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APOLLO PLSS – ENVIRONMENTAL CONTROL OF THE "SMALLEST MANNED SPACE VEHICLE"

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INTRODUCTION

The environmental control system for the "smallest manned space vehicle" had its beginning in October 1962 when NASA awarded Hamilton Standard a contract for development and production of a portable life support system (PLSS) and associated backup equipment for supporting an astronaut working outside of the lunar module (LM) either in space or on the lunar surface. This paper describes the system, outlines the philosophy behind its design, covers the basic requirements imposed on the system, and discusses some of the evolutionary process that led to the present configuration.

DESIGN PHILOSOPHY

Aside from obvious size, weight, and capacity differences of the equipment, the most significant difference between the PLSS and the aircraft environmental control systems with which Hamilton Standard has been involved for many years is the extreme emphasis on system reliability. The very nature of the lunar mission with the attendant hazards to the astronauts, worldwide attention, and involvement of national prestige produced an unprecedented emphasis on achieving a highly reliable system.

Thus, the design philosophy was to devise a system of utmost simplicity using ample performance margins with built-in redundancy, where required, to achieve the desired high system reliability. At the beginning of the design program, reliability targets of 0.99956 for the mission success, and 0.99995 for crew safety were established. To appreciate these numbers, consider that no more than 440 failures of a type that compromises complete accomplishment of mission objectives are allowed per million missions; only 50 failures of a type that would compromise the safety of the astronaut are permitted per million missions. Mathematical models were established and, on the basis of statistical data on the various components required to fabricate the system, a predicted reliability was calculated as an aid to component selection and system design.

These demanding reliability objectives required the basic environmental control system concept to be as simple as possible. A very deliberate attempt was made to reduce the number of moving parts as well as minimize the total number of parts. Where possible, processes were accomplished with static devices.

Examples of this are the components used for heat rejection and removal of excess water from the ventilation loop. The sublimator, which is a special type of boiler described in greater detail in the last section, is free of any moving parts and automatically reacts to a wide range of heat loads. It replaced the original plate-fin wick-fed boiler and back pressure control valve used in the first PLSS. The water separator is likewise free from any moving parts; an elbow in the flow path induces an artificial gravity field and capillary action principles are used in trapping the water and pumping it to a storage area outside the ventilation loop.

Except for a few cases in electrical or electronic devices, redundancy is not employed within the PLSS. Overall redundancy is provided by the oxygen purge system (OPS) and buddy secondary life support system (BSLSS), which substitute for the functions normally provided by a PLSS in case of a significant malfunction. Great emphasis was placed on conservative design of the primary system components so that there is high confidence in the structural integrity of the unit and the margin of performance is great relative to absolute performance requirements.

BASIC REQUIREMENTS

To provide a suitable protective environment outside the LM during lunar surface excursions, the astronaut carries on his back a compact assembly of various environmental control devices that, when joined together, form the PLSS (see fig. 3.1). This package supplies the man with breathing oxygen, controls suit pressure, reprocesses the recirculated gas by removing carbon dioxide, odors, some trace contaminant gasses, and excess moisture, controls system temperature by rejecting excess heat, and provides for warnings of certain malfunctions, voice communication, and telemetry of essential data. The heat rejection system must accommodate, in addition to the metabolic load and heat generated by the functioning PLSS components, heat gained from or lost to the lunar environment through the system insulation. Table 3.1 presents a comparison of the initial requirements, requirements for the PLSS used on Apollo 11 through 14, and requirements for an extended life version of the PLSS that will be used for Apollo 15, 16, and 17.

Figure 3.1 *Apollo 11 using –6 PLSS and OPS.*

An emergency oxygen supply, currently the OPS, can be manually actuated to supply breathing oxygen, control suit pressure, remove contaminants, and cool the astronaut in the event these functions in the PLSS are impaired. A high oxygen flow is introduced directly into the oro-nasal area and dumped overboard through a suit-mounted purge valve.

An umbilical assembly called the BSLSS enables two astronauts to share the liquid cooling capacity of a single PLSS should the other become disabled.

Multiple extravehicular activities (EVAs) are planned for each mission. Therefore, provisions for recharging PLSS expendables such as oxygen, water, contaminant removal cartridges, and power supplies from the LM are made. There is no requirement to recharge the OPS.

Table 3.1 *System requirements.*

Requirement	*Gas-cooled PLSS*	*Liquid Cooled PLSS* *–5*[a] *and –6*[b]	 *–7*[c]
Average metabolic load	930 Btu/hr	1600 Btu/hr	1600 Btu/hr
Peak metabolic load	1600 Btu/hr	2000 Btu/hr	2000 Btu/hr
Maximum heat leak in	250 Btu/hr	250 Btu/hr	300 Btu/hr
Maximum heat leak out	250 Btu/hr	250 Btu/hr	350 Btu/hr
Maximum CO_2 partial pressure	7.6 mm Hg	15 mm Hg	15 mm Hg
PGA pressure	3.5 and 5.0 psia	3.85 psia	3.85 psia
Ventilation flow	18 cfm	5.5 cfm	5.5 cfm
Duration	4 hr at 930 Btu/hr	4 hr at 1200 Btu/hr 3 hr at 1600 Btu/hr	6 hr at 1200 Btu/hr 5 hr at 1600 Btu/hr
O_2 Charge pressure at 70° F	950 psia	1020 psia	1410 psia
Battery capacity	290 W - hr	279 W - hr	360 W - hr
Emergency O_2	*EOS*	*OPS*	
Duration	5 min	30 min	
Maximum flow	2 lb/hr	8 lb/hr	
PGA pressure	3.45 psia	3.7 psia	

[a] Configuration used on Apollo 9 and 10

[b] Configuration used on Apollo 11 through 14

[c] Configuration to be used on Apollo 15 through 17

The combination of these major subsystems with the pressure garment assembly (PGA), or suit as it is commonly called, creates, in effect, a miniature personalized space vehicle that has basically all of the elements for sustenance of life that are found in the Command Module or LM. In fact, for short mission durations, one would merely have to add some form of propulsion and a guidance and stabilization system to have a space vehicle in every sense of the word.

SYSTEM DESCRIPTION

Figure 3.2 is a schematic of the liquid transport PLSS. Gas enters the suit ventilation distribution system and picks up heat, moisture, and metabolic byproduct contaminants as it passes through the suit adjacent to the man's body. This warm, moist, contaminated gas is then transported to a contaminant control package, which consists of an activated charcoal bed for absorption of trace contaminant gasses, and a lithium hydroxide bed, which reacts with carbon dioxide to form lithium carbonate. Byproducts of this chemical reaction are heat and moisture, which are added to that already carried by the recirculating gas stream. The gas stream then enters a heat exchanger where the heat is given up, and the excess moisture in the stream is condensed. Upon leaving the heat exchanger, or sublimator, as it is called, free water is removed from the gas stream by an elbow water separator, and transferred to the backside of the sublimator feedwater reservoir diaphragm. The stream then goes to a centrifugal fan that supplies the energy for overcoming the pressure drop in the PGA-PLSS system. The fan is driven by an electric motor that draws its power from a silver-zinc battery. Some heat is added to the stream because of fan inefficiency. After passing through a back flow check valve, the cooled, dried, decontaminated gas is returned to the suit for recycling.

