li> </ul> 2) Updated User's Guide and Change Log	STS-101 and subs
4/26/00	RTDS Version 5.0a	P. Boehm	1) Corrected problems with RTDS Version 5.0 per verification 2) Updated User's Guide and Change Log 3) Added highlight for lowest EVA PET value	STS-101 and subs
5/18/00	N/A	P. Boehm	1) Updated User's Guide with STS-96 water data and corrected Flight Data book BTU calculation error	

DATE	VERSION AFFECTED	AUTHOR	DETAILED CHANGE	FLIGHT EFFECTIVITY
3/06/01	RTDS Version 6.xls	P. Boehm	1) Incorporated changes: <ul style="list-style-type: none"> <li>➤ Changed 2700 BTU LiOH reduction (30 min resrv) to 1500 BTUs per EC/MOD agreement</li> <li>➤ Added additional rows on Details sheet for 8hr EVA</li> <li>➤ Added O2 limit of 150 psi for recharge to O2 Time Left calculations per MOD/XA/EC agreement</li> <li>➤ Added variable CWS Battery capacity for two part EVA, and corrected CWS %PWR and Time left calculations</li> <li>➤ Revised Initial Data sheet for two part EVA</li> <li>➤ Added SCU time into EVA PET calculations on Updates sheet for two part EVA</li> <li>➤ Deleted sheets for equations and notes, already covered in other sheets</li> </ul> 2) Updated User's Guide and change log	STS-102 and subs
8/16/01	N/A	L. Shore	1) Updated User's Guide with METOX and ICB data per Hamilton Sundstrand EMUM#0598. 2) Incorporated data from STS-104, the first EVA to use METOX and the first out of the ISS Joint Airlock	STS-108/UF-1 and subs
6/09/06	Dec Alpha Xess Application for RTDS Version 6.0	L. Shore	1. Added section 4.0 to incorporate EMU Consumables Spreadsheet for DEC Alpha Workstation Ops Note 2. Added Section 2.2 to document Initial Data Input values 3. Removed references to Yardney battery	STS-114 and subs

## **Introduction**

The Excel Spreadsheet applications are for calculating estimates for Time Left of EMU consumables during an EVA.

The actual downlink RTDS data (Battery Volts, CO2, O2 P) will always have priority when making decisions on EMU consumables if a conflict occurs with the application calculation.

### **STAT VerX.xls File**

This file is designed to be used when no ground data is available and we are relying on EV crew hourly short status of TIME EV, percent PWR, percent O2, TIME LF as inputs to the file.

### **RTDS Version X.xls File**

This file is designed to be used when ground data is available. Inputs for this file are the RTDS TIME EV, Primary O2 Pressure, and Battery Amps.

## **Using the Spreadsheets**

1. Each file (workbook) contains several "sheets" which include:
  - (a) Initial Data Inputs - This sheet contains items from the USA Flight Data Book (Battery, CCC, Water) and at the beginning of the EVA (O2 P, Prebreathe time, EVA Sortie Clean-up time, PWR - SCU, etc).
  - (b) Updates - These are the inputs from the crew call down or RTDS data. This sheet also contains a summary of the Time Left for easy reference without having to flip sheets.
  - (c) Details - This sheet contains the actual consumable calculations
2. The data must be entered in the format specified (i.e. hh:mm) next to the item. (e.g. Time EV is 0:10 or 1:10, not 10 or 70 or 1,10)
3. Times greater than 24 hours will be truncated internally and only the hours and minutes beyond 24 hours will be used in the calculations (i.e. 27:05 will be computed as 03:05)
4. Each row must contain the appropriate equations before entering inputs/updates. Rows can be filled by highlighting the entire row containing the appropriate equations, then holding on the fill series handle on the bottom right of the last block, drag down the sheet to fill the rows in series. This method can be used to fill more rows for additional data inputs.

5. Rows with equations that must be filled are on the "Updates" and "Details" sheets.
6. The Calculated Times on the "Initial Data" sheet are for reference and are not used in any other calculation.
7. The files are write protected (password "emu"), **you must save your data as another file name. Do not change any of the original files** without first contacting DX35/P. Boehm for background rationale about the equations.
8. Equation word notes are included in the cells with **red triangles** in the upper right corner on the spreadsheets. To view the note, just place the cursor over the cell.

### Initial data input GUIDELINES

The following parameters must be entered into the Initial Data Inputs page.

1. Initial EVA O2 P (psi) = Starting Primary O2 pressure (psi)  
Value of primary O2 pressure at SCU disconnect.
2. Scheduled Length of EVA Sortie Clean-up/Ingress (hh:mm) = length of time it will take to the crew to clean-up and ingress the airlock. Set this time to 00:00 if you want the spreadsheet to calculate the time until SCU connect.
3. CCC Capacity (BTUs) = Actual CCC BTU capacity (BTUs)  
Values obtained from the EMU Flight Data book.
4. With 30 minute reserve (1500 Btu) = the number of BTUs that should be subtracted from the capacity to provide 30 minutes of reserve. Use LiOH = 1500 BTUs, METOX = 600 BTUs.
5. Flight Data Book Battery Capacity (amp-hrs) = Battery Amp-hr capacity (Amp-hrs)  
If battery just launched and was charged on the ground, value is obtained from the EMU Flight Data book. If battery has been maintained on-orbit and the capacity as determined from the last maintenance or charge is greater than 32.0 Ah then the initial charge of the ICB is assumed to be 32.0 Ah for the first 20 recharge cycles of a battery. The actual capacity is 45 – 50 Ah in the first few cycles and gradually decreases until it is just above 32.0 Ah at 21 cycles. For battery cycles 21 – 32, the initial charge must be derated by .543 Ah per cycle.
6. Previous EVA Capacity (amp-hrs) = Set to zero. Not needed for ICB with > 32 Ah
7. Previous EVA Usage (amp-hrs) = Set to zero. Not needed for ICB with > 32 Ah

