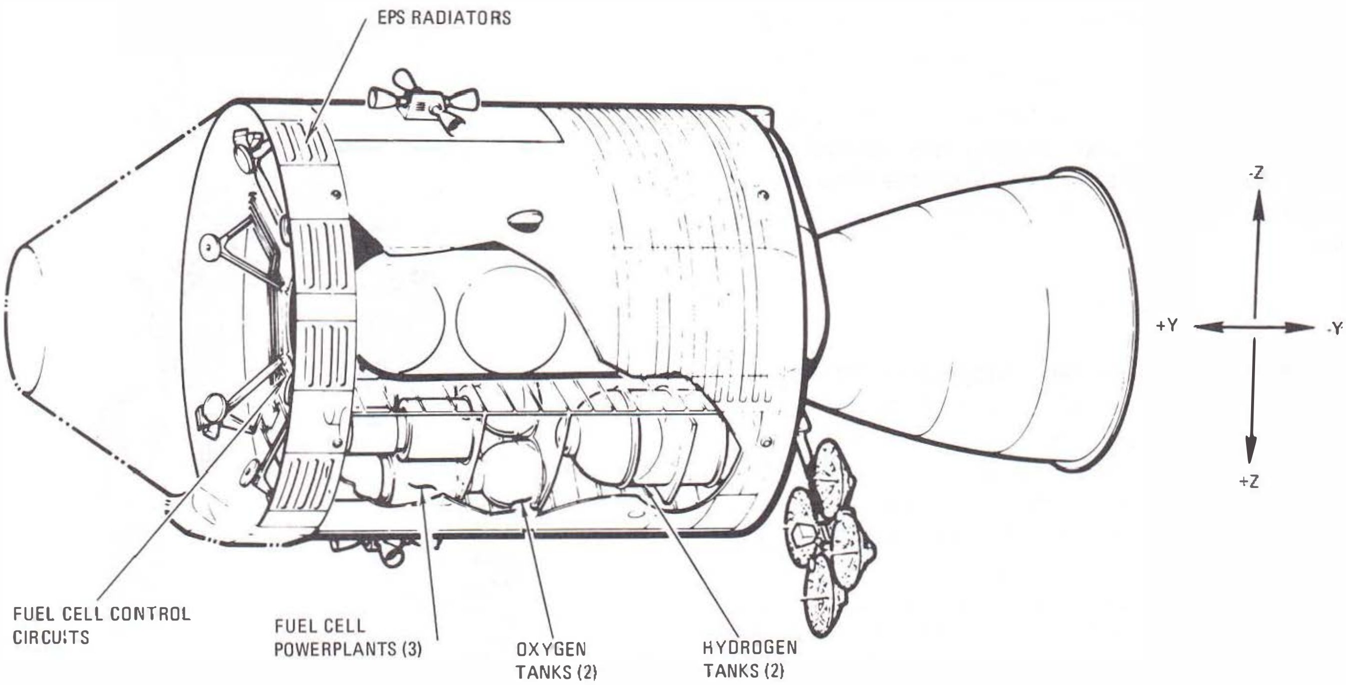
ELECTRICAL POWER



Location of major electrical power subsystem equipment

The electrical power subsystem provides electrical energy sources, power generation and control, power conversion and conditioning, and power distribution to the spacecraft throughout the mission. For checkout before launch, dc electrical power is supplied by ground support equipment. The electrical power subsystem furnishes drinking water to the astronauts as a byproduct of its fuel cell powerplants, and includes the cryogenic gas storage system.

Each of the three fuel cell powerplants (produced by United Aircraft Corp.'s Pratt & Whitney Aircraft Division, Hartford, Conn.) consists of 31 cells connected in series. Each cell consists of a hydrogen compartment, an oxygen compartment, and two electrodes (conductors) – one hydrogen and one oxygen. The electrolyte (substance through which ions are conducted) is a mixture of approximately 72 percent potassium hydroxide and approximately 28 percent water and provides a constant conduction path between electrodes. The hydrogen electrode is nickel and the oxygen electrode is nickel and nickel oxide.

The reactants (hydrogen and oxygen) are supplied to the cell under regulated pressure (referenced to a nitrogen gas supply which also is used to pressurize the powerplants). Chemical reaction produces electricity, water, and heat, with the reactants being consumed in proportion to the electrical load. The byproducts—water and heat—are used to maintain the drinking water supply and to keep the electrolyte at the proper operating temperature. Excess heat is rejected to space through the space radiators. The fuel cell powerplants are located in Sector 4 of the service module.

Three silver oxide-zinc storage batteries supply power to the CM during entry and after landing, provide power for sequence controllers, and supplement the fuel cells during periods of peak power demand. These batteries are located in the lower equipment bay of the CM. A battery charger located in the same bay re-charges the batteries after each use and assures that they will be fully charged before entry. These batteries are produced by Eagle Picher Co., Joplin, Mo.

Two other silver oxide-zinc batteries, independent of and completely isolated from the rest of the dc power system, are used to supply power for explosive devices. These batteries are not recharged. They are produced by the Electric Storage Battery Co., Raleigh, N.C.

The cryogenic (ultra low temperature) gas storage system (produced by Beech Aircraft Corp., Boulder, Colo.) supplies the hydrogen and oxygen used in the fuel cell powerplants, as well as the oxygen used in the environmental control subsystem. The system consists of storage tanks and associated valves, switches, lines, and other plumbing. The hydrogen and oxygen are stored in a semi-gas, semi-liquid state; by the time they reach the fuel cells, however, they have warmed considerably and are in a gaseous state. The system is located in Sector 4 of the service module beneath the fuel cell powerplants.

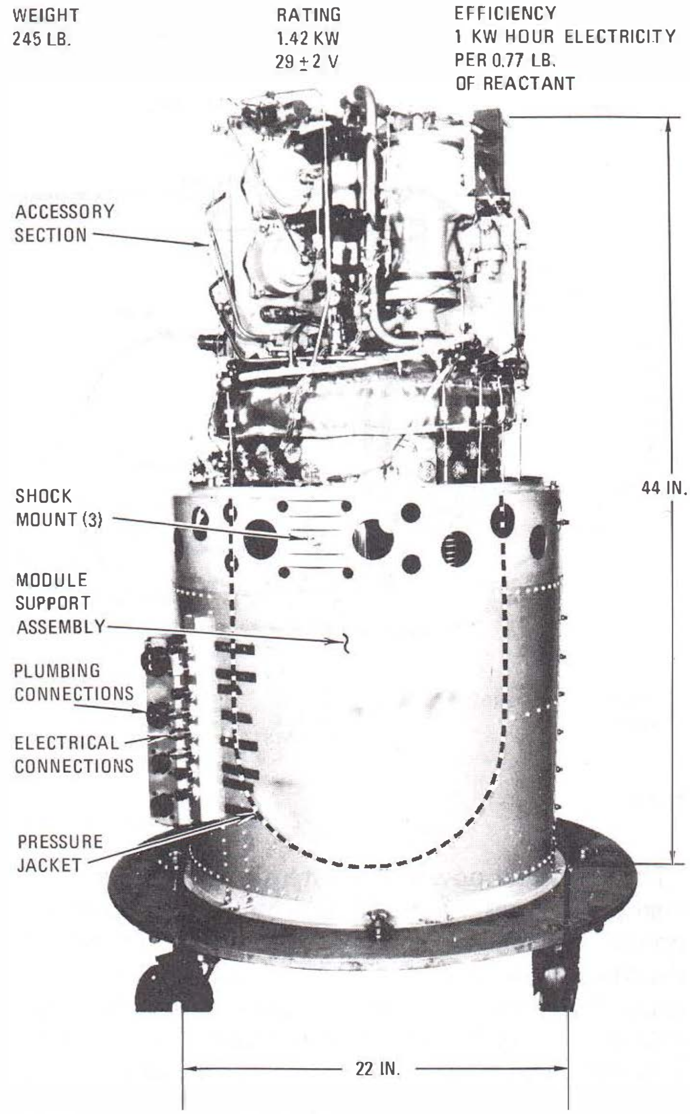
Three solid-state inverters, located in the lower equipment bay of the CM, supply the ac power for the spacecraft. These inverters are devices which convert dc electrical power into ac. Both the fuel cell powerplants and batteries, the two electrical power sources in the spacecraft, produce dc power.

The inverters operate from the two 28-volt dc main buses (connecting circuits) to supply 115/120-volt, 400-cycle, 3-phase ac power to two ac buses. Normally two inverters are used; however, one inverter can supply all primary ac electrical power needed by the spacecraft. If one inverter fails, a crewman can switch in the standby. Two inverters cannot be paralleled (hooked up together).

The inverters are produced by Westinghouse Electric's Aerospace Electrical Division, Lima, Ohio.

EQUIPMENT

Oxygen Tanks (Beech Aircraft Corp., Boulder, Colo.) — Two spherical dewar-type tanks made of Inconel (nickel-steel alloy) in Sector 4 of the service module store oxygen for production of power by fuel cells, for command module pressurization, and for metabolic consumption. Outer diameter of each is 26.55 inches and wall thickness is 0.020 inch. Tanks with accessories are 36.39 inches tall. Each tank has an inner vessel with a diameter of 25.06 inches and wall thickness of 0.061 inch. Rupture pressure of the tanks is 1530 pounds per square inch. Insulation between the inner and outer shells is fiberglass, paper mating, and aluminum foil. In addition, a pump maintains a vacuum between the inner and outer vessels. Each tank weighs 79-1/2 pounds, has a volume of 4.73 cubic feet, and a capacity of 320 pounds — 210 pounds for fuel cells and 110 pounds for environmental control. Each tank has a repressurization probe with two heaters and two fans to keep the tank pressurized and a capacitive probe which measures the amount of oxygen. A resistance element measures temperature.



P-141 *Fuel cell powerplant*

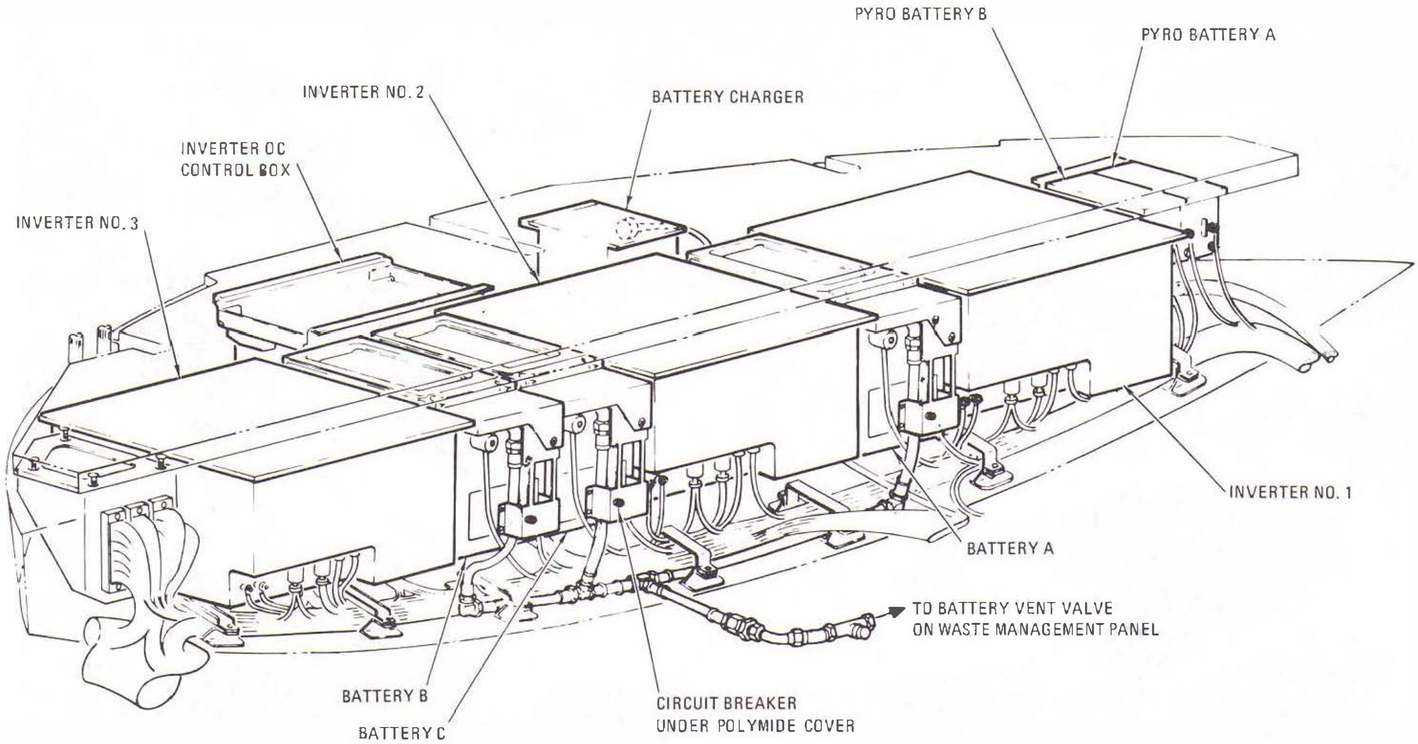
Hydrogen Tanks (Beech) — Two spherical dewar-type titanium tanks located in Sector 4 of the service module contain the hydrogen that powers the fuel cell. Outer diameter of each is 31.80 inches and wall thickness is 0.033 inch. Each tank is 31.9 inches tall and has an inner vessel 28.24 inches in diameter with a wall thickness of 0.046 inch. Rupture pressure is 450 pounds per square inch. Unlike the oxygen tank, which has insulation between the inner and outer shells, the hydrogen tanks have a vapor-cooled shield suspended in a vacuum as a heat barrier. Each tank weighs 69 pounds, has a volume of 6.75 cubic feet, and a capacity of 28 pounds of usable fluid. Similar to the oxygen tanks, they contain repressurization and capacitive probes, a pump to maintain the vacuum, and temperature transducers.

Batteries (Eagle Picher Co., Joplin, Mo.) — Three silver oxide-zinc storage batteries are in the command module lower equipment bay. Each has 20 cells with potassium hydroxide and water as an electrolyte. Battery cases are plastic, coated with fiberglass epoxy, and are vented overboard for outgassing. Each is 6-7/8 by 5-3/4 inches and weighs 28 pounds. The batteries are rated at 40 ampere hours, providing a high power-to-weight ratio. Open circuit voltage is 37.2 volts. The battery characteristics are such that a minimum of 27 volts can be maintained until the battery is depleted. The batteries have been shock-tested to 80-g impact. The batteries provide all CM power during entry and after landing. They also supplement fuel cells during major thrusting maneuvers and provide power for the sequence system and fuel cell and inverter control circuits.

Battery Charger — The constant-voltage, current-limited charger is 4 by 6 by 6 inches and weighs 4.3 pounds. The current is limited to 2.8 amperes so as not to overheat the batteries. It has an operating life of more than 1,000 hours. The charger is located near the entry and postlanding batteries.

Pyrotechnic Batteries (Electric Storage Battery Co., Raleigh, N.C.) — Each of the two silver oxide-zinc batteries in the lower equipment bay has 20 cells with potassium hydroxide and water as an electrolyte. The cases are plastic. There is a relief valve venting arrangement for outgassing. Each is 2-3/4 by 3 by 6-3/4 inches and is rated at 0.75 ampere hours with an open-circuit voltage of 37.2 volts and a 20-volt minimum underrated load. They power mild explosive devices for CM-SM separation, parachute deployment and separation, Saturn third stage separation, launch escape tower separation, and other functions.

Fuel Cell Powerplants (United Aircraft Corporation's Pratt & Whitney Aircraft Division, Hartford, Conn.) — Three fuel cell powerplants, each 44 inches high, 22 inches in diameter, and weighing 245 pounds, are located in Sector 4 of the SM. They are mainly constructed of titanium, stainless steel, and nickel. They are rated at 27 to 31 volts under normal loads. There are 31 separate cells in a stack, each producing 1 volt, with potassium hydroxide and water as electrolyte. Each cell consists of a hydrogen and an oxygen



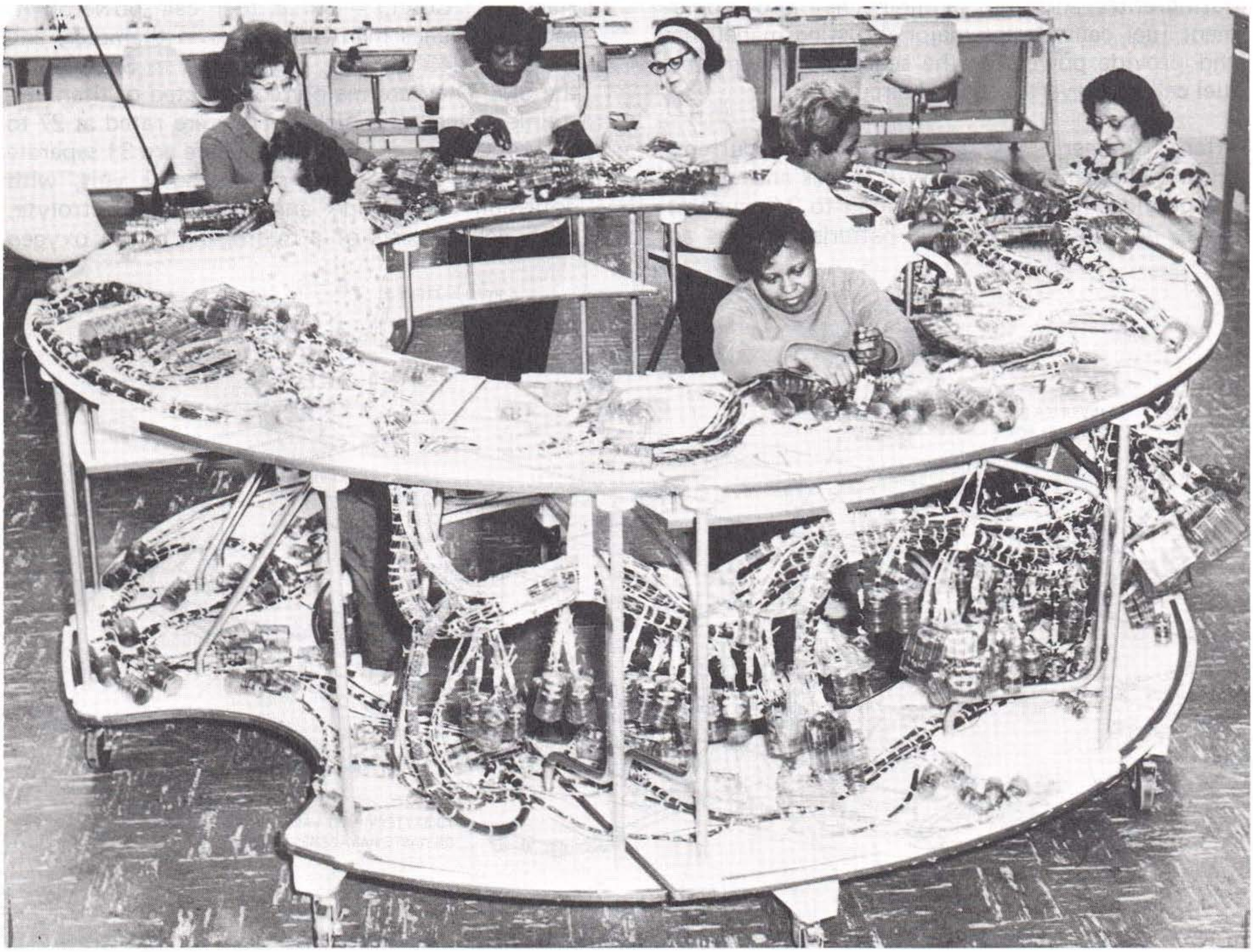
P-142 *Electrical power subsystem components in CM lower equipment bay* electrode, a hydrogen and an oxygen gas compartment, and the electrolyte. Each gas reacts independently to produce a flow of electrons. The fuel cells are nonregenerative. They are normally operated at 400 degrees F with limits of 385 and 500 degrees. Water-glycol is used for temperature control. The fuel cells use hydrogen, oxygen, and nitrogen under regulated pressure to produce power and, as a by-product, water.

Inverters (Westinghouse Electric's Aerospace Electrical Division, Lima, Ohio) — Three solid-state inverters are in the lower equipment bay. Each is contained in an aluminum enclosure and coldplated with a water-glycol loop. The inverters weigh 53 pounds each and are 14-3/4 by 15 by 5 inches. They produce 1250 volt-amperes each. They convert 28-volt dc to 115-volt ac, 3 phase, 400 Hertz. They are designed to compensate for input and output voltage variations. Two of the three inverters are in constant use. They provide alternating current for fuel cell pumps, environmental control system glycol pumps, space suit compressors, and other circuitry.

