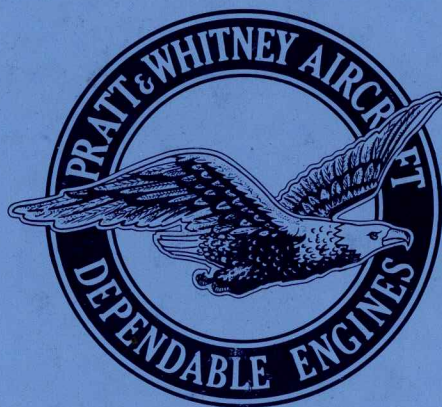


Carroll

Apollo Fuel Cell Powerplant
POWERCEL® Model PC3A-2

Component Descriptions



Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION

U
A

EAST HARTFORD, CONNECTICUT

R. F. Plumley
#57

Apollo Fuel Cell Powerplant
POWERCEL® Model PC3A-2

Component Descriptions



For Internal Use Only

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION



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INTRODUCTION

The Pratt & Whitney Aircraft PC3A-2 Fuel Cell Powerplant is an electrical power source which converts into direct current the energy derived from the chemical reaction of hydrogen and oxygen. Potable water is generated as a by-product of the process. The powerplant utilizes dual-porosity nickel electrodes with a potassium hydroxide electrolyte.

The Apollo Fuel Cell Powerplant consists of a power, or energy conversion section, a reactant control system, a waste heat and water removal system, and flight instrumentation. A schematic diagram of the powerplant follows. The power section consists of 31 Bacon type fuel cells having dual-porosity nickel electrodes and using highly concentrated aqueous potassium hydroxide as the electrolyte. The cells operate at temperatures up to 500°F combining hydrogen and oxygen to produce electrical energy, water, and waste heat. Gaseous hydrogen and oxygen are provided to the power section through reactant regulators which maintain the pressure of the reactants in the fuel cell at desired levels independent of electrical power demand. Preheaters in the reactant supply system utilize a portion of the waste heat to warm the reactants before they enter the pressure regulators.

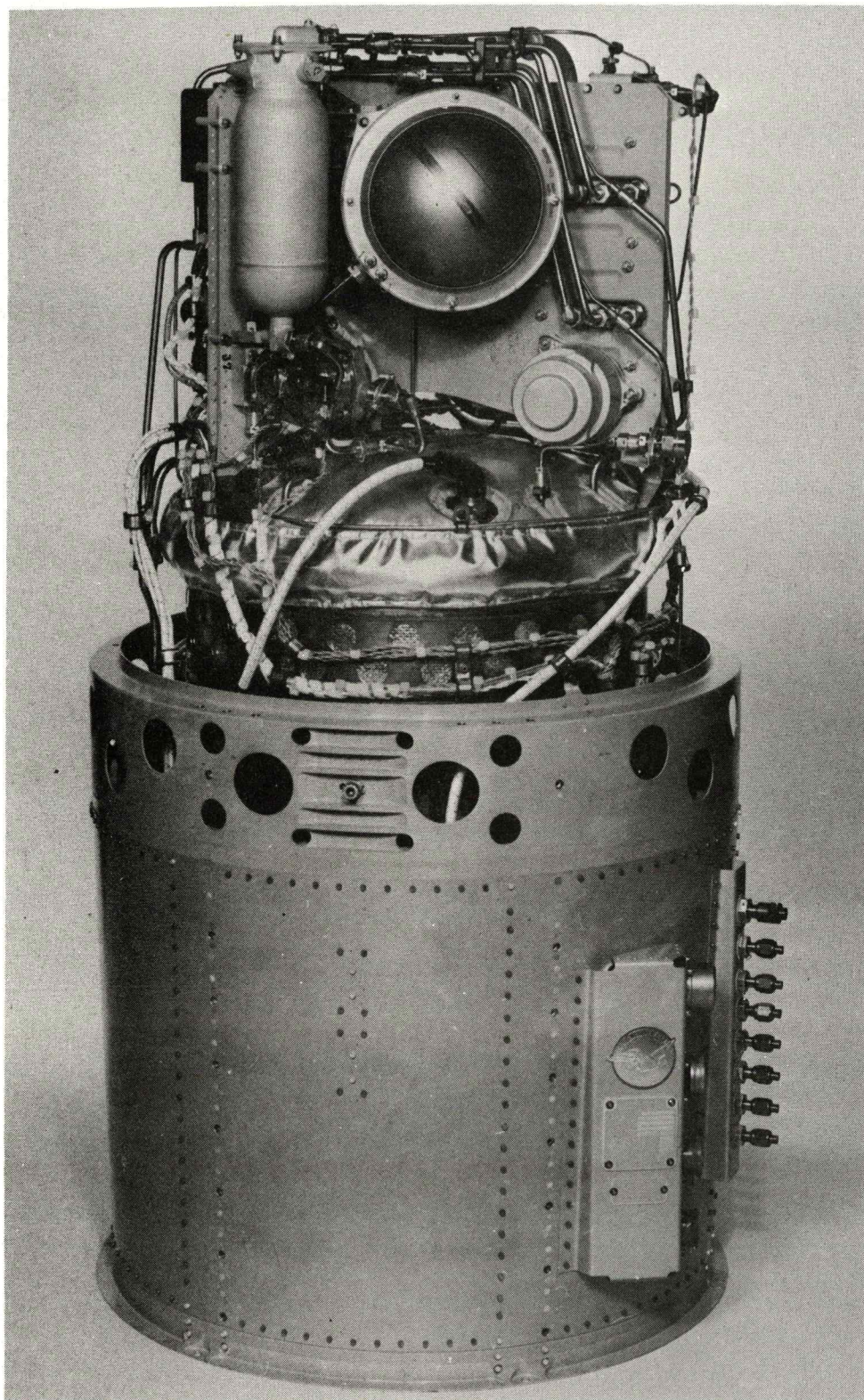
A flow of hydrogen in excess of the instantaneous demand of the fuel cell is maintained to carry water and waste heat away from the cells. If the cell temperature is too low at a given operating condition, the return flow of hydrogen passes through a regenerator. In this primary regenerator the hydrogen supplied to the cells is heated to maintain the temperature of the cells at the desired level. The proportion of the hydrogen return flow passing through the regenerator is controlled by the primary regenerator bypass valve.

The return flow of hydrogen bearing water vapor then passes through a condenser where the water vapor is condensed to a liquid. The condenser is cooled by an ethylene glycol/water mixture which is pumped through the spacecraft radiator. A portion of the return flow from the radiator is bypassed to the secondary regenerator to maintain a constant temperature at the condenser. The amount of coolant bypassed to the regenerator is controlled by the secondary regenerator bypass valve.

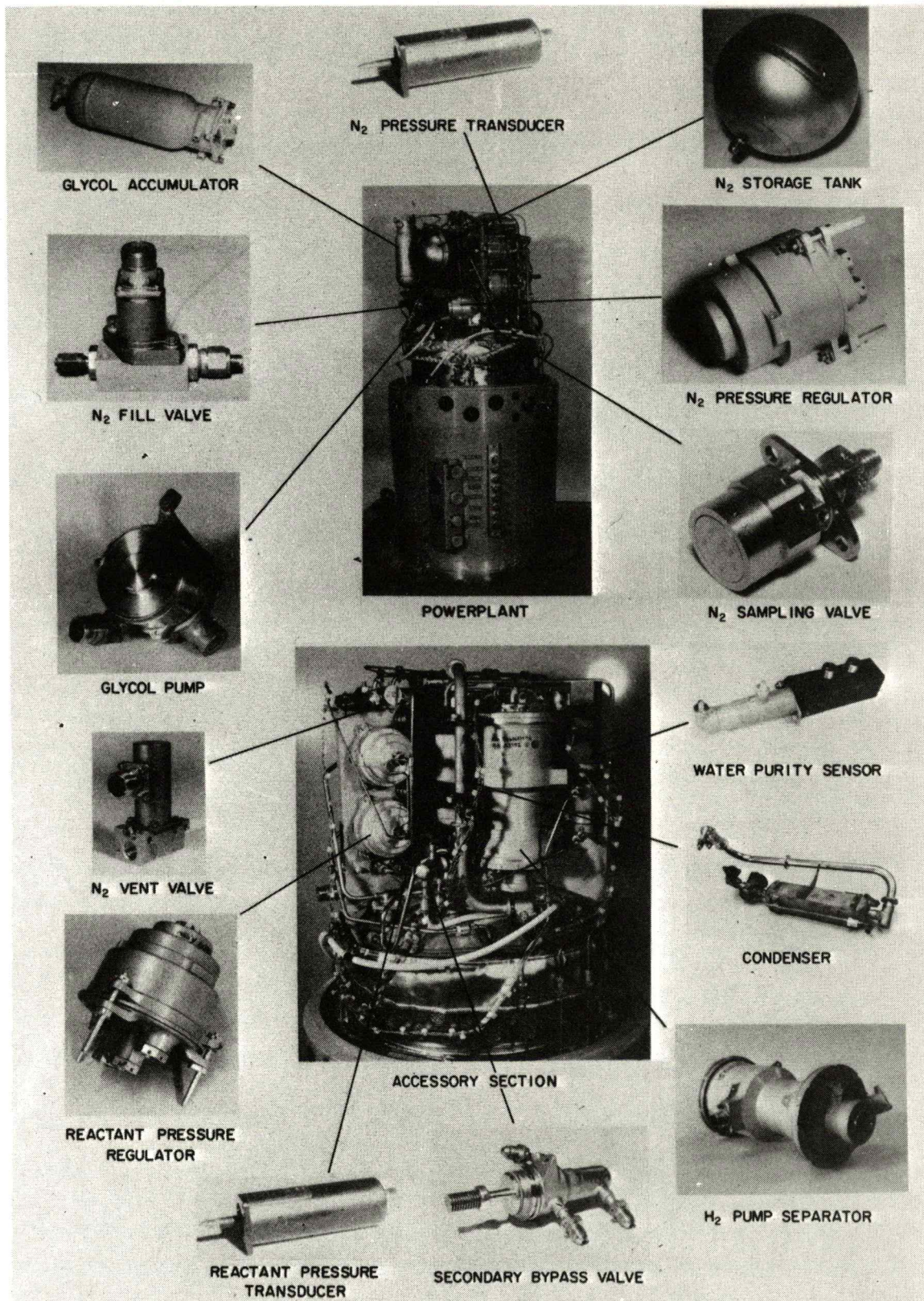
Hydrogen and water leaving the condenser pass through a centrifugal separator where the water is removed from the cool hydrogen and discharged to the spacecraft water system. A redundant water discharge valve diaphragm ensures that no free hydrogen enters the water manifold. The dry hydrogen exiting from the separator is pumped back to the fuel cell through the primary regenerator.

Reactant purge valves are included in the powerplant to permit venting of the reactant systems and fuel cells. This is necessary to remove inert constituents of the reactant gases which are concentrated by the removal of hydrogen and oxygen in the fuel cells. Instrumentation is included to permit significant operating variables to be monitored during checkout and operation of the powerplant.

This pictorial review of the Block I configuration powerplant has been assembled to show the general make-up and location of the major components essential to the operation of the powerplant. The photographs shown are, in many cases, of experimental parts and not necessarily to production quality standards.

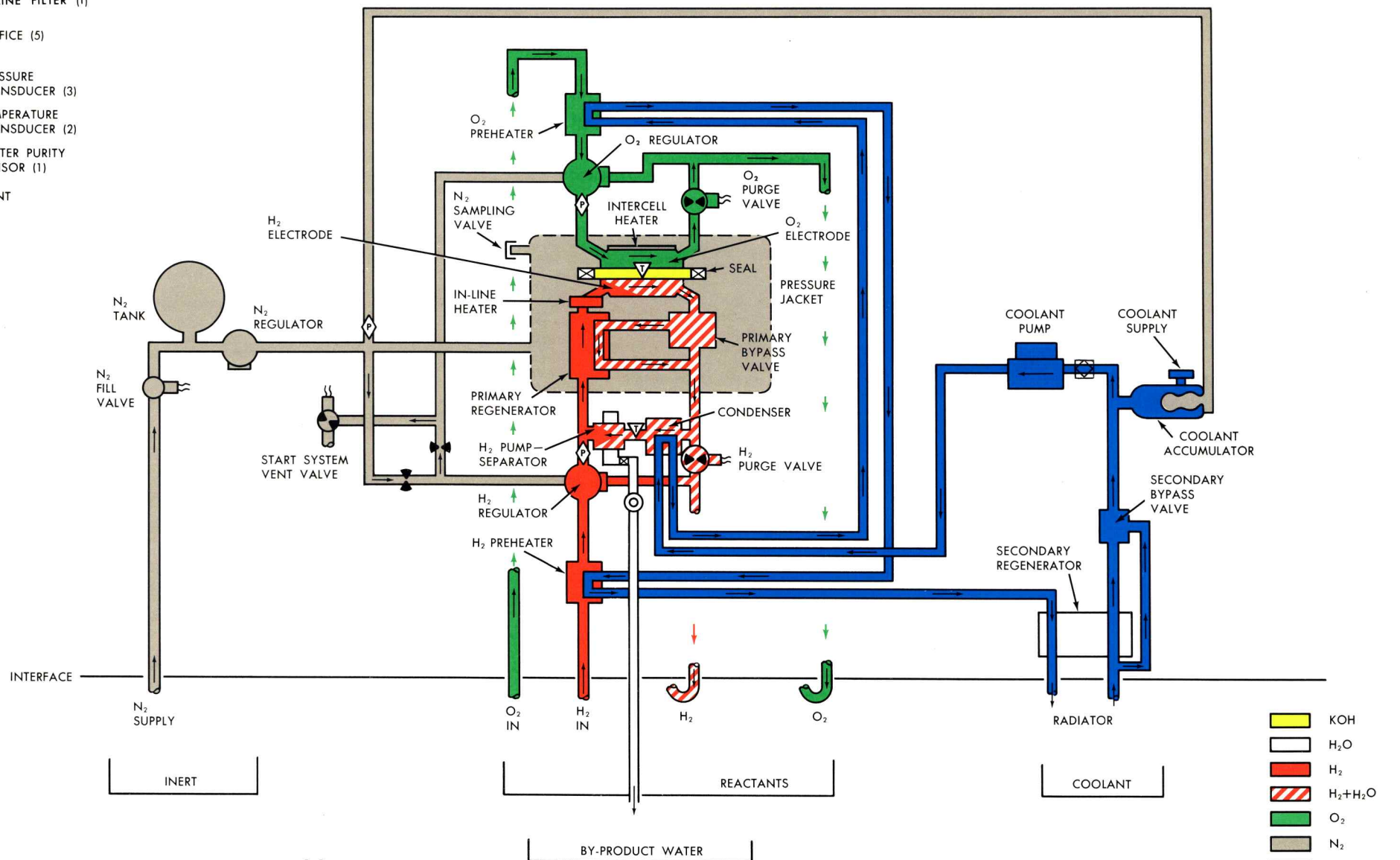


PC3A-2 POWERCEL®



APOLLO FUEL CELL POWERPLANT MODEL PC3A-2 FLOW SCHEMATIC

-  IN-LINE FILTER (1)
-  ORIFICE (5)
-  PRESSURE TRANSDUCER (3)
-  TEMPERATURE TRANSDUCER (2)
-  WATER PURITY SENSOR (1)
-  VENT

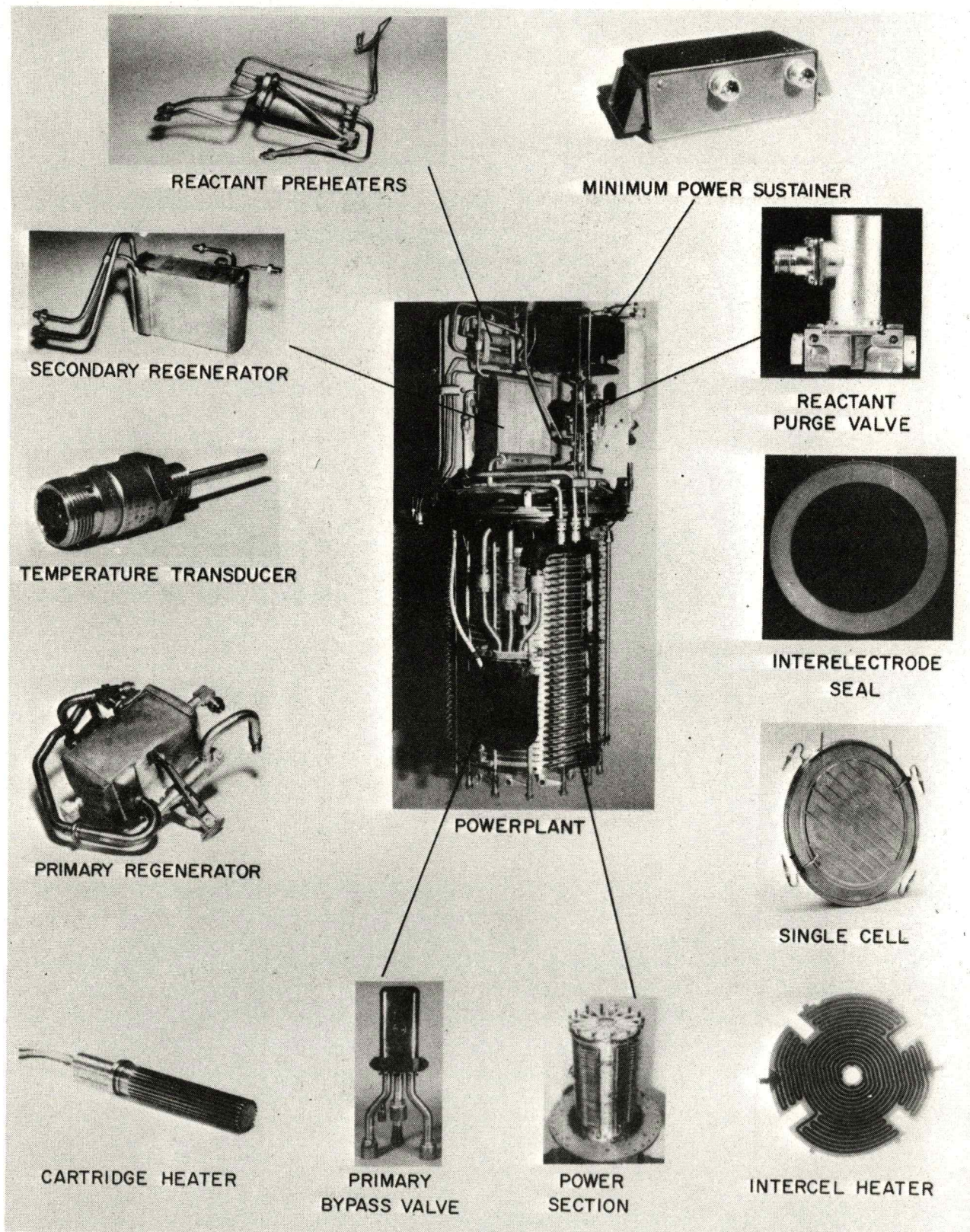


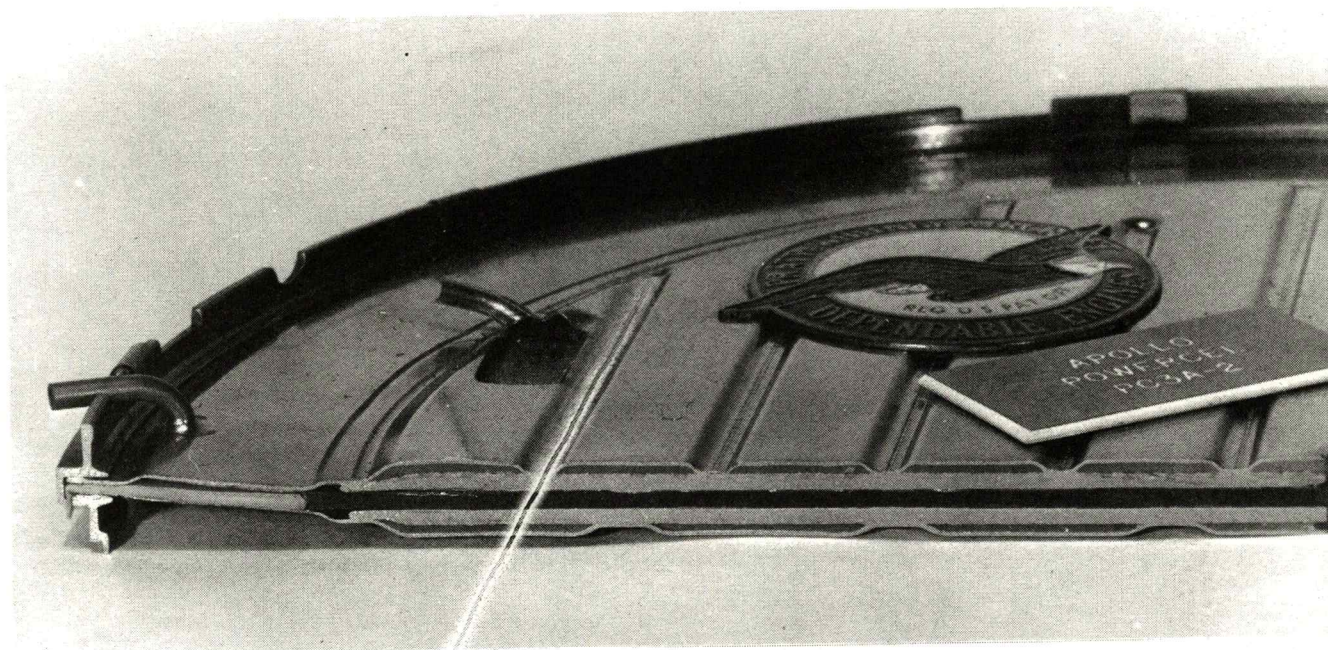
-  KOH
-  H₂O
-  H₂
-  H₂+H₂O
-  O₂
-  N₂
-  COOLANT

Pratt & Whitney Aircraft

DIVISION OF UNITED AIRCRAFT CORPORATION
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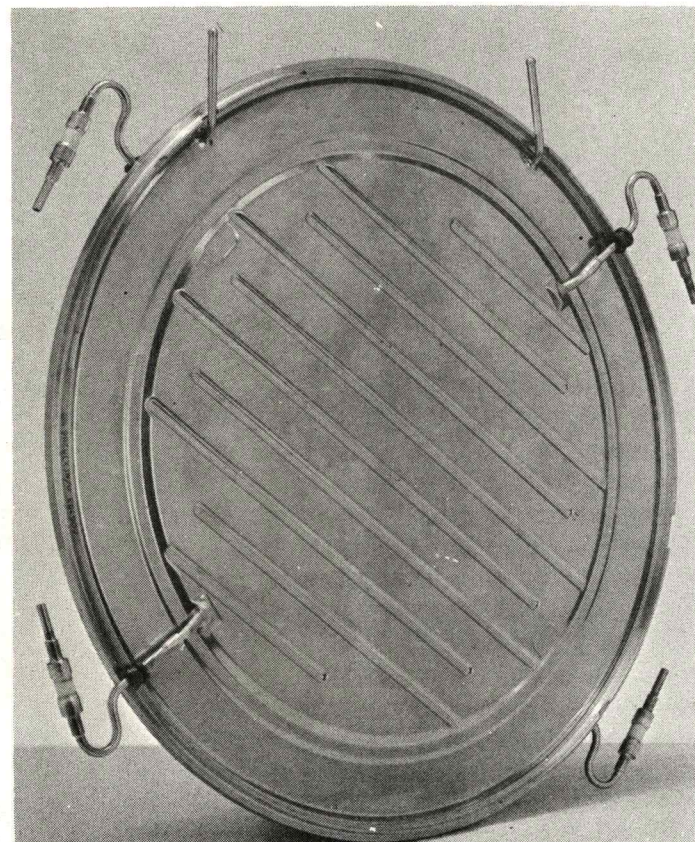
Single Cell

The single cell assembly converts the chemical energy of the reactants to electrical energy and by-product water.