8. Current EVA Capacity (amp-hrs) = For ICB with > 32 Ah = 32.0 (override calculated value)
9. Non-EVA CCC usage time (hh:mm) = Time use of CCC for prebreathe, depress, and SCU (minutes)  
Length of time from Fan-ON to SCU disconnect - purge time
10. Usable water (lb) = Usable water (lbs)  
Value is 7.35 lbs and typically should not need to be changed. Total tank Qty (prime + reserve) = 9.18 lbs, 9.18 lb - 1 lb ullage - 0.83 lb reserv = 7.35 lb
11. Primary O2 Tank Temperature (deg F) = Standard used is 60 deg F (per EMUM 0404) and should not need to be changed
12. Respiratory Quotient = Standard used is 0.87 (per EMUM 0404)
13. BTU / lb O2 (calculated) = Calculated from RQ (do not enter a value)

Note: This gives  $582.66 \times \text{O}_2 \text{ Use Rate (psi/min)} = \text{BTU/hr}$

### **Performing a Two Part EVA**

If the EV crew returns to the airlock to hold on SCU and then returns to complete the EVA (part 2), the following must be done to continue use of the spreadsheets:

1. Save the current file
2. Create a new file for "Part 2" of the EVA
3. Complete the following table for "new" *Initial Data* values based on the remains from "Part 1" of the EVA

New initial item	How calculated	New Value
Initial EVA O2 P (psi)	Refilled tank pressure =	
Scheduled Length of EVA Sortie Clean-up/Ingress (hh:mm)	As required =	
CCC Capacity (BTUs)	CCC Capacity Part 1 – Total BTUs Consumed with P/B Part 1 =	
Current EVA Capacity (amp-hrs) (actual)	Current EVA Capacity Part1 – Total Pwr Used Part 1 = ENTER VALUE MANUALLY IN THE <i>Current EVA Capacity</i> location	
Non-EVA CCC usage time (hh:mm)	Time holding on SCU between Part 1 and Part 2 = This must be entered so that the EVA PET times will be correct on the <i>UPDATES</i> sheet	
Usable Water (lb)	IF LiOH 7.35 – (Part 1 Time EV x 0.8 lb/hr) = IF METOX 7.35 – (Part 1 Time EV x 1.0 lb/hr) =	
TIME EV	TIME EV last data pass (EMU Data Page 1) before going on SCU power =	
CWS Battery Capacity	IF Increased Capacity Battery (ICB) 32.0* – Total Pwr Used Part 1 *if ICB has >20 recharge cycles then IC = 32.0 – (0.543 x # cycles)	

At this point you are ready to continue entering updates with the nominal format.

TIME EV will be continued from when EMUs went to SCU (i.e. first data pass after PWR-BATT). The TIME EV from the EMU will not reset unless a cold restart is performed. It holds at the last time shown when power is taken to SCU and will start counting again when power is taken back to battery.

For a quick sanity check on the Part 2 worksheet:

New O2 EVA PET cleanup = Part 1 cleanup EVA PET + hold time + Part 1 EV time.

New Batt EVA PET cleanup = Part 1 cleanup EVA PET + hold time

New CCC EVA PET cleanup = Part 1 cleanup EVA PET (due to lower Met Rate on SCU)

### **Consumable Calculation Requirements**

#### **STATverX.xls**

Due to the potential time lapse between data, total averages are used for rates.

#### **RTDS Version X.xls**

Due to the rapid changes in O2 USE RATE, an average of the last ten data inputs is used to calculate O2 TIME LF and CCC Time Left. Battery Use Rate is a summation of all inputs.

The Oxygen, Battery, and LiOH ending points are based on a REDLINE with respect to when EVA Sortie Clean-up would need to start in order to protect (by Flight Rule) having a 30 minute reserve of each consumable when SCU connection is made after airlock ingress.

### **O2 Calculations**

The consumption of O2 by the crewmember varies greatly depending on the amount of work the EV crew is doing. O2 TIME LF from the EMU can vary between data passes as great as one or two hours different. Due to this often rapid and constantly changing consumable, an average of the last 10 use rates is used to determine the O2 TIME LF in the spreadsheet. Per agreement with EC/XA/MOD in November 2000, we will use a Primary O2 pressure of 150 psi as the required time for an O2 recharge. This protects the 30 minute reserve of O2 at SCU connection required by the Flight rules. The O2 equation now includes the 150 psi value as the lower O2 P instead of the 75 psi value used by the CWS.

