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THE SHUTTLE EXTRAVEHICULAR MOBILITY UNIT (EMU)

PROVEN HARDWARE FOR SATELLITE SERVICING

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Extravehicular Mobility Unit .

ABSTRACT

A general technical description of the Extravehicular Mobility Unit (EMU) is given. The description provides a basis for understanding EMU mobility capabilities and the environments a payload is exposed to in the vicinity of an EMU.

Introduction

The Crew Systems Division (CSD) of NASA/JSC has responsibility for the Space Transportation System life support efforts. One such system, the Extravehicular Mobility Unit, is planned to play a major role in servicing satellites and other payloads. By correlating data from CSD on EMU capabilities, environmental interfaces and new programs with Flight Operations Directorate (FOD) data on timelines and crew training and also with Spacecraft Design Division (EW) data on equipment and payload structural interfaces, the NASA plans to establish a methodology for efficiently scheduling, and planning a satellite servicing mission.

The Extravehicular Mobility Unit (EMU) is the device which permits the Shuttle astronaut to use the most versatile tools known to man - the human hand and eyes - in the conduct of a wide range of Shuttle space operations - both planned and unanticipated.

To work in space, the crewperson must be mobile and be able to live comfortably in the vacuum environment. Environmental protection and mobility are provided by the Space Suit Assembly (SSA). Life support functions are provided by the Life Support Subsystem (LSS). These are the two main subsystems of the EMU. The purpose of this paper is to provide a technical description of the EMU and demonstrate that the EMU may be used as a safe, efficient EVA tool.

A description of the SSA hardware and resultant mobility will demonstrate extravehicular/intravehicular capabilities of the suited crewperson. These capabilities are described in detail in the paper titled "Crewman Suited IVA/EVA Capabilities" authored by Mr. Jim Jaxx and contained in the Servicing Operations Section of the Workshop Papers. A knowledge of the internal workings of the LSS will help in understanding the EMU mission profile and environments which a payload is exposed to when approached by an EVA crewperson. One purpose of this EMU description is to answer the "How does it work?" questions that are important to payload designers. It is expected that the information contained in this document will assist the Shuttle user community in planning for the use of EVA to effectively support payload and other Shuttle operations.

Space Suit Assembly

The primary function of the Space Suit Assembly (SSA) is to maintain the pressure required for safe operation in a vacuum environment while providing a high degree of mobility to accomplish a wide range of tasks. Other functions include:

° Protection from the extremes of temperature encountered in space

° Protection from radiation and micrometeroid environments

These functions are provided by the SSA which is composed of some nine separable components which are connected together by quick disconnects. Following is a description of components and functions required of the SSA.

<u>Pressure Retention</u>

The pressure vessel is made up of the Helmet/Extravehicular Visor Assembly, (Helmet/EVVA), the Hard Upper Torso (HUT), the Lower Torso Assembly (LTA), and the Arms and Gloves (see Figure 1). These assemblies and components are all connected together by pressure sealing quick disconnects which allow the crewperson to don the LTA, then the HUT (which already has the arms attached) and then the Gloves and Helmet/EVVA.

The suit pressure is maintained with oxygen at 4.3 psia pressure. This pressure level is a compromise between several competing demands. An increased suit pressure has the benefits of reducing or eliminating the prebreathe time required to denitrogenate the body to preclude the bends and of giving ample margin between operating pressure and minimum emergency pressure. A decreased suit pressure has the benefits of reducing space suit operating forces, pressure loads, and structural bulk. For a given space suit design, lower pressure results in increased mobility.

The Helmet/EVVA (Figure 2) provides pressure retention by means of a bubble-shaped, one-piece polycarbonate shell which is attached to the metallic quick disconnect. The HUT (Figure 2) is a conformed fiberglass structure which provides not only pressure retention but the mounting base on which the LSS components are mounted. The LTA, Arms, and Gloves (Figure 2) are softgoods which provide pressure sealing by means of a heat sealed polyurethane coated nylon bladder. The bladder material is not designed to carry the structural loads. The longitudinal structural loads are generated in two ways: (1) pressure area loads and (2) man-induced loads. These longitudinal structural loads range from a low of 150 lbf at the outside of the boot to a high of 1400 lbf at the waist and are carried by a primary restraint which is made of sewn webbing for the LTA (Figure 3), arms, and gloves. To provide high reliability, a secondary restraint system is also provided which remains unloaded unless the primary restraint lines fail. The circumferential loads are carried by a layer of polyester cloth. This material completely encloses the bladder material and provides the structural support required. The restraint materials are selected to minimize stretch since they also determine the shape and size of the SSA under pressure.
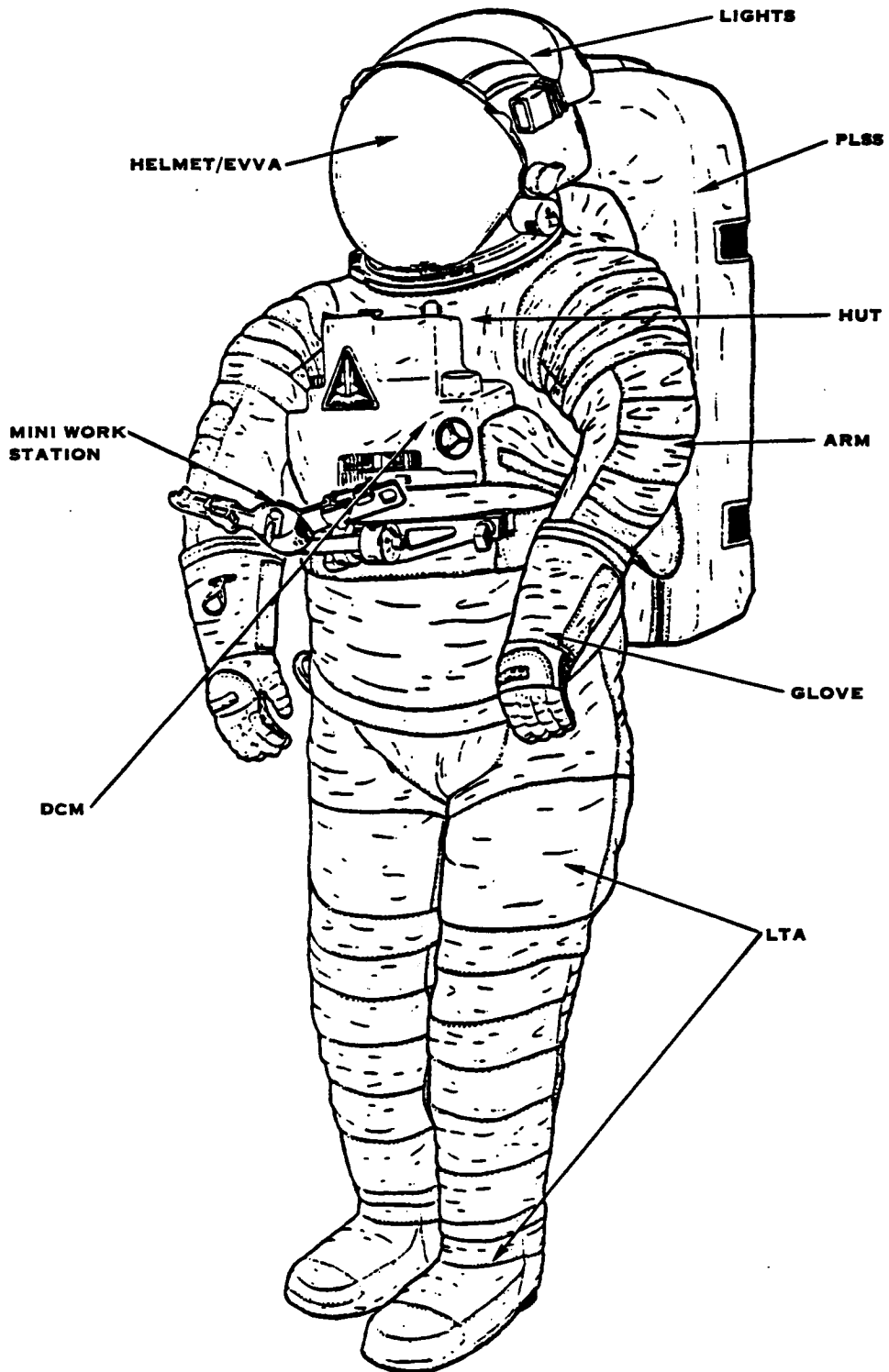
ORIGINAL PAGE IS
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LIGHTS

HELMET/EVVA

PLSS

HUT

ARM

MINI WORK STATION

GLOVE

DCM

LTA

FIGURE 1.