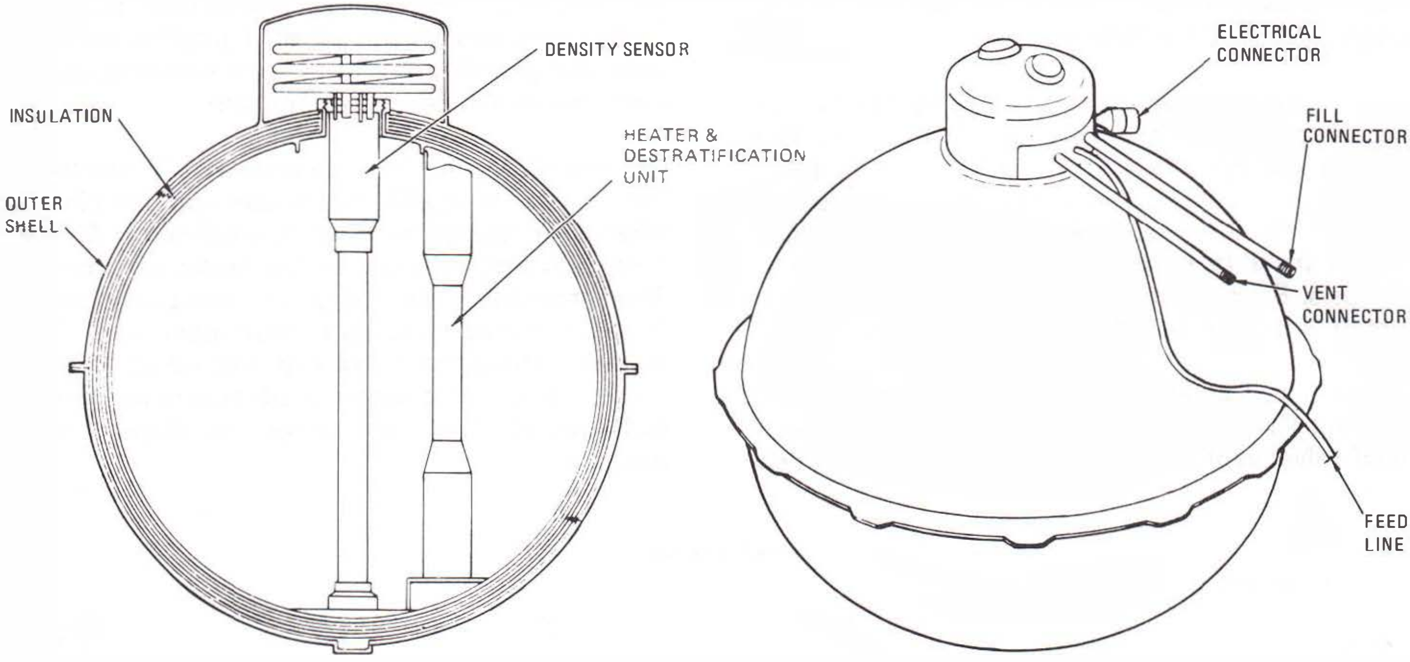
DETAILED DESCRIPTION

CRYOGENIC STORAGE

The cryogenic storage subsystem supplies oxygen and hydrogen to the fuel cell powerplants and oxygen to the environmental control subsystem and for initial pressurization of the lunar module. Each of the two tanks of hydrogen and oxygen holds enough fluid to assure a safe return from the furthest point of the mission. The cryogenic tanks



Command module wire harness is first assembled on this mockup stand



P-144

Cryogenic tank (hydrogen)

are pressurized by internal heaters after filling is complete.

Two parallel dc heaters in each tank supply heat necessary to maintain pressure. Two parallel 3-phase ac circulating fans circulate the fluid over the heating elements to maintain a uniform density and decrease the probability of thermal stratification. Relief valves provide overpressure relief and check valves provide tank isolation. A malfunctioning fuel cell powerplant can be isolated by a shutoff valve. Filters extract particles from the flowing fluid to protect components. Pressure transducers and temperature probes indicate the thermodynamic state of the fluid and capacitive quantity probes indicate the amount of fluid in the tanks.

The systems can be repressurized automatically or manually. The automatic mode is designed to give a single-phase reactant flow into the fuel cell and feed lines at design pressures. The heaters and fans are automatically controlled through pressure and motor switches. As pressure decreases, the pressure switch in each tank closes to energize the motor switch, closing contacts in the heater and fan circuits. Both tanks have to decrease in pressure before heater and fan circuits are energized. When either tank reaches the upper operating pressure limit, its pressure switch opens, again energizing the motor switch and opening the heater and fan circuits to both tanks. The oxygen tank circuits are energized at 865 psia minimum and de-energized at 935 psia maximum. The hydrogen circuits energize at 225 psia minimum and de-energize at 260 psia maximum.

When the systems reach the point where heater and fan cycling is at a minimum (due to a reduced heat requirement), the heat leak of the tank is sufficient to maintain proper pressures provided flow is within proper values. The minimum heat requirement region for oxygen starts at approximately 40-percent quantity in the tanks and ends at approximately 25-percent quantity. Between these tank quantities, minimum heater and fan cycling will occur under normal usage. The heat needed for pressurization at quantities below 25 percent starts to increase until at the 5-percent level practically continuous heater and fan operation is required. In the hydrogen system, the quantity levels for minimum heater and fan cycling are between approximately 53 and 33 percent, with continuous operation occurring at approximately 1 percent.

The oxygen system heaters and fans can sustain proper pressures for 30 minutes at a total flow of 10.4 pounds per hour (5.2 pounds per hour per tank). The hydrogen system heaters and fans can sustain proper pressures at a total flow of 1.02 pounds per hour (0.51 pound per hour per tank).

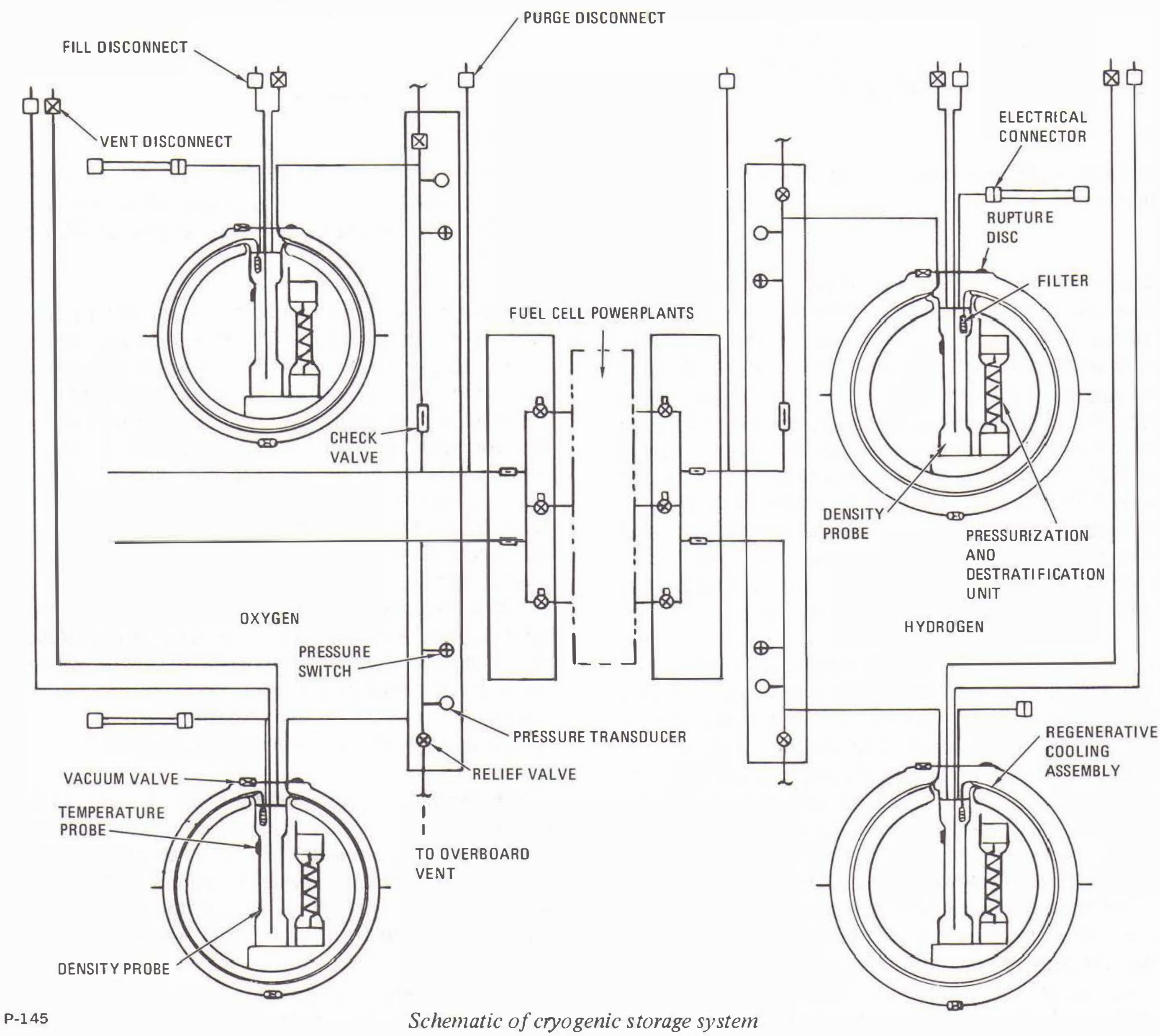
Manual repressurization supplies power directly to the heaters and fans through the control switches.

It can be used in case of automatic control failure, heater failure, or fan failure.

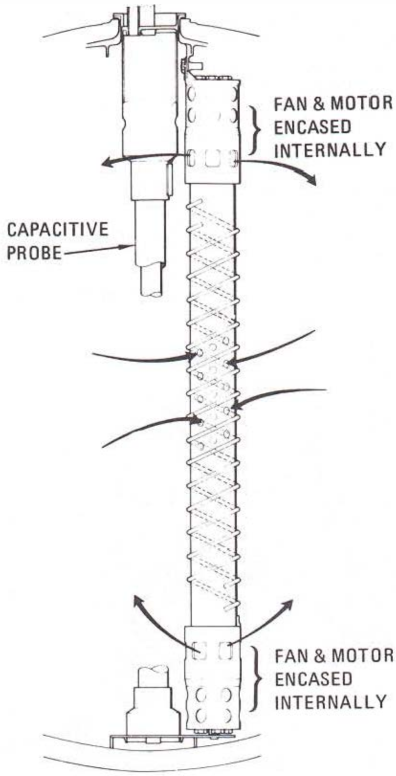
Tank pressure and quantity are monitored on meters located on the main display console. The caution and warning system will activate on alarm when oxygen pressure in either tank exceeds 950 psia or falls below 800 psia or when the hydrogen system pressure exceeds 270 psia or drops below 220 psia. Pressure, quantity, and reactant temperature of each tank are telemetered to MSFN.

Oxygen relief valves vent at a pressure between 983 and 1010 psig and reseat at 965 psig. Hydrogen relief valves vent at a pressure between 273 and 285 psig and reseat at 268 psig. Relief opening of the relief valves will be prevented if possible to minimize the probability of improper reseating, resulting in eventual depletion of one tank.

Overpressurization may be prevented in two ways. The first is to disable the heater and fan circuits when tank quantities reach approximately 55 percent, allowing pressure in the tanks to decrease. This provides wider range for eventual pressure increase during minimum-value operation. This method retains the maximum amount of fluid for spacecraft use. The second method is to perform an unscheduled fuel cell purge to deplete tank pressure.



Schematic of cryogenic storage system



P-146

Cryogenic tank pressure and quantity measurement devices

The reactant tanks have vacuum-ion pumps which function as ion traps to maintain the vacuum between the inner and outer shells.

BATTERIES

The five silver oxide-zinc storage batteries of the electrical power subsystem are located in the lower equipment bay of the CM.

Three rechargeable entry and post-landing batteries (A, B, and C) power the CM systems after CM-SM separation. Before separation, the batteries provide a secondary source of power while the fuel cells are the primary source. They supplement fuel cell power during peak load periods (velocity change maneuvers), provide power during emergency operations (failure of two fuel cells), and provide power for power subsystem control circuitry (relays, indicators, etc.) and sequencer logic. They can also be used to power pyro circuits.

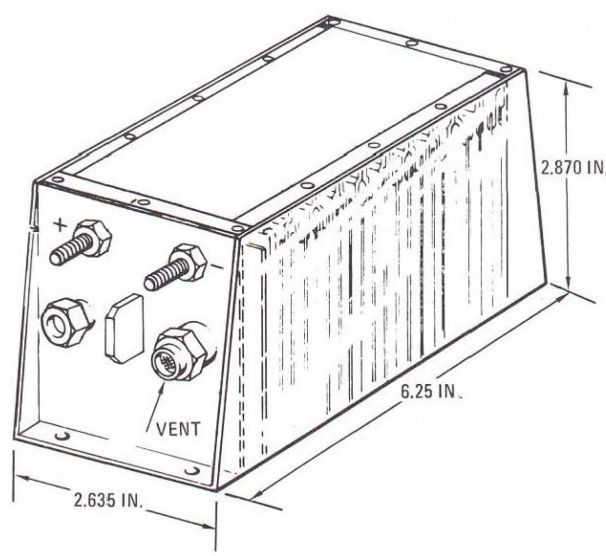
Each entry and post-landing battery consists of 20 silver oxide-zinc cells connected in series. The cells are individually encased in plastic containers which contain relief valves that open at 35 ± 5 psig, venting during an overpressure into the battery case. Each battery case is vented overboard through a common manifold and the urine/water dump line. The vent line prevents battery-generated gas from entering the crew compartment.

In the event a battery case fractures, the vent is closed. The battery manifold pressure is monitored on the meter and when it approaches CM pressure the vent valve is opened to prevent the gas going into the cabin. Battery manifold pressure can be used as an indication of urine/waste water dump line plugging.

Each battery delivers a minimum of 40 ampere-hours at a current output of 35 amps for 15 minutes and a subsequent output of 2 amps, or at a current output of 25 amps for 30 minutes and a subsequent output of 2 amps. At Apollo mission loads, each battery can provide 50 ampere-hours.

Open circuit voltage is 37.2 volts. Since sustained battery loads are extremely light (2 to 3 watts), voltages very close to open circuit voltage will be indicated on the spacecraft voltmeter, except when the main bus tie switches have been activated to tie the battery output to the main dc buses. Normally only batteries A and B will be connected to the main dc buses. Battery C is isolated during the pre-launch period and provides a backup for main dc bus power. The two-battery configuration provides more efficient use of fuel cell power during peak power loads and decreases overall battery recharge time.

The two pyrotechnic batteries supply power to activate ordnance devices in the spacecraft. The



P-147 *Pyrotechnic battery*

pyrotechnic batteries are isolated from the rest of the electrical power system to prevent the high-power surges in the pyrotechnic system from affecting it and to assure source power when required. These batteries are not recharged in flight. The entry and post-landing batteries can be used as a redundant source of power for initiating pyro circuits if either pyro battery fails.

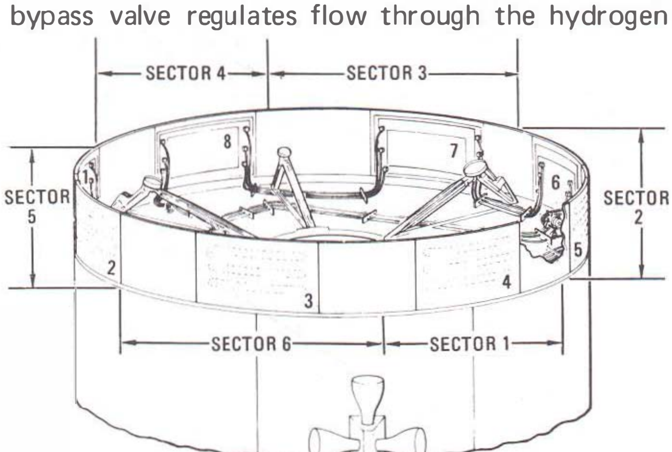
FUEL CELL POWERPLANTS

Each of the three Bacon-type fuel cell powerplants is individually coupled to a heat rejection (radiator) system, the hydrogen and oxygen cryogenic storage systems, a water storage system, and a power distribution system.

The powerplants generate dc power on demand through an exothermic chemical reaction. A byproduct of this chemical reaction is water, which is fed to a potable water storage tank in the CM where it is used for astronaut consumption and for cooling purposes in the environmental control subsystem. The amount of water produced is proportional to the ampere-hours.

Each powerplant consists of 31 single cells connected in series and enclosed in a metal pressure jacket. The water separation, reactant control, and heat transfer components are mounted in a compact accessory section attached directly above the pressure jacket.

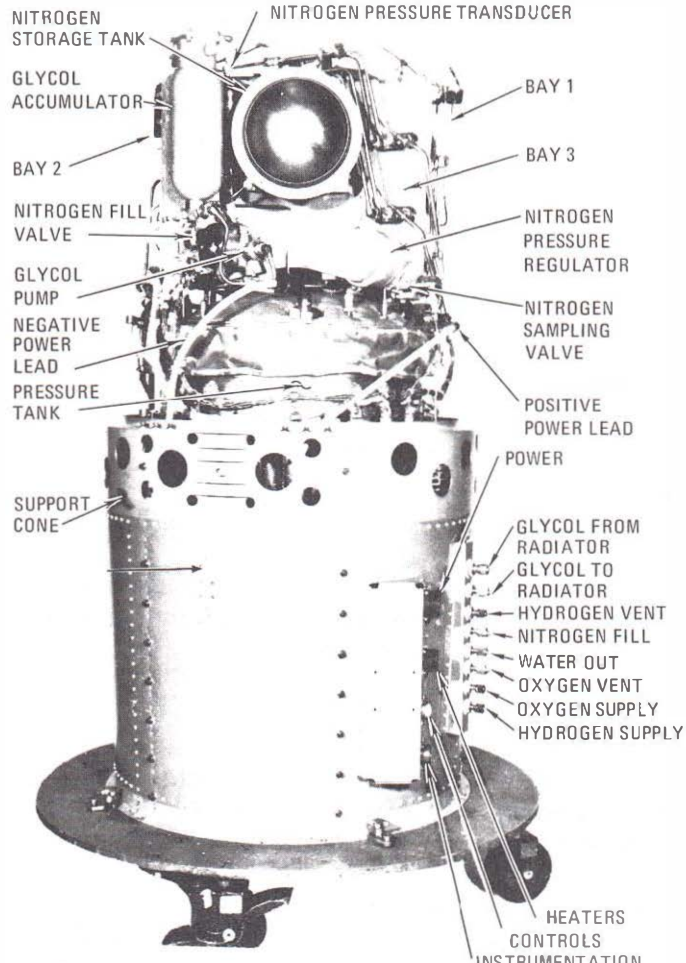
Powerplant temperature is controlled by the primary (hydrogen) and secondary (glycol) loops. The hydrogen pump, providing continuous circulation of hydrogen in the primary loop, withdraws water vapor and heat from the stack of cells. The primary bypass valve regulates flow through the hydrogen regenerator to impart exhaust heat to the incoming hydrogen gas as required to maintain the proper cell temperature. The exhaust gas flows to the condenser where waste heat is transferred to the glycol, the resultant temperature decrease liquifying some of the water vapor. The motor-driven centrifugal water separator extracts the liquid and feeds it to the potable water tank in the CM. The temperature of the hydrogen-water vapor exiting from the condenser is controlled by a bypass valve which regulates flow through a secondary regenerator to a control condenser exhaust within desired limits. The cool gas is then pumped back to the fuel cell through the primary regenerator by a motor-driven



P-148

Location of electrical power subsystem radiators

BAY 1	SECONDARY BYPASS VALVE HYDROGEN, OXYGEN PRESSURE REGULATORS CONDENSER WATER SEPARATOR PUMP WATER PURITY SENSOR HYDROGEN, OXYGEN PRESSURE TRANSDUCERS 2-STEP NITROGEN GAS REGULATOR
BAY 2	HYDROGEN, OXYGEN PREHEATERS GLYCOL REGEN HYDROGEN, OXYGEN PURGE VALVES INLINE HEATER CONTROL



P-149

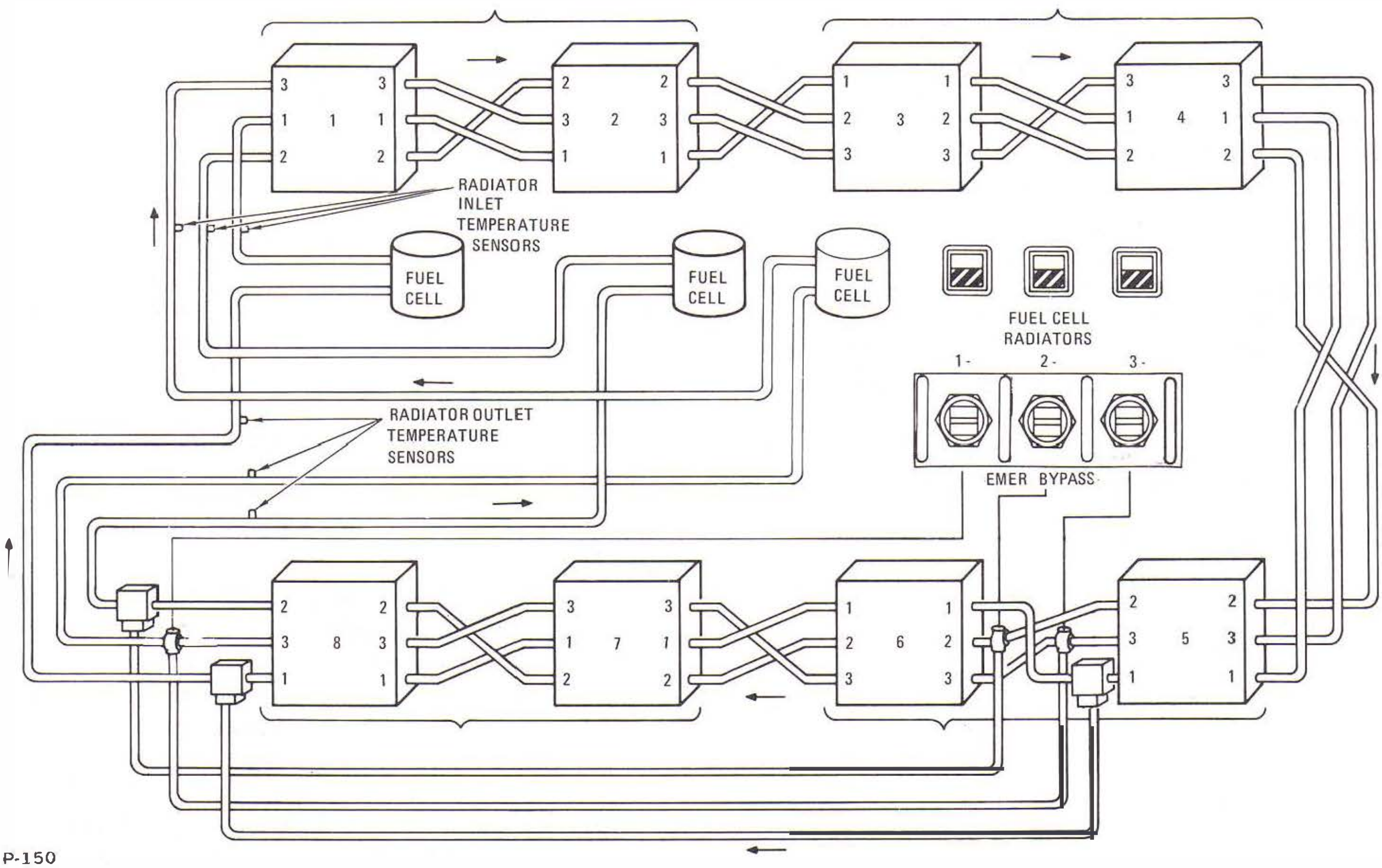
Fuel cell module accessories

vane pump, which also compensates for pressure losses due to water extraction and cooling. Waste heat, transferred to the glycol in the condenser, is transported to the radiators located on the fairing between the CM and SM, where it is radiated into space. Radiator area is sized to reject the waste heat resulting from operation in the normal power range. If an emergency arises in which an extremely low power level is required, individual controls can bypass three of the eight radiator panels for each powerplant. This area reduction improves the margin for radiator freezing which could result from the lack of sufficient waste heat to maintain adequate glycol temperature. This is not a normal procedure and is considered irreversible due to freezing of the bypassed panels.

