

ENVIRONMENTAL CONTROL

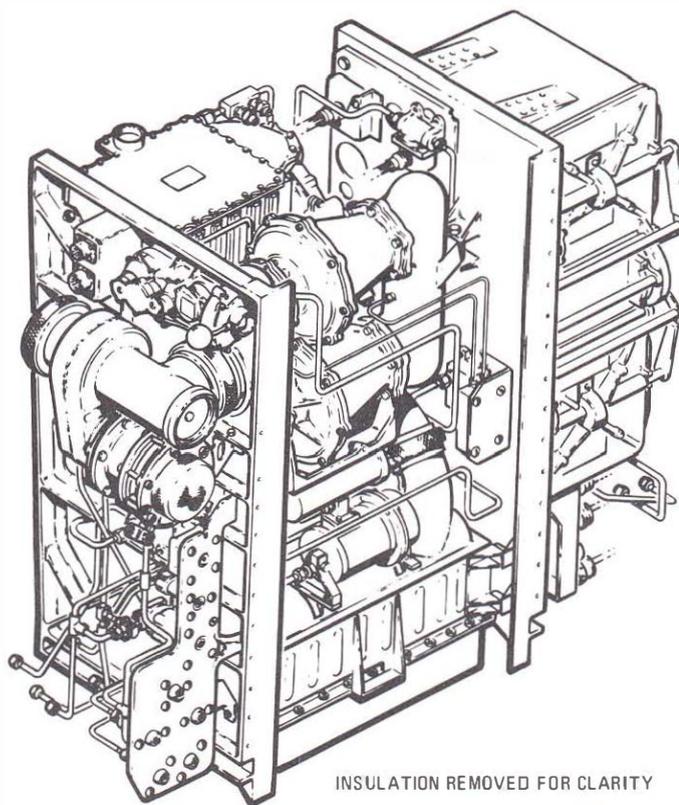
The environmental control subsystem provides a controlled environment for three astronauts for up to 14 days. For normal conditions, this environment includes a pressurized cabin (5 pounds per square inch), a 100-percent oxygen atmosphere, and a cabin temperature of 70 to 75 degrees. For use during critical mission phases and for emergencies, the subsystem provides a pressurized suit circuit. The environmental control unit, a major part of the environmental control subsystem, is produced by Garrett Corp.'s AiResearch Division, Los Angeles.

The subsystem provides oxygen and hot and cold water, removes carbon dioxide and odors from the CM cabin, provides for venting of waste, and dissipates excessive heat from the cabin and from operating electronic equipment. It is designed so that a minimum amount of crew time is needed for its normal operation.

The environmental control unit is the heart of the environmental control subsystem. It is a compact grouping of equipment about 29 inches long, 16 inches deep, and 33 inches at its widest point. It is mounted in the left-hand equipment bay. The unit contains the coolant control panel, water chiller, two water-glycol evaporators, carbon dioxide-odor absorber canisters, and suit heat exchanger, water separator, and compressors. The oxygen surge tank, water glycol pump package and reservoir, and control panels for oxygen and water are adjacent to the unit.

The subsystem is concerned with three major elements: oxygen, water, and coolant (water-glycol). All three are interrelated and intermingled with other subsystems. These three elements provide the major functions of spacecraft atmosphere and thermal control and water management through four major subsystems: oxygen, pressure suit circuit, water, and water-glycol. A fifth subsystem, post-landing ventilation, also is part of the environmental control subsystem; it provides outside air for breathing and cooling after the command module has splashed down in the ocean.

The oxygen subsystem controls the flow of oxygen within the CM, stores a reserve supply for use during entry and emergencies, regulates the pressure of oxygen supplied to subsystem and



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Environmental control unit

pressure suit circuit components, controls cabin pressure, controls pressure in water tanks and the glycol reservoir, and provides for purging the pressure suit circuit.

The pressure suit circuit provides a continuously conditioned atmosphere. It automatically controls suit gas circulation, pressure, and temperature, and removes debris, excess moisture, and carbon dioxide from both suit and cabin gases.

The water subsystem collects and stores potable water, delivers hot and cold water to the crew, and augments the waste water supply for evaporative cooling. The waste water section of the subsystem collects and stores water extracted from the suit heat exchanger and distributes it to the evaporators for cooling.

The water-glycol subsystem provides cooling for the pressure suit circuit, the potable water chiller, and the spacecraft equipment, as well as heating or cooling for the cabin atmosphere.

ATMOSPHERE CONTROL

The three astronauts in the command module are in their space suits and connect to the pressure suit circuit when they first enter the CM. They remain in the suits at least until after they have attained earth orbit confirmation. They also are in their suits whenever critical maneuvers are performed or thrusting is being applied to the spacecraft.

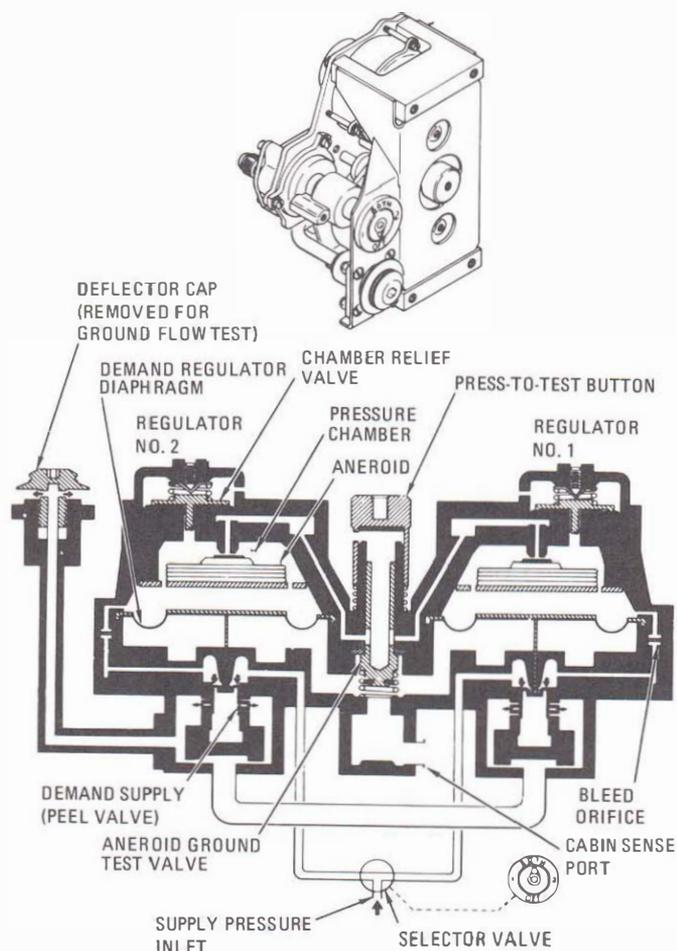
Cabin atmosphere is 60-percent oxygen and 40-percent nitrogen on the launch pad to reduce fire hazard (fire propagates more rapidly in pure oxygen than in a mixed-gas atmosphere). The mixed atmosphere, supplied by ground equipment, will gradually become changed to pure oxygen after launch as the environmental control subsystem supplies oxygen to the cabin to maintain pressure and replenish the atmosphere.

During pre-launch and initial orbital operation, the suit circuit supplies oxygen at a flow rate slightly more than needed for breathing and suit leakage. This results in the suit being pressurized slightly above cabin pressure, which prevents cabin gases from entering and contaminating the suit circuit. The excess oxygen in the suit circuit is vented into the cabin.

Cabin pressure drops from sea level (14.7 psi) as the spacecraft rises during ascent and at a pressure of 6 psi automatic equipment begins operating to keep cabin pressure at that level. As the cabin pressure decreases, oxygen from the suit circuit is dumped into the cabin; in other words, the suit circuit is maintained at a constant differential pressure relative to cabin pressure.

During normal space operations, cabin pressure is maintained at a nominal 5 psia by a cabin pressure regulator at flow rates up to 1.3 pounds of oxygen per hour. In case a high leak rate develops, an emergency cabin pressure regulator supplies oxygen at high flow rates to maintain cabin pressure above 3.5 psia for more than 15 minutes, long enough for the crew to don their suits.

Before entry, the suit circuit is isolated from the cabin; cabin pressure is maintained by the cabin pressure regulator until the ambient (outside) pressure rises to a maximum of 0.9 psi above the cabin pressure. At that point a relief valve will open to allow the outside air to flow into the cabin. As the cabin pressure increases, the oxygen demand regu-



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Emergency cabin pressure regulator

lator admits oxygen into the suit circuit to maintain suit pressure slightly above cabin pressure.