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Mobility

The essential challenge of SSA design is to maintain pressure integrity as described above while providing mobility. A feel for the magnitude of this challenge can be obtained by looking at what forces would be required to operate a SSA which contained no mobility elements at the body joints (see Table 1). The current Shuttle SSA specifications are also shown in the table for comparison of mobility joint performance. The torques and forces required to bend a suit element are generated because bending the joint causes an internal volume change. For example, the volume change associated with bending the knee joint 90° if it does not have a mobility element is 242 in^3. The allowed volume change to stay within the 12 in lbf specification is 2.8 in^3. From this it can be seen that the ideal joint mobility characteristic is one in which the volume stays constant as the joint is articulated, and ideally approaches capabilities by existing SSA joint designs.

Mobility elements are located at the shoulder, elbow, wrist, and fingers in the upper torso area (Figure 2). The lower torso includes mobility elements at the waist, hip, knee, and ankle (Figure 3). Except at the shoulder, where a rolling convolute is used and at the wrist and fingers where tucked fabric joints are used, the mobility elements of the Shuttle suit are flat pattern designs which are tailored to give a stable joint with minimum torque.

Another aspect of mobility is rotation. To allow rotation of the shoulder, arm, and hand, there are pressure sealing ball bearings (Figure 2). There is also a waist bearing (Figure 3) which allows upper torso twisting motions which are very effective in increasing the available reach envelope of the suited crewperson.

The best mobility elements and bearings are of little help, though, unless the bending or twisting axis corresponds with the respective axis of the crewpersons' body. To assure this correspondence, the SSA must fit the crewperson well. The Apollo and Skylab programs used spacesuits which were custom procured for the crewman; this is not feasible for the Shuttle Program because of the expense associated to accommodate the larger number of astronauts and 15 year program lifetime. Consequently, the Shuttle SSA incorporates provisions for modular sizing. Table 2 lists the quantity of sizes of the various components. Vernier sizing of the arms and legs (Figure 3) is incorporated with a sizing insert system which assures that the elbow and knee mobility element bending axis corresponds with the bending axis of the crewperson's joints.
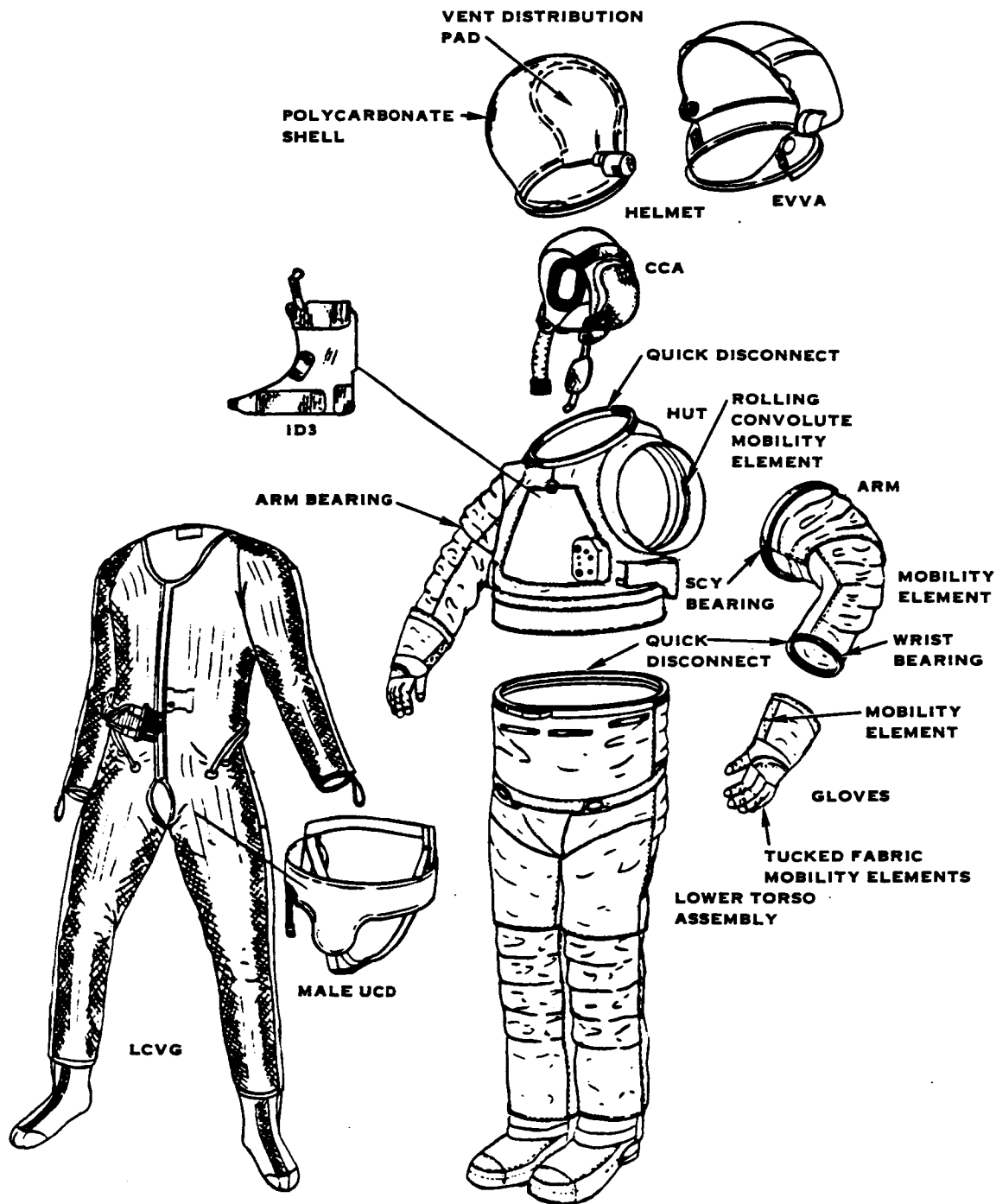
UNITED TECHNOLOGIES HAMILTON STANDARD

VENT DISTRIBUTION PAD

POLYCARBONATE SHELL

HELMET

EVVA

CCA

QUICK DISCONNECT

HUT

ROLLING CONVOLUTE MOBILITY ELEMENT

ARM

ID3

ARM BEARING

SCY BEARING

MOBILITY ELEMENT

QUICK DISCONNECT

WRIST BEARING

MOBILITY ELEMENT

GLOVES

TUCKED FABRIC MOBILITY ELEMENTS

LOWER TORSO ASSEMBLY

MALE UCD

LCVG

FIGURE 2.

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TABLE 1

TORQUES & FORCES REQUIRED TO BEND A
4.3 PSID PRESSURIZED CYLINDER THROUGH 90°
(NO JOINT)

Cylinder Diameter		Joint Represented	Torque Required		Force Needed At End Of Cylinder		Shuttle SSA Torque Spec.	
cm	(Inches)		cm-dyne·10^6	(in-1bf)	dynes·10^8	(1bf)	cm-dyne·10^6	(in-1bf)
2.54	(1)	Finger	9.04	(8)	.0134	(3)	---	---
10.16	(4)	Elbow	599	(530)	.201	(45)	13.6	(12)
12.70	(5)	Knee	1,180	(1,040)	.267	(60)	13.6	(12)
40.64	(16)	Waist	38,400	(34,000)	4.23	(950)	54.2	(48)

$$T = \frac{Pad^3}{46}$$

T = Torque, in-1bf
P = Suit pressure, psid
a = deflection angle, degrees
d = cylinder diameter, inches

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TABLE 2

QUANTITY OF SIZES

COMPONENT	NUMBER OF SIZES
Hard Upper Torso	5
Waist	3
Lower Torso	4
Boots	2 (1)
Gloves	15
Liquid Cooling & Ventilation Garment	5
Communications Carrier Assembly	6
Arm	6

(1) Slipper-like inserts are provided to accomodate a wide range of foot sizes.

