The Apollo Portable Life Support System
By Kenneth S. Thomas

The Apollo spacesuit's Life Support System (LSS) backpack consisted of the Portable Life Support System (PLSS) and the Oxygen Purge System (OPS). The PLSS provided life support to the astronaut during normal lunar surface EVA (extravehicular activity). The PLSS pressurized the suit, supplied breathing oxygen, removed carbon dioxide, particulates and odors, provided cooling, and controlled humidity within safe and comfortable limits. In case the PLSS failed, the OPS provided emergency life support while the astronaut retreated to safety of the LM (lunar module). It was a simple, purge-flow unit located on top of the PLSS.

The Apollo Program had many technical challenges. In direct sunlight, the temperature of exposed items in space and on the surface of the Moon rose to 250°F (121°C). In the shade, these items cooled to approximately a -140°F (-96 °C). Fortunately for U.S. space-farers, NASA had previously developed highly effective space insulation in the early 1960s. However, this insulation's success caused another problem. It held body and PLSS mechanical heat within the spacesuit. Rejecting heat from a spacesuit is not easy. First, the spacesuit's LSS must remove the astronaut's heat so he remains comfortable and can work effectively. This includes not becoming dehydrated or over heated. The latter could be injurious or fatal. The suit's life support system must also transfer heat to the vacuum of space reliably. These were great challenges given the size limitations for the Apollo backpack. And thermal control was only one challenge.

If not removed from the spacesuit, exhaled carbon dioxide (CO_2) will build up inside the spacesuit, leading first to headaches, followed then by impaired judgment and ultimately death. Humidity must also be controlled to maintain comfort and safety. Exhaled water vapor buildup inside the spacesuit could interfere with both the CO_2 removal process and astronaut function. In zero gravity, liquid water forms free-floating drops. Inhaling these inside the suit could cause drowning. However, removing too much water vapor results in low humidity, causing eye and nasal discomfort and buildup of static electricity with potential discharge. The latter could be catastrophic in the suit's pure oxygen environment. These challenges were overcome by an evolutionary invention and development path as the program responded to lessons learned.

The Apollo Program used eight configurations of PLSS. Following an initial PLSS design and four incremental configurations of a second PLSS design, Apollo astronauts were then ready to leave the safety of their spacecraft and venture into the vacuum of space. NASA started development of the Apollo PLSS in 1961 with preparations for completing the Apollo spacesuit. At the beginning of 1962, the Apollo suit-system had not yet been named the Extravehicular Mobility Unit (EMU). Its then title was the Space Suit Assembly (SSA). It consisted of the Pressure Garment Assembly (PGA) and the PLSS. In late 1964, the SSA and PGA became the EMU and Pressure Suit Assembly (PSA). The PLSS acronym remained consistent throughout the program.

Prior to selecting a contractor to provide the Apollo SSA in April of 1962, NASA had already selected the top-level PLSS technical approach. The winning proposal that detailed the approach to both the PLSS and SSA came from the then Hamilton Standard Division (HSD) of the United Aircraft Corporation (now the United Technologies Aerospace Systems subsidiary of United Technologies Corporation). In selecting HSD, NASA, also specified that HSD had to use the then-named International Latex Corporation (ILC) as the PGA provider. As ILC had been an HSD competitor in the SSA competition, this added an interesting complication to the Apollo spacesuit development.

In preparing for the Apollo SSA competition, HSD had conducted a trade study identifying all the possible architectures of an Apollo PLSS. The resulting down-select, a “Fan Driven By Battery-Powered Motor Closed Loop System” (Figure 1), became the proposal recommendation for the competition that NASA chose.

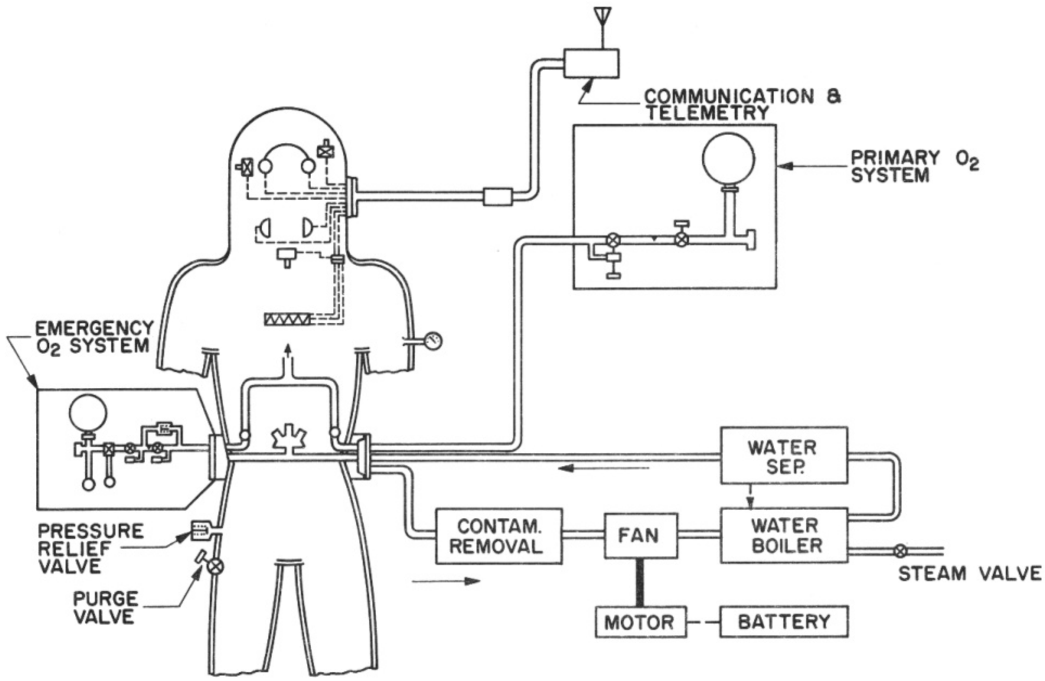

Figure 1 HSD’s 1962 System Concept (Courtesy K. Thomas)

Figure 1 shows a “closed loop” ventilation system in which a battery-powered fan recirculated the oxygen gas flow around the astronaut’s head and body. The Contamination Removal Canister containing Lithium Hydroxide (LiOH) was located upstream of the fan in the ventilation flow path. The HSD studies had also identified a formulation of LiOH that could meet the Apollo requirements. The Primary Oxygen (O_2) System provided pressurization and replaced O_2 lost due to CO_2 removal and suit leakage. Thus began the spacesuit ventilation system concept that was ultimately used on the Moon.

Using the available technology of that time, HSD had proposed using a “water boiler” for SSA heat rejection to space. Here, an integral wick reservoir supplied water to perforated fins. Heat from the gas side fins vaporized (boiled) the water. The boiling temperature would be determined by the gas pressure surrounding the wick, which was controlled by modulating the opening of an outlet valve, located downstream. The valve opening would be controlled to a preset temperature via a thermal sensitive actuator, as in the thermostat of an automobile engine.

At the start of 1962, a significant challenge to the development of the Apollo EMU was lack of a detailed understanding of the metabolic performance requirements of a man in a suit. No one in the U.S. space community knew the correct requirements. A ground rule in NASA’s request for proposal was that the system should be capable of handling an average metabolic load of 11,300 Btu/day. HSD’s 1962 proposal base-lined a system designed to dissipate a metabolic load of 500 Btu/hr. However, early Mercury experiences and preliminary Apollo-related testing were starting to increase these requirements. NASA's announcement of the Apollo SSA winner in April 1962 included an increase in average life support capacity to a 530 Btu/hour. With the formal contract award in October 1962, NASA increased the average life support capacity to 930 Btu/hour for four hours and added a maximum hourly usage rate of 1200 Btu. However, NASA did not increase the volume and weight allowances.

NASA added another challenge to the PLSS development. The SSA contract required that the PLSS and PGA developments be accomplished in time to support the delivery and manned chamber testing of an Apollo SSA in ten months. However, at that time, the best PLSS shape, how the PGA and PLSS would connect, and the placement of controls had yet to be defined. Thus, one of the first Apollo activities became defining these areas. To support this, HSD made an interface mockup-fixture (Figure 2) to allow evaluation of the shape, volume and potential interfaces for life support and controls. This was then shipped to ILC for evaluation (Figure 3) with the first Apollo PGA design, which was a slight variation of ILC's 1962 competition prototype.

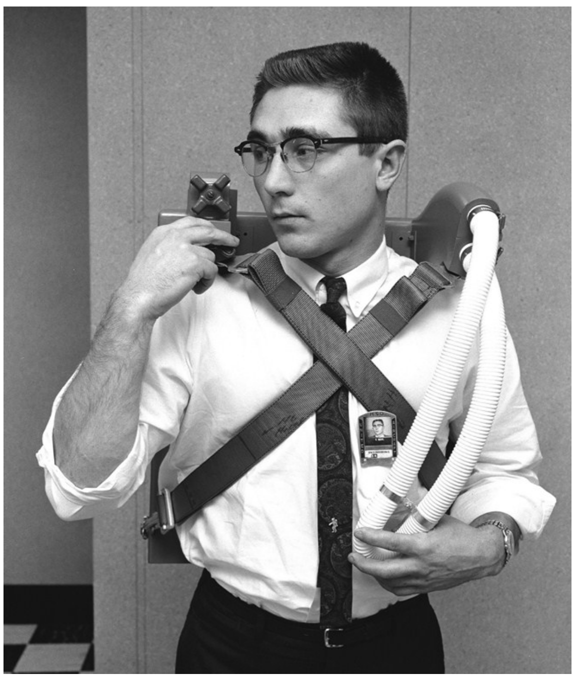

Figure 2 (Above) HSD Designer Earl Bahl Demonstrating Potential Control and Connection Locations (Courtesy United Technologies Aerospace Systems)

Figure 3 (right) ILC's George Durney In Interface Evaluations (Courtesy ILC Dover LP)

HSD successfully developed an Apollo PLSS (Figures 4 and 5) that met all performance requirements in the awarded HSD SSA contract (Table 1).

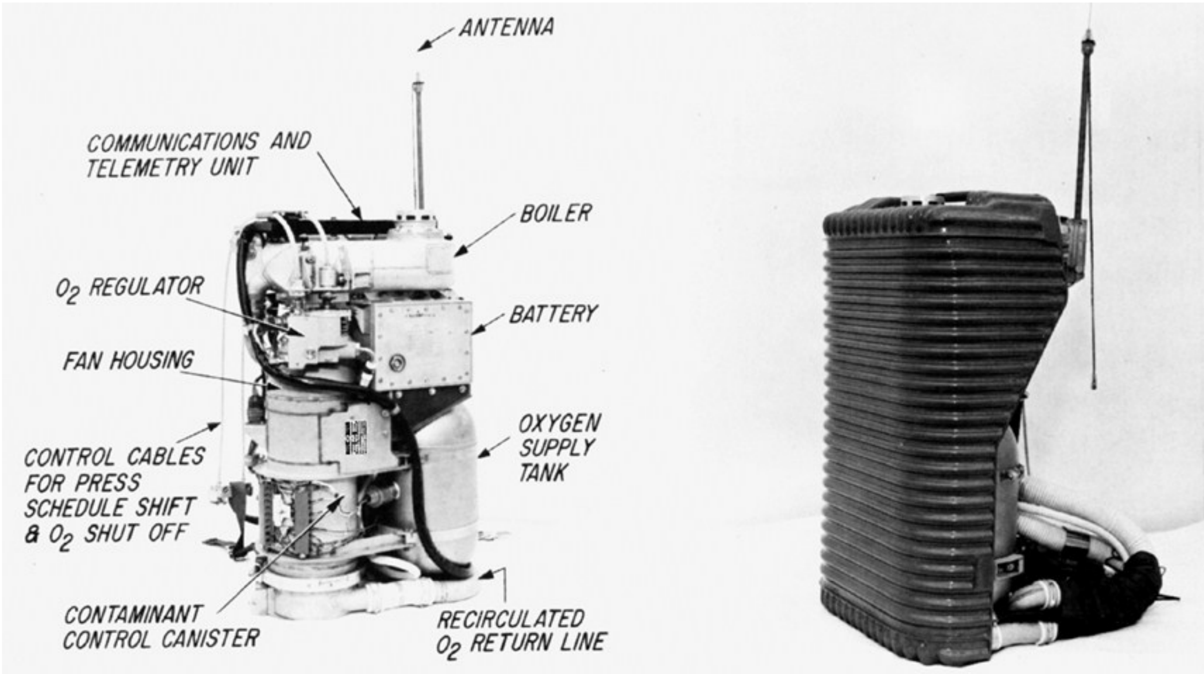

Figure 4 “Gas Cooled” First Apollo PLSS
(Courtesy United Technologies Aerospace Systems)