Oxygen normally is supplied from the cryogenic tanks in the service module. After CM-SM separation, it is supplied from the oxygen surge tank in the command module. In addition an oxygen repressurization package is provided to allow rapid repressurization of the cabin during space flight and to serve as an added entry oxygen supply. After landing, the cabin is ventilated with outside air through the post-landing fan and valves.

The oxygen in the suit circuit becomes heated and contaminated with carbon dioxide, odors, and moisture. This oxygen is circulated through the absorber assembly where the carbon dioxide and odors are removed, then through the heat exchanger where it is cooled and the excess moisture removed. In addition, any debris that might get into the circuit is trapped by the debris trap or in the absorber assembly.

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.

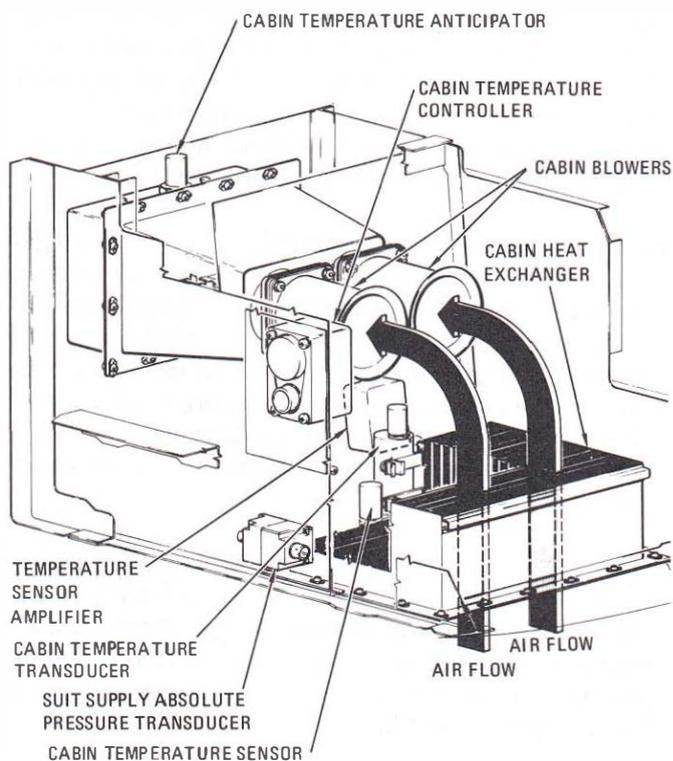
The water-glycol is a heat-absorbing medium; it picks up excess heat from operating equipment and

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.



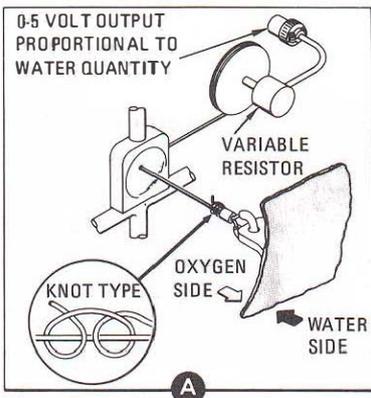
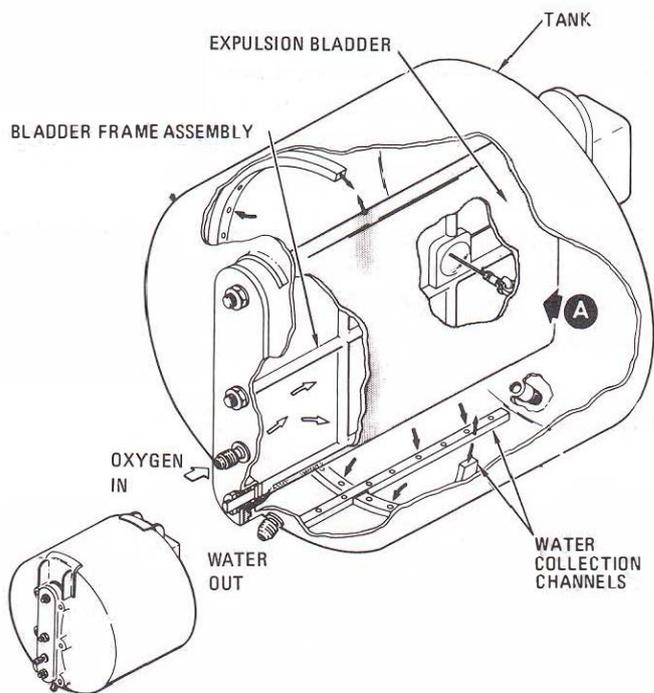
EQUIPMENT

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.



P-164 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.

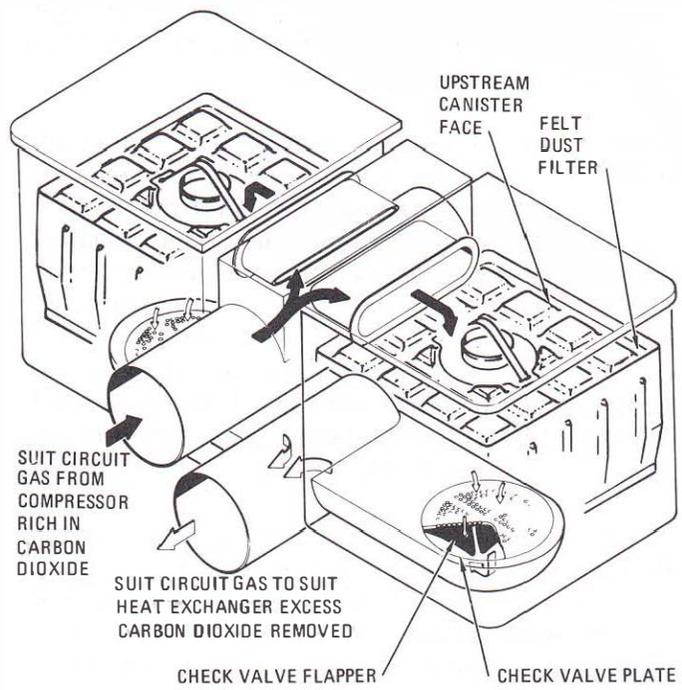
Repressurization Unit – There are three bottles, each containing one pound of oxygen, in an aluminum case with a repressurization valve connected to them. The oxygen is stored at 900 pounds per square inch. Used in conjunction with the oxygen surge tank, it can repressurize the cabin from 0 to 3 pounds 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.

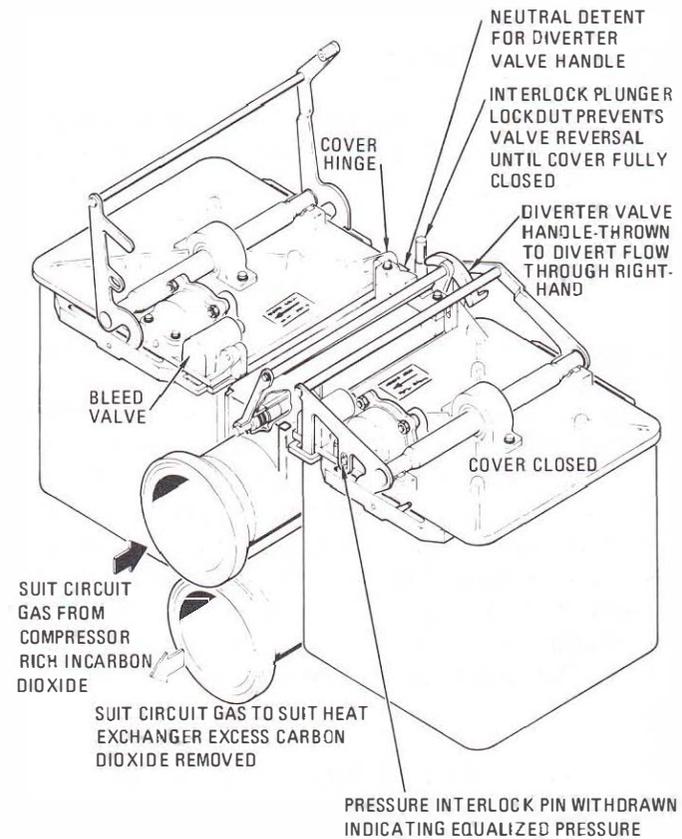
Waste Water Tank – The aluminum tank with a bladder has a diameter of about 12-1/2 inches and is 25 inches deep. It holds 28 quarts. It stores waste water from the suit heat exchanger to be used for cooling purposes through evaporation. It is in the aft compartment of the command module.