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POLYURETHANE SEALED
BLADDER LAYER

MOBILITY
ELEMENT

WAIST
BEARING

MOBILITY
ELEMENT

RESTRAINT LINES
(LONGITUDINAL LOAD
BEARING ELEMENT)

POLYESTER CLOTH LAYER
(CIRCUMFERENTIAL LOAD
BEARING LAYER)

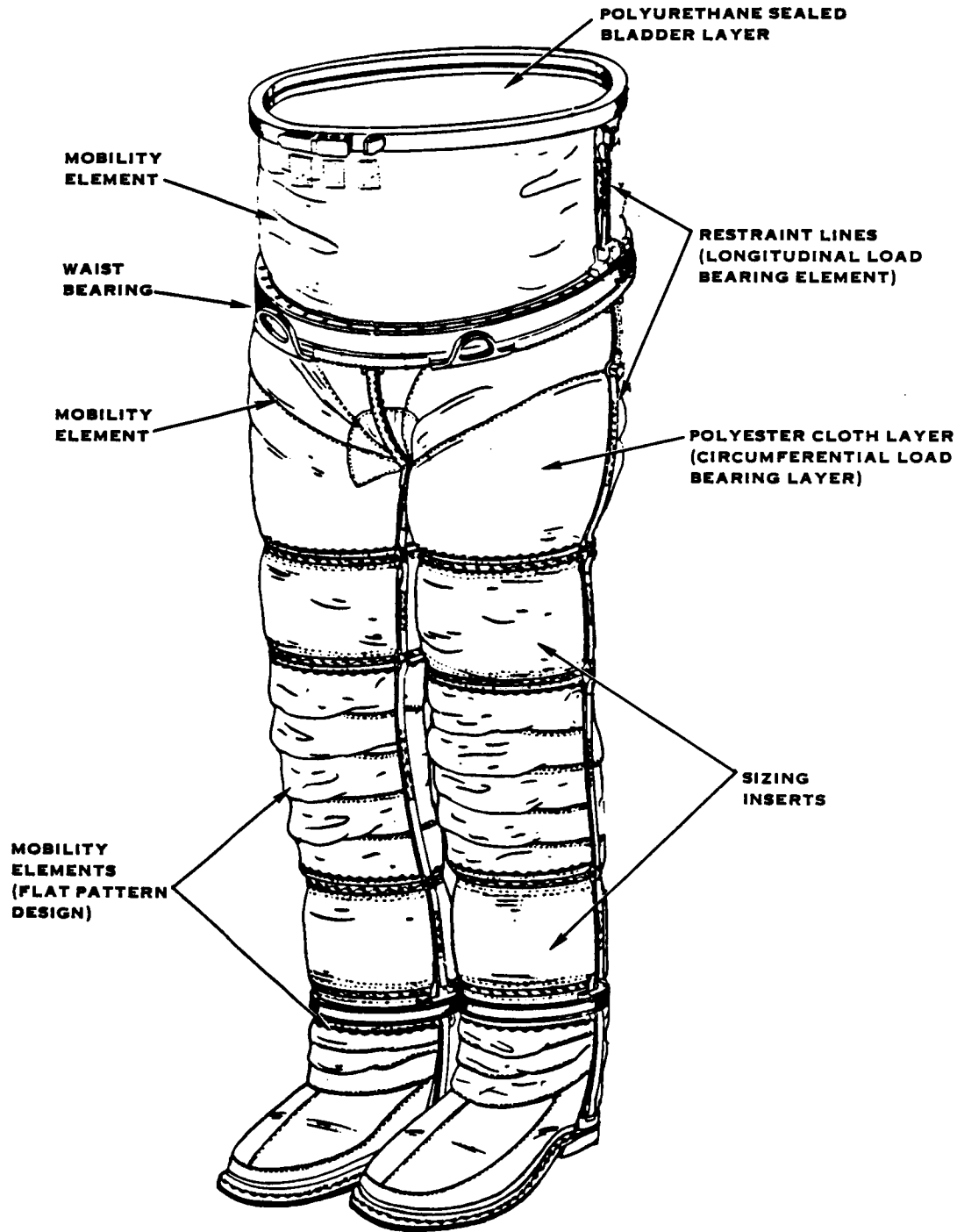SIZING
INSERTS

MOBILITY
ELEMENTS
(FLAT PATTERN
DESIGN)

FIGURE 3.

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Thermal & Micrometeriod Protection

All elements of the EMU are covered with a thermal/micrometeriod garment (TMG) which consists of 5 layers of reinforced aluminized mylar (Figure 4). This type of insulation is a function of operating environment. This insulation limits the EMU heat leaks into or out of the EMU to 330 Btu/hr, whether in full sun or deep space shadow. The outer layer is ortho fabric (expanded teflon yarn surface weave with a nomex/kevlar weave sublayer) and acts as an abrasion resistant layer. These layers provide effective solar radiation protection for the crewperson except for face and eyes. The Extravehicular Visor Assembly (EVVA) provides movable shades to allow eye and face protection from solar glare (Figure 2).

Ventilation Gas Distribution

To assure adequate removal of exhaled gases from the crewpersons oral/nasal area, the LSS provides a minimum rate of 6 ft^3/min of ventilation flow. This fresh incoming gas is directed over and around the crewpersons head by the helmet vent pad (Figure 2). The flow around the crewperson's head directs exhaled gasses to the neck area, where the flow goes between the suit inner layer and the crewperson providing the additional benefit of some cooling and removal of sweat. The flow goes to the hands and feet where it is picked up by a ventilation duct, which is part of the liquid cooling/vent garment (LCVG) (Figure 5). The flow is gathered together in a manifold and returned to the Life Support System.

Metabolic Heat Removal

Although this gas flow distribution does provide the crewperson with some cooling - the majority of the cooling is provided by a liquid transport loop which is also part of the LCVG. This loop consists of four parallel paths of small plastic tubing sewn into a full body garment which gently presses the tubes next to the crewpersons skin. As cool water flows through the tubes, it is warmed by the crewperson's metabolic heat. This warmed water is returned to the LSS where it is cooled and returned to repeat the process.

Communications Interface

To allow a redundant communications interface, the crewperson wears a cap (Figure 2) which contains two microphones and two earphones. This unit is called the Communications Carrier Assembly (CCA) and it connects electrically via the HUT to the radio located in the Primary Life Support Subsystem (PLSS) by way of an electrical cable.
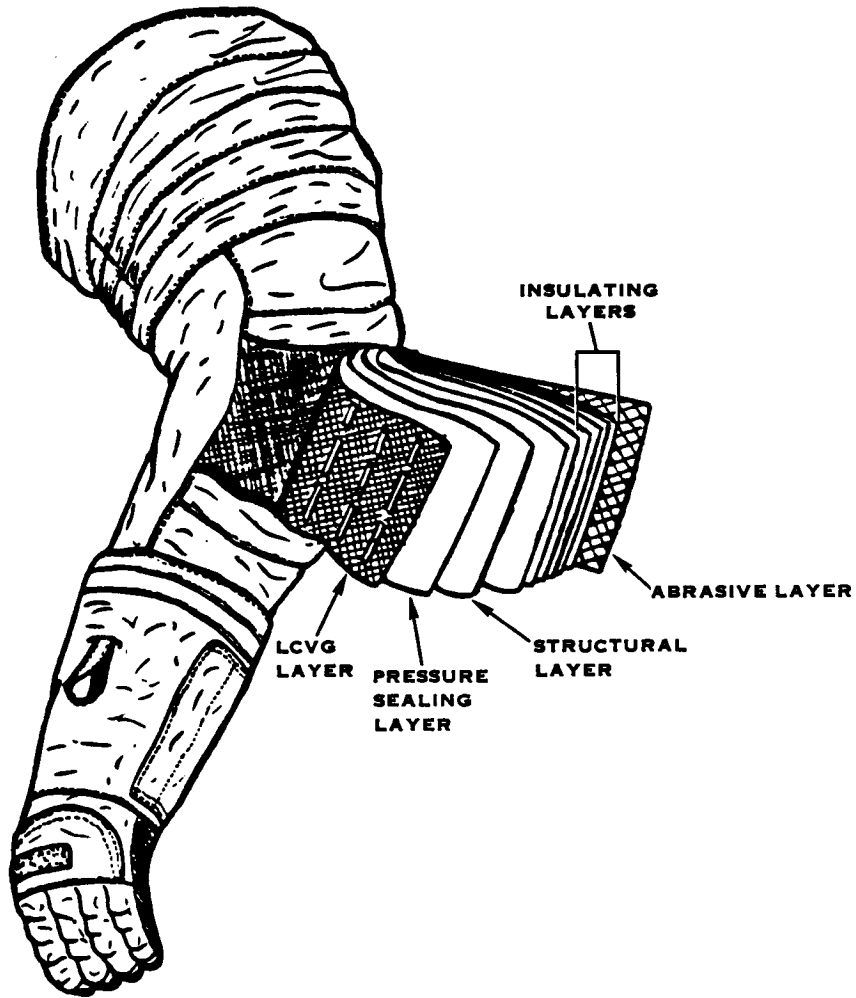
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INSULATING
LAYERS

ABRASIVE LAYER

STRUCTURAL
LAYER

LCVG
LAYER PRESSURE
SEALING
LAYER

FIGURE 4.