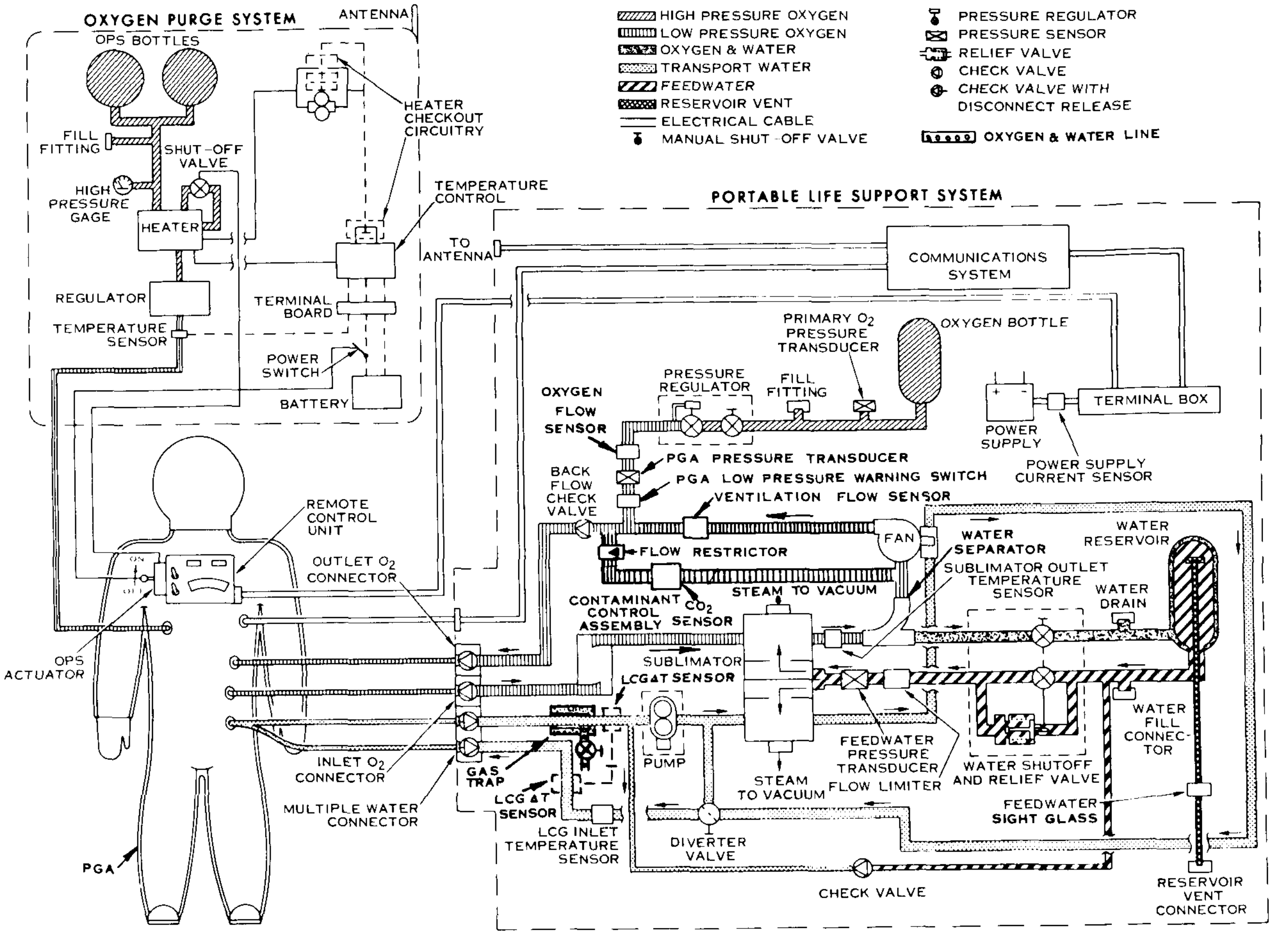

Figure 3.2 *Schematic of -6 PLSS and OPS (with heater).*

Pure gaseous oxygen is stored in a tank and admitted to the suit to make up for leakage losses and metabolic consumption. The single-stage in-flow pressure regulator maintains a suit pressure level of approximately 0.25 atm. Recirculation of oxygen is limited to that required for proper carbon dioxide purging from the helmet and defogging of the visor.

The liquid transport loop is very simple, consisting of a small pump, a set of heat exchange passages within the sublimator, a manually positioned diverter valve for controlling the temperature of the transport water circulated through the suit, and a gas separator to ensure that only water is circulated through the system. Water is circulated through a special plastic tubing heat exchanger/undergarment called the liquid cooling garment (LCG) for transporting heat from the man to the sublimator.

A communications system provides for voice communication and telemetry transmission of performance parameters. Instrumentation is limited to essential parameters that it is felt must be monitored during actual use by either Mission Control at the Manned Spacecraft Center (MSC) or by the astronaut himself. Ten channels of data are telemetered back to earth via a relay system aboard the LM. These data permit comparison of real time mission performance of the PLSS with performance previously recorded during manned simulation tests conducted at MSC during preparations for the flight. The parameters telemetered are: primary oxygen tank pressure; PGA pressure; sublimator outlet temperature; LCG inlet temperature; LCG ΔT (inlet to outlet of transport water); feedwater pressure; carbon dioxide partial pressure; and battery voltage and battery current drain. In addition to the above nine, electrocardiogram (EKG) signals are telemetered, permitting monitoring of the physiological state of the astronaut.

The remote control unit (RCU), which is mounted on the chest of the PGA, houses electrical controls for the PLSS, primary oxygen quantity indicator, and visual warning devices; it also serves as an anchor point for a camera bracket and the OPS actuator mechanism. The controls are: fan on-off switch, pump on-off switch, push-to-talk switch (which can override the voice-operated switch normally used in the communication system), communication system volume control, and a communication system mode selector switch. An audible warning signal is given to the astronaut if certain parameters fall outside desired limits, and visual identification of the problem is given by small "flags" or indicators on the RCU. Warnings are sounded for low feedwater pressure, low ventilation flow, low PGA pressure and high oxygen flow.