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.

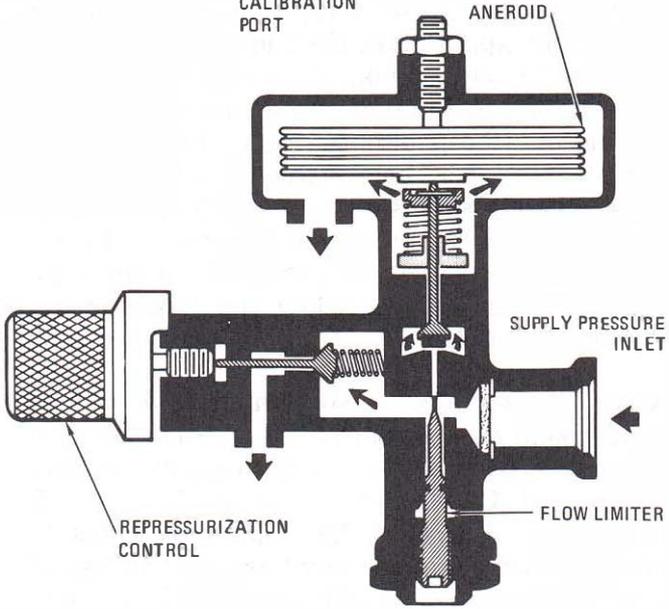
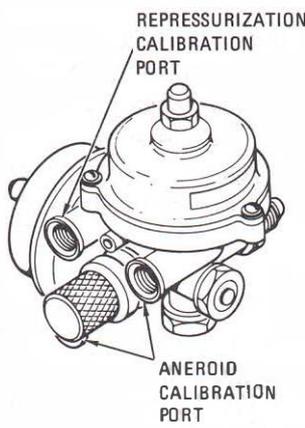
DETAILED DESCRIPTION

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.



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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

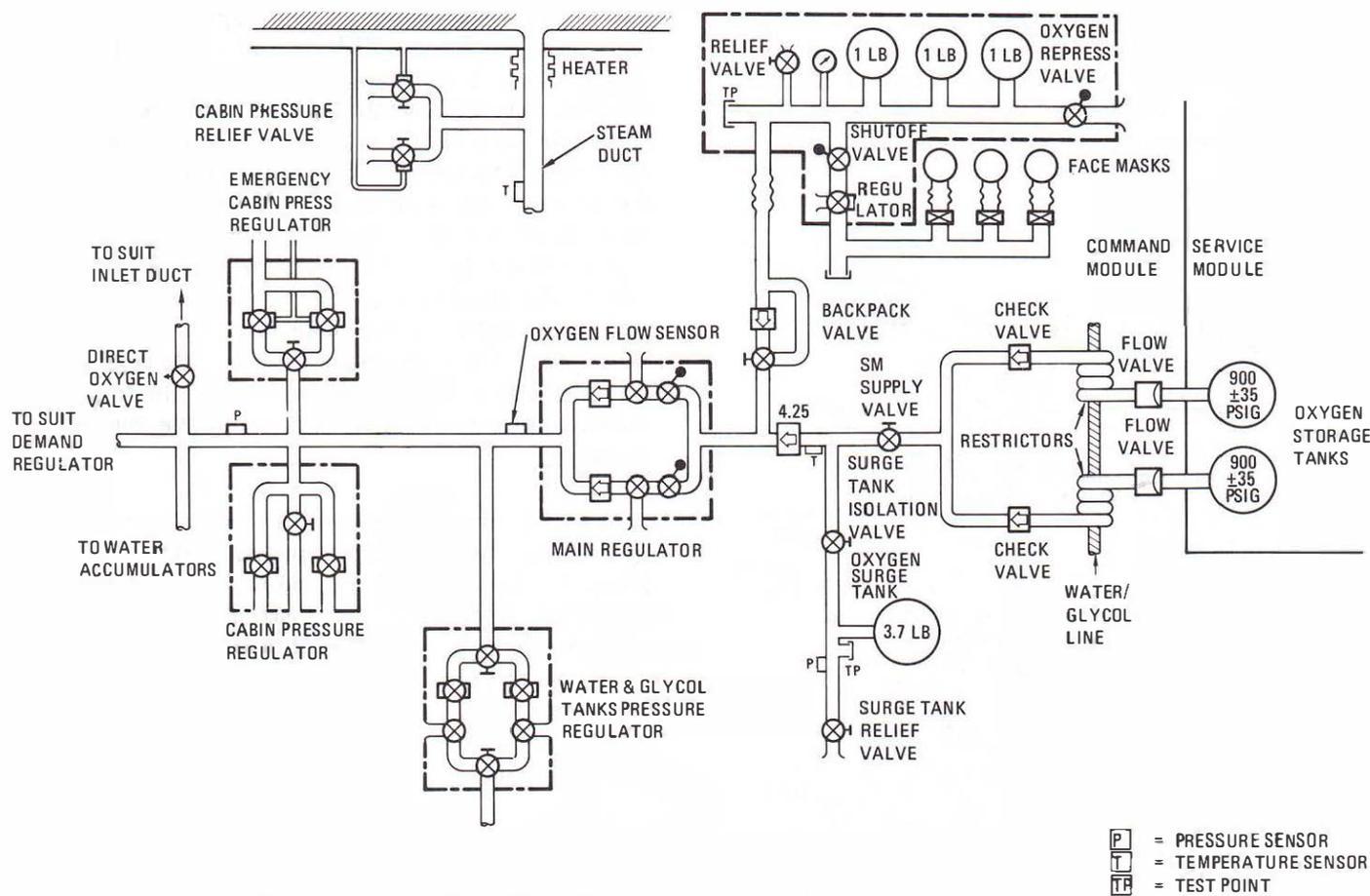
toggle-type fast-acting repressurization valve for dumping oxygen into the cabin at very high flow rates, and a toggle valve and regulator for supplying oxygen to the emergency oxygen face masks. Opening the repressurization valve, with the entry valve in the "fill" position, will dump both the package 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



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

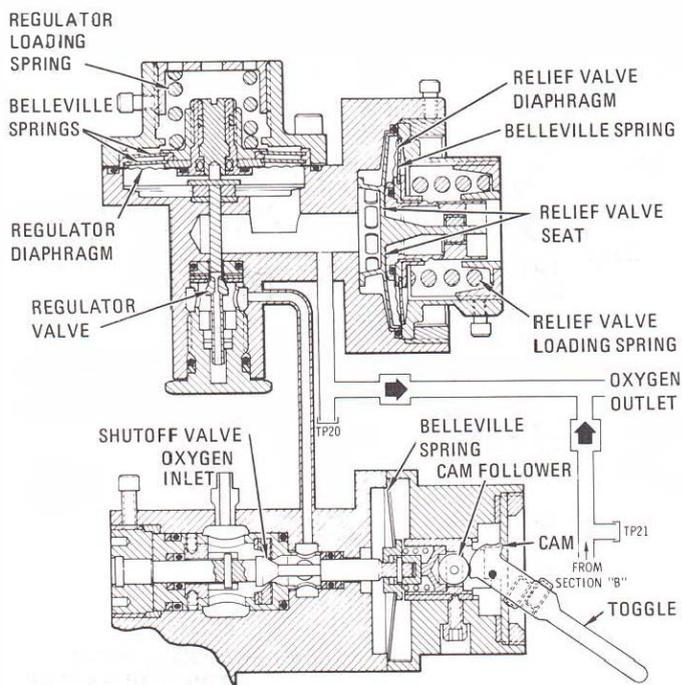
cabin puncture. The valve can provide flow rates that will maintain cabin pressure above 3.5 psia for a period of 15 minutes, against a leakage rate equivalent to 1/4-inch-diameter cabin puncture. The valve is normally used during shirtsleeve operations, and is intended to provide time for donning pressure suits before cabin pressure drops below 3.5 psia. During pressure suit operations, the valve is shut off to prevent unnecessary loss of oxygen.

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.