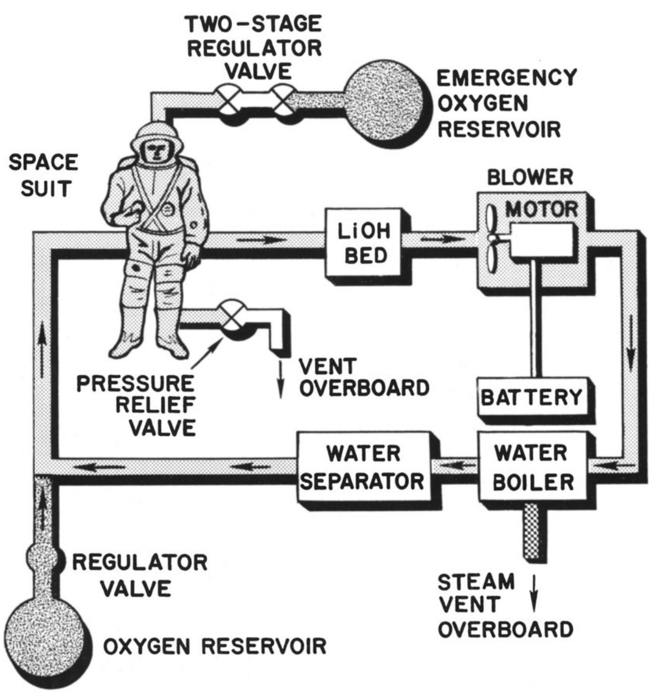

Figure 5 The First Apollo PLSS Schematic
(Courtesy United Technologies Aerospace Systems)

Table 1 - Parameters of the “Gas Cooled” PLSS

Duration (Maximum)	4 Hours
Metabolic Rate:	
Average	930 Btu/hr.
Metabolic Rate Peak	1600 Btu/hr.
Total Heat Leak	±250 Btu/hr.
Total Useful Heat Removal Capacity	4120 Btu
Gas Leakage Rate	200 SCC/min.
Flow Rate	14.7 CFM
Vent Pressure Drop@ 3. 7 psia	4.7 in. H_2O
Weight	50 lbs
Overall Dimensions	9 x 15.5 x 25 in.
Suit Inlet Gas Temp.	43°F
CO2 Partial Pressure Into Helmet (Max.)	7.6 mm Hg.
Power Source	Silver-Zinc Battery (Rechargeable)
Power Required	80 W
O2 Storage Pressure	850 psi
O2 Storage Quantity	0.8 lbs(Recharge)
Water Storage Quantity	6.0 lbs (Recharge)
LiOH Quantity	1.9 lbs
Contaminant Control Cartridge Wt.	3.45 lbs
Reliability (12 Hours)	0.9995 %

The awarded Apollo PLSS contract also included development and delivery of a five minute at 3.34 psi backup life support system named the Emergency Oxygen System (EOS). This first EOS used a spherical 7,500 psi nominal pressure tank with a separate two-stage regulator (Figure 6).

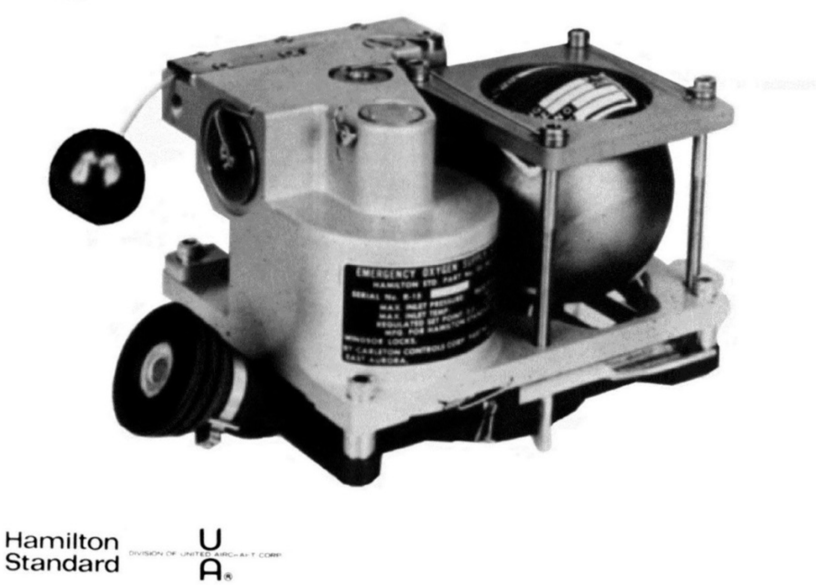

Figure 6 The First Generation Apollo Emergency Oxygen System
(Courtesy United Technologies Aerospace Systems)

The first PLSS was delivered and man-tested in late 1963 (Figure 7). Based on this testing, the average metabolic requirement for the nominal four hour system rose to 1200 Btu/hr (302 kcal/hr) and a peak metabolic rate of 2000 Btu/hr (504 kcal/hr).

Figure 7 First Complete Apollo System Testing
(Courtesy United Technologies Aerospace Systems)

This “gas cooled” PLSS used ventilation gas that circulated around the astronaut’s body and through the PLSS for cooling the astronaut and removing heat generated by the PLSS. However, HSD judged this technical approach would not be adequate to meet increasing Apollo PLSS thermal requirements. This resulted in three HSD inventions for the Apollo Program, the Porous Plate Sublimator, the Liquid Cooling Garment and the Multiple Water Connector.

Vaporizing water to a vacuum is a highly efficient way of rejecting thermal energy to space. However, developing the 1962 gas-cooled PLSS’s water boiler pointed out many complexities associated with wick-type water boilers employing steam back pressuring. To wit: if the wick is exposed to a vacuum or too low a pressure, it will freeze. The solution is to house the wick In a chamber and control the chamber pressure by a downstream valve that opens to space. However, controlling the valve to maintain the needed chamber pressure for all conditions is extremely difficult. Additionally, water molecules collecting on the valve when cold could change its performance and even stop it from functioning. These posed significant reliability issues. To achieve reliable performance, HSD undertook a parallel, company-sponsored, research effort to investigate alternative methods of heat rejection.

HSD engineer John S. Lovell originated the idea to control evaporative cooling to a vacuum through a “porous plate.” While the plate appeared solid to the naked eye, it really had microscopic pores of a controlled size through which water can flow. When exposed to the vacuum of space, the water in the plate boiled off to the vacuum taking away thermal energy and causing the replacing water that entered the plate to freeze and reseal the plate. The pore size was important so that the water supply pressure would result in the desired flow and expansion of the freezing water would not damage the plate. Heat in either the gas or water cooling loops would warm the replacement water. Because Lovell’s idea seemed promising, HSD sponsored his research in 1963. To design and build the first prototype Porous Plate Sublimator, Lovell enlisted the aid of George C. Rannenberg, a resourceful HSD engineer/scientist with a talent for designing and building prototypes that worked. The first sublimator prototype proved successful before the PLSS nominal thermal requirements increased to 1204 Btu/hour in late 1963.

The resulting invention (U. S. Patent No. 3,170,303, "The Porous Plate Sublimator for Cooling Applications in Space") reliably provided heat rejection capability to both the current gas cooling loop and the later liquid cooling loop of the PLSS. HSD also elected to offer sublimators to provide a cooling solution for the Saturn rocket program. Thus, while the Apollo PLSS drove the development of their Sublimator, the first HSD sublimators to reach space were aboard the Saturn 1B lift vehicle (Figure 8).

Sublimators have proved to be so reliable that, after Apollo, they continued to be used in the Space Shuttle’s Extravehicular Mobility Units, and they are still being used on the EMUs aboard the present International Space Station (ISS). Also the Russians used sublimators as part of their lunar program spacesuits and have continued to use them as part of their Orlan suit series aboard the ISS.

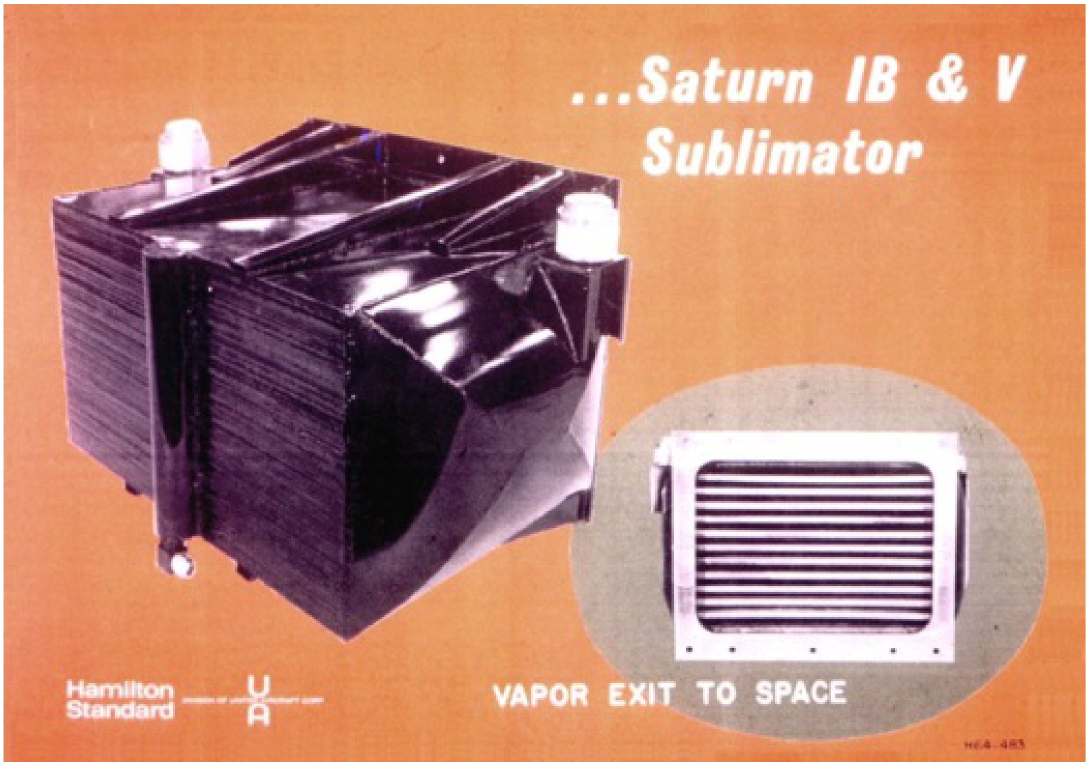

Figure 8 Saturn Rocket Sublimator System (Courtesy United Technologies Aerospace Systems)

HSD engineer David. C. Jennings invented and patented Apollo Liquid Cooling Garment (LCG) (U.S. Patent No. 3,289,748). HSD had become concerned in December 1962 about possible astronaut dehydration and over-heating due to the physical efforts and confined volume associated with pressure suits during initial Apollo manned testing. This caused HSD to internally fund Jennings starting in January 1963 to develop an Apollo cooling garment. Jennings' initial research focused on a cooling garment that would effectively remove body heat by high rate gas flow. However in early October 1963, the HSD cooling garment research turned to liquid cooling. Jennings had been given access to a RAF report from the early 1950s on a liquid cooling vest. This became the genesis for HSD's subsequent LCG developments. Jennings' approach was to cool the torso plus the arms and legs. To test the concept, Jennings wrapped 300 feet of 3/16" vinyl tubing around Harlan Brose, a volunteer HSD engineer test subject, (Figure 9). Brose was then covered with multiple layers of warm clothing and sealed in plastic to retain all perspiration (Figure 10). Under a physician's supervision, Brose then exercised strenuously on a tread mill for periods up to two hours.

Other test subjects repeated the tests, and the results were reported to NASA the following week. The report included how such an LCG would function as part of the spacesuit (Figure 11). The first of two key features of the HSD Apollo LCG are that the garment structure used an open mesh that allowed the ventilation gas to evaporate perspiration in the suit, thus providing additional gas cooling. The second feature was sewing the cooling tubes to the mesh. This assured that the tubes could not shift or kink, which prevented water flow stoppage and diminished cooling. The test results and subsequent analysis then were used for the creation of the first LCG prototype, designated CG1.

Figure 9 LCG Concept Test Preparation
(Courtesy United Technologies Aerospace Systems)

Figure 10 LCG Concept Testing (Courtesy United Technologies Aerospace Systems)

CG1 was a two-piece garment that joined at the waist and featured 232 feet tubing divided up into 40 separate water loops. CG1 assembly and first test were completed in December 1963. During the spring of 1964, extensive testing at HSD and in Houston was highly successful. Analysis of CG1 performance provided the basis for revisions that flowed into the CG2 design.