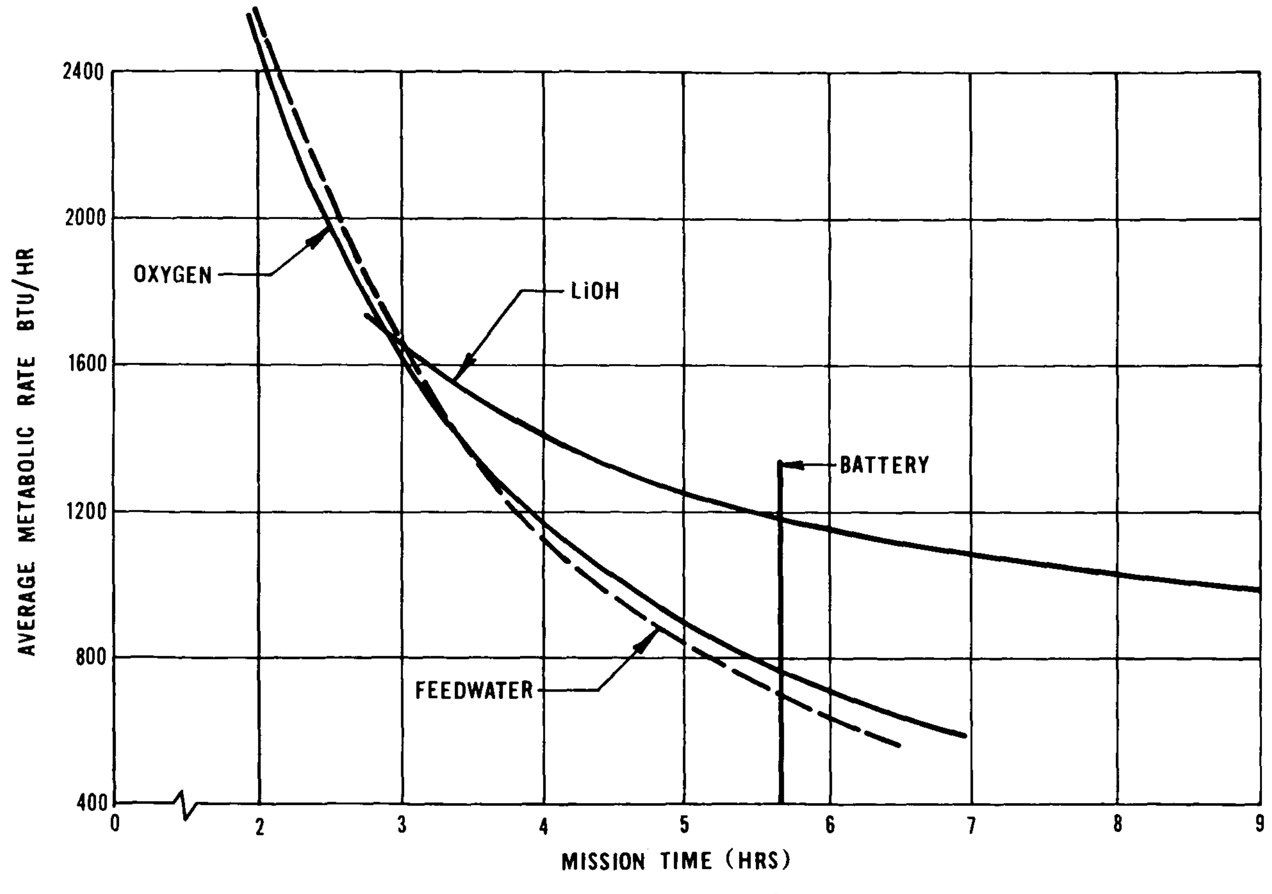

Figure 3.3 *Expendable duration of -6 PLSS.*

Figure 3.3 shows the performance of the -6 PLSS, which was used for all lunar surface missions through Apollo 14, in terms of the duration of the various expendables as affected by the average metabolic rate of the astronaut. All curves shown are based on worst case conditions (suit leakage, thermal environment, etc.) and represent the duration left after all pre-egress checkouts have been completed. Under conditions normally encountered in actual missions, the curves are displaced to the right. For example, if the specified PLSS/PGA gas leakage was reduced to zero, the duration of the oxygen supply at an average metabolic rate of 1200 Btu/hr would increase by about 0.8 hr. Similarly, if the external heat leak was eliminated the feedwater saved would also increase the EVA duration at an average metabolic rate of 1200 Btu/hr by about 0.8 hr. In the -6 PLSS, these two expendables, oxygen and feedwater, have the most limited duration.

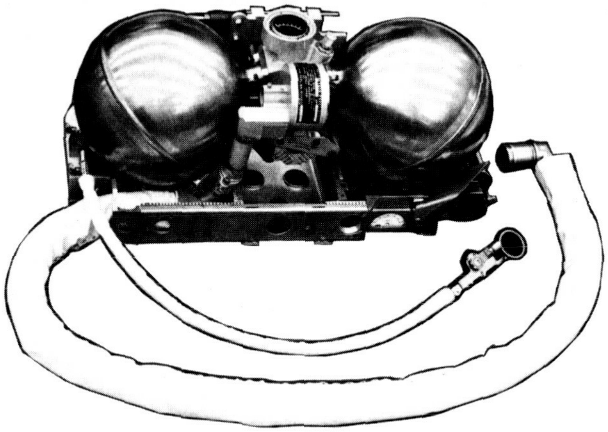

Figure 3.4 *OPS without protective cover and insulation.*

The OPS, shown in figure 3.4 without the protective fiberglas cover and insulation, consists of a pair of spherical tanks that hold 5.8 lb of pure gaseous oxygen at 5800 psi, a shut-off valve that is manually operated by means of a flexible cable and actuator lever assembly, and a single-stage in-flow pressure regulator that regulates PGA pressure to approximately 1/4 atm. A gage indicates the tank pressure level. A second low-range gage, along with a fixed orifice, is used to test for proper regulator performance. Both tank pressure and regulator performance are checked before committing to an EVA. The fold-down ribbon antenna for the communications system is mounted on top of the OPS.

The OPS can be utilized in three ways:

1. It can serve as a replacement for the primary oxygen supply with the remaining PLSS functions continuing normally.
2. With the "purge" valve in the PGA set on "low," 4 lb/hr of oxygen can be passed through the PGA to remove carbon dioxide and humidity with liquid cooling supplied by the BSLSS or PLSS.
3. With the "purge" valve in the PGA set on "high," 8 lb/hr can be passed through the PGA to remove carbon dioxide and provide cooling when completely independent of the PLSS.

Although normally mounted on top of the PLSS, the OPS can be mounted independently against the back of the helmet or against the abdomen for special zero G missions where the PLSS is not required.

The BSLSS (fig. 3.5) consists of a pair of water umbilical hoses with a standard connector on one end and a special divider connector at the other. A tether strap, two snap hooks, and an insulation sheath complete the assembly. If one crewman's PLSS water cooling capacity is impaired or lost, he disconnects the normal PLSS water umbilical and connects the standard connector end of the BSLSS to his suit. The other crewman, whose PLSS is still functioning normally, disconnects his PLSS water umbilical, attaches the divider connector to his PGA, and reconnects the PLSS water umbilical to the other side of the divider connector. The transport water flow from the functioning PLSS is now shared by the two crewmen. The tether hooks are attached to the PGA walls so that the tether relieves the water hoses of any strain.