Reactant valves provide the connection between the powerplants and the cryogenic system. They are opened during pre-launch fuel cell startup and closed only after a powerplant malfunction necessitating its isolation from the cryogenic system. Before launch, a valve switch is operated to apply a holding voltage to the open solenoid of the hydrogen and oxygen reactant valves of the three powerplants. This voltage is required only during boost to prevent inadvertent closure due to the effects of high vibration. The reactant valves cannot be closed with this holding voltage applied. After earth orbit insertion, the holding voltage is removed and three circuit breakers are opened to prevent valve closure through inadvertent activation of the reactant valve switches.

Nitrogen is stored in each powerplant at 1500 psia and regulated to a pressure of 53 psia. Output of the regulator pressurizes the electrolyte in each cell through a diaphragm arrangement, the coolant loop through an accumulator, and is coupled to the oxygen and hydrogen regulators as a reference pressure.

Cryogenic oxygen, supplied to the powerplants at 900 ± 35 psia, absorbs heat in the lines, absorbs additional heat in the fuel cell powerplant reactant preheater, and reaches the oxygen regulator in a gaseous form at temperatures above 0°F. The differential oxygen regulator reduces pressure to 9.5 psia above the nitrogen reference, thus supplying it to the fuel cell stack at 62.5 psia. Within the porous oxygen electrodes, the oxygen reacts with the water in the electrolyte and the electrons

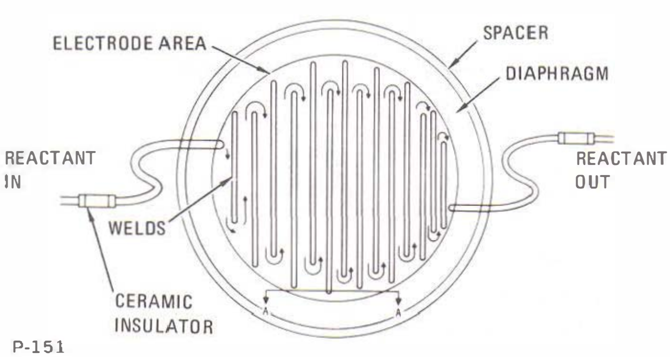


Flow and control of electrical power subsystem radiators provided by the external circuit to produce hydroxyl ions.

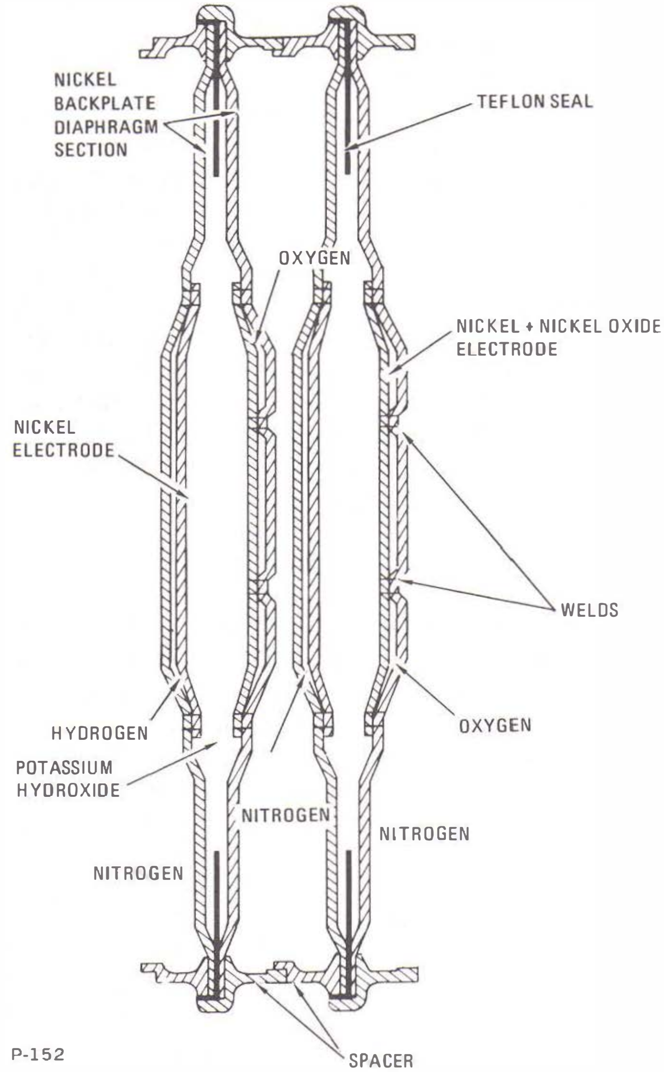
Cryogenic hydrogen, supplied to the powerplants at 245 (+15, -20) psia, is heated in the same manner as the oxygen. The differential hydrogen regulator reduces the pressure to 8.5 psia above the reference nitrogen, thus supplying it in a gaseous form to the fuel cells at 61.5 psia. The hydrogen reacts in the porous hydrogen electrodes with the hydroxyl ions in the electrolyte to produce electrons, water vapor, and heat. The nickel electrodes act as a catalyst in the reaction. The water vapor and heat are withdrawn by the circulation of hydrogen gas in the primary loop and the electrons are supplied to the load.

Each of the 31 cells comprising a powerplant contains electrolyte which on initial fill consists of approximately 83 percent potassium hydroxide (KOH) and 17 percent water by weight. The powerplant is initially conditioned to increase the water ratio, and during normal operation, water content will vary between 23 and 28 percent. At this ratio, the electrolyte has a critical temperature of 360°F. Powerplant electrochemical reaction becomes effective at the critical temperature. The powerplants are heated above the critical temperature by ground support equipment. A load on the powerplant of approximately 563 watts is required to maintain it above the normal minimum operating temperature of 385°F. The automatic in-line heater circuit will maintain powerplant temperature in this range with smaller loads applied.

Purging is a function of power demand and gas purity. Oxygen purging requires 2 minutes and hydrogen purging 80 seconds. The purge frequency is determined by the mission power profile and gas purity as sampled after spacecraft tank fill. A degradation purge can be performed if powerplant current output decreases approximately 3 to 5



Construction of cell



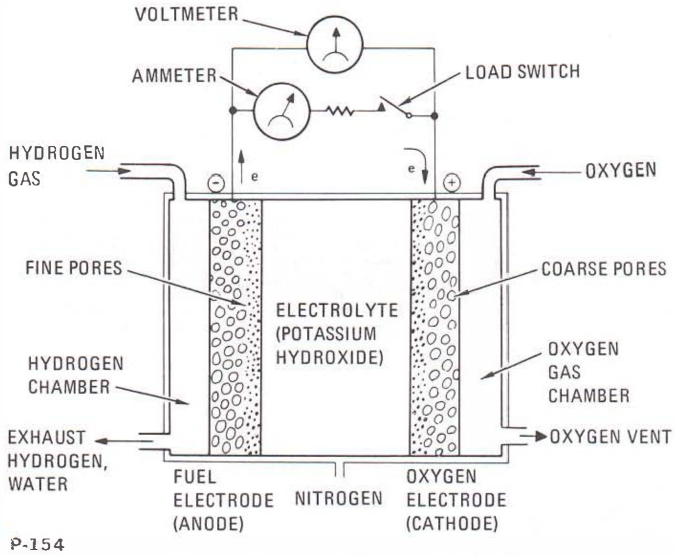
Cutaway view of cell

amps during sustained operation. The oxygen purge has more effect during this type of purge, although it would be followed by a hydrogen purge if recovery to normal were not realized. If the performance degradation were due to powerplant electrolyte flooding, which would be indicated by activation of the pH high indicator, purging would not be performed due to the possibility of increasing the flooding.

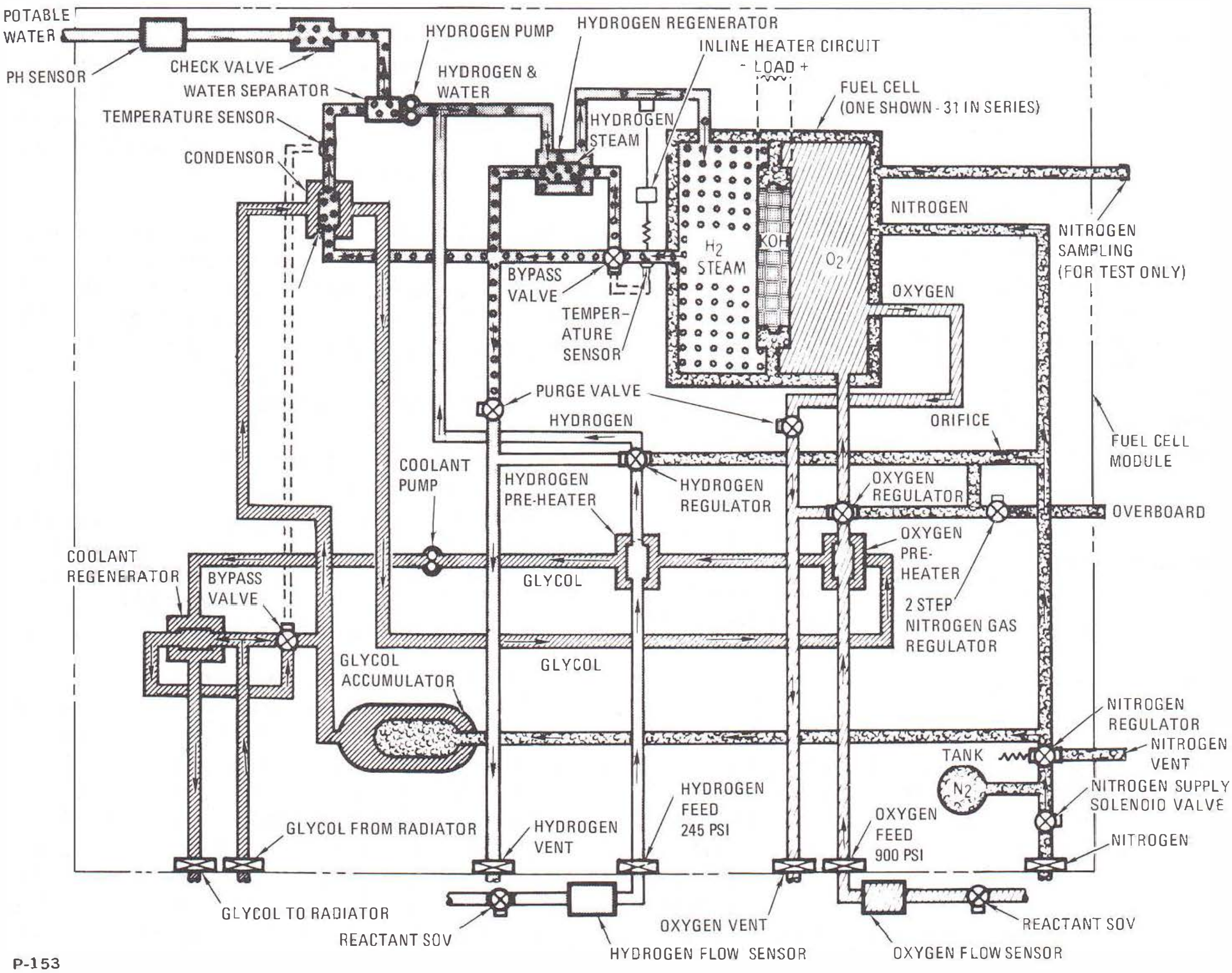
The application and removal of fuel cell loads causes the terminal voltage to decrease and increase, respectively. A decrease in terminal voltage, resulting from an increased load, is followed by a gradual increase in fuel cell skin temperature which causes an increase in terminal voltage. Conversely, an increase in terminal voltage, resulting from a decreased load, is followed by a gradual decrease in fuel cell skin temperature which causes a decrease in terminal voltage. This performance change with temperature is regulated by the primary regenerator bypass valve and provides the capability of operating over an increased power range within voltage regulation limits.

The range in which the terminal voltage is permitted to vary is determined by the high and low voltage input design limits of the components being powered. For most components the limits are 30 volts dc and 25 volts dc. To remain within these design limits, the dc bus voltage must be maintained between 31.0 and 26.2 volts dc. Bus voltage is maintained within prescribed limits during high power requirements by the use of entry and post-landing batteries.

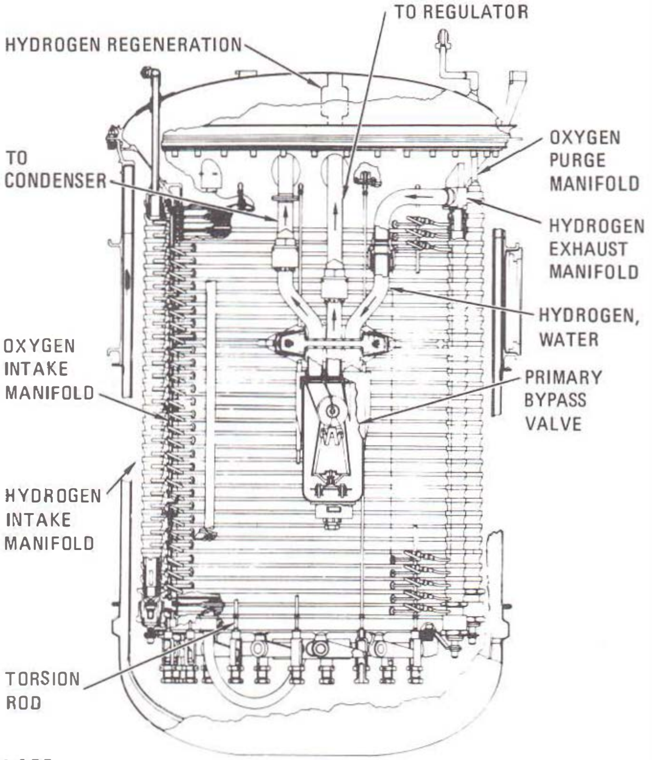
Spacecraft systems are powered up in one continuous sequence providing the main bus voltage does not decrease below 26.2 volts. If bus voltage



Electrochemical flow in fuel cell



Schematic of fuel cell module



Fuel cell module

decreases to this value the power-up sequence can be interrupted for the time required for fuel cell temperatures to increase with the resultant voltage increase, or the batteries can be connected to the main buses reducing the fuel cell load. In most cases, powering up can be performed in one continuous sequence; however, when starting from an extremely low spacecraft load, it is probable that a power-up interruption or batteries will be required. The greatest load increase occurs while powering up for a velocity change maneuver.

Spacecraft systems are powered down in one continuous sequence providing the main bus voltage does not increase above 31.0 volts. In powering down from relatively high spacecraft load levels, the sequence may have to be interrupted for the time required for fuel cell temperature, and thus bus voltage, to decrease.

If a powerplant fails it is disconnected from the main dc buses and the in-line heater circuit is deactivated. Before disconnecting a fuel cell, if a single inverter is being used, the two remaining powerplants are connected to each main dc bus to enhance load sharing since bus loads are unbalanced. If two inverters are being used, each of the remaining powerplants is connected to a separate main dc bus for bus isolation, since bus loads are relatively equal.

INVERTERS

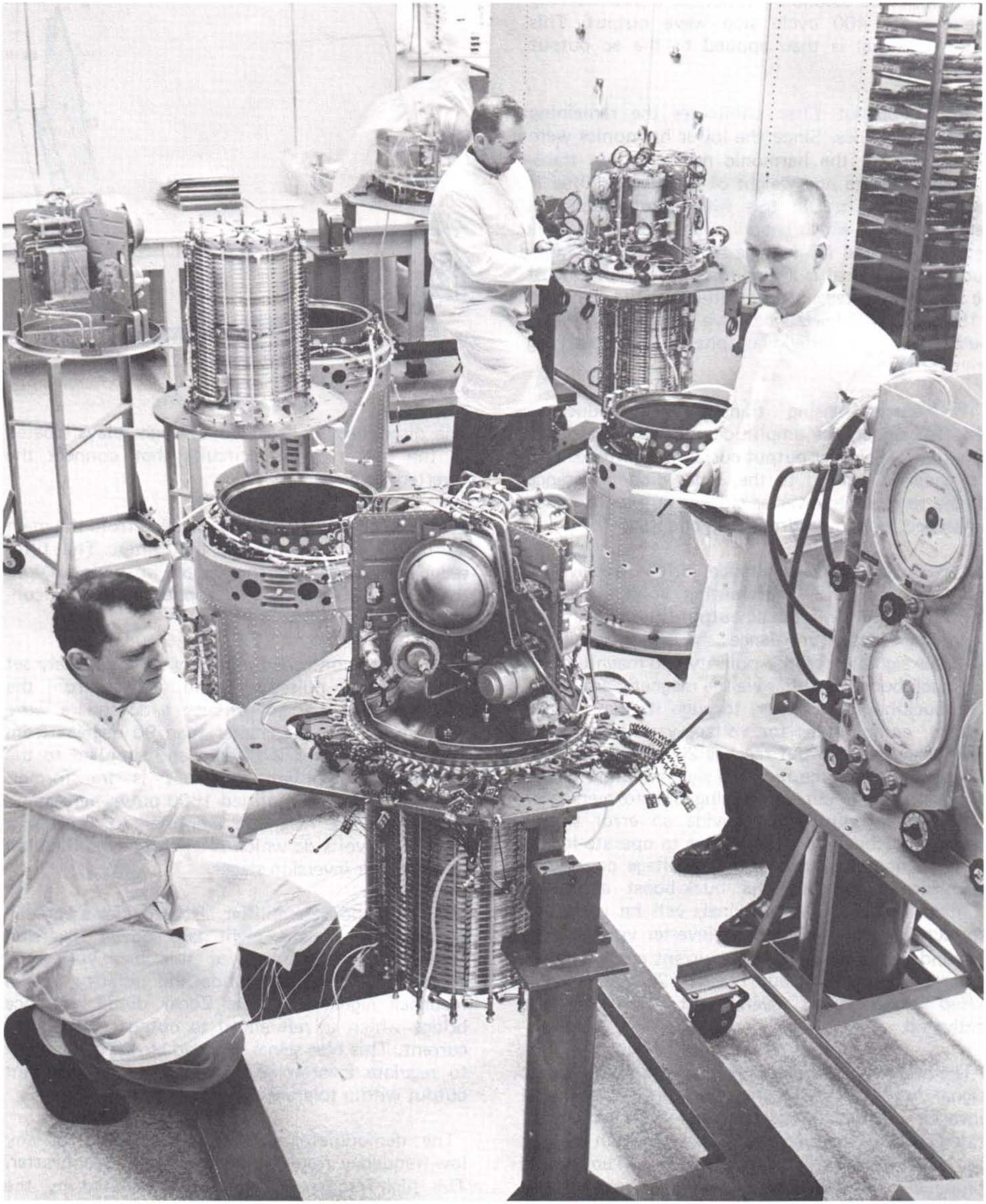
Each inverter is composed of an oscillator, an eight-stage digital countdown section, a dc line filter, two silicon-controlled rectifiers, a magnetic amplifier, a buck-boost amplifier, a demodulator, two dc filters, an eight-stage power inversion section, a harmonic neutralization transformer, an ac output filter, current sensing transformers, a Zener diode reference bridge, a low-voltage control, and an overcurrent trip circuit. The inverter normally uses a 6.4 kiloHertz square wave synchronizing signal from the central timing equipment which maintains inverter output at 400 Hertz. If this external signal is completely lost, the free running oscillator within the inverter will provide pulses that will maintain inverter output within ±7 Hertz. The internal oscillator is normally synchronized by the external pulse.

The 6.4 kiloHertz square wave provided by central timing equipment is applied through the internal oscillator to the eight-stage digital countdown section. The oscillator has two divider circuits which provide a 1600-pulse per second to the magnetic amplifier.

The eight-stage digital countdown section produces eight 400-cycle square waves, each mutually displaced one pulse-time from the preceding and following wave. One pulse-time is 156 microseconds and represents 22.5 electrical degrees. The eight square waves are applied to the eight-stage power inversion section.

The eight-stage power inversion section, fed by a controlled voltage from the buck-boost amplifier, amplifies the eight 400-Hertz, square waves produced by the eight-stage digital countdown section. The amplified square waves, still mutually displaced 22.5 electrical degrees, are next applied to the harmonic neutralization transformer.

The harmonic neutralization section consists of 31 transformer windings on one core. This section accepts the 400-Hertz square-wave output of the eight-stage power inversion section and transforms it into a 3-phase, 400-Hertz 115-volt signal. The manner in which these transformers are wound on a single core produces flux cancellation which eliminates all harmonics up to and including the fifteenth of the fundamental frequency. The 22.5-degree displacement of the square waves provides a means of electrically rotating the square wave excited primary windings around the 3-phase,



P-156

Pratt & Whitney technicians assemble fuel cell powerplants at plant in Hartford, Conn.

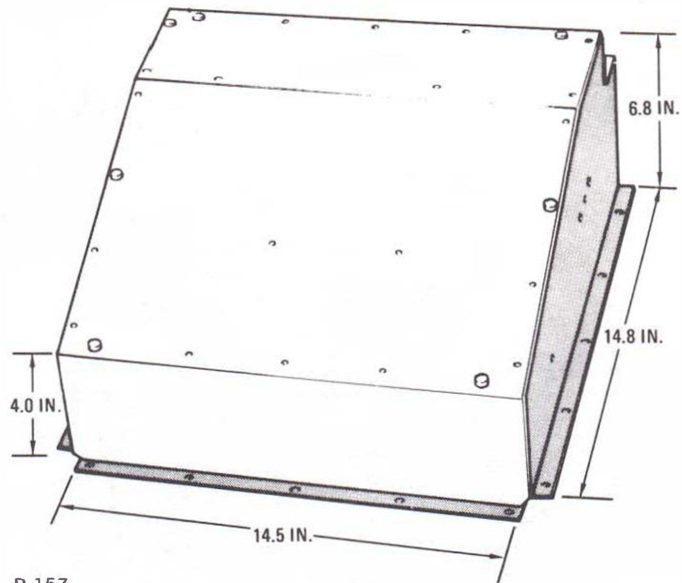
wye-connected secondary windings, thus producing the 3-phase 400 cycle sine wave output. This 115-volt signal is then applied to the ac output filter.