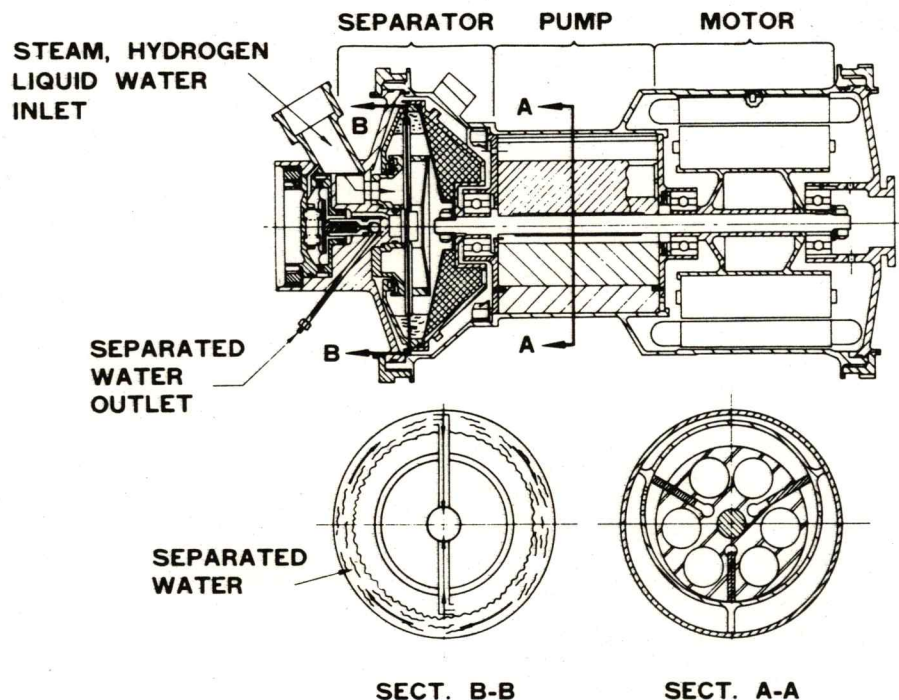
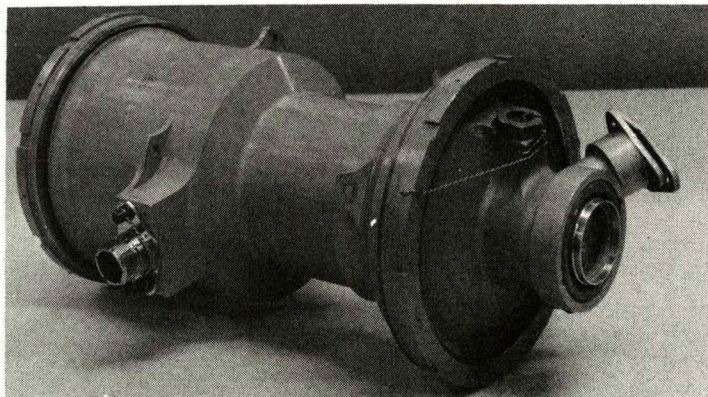
It operates at temperatures up to 500°F with reactant pressures in the order of 50-60 psia. The electrolyte is aqueous KOH—approximately 80% concentration. The hydrogen anode is made up of two layers of porous sintered nickel; the oxygen cathode is a two-layer porous nickel-nickel oxide sintered structure.

The fuel cell product water is formed at the hydrogen electrode. Half the amount of water formed diffuses to the cathode where it participates in the cathode reactions producing hydroxyl ions. The other half of the water formed at the anode must be removed to keep the electrolyte concentration constant. The water evaporates into the hydrogen gas chamber where a stream of hydrogen sweeps it out of the cell.

The sinters are welded into backup plates which serve also to distribute reactant gases over the back surfaces of the electrodes. Suitable connectors, with individual electrical insulators, supply reactant gases, and carry away exhaust products and inerts. A teflon seal around the cell periphery provides electrical insulation between electrodes and contains the electrolyte.

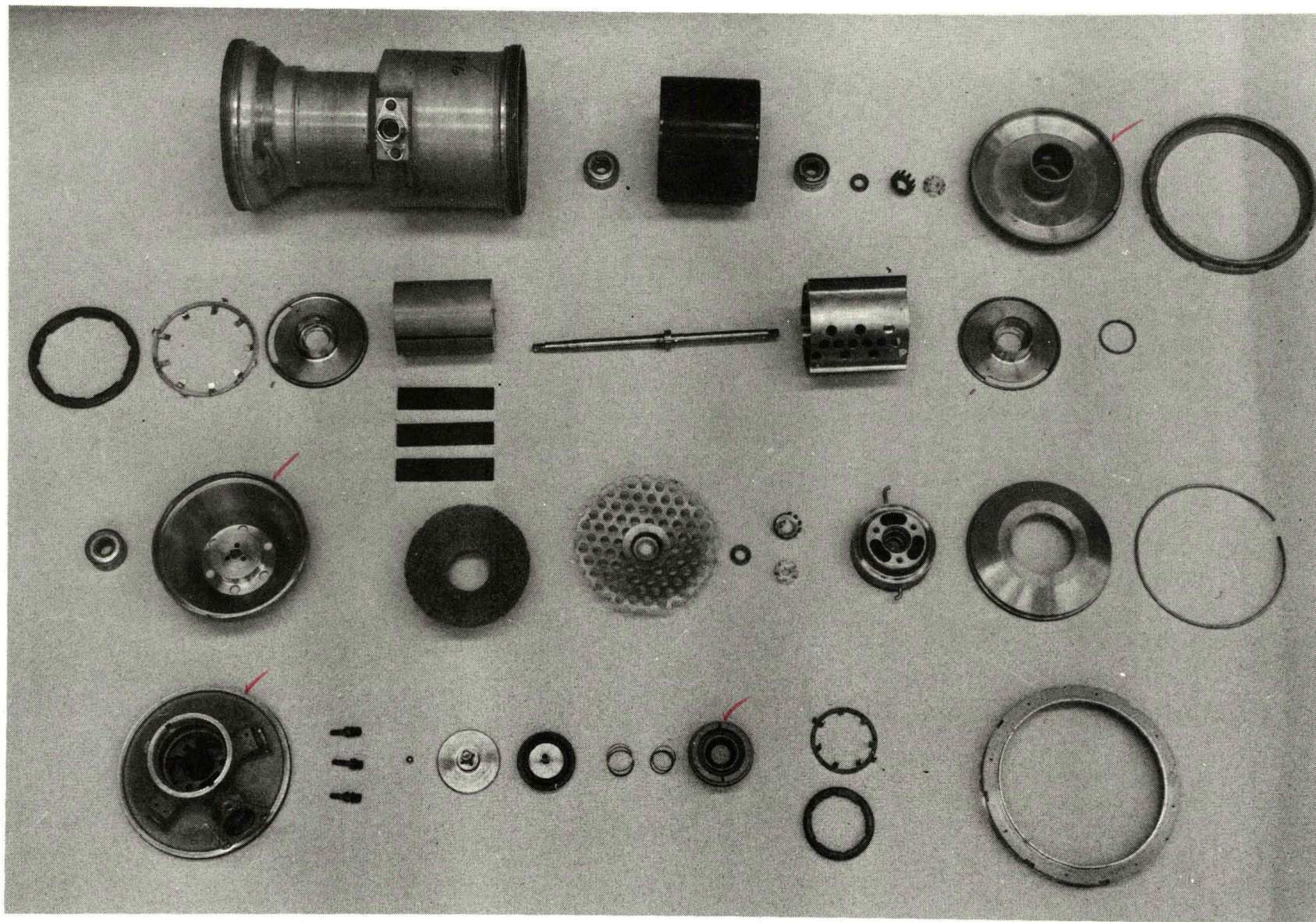


HYDROGEN CIRCULATING PUMP & WATER SEPARATOR

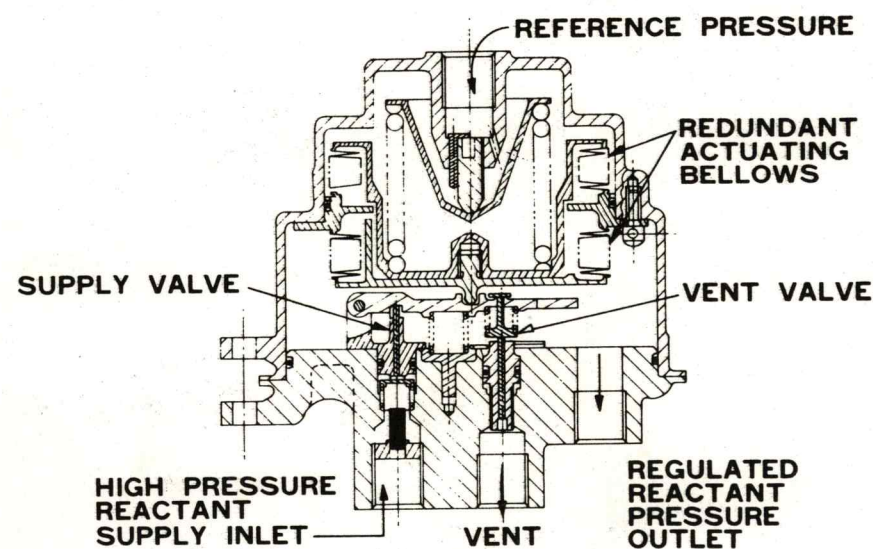
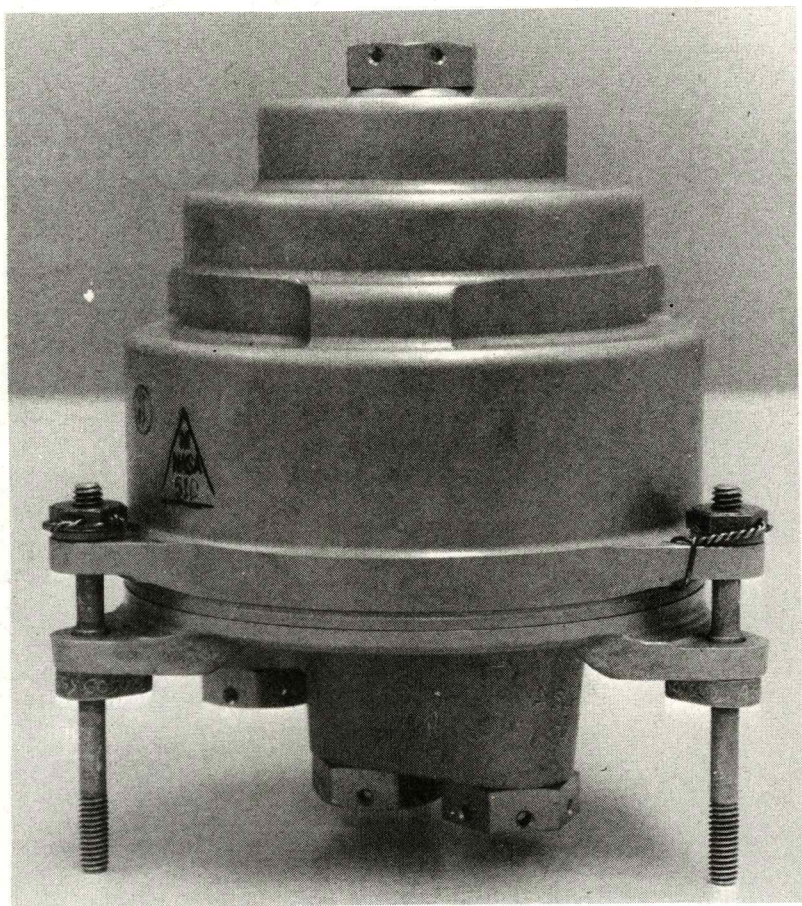


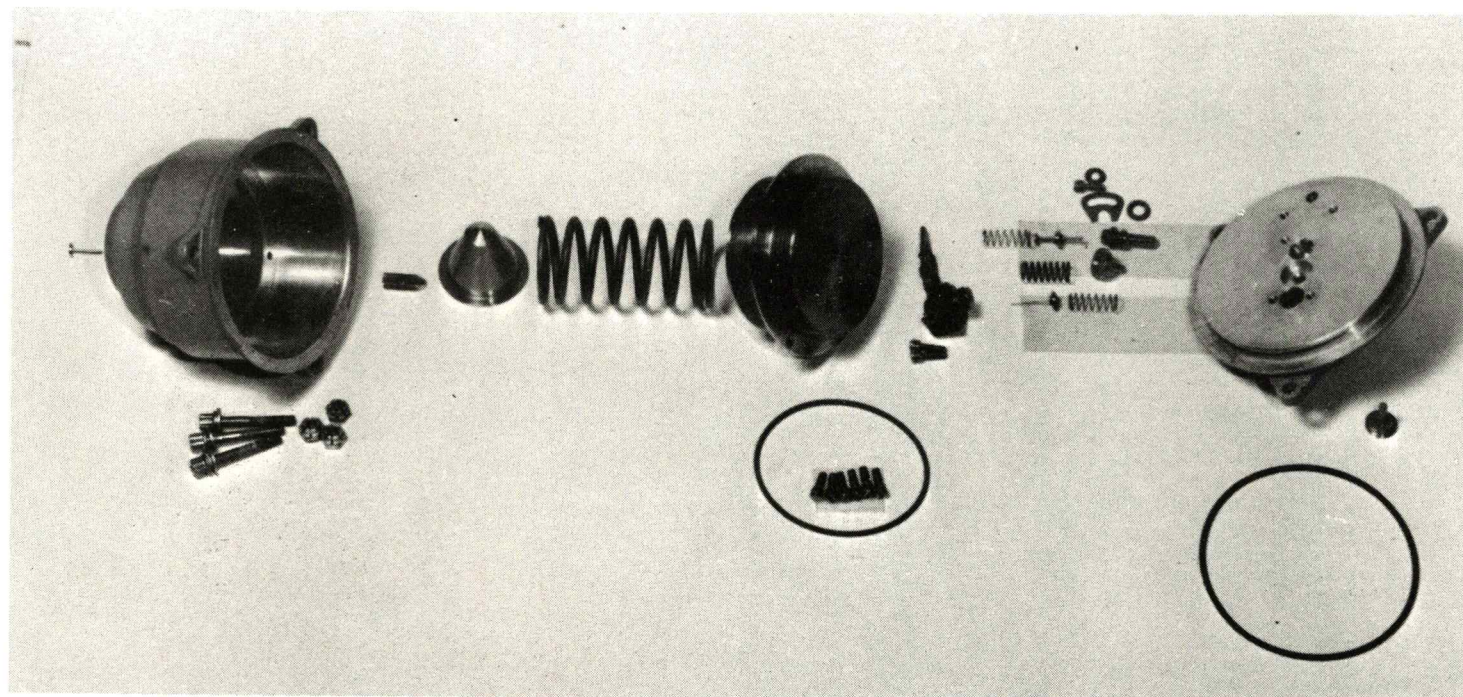
Hydrogen Pump-Separator Assembly

The pump-separator circulates the primary loop hydrogen-water mixture and removes free water from the hydrogen gas stream. The hydrogen pump-separator assembly consists of a vane pump to handle wet hydrogen, a centrifugal water separator, and a 400-cycle, 200/115 volt, 3-phase drive motor.



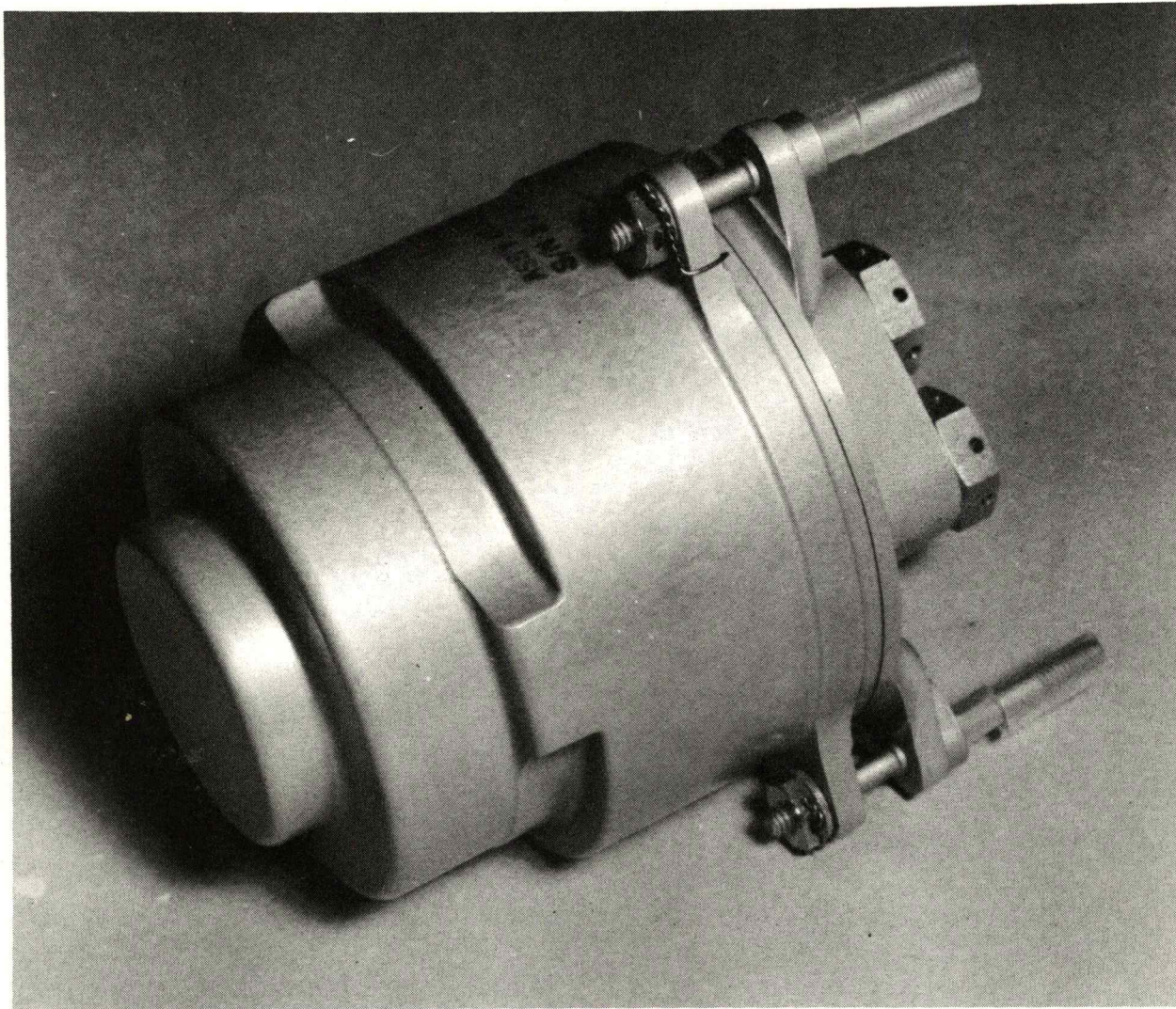
REACTANT PRESSURE REGULATOR





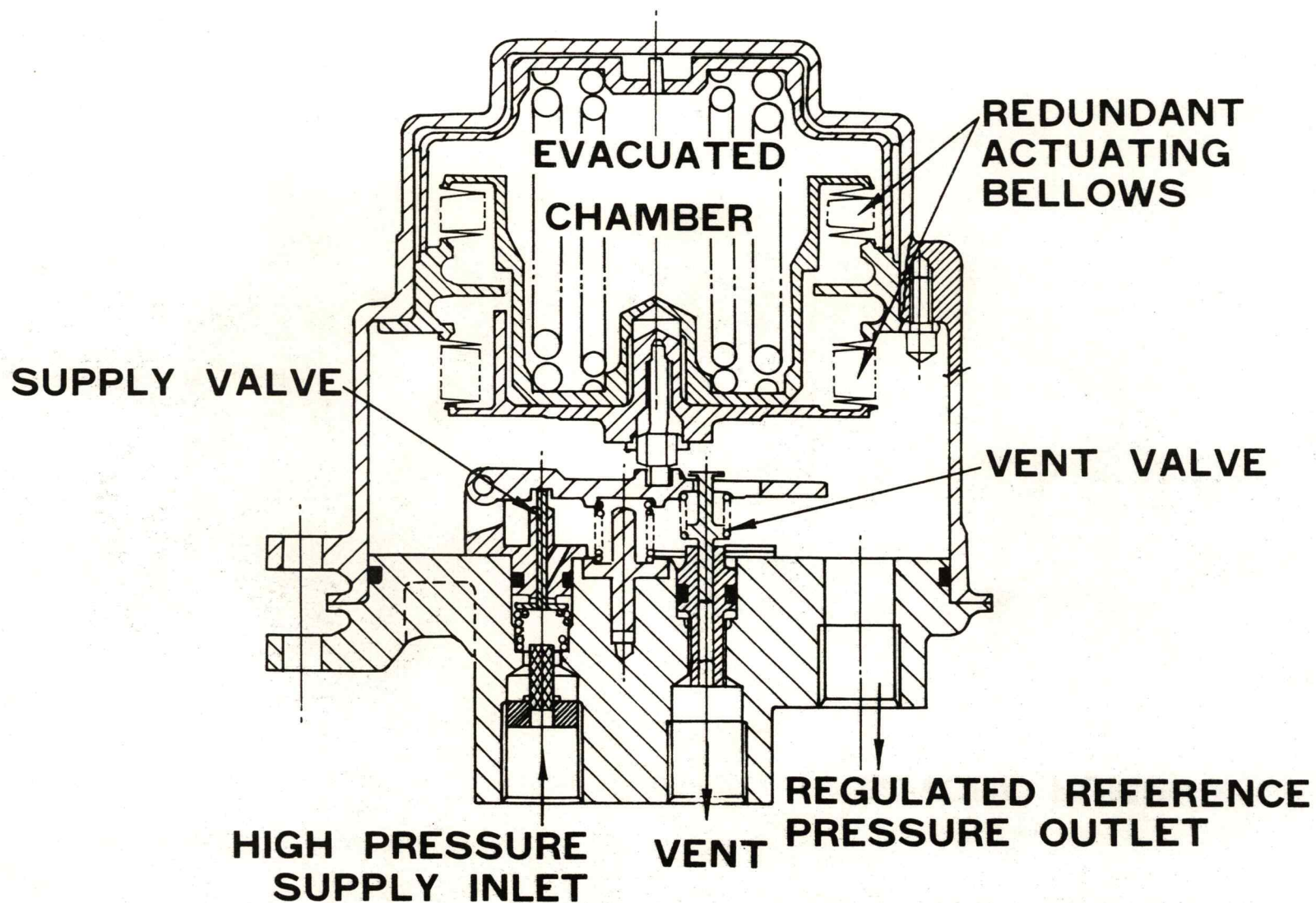
Reactant Regulators

The reactant regulators are bellows operated, lever actuated units which maintain reactant pressure at a constant prescribed level above the nitrogen reference pressure over the full range of gas consumption from zero flow to full power operation. The bellows assembly is composed of two redundant bellows for increased unit reliability. The lever arm is friction damped and actuates a supply and vent valve. A 10-25 micron filter is installed in the supply side of the regulator to maintain cleanliness within the units.



Nitrogen Regulator

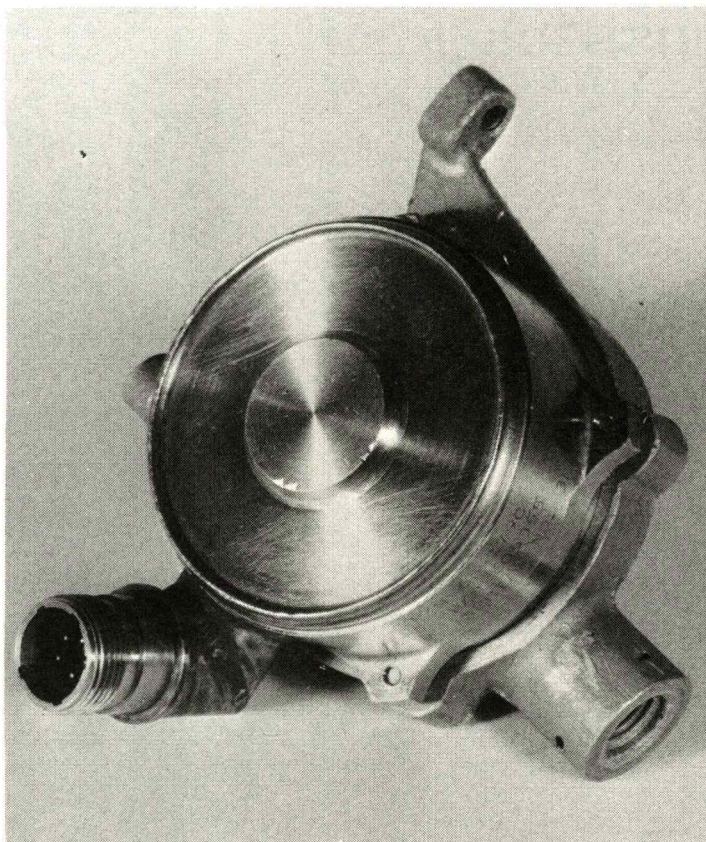
The inert gas regulator is nearly identical to the reactant regulators, but maintains the absolute level of the inert gas blanket pressure over the full range of module operating conditions.