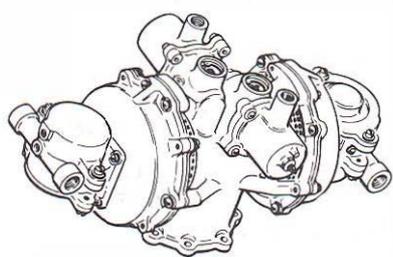
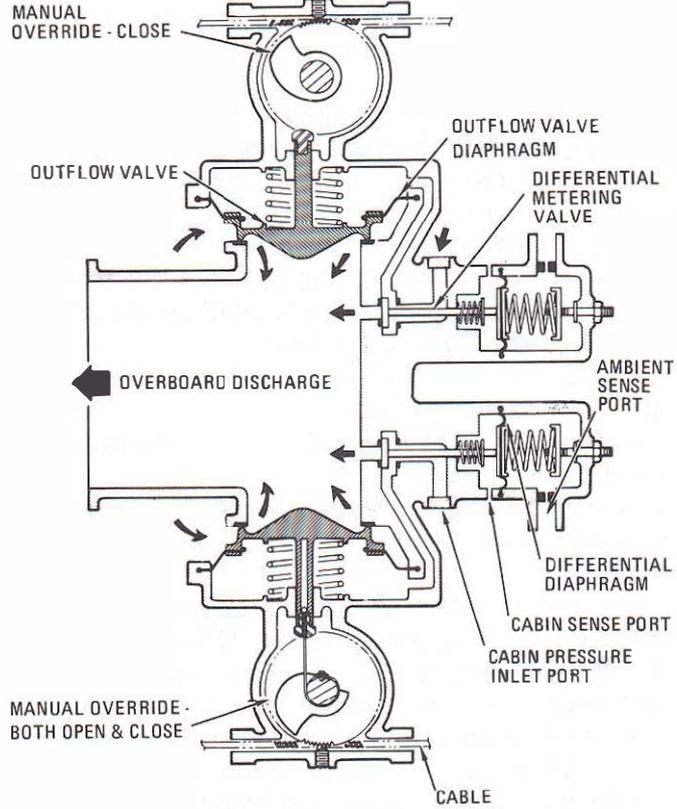
Each regulator section consists of an aneroid control and a differential diaphragm housed in a reference chamber. The diaphragm pushes against a rod connected to the demand valve; the demand valve will be opened whenever a pressure differential is sensed across the diaphragm. In operation, there is a 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



Main oxygen regulator



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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 pre-launch 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,

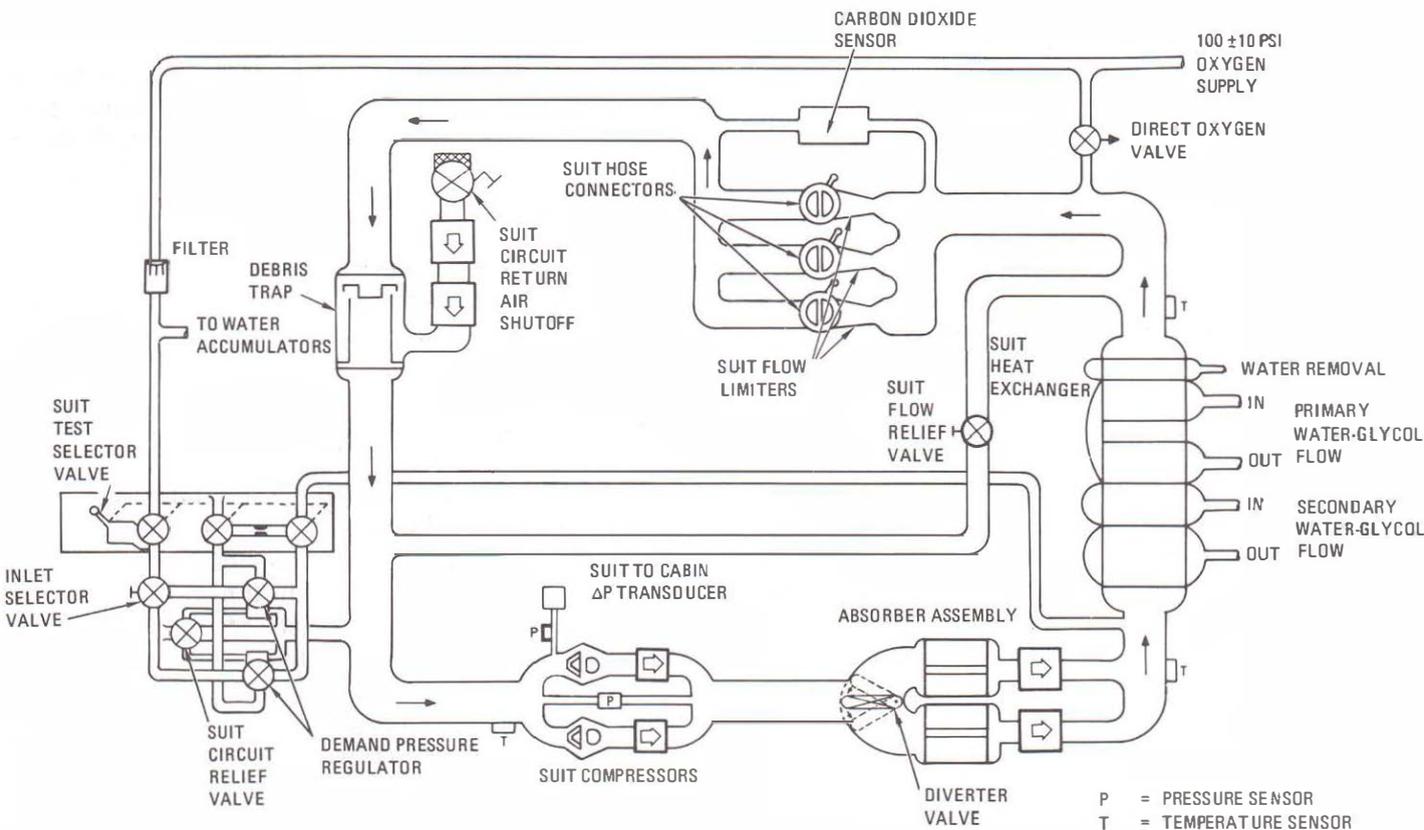
and to the caution and warning system, which will illuminate a light at a differential pressure of 0.22 psi or less. Another differential pressure transducer is connected between the suit compressor inlet manifold and the cabin; the output is displayed on the indicator. A switch on the main display console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

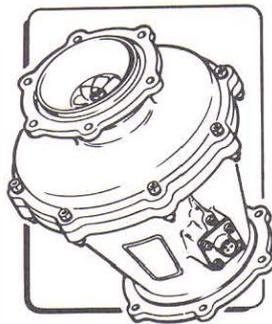
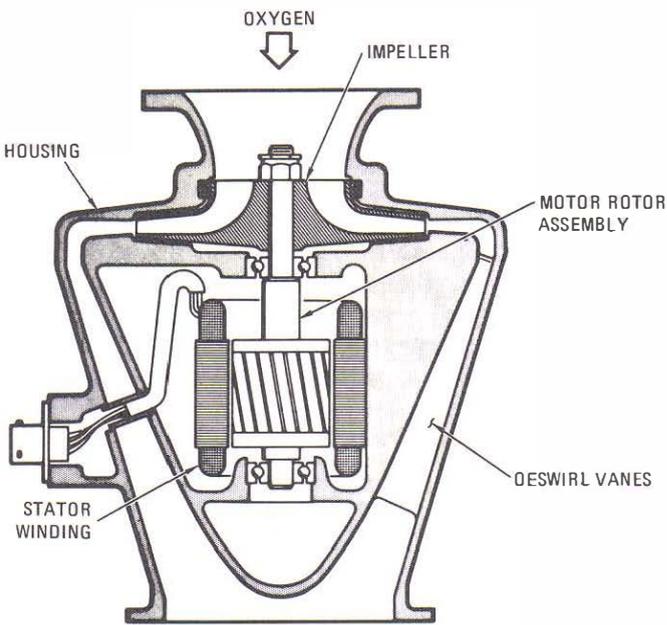
small particles and prevent absorbent materials from entering the gas stream.

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



Simplified schematic of suit circuit



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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.