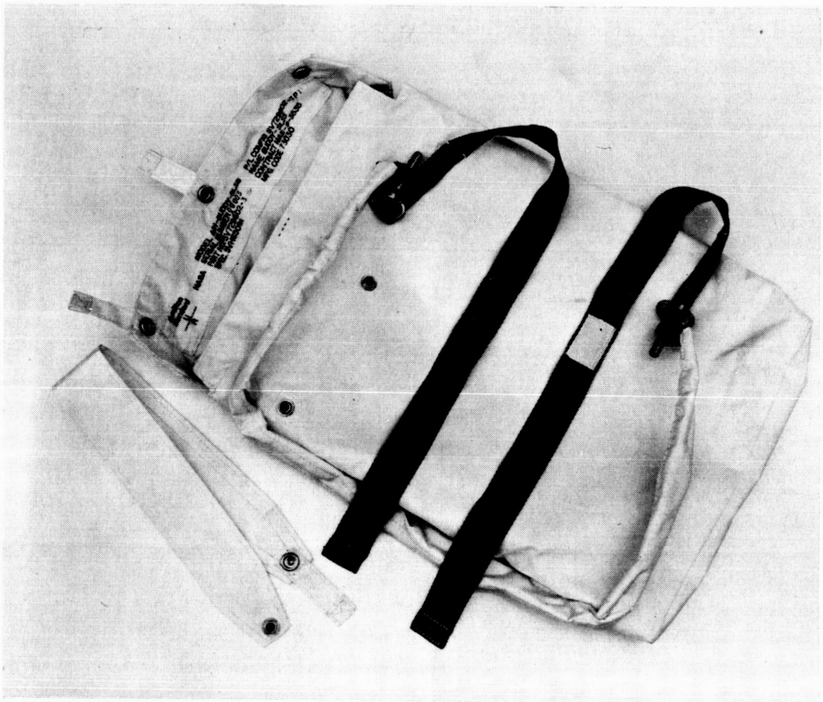

Figure 3.5(a) *BSLSS container.*

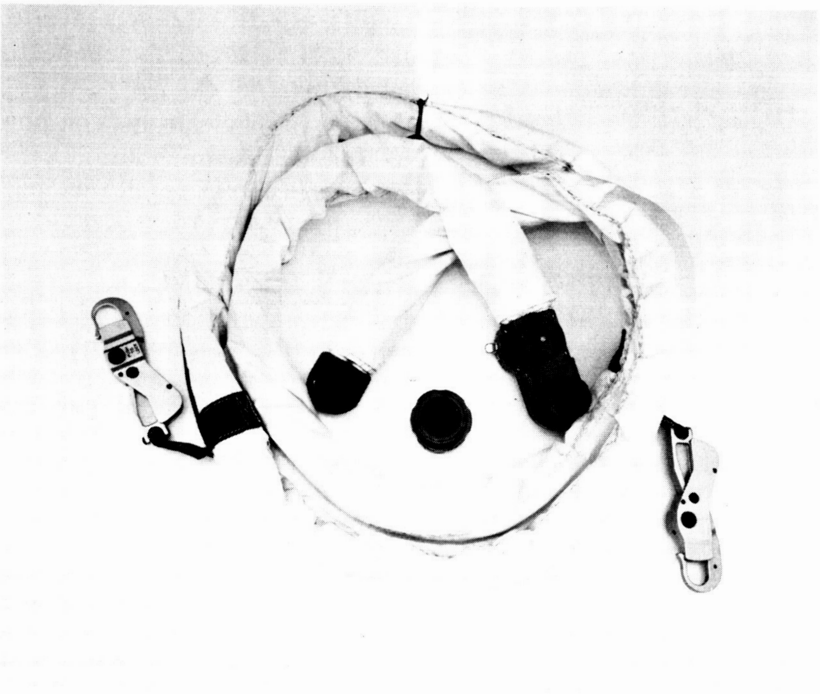

Figure 3.5(b) *BSLSS umbilical hoses.*

Table 3.2 *System configurations.*

Hardware Item	*Part Number*	*Configuration or Changes*
Gas-cooled PLSS	SV585200	n/a
Liquid-cooled PLSS	SV594750	First prototype water cooled system
	SV706100-1	Revised envelope for vehicle stowage Increased duration and heat rejection specification Added instrumentation Incorporated arde oxygen tank
	SV706100-2	Altered complete PLSS electrical system
	SV706100-3	Added H_2O quantity sensor and other instrumentation Relocated EOS from PGA to PLSS Incorporated Whittaker pump Incorporated space suit communications
	SV706100-4	Enlarged H_2O separator Deleted H_2O quantity sensor Incorporated blade antenna
	SV706100-5	Added back flow check valve to vent loop Deleted transport water accumulator Added check valves to Gas connectors Extensive material changes Changed to hi-rel electronic components Added further instrumentation Changed from EOS to OPS Incorporated RCU
	SV706100-6	Replaced SSC with EVCS Added instrumentation and controls Incorporated visual warning flags
	SV706100-7	Increased expendable duration
EOS	SV585115	Two-stage regulator Spherical tank
	SV594200	One-stage regulator Toroidal tank
OPS	SV730101-1	One-stage regulator Two large spherical tanks Heater, battery, and electronic controller
	SV730101-3	Deleted heater, battery, and electronic controller

SYSTEM EVOLUTION

Evolution of the PLSS and emergency oxygen provisions was marked by several changes that resulted from a better appreciation of equipment capability, significant changes in the state-of-art of available equipment, revised mission performance requirements, additional or revised instrumentation and warning system requirements, revised fire safety standards for materials in the presence of oxygen, and improved knowledge of man's requirements and physical limitations. Implementation of the above resulted in eight major configuration changes of the PLSS and three major configuration changes of emergency oxygen systems. Table 3.2 identifies these configurations and their significant differences.

Revisions in the specified metabolic heat rejection rate had the greatest amount of influence on changing the physical makeup of the PLSS. The original requirement for metabolic heat rejection was an average rate of 930 Btu/hr and a peak rate of 1600 Btu/hr. It has been traditional to cool personnel in aircraft by means of gas ventilation systems that carry heat from the generating source to the rejection device by means of a rise in temperature of the ventilating gas (sensible means) or an increase in the absolute humidity of the ventilating gas due to evaporation of available moisture (latent means). This approach was used on the Mercury, Gemini, Apollo command module, and Apollo lunar module vehicles, and was considered appropriate for the original PLSS (figs. 3.6 and 3.7). A limitation of this approach is that the sensible capacity of the ventilating gas is quite small, because of limited flow due to fan power considerations and the small differential between the minimum practical heat exchanger outlet temperature and the allowable maximum skin surface temperature. Assuming the oxygen pressure level to be approximately 3.7 psia and a maximum temperature rise of 45° F, the sensible capacity of the ventilating stream is approximately 9.9 Btu/lb-hr. The original specification allowed a maximum heat leak into the system through suit and PLSS walls of 250 Btu/hr. Since the practical ventilation rate was limited to about 18 lb/hr, the sensible capacity is only about 180 Btu/hr; it is apparent that the bulk of the metabolic heat transport relied on the latent capacity of the ventilation stream. Thus, the average heat rejection of 930 Btu/hr would require a sweat production of at least 3.5 lb for a 4-hr mission. Practically speaking, even more sweat would have to be produced since it is extremely difficult to get distribution of ventilation flow within the suit in such a manner that all of the sweat produced by the body is actually evaporated and carried by the ventilation gas. Sweat not evaporated contributes to dehydration without accomplishing any cooling. Dehydration in excess of 2 percent of body weight is a significant physiological strain on the astronaut.

Since studies indicated that the lunar surface EVA metabolic load might average 1200 Btu/hr over a 4-hr span or 1600 Btu/hr over a 3-hr span with peaks of 2000 Btu/hr, it was apparent that the capacity of the gas ventilation system, considering the limitations of the man, would be exceeded. Therefore, NASA directed that the system be revised to handle the above average loads. Subsequent experience showed just such difficulties were encountered in Gemini EVAs where the rate of metabolic heat generated in zero G maneuvers severely tested the ability of the umbilical ventilation system to carry away the heat produced. Studies were made of new heat transport techniques and new heat rejection devices. In the earlier system, the ventilation gas carried heat from the point of generation to the heat rejection device, which was a plate-fin wick-filled boiler. All of the water required for rejecting heat to space by boiling was carried in the wick reservoir. The temperature at which boiling occurred was controlled by a back pressure valve in the steam duct leading overboard to space vacuum. This valve was actuated by the expansion and contraction of a small quantity of a special wax mixed with metal particles that exhibited a very high rate of volume change with temperature. The valve was adjusted so that