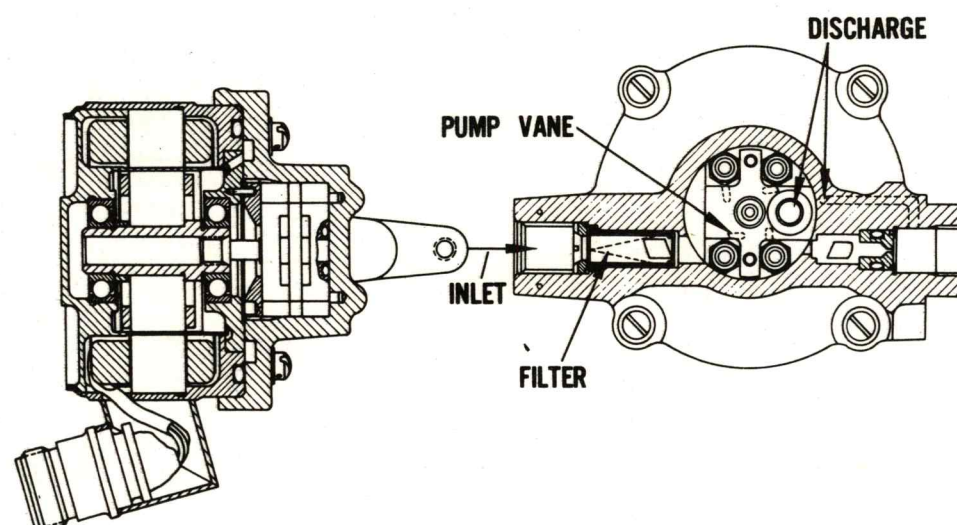
NITROGEN PRESSURE REGULATOR

BL II
1. NO BYPASS IN PUMP

PAGE NO. 12

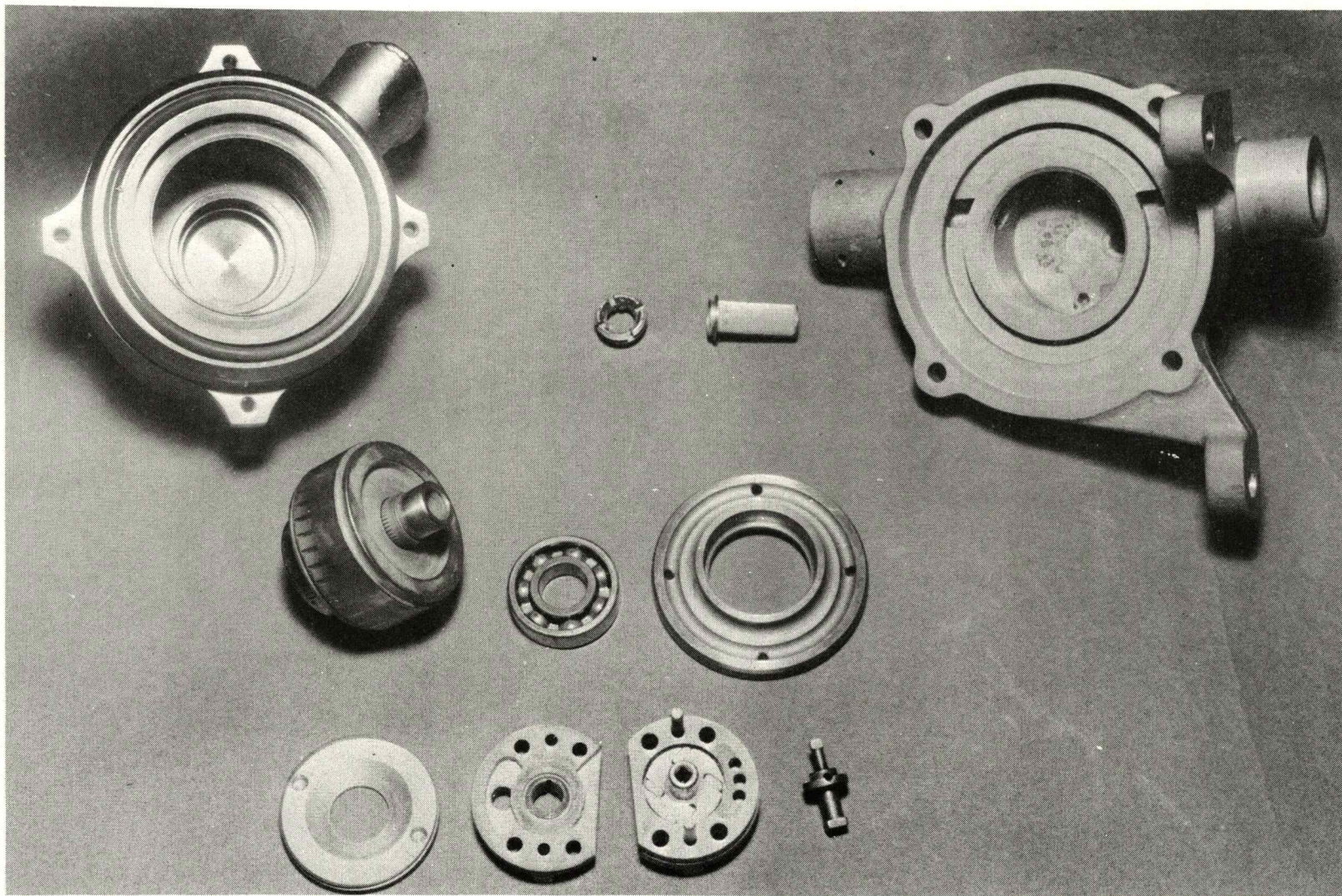


GLYCOL PUMP

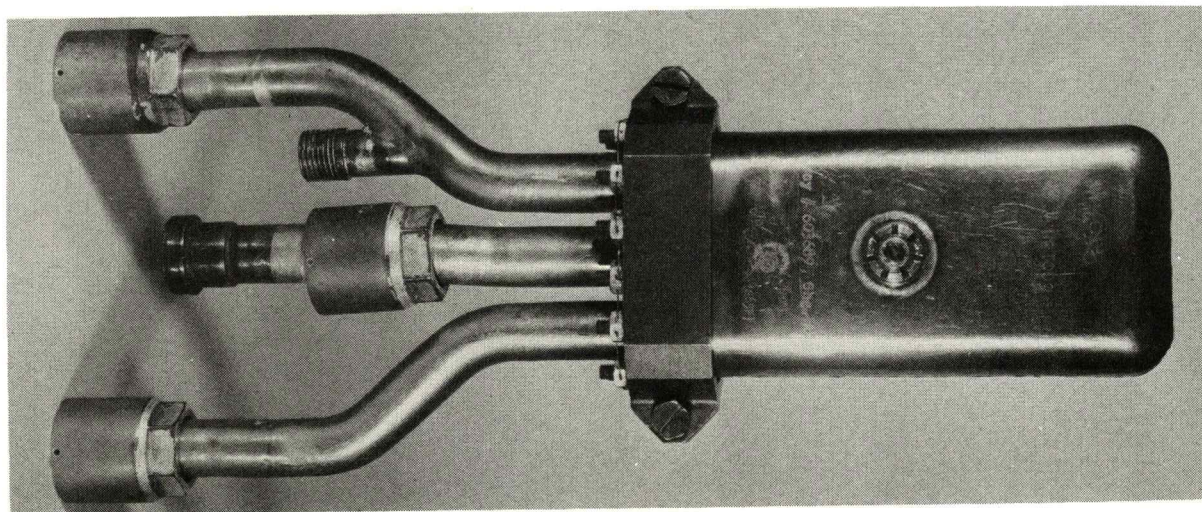


Glycol Pump Assembly

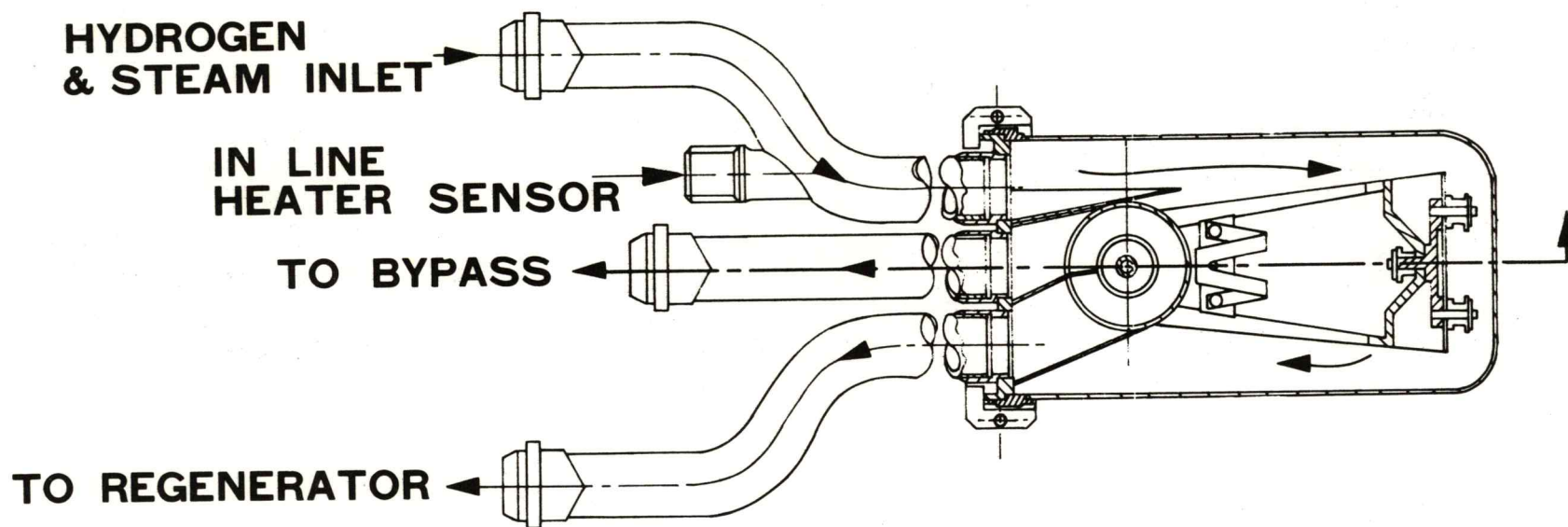
The glycol pump circulates a glycol/water mixture through the secondary coolant loop of the powerplant to the spacecraft radiator. This component is a vane pump driven by a three-phase, 400-cycle, wye-connected induction motor.

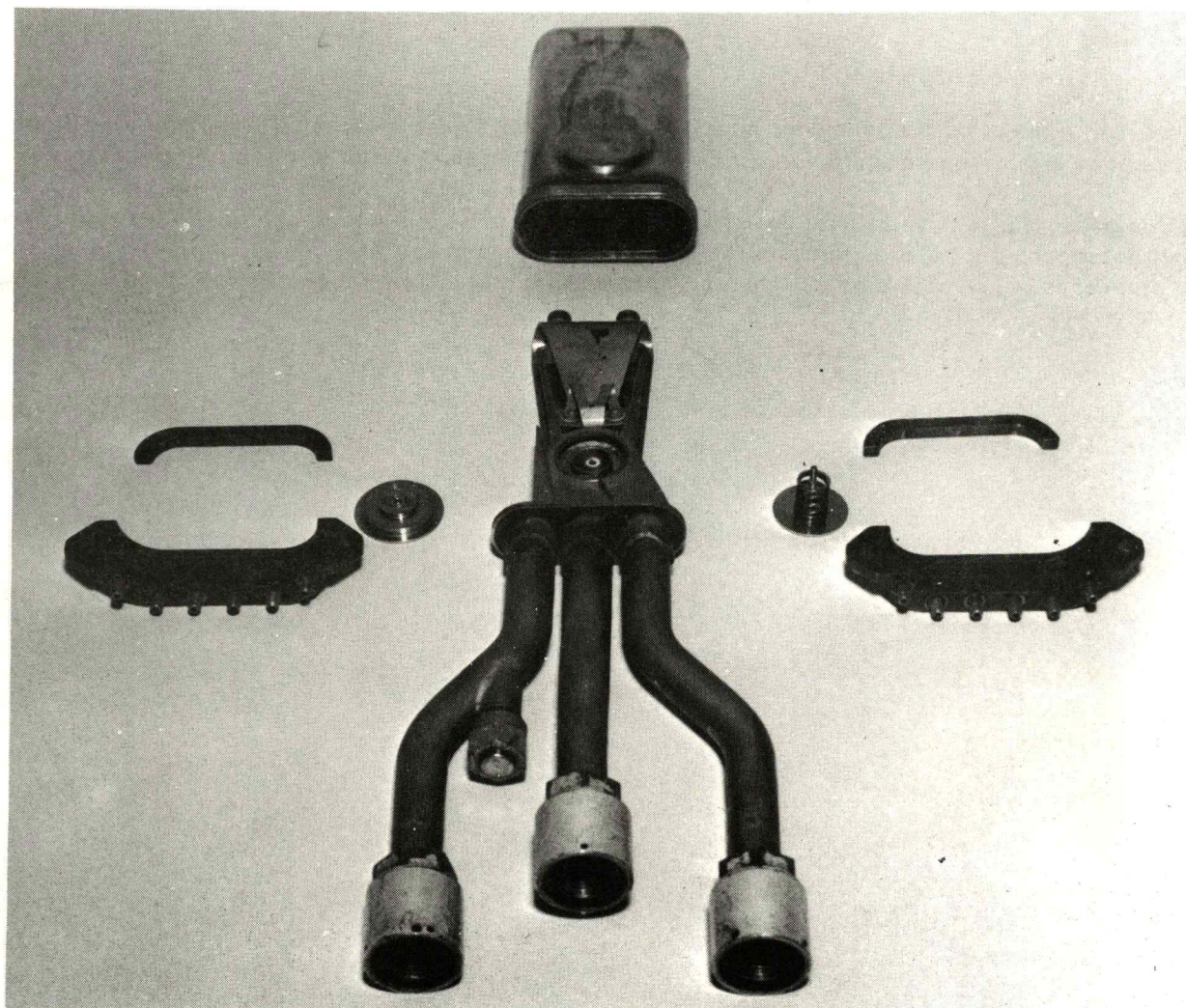


PRIMARY REGENERATOR BYPASS VALVE



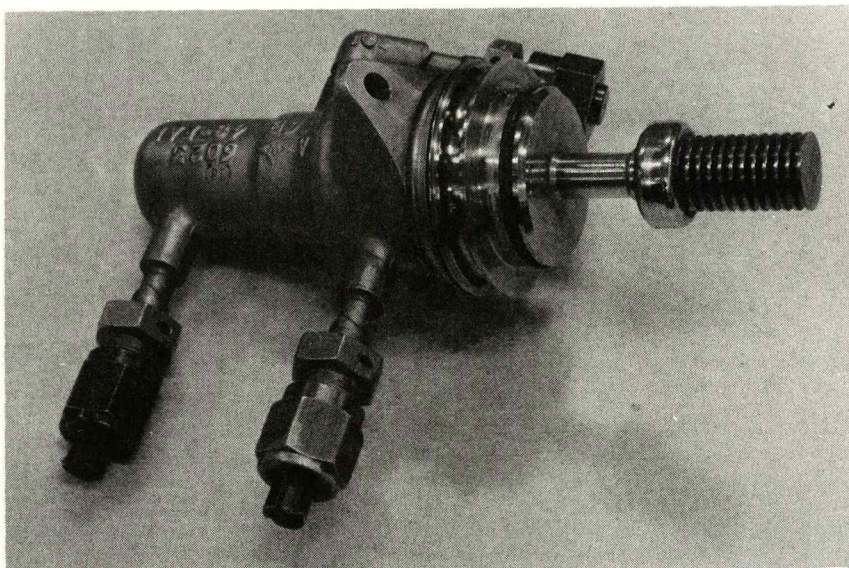
PAGE NO. 14



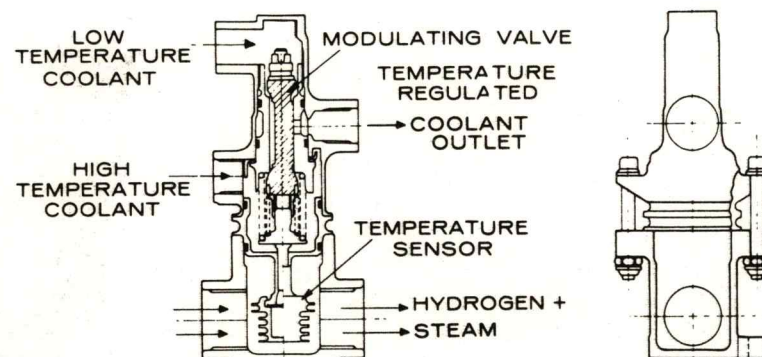


Primary Bypass Control Valve

The primary bypass control regulates the fraction of cell exhaust hydrogen bypassing the regenerator, thereby indirectly controlling the operating temperature of the cell stack. The primary bypass control is a variable position valve which senses the temperature of the hydrogen exhaust system and regulates the fraction which bypasses the primary regenerator through a bimetallic thermostatic actuating element.



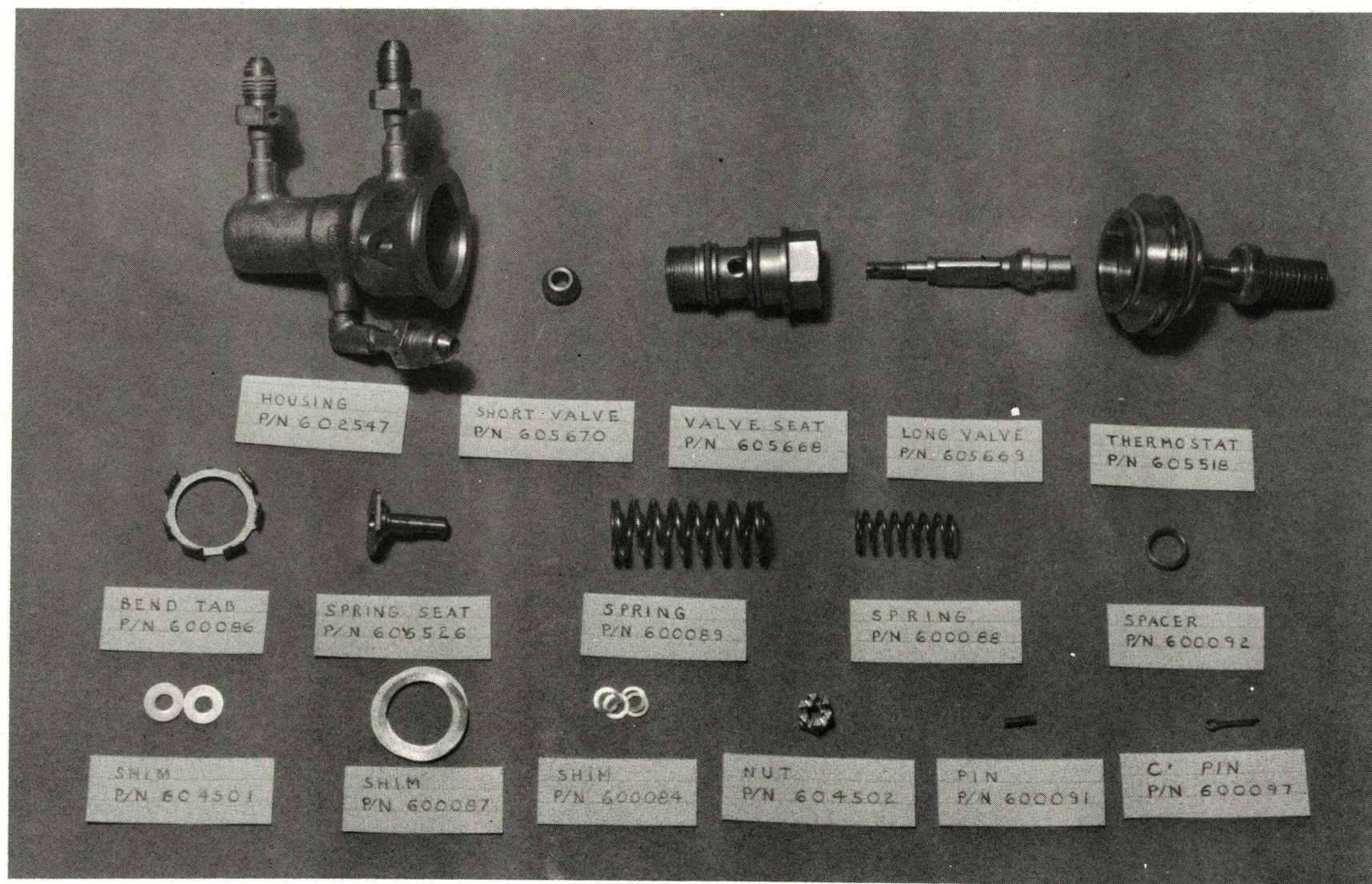
SECONDARY BYPASS VALVE



Secondary Bypass Control Valve

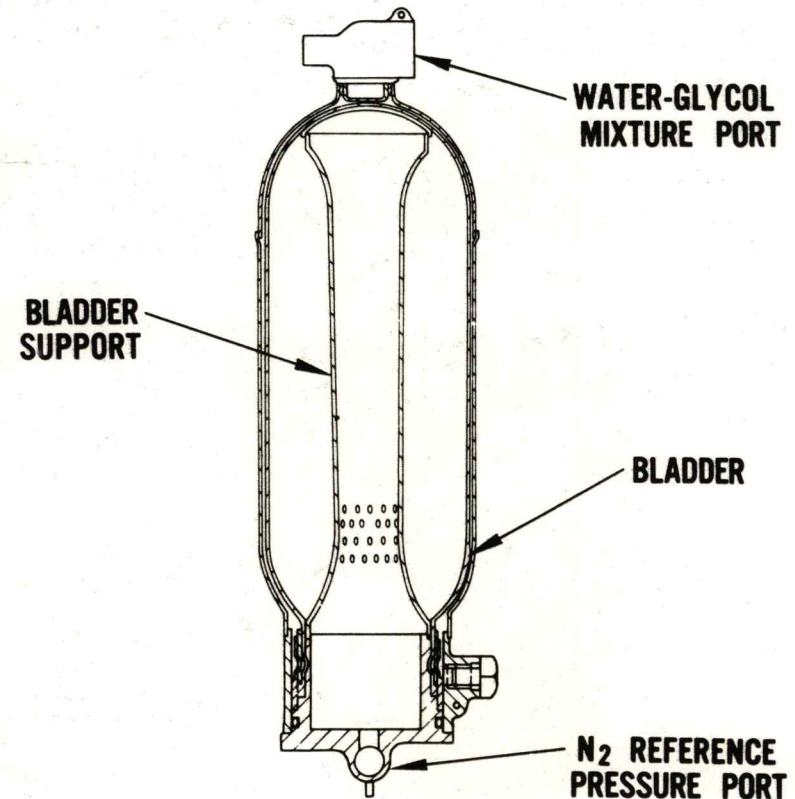
The secondary bypass control modulates the coolant flow passing through the cold side of the secondary regenerator to maintain the condenser outlet temperature within a specified range. The control senses the condenser exit hydrogen temperature and bypasses more of the glycol flow if this temperature is too high, or less if the temperature is too low.

This unit uses a liquid-filled bellows and subassembly to sense hydrogen gas temperature at the condenser exit. Expansion of the liquid in the bellows actuates a double poppet valve in order to maintain a preset exit temperature.