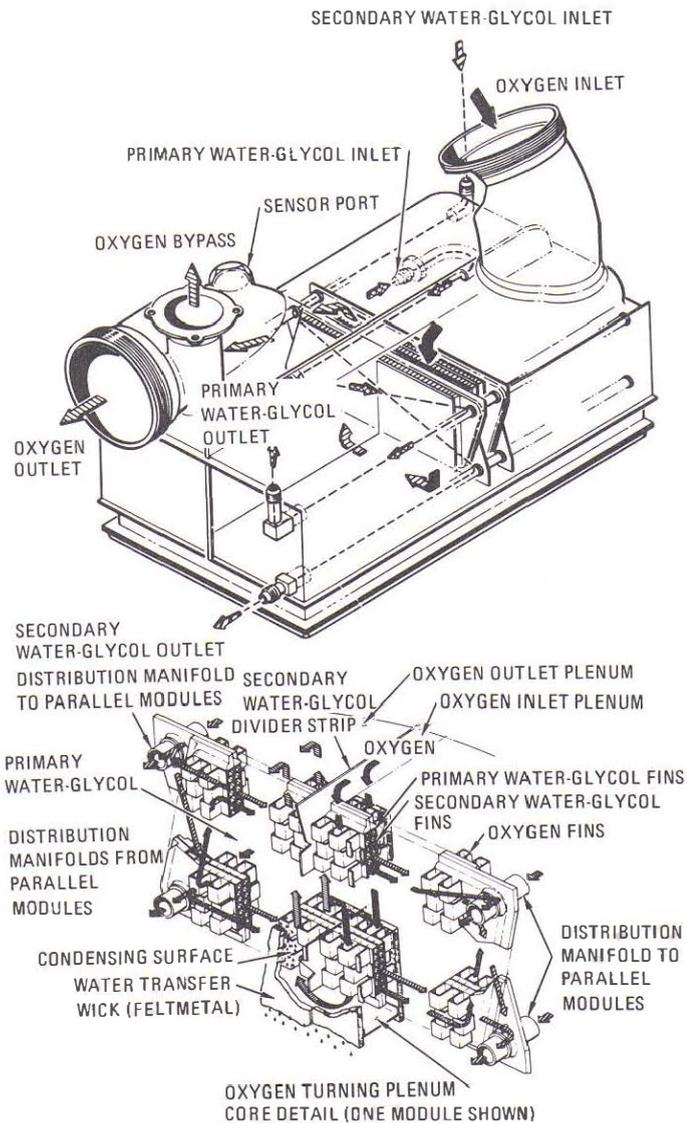
The cool gas (55°F nominal) flows from the heat exchanger through the suit flow limiters and the flow control valves into the suits. The suit temperature is measured at the heat exchanger outlet, and is displayed on the main display console and telemetered.

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.

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.

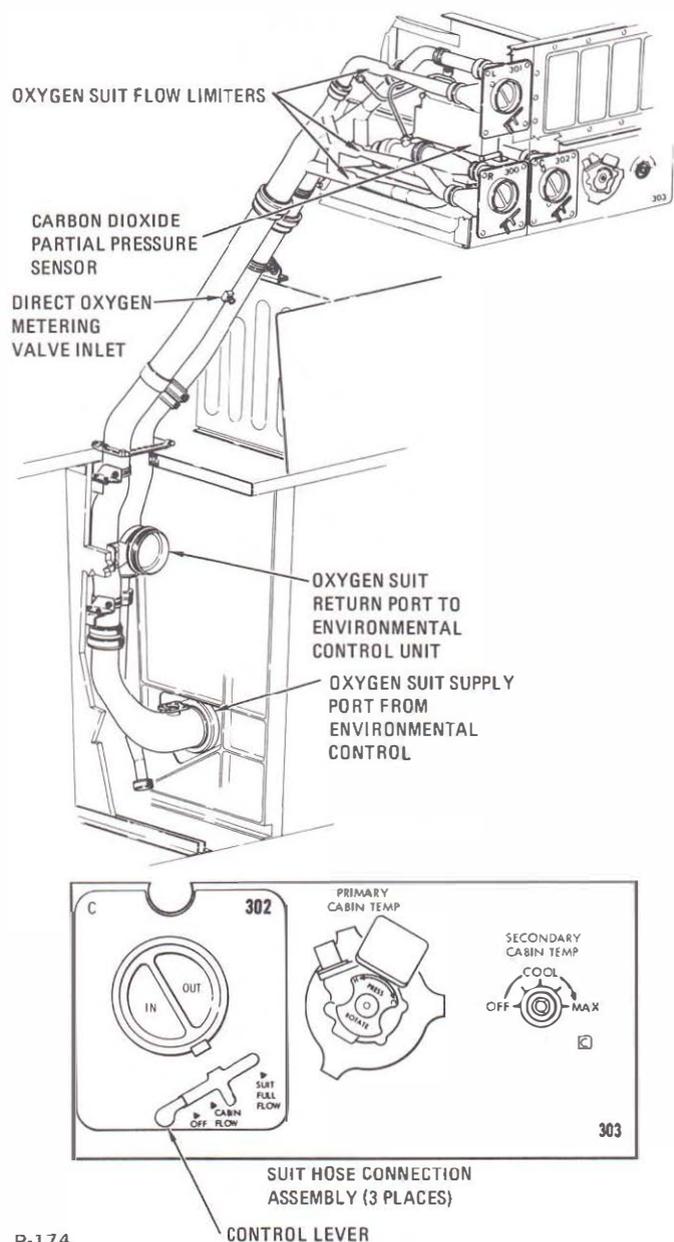
WATER SUBSYSTEM

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



Suit distribution duct and hose connectors

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.

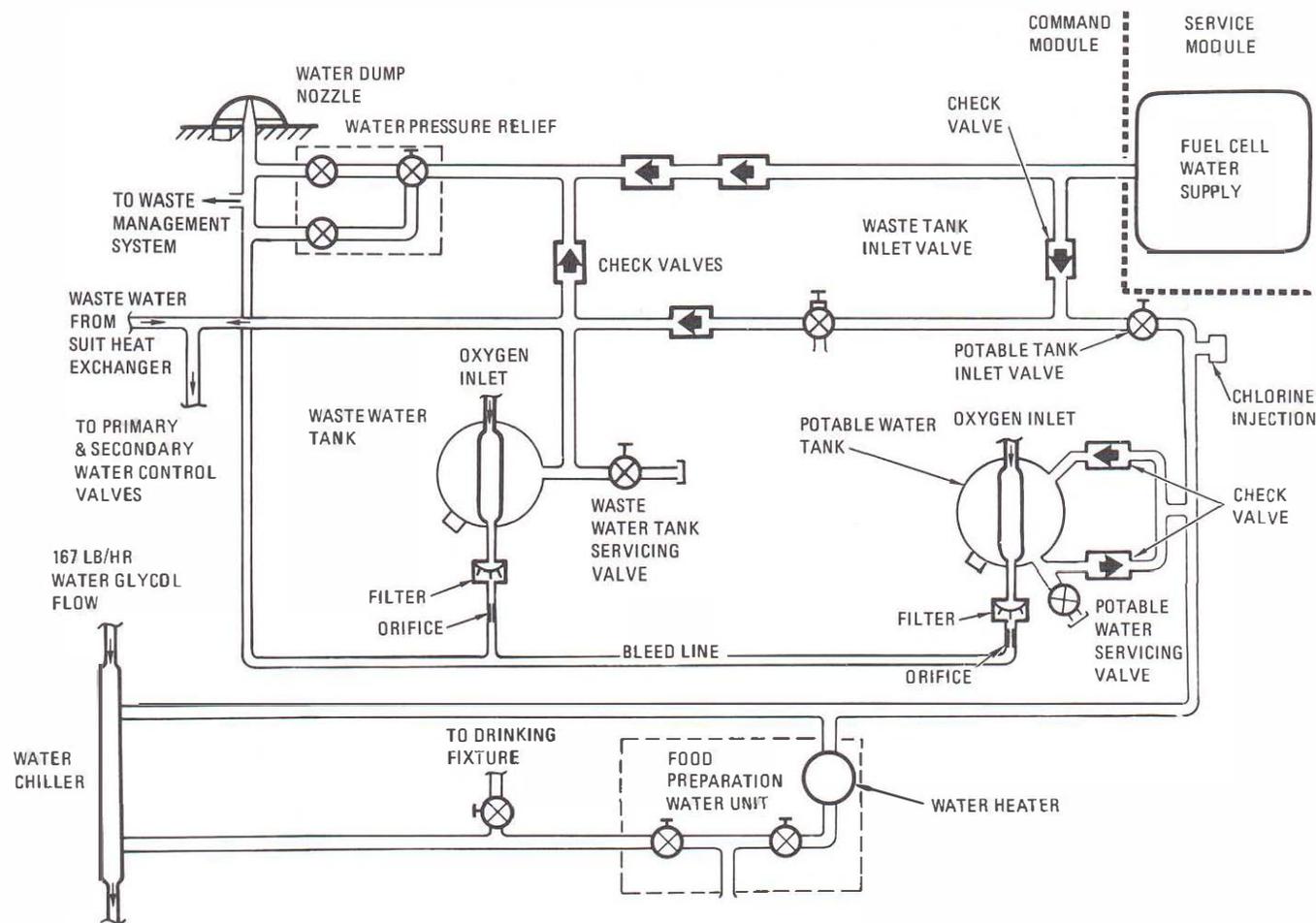
In the event that both water tanks are full at the time the fuel cells are pumping, the excess potable water will be dumped overboard through a pressure relief valve. This is a dual unit with a selector valve for placing either or both relief valves on-stream or shutting the unit off.