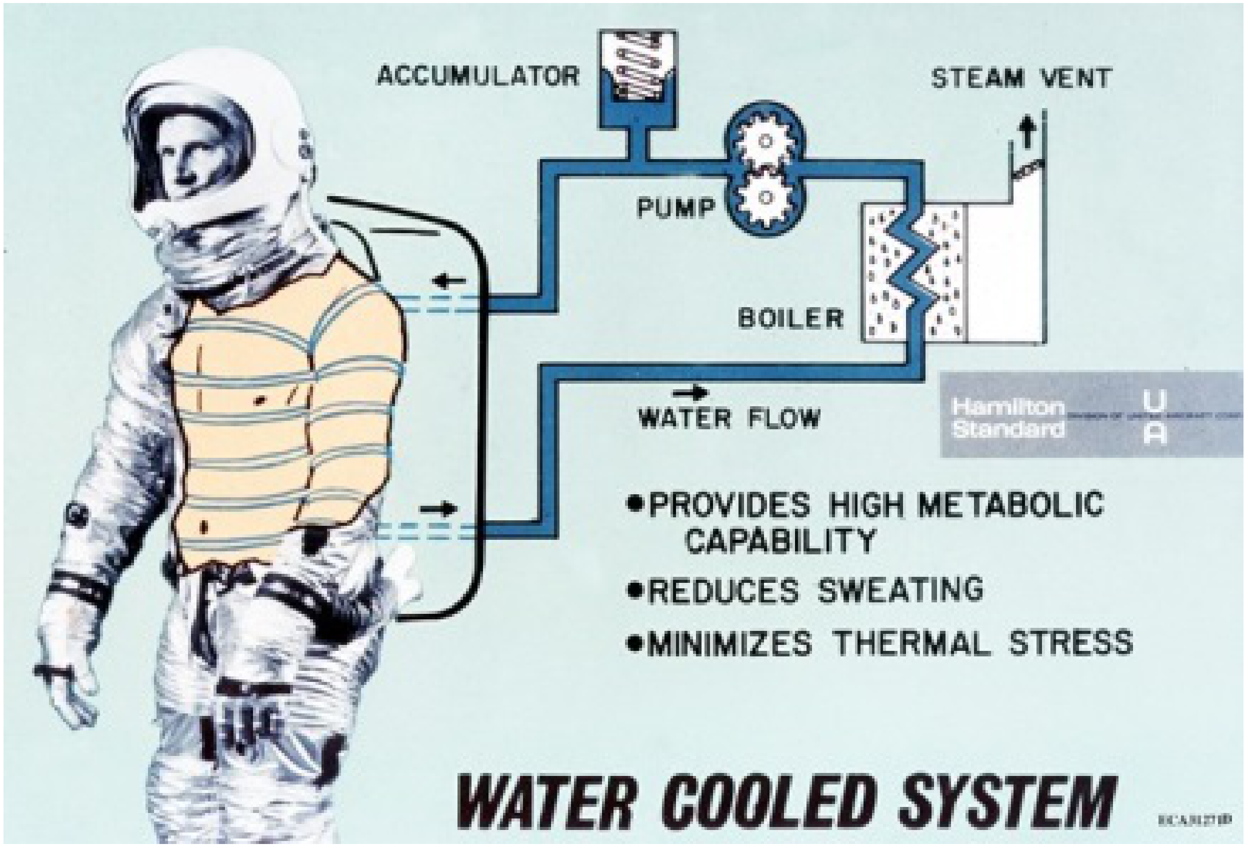

Figure 11 LCG Concept Presentation Slide
(Courtesy United Technologies Aerospace Systems)

The CG2 prototype (Figure 12) and subsequent Apollo and Skylab LCGs were one-piece garments that covered both the torso and arms and legs. Manufacture of CG2s began in April 1964 and supported manned testing in Houston in May. Between June 1964 and April 1965, prototypes CG3 to CG10 refined the design, materials and manufacturing processes used in the production that followed (Figure 13).

In March 1966, NASA purchased the rights to the Jennings LCG patent to permit the design to be available all U.S. corporations and individuals as well as for subsequent Apollo suits under subsequent manufacturers. Worldwide, most spacesuits of today have LCGs as part of the suit-system and those LCGs still bear a strong resemblance to the Jennings LCGs of 1965.

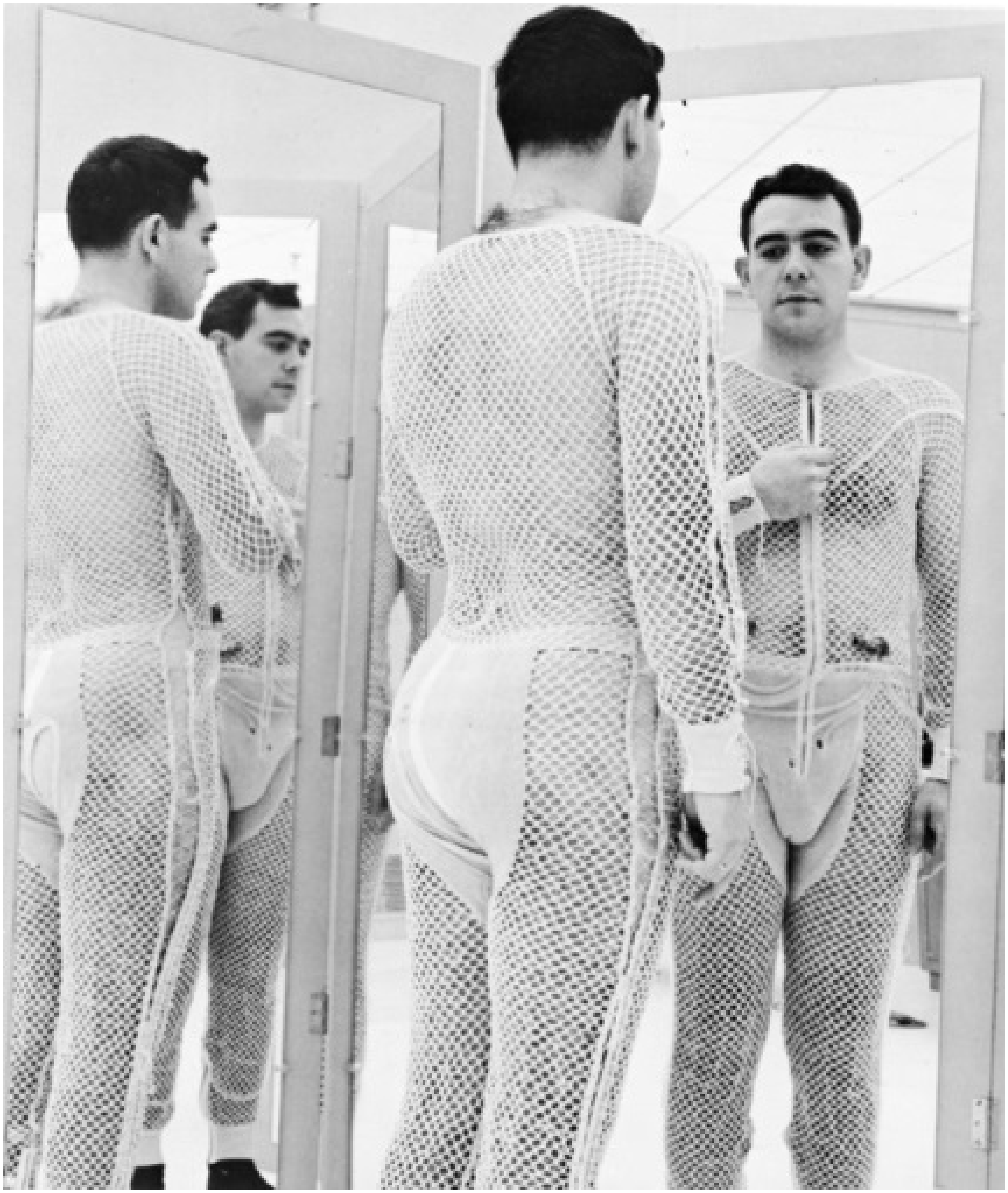

Figure 12 HSD Engineer Mark Britanisky Demonstrating The CG2 Liquid Cooling Garment (Courtesy United Technologies Aerospace Systems)

Figure 13   An Apollo 9-17 Type Liquid Cooling Garment
(Courtesy National Air and Space Museum, Smithsonian Institution)

The introduction of the LCG caused a challenge to the suit-system; how to connect the PLSS and LCG independently to the pressure suit to allow the cooling water to flow to and from the PLSS to the astronaut. The solution was another HSD invention, conceived and designed by Bradford Booker, called the Multiple Water Connector (Figure 14). This compact, light-weight port system allowed the PLSS and LCG to connect and disconnect without water or gas leakage.

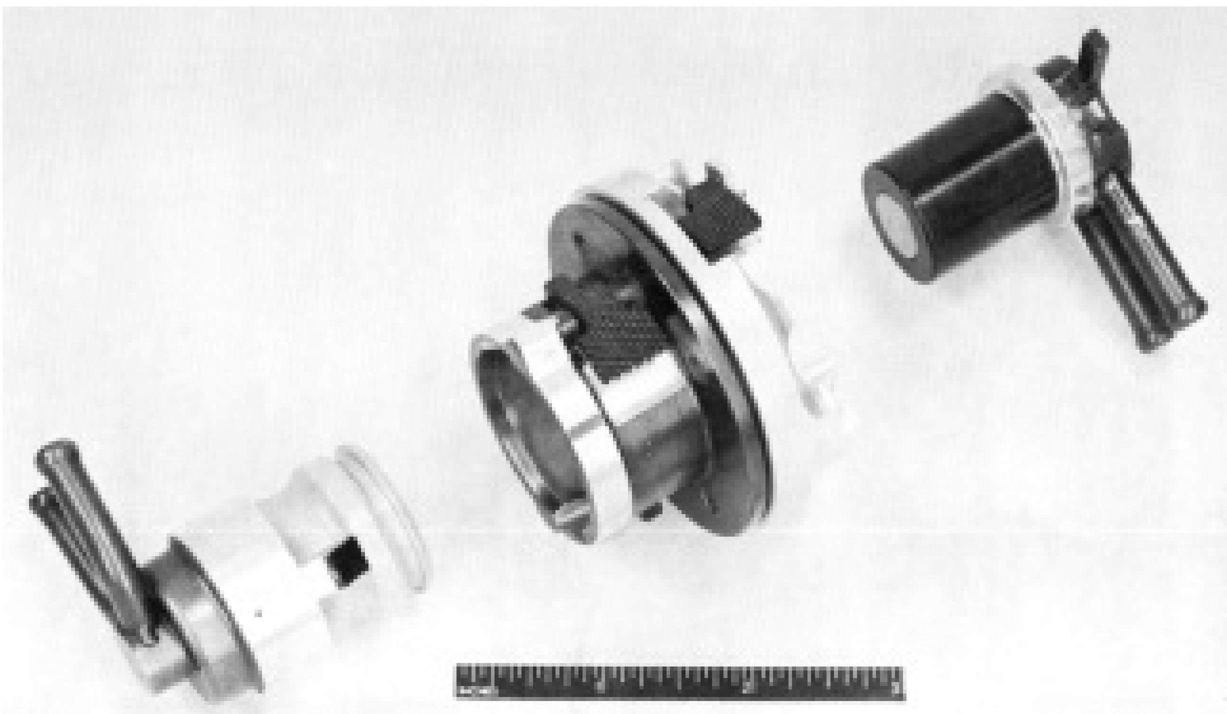

Figure 14 Apollo's Second Generation PLSS
(Courtesy United Technologies Aerospace Systems)

Added liquid cooling required developing a Portable Life Support System that would cool and circulate both water and ventilation gas. Apollo's Second Generation PLSS (Figure 15) was called the "Liquid-Cooled" PLSS because the primary heat removal method during periods of strenuous activity was the liquid cooling loop. Ventilation gas circulation still provided additional cooling while removing humidity to enhance comfort and lunar exploration capacity (Table 2 and Figure 16).