**REDLINE:** The latest O2 EVA PET for EVA Cleanup = [Current O2 P – 150 – {Cleanup time} x 10 Avg Use Rate] / 10 Average Use Rate

OR

**REDLINE:** Primary O2 P = 150 psi must recharge O2

### **Battery Power Calculations**

Calculation of power time left by the EMU flight controller is critical in determining the *actual* battery power time left as opposed to the CWS power time left (based on 26.6 amp-hrs). The actual PWR Time Left can be calculated by

Actual PWR TIME LF = (Actual Amp-hrs Remaining) / Amps

The application begins by calculating:

- (1) Total Amp-hr Used = (Current Time EV-Last Time EV) x Amps +  
SUM (previous Amp-hr Used)

Equation (1) is used instead of the straight forward:

- (2) Total Amp-hr Used = Average Amps x Total Time EV

since it will not quickly reflect a decrease in amp usage (i.e. due to LCVG Bypass or other amp decrease) and therefore give an Amp-hr used value higher than actual. The table below illustrates this for the case of EMU1 on STS-82 EVA#5 when a decrease in amps occurred near the end of the EVA.

Time EV	Amps(RTDS)	Amp*Hr Used (delta)	Total Amp*Hr Used (Eq 1)	Total Amp*Hr Used (Eq 2)
2:53	3.14	0.104667	9.095667	9.098839
2:55	3.13	0.104333	9.2	9.202801
2:57	3.14	0.104667	9.304667	9.30725
3:01	3.14	0.209333	9.514	9.516865
3:03	3.14	0.104667	9.618667	9.62132
3:09	3.14	0.314	<b>9.932667</b>	<b>9.936069</b>
3:17	2.99	0.398667	10.33133	10.34847
3:25	2.85	0.38	10.71133	10.75332
3:29	2.85	0.19	10.90133	10.94791
3:35	2.85	0.285	11.18633	11.24699
3:47	2.87	0.574	11.76033	11.86021
3:53	2.88	0.288	12.04833	12.15976
4:01	2.88	0.384	<b>12.43233</b>	<b>12.56324</b>

Equations (1) and (2) are the same for a relatively stable amp value ~3.13 throughout the EVA until Time EV = 3:09, At this point, the averaged value (Eq. 2) does not track the drop in amps as rapidly as the addition method (Eq. 1). This is a difference of 2.7 minutes in TIME LF(at 2.88 amps) at this point. An increase in amps is also tracked faster.

Once the Amp-hr used is determined, the actual Amp-hr remaining can be determined.

First the actual capacity of the battery must be determined. For a battery that was just launched and last serviced on the ground, look up the battery capacity in the USA Flight Data Book value per EMUM 0404. For batteries that have been charged on-orbit, reference the EVA Systems Logistics Spreadsheet that is maintained on the V: Drive

For Increased Capacity Batteries (ICB):

If the USA Flight Data Book (Red Book) shows battery capacity to be greater than 32.0 Ah, or the capacity as determined from the last maintenance or charge is greater than 32.0 Ah then the initial charge of the ICB is assumed to be 32.0 Ah for the first 20 recharge cycles of a battery. The actual capacity is 45 – 50 Ah in the first few cycles and gradually decreases until it is just above 32.0 Ah at 21 cycles. For battery cycles 21 – 32, the initial charge must be de-rated by 0.543 Ah per cycle.

Initial Charge = 32.0 Ah - 0.543 Ah x Num. Recharge cycles

Note: This de-rating value assumes full, uninterrupted charges. For interrupted or incomplete charges the battery capacity will be less and may not be known.



Subtracting the Total Used amp-hr from the Initial Capacity gives the remaining capacity. The time for EVA sortie cleanup and 30 minute reserve (i.e. time to 16.0 volts) are multiplied by the average of the last two current amps readings to determine amp-hrs to be subtracted from the remaining capacity. Dividing by the current amps gives the latest EVA PET time to begin cleanup.

**REDLINE:** Latest Actual PWR EVA PET to start Cleanup = [Initial Batt Capacity – Total Used – {(Cleanup time + 30 min) x avg amps} ] / Current Amps

The Flight Data Book capacity is the capacity to discharge the battery to 16.0 volts, which is considered as a fully discharged battery. The discharge voltage curves in the USA Flight Data Book are measured at the battery terminal (per USA/C. Thorp) and therefore do not reflect the line loss in the EMU to the DCM sensor. Per Hamilton Standard EMUM 0404 and HSWL/V. Margiott, the max resistance is 0.06 ohms resulting in a max line loss of ~ 0.2 volts. Per the EMUM, based on 25 of these discharge curves, the time from 16.5 volts to 16.0 volts was ~ 30 minutes. Therefore it has been decided to use 16.4 volts (with 0.1 volt conservative) as the voltage level for 30 minutes remaining.

**REDLINE:** Battery voltage in EMU of 16.4 = 30 minutes until 16.0 volts (This is actually the reserve margin required per Flight Rules, therefore this level should be reached only when the SCU is being connected)

It should be noted that the voltage sensor has an error range of +/- 0.6 volts per EVA Console Handbook

Note: The above calculations were performed for the Yardney battery which is no longer flown.

### **CCC (METOX and LiOH) Calculations**

The time left of the CCC (LiOH or METOX) is calculated by first determining the total BTUs consumed (from delta O<sub>2</sub> pressure) and then dividing the remaining BTU capacity by the BTU/Hr use rate. Since the BTU/Hr use rate is dependent on the O<sub>2</sub> Use Rate (which can vary rapidly), the average of 10 O<sub>2</sub> use rates is used when determining the BTU/Hr rate for CCC time remaining. The total time EV along with the total delta pressure in O<sub>2</sub> (from start of EVA) is used to determine the EVA AVG Met Rate.