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.

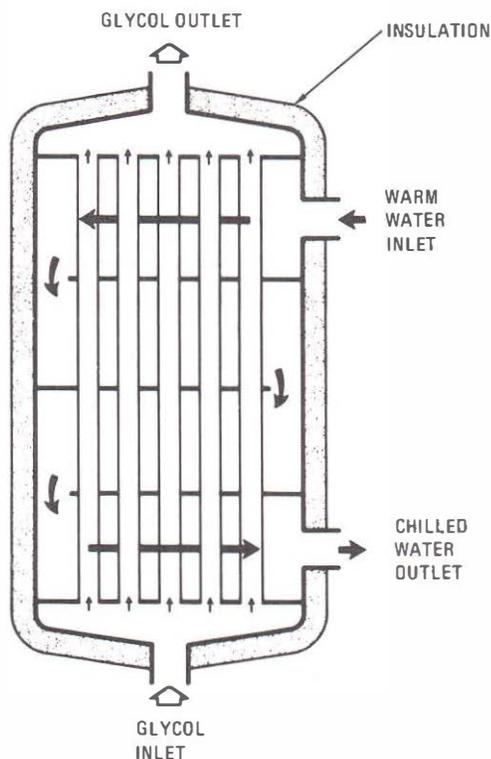
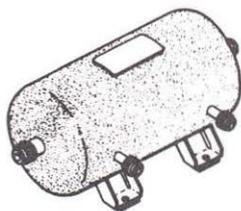
The water chiller cools and stores 0.5 pound of potable water for crew consumption. The water chiller is designed to supply 6 ounces of 50°F water every 24 minutes. The unit consists of an internally baffled reservoir containing a coiled tube assembly which is used as the coolant conduit. The baffles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



T = TEMPERATURE SENSOR
Q = QUANTITY SENSOR

Schematic of water management subsystem



Water chiller

P-176

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.

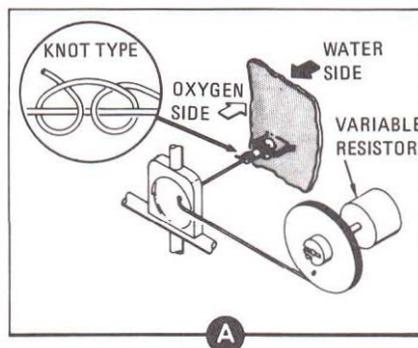
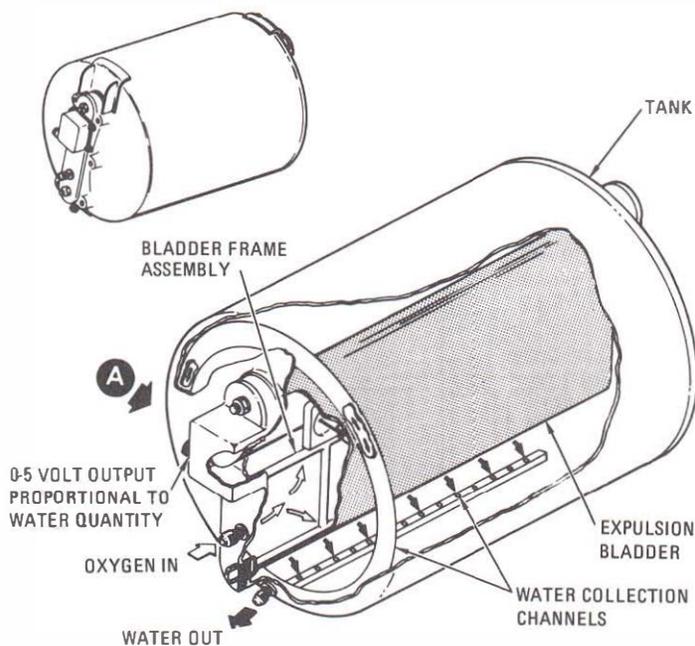
The drinking water supply valve is used to shut off the flow of water to the drinking water dispenser (water pistol), in case of a leak in the flex hose.

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.



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Waste water tank

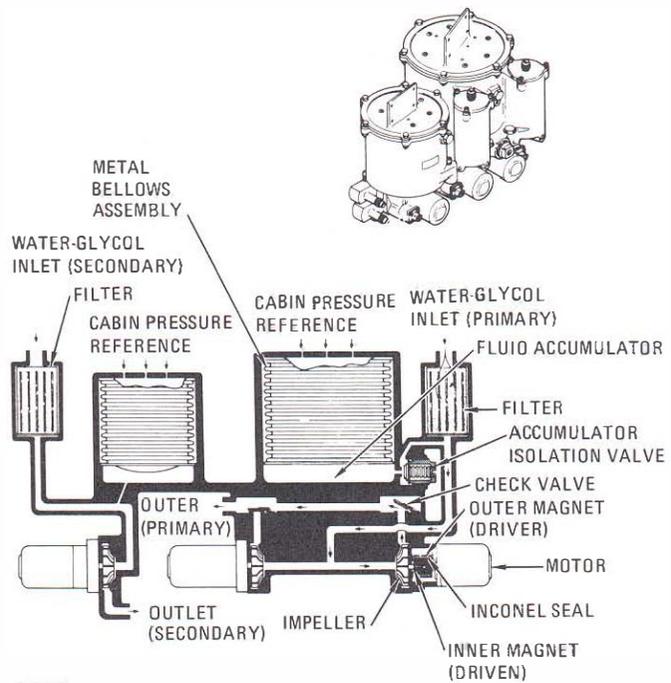
WATER-GLYCOL COOLANT SUBSYSTEM

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.



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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.

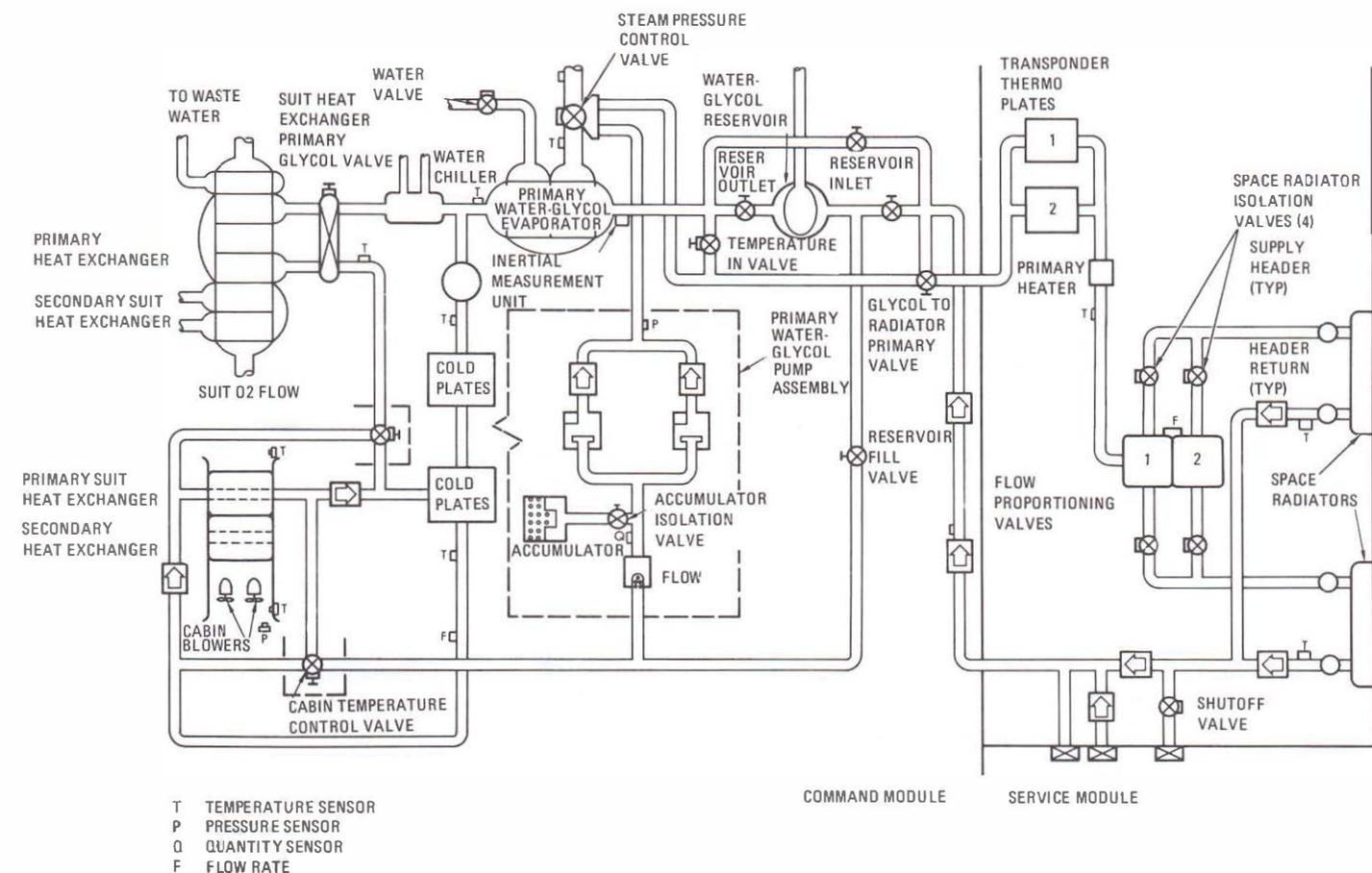
The primary cabin temperature control valve routes the coolant to either the cabin heat exchanger or to the coldplate network. The valve is positioned automatically by the cabin temperature control, or manually by means of an override control on the face of the valve. The valve is so constructed that 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