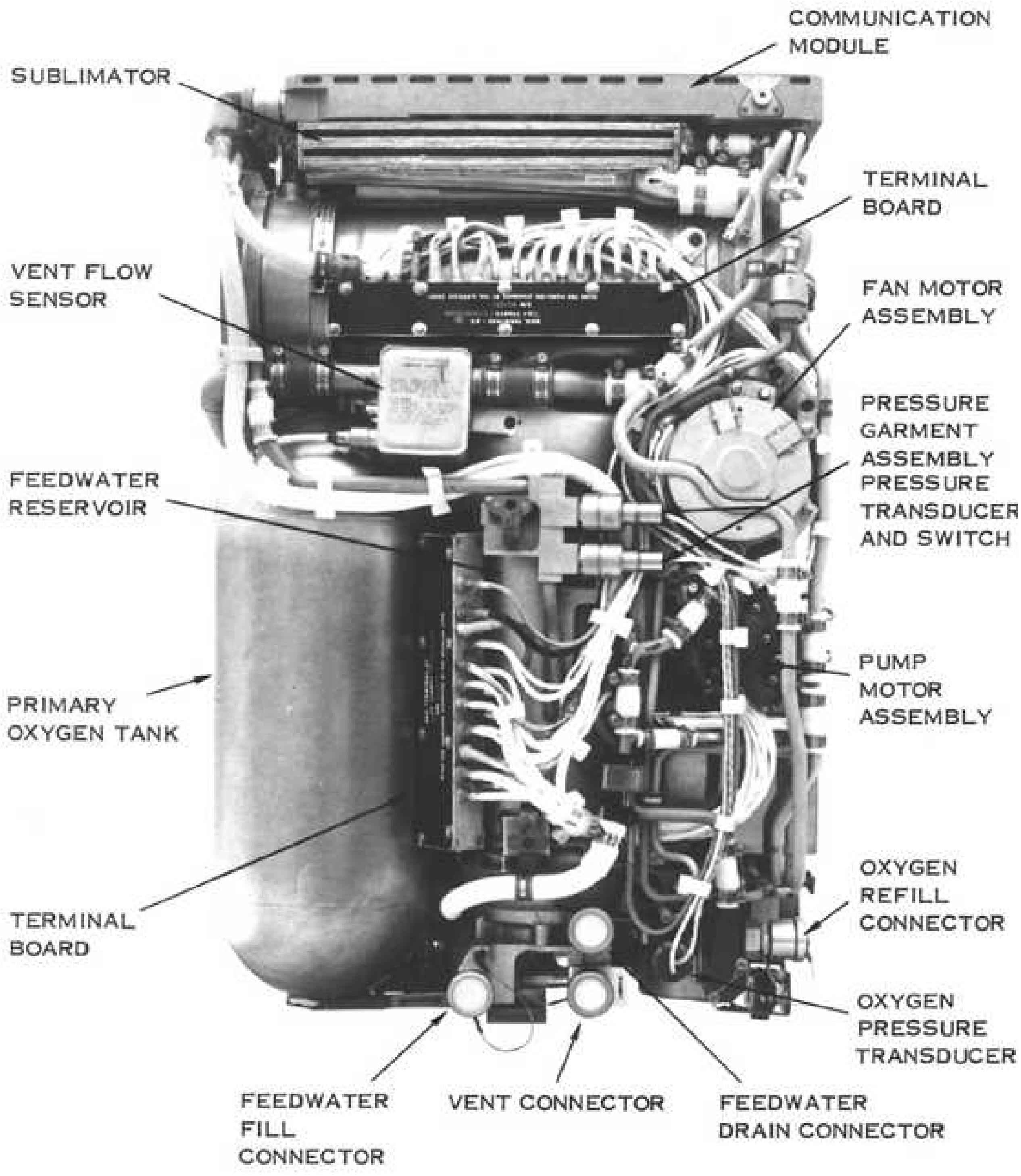

Figure 15 Apollo's Second Generation PLSS
(Courtesy United Technologies Aerospace Systems)

Table 2 - Parameters of the 1965 “Dash One” (-1) PLSS

Duration (Maximum)	4 Hours
Metabolic Rate	
Average (3 Hours)	1600 Btu/hr.
Average (4 Hours)	1200 Btu/hr.
Average (6 Hours)	930 Btu/hr..
Peak	2000 + Btu/hr.
Total Heat Leak	+250 to -350 Btu/hr.
Total Useful Heat Removal Capability	5550 Btu
Gas Leakage Rage	200 scc/min.
Gas Flow Rate	6 CFM
Liquid Flow Rate	4 lbs/min.
Suit Pressure Drop @ 3.7 psia	1.6 in. H_20
Weight (fully charged)	80 lbs (nominal)
Overall Dimensions	8.4 x 16.6 x 27.2 in.
Suit Inlet Gas Temp.	75°F
Suit Inlet Liquid Temp.	Variable (45°F Minimum)
CO_2 Partial Pressure into Helmet (Maximum)	
@ 3 Hours	10 mm Hg.
@ 4 Hours	15 mm Hg.
Power Source	Silver-Zinc Battery (Rechargeable)
Power Required	33 W
O_2 Storage Pressure	1000 psi
O_2 Storage Quantity	1.0 lbs (Recharge)
Water Storage Quantity	7.5 lbs (Recharge)
LiOH Quantity	2.7 lbs
Contaminant Control Cartridge Wt.	4.7 lbs
Reliability (12 Hours)	0.9995 %

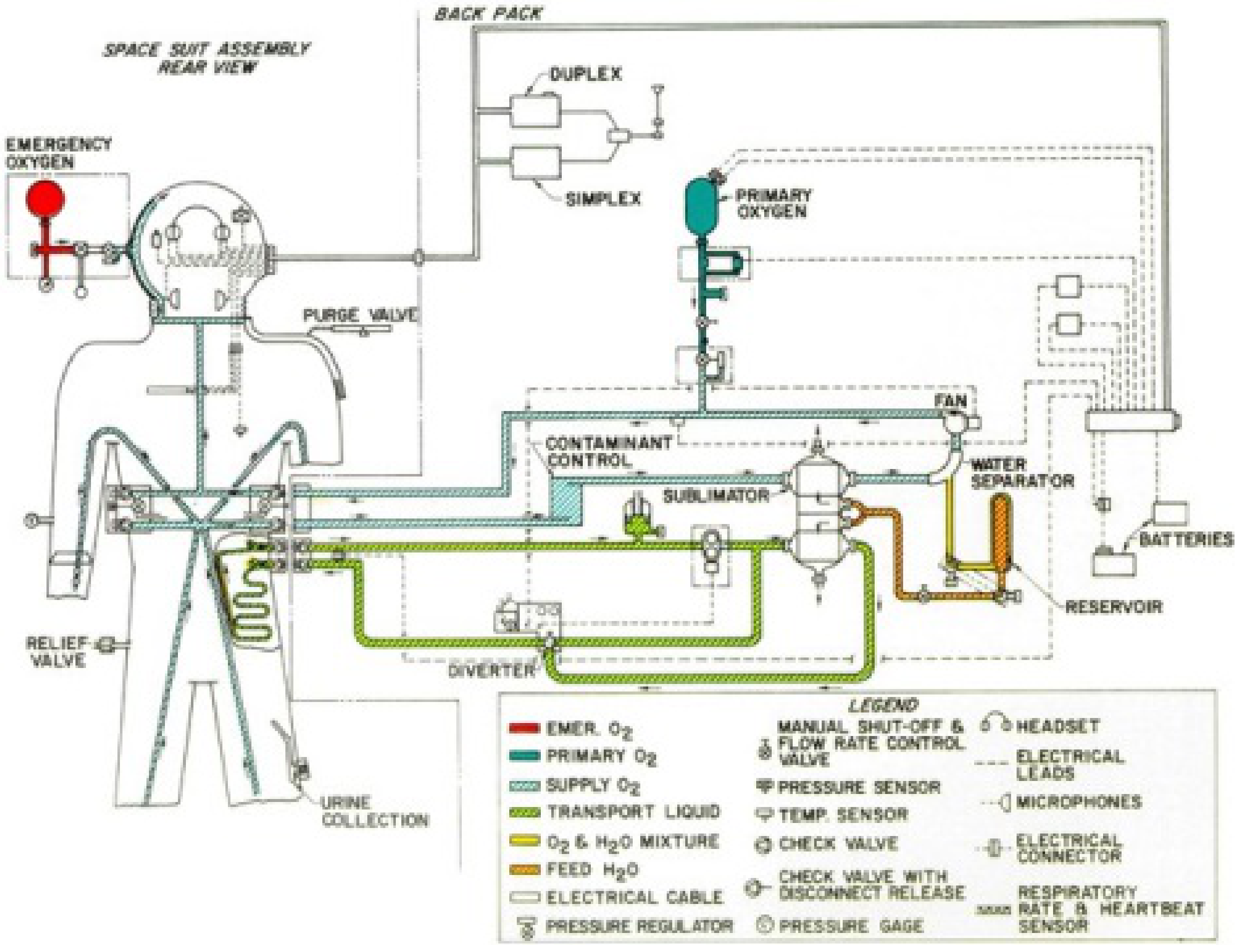

Figure 16 The -1 (Dash One) Liquid-Cooled PLSS Schematic
(Courtesy United Technologies Aerospace Systems)

One ground rule established in 1965 was that all subsequent improvements and changes to -1 PLSS had to be capable of being retrofitted into existing units. Thus, the base part number, SV706100, remained the same for the remainder of the Apollo program. Changes due to the backup life support system, material changes, or adding a chest control and display system were reflected in changes to the dash numbers that follow the base part number. This resulted in the dash number becoming the "name" of the subsequent types of Apollo PLSSs. The SV706100-1 or "dash one" PLSS reached successful manned testing in late 1965 (Figure 17).

Figure 17 1965 Successful Apollo EMU Chamber Testing
(Courtesy United Technologies Aerospace Systems)

To continue to meet the volume and weight requirements, a lighter and more compact Emergency Oxygen Supply (EOS, Figure 18) was developed that provided the same operating pressure and performance as the preceding design (Table 3).

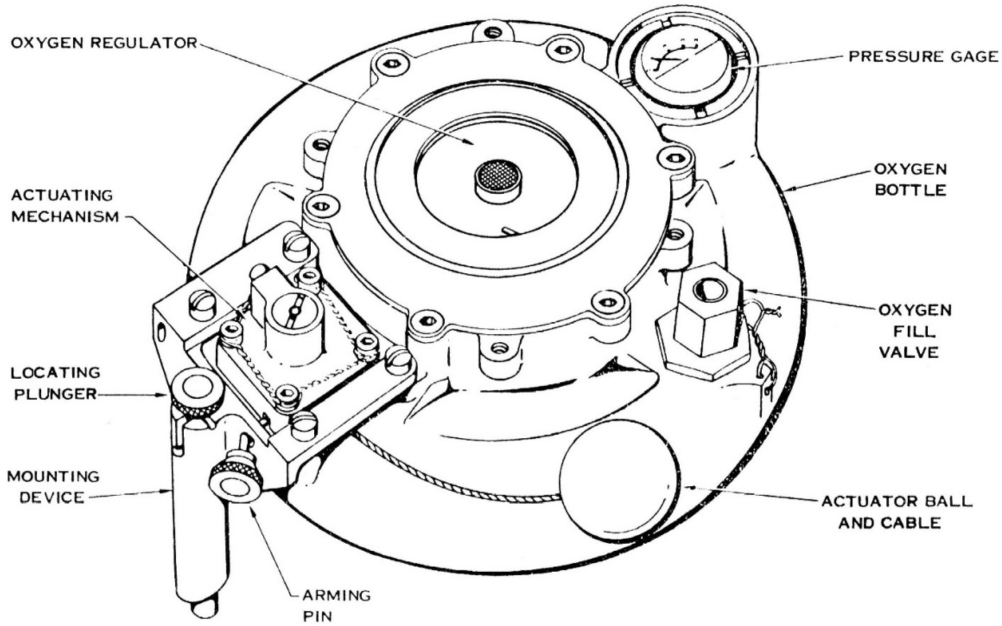

Figure 18 The Second Apollo EOS (Courtesy K. Thomas)

Table 3 - Emergency Oxygen System Comparison

	First Design	Second Design
Weight	5.0 lbs.	3.2 lbs.
Volume	90 in^3	35 in^3
Bottle Material	AMS 4340 (Nickel-plated)	Inconel 718
Number of Regulation Stages	Two	One
Bottle Operating Pressure	8770 psig max.	8770 psig max.
Regulated Pressure	3.5 $\pm$ 0.2 psig	3.7$\pm$ 0.3 psig
Outlet flow	0-2.0 lbs/hr.	0-2.0 lbs/hr
O_2 Storage Capacity	0.2 lbs.	0.2 lbs.

The first mounting location for the second design EOS was on the rear of helmet (Figure 19). This concept was probably the most interesting in that it permitted utilization of the unused space behind the helmet and above the backpack, but did not require separate storage. However, in 1965, the EOS was relocated to the side of the suit with a hose attaching directly into the LSS connectors on the front of the pressure suit.