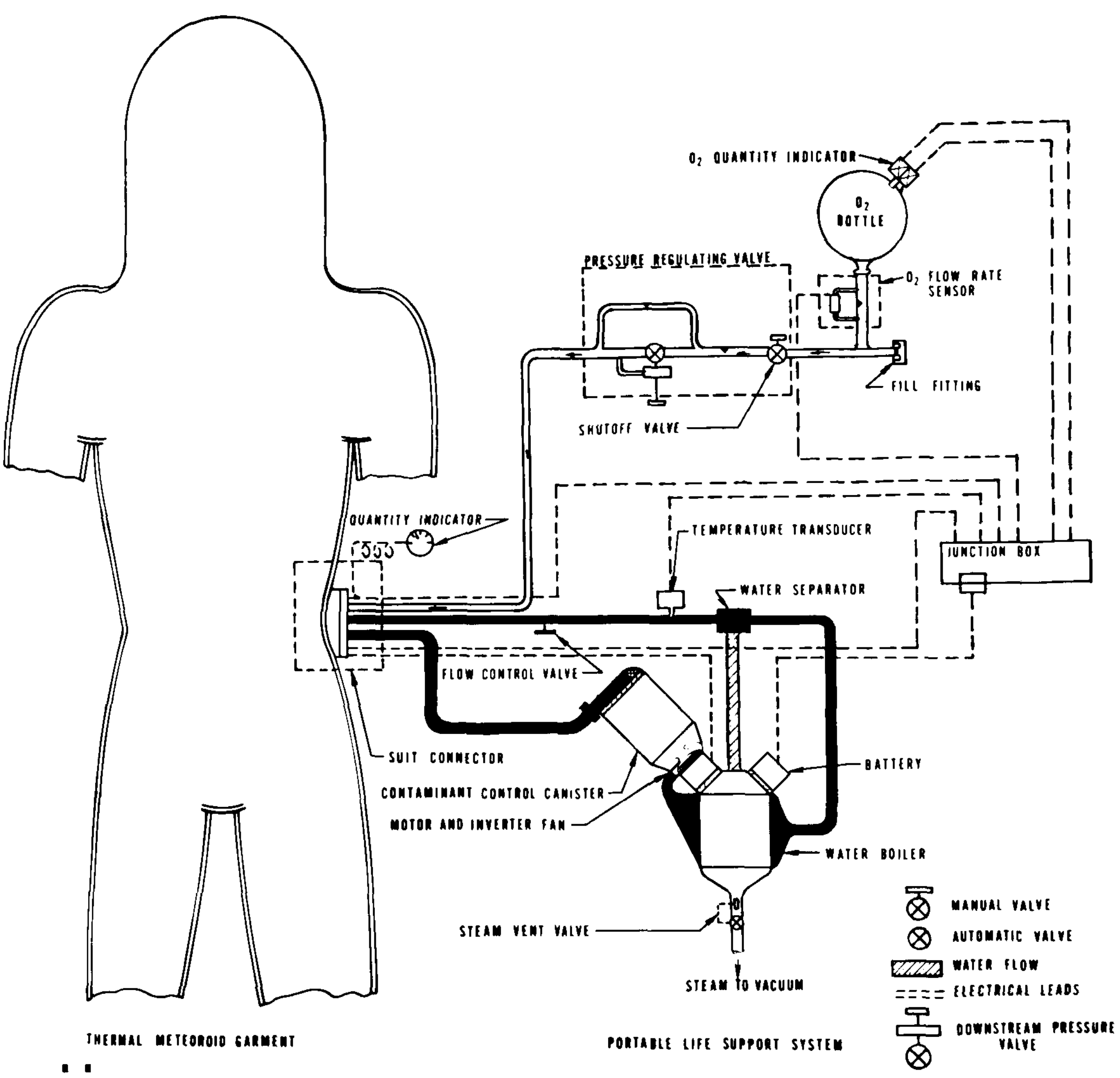

Figure 3.6 *Original PLSS.*

the temperature at which boiling occurred was maintained in the 35° to 50° F range. If the rate of heat rejection increased, the rate of steam production would increase and cause a rise in pressure and consequently elevate the boiling temperature. The temperature-sensitive valve would then respond by opening. The reverse would be true for a reduction in heat rejection rate.

In the system used at present, the ventilating gas still serves to transport a limited amount of heat, but a water loop is introduced for the express purpose of transporting metabolic heat sensibly rather than latently. A special undergarment, called the liquid cooling garment, was devised to form, in effect, a plastic tubing heat exchanger. It is worn against the astronaut's body surface. Water is recirculated at about 4 lb/min through a network of tubing distributed over the body surface roughly in proportion to the body mass, from the wrist and ankle of the limbs, to the neck on the upper torso. Heat is transferred from the astronaut's skin through the tubing wall into the water, which carries it to the sublimator in the PLSS. The large sensible capacity of water permits the 4-lb/min flow to carry the maximum design load of 2000 Btu/hr with a temperature rise of only 8.3° F. The astronaut's skin temperature can be held sufficiently low to inhibit sweating.

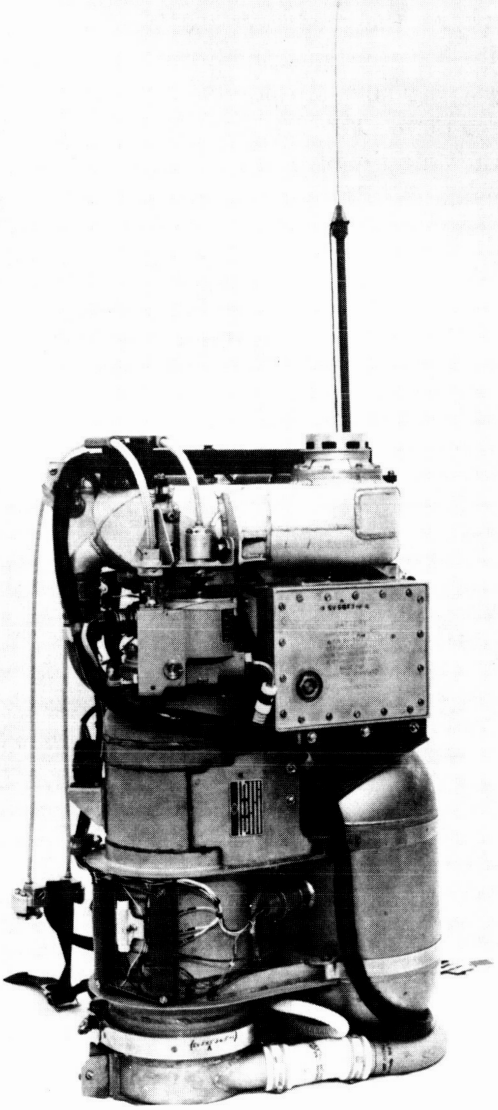

Figure 3.7 *Gas-cooled PLSS without protective cover and insulation.*

Hamilton Standard's independent development work on a new type of space heat exchanger called a sublimator showed improvements of about 30 percent more Btu/hr heat rejection per pound of equipment and about 40 percent greater Btu/hr heat rejection per unit of volume over the earlier wick-fed, plate-fin boiler. The first application of this new concept was its very successful use in cooling Saturn 1B and Saturn 5 booster vehicle instrumentation packages. Since the original PLSS boiler only had a ventilating gas loop, the addition of the water transport loop made redesign of the heat rejection device mandatory. Therefore, it was decided to take advantage of the improved performance offered by the sublimator. It contains flow paths for both the ventilating gas and the transport water. Adjacent to the plates that form the walls of these passages are sintered nickel plates having very fine pores. One side of the porous plate is exposed to vacuum; the cavity between the other side of the porous plate and the transport fluid passage plate is filled with water under slight pressure. The slight pressurization is derived from internal suit pressure. This "feedwater" is carried in a reservoir in sufficient quantity to satisfy all heat rejection requirements. As the feedwater exudes through the pores of the sintered plate it freezes when coming to the vacuum side and forms, in effect, a seal against feedwater loss. Heat, transferred from the gas path, or transport water path, is carried via fins and through the feedwater to the porous metal plate. The rate of sublimation of the ice formed on the porous plate is a direct function of the amount of heat carried to the sublimator by the transport fluids. This system is entirely self-regulating. It requires no valving to control the amount of feedwater admitted to the sublimation section, nor does it require a temperature-sensitive or pressure-sensitive valve to maintain a controlled pressure in the boiling chamber for temperature control.