The ac output filter eliminates the remaining higher harmonics. Since the lower harmonics were eliminated by the harmonic neutralization transformer, the size and weight of this output filter is reduced. Circuitry in this filter also produces a rectified signal which is applied to the Zener diode reference bridge for voltage regulation. The amplitude of this signal is a function of the amplitude of ac output voltage. After filtering, the 3-phase, 115-volt ac 400-hertz sine wave is applied to the ac buses through individual phase current-sensing transformers.

The current-sensing transformers produce a rectified signal, the amplitude of which is a direct function of inverter output current magnitude. This dc signal is applied to the Zener diode reference bridge to regulate inverter current output; it is also paralleled to an overcurrent trip circuit.

The Zener diode reference bridge receives a rectified dc signal, representing voltage output, from the circuitry in the ac output filter. A variance in voltage output unbalances the bridge, providing an error signal of proper polarity and magnitude to the buck-boost amplifier via the magnetic amplifier. The buck-boost amplifier, through its bias voltage output, compensates for voltage variations. When inverter current output reaches 200 to 250 percent of rated current, the rectified signal applied to the bridge from the current sensing transformers is of sufficient magnitude to provide an error signal, causing the buck-boost amplifier to operate in the same manner as during an overvoltage condition. The bias output of the buck-boost amplifier, controlled by the error signal, will be varied to correct for any variation in inverter voltage or a beyond-tolerance increase in current output. When inverter current output reaches 250 percent of rated current, the overcurrent trip circuit is activated.

The overcurrent trip circuit monitors a rectified dc signal representing current output. When total inverter current output exceeds 250 percent of rated current, this circuit will disconnect an inverter in 15±5 seconds. If current output of any single phase exceeds 300 percent of rated current, this circuit will disconnect an inverter in 5±1 seconds.



Size of static inverter

The disconnect is provided through relays located in the motor switch circuits that connect the inverters to the ac buses.

Dc power to the inverter is supplied from the main dc buses through the dc line filter. The filter reduces the high-frequency ripple in the input, and the 25 to 30 volts dc is applied to the silicon-controlled rectifiers.

The silicon-controlled rectifiers are alternately set by the 1600 pulses-per-second signal from the magnetic amplifier to produce a dc square wave with an on-time of greater than 90 degrees from each rectifier. This is filtered and supplied to the buck-boost amplifier where it is transformer-coupled with the amplified 1600 pulses-per-second output of the magnetic amplifier to develop a filtered 35 volts dc which is used for amplification in the power inversion stages.

The buck-boost amplifier also provides a variable bias voltage to the eight-stage power inversion section. The amplitude of this bias voltage is controlled by the amplitude and polarity of the feedback signal from the Zener diode reference bridge which is referenced to output voltage and current. This bias signal is varied by the error signal to regulate inverter voltage and maintain current output within tolerance.

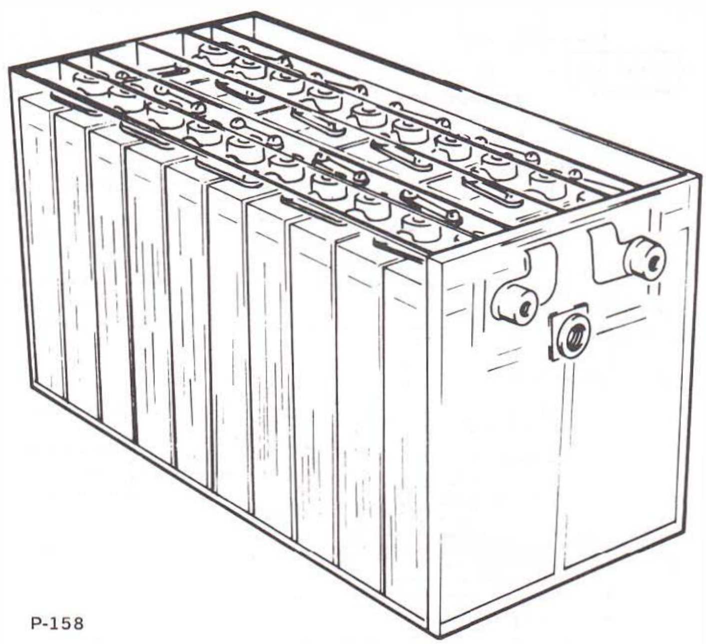
The demodulator circuit compensates for any low-frequency ripple in the dc input to the inverter. The high-frequency ripple is attenuated by the input filters. The demodulator senses the 35-volt dc output of the buck-boost amplifier and the current input to the buck-boost amplifier. An input dc voltage drop or increase will be reflected in a drop or increase in the 35-volt dc output of the buck-boost amplifier, as well as a drop or increase in current input to the buck-boost amplifier. A sensed decrease in the buck-boost amplifier voltage output is compensated for by a demodulator output, coupled through the magnetic amplifier to the silicon-controlled rectifiers. The demodulator output causes the silicon-controlled rectifiers to conduct for a longer time, thus increasing their filtered dc output. An increase in buck-boost amplifier voltage output caused by an increase in dc input to the inverter is compensated for by a demodulator output coupled through the magnetic amplifier to the silicon-controlled rectifiers causing them to conduct for shorter periods, thus producing a lower filtered dc output to the buck-boost amplifier. In this manner, the 35-volt dc input to the power inversion section is maintained at a relatively constant level irrespective of the fluctuations in dc input voltage.

The low-voltage control circuit samples the input voltage to the inverter and can terminate inverter operation. Since the buck-boost amplifier provides a boost action during a decrease in input voltage to the inverter, in an attempt to maintain a constant 35 volts dc to the power inversion section and a regulated 115-volt inverter output, the high boost required during a low-voltage input would tend to overheat the solid-state buck-boost amplifier. As a precautionary measure, the low-voltage control will terminate inverter operation by disconnecting operating voltage to the magnetic amplifier and the first power inversion stage when input voltage decreases to between 16 and 19 volts dc.

A temperature sensor with a range of 32° to 248°F is installed in each inverter and will illuminate a light in the caution and warning system at an inverter overtemperature of 190°F. Inverter temperature is telemetered to the ground.

BATTERY CHARGER

A constant-voltage, solid-state battery charger is located in the CM lower equipment bay. It is provided 25 to 30 volts from both main dc buses and 115 volts 400-cps 3-phase from either of the ac buses. All three phases of ac are used to boost the 25 to 30-volt dc input and produce 40 volts dc for charging. In addition, Phase A of the ac is used to supply power for the charger circuitry. The logic network in the charger, which consists of a two-stage differential amplifier (comparator), Schmitt trigger, current-sensing resistor, and a voltage amplifier, sets up the initial condition for operation. The first stage of the comparator is on, with the second stage off, thus setting the Schmitt trigger first stage to on with the second stage off. Maximum base drive is provided to the current amplifier which turns on the switching transistor. With the switching transistor on, current flows from the transformer rectifier through the switching transistor, current sensing resistor, and switch choke to the battery being charged. Current lags voltage due to switching choke action. As current flow increases, the voltage drop across the sensing resistor increases, and at a specific level sets the first stage of the comparator off and the second stage on. The voltage amplifier is set off to reverse the Schmitt trigger to first stage off and second stage on. This sets the current amplifier off, which in turn sets the switching transistor off. This terminates power from the source, causing the field in the choke to continue collapsing, discharging into the battery, then through the switching diode and the current sensing resistor to the opposite side of the choke. As the electromagnetic field in the choke decreases, current through the sensing resistor decreases, reducing the voltage drop across the resistor. At some point, the decrease in voltage drop across the sensing resistor reverses the comparator circuit, setting up the initial condition and completing one cycle of operation. The output load current, due to the choke action, remains relatively



Entry and post-landing battery

constant except for the small variation through the sensing resistor. This variation is required to set and reset the switching transistor and Schmitt trigger through the action of the comparator.

Battery charger output is regulated by the sensing resistor until battery voltage reaches approximately 36 volts. At this point, the biased voltage control network is unbiased, and in conjunction with the sensing resistor provides a signal for cycling the battery charger. As battery voltage increases, the internal impedance of the battery increases, decreasing current flow from the charger. At 39 volts minimum, the battery is considered fully charged and current flow becomes negligible.

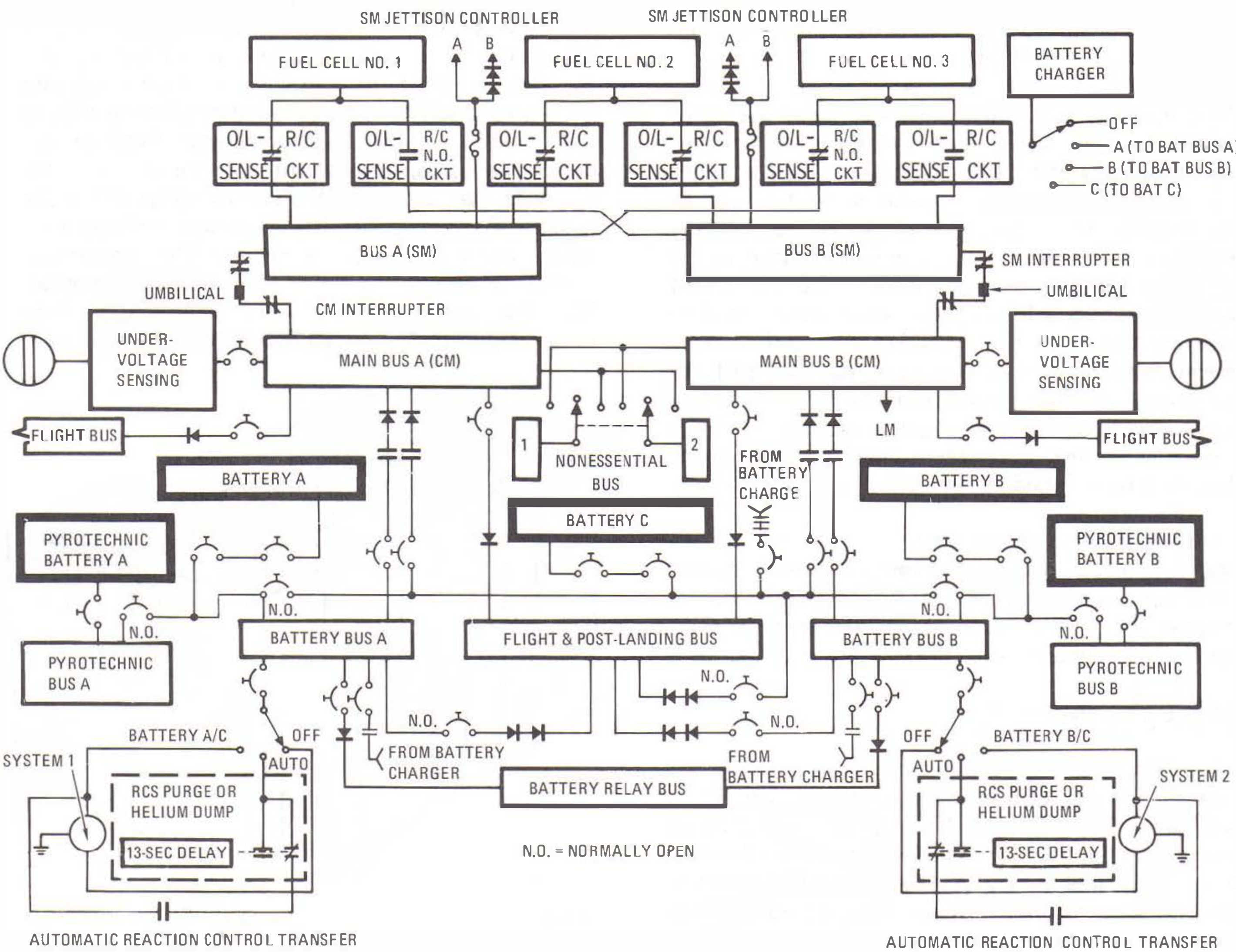
POWER DISTRIBUTION

Dc and ac power distribution is provided by two redundant buses in each system. A single-point ground on the spacecraft structure is used to eliminate ground loop effects. Sensing and control circuits are provided for monitoring and protection of each system.

Dc power is distributed with a two-wire system and a series of interconnected buses, switches, circuit breakers, and isolation diodes. The dc negative buses are connected to the single-point ground. The buses consist of the following:

1. Two main dc buses (A and B), powered by the three fuel cell powerplants and/or entry and post-landing Batteries A, B, and C.

2. Two battery buses (A and B), each powered by its respective entry and post-landing battery. Battery C can power either or both buses if the Batteries A or B fail.



P-159

DC power distribution

3. Flight and post-landing bus, powered through both main dc buses and diodes, or directly by the three entry and post-landing batteries through dual diodes.

4. Flight bus, powered through both main dc buses and isolation diodes.

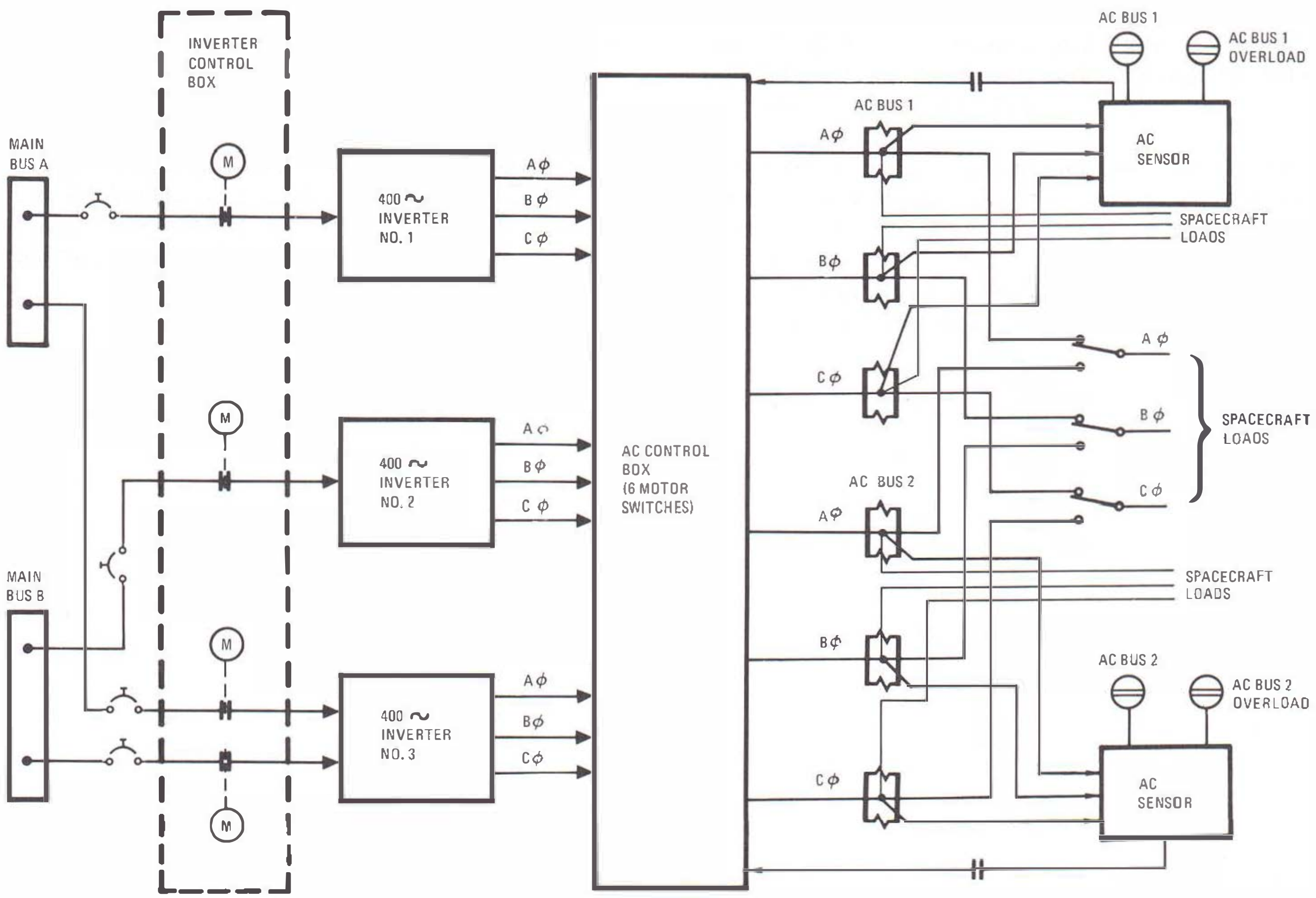
5. Nonessential bus, powered through either dc Main Bus A or B.

6. Battery relay bus, powered by two entry and post-landing batteries (A and B) through the individual battery buses and isolation diodes.

7. Pyro buses, isolated from the main electrical power subsystem when powered by the pyro batteries. Entry batteries can be connected to the A or B pyro system in case of loss of a pyro battery.

8. SM jettison controllers, powered by the fuel cell powerplants and completely isolated from the main electrical power subsystem until activated during CSM separation.

Power from the fuel cell powerplants can be connected to the main dc buses through six motor switches (part of overload/reverse current circuits in the SM) which are controlled by switches in the CM. Fuel cell power can be connected to either or both of the main dc buses. When an overload occurs, the overload-reverse current circuits in the SM automatically disconnect the fuel cell powerplants from the overloaded bus and provide visual displays for isolation of the trouble. A reverse current condition will disconnect the malfunctioning powerplant from the dc system. Dc undervoltage sensing circuits are provided to indicate bus low-voltage conditions. If voltage drops below 26.25 volts dc, the applicable dc undervoltage light on the caution and warning panel will illuminate. Since each bus is capable of handling all loads, an undervoltage condition should not occur except in an isolated instance (if too many electrical units are



P-160

AC power distribution

placed on the bus simultaneously or if a malfunction exists in the subsystem). A voltmeter is provided to monitor voltage of each main dc bus, the battery charger, and each of the five batteries. An ammeter monitors current output of the powerplants, batteries, and battery charger.

During high power demand or emergencies, supplemental power to the main dc buses can be supplied from batteries A and B via the battery buses and directly from battery C. During entry, spacecraft power is provided by the three entry and post-landing batteries which are connected to the main dc buses before CM-SM separation.

The nonessential bus permits nonessential equipment to be shut off during a shortage of power (two fuel cell powerplants out). The flight bus distributes power to in-flight telecommunications equipment. The flight and post-landing bus distributes power to some of the in-flight telecommunications equipment and float bag No. 3 controls. The post-landing bus receives power from the fuel cells or entry and post-landing batteries through the main dc buses. After completion of reaction control subsystem purge during main chute descent, the entry batteries supply power to the post-landing bus directly through individual circuit breakers.

The battery relay bus provides dc power to the dc and ac sensing unit, the fuel cell, inverter control circuits, and some of the indicators on the main display console. The pyrotechnic batteries supply power to ordnance devices used during the course of the mission. The three fuel cell powerplants supply power to the SM jettison controllers for the SM separation maneuver.

Ac power is distributed with a four-wire system via two redundant buses, 1 and 2. The ac neutral bus is connected to the single-point ground. Ac power is provided by one or two of the solid-state 115/200-volt 400-cps 3-phase inverters. Dc power is routed to the inverters through the main dc buses. Inverter No. 1 is powered through dc Main Bus A, inverter No. 2 through dc Main Bus B, and inverter No. 3 through either dc Main Bus A or B by switch selection. Each of these circuits has a separate circuit breaker and a power control motor switch. The three inverters are identical and are provided with overtemperature circuitry. A light indicator in the caution and warning group illuminates at 190°F to indicate overtemperature. Inverter output is routed through a series of control motor switches to the ac buses. Six switches control motor switches which operate contacts to connect or disconnect the inverters from the ac buses. The motor switch circuits are designed to prevent connecting two inverters to the same ac bus at the same time. Ac loads receive power from either ac bus through bus selector switches. In some instances, a single phase is used for operation of equipment and in others all three. Over- or undervoltage and overload sensing circuits are provided for each bus. Inverters are automatically disconnected during overvoltage or overload. Ac bus voltage fail and overload lights in the caution and warning group indicate voltage or overload malfunctions. Phase A voltage of each bus is telemetered to ground stations.

WATER MANAGEMENT

The potable and waste water tanks are partially filled before launch to assure an adequate supply during early stages of the mission. Through the rest of the mission until CM-SM separation, the fuel cell powerplants supply potable water. A portion of the water is chilled for drinking and food preparation, and the remainder is heated and delivered through a separate valve in the food preparation unit. Provision is made to sterilize the potable water.

THERMAL CONTROL

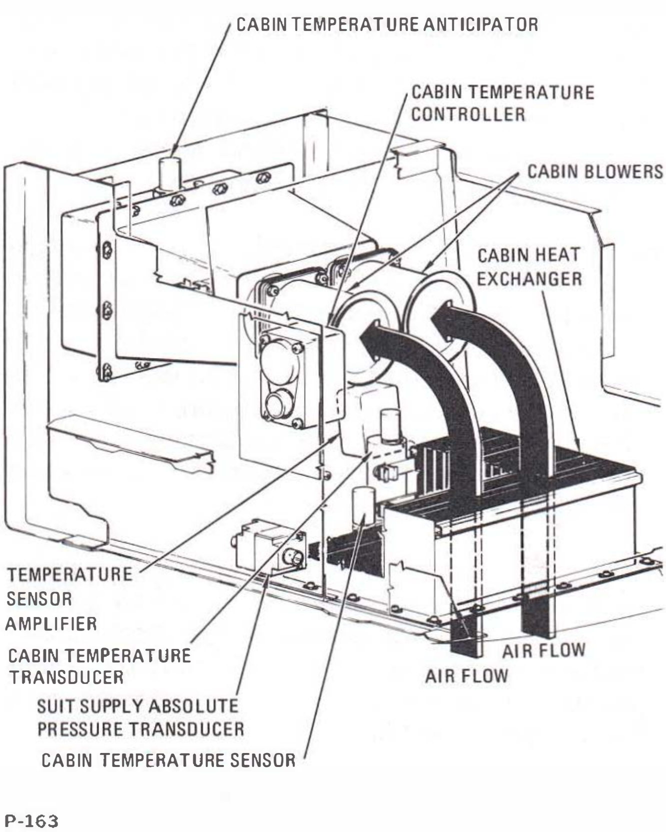
Spacecraft heating and cooling is performed through two water-glycol coolant loops. The water-glycol, initially cooled through ground equipment, is pumped through the primary loop to cool operating electric and electronic equipment and the suit and cabin heat exchangers. The water-glycol also is circulated through a reservoir in the CM to provide a heat sink (heat-absorbing area) during ascent.