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HAND/VENT DUCT

VENT TUBE TUNNEL

VENT PLENUM

WATER MANIFOLD FITTING ASSEMBLY

CHIFFON LINER

LIQUID TRANSPORT TUBES WOVEN INTO GARMENT ASSEMBLY
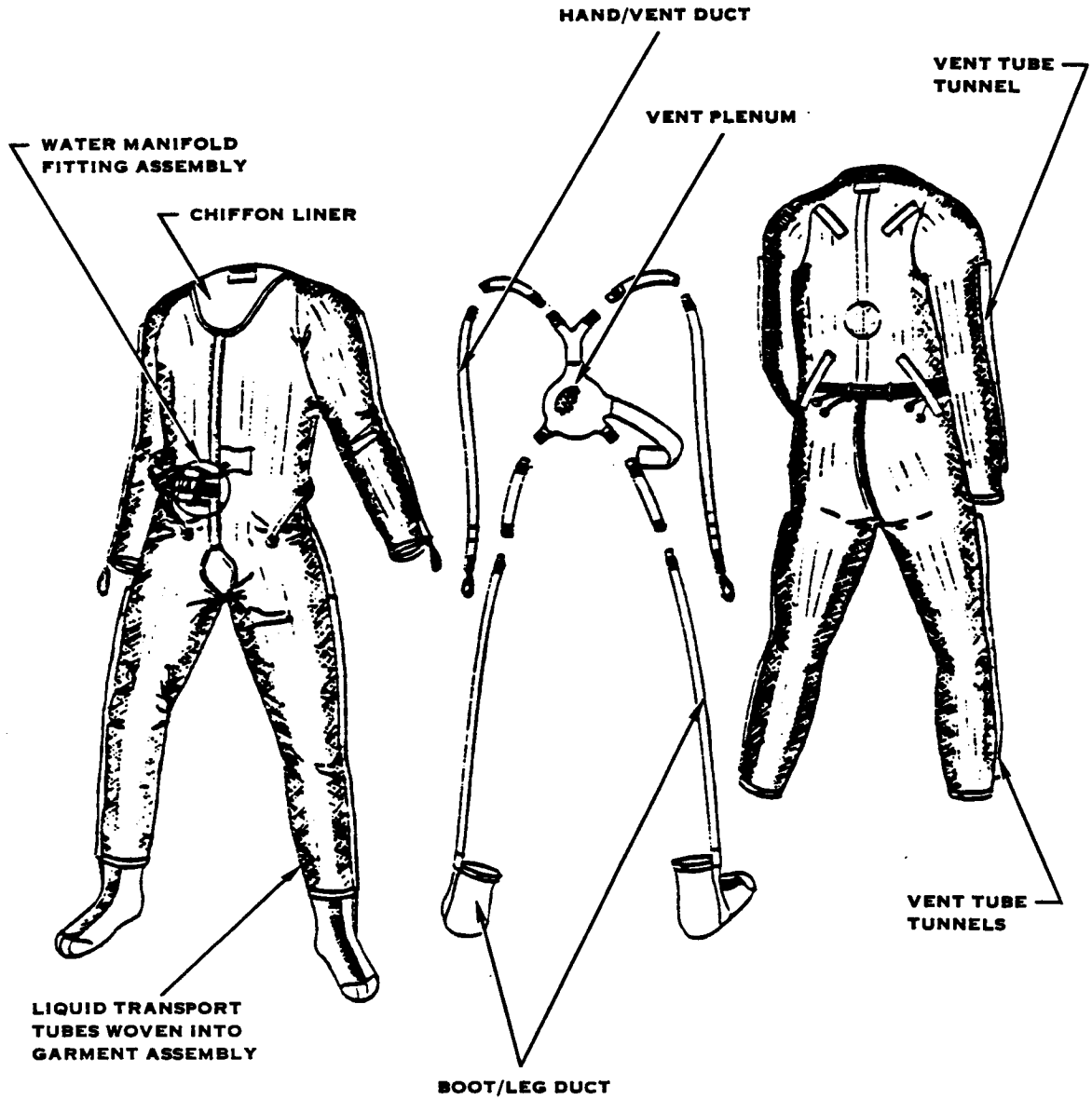
BOOT/LEG DUCT

VENT TUBE TUNNELS

FIGURE 5. LIQUID COOLING VENT GARMENT (LCVG)

Food & Drink

The crewperson may take a drink from the Insuit Drink Bag which is a urethane film bag RF heat sealed together in the shape of the volume available in the front of the HUT (Figure 6). The bag contains a valve which is activated by a sucking motion so the crewperson obtains a drink as if he were using a straw. The valve precludes spillage caused by pressing on the bag. The bag is attached by velcro into the front of the HUT so the drink tube is easily available. Additionally, a food stick is located between the IDB and the HUT. The food stick is in a paper sheath which allows the crewperson to grip it with his teeth and pull it up and take a bite.

Waste Control

Liquid waste is collected in a urethane coated nylon bag which is worn by the crewman under the LCVG (Figure 2). Females wear a disposable containment device which collects liquid waste in a super absorbent material.

Hopefully this gives you an idea of what it means to get dressed to go to work in space. To maintain life in the vacuum environment of space is the job of the LSS which will be described next.

LIFE SUPPORT SUBSYSTEM

The Life Support Subsystem (LSS) supplies a pressurized flow of breathable ventilation gas to the helmet inlet and removes the metabolic heat from the liquid cooling loop of the LCVG. Functionally, the LSS is very simple. It consists of two separate closed flow loops which are interconnected in order to maintain fluid phase separation. The two main loops are the ventilation loop and the liquid cooling loop. Both loops have make up supplies in order to maintain their operating pressures at the prescribed levels (Figure 7).