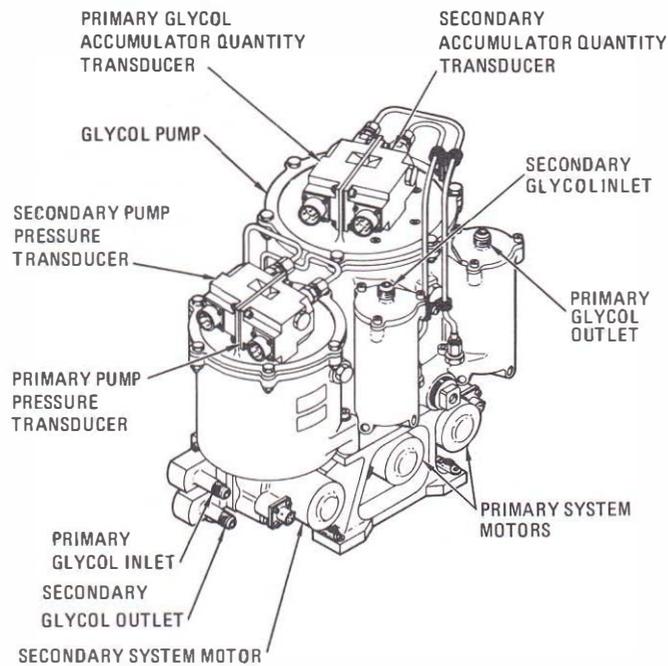
through the cabin heat exchanger will vary, the total flow through the thermal coldplates will always be total system flow. An orifice restrictor is installed between the cabin temperature control valve and the inlet to the coldplates. Its purpose is to maintain a constant flow rate through the coldplates 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





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Glycol pump assembly

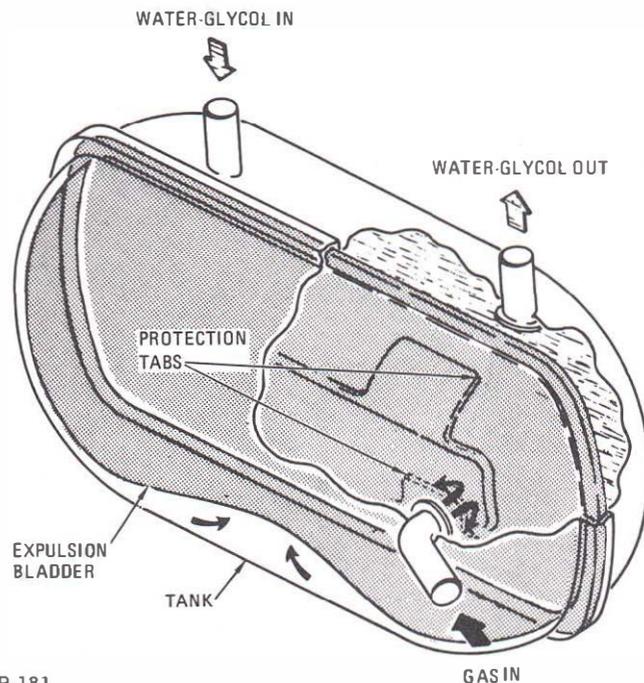
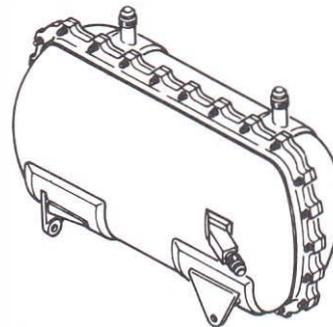
radiators to produce a mixed temperature at the inlet to the evaporator between 43° and 48°F. There is no mixing mode in the secondary loop. If the temperature of the coolant returning from the secondary radiator is lower than 45°F nominal, the secondary radiator inlet heater will be turned on to maintain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



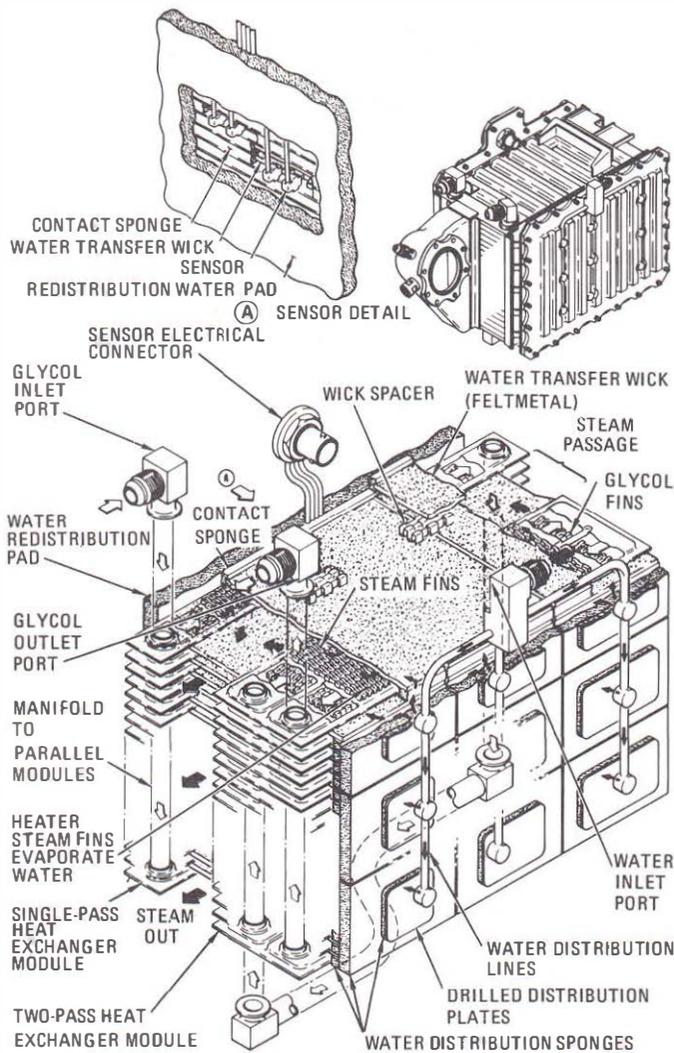
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Water-glycol reservoir