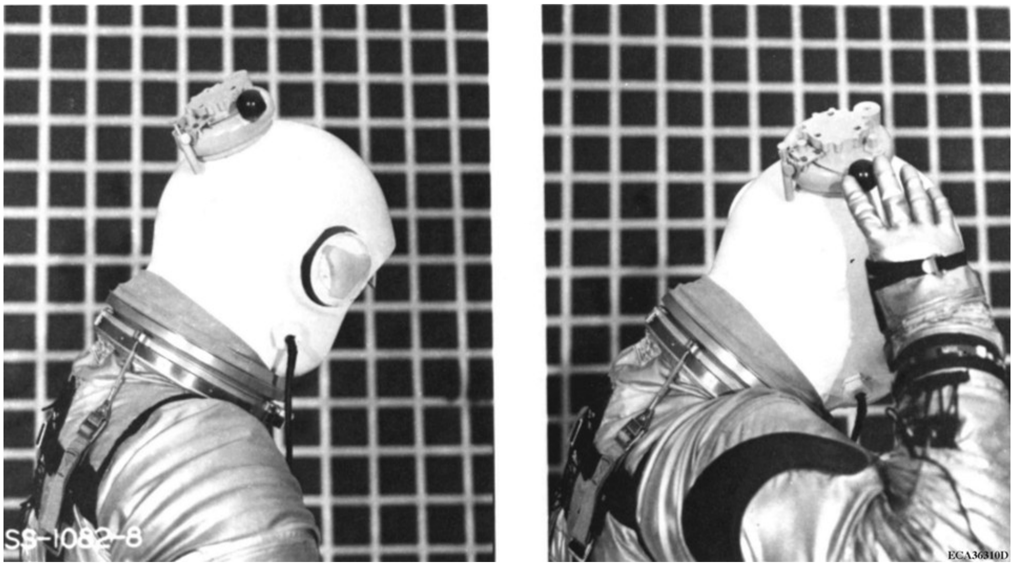

Figure 19 1964 Apollo EOS Activation (Courtesy United Technologies Aerospace Systems)

In 1966, the backup life support requirements changed. Considerations for vehicle-to-vehicle off-nominal transfers through restrictive hatches and other possible longer emergency durations caused backup life support requirement to increase from 5 minutes to 30 minutes. This resulted in the Apollo Oxygen Purge System (OPS, Figures 20 to 22) and the -2 PLSS configuration. To minimize weight, the protective outer shells of the PLSS and OPS made with low-mass inner and outer skins of fiberglass, plus high tensile strength aluminum honeycomb filler.

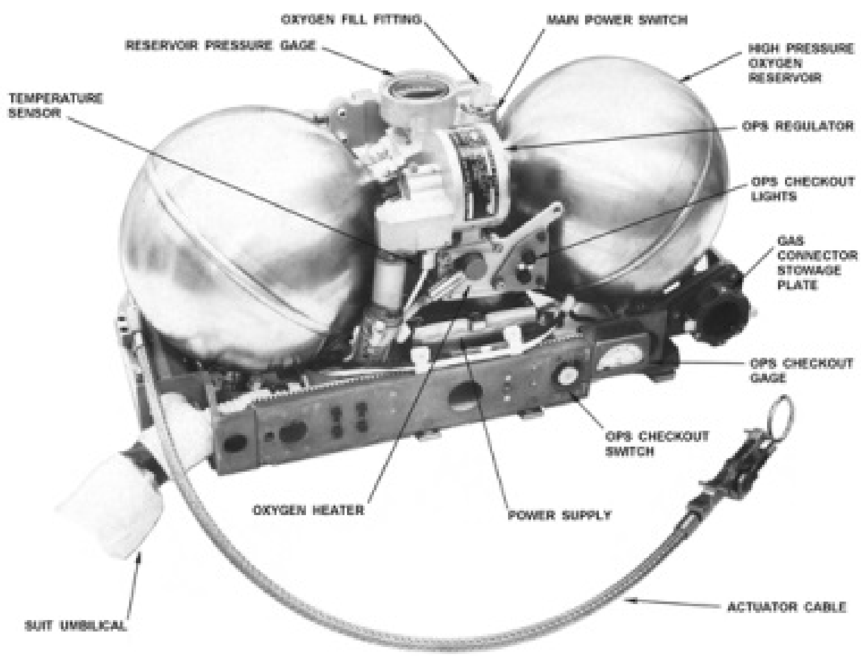

Figure 20 Oxygen Purge System (OPS) Components
(Courtesy United Technologies Aerospace Systems)

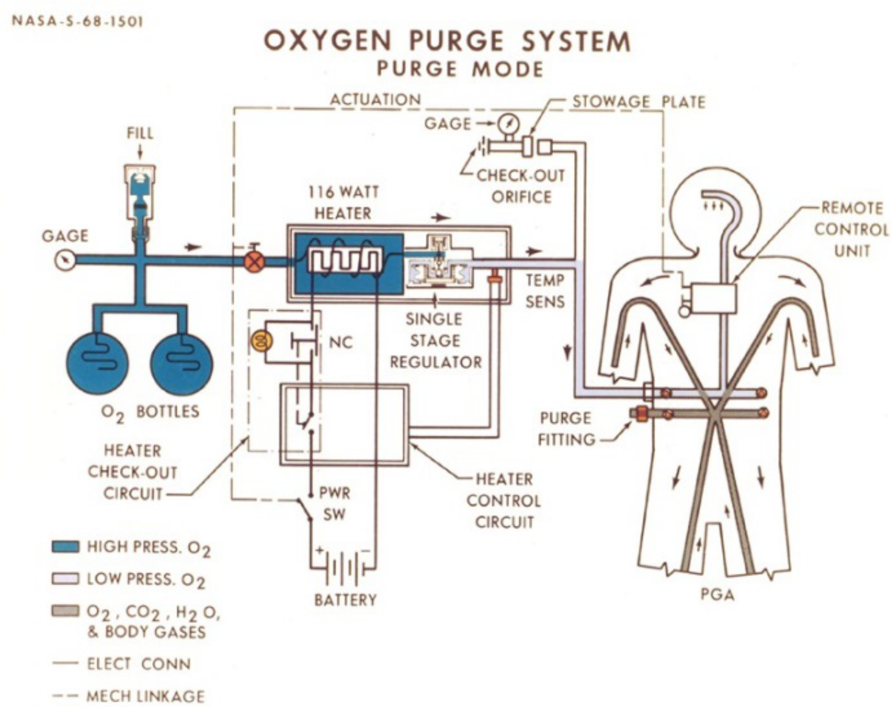

Figure 21 The Apollo 9-14 Oxygen Purge System (Courtesy NASA)

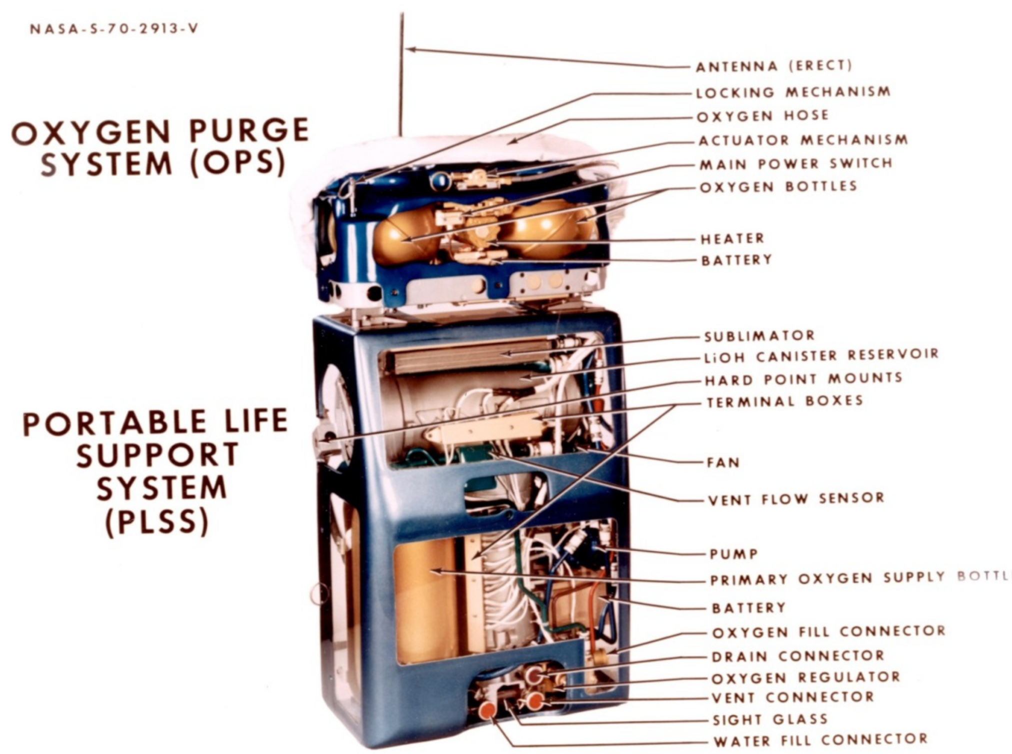

Figure 22 The OPS / PLSS Relationship (Courtesy NASA)

The fully charged OPS weighed nominally 40 pounds and could provide an astronaut with more than 30 minutes of gas management and convective cooling at an O_2 flow rate of 8 lb/hr. A secondary "low flow" rate of 4 lb/hr. was also incorporated. These rates provided adequate oxygen supply and CO_2 removal via purging gases overboard. If OPS cooling was not required, as in the case of a PLSS oxygen system malfunction where PLSS liquid cooling remained, the OPS could supply 75 minutes of gas life support with margin. The OPS contained of a pair of spherical tanks which held 5.8 pounds of pure gaseous oxygen at 5800 psi. To activate the backup life support, the astronaut moved a lever mounted on the front of the pressure suit. This caused a flexible cable to activate a single-stage in-flow pressure regulator that regulated the suit pressure to approximately 1/4 of an atmosphere.

The OPS was stored separately in the Lunar Module and attached to the top of the PLSS via slide-in brackets for EVA assembly and use. The OPS could also be mounted independently against the back of the helmet or against the abdomen for special zero “G” missions where the PLSS was not required. This allowed the deep space extravehicular activities or spacewalks on the return trips of Apollo 15, 16 and 17.

The Apollo capsule fire on January 27, 1967 caused all facets of the Apollo program to stand-down for a safety review. Material changes from fire resulted in the -3 PLSS configuration. Separately, the program delay allowed consideration for a chest mounted display and control module named the Remote Control Unit (RCU, Figure 23). The RCU allowed the astronaut to see his oxygen supply, receive warnings if malfunctions occurred, control radio and PLSS functions plus activate the OPS if needed, all within range of easy eyesight and reach. The resulting RCU had a maximum weight of five pounds. As the RCU was a component of the PLSS, this raised the fully charged weight of the -5 PLSS to approximately 85 pounds.

The -3 and -4 PLSS developments and certifications were performed in separate parallel efforts during 1967 to mitigate schedule risk and support the aggressive timeline to support 1968 flight PLSS manufacturing. At the same time, changes were incorporated into the -5 configuration (Figures 24 and 25), which were used on Apollo 9 in May of 1969 (Figure 26).

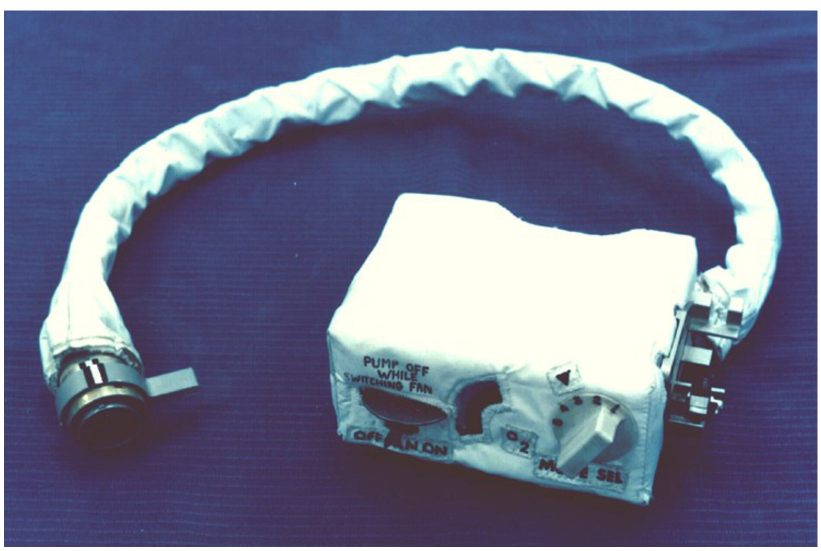

Figure 23 The Apollo 9 and 10 Type RCU (Courtesy United Technologies Aerospace Systems)