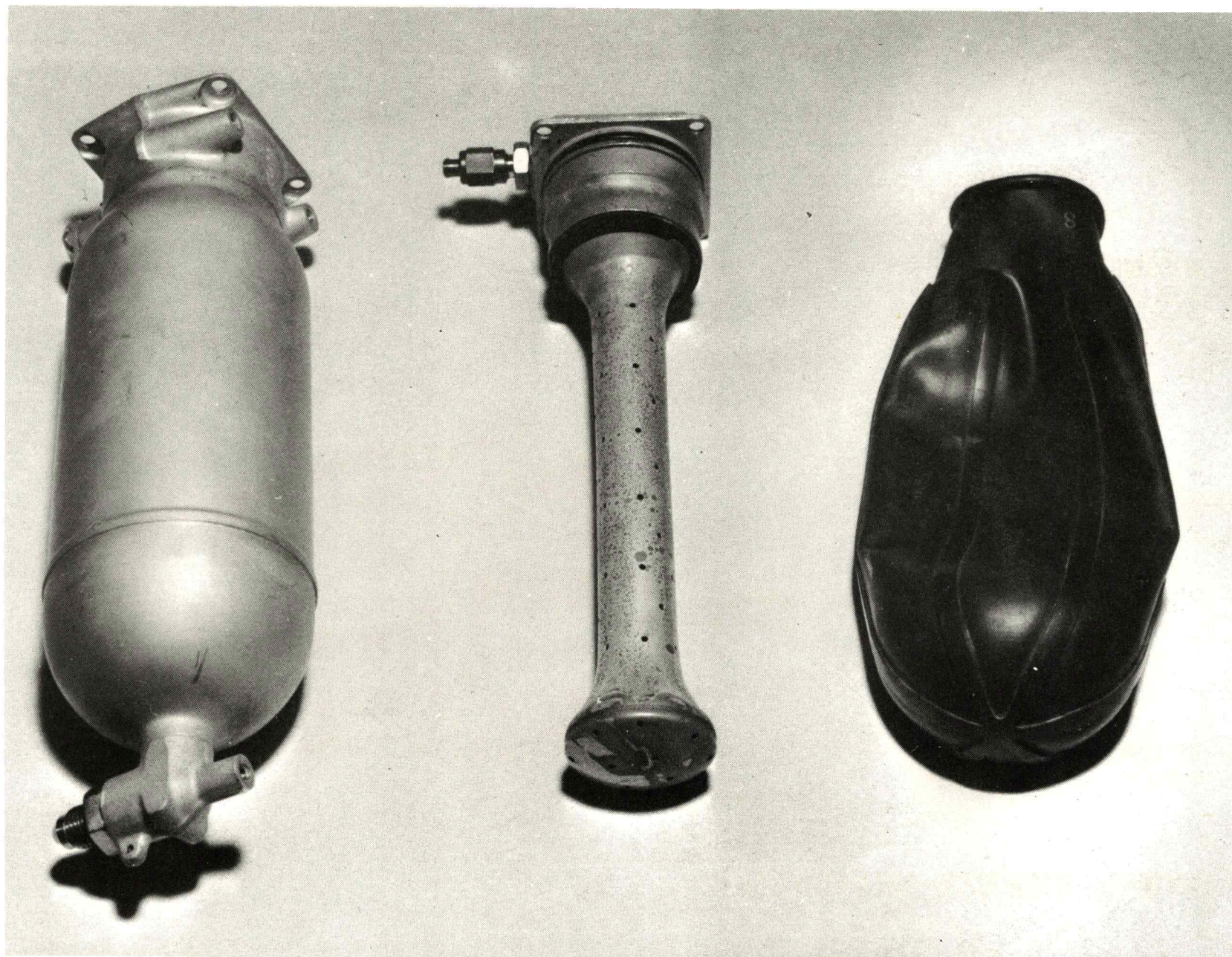


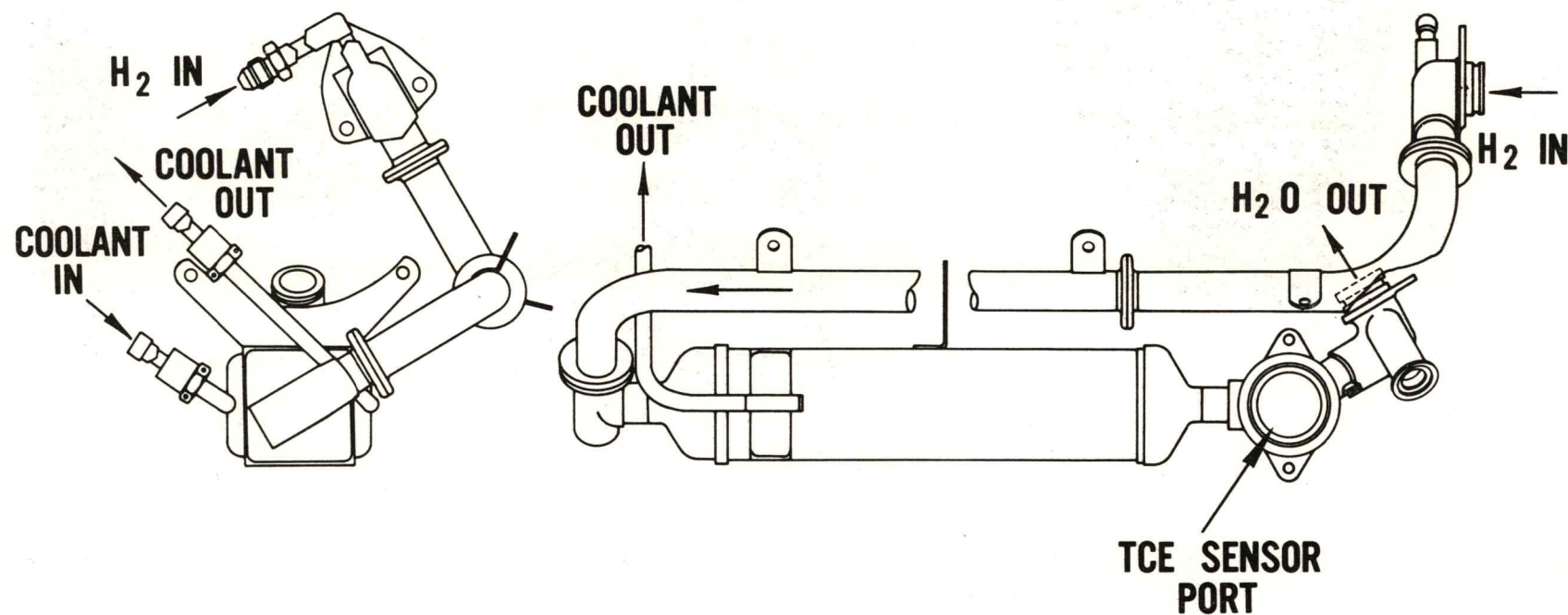
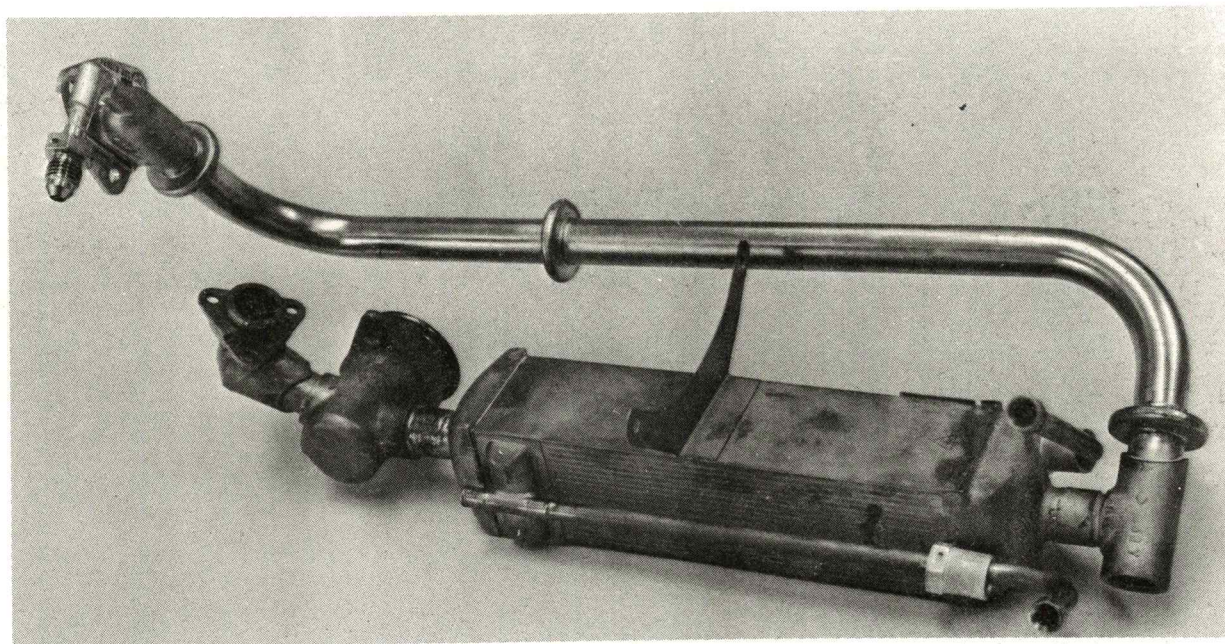
ACCUMULATOR ASSEMBLY - COOLANT



Glycol Accumulator

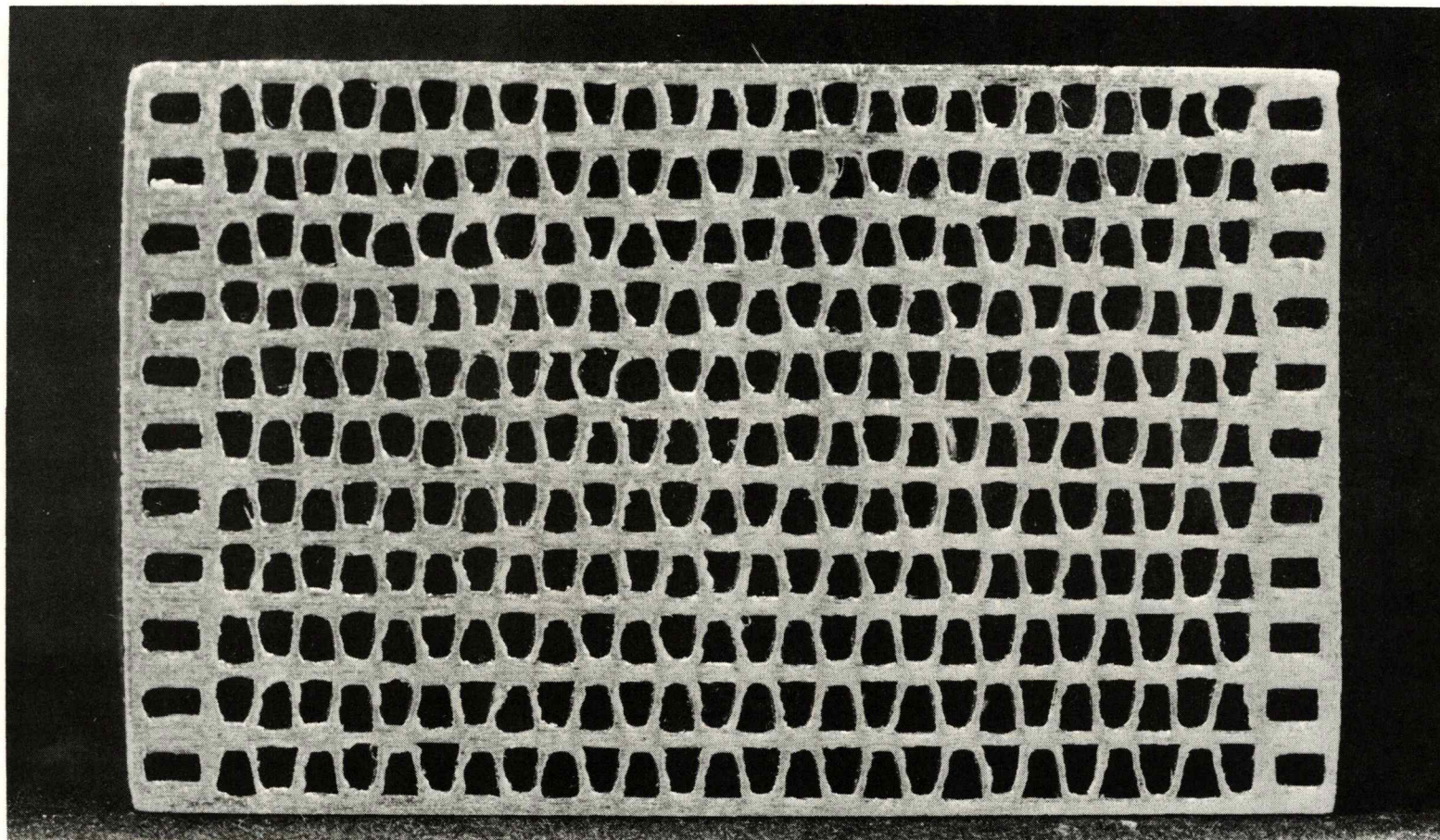
The accumulator is provided to maintain a constant pressure within the coolant system regardless of volumetric changes associated with coolant temperature variations. This is accomplished by introducing nitrogen blanket pressure to the coolant system via a flexible bladder.



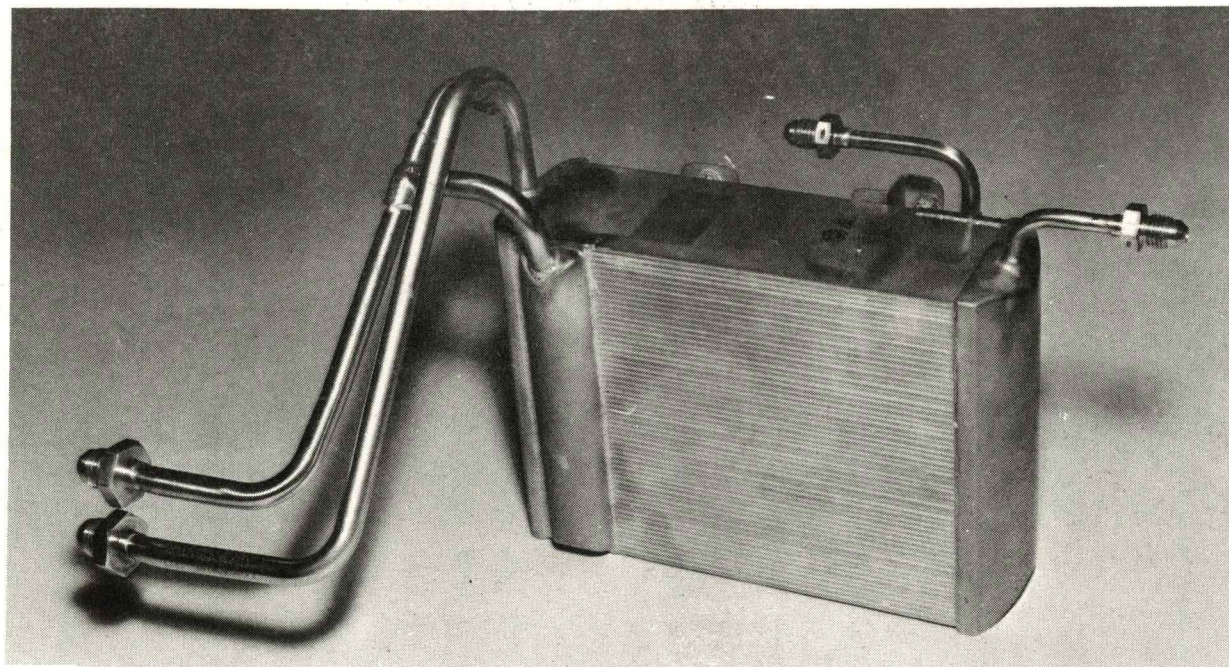


Condenser

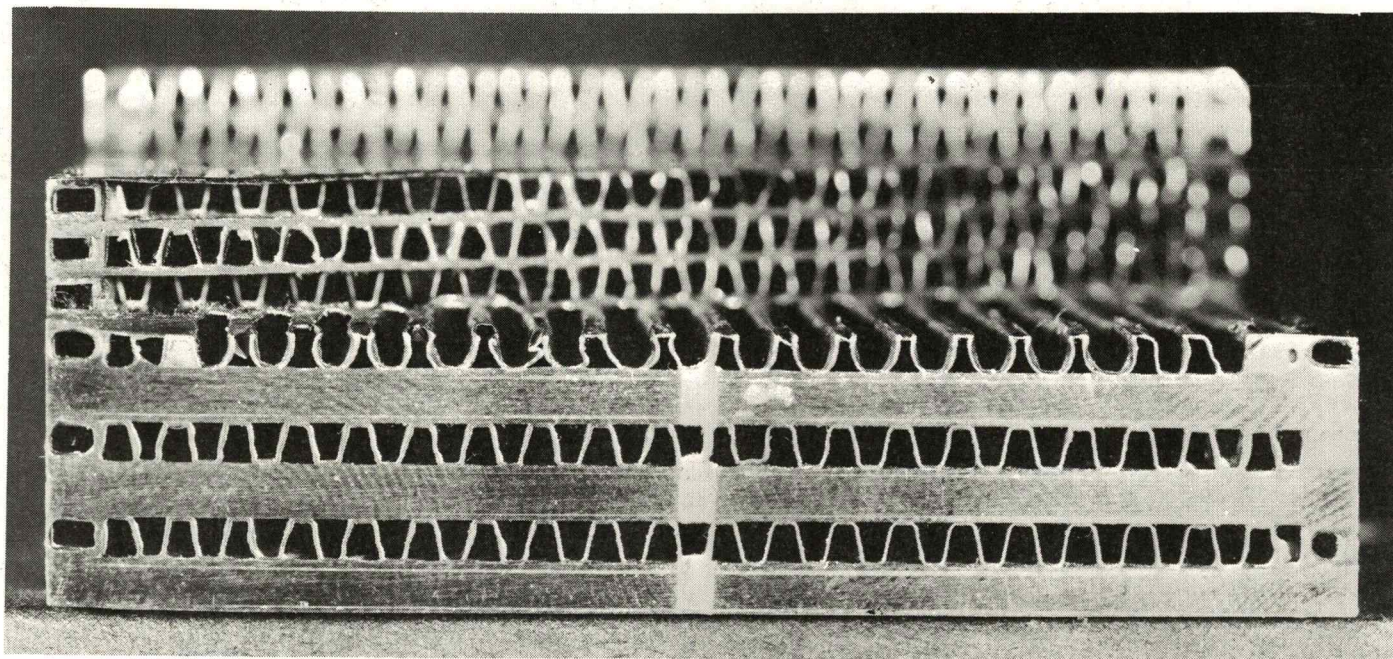
The condenser condenses the water vapor removed from the fuel cell and transfers fuel cell waste heat to the glycol solution in the secondary loop. A mixture of hydrogen and super-heated water vapor enters the condenser, transfers latent and sensible heat to the coolant fluid, and emerges as a mixture of liquid water and saturated hydrogen. The condenser is similar to the primary regenerator. It is a compact counterflow plate-fin heat exchanger.

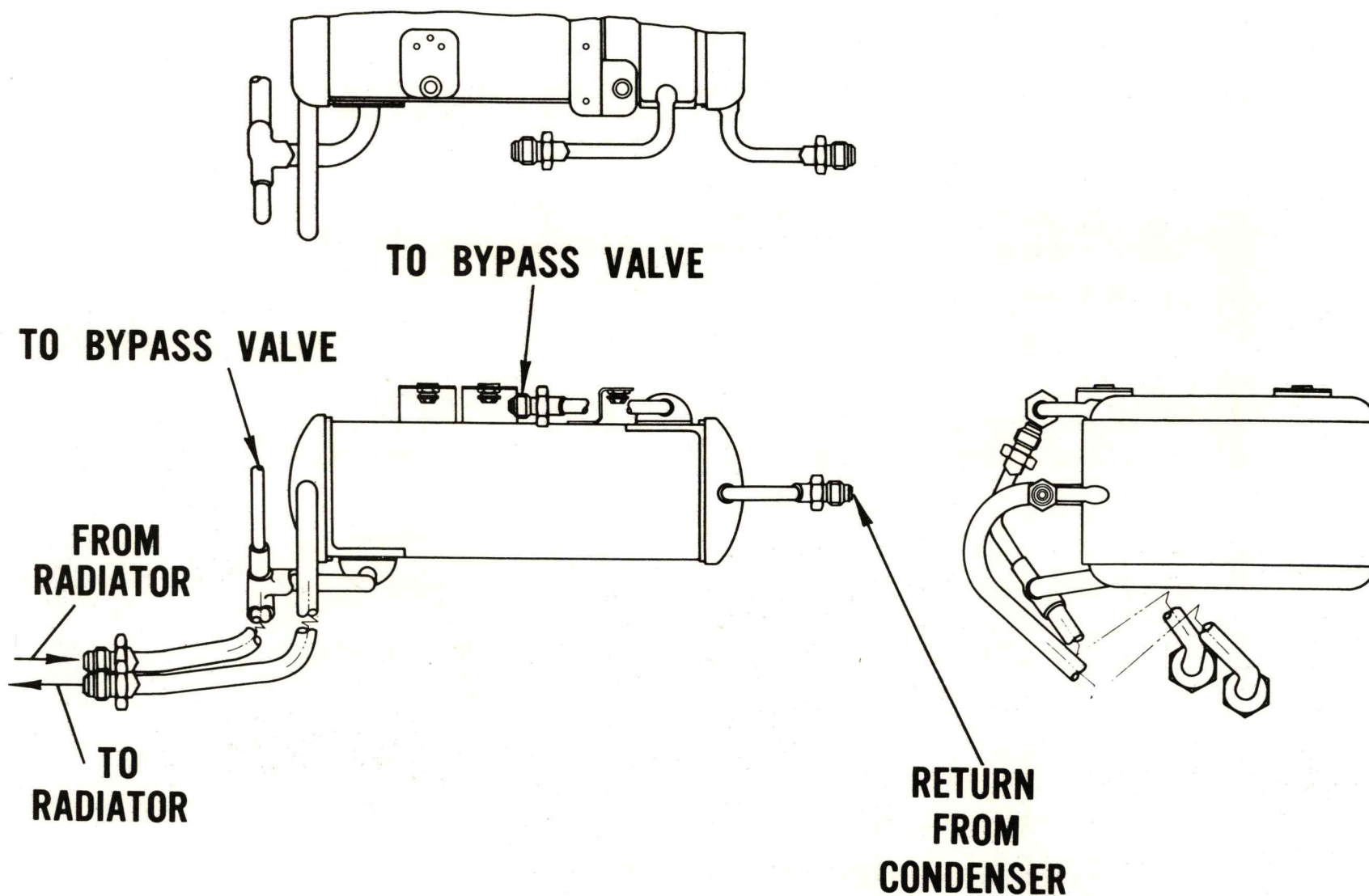


CONDENSER CORE CROSS-SECTION



PAGE NO. 22

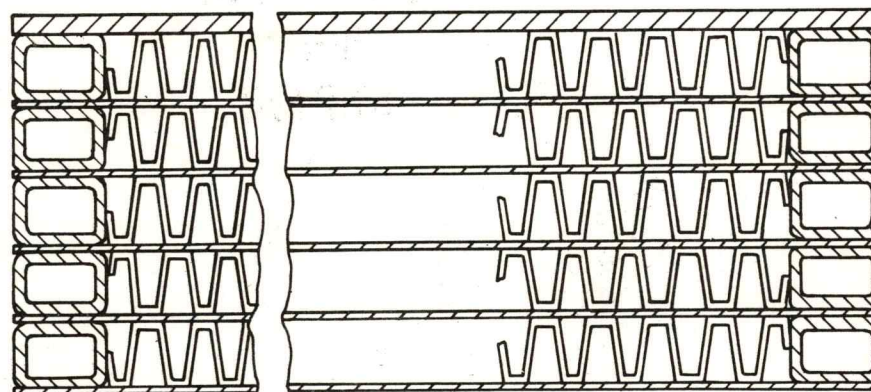
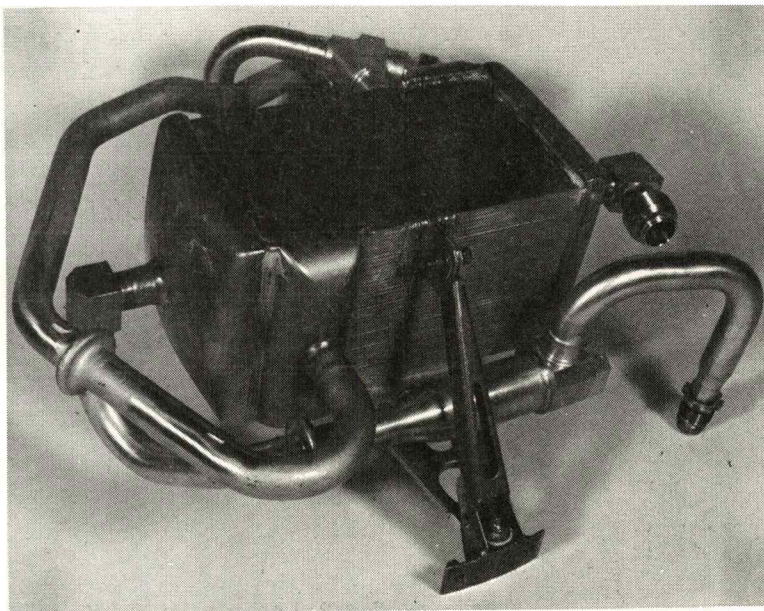




Secondary Regenerator

The regenerator, with its bypass control, controls the heat transferred from the fuel cell powerplant to the heat rejection system to maintain a constant glycol temperature at the condenser inlet. The regenerator is a counterflow plate-fin heat exchanger.