The water-glycol is a heat-absorbing medium; it picks up excess heat from operating equipment and the heat exchangers and is routed to the service module, where it passes through radiator tubes on the outside skin. The glycol mixture radiates its heat to space in its passage through these tubes, which are exposed to the cold of space. Then the mixture, now cold again, returns to the CM and repeats the cycle.

During ascent the radiators are heated by aerodynamic friction so a bypass valve is used to shut off the SM portion of the water-glycol loop. From liftoff until 110,000 feet excess heat is absorbed by the coolant and by pre-chilling of the structure; above 110,000 feet the excess heat is rejected by evaporating water in the primary glycol evaporator.

Temperature in the cabin is controlled by the way the water-glycol is routed. Normally it passes through the space radiators and returns to pick up and dissipate heat, thus cooling the cabin. If heating is needed, the coolant can be routed so that it returns to the cabin heat exchanger after absorbing heat from the operating equipment; this heat would be absorbed into the cabin gas circulated through the cabin heat exchanger by dual fans.

The secondary water-glycol loop is used when additional cooling is needed and before entry. Dual-loop operation may be used to "cold-soak" the CM interior for the plunge into the atmosphere.



Cabin temperature unit

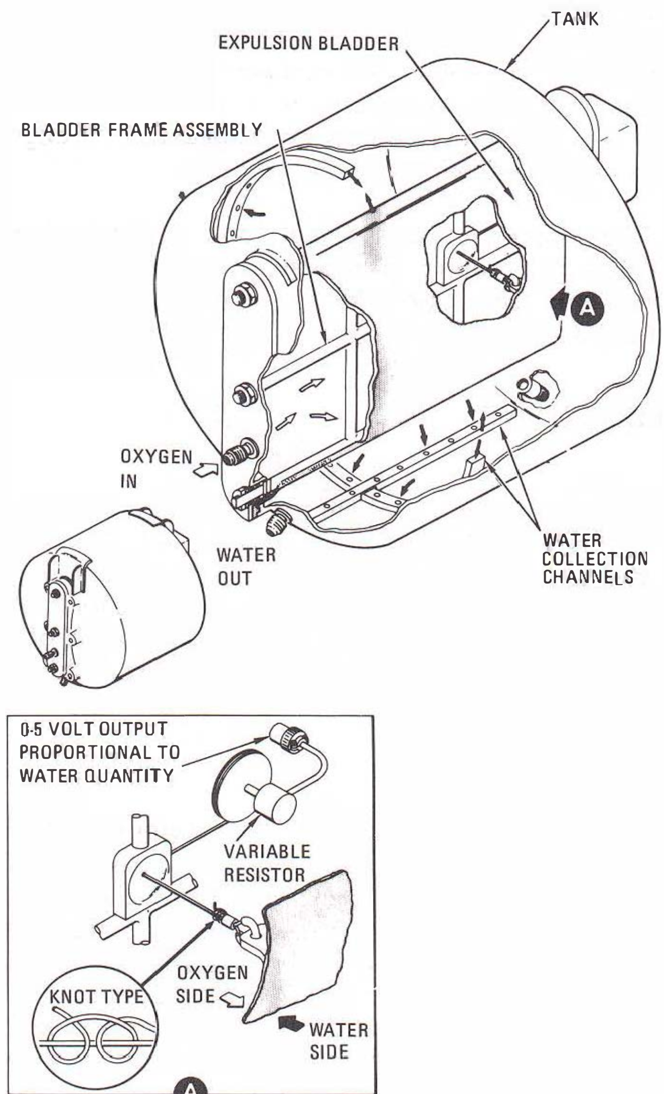
EQUIPMENT

Environmental Control Unit (Garrett Corporation's AiResearch Division, Los Angeles) — Located in the command module left-hand equipment bay. Unit weighs 158 pounds and is 29 inches long, 16 inches high, and 33 inches wide. It consists of a water chiller, water-glycol evaporators, lithium hydroxide canisters, and suit heat exchanger and compressors.

Water-Glycol Reservoir — This aluminum tank contains a bladder under oxygen pressure of 20 pounds per square inch (psi) from the 20-psi oxygen supply system. The bladder stores one gallon of water-glycol and has a volume of 210 cubic inches. The tank is 7.13 by 13.38 by 4.67 inches and weighs 4-1/2 pounds. The reservoir is used to replenish the system and as a spare accumulator.

Water Chiller — It consists of stainless steel coil tubing with a 1/4-inch water inlet and outlet and 5/8-inch water-glycol inlet and outlet. The tubing holds about a tenth of a gallon of water. The water-glycol flows around the tubing, which contains the water, at 20 gallons an hour at about 45 degrees F to cool the water. The cooled water is used for drinking.

Evaporators — Two evaporators, one for the primary and the other for the secondary coolant system, are made of special corrosion-resistant stainless steel plate and fin passages for the water glycol arranged in a series of stacks alternated with sintered Feltmetal wicks. Each wick pad is fed water through a plate which has tiny holes (5/1000 of an inch in diameter). Each evaporator is 8 by 4.7 by 6.62 inches and weighs 18 pounds.



Potable water tank

The wicks are vented to the very low space pressure and water boils at 35 to 40 degrees F. Its evaporation cools the plates, through which the water-glycol passes, thus cooling the water-glycol to between 37 and 45 degrees F. The water-glycol flow is about 24 gallons an hour. About 8000 Btu per hour can be removed.

Lithium Hydroxide Canisters — There are two canisters in aluminum housings of 8-1/2 by 20 by 7-1/2 inches. The canisters, a diverter valve, and inlet and outlet ducts weigh 19.7 pounds. The canisters have removable lithium hydroxide elements. The elements are alternately changed, one every 12 hours. The elements absorb carbon dioxide and also contain activated charcoal, which absorbs odors.

Suit Heat Exchanger — The suit heat exchanger is made of two separate stacks of stainless steel fins and plates. One set is connected to the primary coolant system and the other is connected to the secondary coolant system. The unit is 15 by 11 by 5.2 inches. It cools suit gas to 50 to 55 degrees F and controls humidity by removing excess water. The water is collected by metal wicks and transported to the waste water storage tank.

Accumulators — Two reciprocating water pumps on the suit heat exchangers collect condensate from the suit circuit and pump it into the waste water tank. One accumulator is operated at a time; the other is standby. On automatic mode, a pump goes through a cycle every 10 minutes.

Suit Compressors (AiResearch) — Two centrifugal blowers made of aluminum are conical with a diameter of 6-1/2 inches and a length of 7/8 inches. One is used at a time. It circulates gasses through the suit circuit at a rate of 30 cubic feet per minute during normal operation. Each weighs 10.8 pounds. They operate on 3-phase, 110-volt, 400-Hertz power. Power consumption is 85 watts during normal operation.

Cabin Heat Exchanger — The plate fin, stainless steel, sandwich construction unit is 5.7 by 2.23 by 16.2 inches. It uses water-glycol as heat-transfer medium. It controls cabin temperature by cooling gas that flows through it. It is in the left-hand forward equipment bay.

Oxygen Surge Tank — The Inconel (nickel-steel alloy) tank has a diameter of 13 inches and is 14 inches high. It weighs 8.86 pounds. It holds 3.7 pounds of oxygen at a pressure of about 900 pounds per square inch. The volume is 0.742 cubic foot. It provides oxygen during entry. In emergencies, it can supply oxygen at a high flow rate. It is in the left-hand equipment bay of the command module.

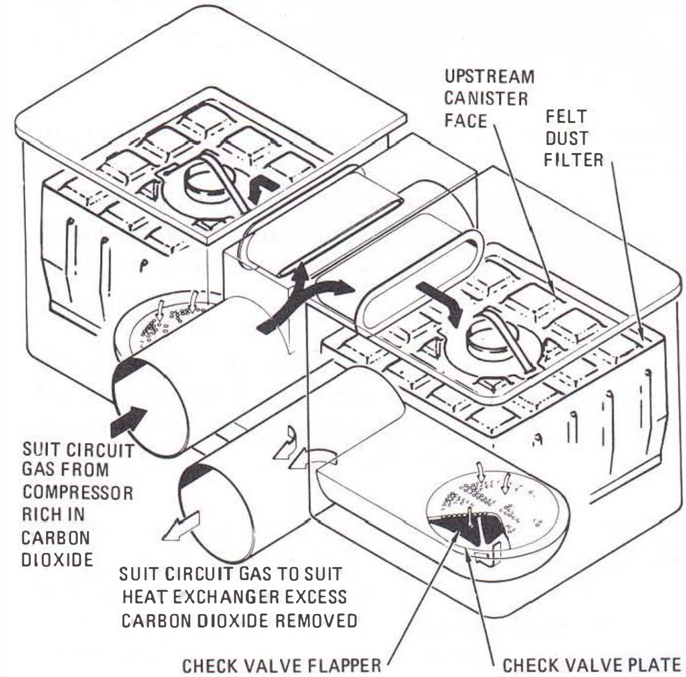
Repressurization Unit – There are three bottles, each containing one pound of oxygen, in an aluminum case with a repressurization valve connected to them. The oxygen is stored at 900 pounds per square inch. Used in conjunction with the oxygen surge tank, it can repressurize the cabin from 0 to 3 pounds per square inch in about 2 minutes. It can also be used with three face masks stored just below the bottles. With the masks, the pressure is reduced to 100 pounds per square inch to the face mask regulator. There is also a direct reading pressure gauge to show the pressure. The unit is below the hatch in the command module.

Potable Water Tank – Aluminum tank with a bladder kept at a pressure of about 20 pounds per square inch by the 20 psi oxygen system. It has a diameter of 12-1/2 inches, and is about 12-1/2 inches deep. It weighs 7.9 pounds. It holds 17 quarts of drinking water and is used for storage of water from the fuel cells. It is in the aft compartment of the command module.

Waste Water Tank – The aluminum tank with a bladder has a diameter of about 12-1/2 inches and is 25 inches deep. It holds 28 quarts. It stores waste water from the suit heat exchanger to be used for cooling purposes through evaporation. It is in the aft compartment of the command module.

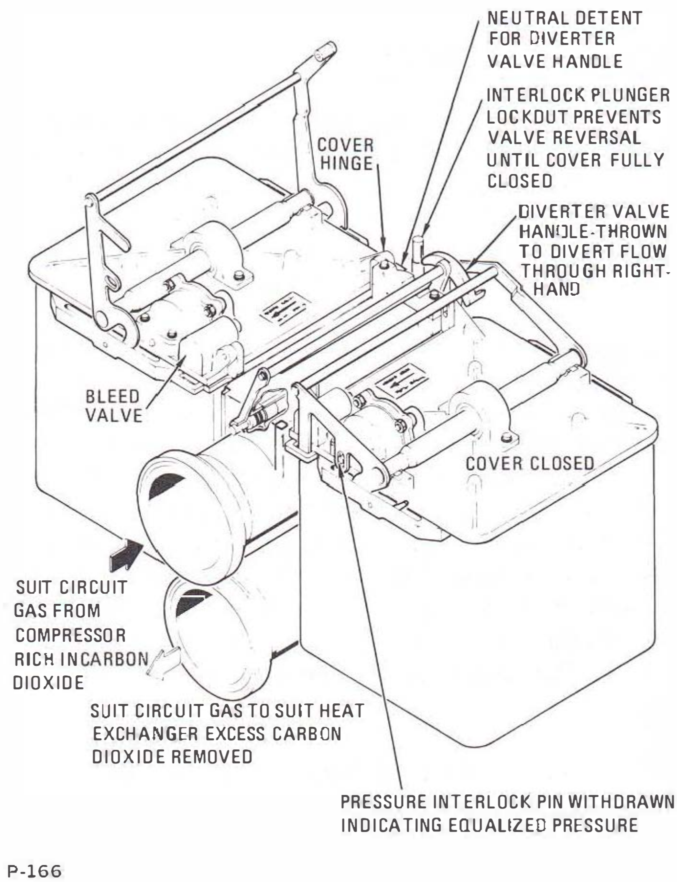
Coldplates – Two aluminum sheets about one-eighth of an inch apart are bonded together and have thousands of tiny posts. Water-glycol flows through the assembly absorbing heat from electronic equipment attached to the plates. The plates' sizes depend on the equipment they cool. Largest coldplate is about 2 by 3 feet; the smallest is about 2 by 10 inches.

Space Radiators – Two aluminum panels about 49 square feet each are around the outside surface of the service module in a 130-degree arc. Each panel has five tubes through which water-glycol flows. There is also a secondary tube for the secondary



P-165

Operational schematic of carbon dioxide canister (cover removed)



P-166

Operational schematic of carbon dioxide canister coolant systems. As the water-glycol flows through the tubes, its heat is rejected through radiation to space. About 4415 Btu per hour can be removed through each panel.

Water Glycol Pumps (AiResearch) — Aluminum housing of 12.9 by 8.4 by 9.89 inches contains three centrifugal-type pumps, two for the primary system and one for the secondary coolant system, and two bellow-type stainless steel accumulators, one for the primary and one for the secondary. The primary accumulator has a volume of 60 cubic inches; the secondary has 35 cubic inches. Only one pump is used at a time. They operate off 3-phase, 110-volt, 400-Hertz power. They pump water glycol through the system.

Glycol — Ethylene glycol, one of a large class of dihydroxy alcohols, is mixed with water (62.5 percent glycol to 37.5 percent water) to carry heat to the space radiator from cabin, space suits, electronic equipment, and the potable water chiller. Fluid can also provide heat or cooling for the cabin.

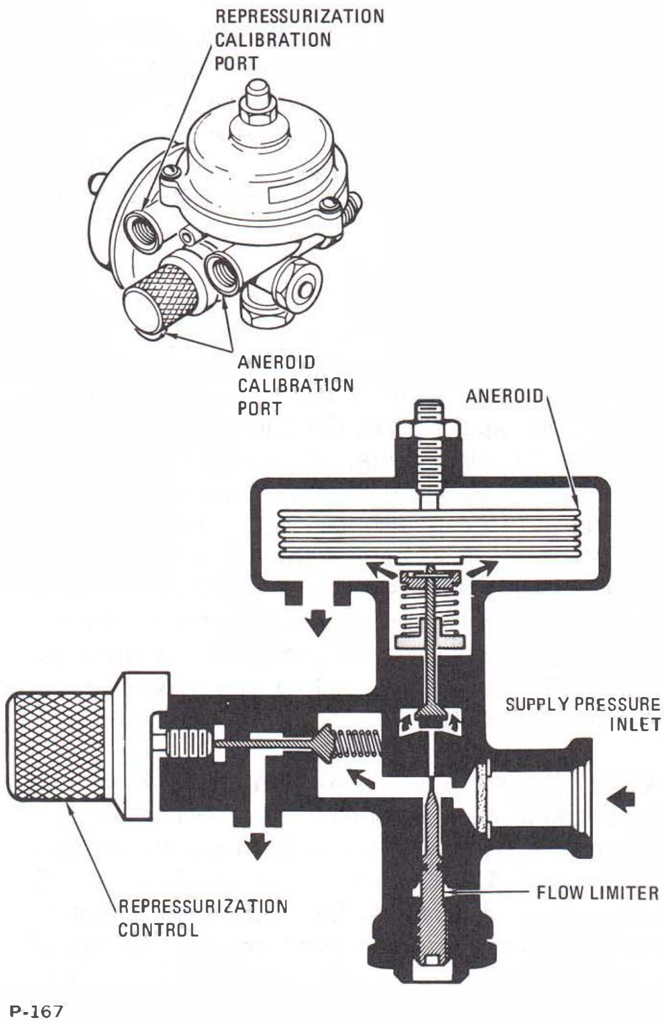
DETAILED DESCRIPTION

OXYGEN SUBSYSTEM

The oxygen subsystem shares the oxygen supply with the electrical power subsystem. Approximately 640 pounds of oxygen is stored in two cryogenic tanks located in the SM. Heaters in the tanks pressurize the oxygen to 900 psig for distribution to the using equipment.

Oxygen is delivered to the CM through two separate supply lines, each of which enters at an oxygen inlet restrictor assembly. Each assembly contains a filter, a capillary line, and a check valve. The filters provide final filtration of gas entering the CM. The capillaries, which are wound around the hot glycol line, serve two purposes: they restrict the total oxygen flow to 9 pounds per hour to prevent starvation of the fuel cells, and they heat the oxygen to prevent it from entering the CM as a liquid. The check valves serve to isolate the two supply lines.

After passing the inlet check valves, the two lines merge and a single line is routed to the oxygen-SM supply valve. This valve is used in flight as a shutoff valve to back up the inlet check valves during entry. It is closed before CM-SM separation.



Cabin pressure regulator

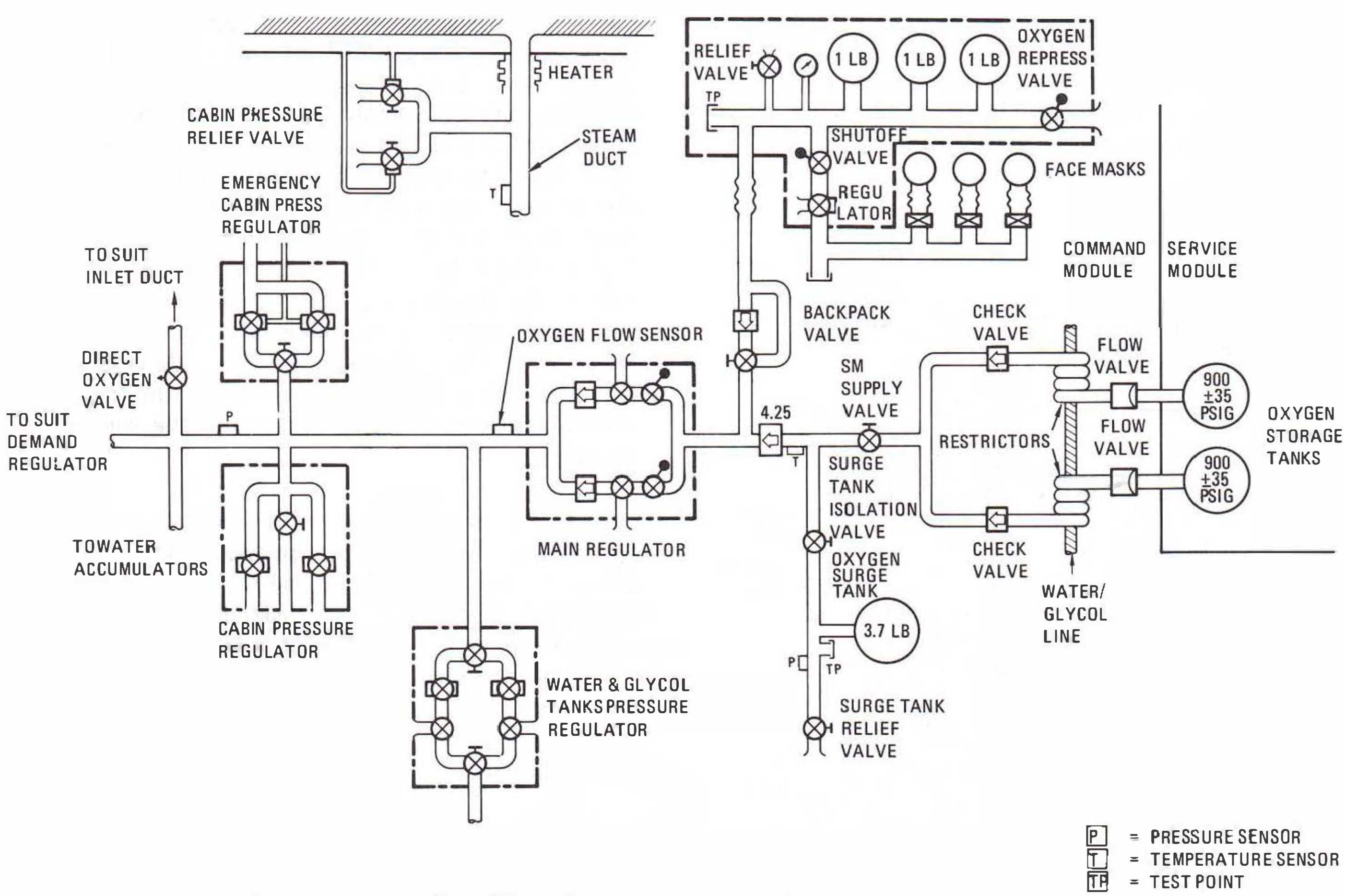
The outlet of the supply valve is connected in parallel to the oxygen-surge tank valve and to a check valve on the oxygen control panel. The surge tank valve is closed only when it is necessary to isolate the surge tank from the system. The surge tank stores approximately 3.7 pounds of oxygen at 900 psig for use during entry, and for augmenting the SM supply when the operational demand exceeds the flow capacity of the inlet-restrictors. A surge tank pressure relief and shutoff valve prevents overpressurization of the surge tank, and provides a means for shutting off the flow in case the relief valve fails. A pressure transducer puts out a signal proportional to surge tank pressure for telemetry and for display to the crew.

An oxygen entry valve is used to control the flow of oxygen to and from the oxygen repressurization package. The package consists of three one-pound capacity oxygen tanks connected in parallel; a toggle-type fast-acting repressurization valve for dumping oxygen into the cabin at very high flow rates, and a toggle valve and regulator for supplying oxygen to the emergency oxygen face masks. Opening the repressurization valve, with the entry valve in the "fill" position, will dump both the package tanks and the surge tank at a rate that will pressurize the command module from 0 to 3 psia in one minute. When the entry valve is in the "on" position, the package tanks augment the surge tank supply for entry and emergencies.