Ventilation Loop

The ventilation loop receives warm, moist oxygen and exhalation products (mostly CO_2) from the SSA and directs it to the Contaminant Control Cartridge (CCC) (Figure 8). This gas is filtered by a layer of nomex felt and directed into a bed of Lithium Hydroxide. The carbon dioxide reacts with the Lithium Hydroxide (LiOH) to form Lithium carbonate. This process also adds heat and moisture to the flowing gas stream. Activated charcoal follows the LiOH bed and removes trace contaminants and odors. Finally, the gas passes through an exit nomex felt filter which precludes the migration of LiOH particles.
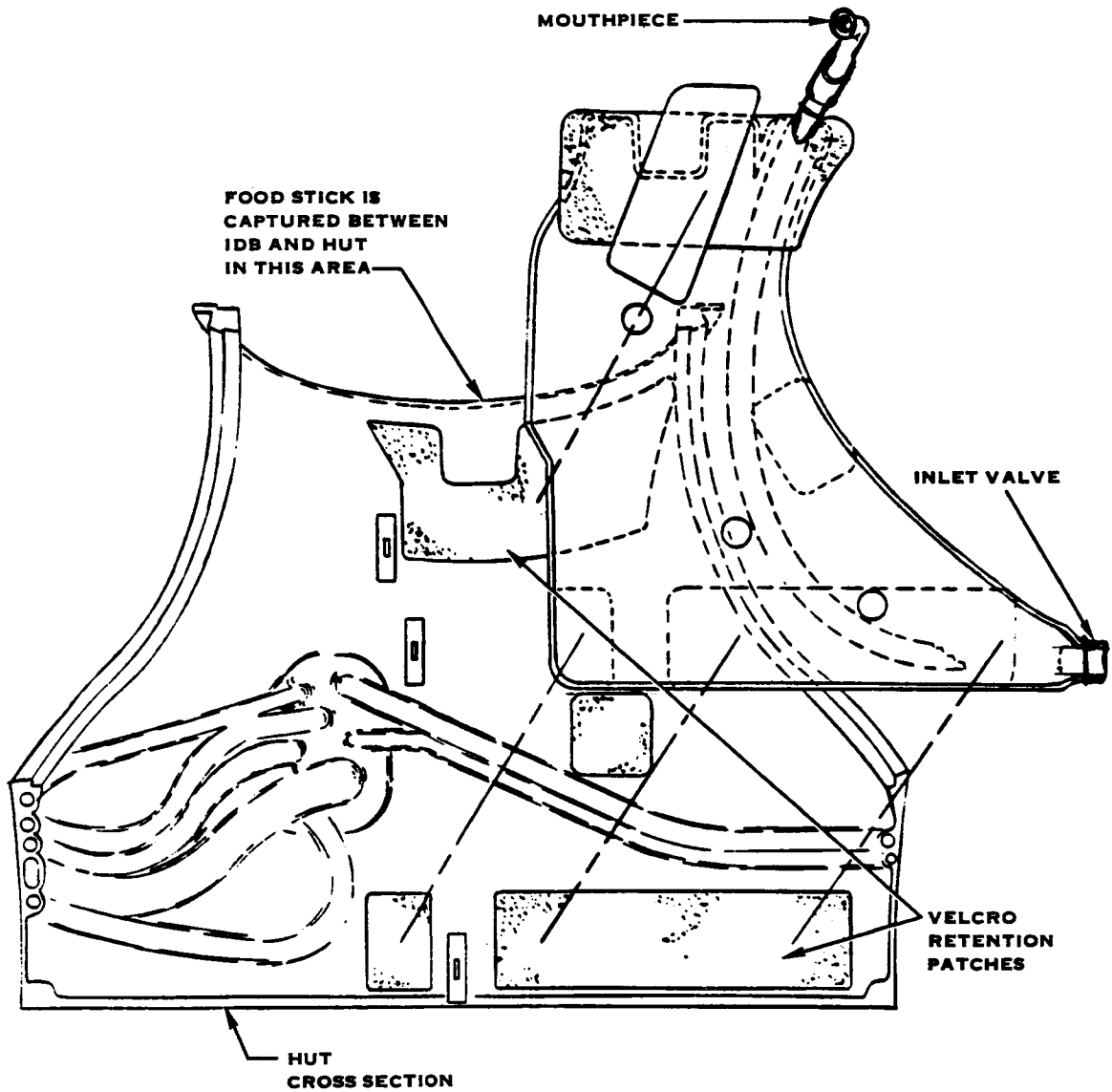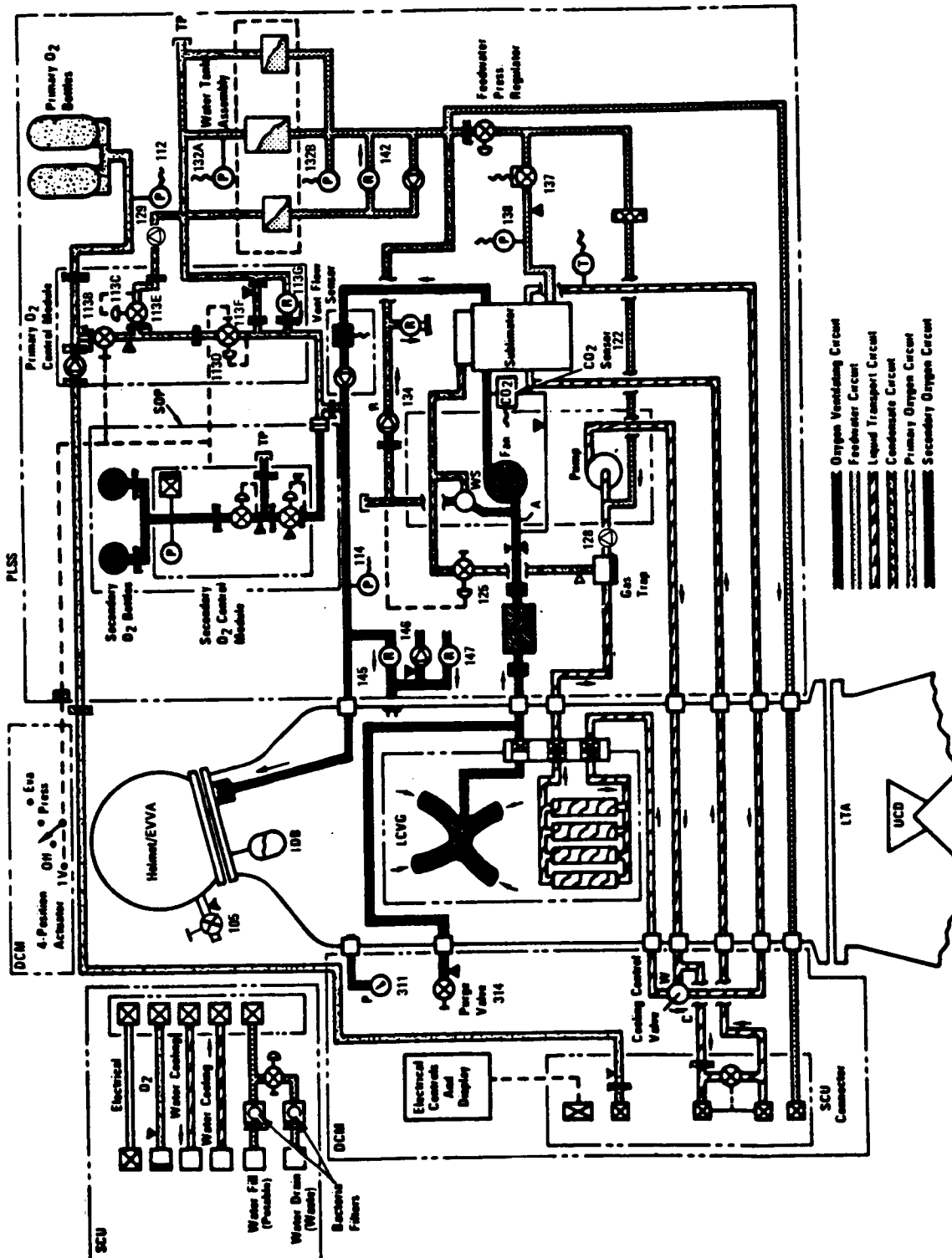
MOUTHPIECE

FOOD STICK IS
CAPTURED BETWEEN
IDB AND HUT
IN THIS AREA

INLET VALVE

VELCRO
RETENTION
PATCHES

HUT
CROSS SECTION

FIGURE 6. INSUIT DRINK BAG

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FIGURE 7 SPACE SHUTTLE EXTRAVEHICULAR MOBILITY UNIT SCHEMATIC

$O_2 + CO_2$ IN

OUTLET HEADER

O_2 OUT   PARTICULATE
FILTER

TEFLON
SCREEN

PERFORATED
PLATE

CHARCOAL BED

LiOH BED

COVER
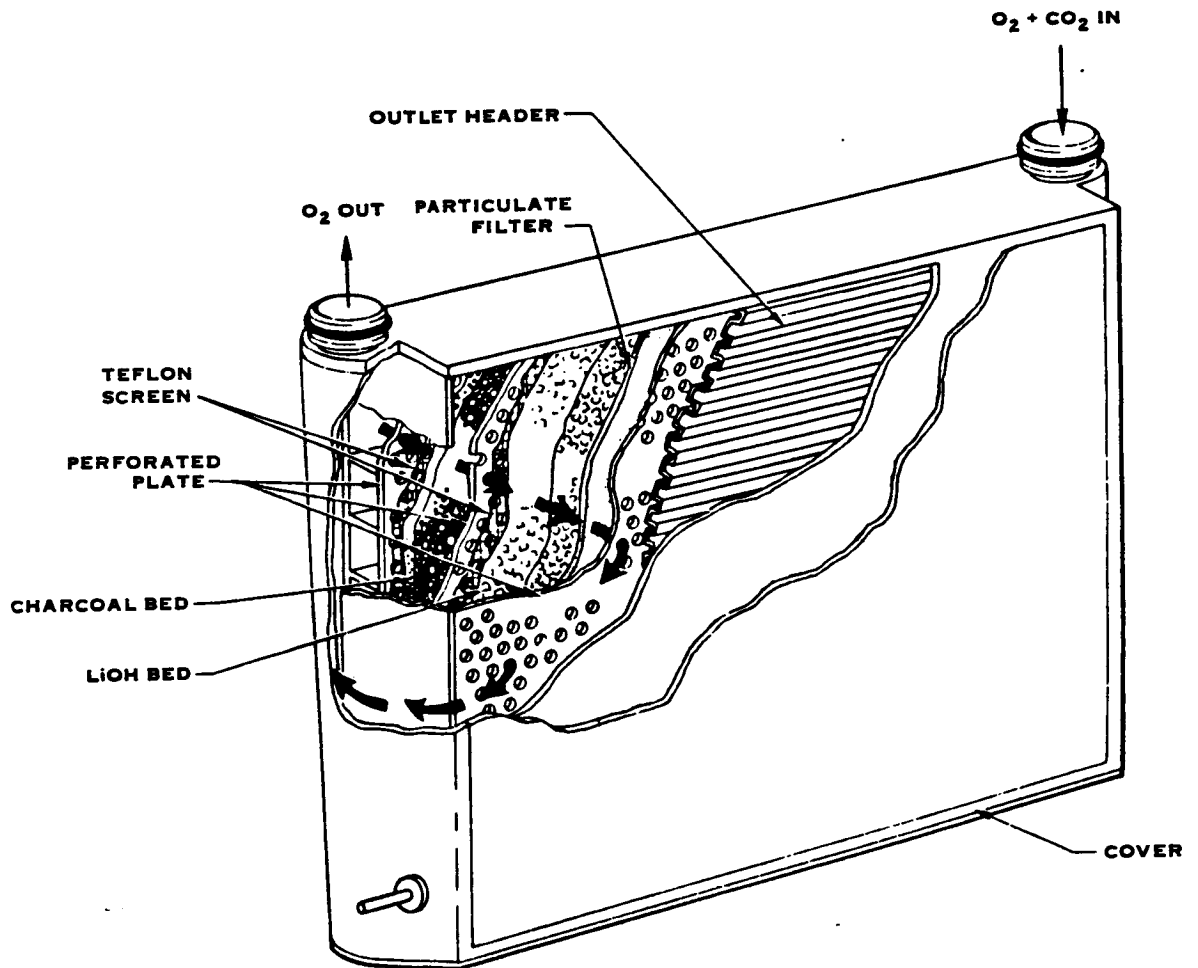
FIGURE 8. CONTAMINANT CONTROL CARTRIDGE

The ventilation gas then flows from the CCC into the fan (Figure 9) which maintains the flow velocity. The fan provides a minimum of 3 in of H_2O pressure rise. The fan is driven by a Hall sensor commutated DC motor at 19,000 rpm. The motor draws 2.3 amps at 16.3 volts. The fan directs the flow into the sublimator. The sublimator is the heat sink for the entire EMU. In the sublimator, the ventilation gas is cooled and the moisture it contains is condensed. The outlet dry bulb and dewpoint of the gas leaving the sublimator is about 55°F.