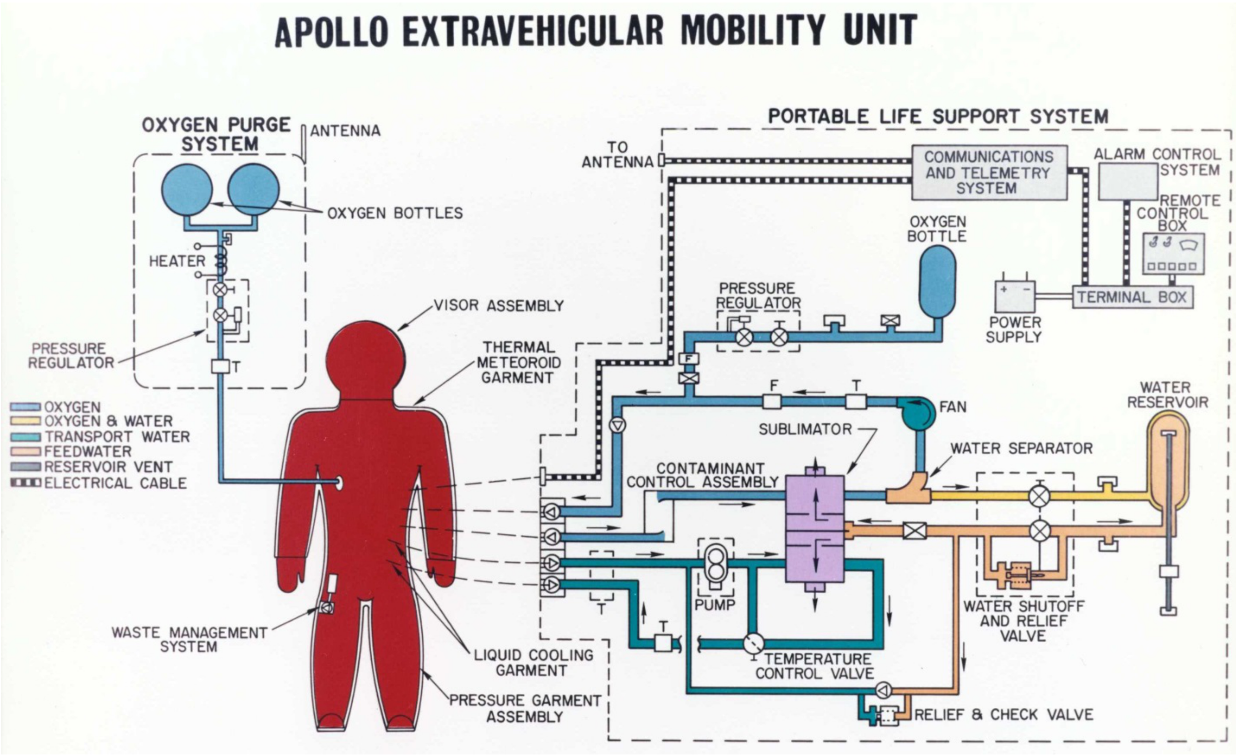

Figure 24 The Apollo 9 to 14 EMU Schematic (Courtesy NASA)

Figure 25 Apollo 9-10 PLSS In Flight Configuration
(Courtesy United Technologies Aerospace Systems)

Figure 26 Schweickart About To Photograph Scott On Apollo 9(Courtesy NASA)

Apollo also had an umbilical, primary life support system that was based on the use of a Pressure Control Valve (Figures 27 and 28). This was created in 1967 to allow a stand-up EVA from a hatch or extremely short ventures outside the Command or Lunar Modules. The Pressure Control Valve was installed in a suit outlet connector. When manually actuated, the PCV modulated the outflow of oxygen to maintain the required suit pressure. The 27.4 foot (8.3 m) umbilical contained an orifice to control the oxygen inflow rate to the suit. When deactivated, a no-flow pressure seal resulted. A locking mechanism prevented unintentional change in either valve position. When the PCV and umbilical were used, the OPS provided backup life support.   This system was first used on Apollo 9

(Figure 29), permitting observation of the first EVA test of one PLSS without risking of using two PLSSs. **<u>KEN, FIGURE 29 IS MISSING!</u>** After the Apollo 15 Lunar Module landing, a PCV and umbilical allowed a rapid and precise visual determination of the landing location prior to starting the surface EVAs. PCV/umbilical combinations also supported the deep space EVAs of Apollo 15, 16 and 17 return flights.

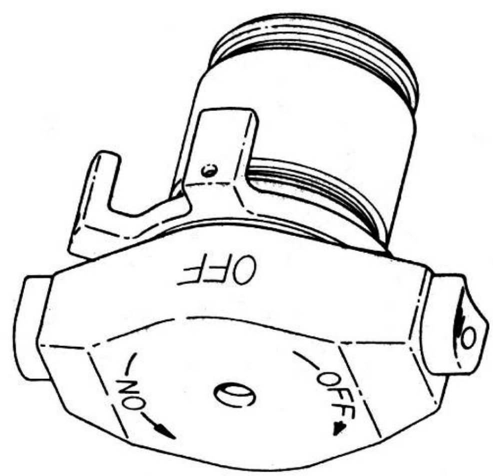

Figure 27 The Pressure Control Valve (PCV) (Courtesy K. Thomas)

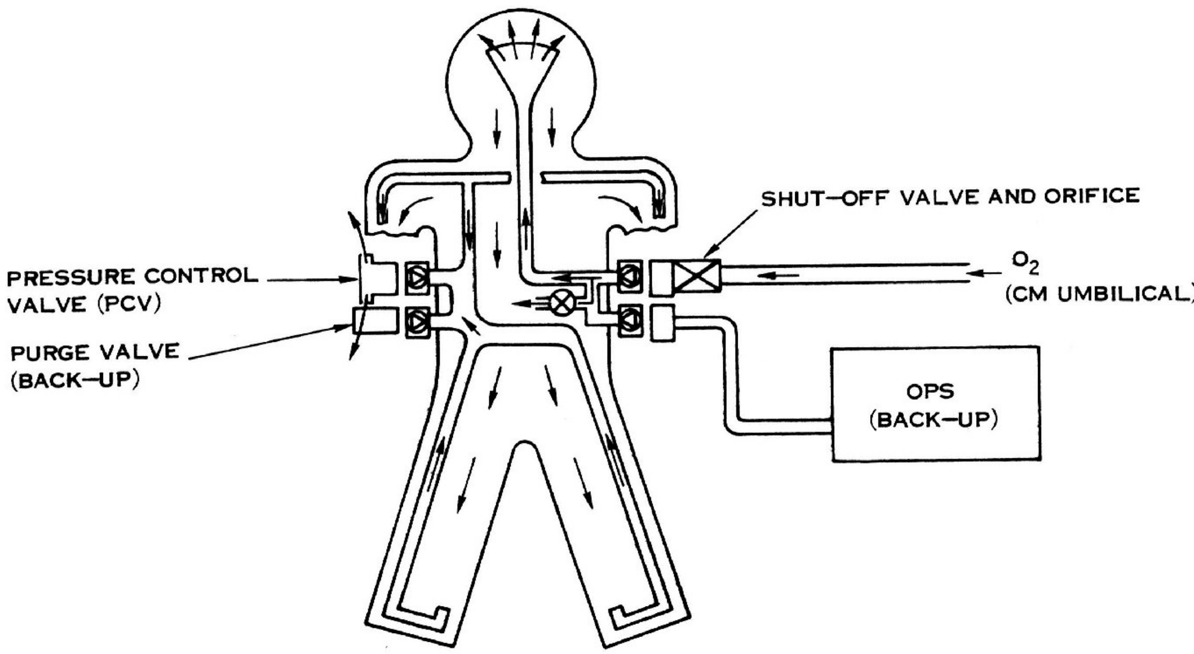

Figure 28 EMU Schematic Using PCV (Courtesy K. Thomas)

Figure 30 Scott Emerging From Command Module On Apollo 9 (Courtesy NASA)

During Apollo 10's preparation for its flight to the Moon, Apollo 9's lessons were being incorporated into the EMU, more specifically to the RCU to permit it to mount the latest iteration of world's most expensive camera. When hand-held by a suited astronaut in zero gravity, the camera produced many blurry pictures like those that had plagued the Gemini program. The RCU gained a front bracket (Figures 31 and 32) that held the camera rigidly. This facilitated hands-free lunar photography. While the bracket added some weight, the 5 pound maximum requirement was retained, and kept the -6 PLSS weight, used on Apollo 11 to 14, to nominally 85 pounds fully charged. The -6 PLSS, like its predecessors, provided 4 hour life support at 1204 Btu/hr. average metabolic rate, 6 hours at 930 Btu/hr. and had an operating pressure of 3.85 psi. This furnished the suited crewmen with their life support requirements, communications, telemetry and controls and displays for the lunar exploration missions. The -6 PLSS was first used on Apollo 11 to support man's initial setting foot on the Moon (Figures 33 and 34). As this was the culmination of many years of effort and sacrifice by many, HSD personnel monitored the Apollo 11 mission with great interest (Figure 35)

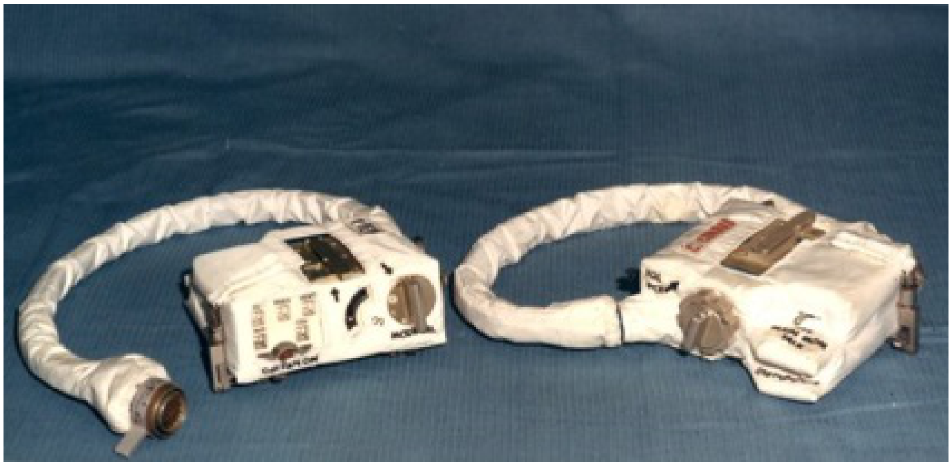

Figure 31 The Apollo 11-17 RCU (Courtesy United Technologies Aerospace Systems)

Figure 32 Camera and Bracket Attached To The RCU
(Courtesy United Technologies Aerospace Systems)

Figure 33 Front View of an Apollo 11 EMU (Courtesy NASA)

Figure 34 A Side View of an Apollo 11 EMU (Courtesy NASA)

Figure 35 Apollo HSD Engineers Waiting For An Apollo 11 Safe Return
(Courtesy United Technologies Aerospace Systems)

Even before walking on the Moon, preparations were underway for a subsequent configuration of Apollo EMU to allow longer duration lunar exploration using a lunar Rover. This required a longer duration life support system with greater considerations for safety. This drove the creation of the -7 PLSS. Initially, the creation of the -7 PLSS paralleled an effort to replace the OPS with a like-sized and located Secondary Life Support System (SLSS) that could provide liquid cooling and an hour of autonomous life support. However, cost considerations terminated the SLSS in favor of the Buddy Life Support System (BLSS). The BLSS (Figures 36 to 38) allowed a crewmember with a working PLSS to support his EVA "buddy" with a failed PLSS to return safely. The OPS on the failed PLSS provided the life-sustaining O_2, but at a reduced flow rate for longer life support. The working PLSS provided the necessary liquid cooling for both crewmembers. With an OPS on the "low flow" setting, the BLSS provided a simple, inexpensive and complete 75-minute emergency EVA life support. The BLSS system was used extensively in vacuum chamber and Zero-G training for the crews of Apollo missions 14-17. However, while the BLSS was carried on Apollo 14 and subsequent missions, it never had to be used.

Figure 36 The Buddy Life Support System (BLSS)
(Courtesy United Technologies Aerospace Systems)

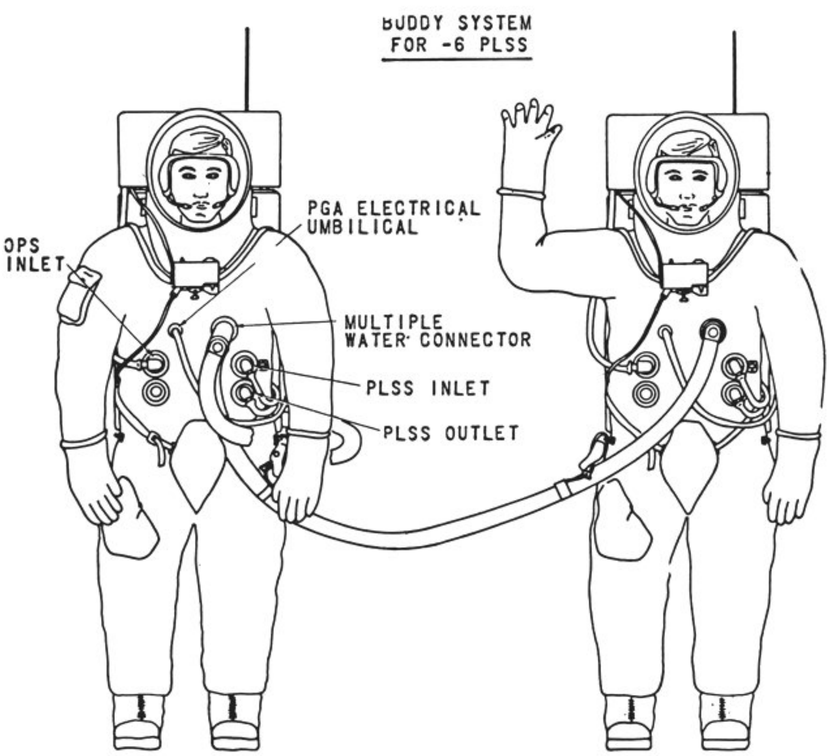

Figure 37 The BLSS Use Concept (Courtesy K. Thomas)