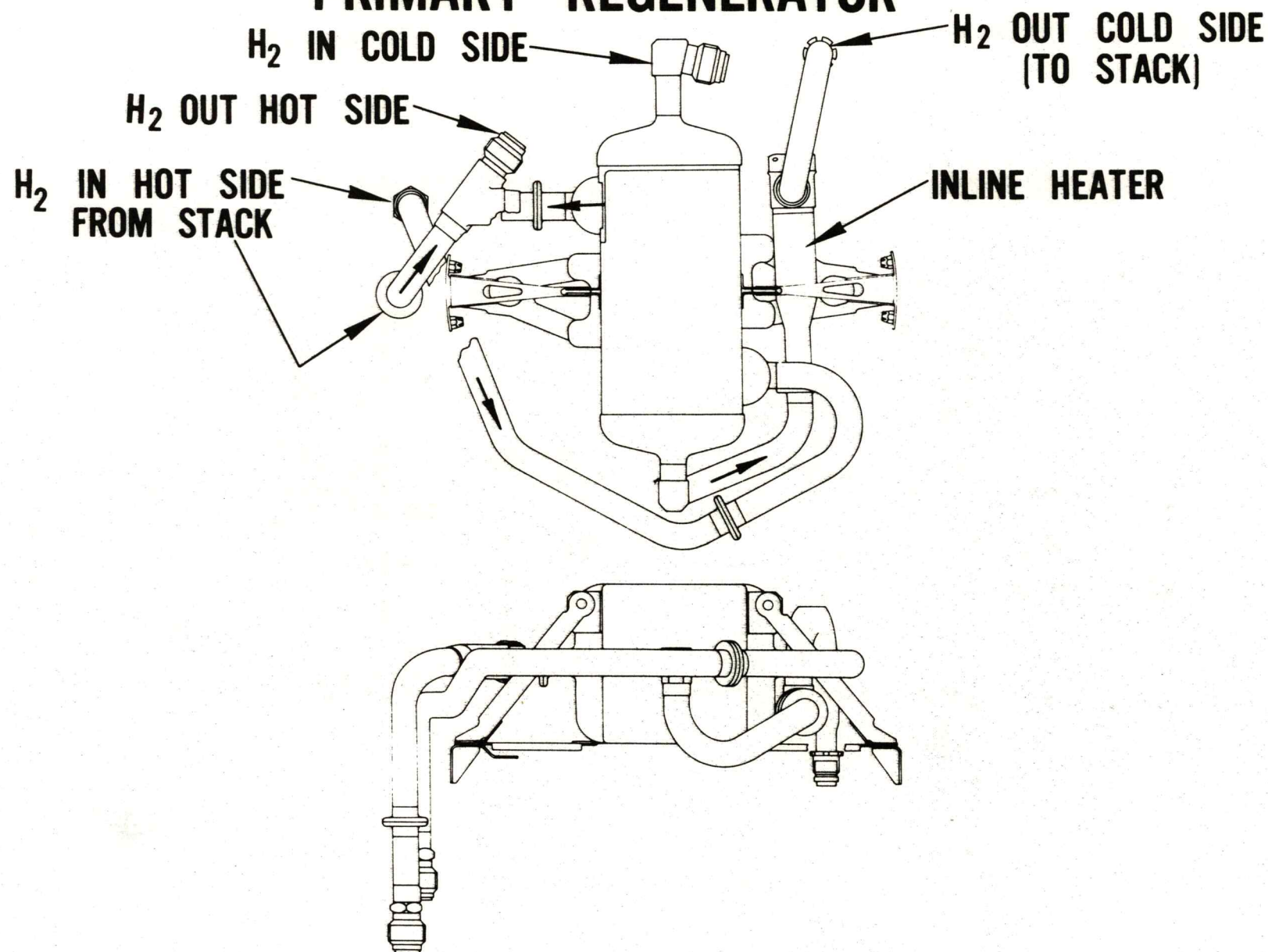
PRIMARY REGENERATOR CORE CROSS-SECTION

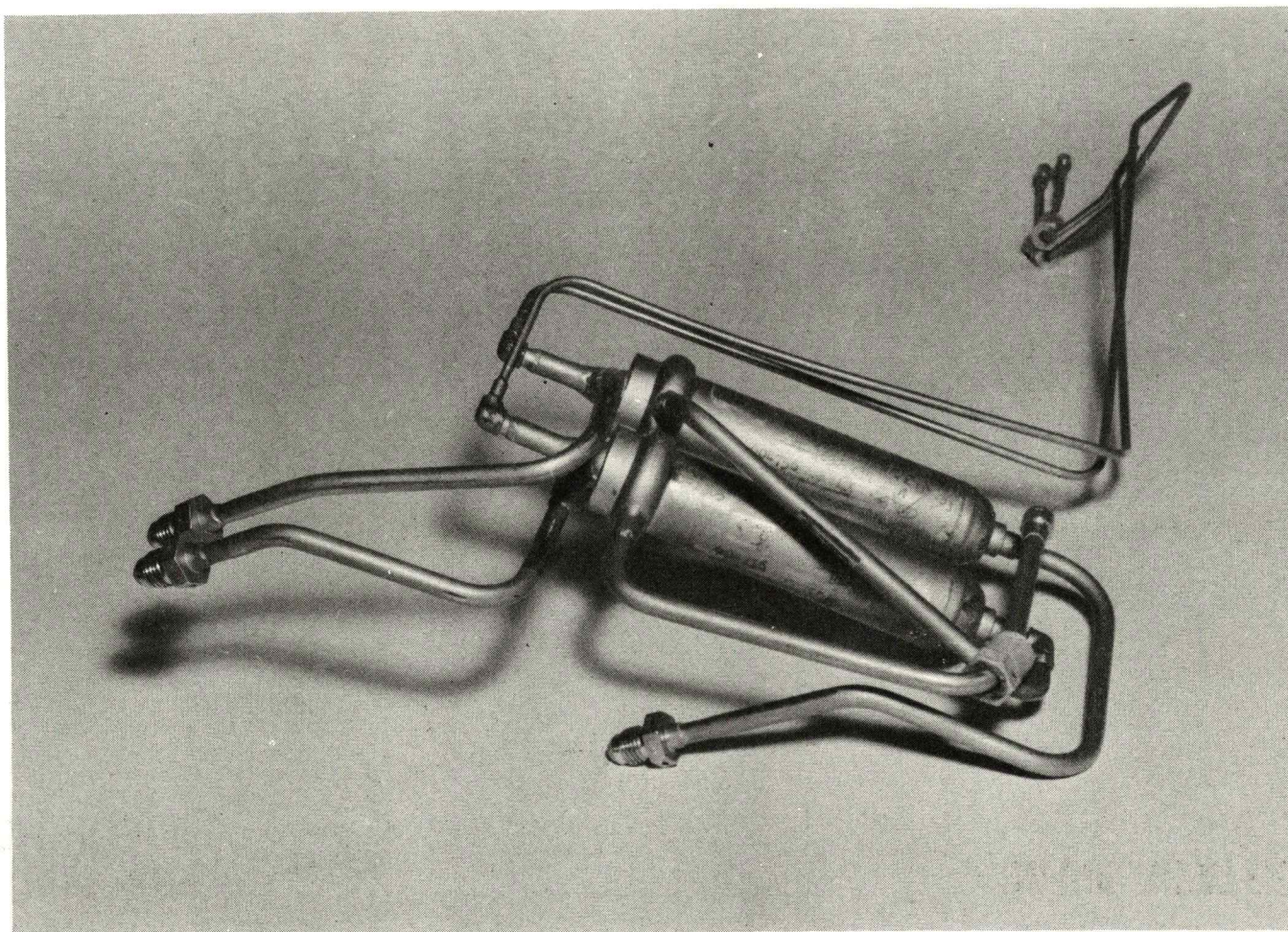


Primary Regenerator

The primary regenerator maintains the fuel cell in thermal equilibrium by providing the proper recirculating hydrogen temperatures required for both fuel cell cooling and water removal. At reduced power levels, operating efficiency is high and heat leaving the module must be conserved to maintain operating temperature. The hydrogen return stream is heated in the regenerator by the hydrogen exhaust stream. The regenerator is a compact counterflow plate-fin heat exchanger consisting of alternate layers of stainless steel flat plates and corrugated sheets.

PRIMARY REGENERATOR

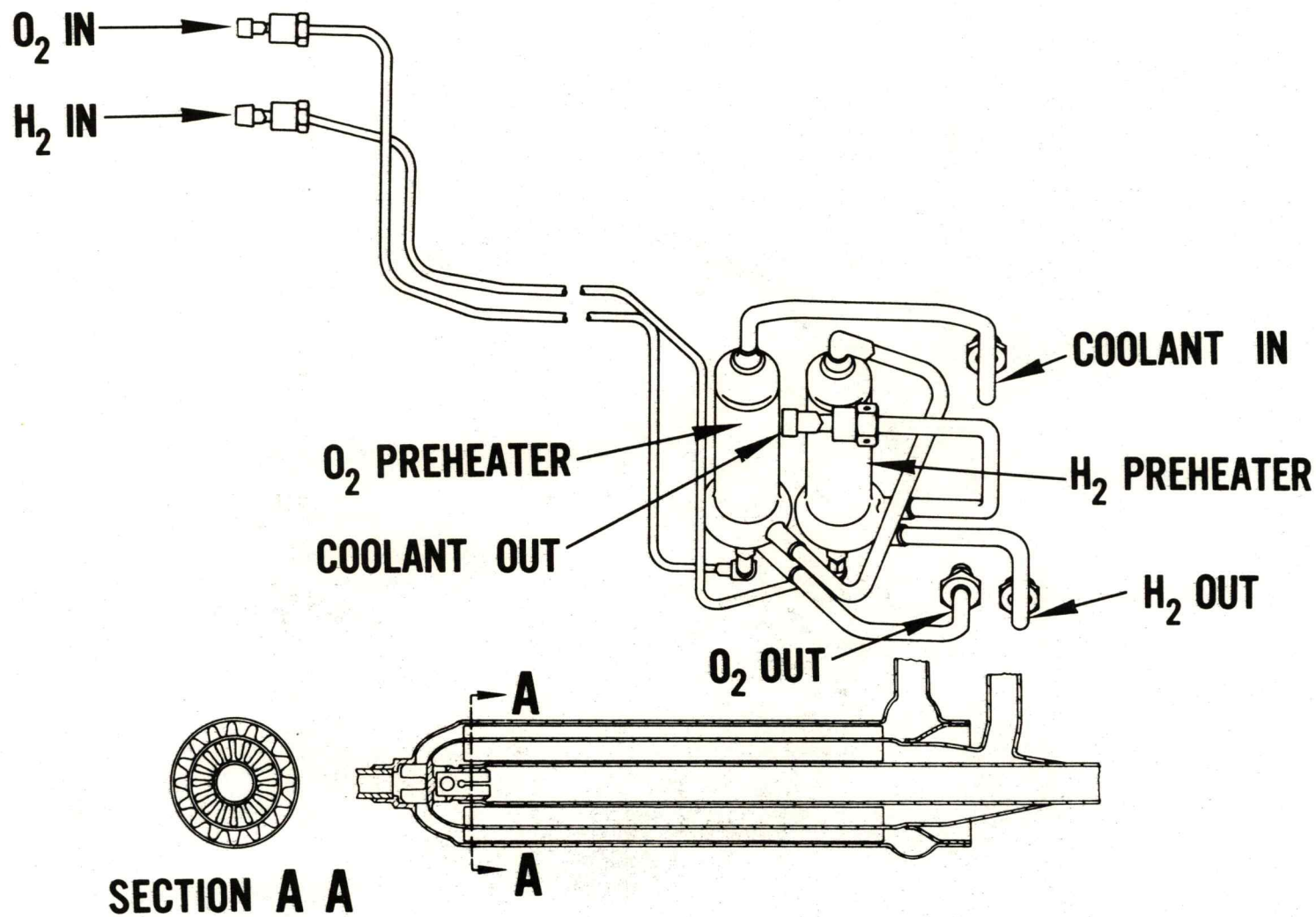


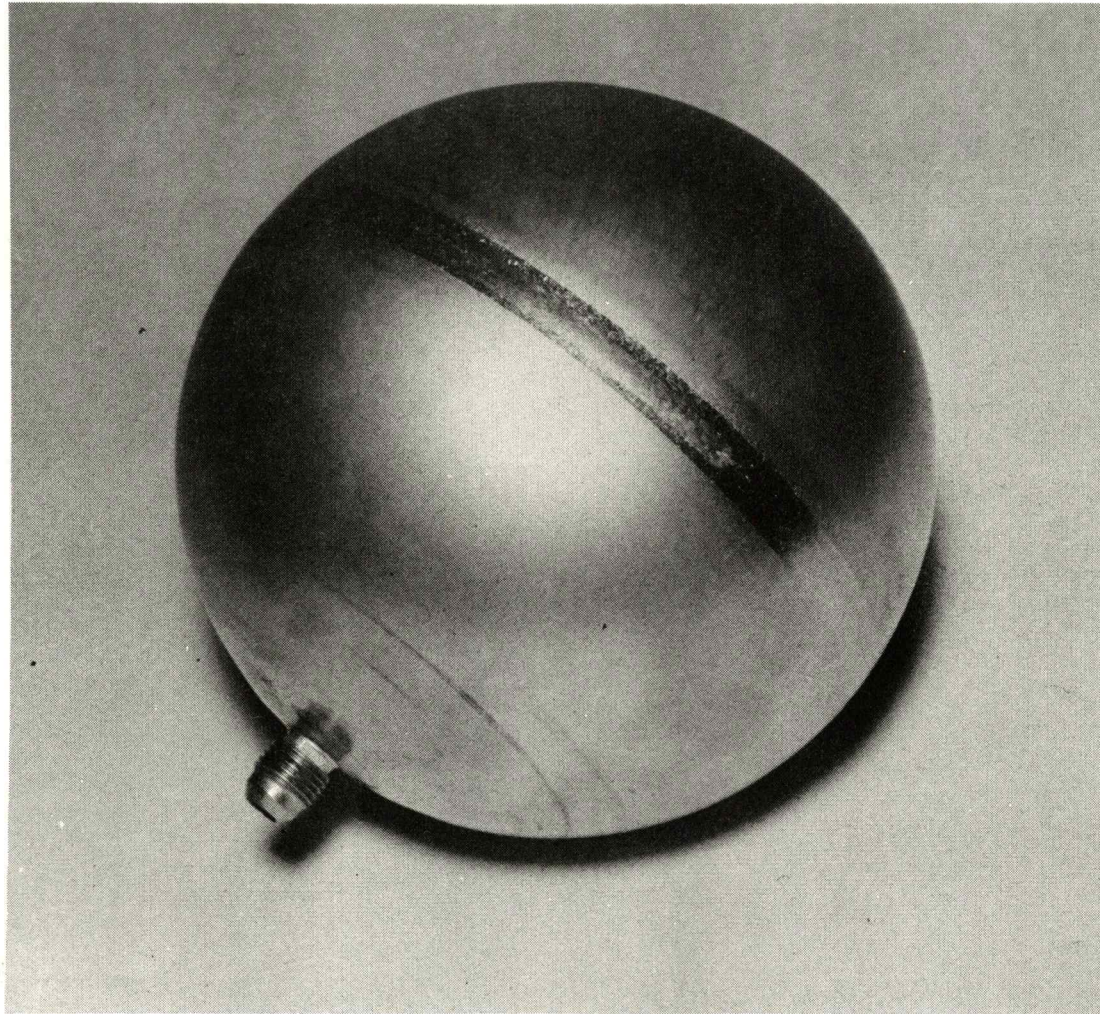


Reactant Preheaters

The reactant preheaters heat the hydrogen and oxygen from the cryogenic supply system prior to pressure regulation and consumption by the powerplant. Heat for this purpose is extracted from the glycol stream in the secondary loop of the heat rejection system. Each preheater is a small compact heat exchanger constructed of longitudinally finned concentric tubes.

REACTANT HEATER

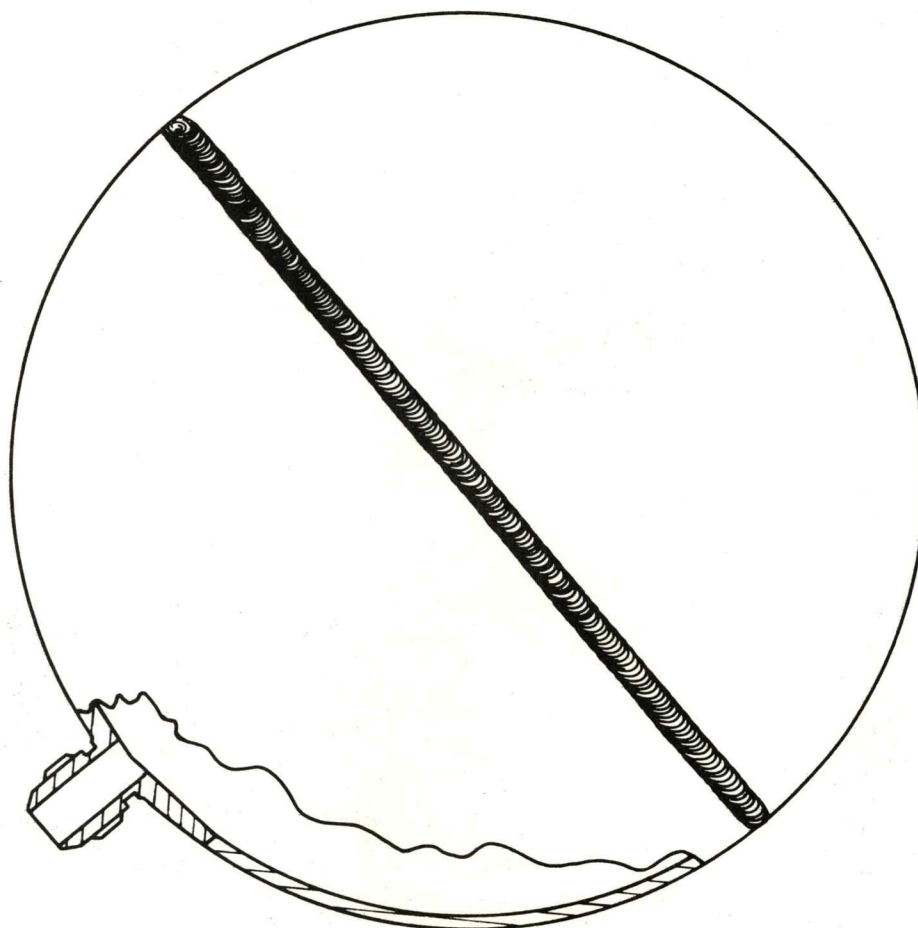




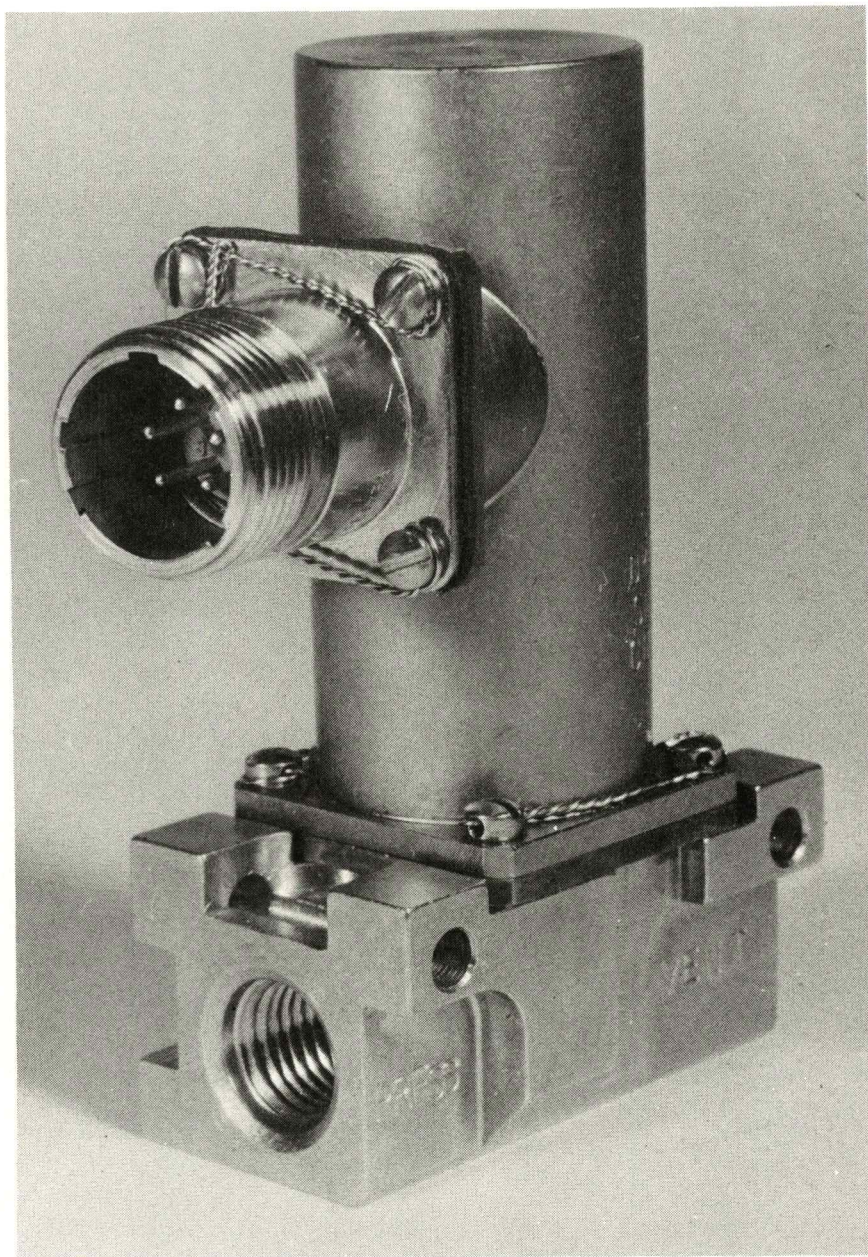
Nitrogen Tank

This component serves to store gaseous nitrogen in sufficient quantity to allow for pressurizing the powerplant power section pressure vessel, coolant system, and reactant control reference pressure lines.

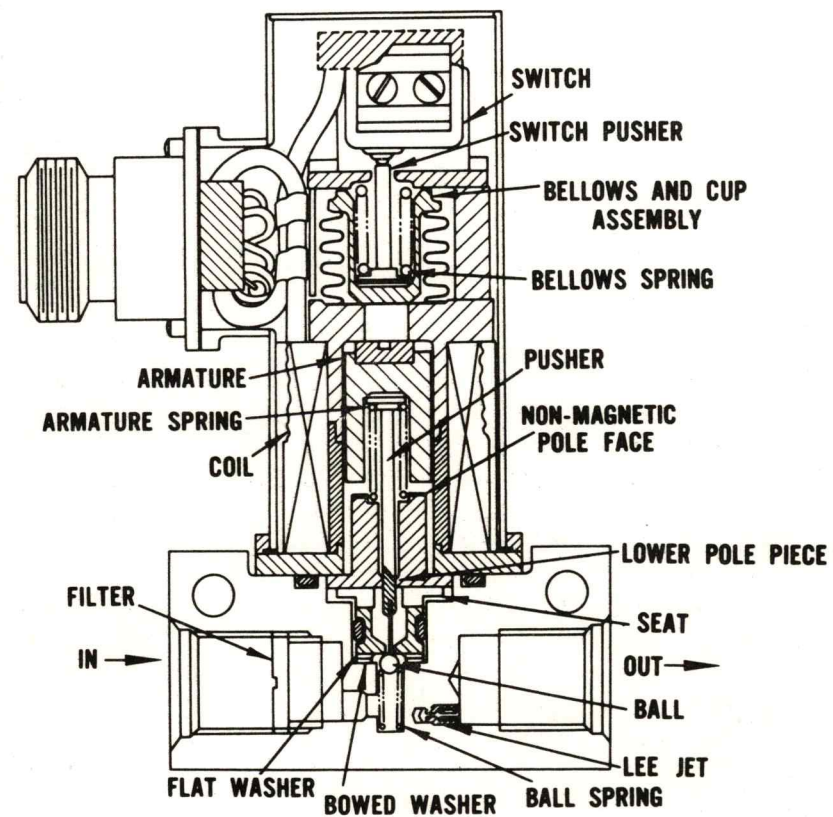
NITROGEN TANK

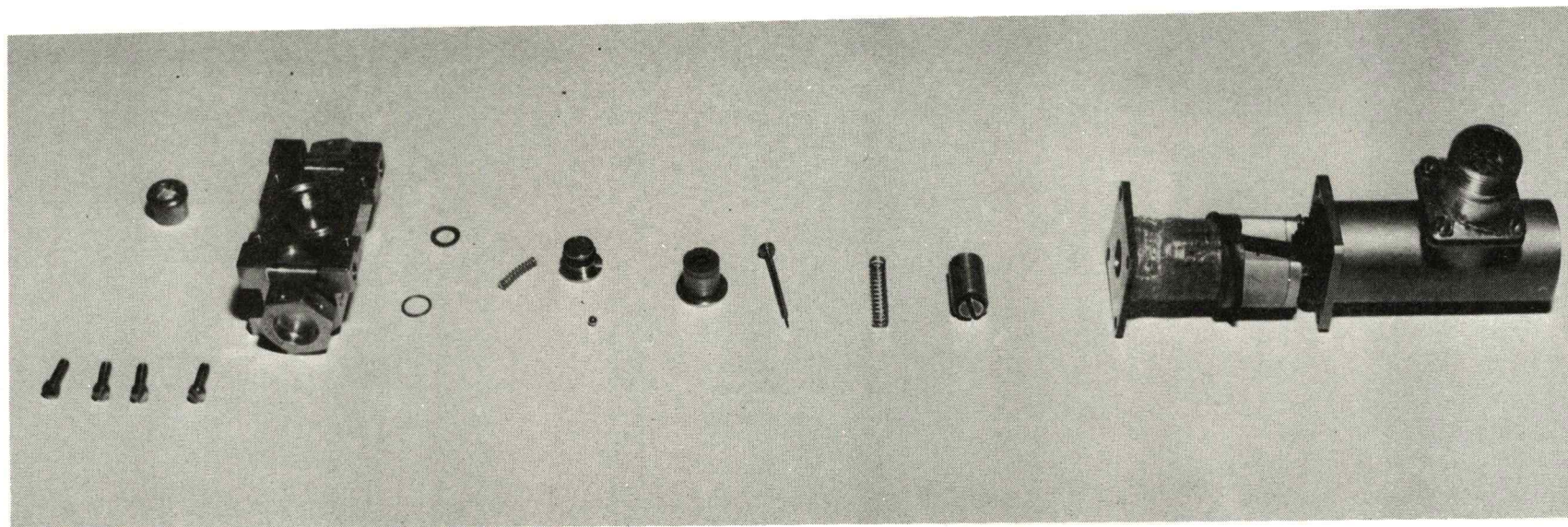


This component serves to store gaseous nitrogen in sufficient quantity to allow for pressurizing the powerplant power section pressure vessel, coolant system, and reactant control reference pressure lines.