The condensed moisture is removed from the sublimator ventilation passages through a series of holes located at the end of the cooling fins. This is called a slurper (Figure 10). The driving potential for this flow is the delta pressure across the fan because the slurper header is connected to the fan inlet. This allows a small percentage of the gas flow to be used to carry the condensed moisture to the water separator (Figure 8). At the water separator, the mixture of gas and water is forced to impinge on a rotating drum. The drum is mounted to the fan shaft and receives its driving power from the same motor as the fan. The drum is shaped so that the rotation causes the water to flow into a trough where it (by now rotating at the same speed as the drum) impinges on a stationary pitot tube. This arrangement pumps the water pressure up to the 15 psi required to flow past the back flow check valve (item 134, Figure 7) and into the water reservoir. Thus the condensate removal process is a two-stage phase separation process which begins in the sublimator and is completed at the water separator, where the water is pumped to the storage tank and the gas used to carry the water from the sublimator is returned to the ventilation loop.

After the ventilation flow leaves the sublimator it goes through a ventilation flow sensor (which also acts as a backflow check valve), and past the makeup supply inlet. A differential pressure sensor (Item 114, Figure 7) and a CO_2 sensor (Item 122, Figure 7) measure suit to ambient differential pressure and the partial pressure of CO_2 just prior to the ventilation flow reentering the SSA at the helmet inlet. A mechanical gage backup to the pressure transducer (Item 311, Figure 7) is placed on the display panel in front of the crewperson.

The makeup supply of the ventilation loop comes from the primary O_2 bottles which hold 1.2 lbm usable oxygen at 850 psi for the 7-hour EVA mission. This oxygen flows from the bottles into the primary oxygen control module which contains a flow limiting orifice (Item 113B, Figure 7), a shutoff valve (Item 113C, Figure 7) and a single stage demand regulator (Item 113D, Figure 7). This regulator maintains the ventilation loop (including the SSA) at a pressure of 4.3 psi above ambient pressure. A pressure transducer, (Item 112, Figure 7) is used to keep track of remaining oxygen.

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ROTOR

PUMP OUTLET

PUMP IMPELLER

PUMP INLET

PUMP DIFFUSER

H_2O PUMP

MAGNETIC COUPLING

MOTOR ELECTRONICS

HALL SENSOR

SENSOR ADJUST MECHANISM

STATOR

HALL EFFECT MOTOR

FAN VOLUTE

FAN ROTOR

H_2O SEPARATOR DRUM
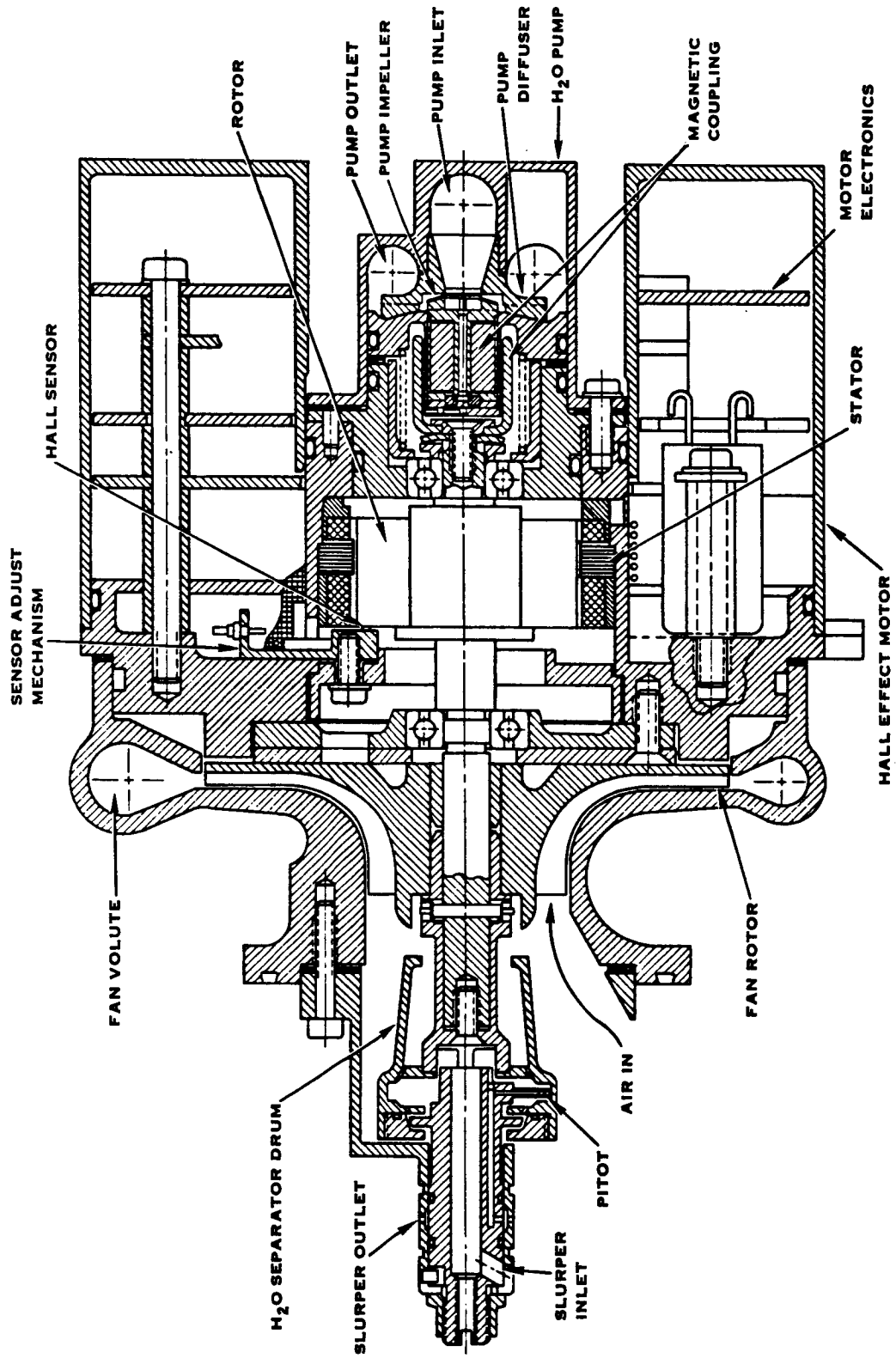
SLURPER OUTLET

PITOT

AIR IN

SLURPER INLET

FIGURE 9. FAN, MOTOR, WATER SEPARATOR AND PUMP ASSEMBLY

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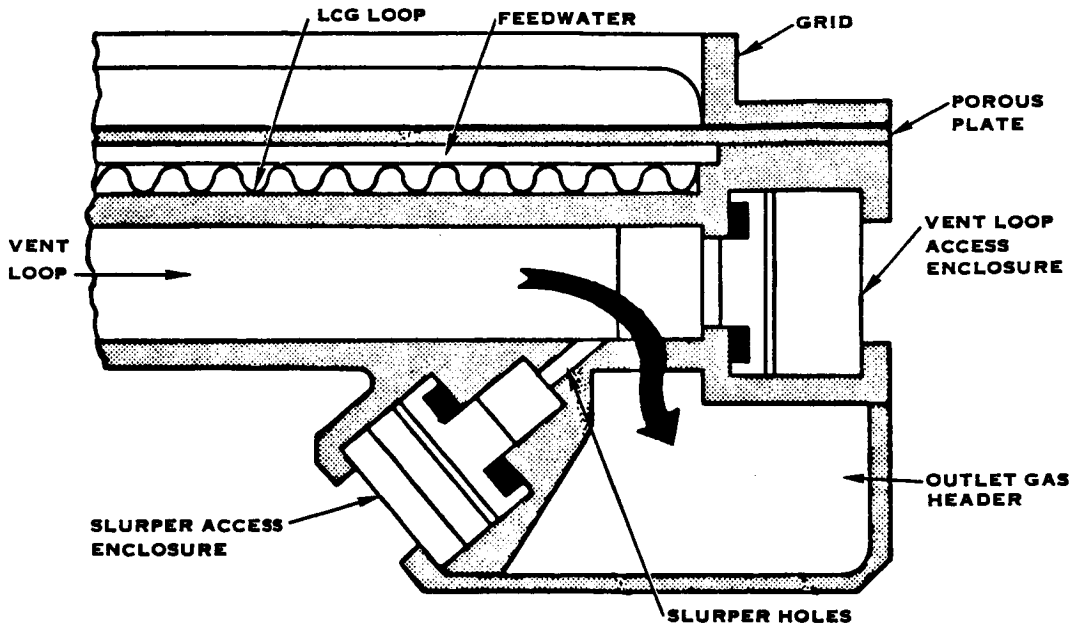
FIGURE 10. SLURPER CONFIGURATION