BTUs consumed is determined by first calculating the mass of O<sub>2</sub> consumed (lbs) per the  $PV=mRT$  equation for the primary O<sub>2</sub> tanks, then multiplying by the conversion factor of BTUs/lb O<sub>2</sub>

For the mass of O<sub>2</sub>

Initial conditions and assumptions:

T = Primary O<sub>2</sub> Tank Temp (F°) = *Initial Data Inputs* sheet = 60 F°

V = Primary O<sub>2</sub> Tank Volume = 480 in<sup>3</sup>

R<sub>u</sub> = Universal Gas Constant = 1546 ft-lb/lb•mol R°

m = Molecular Weight of O<sub>2</sub> = 32 lb/lb•mol

R = O<sub>2</sub> Gas Constant = R<sub>u</sub> / m

$$m = PV / R T$$

$$\text{lb O}_2 = \frac{[ (\Delta\text{O}_2 \text{ P lb/in}^2) \times (144 \text{ in}^2/\text{ft}^2) ] \times (32 \text{ lb/lb}\cdot\text{mol}) \times [ (480\text{in}^3) / (1728 \text{ in}^3/\text{ft}^3) ]}{[ (1546 \text{ ft-lb/lb}\cdot\text{mol R}^\circ) \times (60 \text{ F}^\circ + 460 \text{ R}^\circ) ]}$$

$$(a) \quad \text{lb O}_2 = (\Delta\text{O}_2 \text{ P lb/in}^2) \times 0.001592198$$

to determine a use rate: lb O<sub>2</sub> / hr = (ΔO<sub>2</sub> psi/min) x 60 min/hr x 0. 0.00159219

$$(b) \quad \text{lb O}_2 / \text{hr} = (\Delta\text{O}_2 \text{ psi/min}) \times 0.0955318$$

It should be noted that the O<sub>2</sub> tank temperature used (60) would be fairly close to the observed external airlock temperatures from STS-82 and other flights. The external airlock was noted to be 10 degrees F cooler than the middeck during STS-82 EMU C/O. The EMUs in the airlock recorded an ambient H<sub>2</sub>O temperature of 62 degrees, while the middeck stowed EMU recorded an ambient H<sub>2</sub>O temperature of 72 degrees. Per EMUM 0404, the standard temperature used will be 60 deg F.

The BTU/lb O<sub>2</sub> conversion

Per data obtained from Hamilton Standard Maria Keilich, she references Hamilton Standard Internal Memo Sept. 30, 1988 ANL 88-333 *O<sub>2</sub> Consumption and CO<sub>2</sub> Production in the Shuttle EMU* which provides the following equation:

$$\text{lb O}_2 / \text{BTU} = (0.1708\text{E-}3 - (\text{RQ} - 0.707) \times (0.123\text{E-}4 / 0.293))$$

Where RQ = Respiratory Quotient

The RQ value is actual dependent on the crewmember's diet. A carbohydrate diet yields a higher RQ =1.0 while a fat diet yields RQ=0.7. The SVHS 7800 Hamilton Standard document uses 0.9 for RQ. The referenced memo indicates an EMU standard of 0.881 while Hamilton Standard at JSC uses 0.87. Reference also *Bioastronautics Data Book, 2<sup>nd</sup> Ed. NASA 1973*. Per Hamilton EMUM 0404, the standard the community will use is 0.87. This gives:

$$\text{lb O}_2 / \text{BTU} = (0.1708\text{E-}3 - (\text{RQ} - 0.707) \times (0.123\text{E-}4 / 0.293)) = 0.0001639573$$

$$0.1639573 \text{ lb O}_2 / 1000 \text{ BTU}$$

$$(c) \quad \text{BTU} / \text{lb O}_2 = 6099.148$$

Using Eqs (a) and (c) above, the BTUs consumed can be calculated from the O<sub>2</sub> tank pressure delta:

$$\text{BTU consumed} = \text{lb O}_2 \times \text{BTU} / \text{lb O}_2$$

The Metabolic rate is also calculated from the O<sub>2</sub> tank pressure decrease in psi/min. Using Eqs (b) and (c) we can obtain the metabolic rate:

$$\text{Met Rate (BTU/hr)} = (\text{lb O}_2/\text{hr}) \times \text{BTU} / \text{lb O}_2$$

or the more commonly known

$$\text{Met Rate (BTU/hr)} = 582.66 \times (\text{O}_2 \text{ rate psi/min})$$

from which the remaining CCC capacity in BTUs can be determined and thus the CCC time left can be calculated:

$$\text{CCC Time Left} = \text{BTUs remaining} / \text{Met Rate (10 Average)}$$

**METOX Initial Capacity Calculation:**

Start with 8000 BTUs which equates to approximately 1.6 lbs CO<sub>2</sub> absorption. Subtract off 600 BTUs to protect a 30 minute margin (30 min @ 1200 BTU/hr ref. EMUM1-0598). The basis for 1.6 lbs is the acceptance test data from every canister, which has been at 1.8 lbs and the consistent capacity of the cans over the 55 cycle life.

The limit for METOX to get on the SCU is 2.0 mmHg with rising trend. METOX breakthrough curves for both ISS and STS profiles indicate that it is approximately 20 – 30 minutes between 2.0 to 3.0 mmHg CWS alert. It is another 20 – 40 minutes between the CWS alert at 3.0 mmHg and CWS warning at 8.0 mmHg. Both assume ~850 BTU/hr.

Without preconditioning the Metox canister, there is not enough water to promote CO<sub>2</sub> absorption. This can cause an initial spike or rise in PP CO<sub>2</sub> and has been seen in several chamber tests.