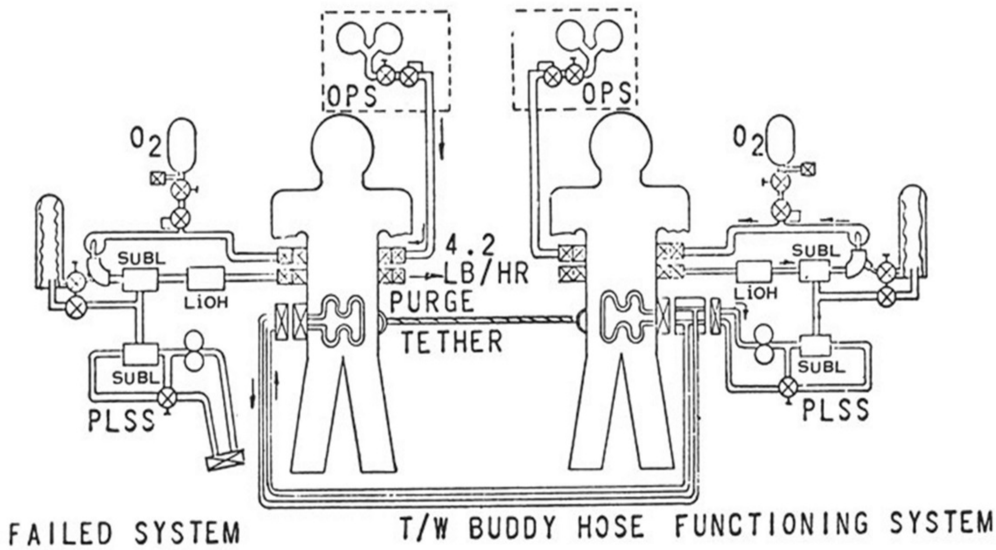

Figure 38 The BLSS System Schematic (Courtesy K. Thomas)

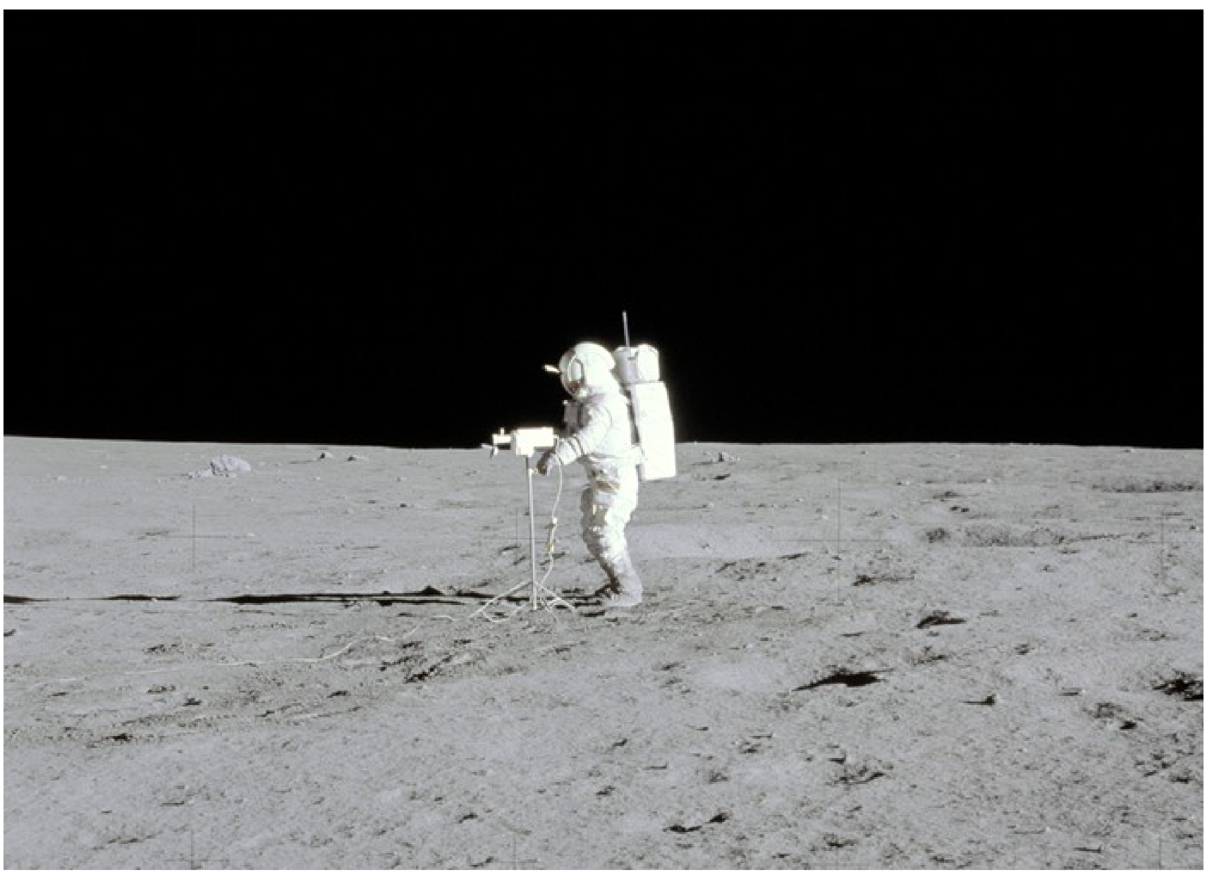

Figure 39 Apollo 14, The First Color Television From The Moon (Courtesy NASA)

While The -7 PLSS was to debut on Apollo 14 (Figure 39), NASA ultimately used the -6 PLSS due to cost considerations. Evaluation of the -6 PLSS revealed that an 8-hour capacity could be easily obtained in all but two areas, oxygen and water storage. The increased oxygen storage requirement was met by increasing the fully charged pressure from 1110 to 1500 psi. The problem of increasing the water storage for extra duration was not as simple. There was not enough allowable volume remaining in the PLSS to cost-effectively add the increased water capacity. A review of the Lunar Module interfaces with Grumman and NASA showed that a protrusion on the right side of the PLSS (as worn) up to 1.625 inches would not require a Lunar Module interface redesign or cause a crew mobility constraint. A right side mounted, Auxiliary Feedwater Reservoir Assembly was designed and added to create the cooling water capacity to support 8-hr. EVAs

The -7 was the last version of the Apollo PLSS (Figures 40-43). It supported the EVAs of Apollo missions 15-17. The introduction of the Rover and missions traveling farther from the Lunar Module necessitated 8-hr. support durations rather than the 4-hr. durations that the -6 PLSSs could provide. The challenge of creating the -7 PLSS was to retain the -6 PLSS's external envelope as much as possible, but to operate for up to 8 hours. Also, NASA wanted to be able to upgrade existing -6 PLSSs to the -7 configuration at minimum expense.

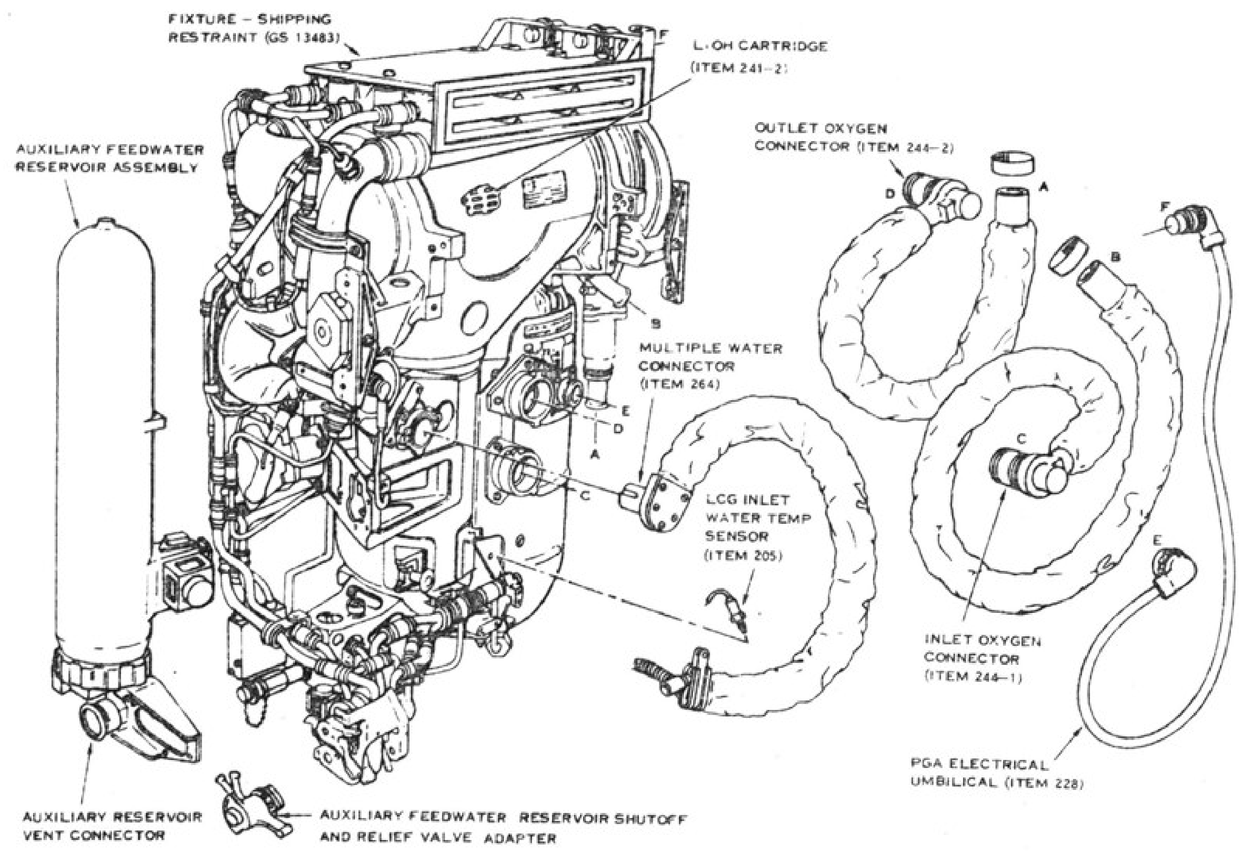

Figure 40 The Apollo 15-17 PLSS (Courtesy K. Thomas)

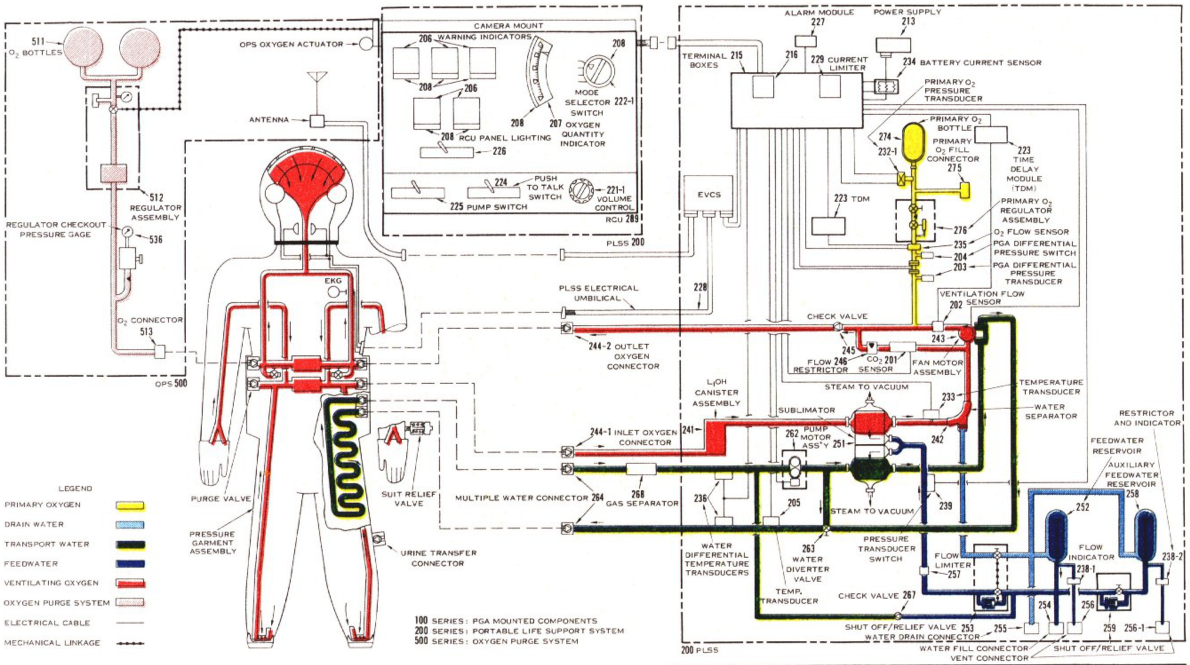

Figure 41 The Apollo 15-17 PLSS (Courtesy United Technologies Aerospace Systems)

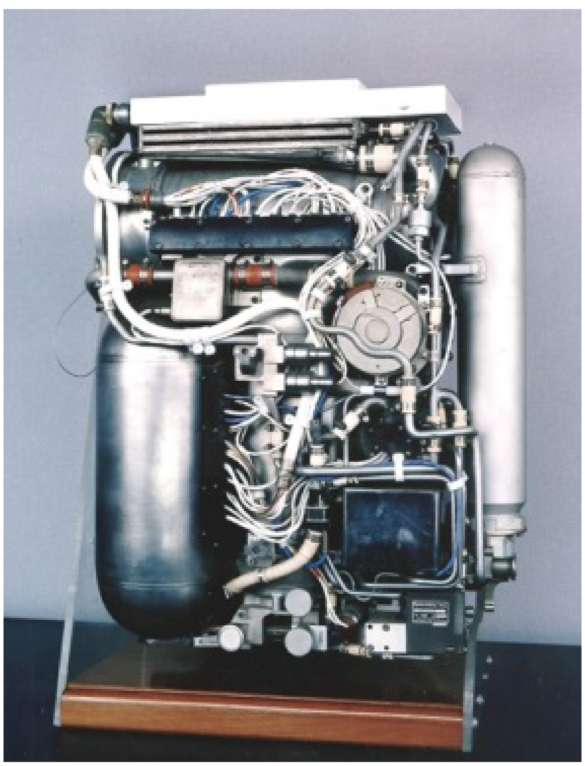

Figure 42 The Apollo 15-17 PLSS (Courtesy United Technologies Aerospace Systems)

Figure 43 The Apollo 15-17 PLSS (Courtesy United Technologies Aerospace Systems)

To facilitate lunar surface exploration, the outside of the life support system inevitably gained accessories for sample and tool storage (Figure 44).