Liquid Cooling Loop

The liquid cooling loop receives warm water from the LCVG and directs it into a gas trap to remove any gas bubbles. The gas trap separates gas from the liquid cooling loop by means of a hydrophilic (water loving) screen. The screen is a fine mesh and since it is hydrophilic requires more pressure than is available for gas bubbles to go pass but very little pressure drop for water to go through it. The collected gas is continuously bled off through an orifice which controls the flow rate of water to be carried out of the gas trap when no gas is present. The mixture of gas and water then goes past an isolation valve Item 125, Figure 7 which is used to isolate the liquid cooling loop from the ventilation loop when the water separator is not open and flows into the water separator for the final stage of phase separation.

Returning from this subloop to the main liquid cooling loop, the water flow goes from the gas trap through a back flow check valve (Item 128, Figure 7), past the makeup inlet and into the pump (Figure 9). The pump is a centrifugal type (Barske to be specific) which is connected to the fan motor shaft by a magnetic coupling. The pump operates at fan speed (19,000 rpm) and flows 240 lbm/hr of water at a pressure rise of 4.8 psi. From the pump, the flow goes toward the cooling control valve. Along the way, the flow is split into two parallel paths. Part of the flow goes to the sublimator to be cooled and the remainder continues on to the cooling control valve. The continuing flow has been warmed by the crewman and so constitutes a warm water input to the cooling control valve. The part that has gone to the sublimator constitutes a cold water input. These two inputs are mixed in the cooling control valve to obtain a comfortable temperature and returned to the LCVG to remove the crewpersons metabolic heat. The cooling control valve is manually operated by the crewperson.

The makeup water which is used to maintain liquid cooling loop pressure comes from the water tank assembly. The water tank assembly consists of three tanks, two of which are connected together. The third tank is connected to the others through a relief valve (Item 142, Figure 7) which assures the third tank is the last one to be used. To drive the water out of the tanks, a soft neoprene rubber bladder is pressurized with oxygen from the primary oxygen bottles through a 15 psid demand regulator (Item 113F, Figure 7). This pressurant gas is supplied through a back flow check valve (Item 129, Figure 7) to the tanks. But, since the flow rate of pressurant needed is very small, the regulator would tend to cycle from closed to open and back again causing unwanted pressure variations. To keep this from happening, a constant demand is placed on the regulator through an orifice (Item 113F, Figure 7). To preclude water tank overpressurization in the event of a failed open regulator, a relief valve (Item 113G) has been included. There is also a pressure transucer (Item 132A, Figure 7) to monitor pressurant gas pressure. A similar transducer (Item 132B, Figure 7) is used to monitor the pressure of the water in the tanks. When these pressures are different by the 4 psid setting of the water tank isolation relief valve (Item 142, Figure 7) the crewperson is given a warning that there is only 1/2 hour of water supply left.

The makeup water supply comes to the liquid cooling loop from the water tanks and is also pressurized to 15 psid. Water leaves the liquid cooling loop at the gas trap to carry gas to the water separator. But after the water separator has completed the phase separation process, it returns the water to the water tanks. So, on an average basis, the liquid cooling loop is not a consumer of water and the water tanks acts only as an accumulator to maintain the pressure in the liquid cooling loop at a constant value. This completes the description of the Liquid Cooling Loop along with its makeup water supply. The interconnection between the ventilation loop and the liquid cooling loop has been described in order to define the fluid interfaces. Left undescribed in this section is the water consuming device, the water sublimator, and its associated hardware.

Feedwater Loop

The sublimator is supplied from the water tanks through a regulator which regulates the pressure to 2.9 psid. The flow then goes past a shutoff valve (Item 137, Figure 7) and a pressure transducer (Item 138, Figure 7) to the sublimator (Figure 11). The sublimator is a stack up of heat exchangers where the ventilation loop is cooled by the liquid cooling loop and the liquid cooling loop is cooled by the sublimation process which works as follows. Water enters from the feedwater supply and flows down the feedwater distribution channel. From there it spreads out under the porous plate and turns to go through the plate out to the vacuum which is on the outlet of the plate. But as the water pressure drops below the triple point pressure the water freezes to an ice layer in the plate. Heat is added to this ice from the flow loops and it sublimes away (i.e. goes from the solid to gas phase without again becoming liquid) into the vacuum, carrying with it the heat. If the ice layer is sublimed away completely, the feedwater again starts up toward the vacuum and is frozen forming a new ice layer. In this manner, the sublimator is a self-regulating, demand heat rejection device with a near constant heat sink temperature of about 32°F. The flow rate of steam to the vacuum is dependant on metabolic rate, equipment heat load, and heat leak into the suit. For the Shuttle LSS with a 330 Btu/hr heat leak (maximum) the steam output rate is

$$W = (M/1027) + 0.75$$

where W = water use rate   lbm/hr
       M = metabolic rate   Btu/hr
          (300 - 2,000 Btu/hr range with
          1,000 Btu/hr average over 7 hours)

This completes the functional description of the Life Support System for normal operations.

The rest of the items seen on the schematic (Figure 7) are associated with the caution and warning system or are there to handle either emergency situations or to accomplish recharge between EVA's. For recharge, the service and cooling umbilical (SCU) connects the EMU to the vehicle from which water and oxygen are received to refill the respective tanks. Power is also received to recharge the silver-zinc battery. The CCC is removed and replaced with a fresh cartridge.

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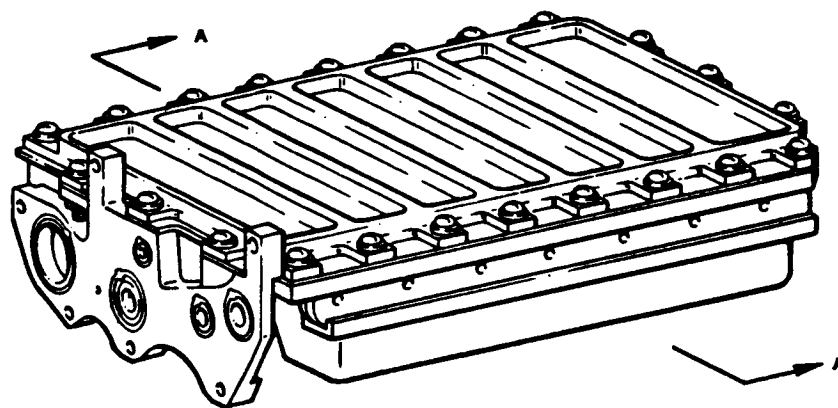OF POOR QUALITY
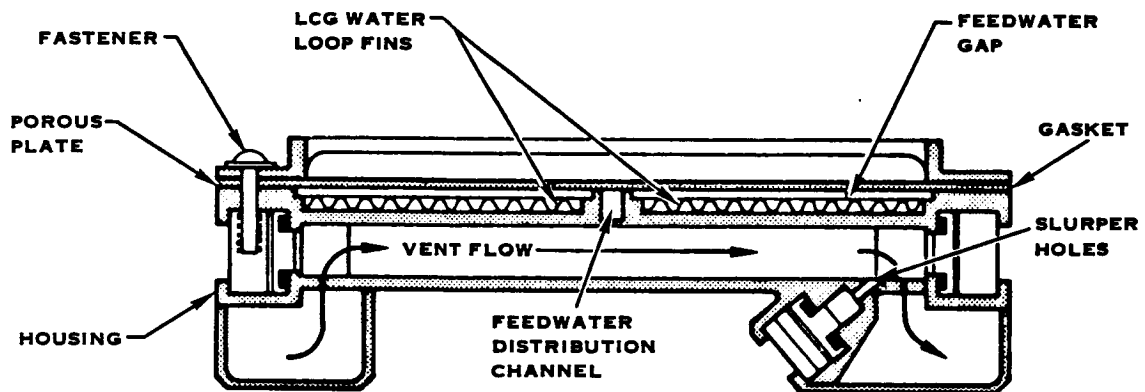
SECTION A-A

FIGURE 11. SUBLIMATOR

The warning system takes inputs from all of the instrumentation shown and provides the crewperson warnings when an expendable is within 1/2 hour of being expended and also indicates any malfunction. Displays are located on the Display and Control Module (DCM). The DCM also contains all of the controls necessary to operate the LSS. Included are relief valves (Items 134, 145, 146 and 147) to preclude any overpressure situations from damaging any of the LSS hardware as well.