The main regulator reduces the supply pressure to 100 ± 10 psig for use by subsystem components. The regulator assembly is a dual unit which is normally operated in parallel. Selector valves at the inlet to the assembly provide a means of isolating either of the units in case of failure, or for shutting them both off. Integral relief valves limit the downstream pressure to 140 psig maximum. The output of the main regulator passes through a flowmeter, then is delivered directly to the water and glycol tank pressure regulator and through the oxygen supply valve in parallel to the cabin pressure regulator, emergency cabin pressure regulator, the oxygen demand regulator, the direct oxygen valve, and the water accumulator valves.

The output of the flowmeter is displayed on an oxygen flow indicator which has a range of 0.2 to 1.0 pound per hour. Nominal flow for metabolic consumption and cabin leakage is approximately 0.43 pound per hour. Flow rates of 1 pound per hour or more with a duration in excess of 16.5 seconds will illuminate a light on the caution and warning panel to alert the crew to the fact that the oxygen flow rate is greater than is normally required. It does not necessarily mean that a malfunction has occurred, since there are a number of flight operations in which a high oxygen flow rate is normal.

The water and glycol tank pressure regulator assembly also is a dual unit, normally operating in parallel, which reduces the 100-psi oxygen to 20±2 psig for pressurizing the positive expulsion bladders in the waste and potable water tanks and in the glycol reservoir. Integral relief valves limit the

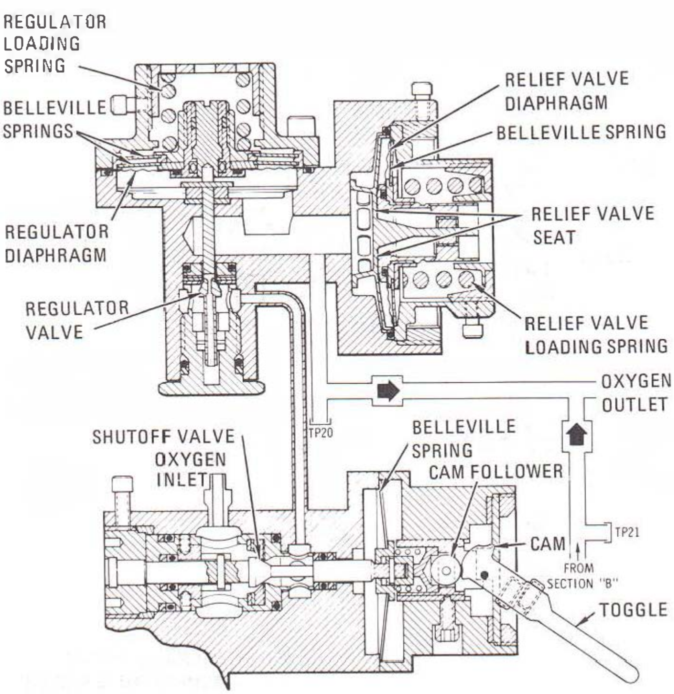


P-168

Simplified schematic of oxygen subsystem downstream pressure to 25±2 psi above cabin pressure. Inlet and outlet selector valves are provided for selecting either or both regulators and relief valves, or for shutting the unit off.

The cabin pressure regulator controls the flow of oxygen into the cabin to make up for depletion of the gas due to metabolic consumption, normal leakage, or repressurization. The assembly consists of two absolute pressure regulators operating in parallel, and a manually operated cabin repressurization valve. The regulator is designed to maintain cabin pressure at 5±0.2 psia with losses up to 1.3 pounds per hour. Losses in excess of this value will result in a continual decrease in cabin pressure. When cabin pressure falls to 3.5 psia minimum, the regulator will automatically shut off to prevent wasting the oxygen supply. Following depressurization, the cabin can be repressurized by manually opening the cabin repressurization valve. This will result in a minimum flow of 6 pounds per hour.

An emergency cabin pressure regulator provides emergency protection for the crew in the event of a severe leak in the cabin. The regulator valve starts to open when cabin pressure decreases to 4.6 psia; and at 4.2 psia, the valve is fully open, flooding the cabin with oxygen. The regulator supplies oxygen to the cabin at flow rates up to 0.66 pound per minute to prevent rapid decompression in case of cabin puncture. The valve can provide flow rates that will maintain cabin pressure above 3.5 psia for a period of 15 minutes, against a leakage rate equivalent to 1/4-inch-diameter cabin puncture. The valve is normally used during shirtsleeve operations, and is intended to provide time for donning pressure suits before cabin pressure drops below 3.5 psia. During pressure suit operations, the valve is shut off to prevent unnecessary loss of oxygen.



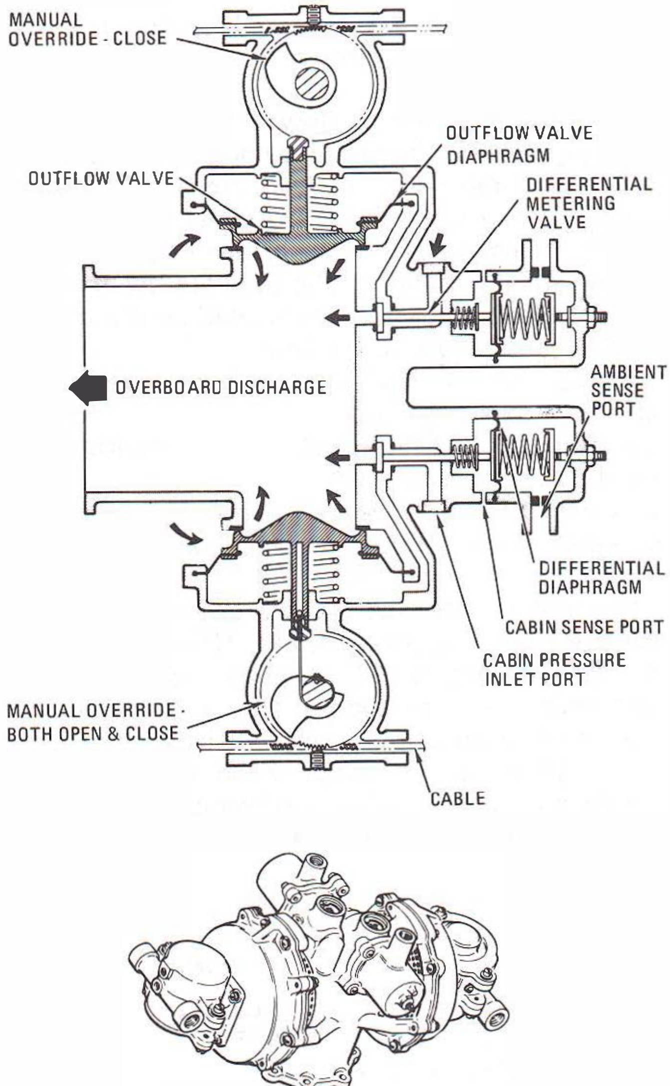
P-169 *Main oxygen regulator*

An oxygen demand regulator supplies oxygen to the suit circuit whenever the suit circuit is isolated from the cabin and during depressurized operations. It also relieves excess gas to prevent overpressurizing the suits. The assembly contains redundant regulators, a single relief valve for venting excess suit pressure, an inlet selector valve for selecting either or both regulators, and a suit test valve for performing suit integrity tests.

Each regulator section consists of an aneroid control and a differential diaphragm housed in a reference chamber. The diaphragm pushes against a rod connected to the demand valve; the demand valve will be opened whenever a pressure differential is sensed across the diaphragm. In operation, there is a constant bleed flow of oxygen from the supply into the reference chamber, around the aneroid, and out through the control port into the cabin. As long as the cabin pressure is greater than 3.75 psia (nominal), the flow of oxygen through the control port is virtually unrestricted, so that the pressure within the reference chamber is essentially that of the cabin. This pressure acts on the upper side of the diaphragm, while suit pressure is applied to the underside of the diaphragm through the suit sense port. The diaphragm can be made to open the demand valve by either increasing the reference chamber pressure or by decreasing the sensed suit pressure.

Increased pressure occurs during depressurized operations. As the cabin pressure decreases, the aneroid expands. At 3.75 psia the aneroid will have expanded sufficiently to restrict the outflow of oxygen through the control port, thus increasing the reference chamber pressure. When the pressure rises approximately 3 inches of water pressure above the sensed suit pressure, the demand valve will be opened.

Decreased pressure occurs whenever the suit circuit is isolated from the cabin, and cabin pressure is above 5 psia. In the process of respiration, the crew



P-170

Cabin pressure relief valve

will exhale carbon dioxide and water vapor. In circulating the suit gases through the carbon dioxide and odor absorber and the suit heat exchanger, the carbon dioxide and water are removed. The removal reduces the pressure in the suit circuit, which is sensed by the regulator on the underside of the diaphragm. When the pressure drops approximately 3 inches of water pressure below the cabin pressure, the diaphragm will open the demand valve.

The regulator assembly contains a poppet-type relief valve which is integral with the suit pressure sense port. During operations where the cabin pressure is above 3.75 psia, the relief valve is loaded by a coil spring which allows excess suit gas to be vented whenever suit pressure rises to 2 to 9 inches of water pressure above cabin pressure. When the cabin pressure decreases to 3.75 psia, the reference chamber pressure is increased by the throttling effect of the expanding aneroid. The reference chamber pressure is applied, through ducts, to two relief valve loading chambers which are arranged in tandem above the relief valve poppet. The pressure in the loading chambers acts on tandem diaphragms which are forced against the relief valve poppet. The relief value of the valve is thus increased to 3.75 psia plus 2 to 9 inches of water pressure.

The suit test valve provides a means for pressurizing and depressurizing the suit circuit, at controlled rates, for performing suit integrity tests. In the "Press" position the valve supplies oxygen through a restrictor to pressurize the suit circuit to a nominal 4 psi above the cabin in not less than 75 seconds. The maximum time required for pressurizing or depressurizing the suits depends on the density of the suit and cabin gases. It will take longer to pressurize or depressurize during prelaunch than in orbit because of the higher density of the gas at sea-level pressure. In the "Depress" position the valve will depressurize the suits in not less than 75 seconds. Moving the valve from "Press" to "Off" will dump the suit pressure immediately. Also, if any one of the three suits is vented to the cabin while the valve is in the "Press" position, all three suits will collapse immediately. This is due to the restrictor in the pressurizing port which prevents the demand regulator from supplying the high oxygen flow rate required for maintaining the pressure in the other two suits.

The direct oxygen valve is a manual metering valve with a flow capability of zero to 0.67 pound per minute. The primary purpose is for purging the pressure suit circuit.

PRESSURE SUIT CIRCUIT

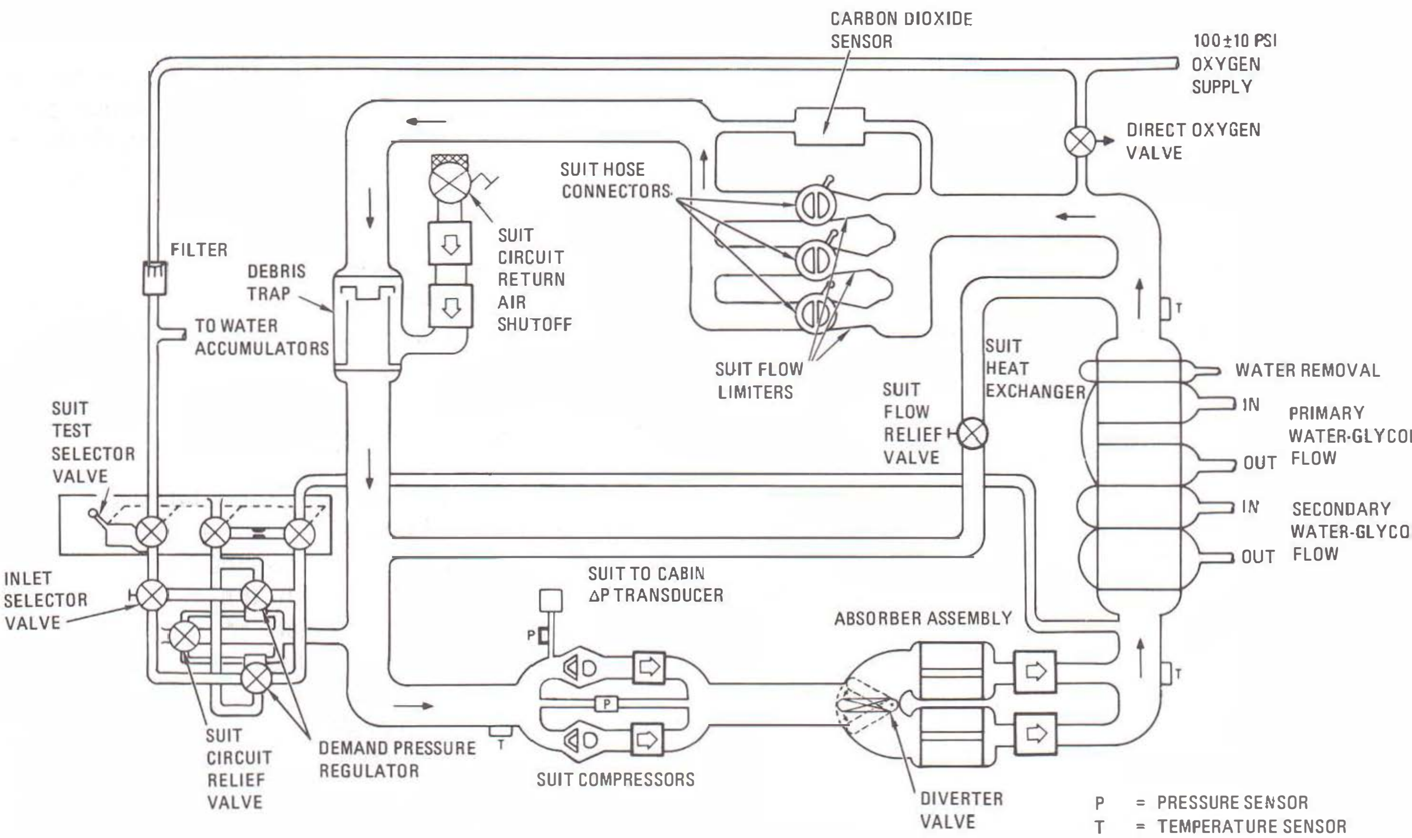
The pressure suit circuit is a circulating gas loop which provides the crew with a continuously conditioned atmosphere throughout the mission. The gas is circulated through the circuit by two centrifugal compressors which are controlled by individual switches. Normally only one of the compressors is operated at a time; however, the individual switches provide a means for connecting either or both of the compressors to either ac bus.

A differential pressure transducer connected across the compressors provides a signal to an indicator on the main display console, to telemetry, and to the caution and warning system, which will illuminate a light at a differential pressure of 0.22 psi or less. Another differential pressure transducer is connected between the suit compressor inlet manifold and the cabin; the output is displayed on the indicator. A switch on the main display console selects the output of either transducer for display on the indicator. A pressure transducer connected to the compressor inlet manifold provides a signal to another indicator and to telemetry.

The gas leaving the compressor flows through the carbon dioxide and odor absorber assembly. The assembly is a dual unit containing two absorber elements in separate compartments with inlet and outlet manifolds common to both. A diverter valve in the inlet manifold provides a means of isolating one compartment (without interrupting the gas flow through the suit circuit) to replace a spent absorber. An interlock mechanism between the diverter valve handle and the cover handles is intended to prevent opening both compartments at the same time. The absorber elements contain lithium hydroxide and activated charcoal for removing carbon dioxide and odors from the suit gases. Orlon pads on the inlet and outlet sides trap small particles and prevent absorbent materials from entering the gas stream.

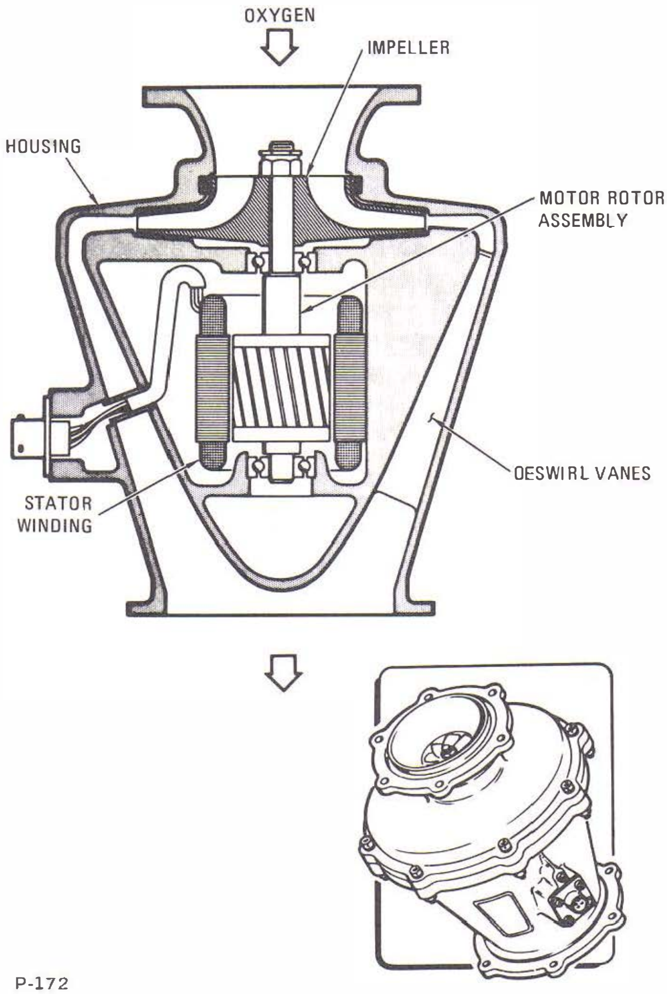
From the filter the gas flows through the suit heat exchanger where the gases are cooled and the excess moisture is removed. The heat exchanger assembly is made up of two sets of broad flat tubes through which the coolant from the primary and secondary loops can be circulated. The coolant flow or bypass is controlled by two valves located on the coolant control panel. The space between the tubes forms passages through which the suit gases flow. The coolant flowing through the tubes absorbs some of the heat from the suit gases. As the gases are cooled to about 55°F, the excess moisture condenses and is removed from the heat exchanger by one or both of a pair of water accumulator pumps.

The water accumulators are piston-type pumps actuated by oxygen pressure (100 psi) on the discharge stroke and by a return spring for the suction stroke. The oxygen flow is controlled by two water accumulator selector valve assemblies on the coolant control panel. Each valve assembly contains a selector valve, a solenoid valve, and an integral bypass. Oxygen flow can be controlled



P-171

Simplified schematic of suit circuit



P-172

Suit compressor

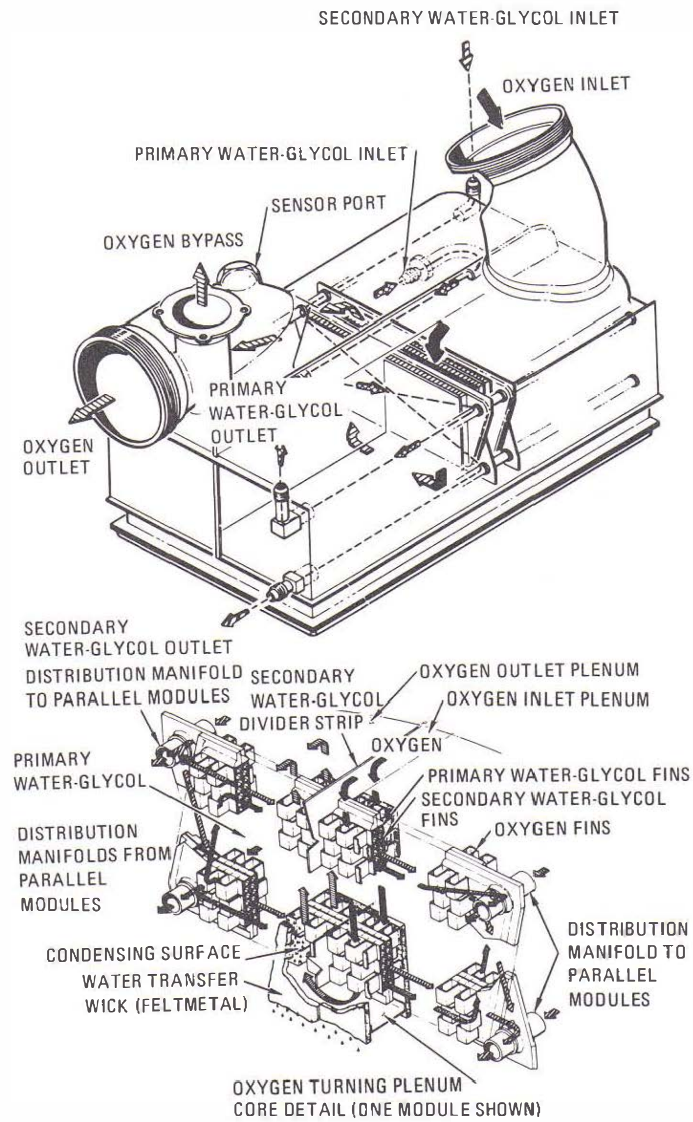
automatically by the solenoid valve through signals from the central timing equipment. These signals will cause one of the accumulators to complete a cycle every ten minutes. If it becomes necessary to cycle the accumulators at more frequent intervals the solenoid valve can be controlled manually.

The cool gas (55°F nominal) flows from the heat exchanger through the suit flow limiters and the flow control valves into the suits. The suit temperature is measured at the heat exchanger outlet, and is displayed on the main display console and telemetered.

A suit flow limiter is installed in each suit supply duct to restrict the gas flow rate through any one suit. The flow limiter is a tube with a Venturi section sized to limit flow to 0.7 pound per minute. The limiter offers maximum resistance to gas flow through a torn suit, when cabin pressure is near zero psia. The oxygen demand regulator will supply oxygen at flow rates up to 0.67 pound per minute (for at least 5 minutes) to maintain pressure in the circuit while the torn suit is being repaired.

Flow control valves are part of the suit hose connector assembly. These valves provide a means for adjusting the gas flow through each suit individually. When operating in a shirtsleeve environment with the inlet hose disconnected from the suit, approximately 12 cubic feet of suit gas per minute flows into the cabin.