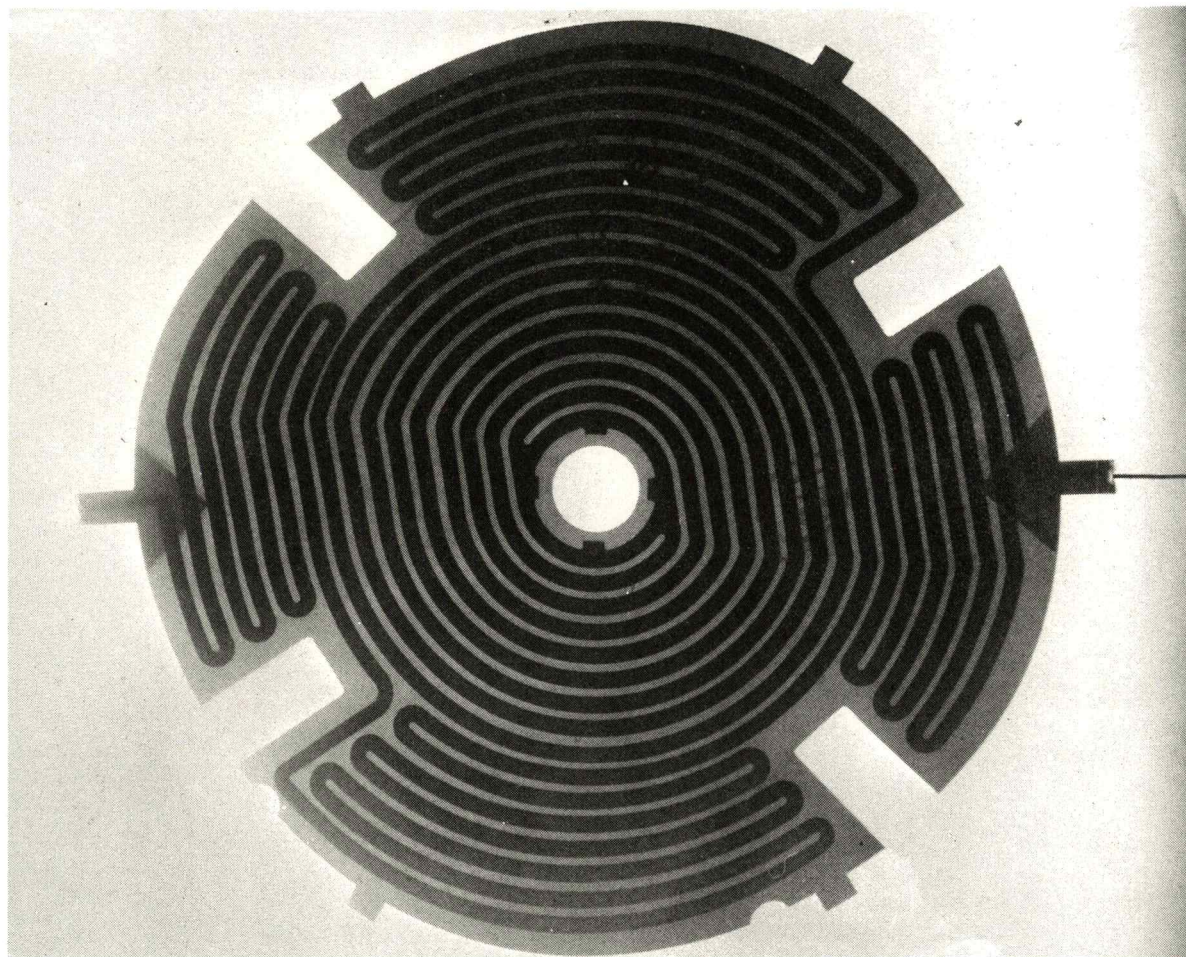
REACTANT PURGE VALVE





Reactant Purge Valves

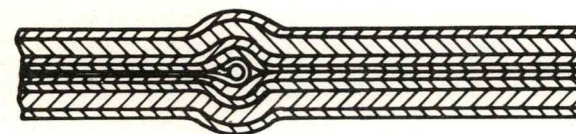
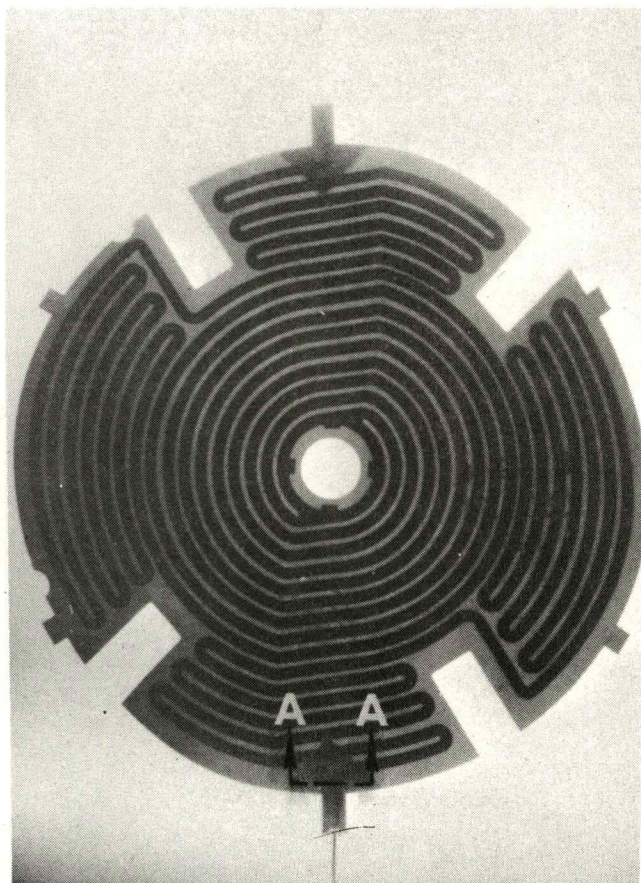
The reactant purge valves vent reactant gases from the module to purge the cells of accumulated non-consumable inerts. The electrically actuated solenoid valve operates on 28 volts d.c. power. Reactant flow rate is set for a fixed diameter interchangeable orifice located downstream of the valve. The solenoid coil circuit has diode noise suppression.



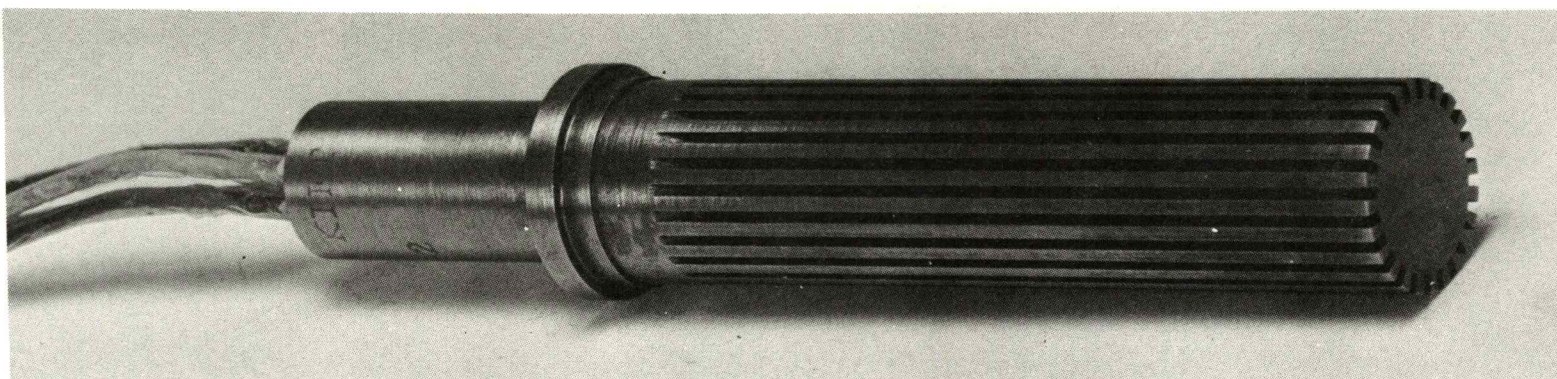
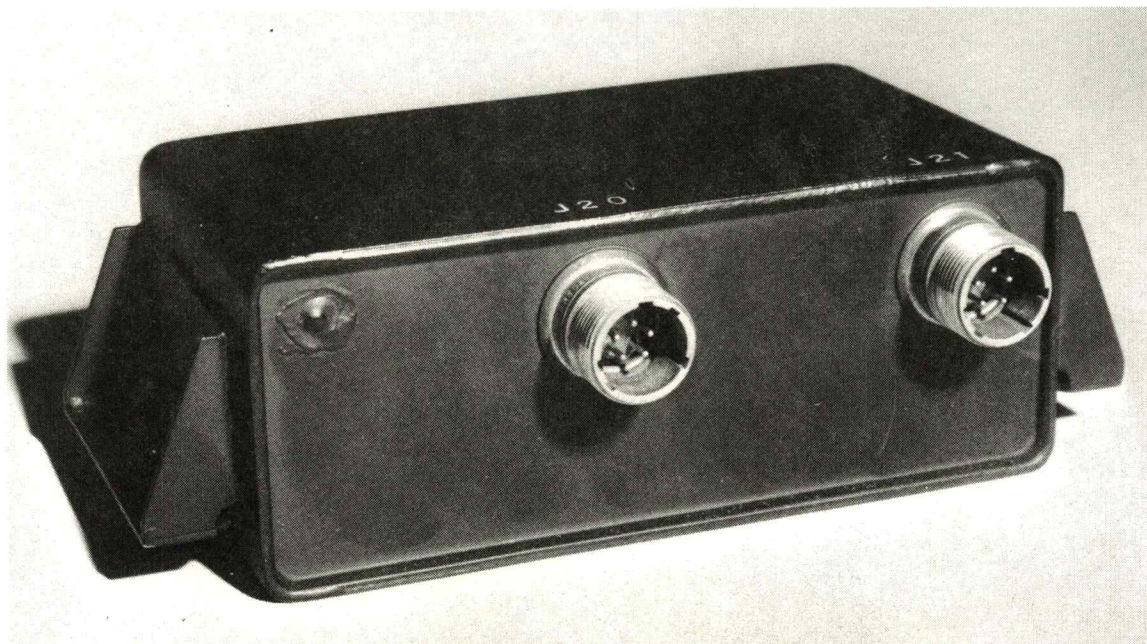
Intercel Heater

The function of the intercel heater is to heat the power stack above the melting point of the electrolyte permitting the powerplant to be put on load.

FUEL CELL HEATING ELEMENT

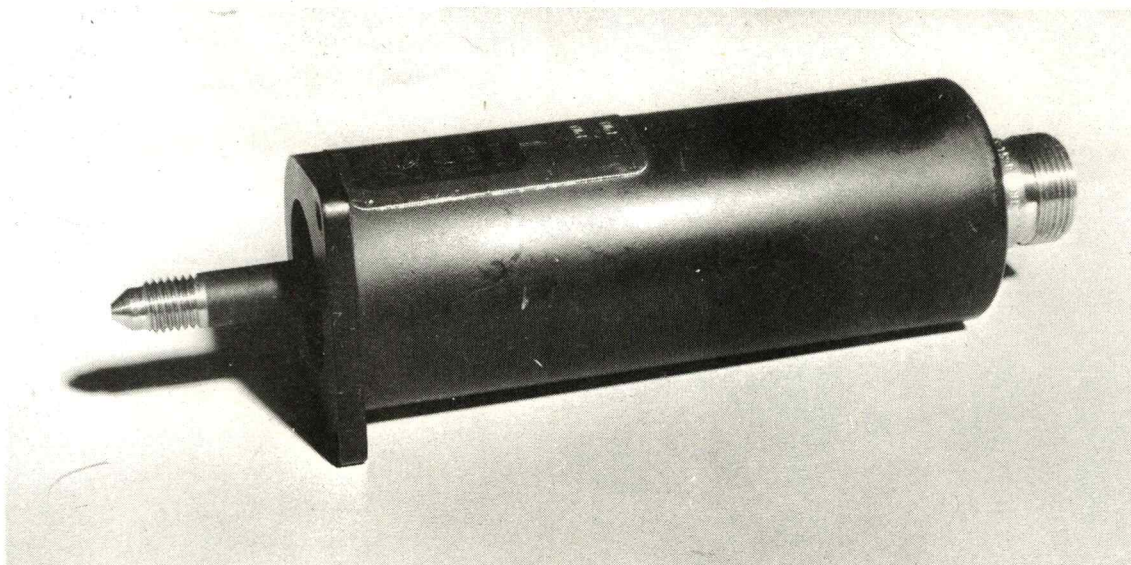


SECTION A-A



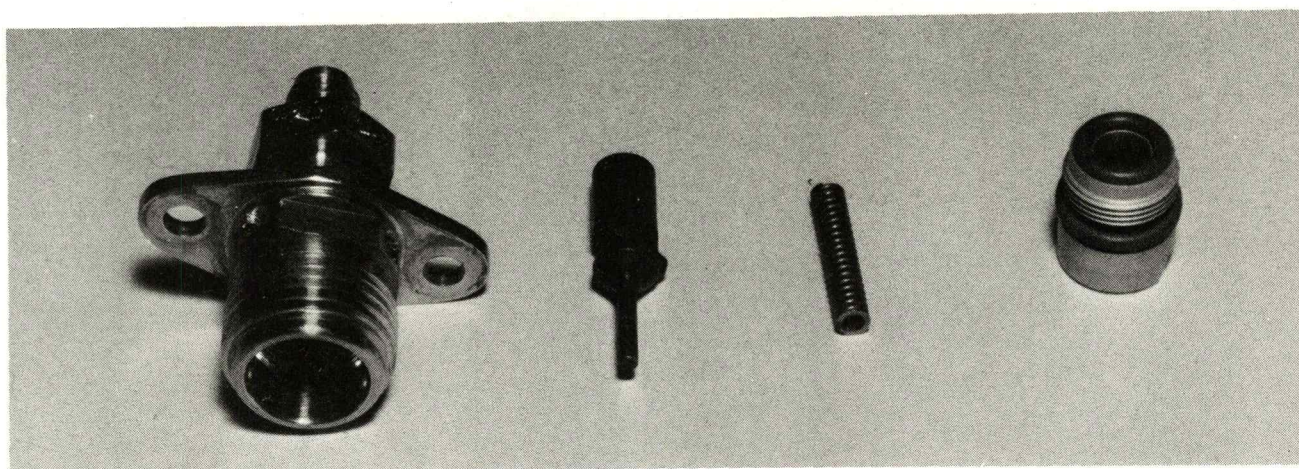
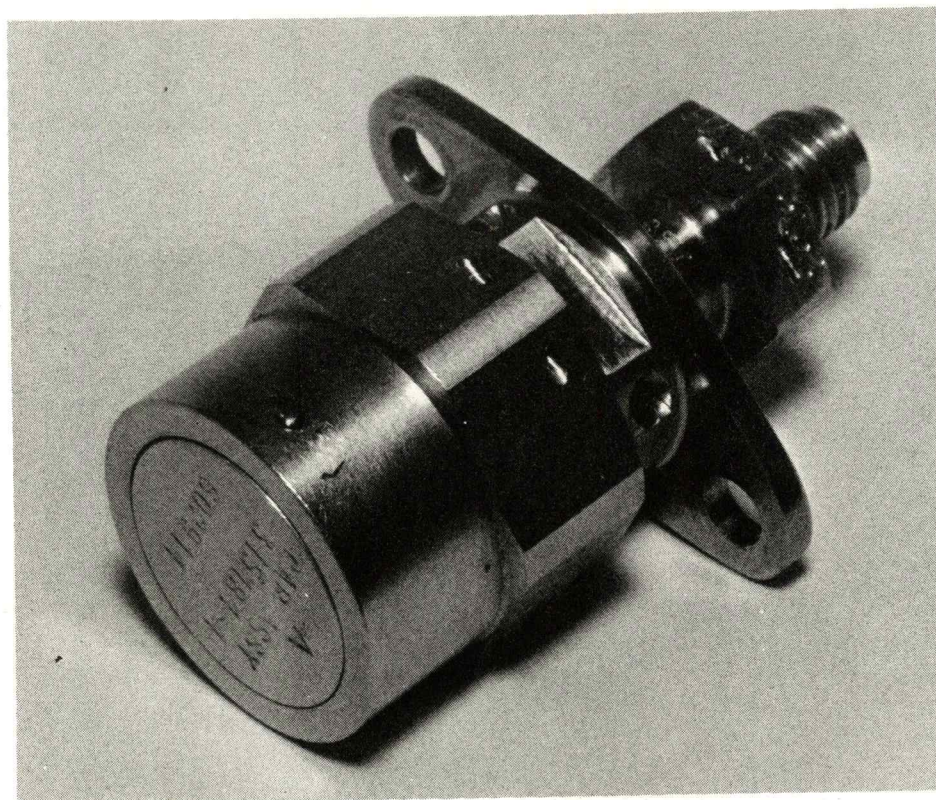
Inline Heater (Cartridge Heater) and Minimum Power Sustainer

The inline heater and minimum power sustainer provide sufficient heat during low power operation to maintain the power stack operating temperature.



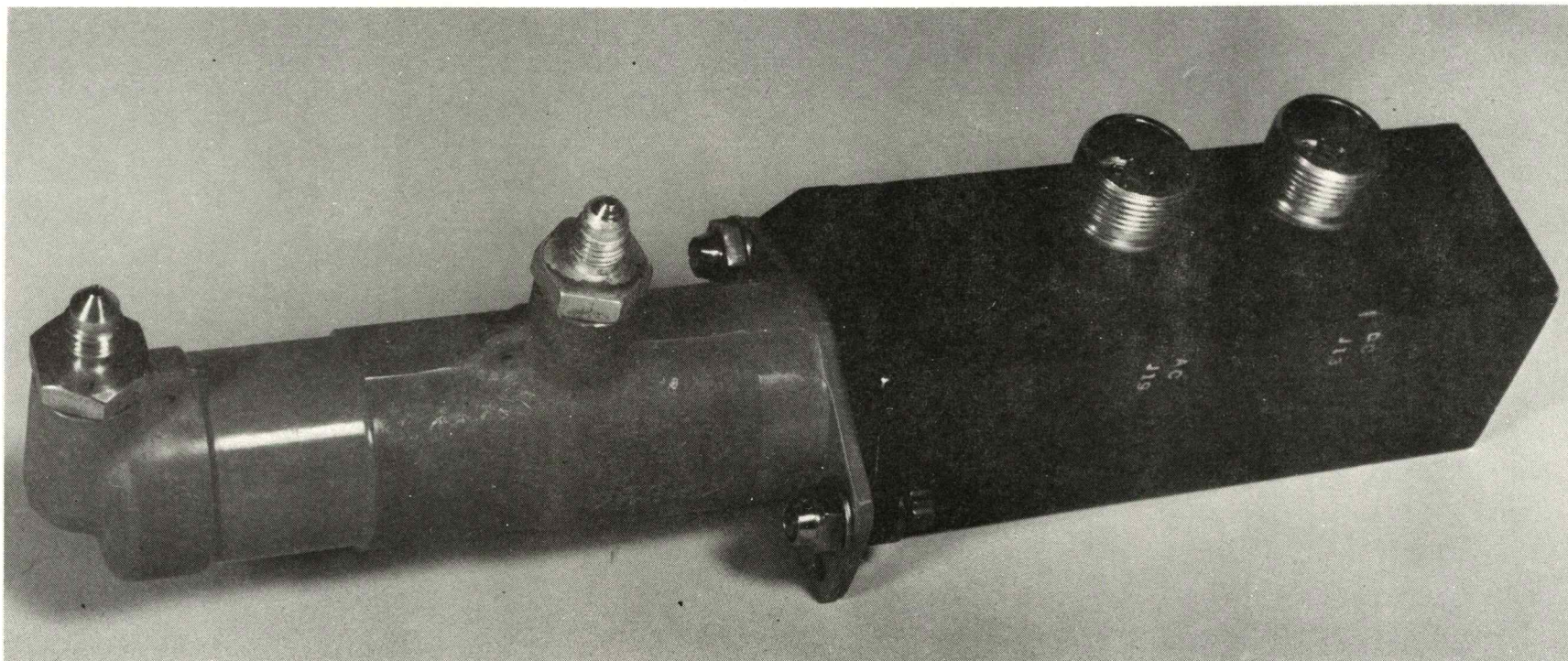
Pressure Transducer

The pressure transducers are used to measure the pressure of the reactant gases and the pressure of the inert gas.