The prototype of the new PLSS, utilizing the water transport and sublimator concept is shown in figure 3.8.

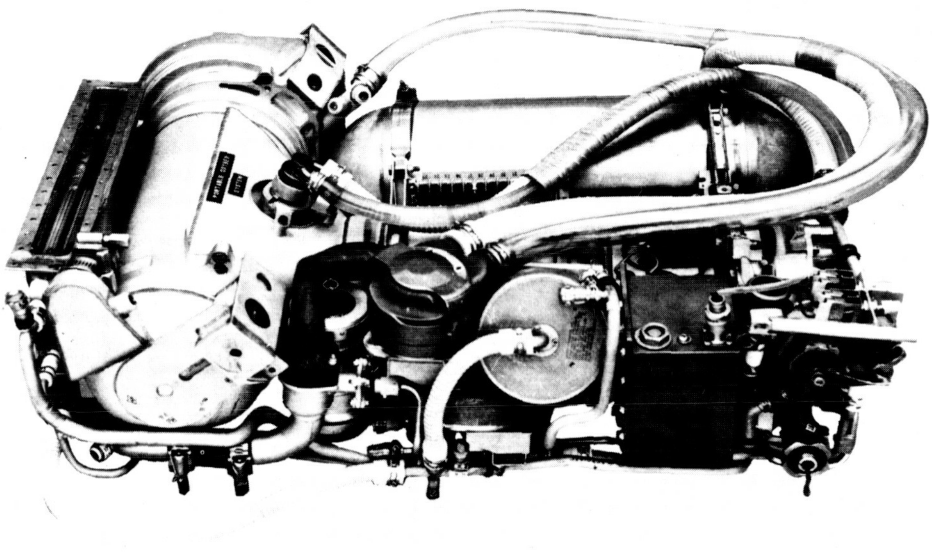

Figure 3.8 *Prototype liquid-cooled PLSS.*

The state-of-art in high-pressure oxygen tanks was advanced in the PLSS program. Tanks used on the first PLSS, built in 1963, were constructed of heat-treated AISI 4130 alloy steel with a protective coating of electroless nickel to prevent corrosion. Considerable difficulty was encountered in obtaining a satisfactory protective coating on the inside tank surface. Inspection techniques were quite difficult and, because of the lack of assurance of a satisfactory continuous coating of electroless nickel, frequent inspection was necessary to ensure that no degradation of the inner surface occurred in the presence of small amounts of moisture and pure oxygen.

At that time, the Ardé Corporation was engaged in developing a process that showed promise of achieving excellent high strength characteristics in a material having inherently high corrosion resistance in the presence of pure oxygen. Consequently, a subcontract was awarded to them for development of a tank for the PLSS.

Basically, the Ardé manufacturing process involves stretch forming a semifinished tank of a special grade of AISI 301 stainless steel to a finish die by pressurizing it with liquid nitrogen.

The resultant work hardening of the material at the very low temperature gives excellent unaged physical properties; for example, the ultimate tensile strength for design purposes is 240 KSI compared to about 180 KSI for the heat treated AISI 4130.

Recent work indicates that still higher design strengths could be safely used if the material is aged after cryogenically stretching, although unaged material is used in PLSS tanks for conservatism. With proper design, tanks could be based on an ultimate tensile strength of 290 KSI.

Another interesting example of state-of-art advancement in the PLSS is the small pump used to recirculate coolant water through the LCG and PLSS. This development was aimed at minimizing the amount of power consumed so that the battery, which is one of the heavier and more bulky of the components, could be reduced in both size and weight. The initial concepts for pumping the coolant flow were based on centrifugal pumping principles. The basic difficulty was that the efficiency of a centrifugal machine for the small flow and low head requirement was unacceptably low. When it was determined that the Whittaker Corporation was in the process of developing a small diaphragm pump, they were contracted to develop a model meeting PLSS requirements. The concept of the pump is quite interesting. Two small diaphragms are located at the end of a walking beam which is supported by a torsion rod. Inlet and outlet valves are provided for each diaphragm chamber. Part of the walking beam structure is a magnetic armature that can be moved in one or the other direction by an electromagnetic field causing the walking beam to displace the diaphragms. The electromagnetic field polarity can be reversed by an electronic control at a frequency chosen to nearly coincide with the natural frequency of the spring mass system supported by the torsion bars. Properly tuning the driving frequency to that of the resonance of the system, significantly reduces electrical input power for a given pumping load. This pump requires about 10 W input power to pump 4 lb/min with a head of 5.65 lb/sq in. Equivalent performance by the centrifugal machine required 30 W of input power.

The original liquid PLSS was designed to accommodate one extravehicular astronaut. Early in 1967, NASA established the requirement for two extravehicular astronauts. For a dual EVA, the communications system that existed at that time [space suit communications (SSC) system] provided for voice communications of both astronauts plus telemetry transmission of either astronaut but not both simultaneously. Furthermore, extravehicular activity was limited to line of sight between the LM and the astronauts if communications with earth were to be maintained. Consequently, a new communications system, named the extravehicular communications system (EVCS), was designed and incorporated into the PLSS. The EVCS provides the following additional capability: continuous telemetry data relayed to earth simultaneously from both astronauts; additional telemetry channels; line of sight limitation for extravehicular exploration eliminated for one astronaut (the other astronaut's communication system serves as a relay station to the LM); and greater output power to increase the operating range from the LM.

Three emergency oxygen systems were developed or qualified during the program. The first and second configurations, called 'the emergency oxygen system (EOS) shown on figure 3.9, are extremely simple schematically (see fig. 3.10) and performed identical functions. Both units provided for a 5-min emergency flow at 2 lb/hr but the later configuration, which used a single-stage pressure regulator nested in a toroidal tank rather than a 2-stage regulator and sperical tank, reduced the volume to one-third, and the weight to two-thirds of the original configuration.