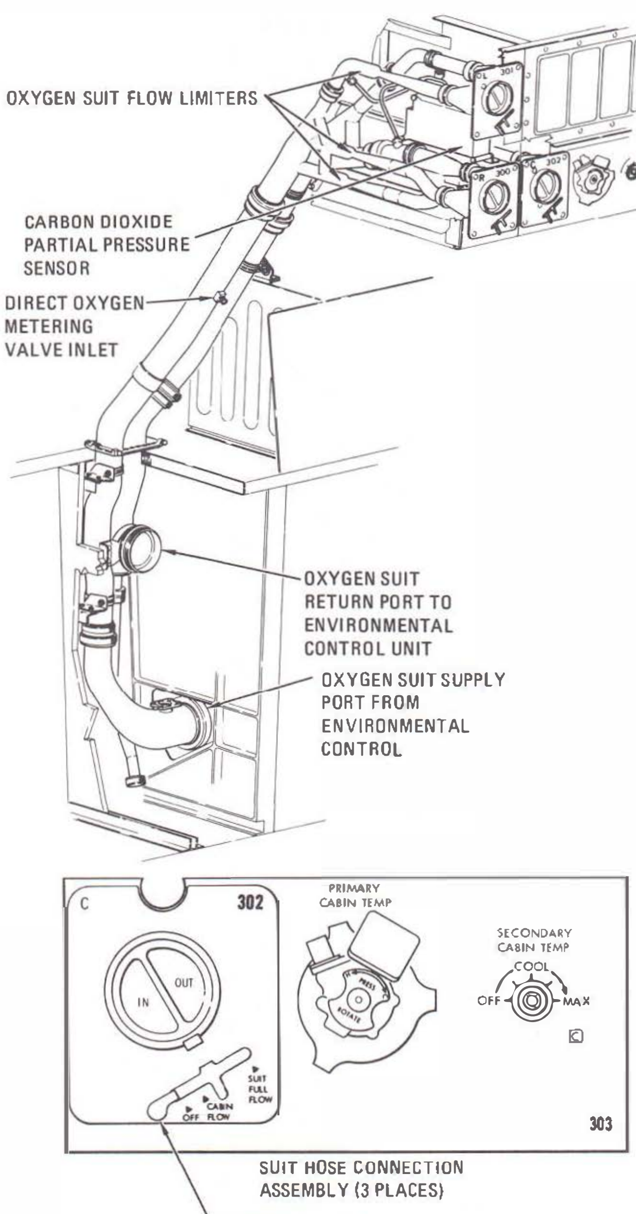
A suit flow relief valve is installed between the suit heat exchanger outlet and the compressor inlet, and is intended to maintain a relatively constant pressure at the inlets to the three suits by relieving transient pressure surges. A control is provided for manually closing the valve; the valve is normally off throughout the mission.



P-173 *Suit heat exchanger*

Gas leaving the suits flows through the debris trap assembly into the suit compressor. The debris trap is a mechanical filter for screening out solid matter that might otherwise clog or damage the system. The trap consists of a stainless steel screen designed to block particles larger than 0.040 inch, and a bypass valve which will open at differential pressure of 0.5 inch of water pressure in the event the screen becomes clogged.

A suit circuit return valve is installed on the debris trap upstream of the screen. It permits cabin gases to enter the suit circuit for scrubbing. The valve consists of two flapper-type check valves and a manual shutoff valve, in series. The shutoff valve provides a means of isolating the suit circuit from the cabin manually by means of a remote control. This is done to prevent inducting cabin gases into the suit circuit in the event the cabin gases become contaminated. The valve is located at the suit compressor inlet manifold, which is normally 1 to 2 inches of water pressure below cabin pressure. The differential pressure causes cabin gases to flow into the suit circuit. The reconditioned cabin gases are recirculated through the suits or cabin. During emergency operation, the valves prevent gases from flowing into the depressurized cabin from the suit circuit.



Suit distribution duct and hose connectors

A carbon dioxide sensor is connected between the suit inlet and return manifold. It is connected to an indicator on the main display console, to telemetry, and to the caution and warning system and will activate a warning if the carbon dioxide partial pressure reaches 7.6 millimeters of mercury.

WATER SUBSYSTEM

The water subsystem consists of two individual fluid management networks which control the collection, storage, and distribution of potable and waste water. The potable water is used primarily for metabolic and hygienic purposes. The waste water is used solely as the evaporant in the primary and secondary glycol evaporators. Although the two networks operate and are controlled independently, they are interconnected in a manner which allows potable water to flow into the waste system under certain conditions.

Potable water produced in the fuel cells is pumped into the CM at a flow rate of approximately 1.5 pounds per hour. The water flows through a check valve to the inlet ports of the potable tank inlet and waste tank inlet valves. The check valve at the inlet prevents loss of potable water after CM-SM separation.

The potable tank inlet is a manual shutoff valve used to prevent the flow of fuel cell water into the potable system in the event the fuel cell water becomes contaminated.

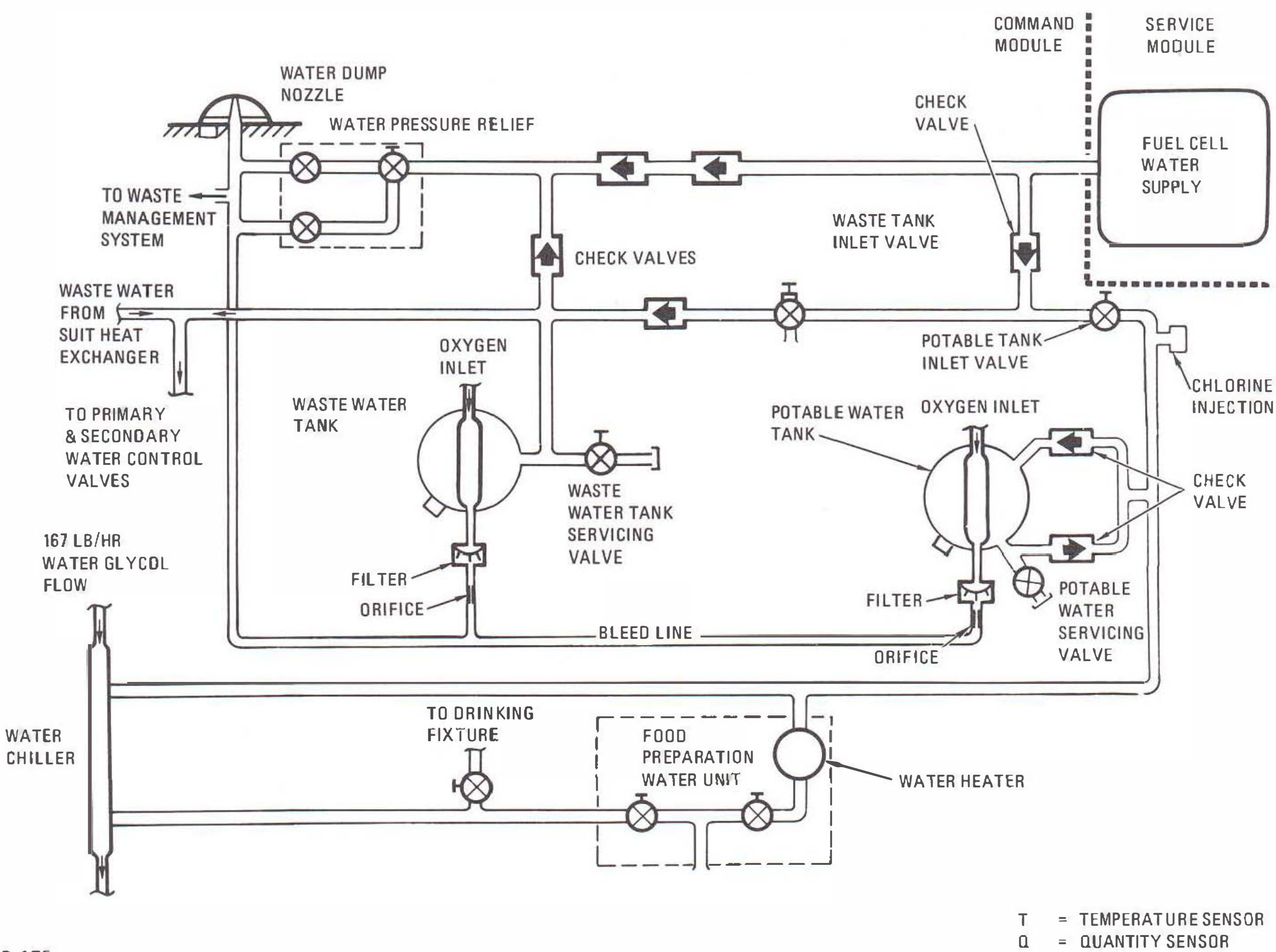
The waste tank inlet is an in-line relief valve with an integral shutoff valve. The relief valve allows potable water to flow into the waste water tank whenever the potable water pressure is 6 psi above waste water pressure. This pressure differential will occur when the fuel cells are pumping water, and either the potable water tank is full, or the potable tank inlet valve is closed; or when the waste water tank is completely empty and the glycol evaporators are demanding water for cooling. In the latter case, the water flow is only that quantity which is demanded. The shutoff valve is used to block flow in case the relief valve fails. If such a failure occurs, potable water can flow through the valve (provided the potable water pressure is higher than the waste), until the two pressures are equal. Reverse flow is prevented by a check valve.

In the event that both water tanks are full at the time the fuel cells are pumping, the excess potable water will be dumped overboard through a pressure relief valve. This is a dual unit with a selector valve for placing either or both relief valves on-stream or shutting the unit off.

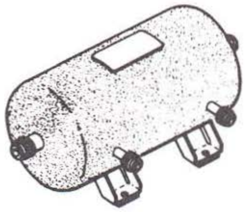
Water flows from the control panel to the potable water tank, the food preparation water unit, and the water chiller. Chilled water is delivered to the food preparation water unit and to the drinking water dispenser through the drinking water supply valve.

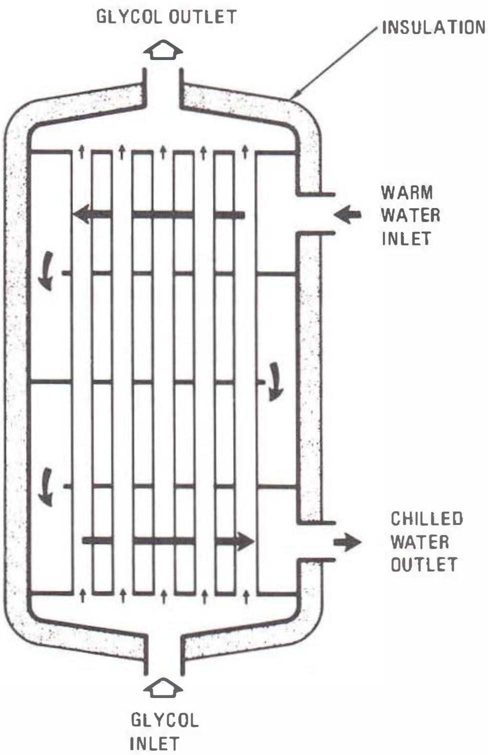
The water chiller cools and stores 0.5 pound of potable water for crew consumption. The water chiller is designed to supply 6 ounces of 50°F water every 24 minutes. The unit consists of an internally baffled reservoir containing a coiled tube assembly which is used as the coolant conduit. The baffles are used to prevent the incoming hot water from mixing with and raising the temperature of the previously chilled water.

The food preparation water unit heats potable water for use by the crew and allows manual selection of hot or cold potable water; the cold potable water is supplied by the water chiller. The unit consists of an electrically heated water reservoir and two manually operated valves which meter



Schematic of water management subsystem





P-176

Water chiller

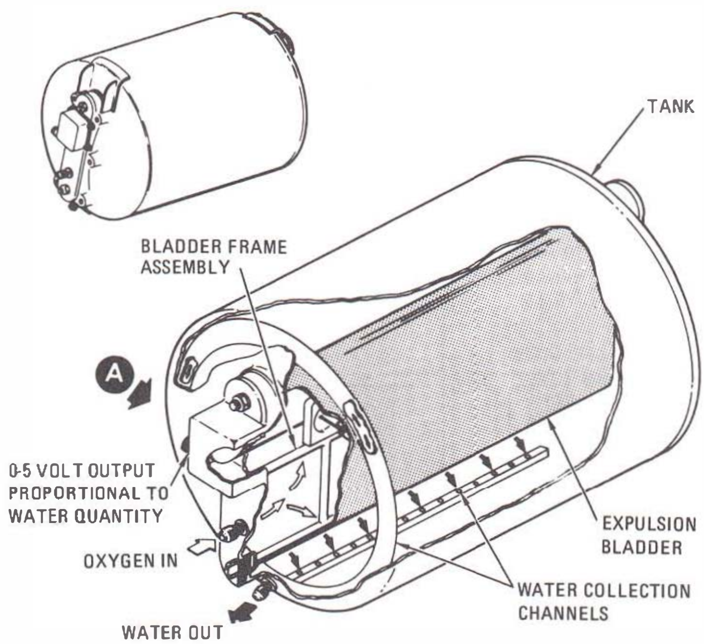
water in 1-ounce increments. The insulated reservoir has a capacity of 2.5 pounds of water. Thermostatically controlled heating elements in the reservoir heat the water and maintain it at 154°F nominal. Two metering valves dispense either hot or cold water, in 1-ounce increments, through a common nozzle. The hot water delivery rate is approximately 10 ounces every 30 minutes.

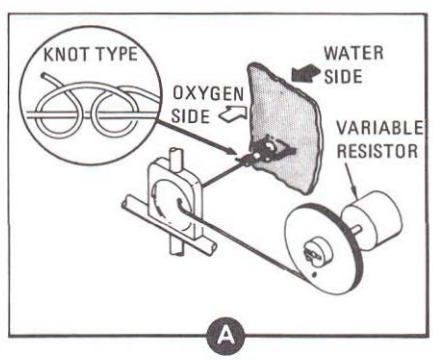
The drinking water supply valve is used to shut off the flow of water to the drinking water dispenser (water pistol), in case of a leak in the flex hose.

The waste water and potable water are stored in positive expulsion tanks, which with the exception of capacity are identical in function, operation, and design. The positive expulsion feature is obtained by an integrally supported bladder, installed longitudinally in the tank. Water collector channels, integral with the tank walls, prevent water from being trapped within the tank by the expanding bladder. Quantity transducers provide signals to an indicator on the main display console.

Bacteria from the waste water system can migrate through the isolating valves into the potable water system. A syringe injection system provides for periodic injection of bactericide to kill bacteria in the potable water system.

Waste water extracted from the suit heat exchanger is pumped into the waste water tank, and is delivered to the evaporator control valves. When the tank is full, excess waste water is dumped overboard through the water pressure relief valve. The evaporator control valves consist of a manually operated inlet valve and a solenoid valve. The primary solenoid valve can be controlled automatically or manually. The secondary solenoid valve is controlled automatically.





P-177

Waste water tank

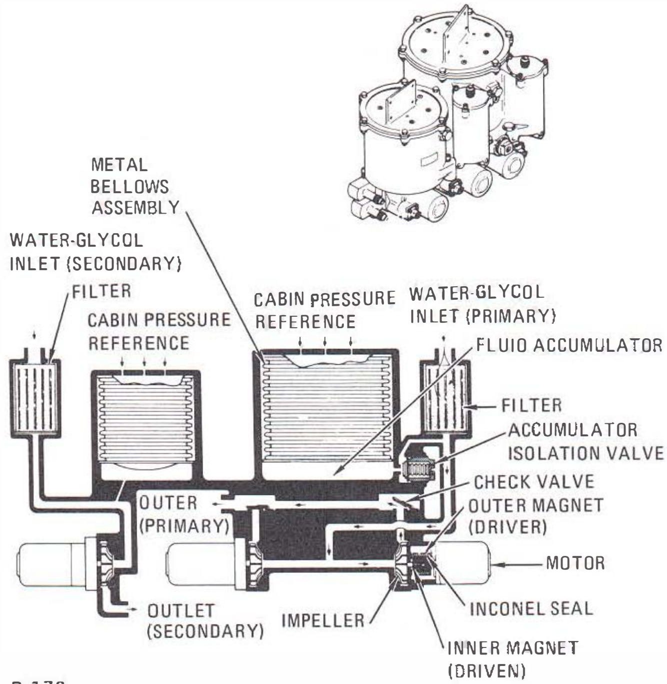
WATER-GLYCOL COOLANT SUBSYSTEM

The water-glycol coolant subsystem consists of two independently operated closed coolant loops. The primary loop is operated continuously throughout the mission unless damage to the equipment necessitates shutdown. The secondary loop is operated at the discretion of the crew, and provides a backup for the primary loop. Both loops provide cooling for the suit and cabin atmospheres, the electronic equipment, and a portion of the potable water supply. The primary loop also serves as a source of heat for the cabin atmosphere when required.

The coolant is circulated through the loops by a pumping unit consisting of two pumps, a full-flow filter, and an accumulator for the primary loop, and a single pump, filter, and accumulator for the secondary loop. The purpose of the accumulators is to maintain a positive pressure at the pump inlets by accepting volumetric changes due to changes in coolant temperature. If the primary accumulator leaks, it can be isolated from the loop. Then the reservoir must be placed in the loop to act as an accumulator. Accumulator quantity is displayed on the main display console. A switch on the console permits either of the pumps to be connected to either ac bus. The secondary permits either of the pumps to be connected to either ac bus. The secondary pump also has a switch which allows it to be connected to either ac bus.

The output of the primary pump flows through a passage in the evaporator steam pressure control valve to de-ice the valve throat. The coolant next flows through a diverter valve, through the radiators, and returns to the CM. The diverter valve is placed in the "Bypass" position before launch to isolate the radiators from the loop, and before CM-SM separation to prevent loss of coolant when the CSM umbilical is cut. Otherwise it is in the normal operating position.

Coolant returning to the CM flows to the glycol reservoir valves. From pre-launch until after orbit insertion, the reservoir inlet and outlet valves are open and the bypass valve is closed, allowing coolant to circulate through the reservoir. This provides a quantity of cold coolant to be used as a heat sink during the early stage of launch. After orbit insertion, the reservoir is isolated from the primary loop to provide a reserve supply of coolant for refilling the loop in the event a leak occurs.



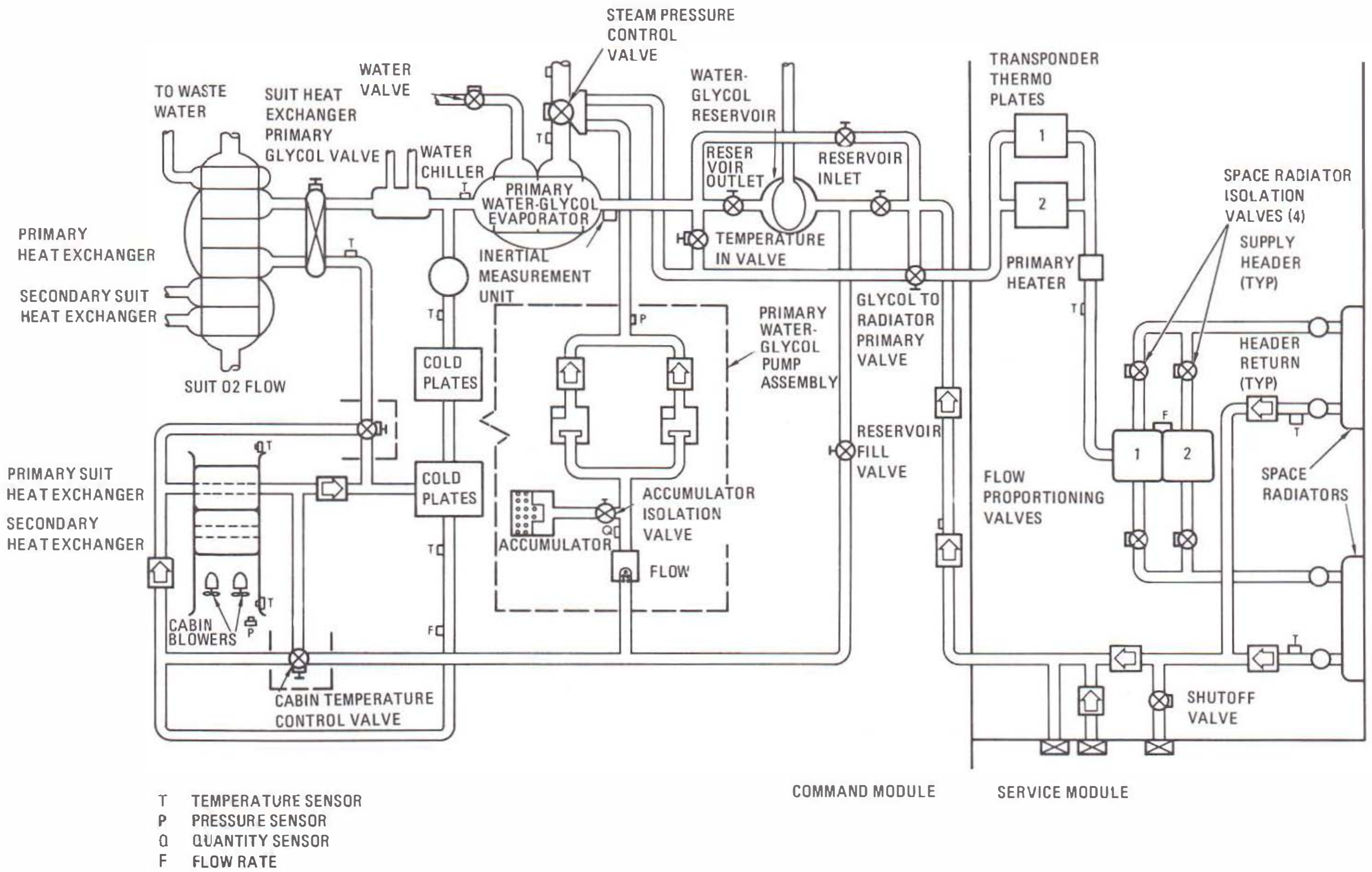
Water-glycol pump assembly

The coolant flow from the evaporator divides into two branches. One carries a flow of 33 pounds per hour to the inertial measurement unit and into the coldplate network. The other branch carries a flow of 167 pounds per hour to the water chiller through the suit heat exchanger primary glycol valve and the suit heat exchanger to the primary cabin temperature control valve.