**For METOX real-time determination:**

- A. The calculation shall be used when the CO<sub>2</sub> sensor reading is less than 2.0 mmHg. If the EVA PET clean-up calculation end is reached BEFORE the CO<sub>2</sub> reaches the 2.0 mmHg indicated, then the EV crewmember should begin clean-up without delay – since the slope of CO<sub>2</sub> increase is now more likely to be greater.

B. If the CO2 sensor increases above 2.0 mmHg and continues rising BEFORE the EVA PET Clean-up time calculation expires, monitoring of the CO2 level will determine when clean-up should occur. At a CO2 value of 2.0 mmHg the affected crewmember should begin back to the airlock to connect to the SCU.

**REDLINE:** Latest EVA PET CCC Time to start Cleanup = (30 min CCC Capacity - Total BTUs Consumed - EVA Cleanup BTUs) / 10 AVG Met Rate reached BEFORE CO2 sensor is reading 2.0 mmHg.

OR

**REDLINE:** CO2 sensor reading 2.0 mmHg and rising trend BEFORE calculation. Monitoring of CO2 beginning at 1.7 mmHg will determine real-time when clean-up should commence. Action should begin at 2.0 mm Hg with a rising trend.

LiOH Initial Capacity Calculation:

Per EMUM 0404 and HSWL/V. Margiott, the following values were derived using canned man LiOH breakthrough curves and the calibration of the CO2 sensor at 8.0 psi:

<b>Actual CO2</b>	<b>IR CO2 reading</b>	<b>CWS Message</b>
1.5 mmHg	1.7 mmHg	
5.6 mmHg	3.0 mmHg	MONITOR CO2
13.0 mmHg	8.0 mmHg	CO2 HIGH/OPEN PURGE VLV

CCC Capacity (in BTUs) is listed in the USA Flight Data Book. These values are derived from the amount of LiOH packaged in the container. The equations for the conversion were provided by HSWL/V. Margiott on 4-20-00:

$$\begin{aligned} \text{CO2 removal capability (lbs)} &= \text{LiOH Qty (g)} \times (\text{lb}/453.593\text{g}) \times (\text{mol LiOH}/23.94 \text{ lb}) \times \\ \text{at 85\% efficiency} & \quad (\text{mol CO2}/2 \text{ mol LiOH}) \times (44.01 \text{ lb CO2}/\text{mol CO2}) \times 0.85 \\ &= \text{LiOH Qty (g)} \times 0.001722463 \end{aligned}$$

$$\begin{aligned} \text{Metabolic Capacity (Btus)} &= [ \text{LiOH Qty (g)} \times (\text{lb}/453.593\text{g}) \times (6099.15 \text{ Btu}/\text{lb O2}) \times \text{at} \\ \text{85\% efficiency} & \quad (32 \text{ lb O2}/\text{mol O2}) ] / [ \text{RQ} / 47.88 \text{ lb}/\text{LiOH}/\text{mol O2} ] \times 0.85 \\ &= \text{LiOH Qty (g)} \times 8.780065751 \end{aligned}$$

It should be noted that the LiOH performance depends on the temperature environment. For a Hot/Neutral environment, the BTU capacity is multiplied by 0.85 for efficiency of the reaction conversion. For a cold environment (< -75 deg F) than the BTU capacity is multiplied by 0.70. The USA Flight Data Book provides the 85% capacity number for BTUs. This is the value used as our initial condition in the spreadsheet. The full Btu capacity is the point of 15.0 mmHg actual in the EMU. LiOH performance also depends

on conditioning of the LiOH with moisture during prebreathe. A longer prebreathe provides greater Btu capacity. During a SESL run in April 2000, a LiOH was installed only 24 minutes prior to depress. The crewmember also had a very high metabolic rate during prebreathe (~600 Btu/hr) and the run (~1200). The crewmember received several MONITOR CO2 messages. It is suspected that the high met rate (producing heat) and the short duration before lower pressure (retaining heat in the CCC) did not provide enough moisture for the intermediate reaction to fully convert. A Post-run evaluation of the LiOH revealed conversion rates of only 50-60%.

The quantity for 1.5 mmHg actual to 15.0 mmHg actual was initially decided to be 2700 BTUs based on 1000 Btu/hr met rate for 2.7 hours. This was the worst case Btu quantity for the breakthrough curves available. Other curves showed per HSWL/V. Margiott:

“Most of the data came from canned manned testing where there is a met rate profile which ends with "continue at 1000 BTU/HR until 15 mmHG CO2 is reached. The system is a function of met rate. The worst case was 2700 Btu which was 2.7 hours at 1000 Btu/Hr. I had data points where 15 minutes at 2000 + 1 hour at 1500 + 1/2 hour at 800 = 2400 Btu. Another was 15 min at 1600 + 15 min at 1000+ 30 min at 400 + 30 min at 800 + 1.25 hrs at 1000 = 2320 Btu. LiOH capacity and breakthrough is a function of many things such as water loading and met rate. The data I had was variable - sometimes there would be 1500 Btus however, seventy percent of the data points were above 2000 Btus.”

Discussions in late 2000 and early 2001 between EC/MOD have agreed now upon a less conservative 1500 Btus to be deducted from the CCC Capacity since the 2700 value was making LiOH a limiting consumable and did not reflect real experience with the CCCs.

Further review of the breakthrough curves, indicates that for the 1500 Btu case (1000 Btu/hr @1.5 hr), the 30 minute reserve can be accomplished with a CO2 value of 2.0 mmHg worst case (i.e. 30 minutes from 2.0 to 3.0 mmHg sensor reading on that curve).