The -7 Apollo PLSSs, like their -6 predecessors, operated flawlessly within their operating parameters on all the their Lunar missions. The -7 PLSS proved to be an excellent platform for carrying tools/samples (Figure 44) and routinely performed 7-hour plus EVAs, returning to the Lunar Module with capacity to spare.

Figure 44 PLSS EVA Accessories
(Courtesy United Technologies
Aerospace Systems)

To compensate for increases in mass and weight associated with the -7 PLSS to meet needs of extended duration Apollo missions, other areas were reviewed for potential weight reduction. Manned test data from the early Apollo missions indicated the thermal conditions inside the OPS were not as severe as originally expected, making the electric heater and battery in the Apollo 9-14

OPS unnecessary. For Apollo 15-17, these OPS components were eliminated (see Figure 45). The resulting Apollo 15 through 17 PLSS/OPS system nominally weighed 129 pounds.

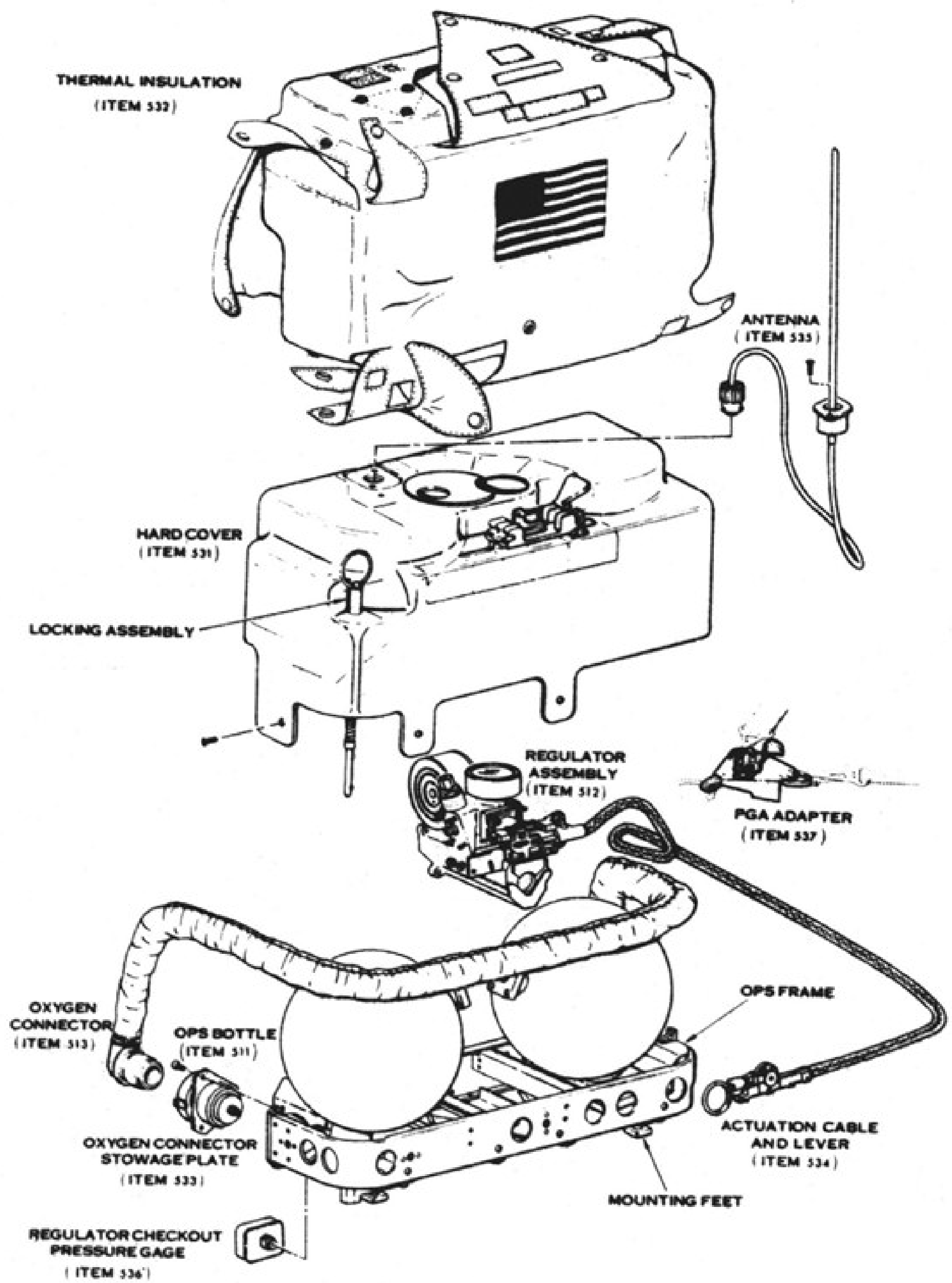

Figure 45 The Apollo 15-17 Oxygen Purge System
(Courtesy K. Thomas)

The Apollo 15-17 PLSS and OPS supported 15 EVAs and over 124 man-hours in the vacuum in space. Apollo 15, 16, and 17 missions introduced two historic elements to human space exploration. First, these missions utilized the Lunar Rover Vehicle (Figure 46), which allowed astronauts to travel 110 miles in their lunar explorations. Second, during the second of three surface EVAs on Apollo 17, Astronauts Cernan and Schmitt set the world's record for the longest EVA at 7 hours and 37 minutes on December 12, 1972. This record stood for almost twenty years.

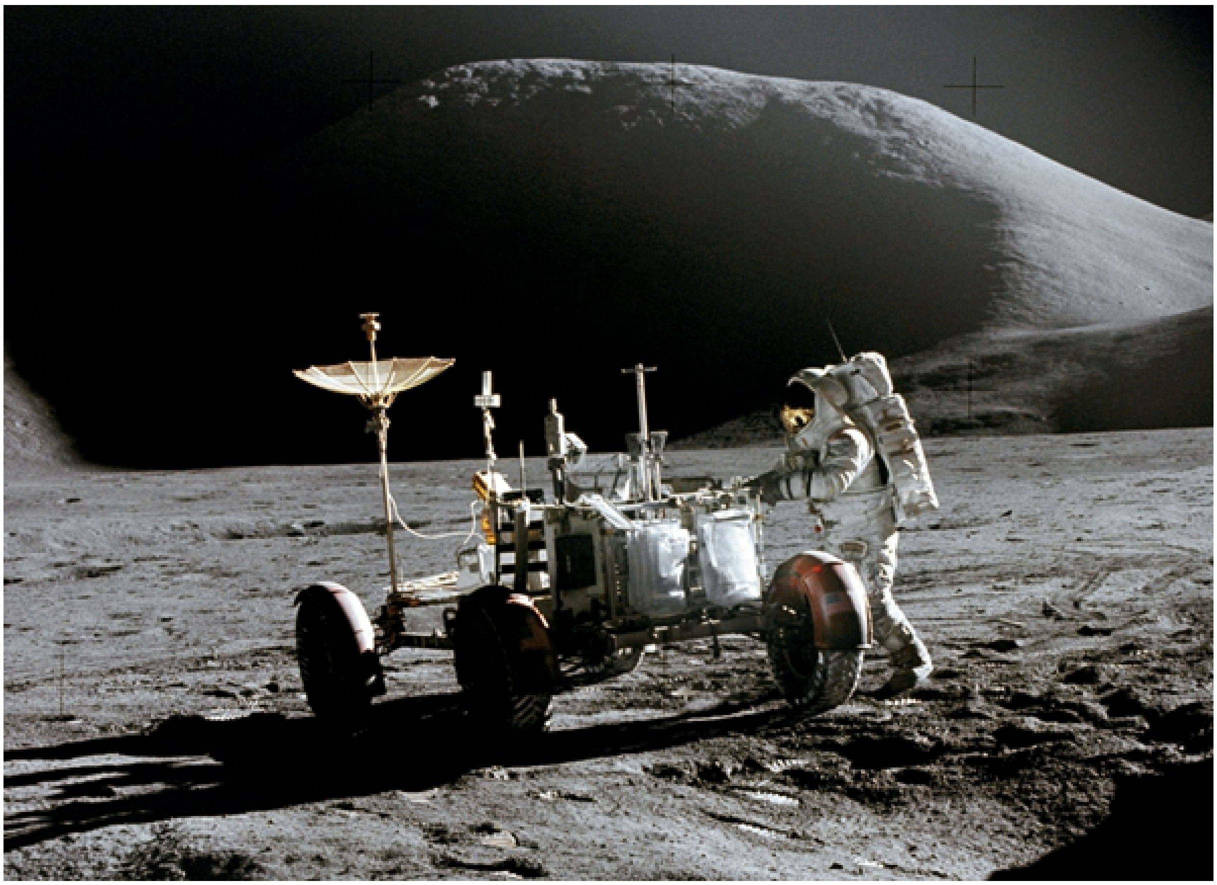

Figure 46 Apollo 15 On The Road (Courtesy NASA)

Beyond the well-remembered lunar-surface explorations, Apollo 15-17 also featured spacewalks on the return voyages by the Command Module Pilots (CMP). For these spacewalks, the PLSSs were not available as they were left on the lunar surface to increase the sample payload being brought back to Earth. Instead, the primary life support was provided by the aforementioned umbilical/PCV combination attached to an inlet connector of his suit and a Pressure Control Valve (PCV) attached to the outlet connector (Figures 27 and 28). The first of these EVAs was supported by James Irwin who guided CMP Alfred Worden's umbilical from the hatch of the Command Module on August 5, 1971. This allowed Worden to perform the world's first deep space EVA some 171,000 miles (273,600 km) from Earth.

The Apollo 16 deep space EVA was performed on April 25 CMP Thomas Mattingly. This EVA lasted 1 hour and 24 minutes. The EVA permitted recovery of mapping and panoramic camera film packages, an inspection of the spacecraft's exterior and retrieval of a Microbial Ecological Evaluation Device. Before returning to the cabin, he opened his visor briefly so he could see the stars, taking care not to look in the direction of the Sun.

During the Apollo 17 return voyage on December 17, 1972, Command Module Pilot Ronald Evans performed a 1 hour and 7 minute EVA to retrieve film from the Service Module. This had the dual distinction of being the last Apollo EVA and man's last deep space EVA to date (see Figure 47).

Figure 47 The World's Last Deep Space EVA (Courtesy NASA)

Note: The author wishes to thank Maurice Carson, Earl Bahl and William “Dick” Wilde. For those who are not familiar with these distinguished engineers, Maurice Carson was the NASA engineer overseeing Portable Life Support System (PLSS) development during the Apollo program. Earl Bahl (pictured in Figure 2) was a Mechanical Design Engineer who made numerous contributions and supported PLSS efforts from the beginning of Apollo to its completion. Dick Wilde was a Systems Engineer who supported Apollo in many capacities and who wrote the “Mini-Data Book” that was the technical reference that many engineers carried in their shirt pockets. The print was so small that it was barely readable without a magnifying glass. However, that was not a problem in the age of Apollo as scientific calculations were performed by slide rule and virtually all engineers had quality magnifying glasses to estimate extended decimal point accuracy.