The primary cabin temperature control valve routes the coolant to either the cabin heat exchanger or to the coldplate network. The valve is positioned automatically by the cabin temperature control, or manually by means of an override control on the face of the valve. The valve is so constructed that in the cabin full cooling mode, the flow of coolant from the suit heat exchanger (167 pounds per hour) is routed first through the cabin heat exchanger and then through the thermal coldplates where it joins with the flow (33 pounds per hour) from the inertial measurement unit. In the cabin full heating mode, the total flow (200 pounds per hour) is routed through the thermal coldplates first, where the water-glycol absorbs heat; from there it flows through the cabin heat exchanger. In the intermediate valve position, the quantity of cool or warm water-glycol flowing through the heat exchanger is reduced in proportion to the demand for cooling or heating. Although the amount of water-glycol flowing through the cabin heat exchanger will vary, the total flow through the thermal coldplates will always be total system flow. An orifice restrictor is installed between the cabin temperature control valve and the inlet to the coldplates. Its purpose is to maintain a constant flow rate through the coldplates by reducing the heating mode flow rate to that of the cooling mode flow rate. Another orifice restrictor, located in the coolant line from the inertial measurement unit, maintains a constant flow rate through this component regardless of system flow fluctuations. The total flow leaving the primary cabin temperature valve enters the primary pump and is recirculated.

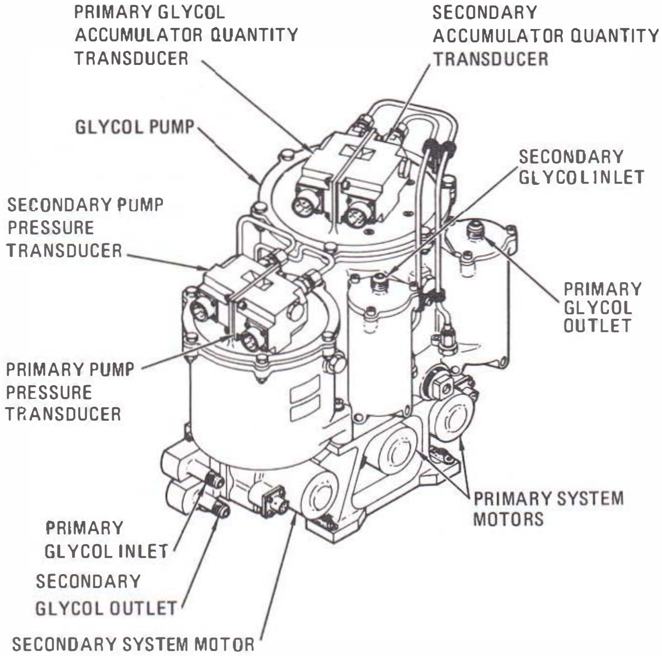
The output of the secondary pump flows through a passage in the secondary evaporator steam pressure control valve for de-icing the valve throat. The coolant next flows through a diverter valve, through the radiators, and returns to the CM. This valve also is placed in the bypass position before CM-SM separation to prevent loss of coolant when the CSM umbilical is severed. After returning to the CM the coolant flows through the secondary evaporator, the suit heat exchanger secondary glycol valve, and the suit heat exchanger to the secondary cabin temperature control valve. The secondary cabin temperature control valve regulates the quantity of coolant flowing through the cabin heat exchanger in the cooling mode (there is not heating capability in the secondary loop). The coolant from the secondary cabin temperature control valve and/or the cabin heat exchanger then flows through redundant passages in the coldplates and returns to the secondary pump inlet.

The heat absorbed by the coolant in the primary loop is transported to the radiators where a portion is rejected to space. If the quantity of heat rejected by the radiators is excessive, the temperature of the coolant returning to the CM will be lower than desired (45°F nominal). If the temperature of the coolant entering the evaporator drops below a nominal 43°F, the mixing mode of temperature control is initiated. The automatic control opens the glycol evaporator temperature valve, which allows a sufficient quantity of hot coolant from the pump to mix with the coolant returning from the



P-179

Schematic of primary water-glycol subsystem



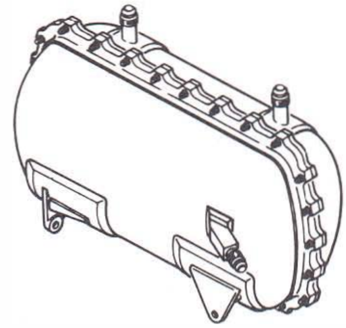
P-180 *Glycol pump assembly*

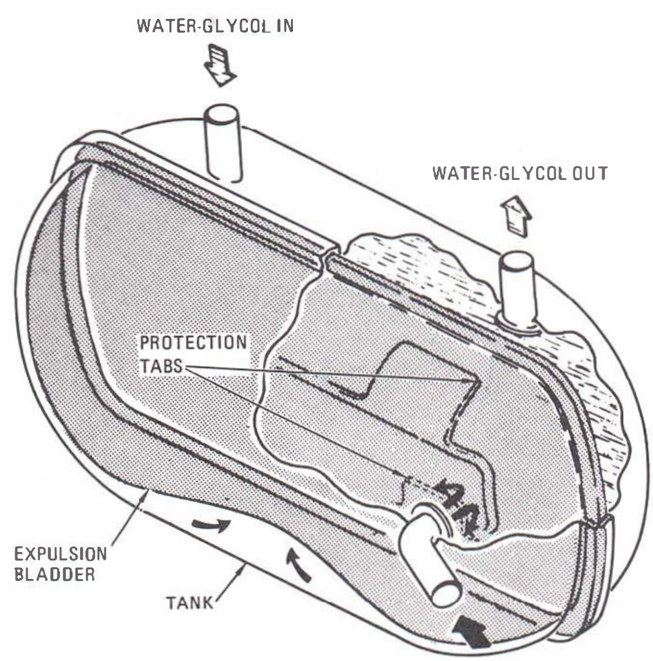
radiators to produce a mixed temperature at the inlet to the evaporator between 43° and 48°F. There is no mixing mode in the secondary loop. If the temperature of the coolant returning from the secondary radiator is lower than 45°F nominal, the secondary radiator inlet heater will be turned on to maintain the outlet temperature between 42° and 48°F.

If the radiators fail to radiate a sufficient quantity of heat, the coolant returning to the CM will be above the desired temperature. When the temperature of the coolant entering the evaporator rises to 48° to 50.5°F, the evaporator mode of cooling is initiated. The glycol temperature control opens the steam pressure valve allowing the water in the evaporator wicks to evaporate, using some of the heat contained in the coolant for the heat of vaporization. A temperature sensor at the outlet of the evaporator controls the position of the steam pressure valve to establish a rate of evaporation that will result in a coolant outlet temperature between 40° to 43°F. The evaporator wicks are maintained in a wet condition by wetness control which uses the wick temperature as an indication of water content. As the wicks become dryer, the wick temperature increases and the water control valve is opened. As the wicks become wetter, the wick temperature decreases and the water valve closes. The evaporative mode of cooling is the same for both loops. The steam pressure valve can be controlled remotely, using evaporator outlet temperature as an indicator. The secondary evaporator is controlled automatically.

Each coolant loop includes a radiator circuit. The primary radiator circuit consists basically of two radiator panels in parallel with a flow-proportioning control for dividing the flow between them, and a heater control for adding heat to the loop. The secondary circuit consists of a series loop utilizing some of the area of both panels, and a heater control for adding heat to the loop.

The radiator panels are an integral part of the SM skin and are located on opposite sides of the SM in Sectors 2 and 3 and in Sectors 5 and 6. With the radiators being diametrically opposite, it is possible that one primary panel may face deep space while the other faces the sun, earth, or moon. These



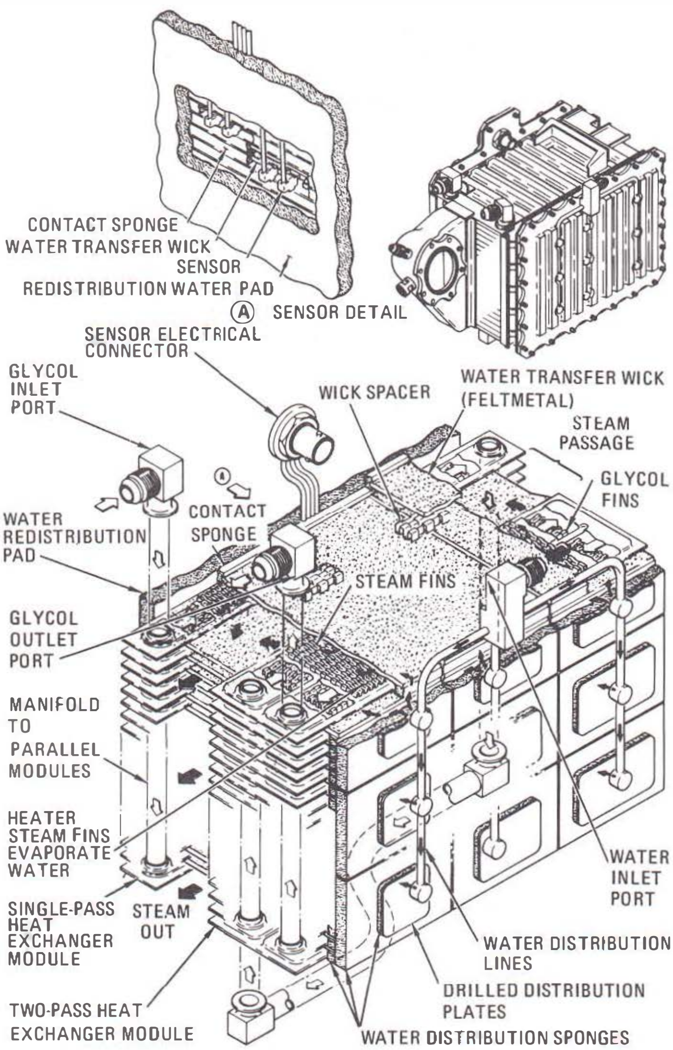


P-181 *Water-glycol reservoir*

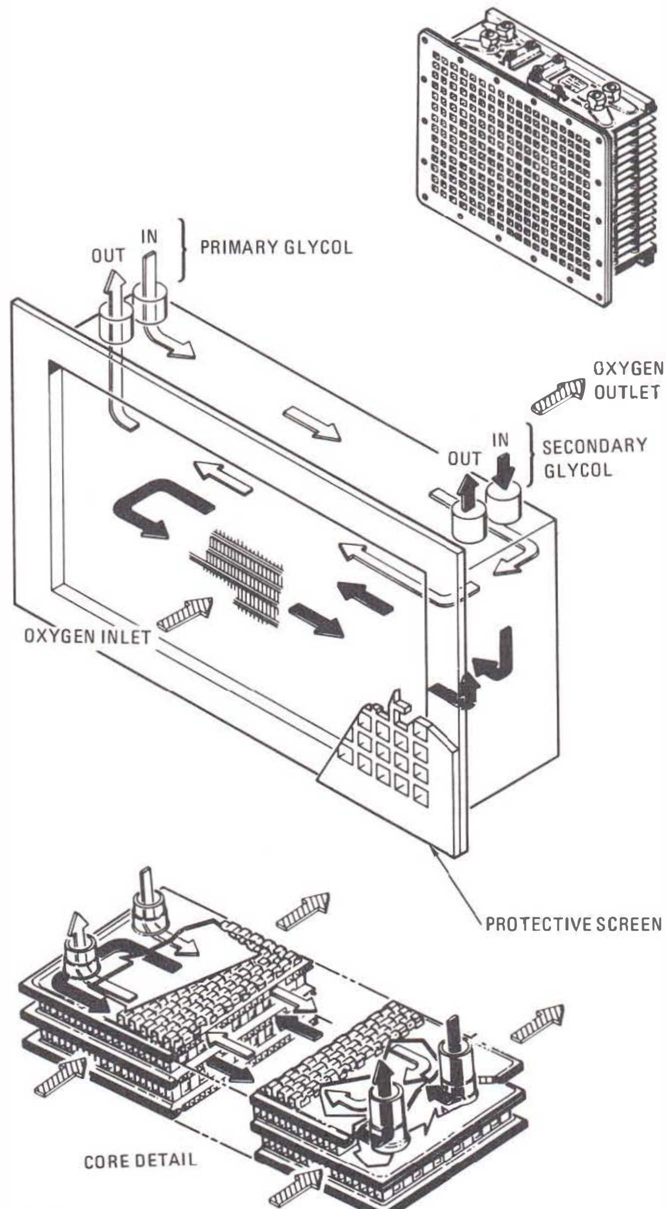
extremes in environments mean large differences in panel efficiencies and outlet temperatures. The panel facing deep space can reject more heat than the panel receiving external radiation; therefore, the overall efficiency of the subsystem can be improved by increasing the flow to the cold panel. The higher flow rate reduces the transit time of the coolant through the radiator, which decreases the quantity of heat radiated.

The flow through the radiators is controlled by a flow-proportioning valve. When the differential temperature between the outlets of the two panels exceeds 10°F, the flow-proportioning valve is positioned to increase the flow to the colder panel.

The flow-proportioning valve assembly contains two individually controlled valves, only one of which can be in operation. When the switches are on automatic the flow controller selects the No. 1 valve and positions the appropriate radiator isolation valves. Manual selection and transfer also is possible. Automatic transfer will occur when the temperature differential exceeds 15°F, providing a failure has occurred. In the absence of a failure, the transfer signal will be inhibited. In situations where the radiator inlet temperature is low and the panels have a favorable environment for heat rejection, the radiator outlet temperature starts to decrease and thus the bypass ratio starts to increase. As more flow is bypassed, the radiator outlet temperature decreases until the -20°F minimum desired temperature would be exceeded. To prevent this from occurring, a heater is automatically turned on when



P-182 *Glycol evaporator*



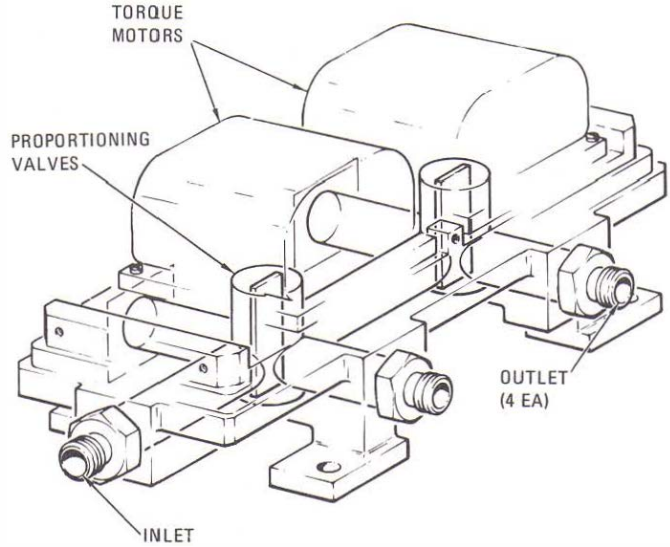
P-183 *Cabin heat exchanger*

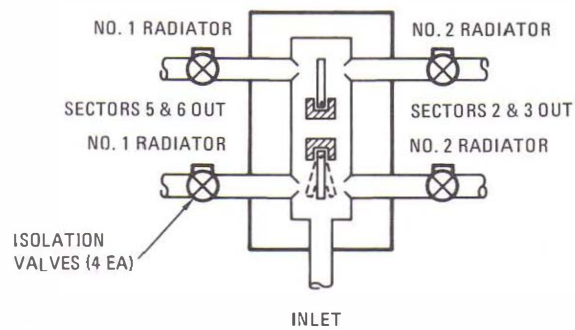
radiator mixed outlet temperature drops to $-15^{\circ}F$ and remains on until $-10^{\circ}F$ is reached. The controller provides only on-off heater control which results in a nominal 450 watts being added to the coolant each time the heater is energized. The crew can switch to a redundant heater system if the temperature decreases to $-20^{\circ}F$.

If the radiator outlet temperature falls below the desired minimum, the effective radiator surface temperature will be controlled passively by the selective stagnation method. The two primary circuits are identical, consisting of five tubes in parallel and one downstream series tube. The two panels, as explained in the flow proportioning control system, are in parallel with respect to each other. The five parallel tubes of each panel have manifolds sized to provide specific flow rate ratios in the tubes, numbered 1 through 5. Tube 5 has a lower flow rate than Tube 4, and so on, through Tube 1 which has the highest flow. For equal fin areas, therefore, the tube with the lower flow rate will have a lower coolant temperature. During minimum CM heat loads, stagnation begins to occur in Tube 5 as its temperature decreases; for as its temperature decreases, the fluid resistance increases, and the flow rate decreases. As the fin area around Tube 5 gets colder, it draws heat from Tube 4 and the same process occurs with Tube 4. In a fully stagnated condition, there is essentially no flow in Tubes 3, 4, and 5, and some flow in Tubes 1 and 2, with most of it in Tube 1.

When the CM heat load increases and the radiator inlet starts to increase, the temperature in Tube 1 increases and more heat is transferred through the fin toward Tube 2. At the same time, the glycol evaporator temperature valve starts to close and force more coolant to the radiators, thus helping to thaw the stagnant portion of the panels. As Tube 2 starts to get warmer and receives more flow it in turn starts to thaw Tube 3, and so on. This combination of higher inlet temperatures and higher flow rates quickly thaws out the panel. The panels automatically provide a high effectiveness (completely thawed panels operating at a high average fin temperature) at high heat loads, and a low effectiveness (stagnated panels operating at a low average fin temperature) at low heat loads.

The secondary radiator consists of four tubes which are an integral part of the radiator panel structure. Each tube is purposely placed close to the hottest primary radiator tubes (i.e., Tube 1 and



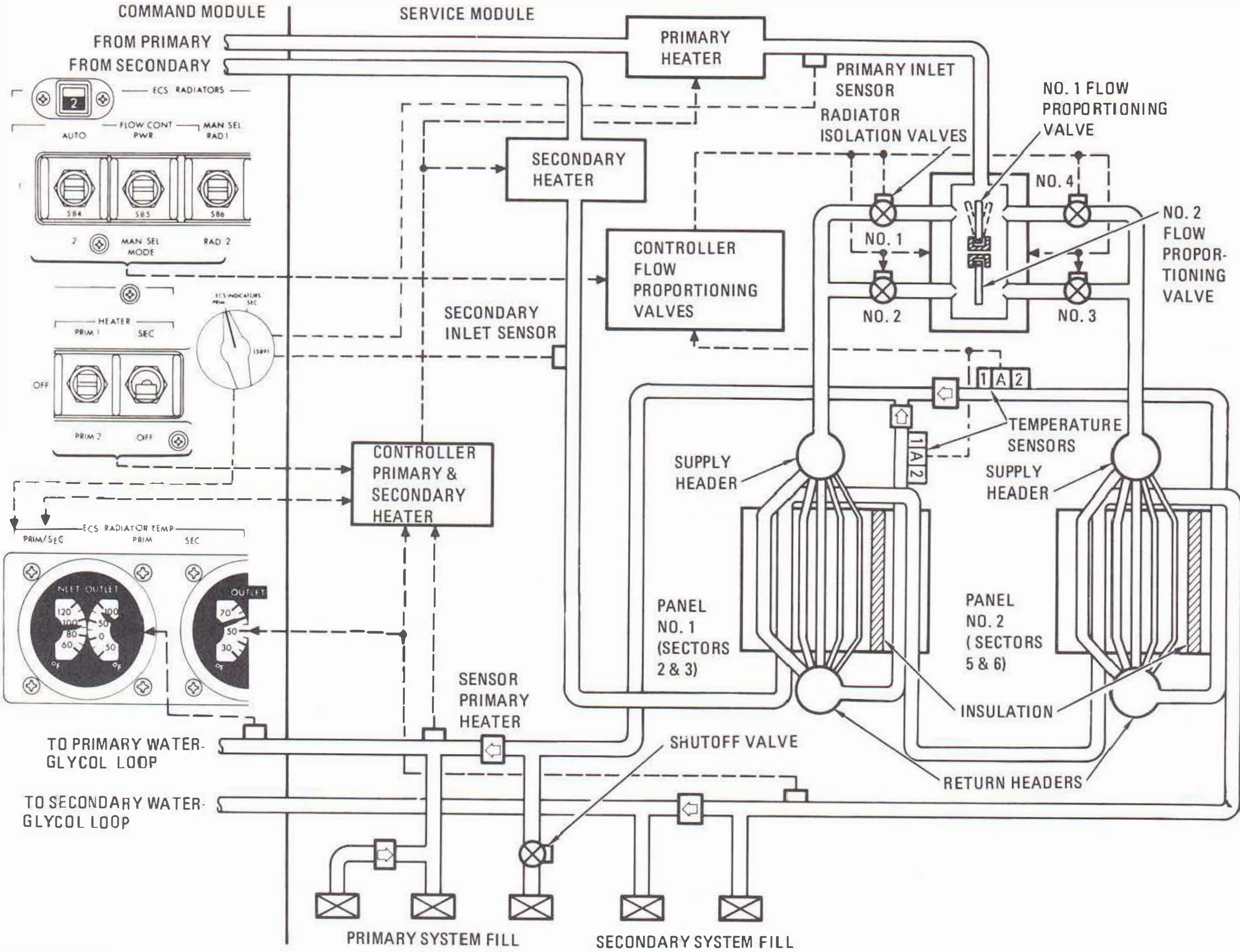


P-184

Space radiator flow proportioning valves

the downstream series tube on each panel) to keep the water-glycol in the secondary tubes from freezing while the secondary circuit is inoperative. The selective stagnation principle is not utilized in the secondary radiator because of the narrower heat load range requirements. This is also the reason the secondary radiator is a series loop. Because of the lack of this passive control mechanism, the secondary circuit depends on the heater control system at low heat loads and the evaporator at high heat loads for control of the water-glycol temperature.

The secondary heaters differ from the primary in that they can be operated simultaneously. When the secondary outlet temperature reaches $43^{\circ}F$ the No. 1 heater comes on, and at $42^{\circ}F$ the No. 2 heater comes on; at $44^{\circ}F$ No. 2 goes off, and at $45^{\circ}F$ No. 1 goes off.



P-185

Schematic of radiator subsystem