For use on console, it has been agreed to use the CO2 reading (sensor) of 1.7 mmHg and steady/rising as the point at which action would need to be taken in order to provide slightly more time for crew response to be on SCU at 2.0 mmHg. Monitoring of the CO2 will begin at 1.5 mmHg to determine rates for the increase and time remaining estimate.

#### **For real-time LiOH determination**

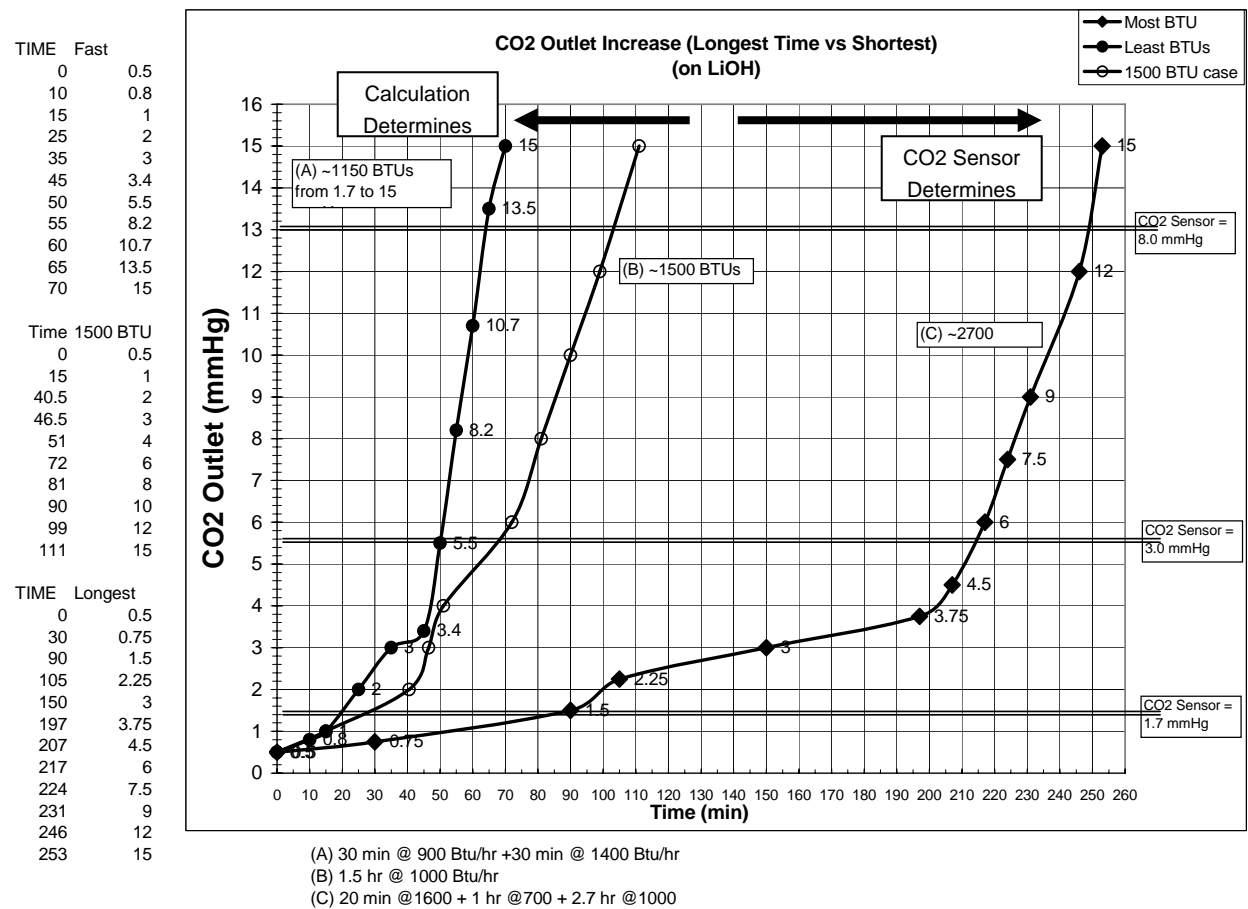
- A. The calculation shall be used when the CO2 sensor reading is less than 1.7 mmHg. If the EVA PET clean-up calculation end is reached BEFORE the CO2 reaches the 1.7 mmHg indicated, then the EV crewmember should begin clean-up without delay – since the slope of CO2 increase is now more likely to be greater.
- B. If the CO2 sensor increases above 1.7 mmHg BEFORE the EVA PET clean-up time calculation expires, monitoring of the CO2 level will determine when clean-up should occur. At a CO2 value of 2.0 mmHg the affected crewmember should be

connecting to the SCU. This monitoring is due to the fact that the slope of the CO2 increase will likely be less and therefore there will be more time than 30 minutes between 2.0 and 3.0 mmHg.

**REDLINE:** Latest EVA PET CCC Time to start Cleanup = (30 min CCC Capacity - Total BTUs Consumed - EVA Cleanup BTUs) / 10 AVG Met Rate reached BEFORE CO2 sensor is reading 2.0 mmHg.

OR

**REDLINE:** CO2 sensor reading 2.0 mmHg BEFORE calculation will be on SCU. Monitoring of CO2 beginning at 1.5 mmHg will determine real-time when clean-up should commence. Action should begin at 1.7 mm Hg



**Figure C-1. CO2 outlet increase**

Figure C-1 shows the shortest time rise (1150 Btus case), 1500 Btus case, and longest time rise (2700 Btus) all on the same plot. As a reminder, about 70 percent of the

curves fall to the right of a 2000 Btu curve (to the right of the 1500 curve shown). Therefore, most increases will be gradual, and the calculation protects for the sharp increase (1500 Btu or less) to the left.