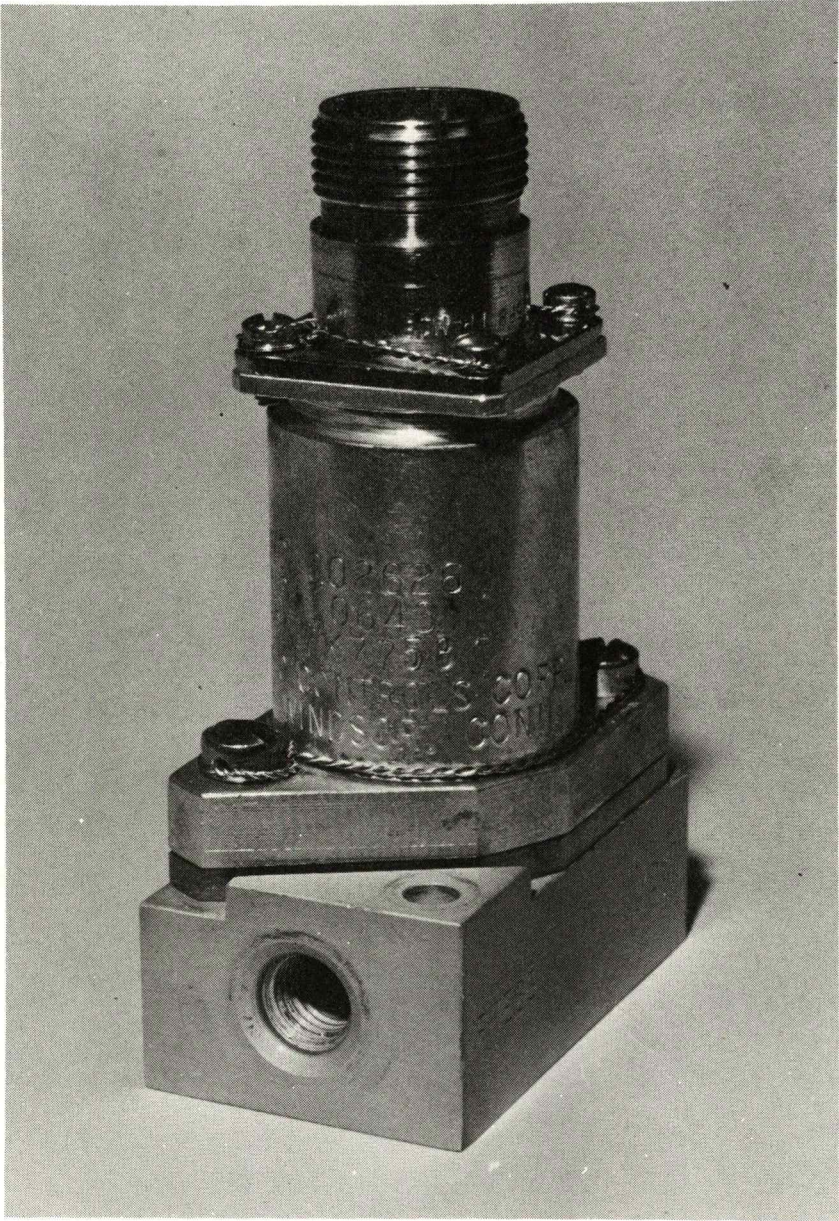
Nitrogen Sampling Valve

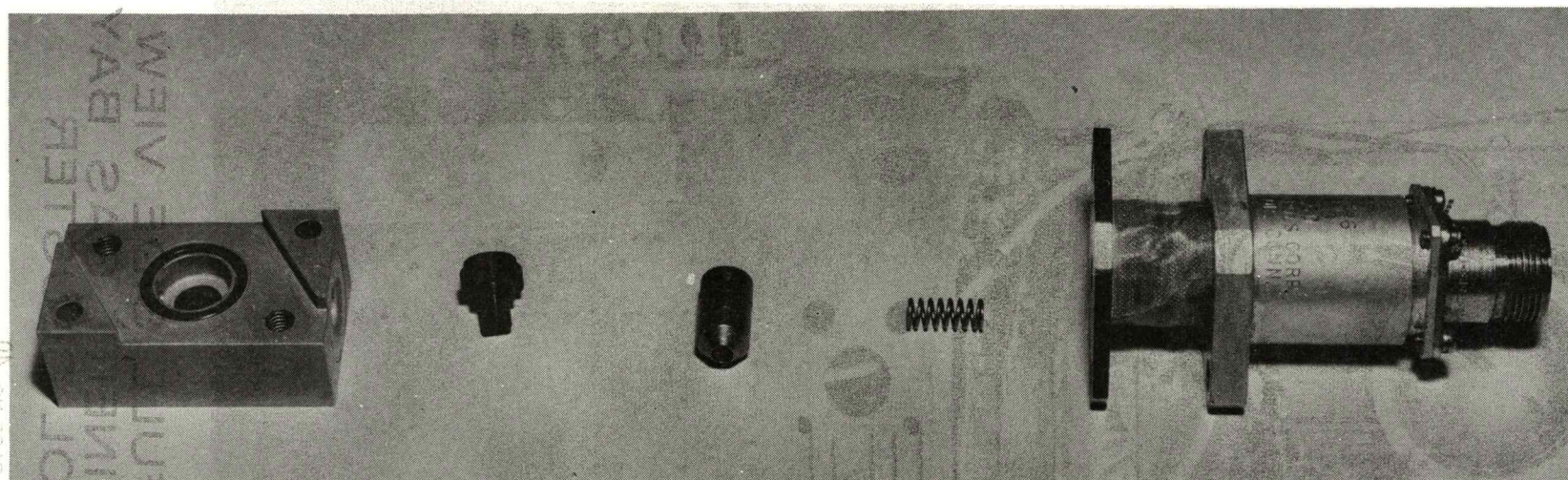
The nitrogen sampling valve permits a sample of gas to be withdrawn from the cell stack nitrogen blanket.



Water Purity Sensor

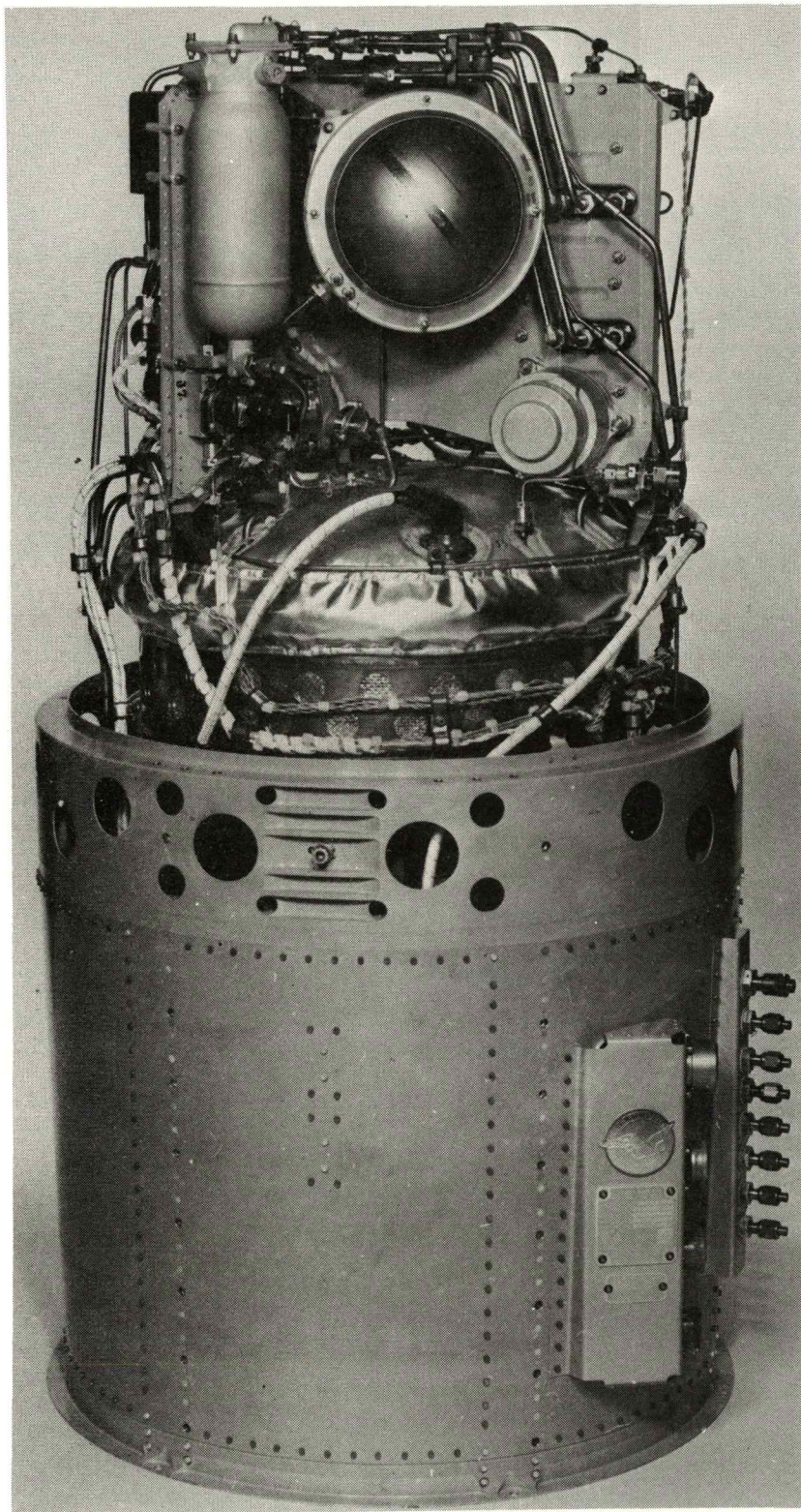
The water purity sensor measures the conductivity of the powerplant product water and provides a signal to external readout equipment.



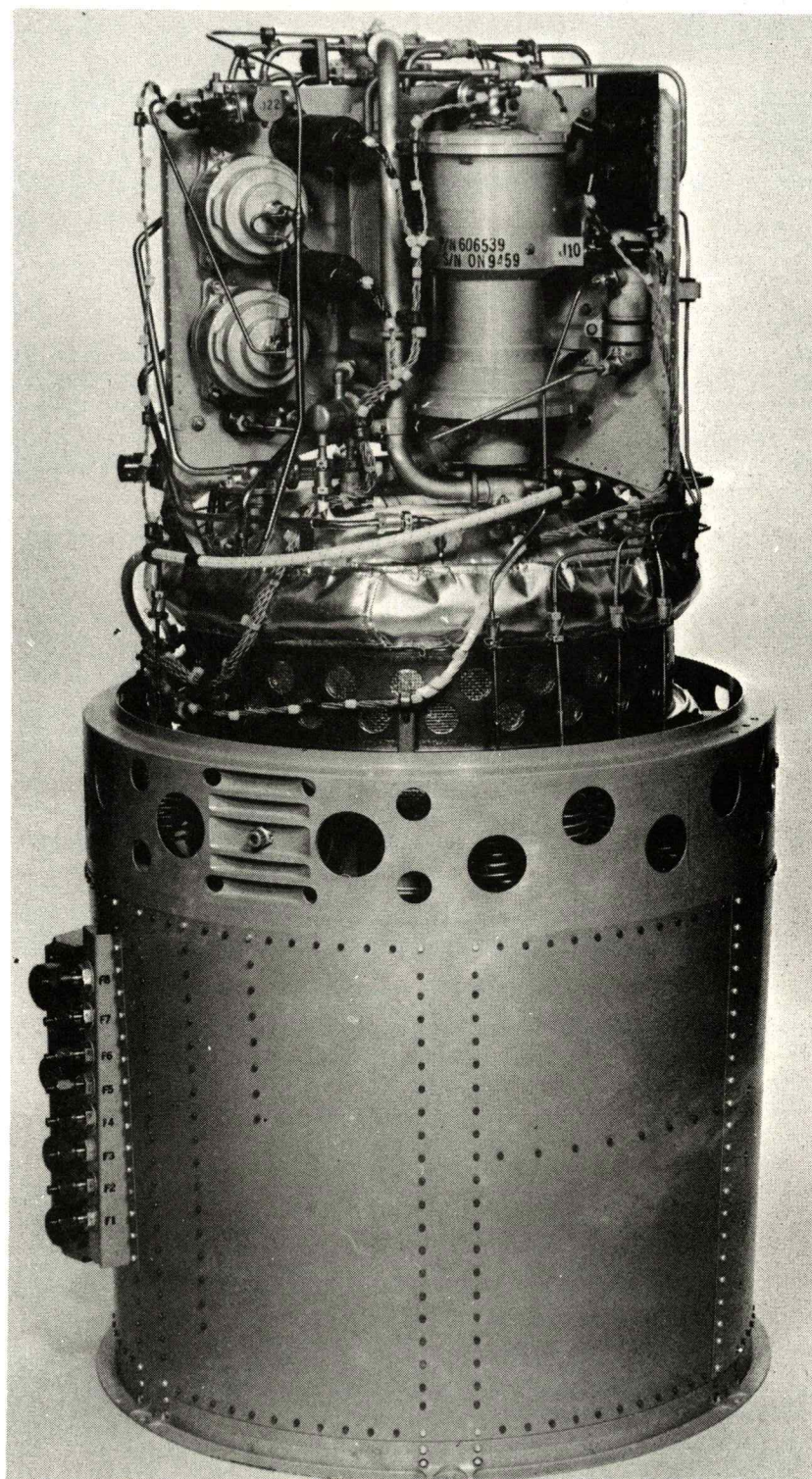


Nitrogen Fill Valve

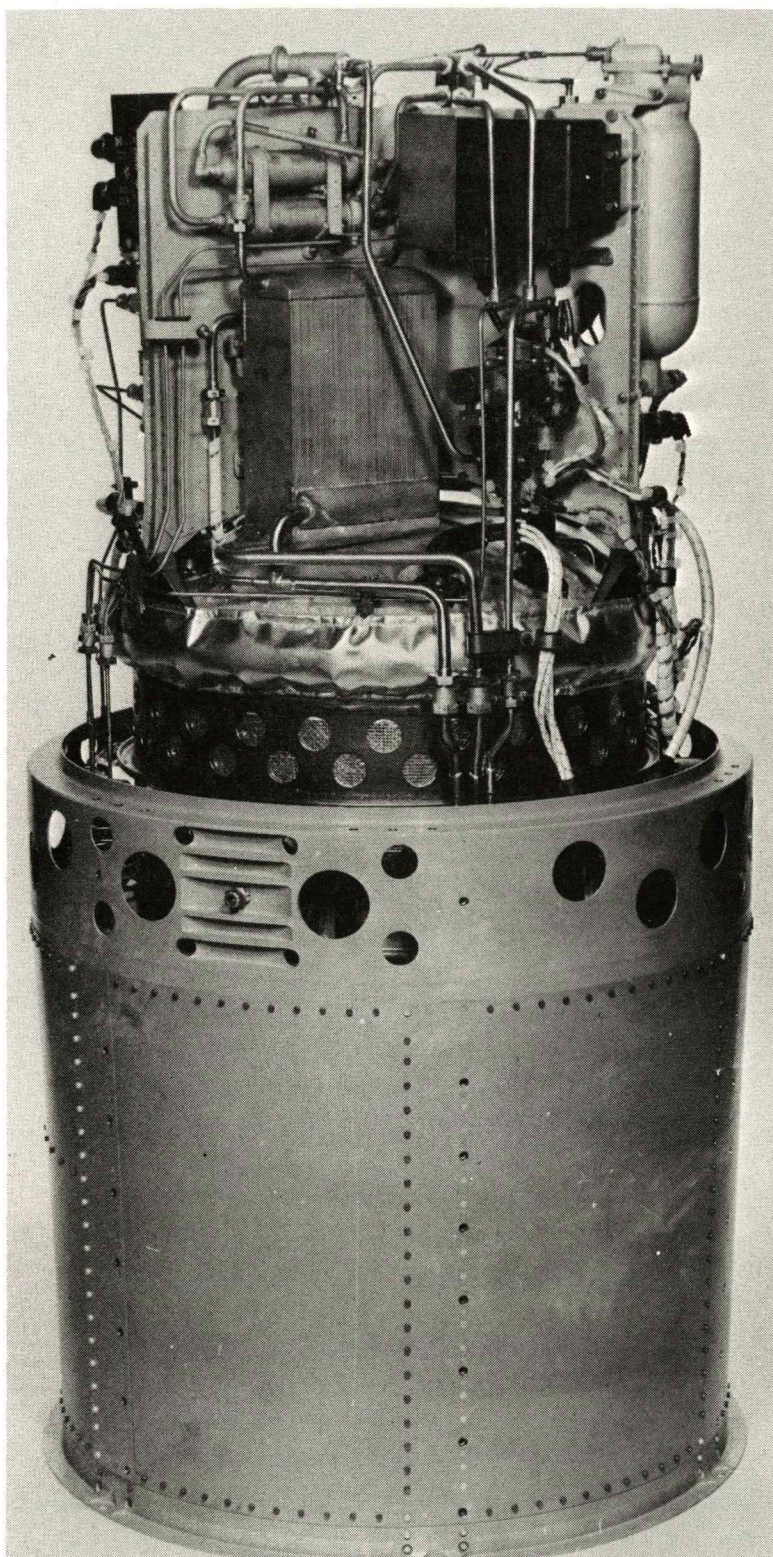
The nitrogen fill valve permits filling and dumping of the high pressure nitrogen system.



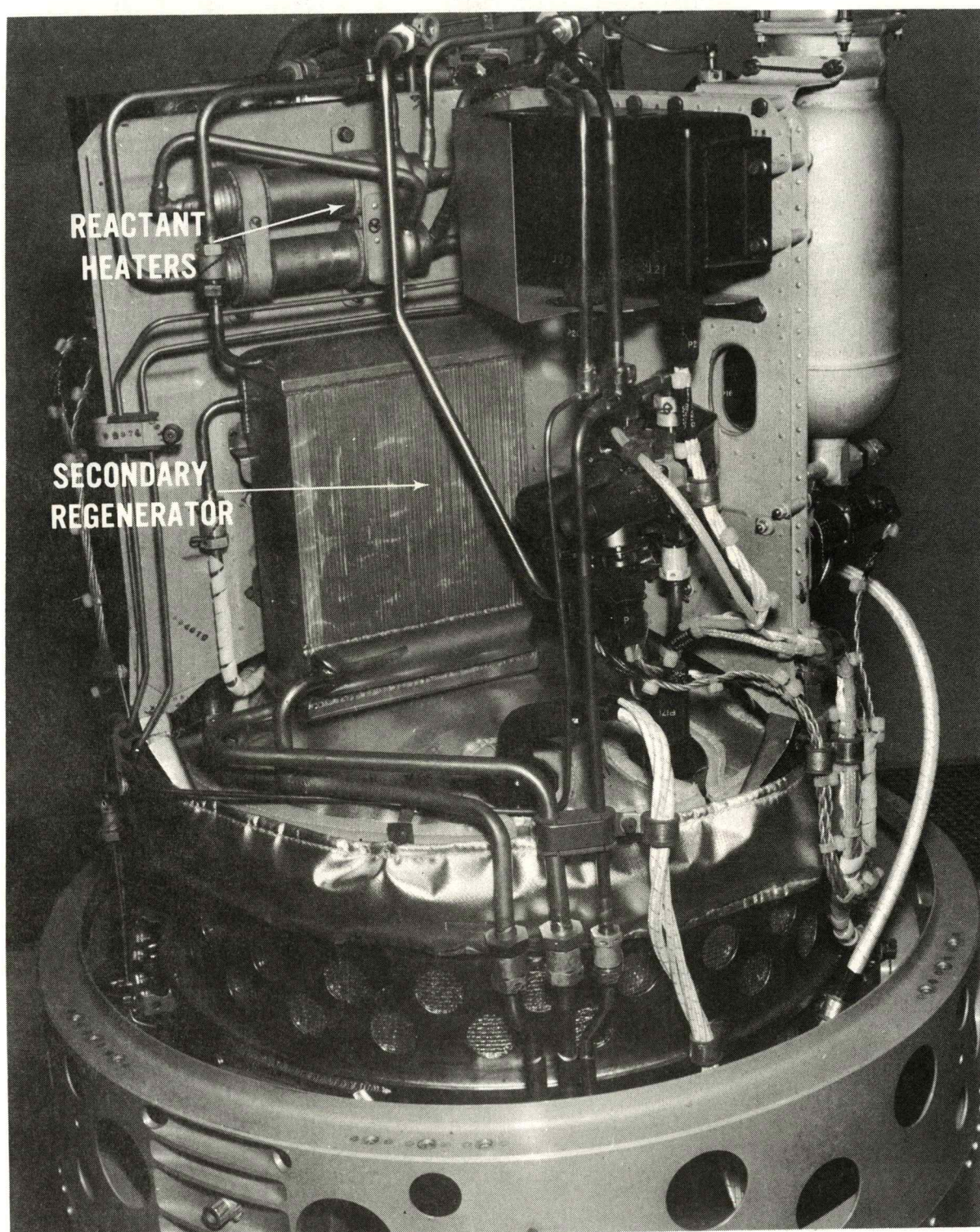
PC3A-2 FULL SIDE VIEW
SHOWING INERT GAS BAY
CONTROL CLUSTER



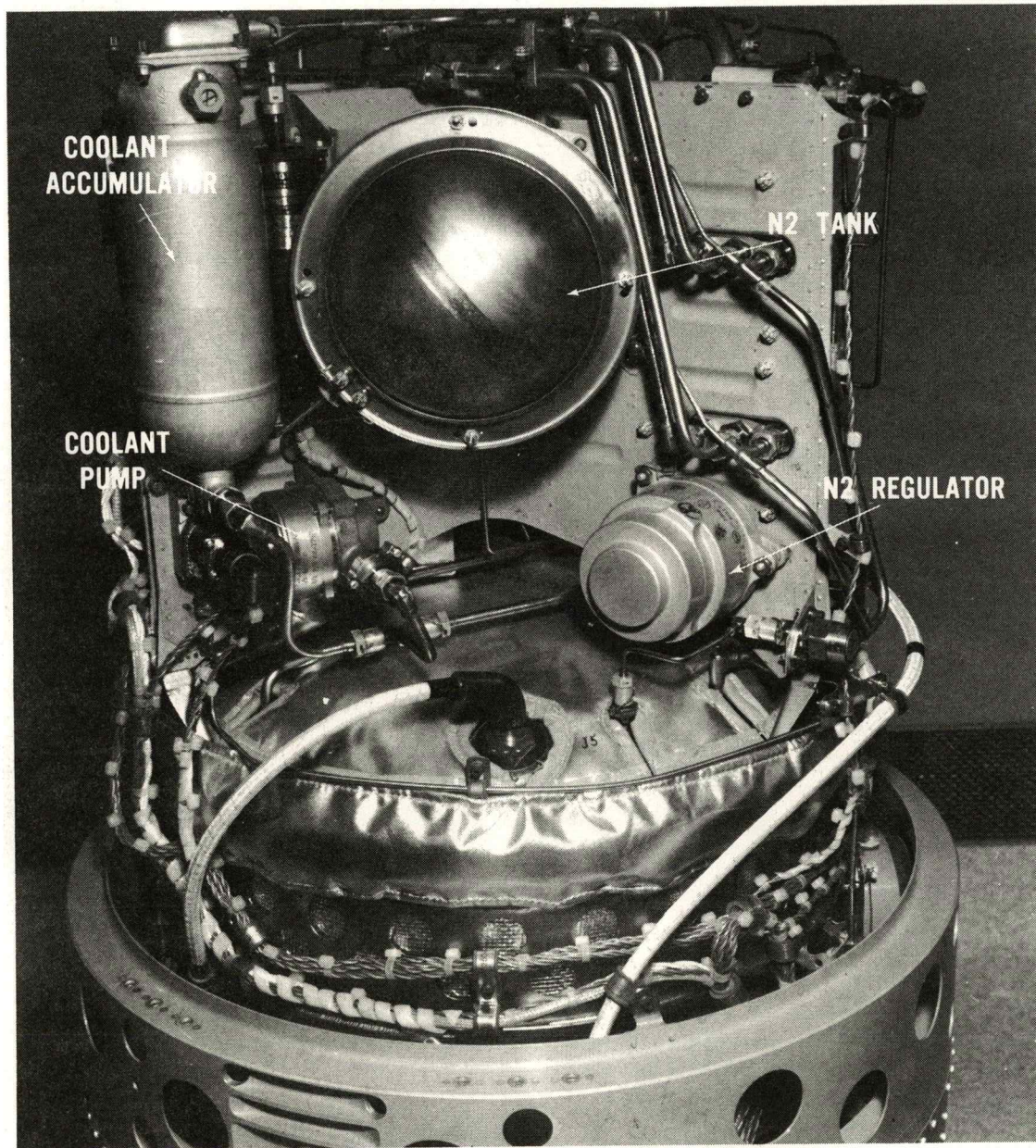
PC3A-2 FULL SIDE VIEW
SHOWING REACTANT
BAY CONTROL CLUSTER



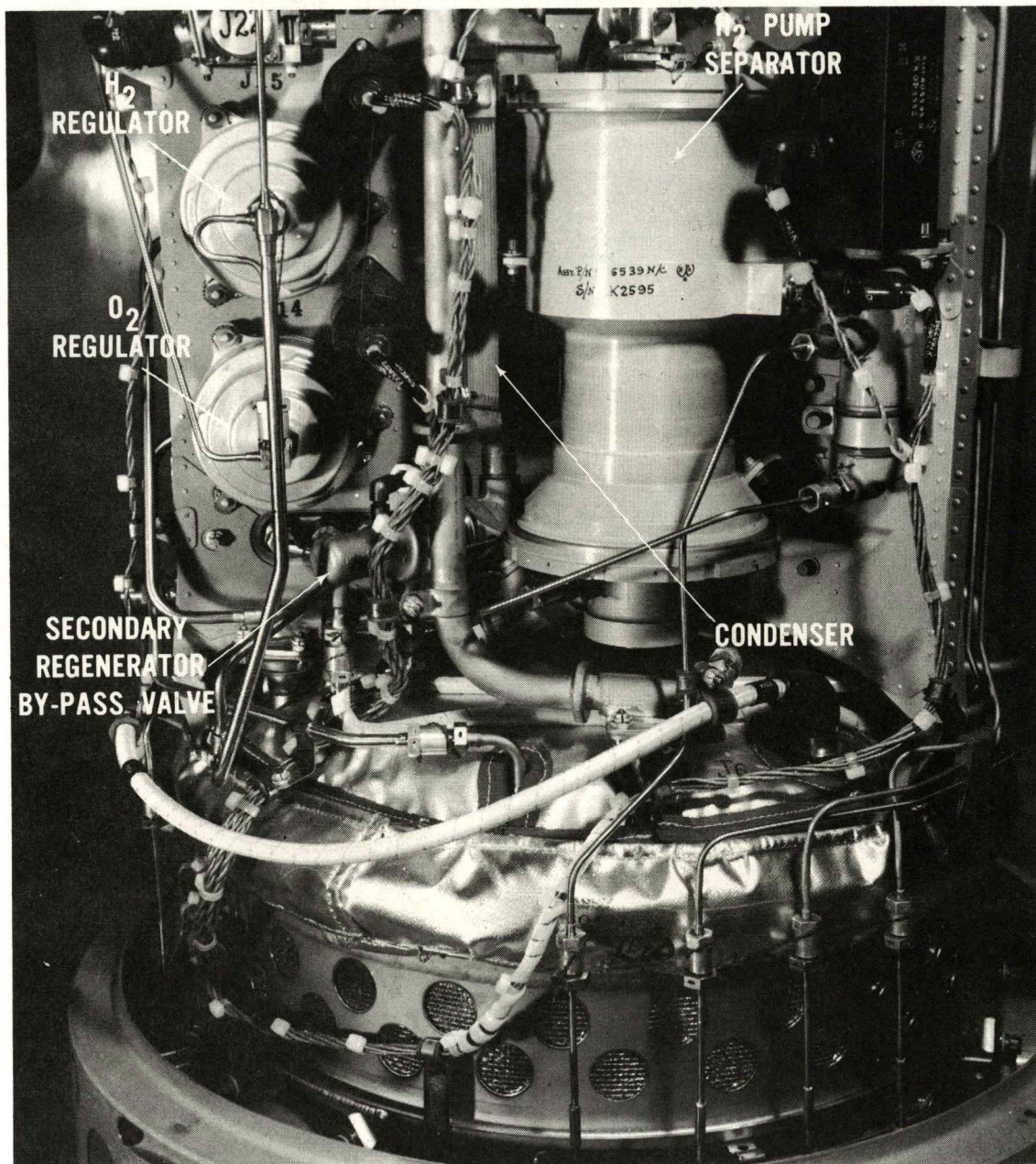
**PC3A-2 FULL SIDE VIEW
SHOWING COOLANT
BAY CONTROL CLUSTER**