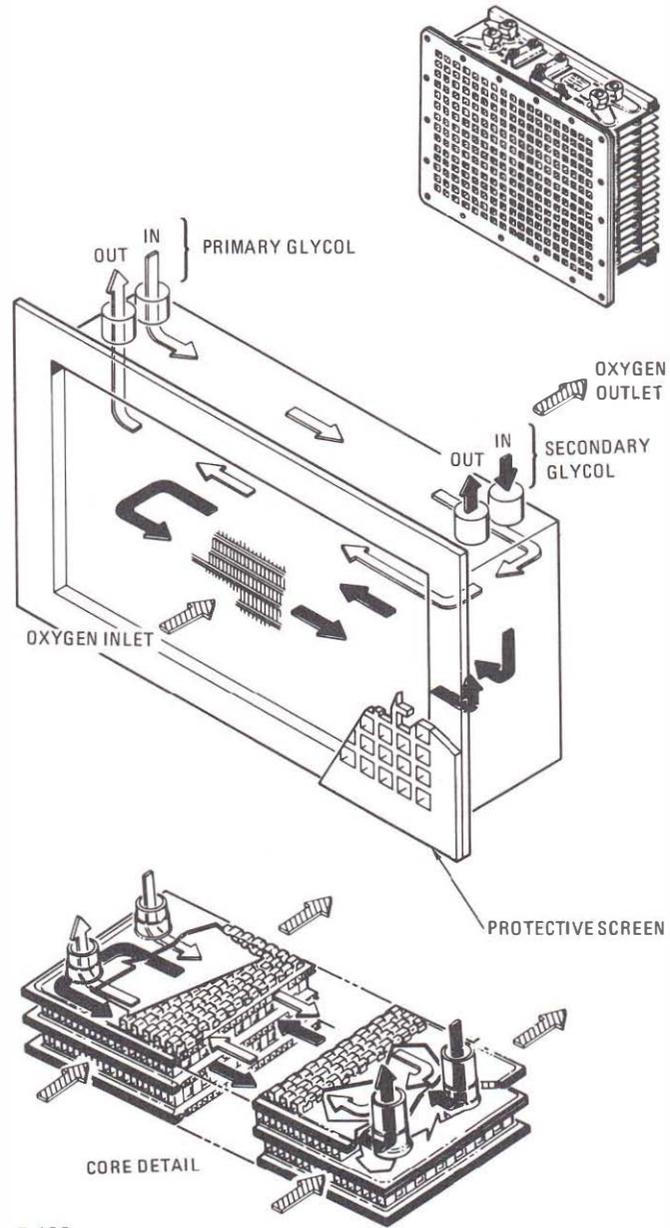
extremes in environments mean large differences in panel efficiencies and outlet temperatures. The panel facing deep space can reject more heat than the panel receiving external radiation; therefore, the overall efficiency of the subsystem can be improved by increasing the flow to the cold panel. The 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



P-182 *Glycol evaporator*



P-183 *Cabin heat exchanger*

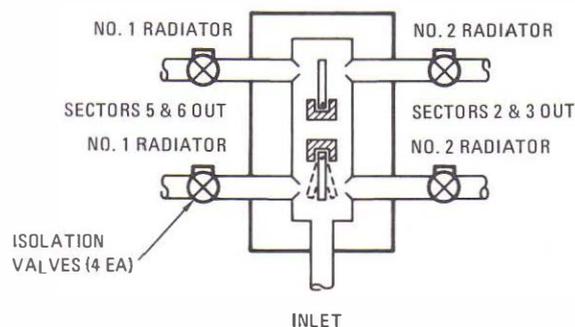
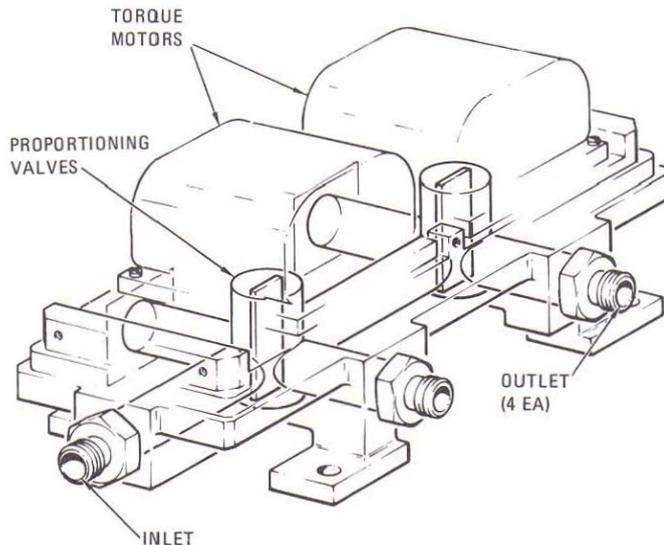
on automatic the flow controller selects the No. 1 valve and positions the appropriate radiator isolation valves. Manual selection and transfer also is possible. Automatic transfer will occur when the temperature differential exceeds 15°F, providing a failure has occurred. In the absence of a failure, 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

radiator mixed outlet temperature drops to -15°F and remains on until -10°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°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

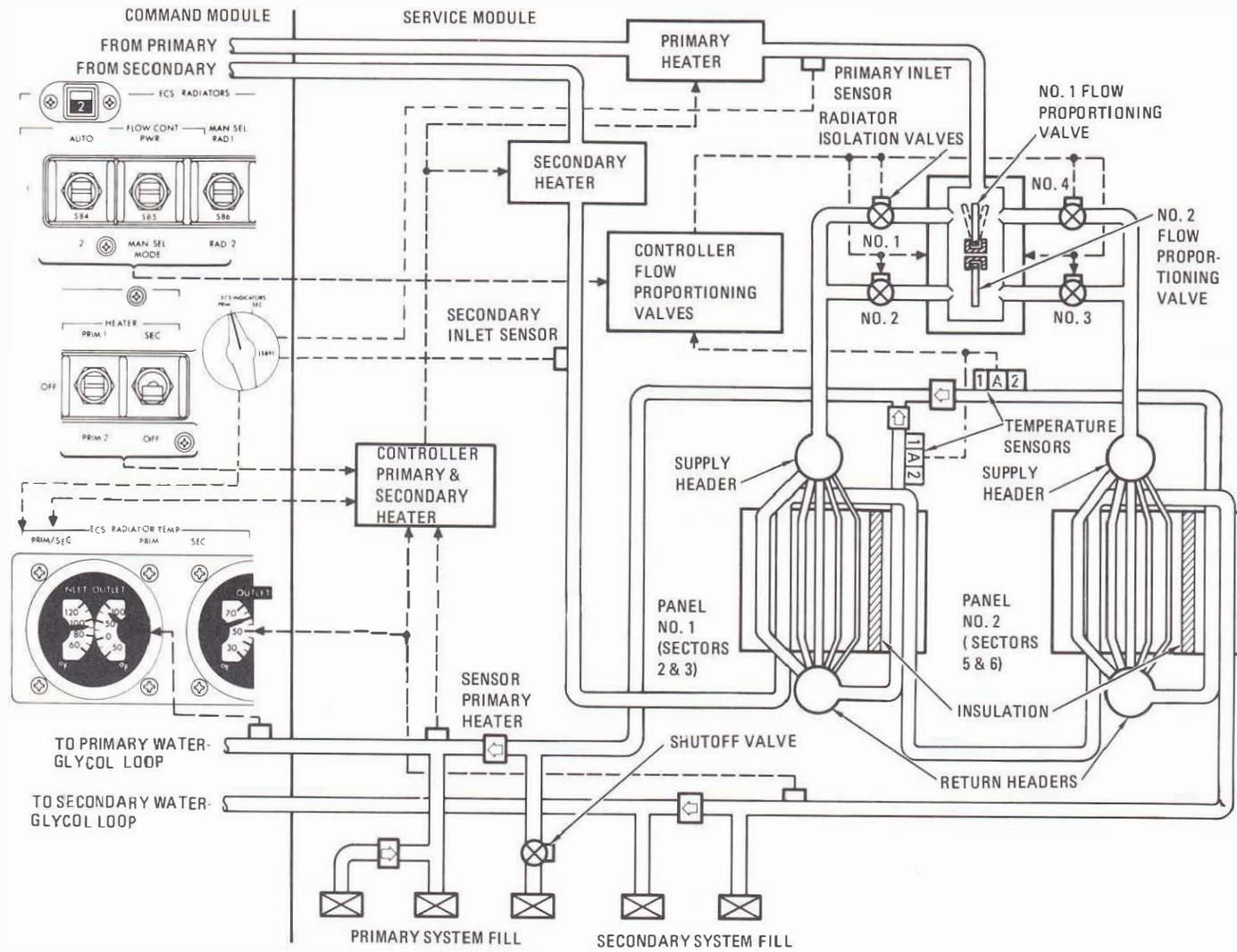


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Space radiator flow proportioning valves

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°F the No. 1 heater comes on, and at 42°F the No. 2 heater comes on; at 44°F No. 2 goes off, and at 45°F No. 1 goes off.



Schematic of radiator subsystem

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