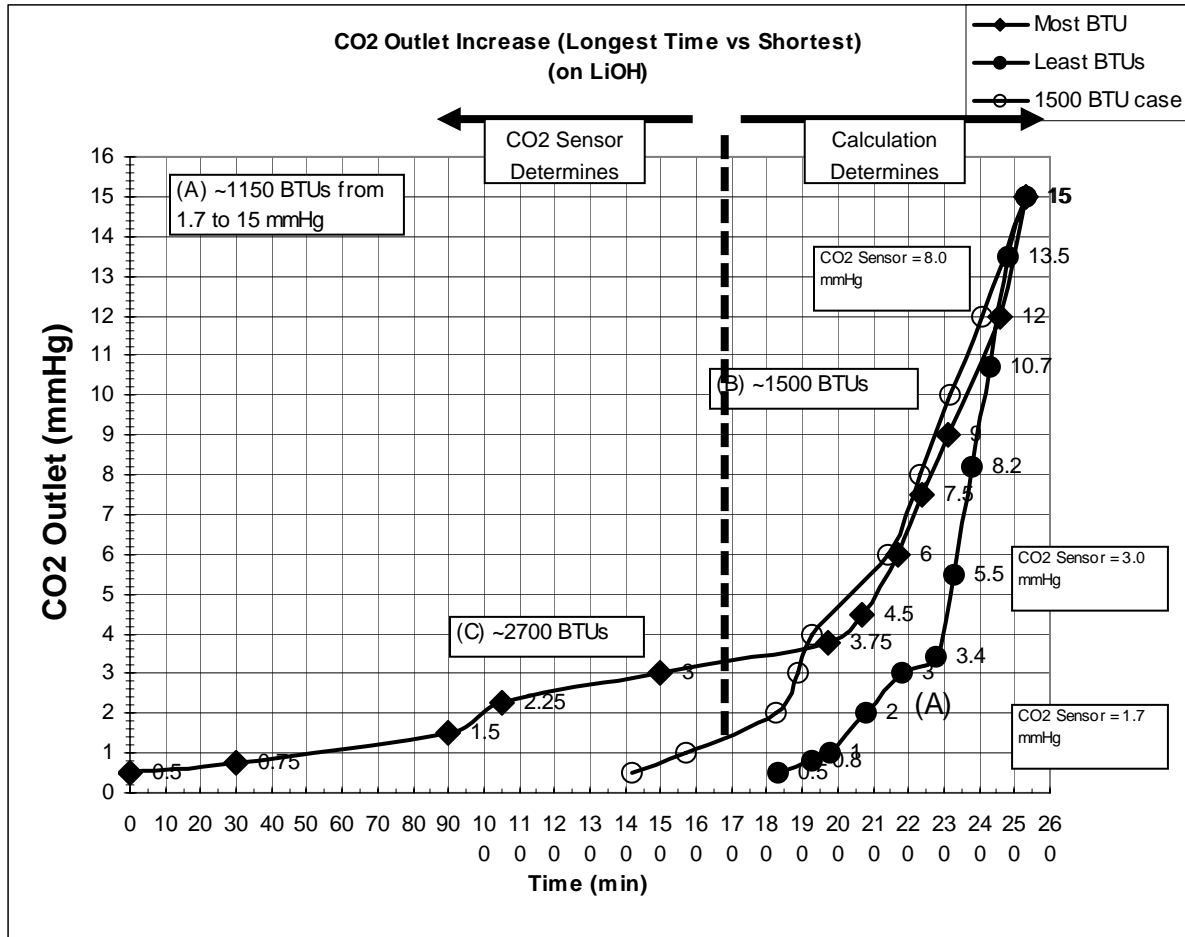


Figure C-2. CO2 outlet increase

**Water Usage Calculations**

There is no insight into the water usage rate during an EVA. For LiOH based EVAs, a rate of 0.8 lb/hr is assumed as a conservative rate. For a METOX based EVA, this rate increases to 1.0 lb/hr as a realistic usage rate.

Rates for the 5 EVAs for STS-82 and the 3 EVAs for STS-104 based on the refill quantity are shown below for reference.

STS-82

EV A	EVA Tim	Met Rate	TK C Qty	H <sub>2</sub> O lb refill	H <sub>2</sub> O lb refill (per EMU,	Usage Rate	% Used of primary

	e	(Avg)	(%)	(2 EMUs)	w/ 1lb ullage)	(lb/hr)	tanks (7.47 lbs)
1	6:42	758/800	5.2	8.666	3.407	0.508	45.6
2	7:27	760/800	5.1	8.5	3.324	0.443	44.5
3	7:11	732/782	5.6	9.333	3.74	0.521	50.1
4	6:34	743/690	4.6	7.666	2.907	0.447	38.9
5	5:17	751/695	3.3	5.5	1.824	0.345	24.4

STS-104

EV A	EVA Time	Met Rate (Avg)	TK C Qty (%)	H <sub>2</sub> O lb refill (2 EMUs)	H <sub>2</sub> O lb refill (per EMU, w/ ullage)	Usage Rate (lb/hr)	% Used of primary tanks (7.47 lbs)
1	5:59	??/?	4.6	7.6	2.8	0.468	37.3
2	6:29	744/668	4.4	7.25	2.6	0.401	34.7
3*	3:55	957/797	N/A	12.8	3.9	0.996	52.0

\* EVA 3 was the first out of the ISS Joint Airlock and the first to use METOX

During water dump after fill, a dump rate of 0.9257 lb/min was used in the above table based on data of 420 cc/min from the STS-82 V1103.01 (Airlock Functional) test. Data during STS-104 indicates 1.0 lb/min dump also for Joint Airlock.