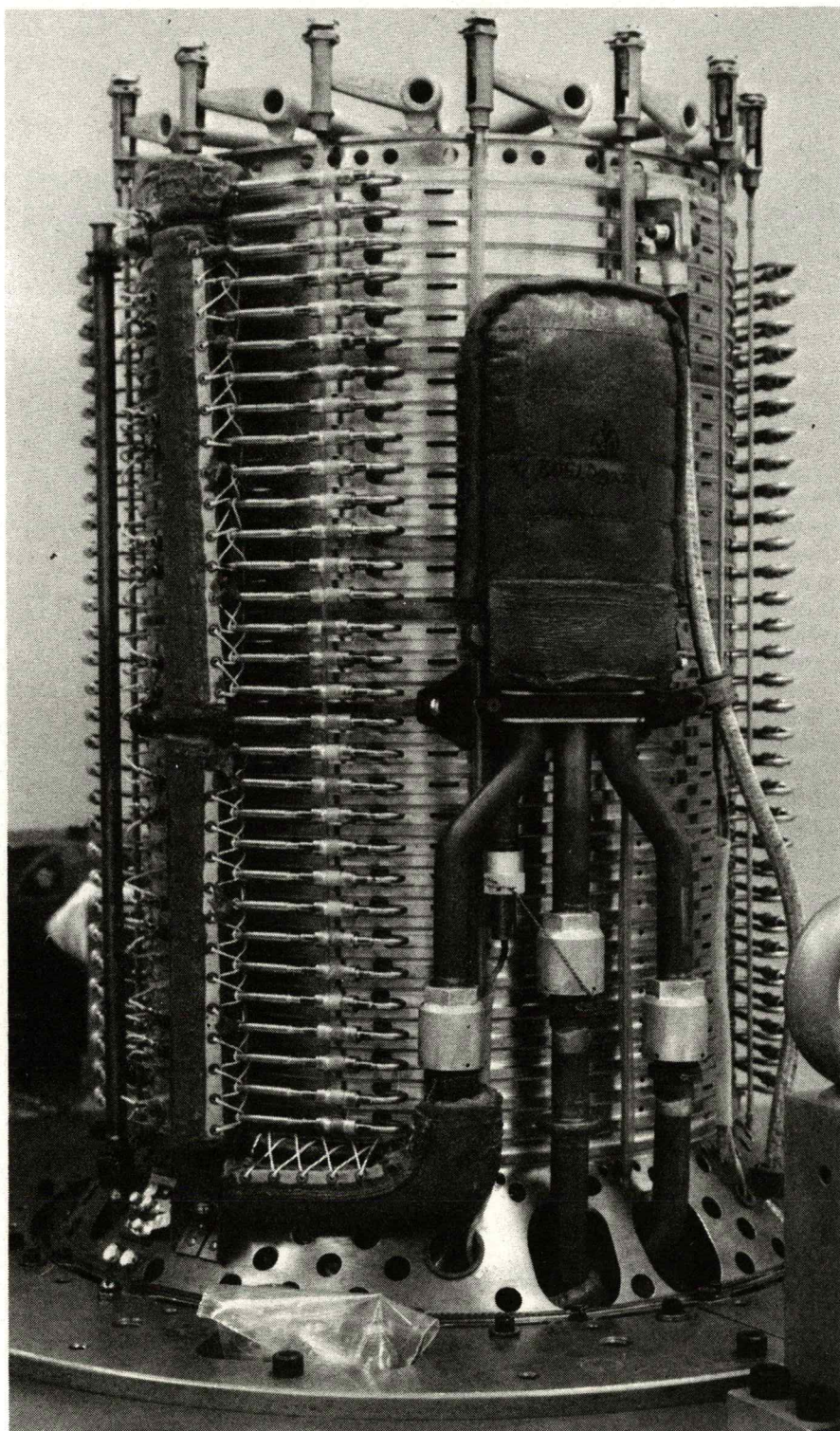
PC3A-2 COOLANT
BAY CONTROL CLUSTER



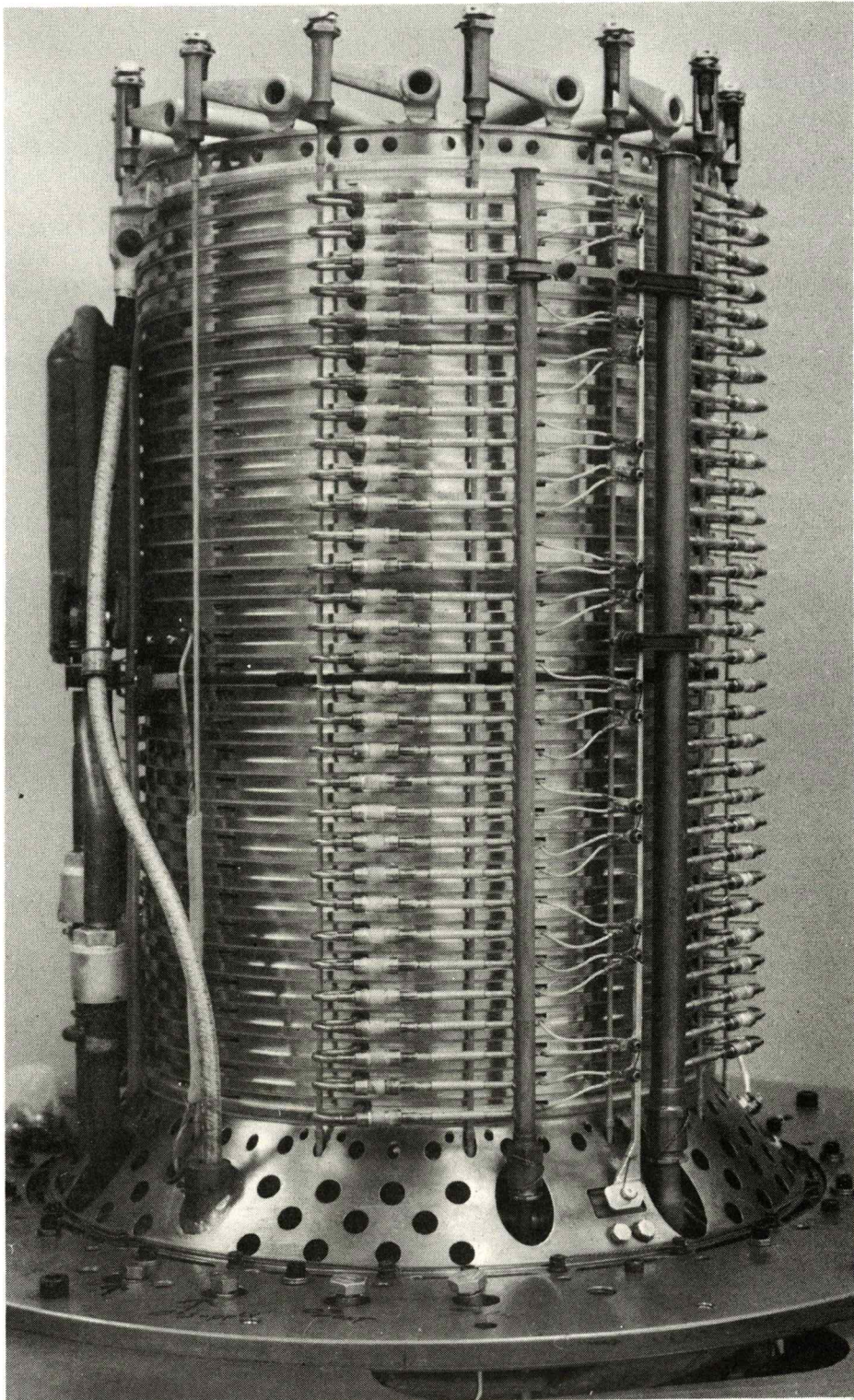
PC3A-2 INERT GAS
BAY CONTROL CLUSTER



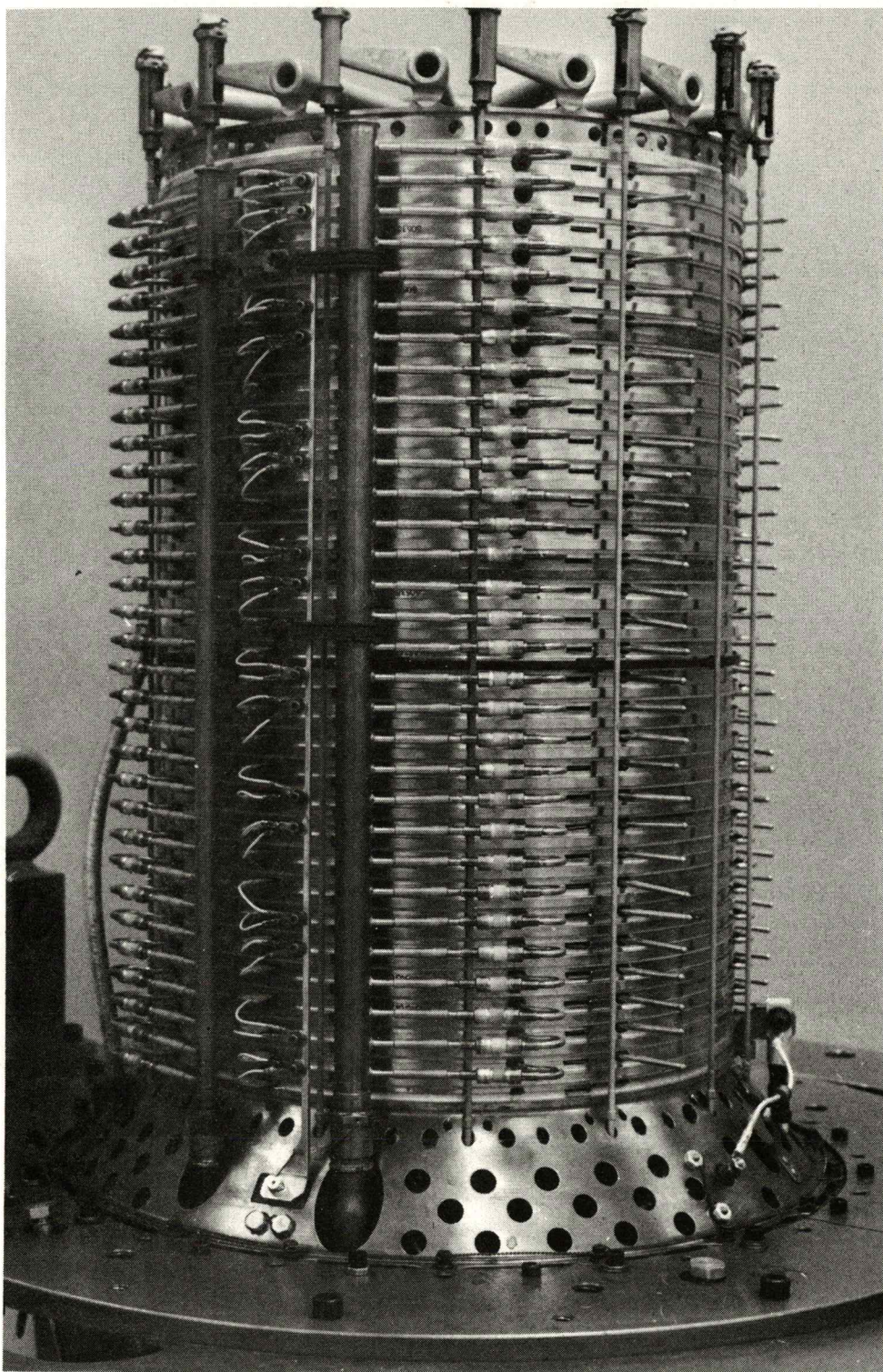
PC3A-2 REACTANT
BAY CONTROL CLUSTER



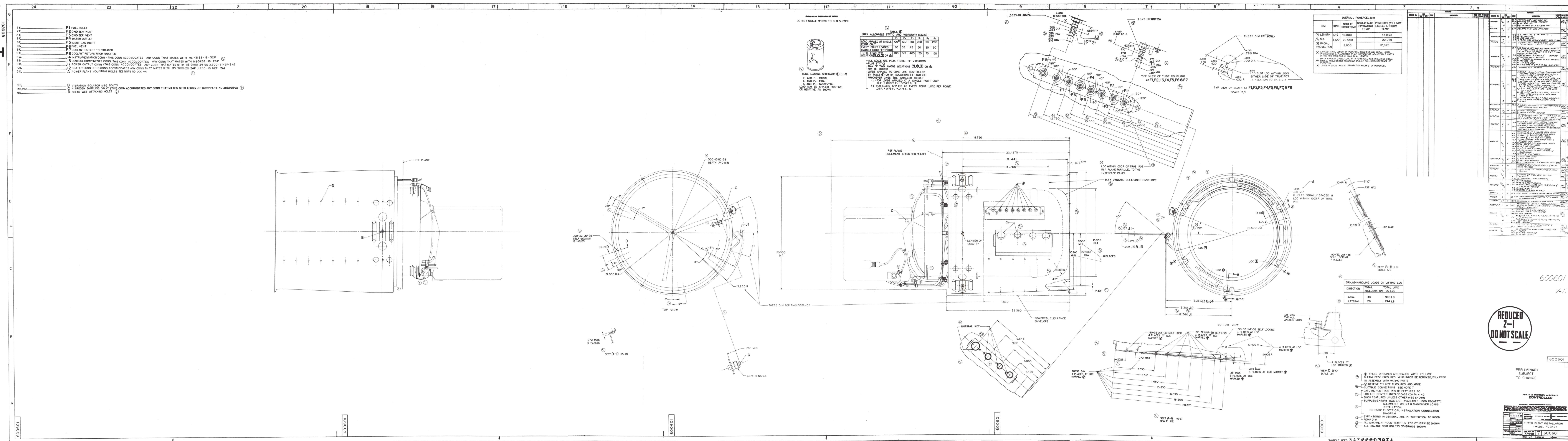
**PC3A-2 POWER SECTION
FULL SIDE VIEW SHOWING PRIMARY
REGENERATOR BY-PASS VALVE**



PC3A-2 POWER
SECTION FULL SIDE VIEW (1)

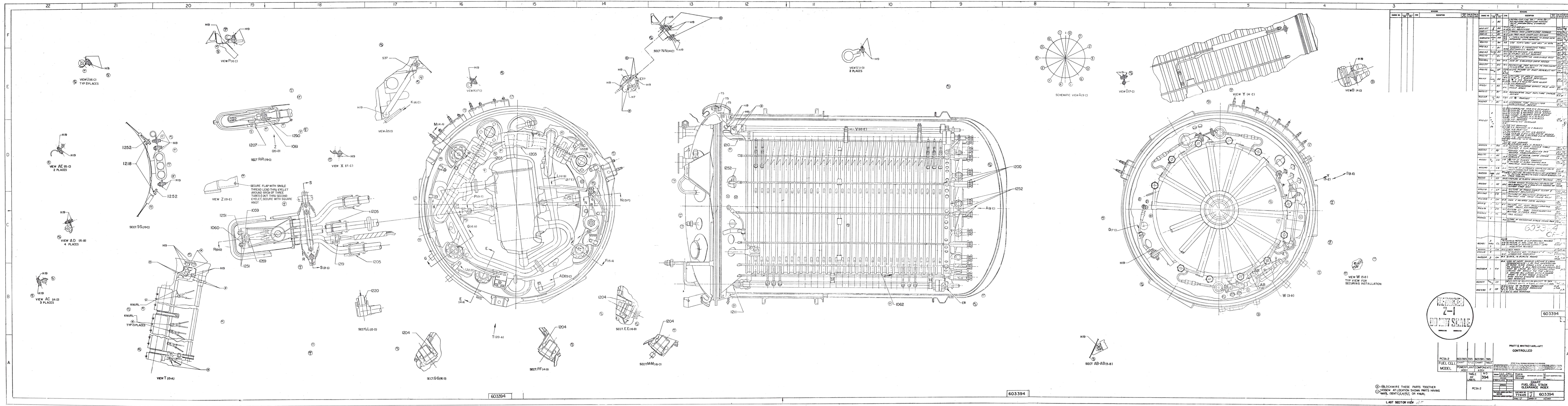


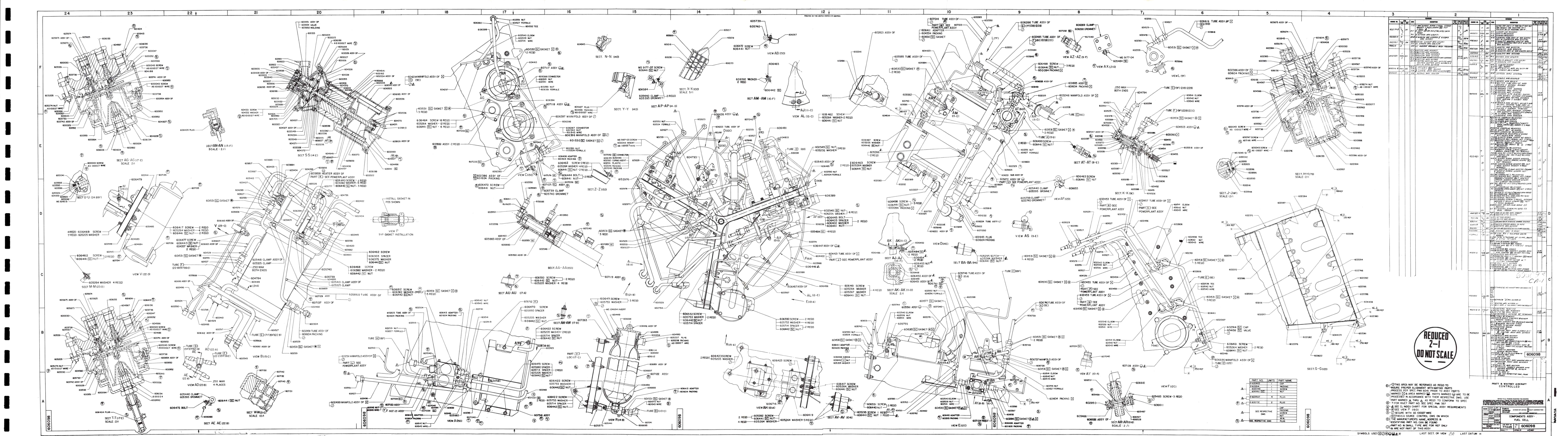
PC3A-2 POWER SECTION
FULL SIDE VIEW (2)

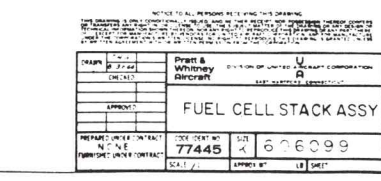


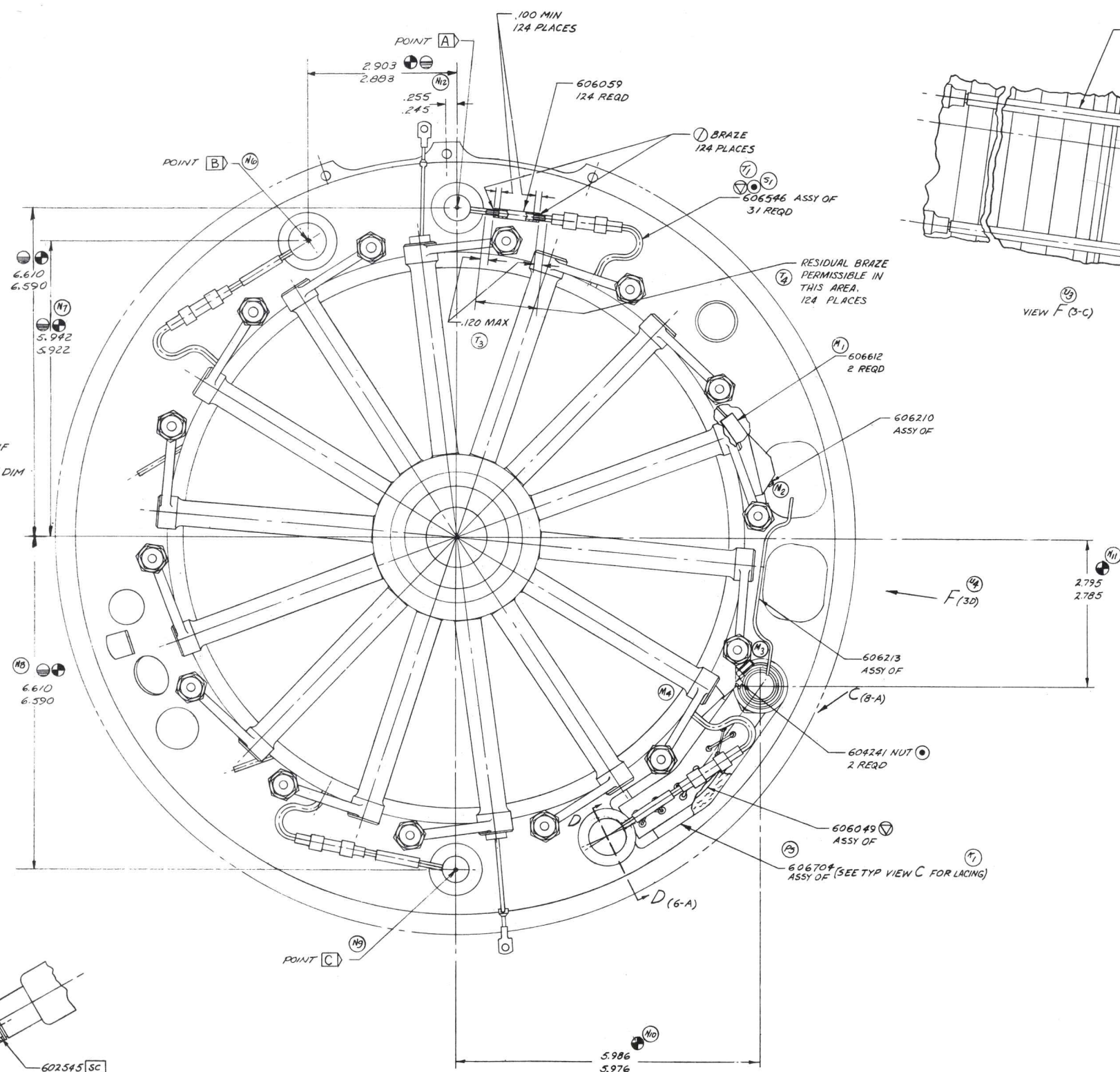
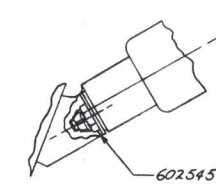
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SUBJECT
TO CHANGE

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DRAWN 1-25 (1-53) J-3-5 CHECKED J-25-51 DATE 1-25-51 PERMITS J-2-5-51	Pratt & Whitney Aircraft DIVISION OF UNITED STATES GOVERNMENT WASHINGTON, D. C. AIRCRAFT DIVISION, CONTRACT F-POWER PLANT INSTALLATION (MODEL PC 342)	ORDER NO. 77445 PART NO. NONE PREPARED UNDER CONTRACT NONE	SIZE 1/2 SHEETS OF 13 SHEET









REMEMBER
2-1
DO NOT SCALE
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