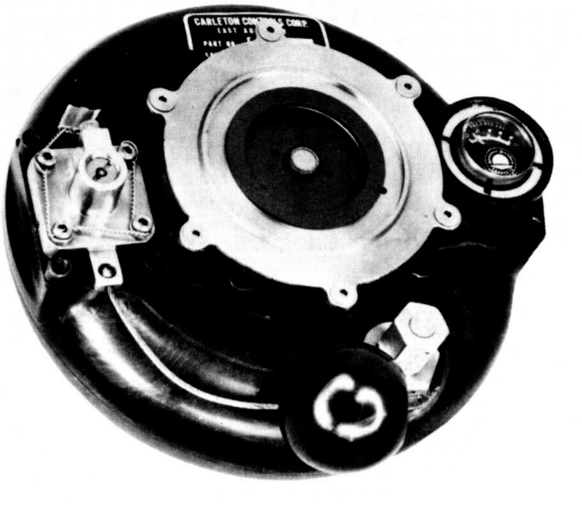

Figure 3.9(a) *EOS single-stage configuration.*

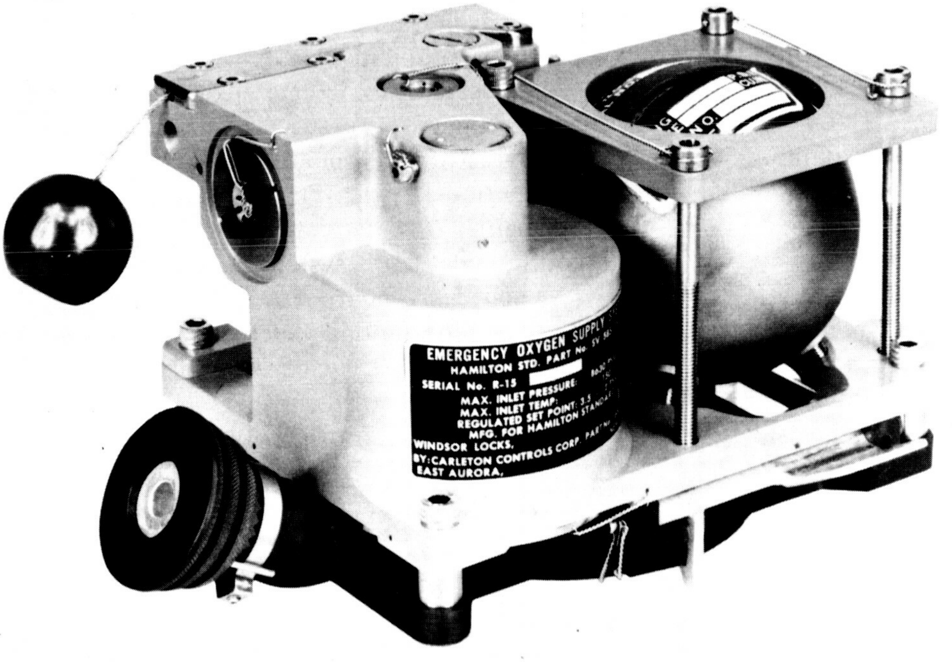

Figure 3.9(b) *EOS two-stage configuration.*

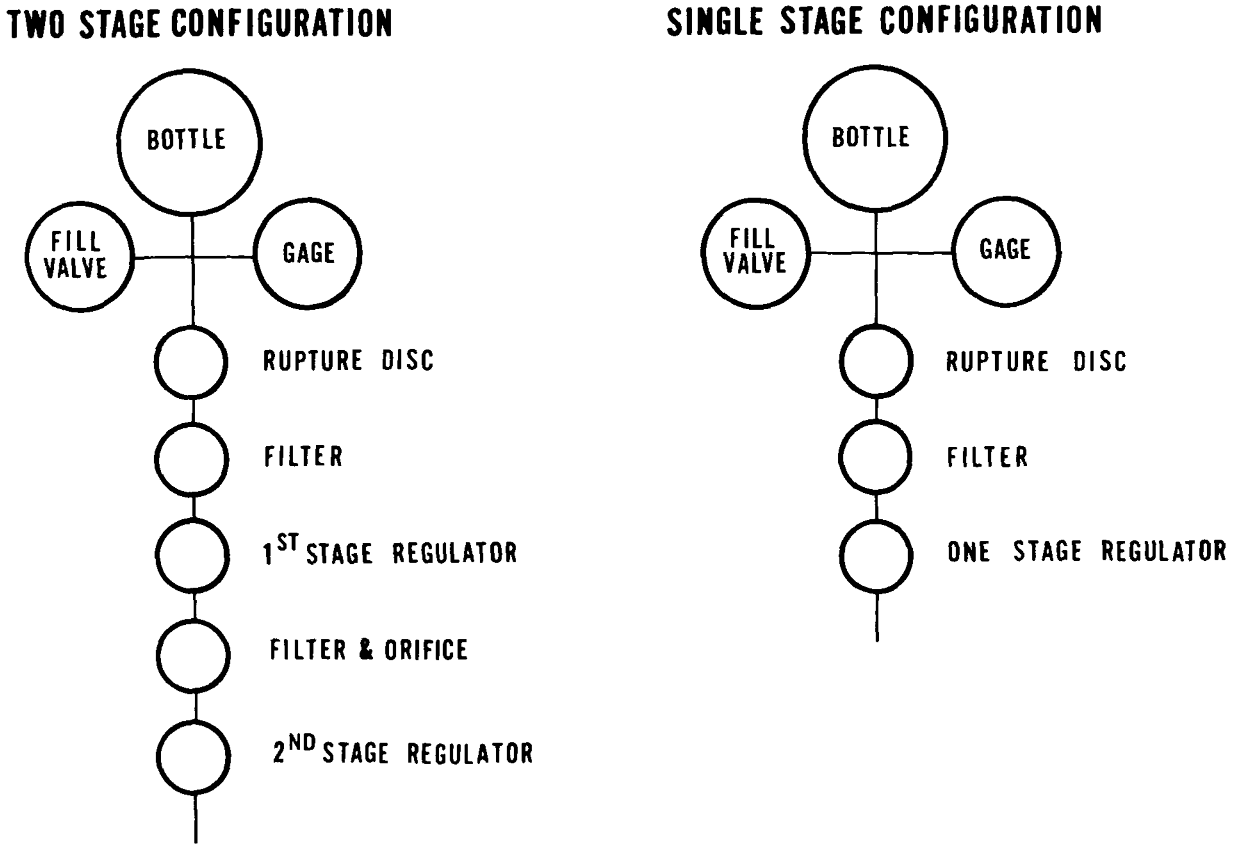

Figure 3.10 *EOS configuration.*

In mid-1967 NASA reviewed and revised mission requirements to establish the need for additional emergency oxygen to permit extravehicular excursions to greater distances from the LM. The oxygen purge system, which was designed for the new requirement, performs the same function as the EOS; however, it provides a minimum of 30 min of flow at 8 lb/hr (for increased metabolic heat rejection) and extends the safe EVA range. The rate of flow is determined by a purge valve located on the PGA. Full open valve position creates an 8 lb/hr deliberate "leak" in the system; a second valve setting creates a 4 lb/hr flow that can be used to conserve oxygen and provide at least 1 hr of emergency "get-back" capability when the BSLSS is used to handle the majority of heat removal.

The fill valve, regulator, and pressure gage designs were direct derivations from the EOS system. The EOS was sealed by a rupture disc, which was punctured by an actuation system to allow the release of the gas when needed. This concept was dropped in the OPS in favor of a multicycle shut-off valve as field experience gained with the EOS revealed that training and preflight acceptance testing was excessively limited by the one-cycle feature of the EOS. The original OPS incorporated a heater to preheat the gas introduced to the regulator and to maintain gas temperature delivered to the suit above 30° F. Subsequent OPS and manned testing revealed that flow, pressure regulation, and astronaut thermal conform could be maintained without the OPS heater. A schematic of the current OPS, which does not use a heater, is shown in figure 3.11.