Since we did not perform a feedwater recharge on-orbit on STS-96, we had a rare occasion to find out the actual water used during the EVA. Using the pre-flight water charge data and the post-flight water drain performed at USA FCE/EVA, the actual water usage was: 2.69 lb for EV1 (on RMS) and 5.43 lb for EV2 (free-floater).

The average metabolic rate for EV1 was approx. 615 BTU/Hr and the average metabolic rate for EV2 was approx. 875 BTU/Hr.



## Deltas for manual entry of DATA on the DEC alpha workstations

### **EMU Consumables Spreadsheet for DEC Alpha Workstation Ops Note RTDS Version 6.0, March 6, 2001**

The following is a quick user's guide which is in addition to the standard Consumables spreadsheet User's guide. This outlines deltas required for use of the workstation version.

- The spreadsheet uses the application "Xess"
- Start the Spreadsheet by using the DNAV (ISS or Shuttle) menu item "EMU Consumables Xess"
- This will open the RTDS\_Version\_6.xls file
- Manually enter data just as normal with the following exceptions:

ALL **time** entries must be entered in the format /00:00 - with the slash included in front.

- Lock the Titles on the updates page so you can still see them as you scroll down the window
- Make sure the upper left most corner of the display is visible. (i.e. you can see column A and row 1)
- Click on row 1, hold the shift key down and click on row 5 (they should now be highlighted)
- Go to the VIEW menu at the top of the page and select "Lock View Titles"

### **Display Issue**

Sometimes cells may appear corrupted, just minimize window and then max again, appears to be a display only problem

For Printing

**DO NOT** CLICK ON THE PRINTER ICON. This will lock up the application. You will have to call WSS to get the application process killed.

YOU MUST HIGHLIGHT what you want to print FIRST, then you can click the printer icon to print the highlighted area. Note that shaded areas will print as black.

For Saving file

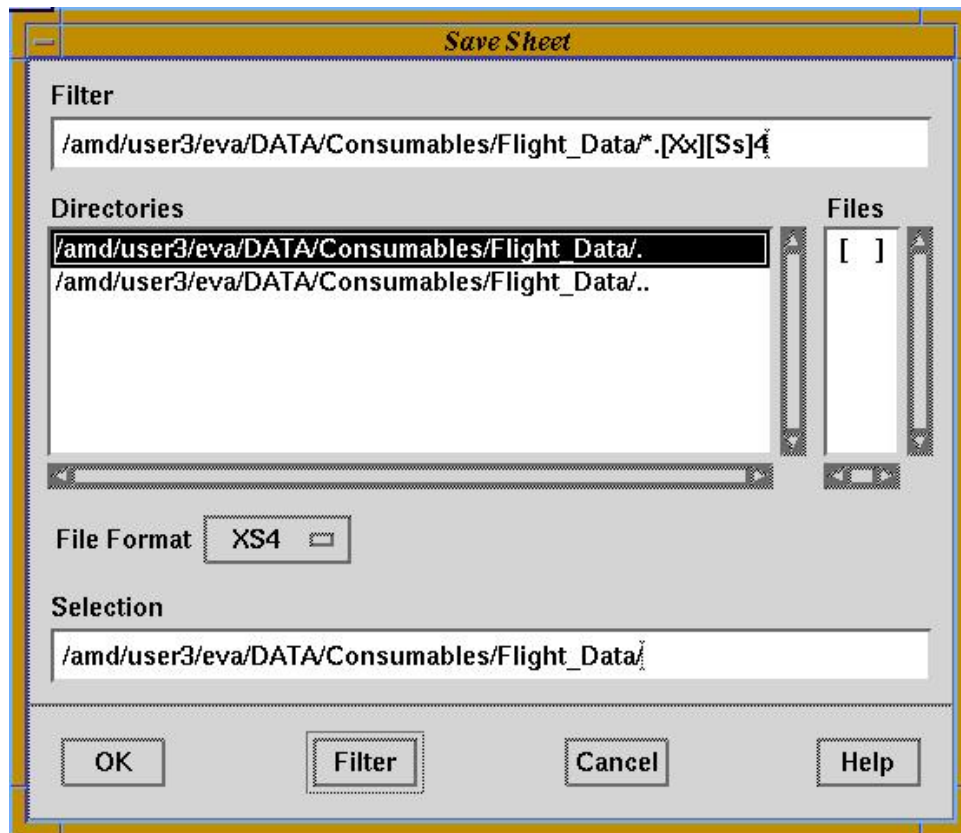
The original opened file can not be saved, you will have to save as another named file.

Save your file to the following directory shown below

Use the Flight ID and EVA # as part of the file name (i.e. STS\_XXX\_EVA\_X)

Constraint Checking (not currently enabled)

- If you have constraints in your equations to show the most limiting consumable then you need to make sure that constraint checking is turned on.
  - Under the Options menu, select Recalc Options
  - Make sure Constraint Checking is checked
  - The colors of the constraints are controlled by the Highlight Options



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