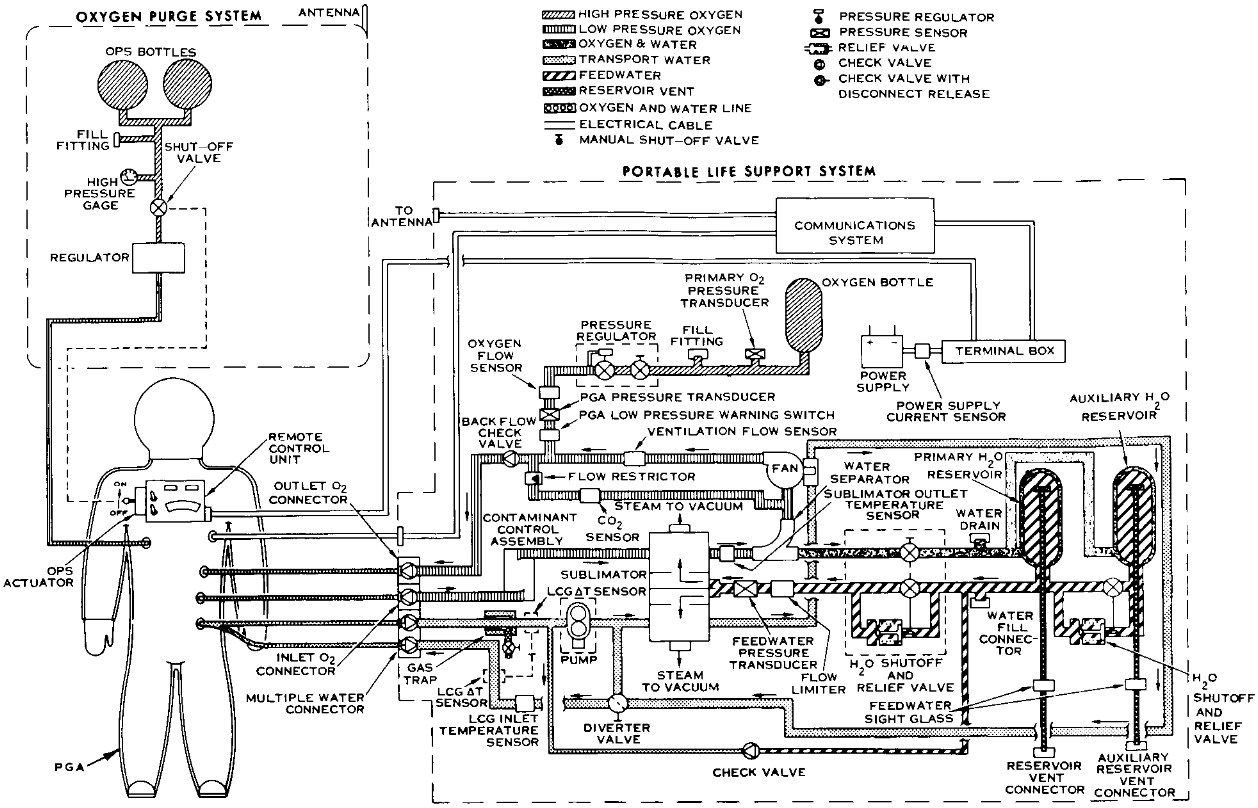

Figure 3.11 *Schematic of -7 PLSS and OPS (without heater).*

The -7 PLSS, which is to be used on the Apollo 15, 16, and 17 missions, is shown in figure 3.12. The PLSS has been modified to support longer lunar surface missions of up to 8-hr duration. The schematic of the modified system is shown in figure 3.11 and is the same as the -6 PLSS schematic except that an auxiliary water tank with associated valving and recharge system has been added. The metabolic rate versus mission duration relationship for this configuration under worst case conditions is shown in figure 3.13. The extended capability was achieved by increasing the operating pressure level in the high pressure oxygen subsystem with corresponding redesign of the subsystem components' incorporating an auxiliary water tank for storage of additional feedwater; increasing the size of the power supply with corresponding mounting provisions redesigned to support the increased weight; and increasing the amount of lithium hydroxide by using revised cartridge packing techniques.

CONCLUSION

The PLSS and associated Apollo life support equipment, having benefited from a thorough design period, extensive development through a number of stages, complete qualification, and repeated successful mission use, now represent the state-of-art in portable equipment for environmental control of man in space. The system has now evolved to the point where it can support an astronaut for any reasonable work-time cycle that can be expected of a man, with an ample margin of safety.

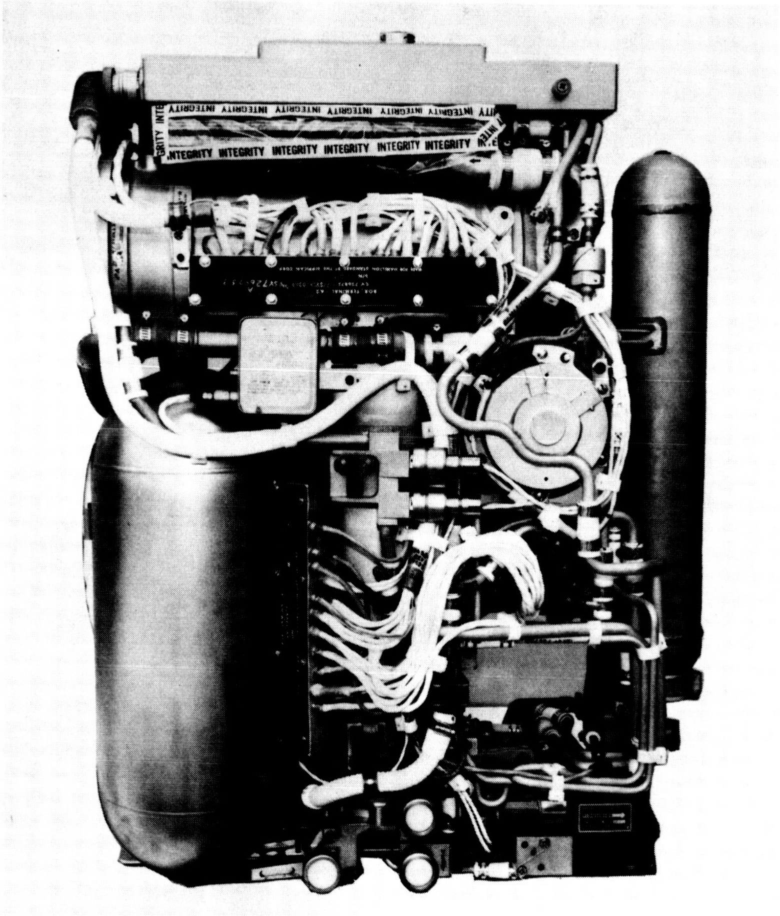

Figure 3.12 *−7 PLSS without protective cover and insulation.*

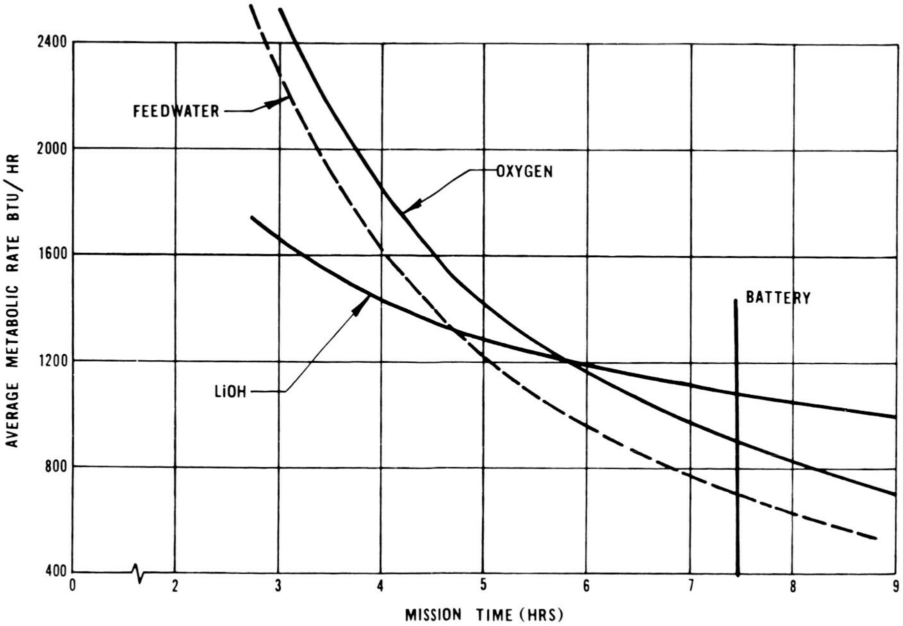

Figure 3.13 *Expendable duration of −7 PLSS.*