In the event of primary life support subsystem (PLSS) malfunction the secondary oxygen pack (SOP) provides a 1/2 hr supply of oxygen which can be directed over the crewpersons face and exhausted to space through either the DCM located purge valve (Item 314, Figure 7) or the redundant helmet located purge valve (Item 105, Figure 7). This flow provides some cooling and carbon dioxide washout as well as suit pressurization, thereby allowing the crewperson to make an emergency return to the airlock.

Payload Interface[1]

Now that the reader is well on his way to being an EMU engineer, its time to turn our attention to alterations of the free space environment generated by the EMU. These alterations fall into two categories: (1) the nominal alterations and (2) those associated with EMU contingency operations. The latter are normally limited to 1/2 hour duration and the larger frustration associated with that situation will probably be loss of EVA capability.

The sources of environment altering products for EMU are:

1) Water vapor from the heat rejection system

2) EMU leakage which includes water vapor, gases (i.e., O_2, CO_2) and trace organics.

3) Particles from EMU surfaces. (0.5 to 500 micron dust, lint, and metal)

The first of these was discussed earlier and for a nominal metabolic rate of 1000 Btu/hr which results in a steam production rate of 1.68 lbm/hr. Water vapor from leakage is estimated to be 5.4×10^{-4} lbm/hr. The rates for gases and organics are estimated to be 0.016 lbm/hr and 9.5×10^{-6} lbm/hr respectively.

Particles

The amount of particle disposition is unknown but the EMU particle generation surface area is 1/500 of the Shuttle so the EMU will not alter the environment when near the Shuttle vehicle.

(1) The authors are indepted to Mr. S. Martin NASA/JSC for use of the payload interface material.

TABLE III

LOCAL CONTAMINATION BY PARTICLES

Particle Size	Altitude	Estimated Time To Clear 40 ft Area
5 micron	100 nm	1.8 sec.
100 micron	100 nm	7.8 sec.
5 micron	300 nm	50 sec.
100 micron	300 nm	181 sec.

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TABLE IV

SCATTERING, ABSORBTION AND EMISSION

BY PARTICLES WITHIN ORBITER WAKE

Particle Size	Altitude	Estimated Time To Sweep over Horizon
5 micron	100 nm	15 min.
100 micron	100 nm	66 min.
5 micron	300 nm	9.4 hrs.
100 micron	300 nm	34.4 hrs.

Water Vapor

Water vapor freezing on cold surfaces obscures sensors. This type of contamination is dependent on sensor surface temperature, distance from water source to sensor, and water flow rate. Water contamination can occur on a surface which is below 150°K and occurs within fractions of a second. Therefore, any payload with optical systems colder than 150°K must be shielded or suffer the effects of permanant water contamination (again the majority from the Orbiter as well as EMU unless Orbiter H_2O dumps are specifically controlled).

For average metabolic rate (1000 Btu/hr), history and analysis indicate that the EMU steam cloud dissipates within 3 feet of the PLSS. This is an upper limit with envelope size being a function of heat rejection rate.

The only guaranteed method of insuring near zero steam contamination is in removing the water sublimator loop and providing thermal control via either an umbilical or heat transfer device. The umbilical, while apparently a simple solution, proves unattractive due to the management problem associated in zero gravity. Considering that in many instances the EVA crewmember will be required to transverse a distance of many meters, the umbilical becomes impractical in length due to the possibility of snag and eventual puncture. In addition, for distances greater than a few meters the umbilical becomes cumbersome and difficult to manage.

EMU Leakage

Since the bulk of the gases have low condensation temperatures (CO_2 167°K, N_2 90°K, and O_2 77°K) they present no problem on uncooled sensors. For cooled sensors the primary problem is water condensation.

EVA Crewmember Safety

Payload users have expressed concern for crewmember safety in areas of microwave radiation and ionizing radiation. Microwave radiation originates from the orbiter antennas, which produce a radiation beam. During flight the following antennas are active:

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S-Band (1.7 - 2.2 ghz)	Locations	Aperture	Power
Payload Bay (PLB)	Cabin Top	-	1 watt
Hemi	Cabin Top	1 - 3 in. rectangular cavity	10 watts
Hemi	Cabin Bottoms	1 - 3 in. rectangular cavity	10 watts
Quads - Phase Array Steerable	Cabin Sides	7 - 3 in. rectangular	50 watts & 5db within 5° of beam C/L

Ku-Band (15 ghz)

Tracking & Data Relay Satellite (TDRS)	Forward PLB Bulkhead	36 in. dish	30 watts & 38 db within 1.5° of beam C/L

Human safety limits are: unlimited exposure to power densities below 10 mw/ cm^2, and exposure to less than 25 mw/cm^2 for up to 25 minutes. Thus, there is a minimum distance from the antennas which guarantees exposure to less than the safety limits. The minimum long term safe distances from the S-Band hemis, quads and Ku-Band and TDRS antennas are 4 in., 55 in., and 324 ft respectively considering near and far field effects.

A mission rule is in place that requires turning off nearby antennas during EVA. Discussion of microwave radiation safety procedures is planned to be addressed in the "Ionizing Radiation Evaluation Study". Payload designers may wish to contact Mr. M. Rodriquez of CSD for this information.

Ionizing Radiation

Planned or backup EVA in equatorial orbit will be timed to minimize exposure to the South Atlantic Anomaly (SSA), even though it may miss the highest energy portion of the SAA for approximately 18 out of every 24 hours. Timing in polar orbits is less practical because the orbiter will pass through the polar horns approximately every 15 to 30 minutes.

Other EMU Factors

The EMU is designed and has been tested to meet a requirement to operate in the presence of an RF field intensity of 1 volt/meter over the frequency range of 10 KHz to 10 GHz. The EMU does not present any EMI anomalies and is not foreseen to affect any payload electronics.

Payload Interfaces Summary

EMU environments can only be a problem to an uncovered sensor system and of such systems only cooled systems have a known definite problem. The significance of EVA contaminants compared to the Shuttle Orbiter is as follows:

°   Particulate generation surface area of EVA equipment   1/500 Shuttle

°   Water vapor from EVA equipment   1/30 Shuttle

°   EMU leakage gas   1/25 Shuttle cabin leakage

This shows any EMU contamination is negligible when compared to the contaminant envelope produced by the Shuttle Orbiter. Payload designers who are planning payloads sensitive to currently defined contamination levels should contact Mr. James Jaax of NASA/JSC Crew Systems Division for evaluation of requirements.

Supplemental EMU Capabilities

Analysis and tests have demonstrated that the present EMU is capable of performing the standard satellite servicing tasks (e.g. module replacement, appendage retraction, override of latches and release mechanisms). However, satellite servicing tasks need not be constrained by current capabilities, since the EMU is flexible enough to adjust to a myriad of satellite servicing operating conditions. R&D programs currently exist to demonstrate concepts for prebreathe elimination and water vapor venting elimination. The following paragraphs describe conditions and program status of each.

"No-Prebreathe" EMU

Early EVA planning for supporting STS flights and satellite servicing calls for conducting EVA at 4.0 psia from a 14.7 psia Shuttle Orbiter cabin. To preclude "the bends", a painful and potentially dangerous physiological condition, STS crewmembers prebreathe pure O_2 for 3 to 4 hours to purge body tissues of dissolved N_2, the prime constituent of bends bubbles. However, prebreathing has several drawbacks: the crew considers the Portable Oxygen System (POS) restrictive to intravehicular activity (IVA), and denitrogenation effectiveness can be significantly reduced during EMU donning by inadvertently taking just one or two breaths of air, increasing likelihood of bends considerably unless specific (and cumbersome) procedures are followed rigorously.

Planning for OFT side-steps prebreathing by requiring reduction of cabin pressure to 9 psia for approximately 12 hours prior to EVA, which promotes sufficient washout of dissolved gases from tissues to minimize likelihood of bends. This is not a permanent solution, because it does not address many Orbiter, payload, operational, and EVA issues relevant to both operational STS flights and satellite servicing.

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The present Shuttle EVA baseline combines use of a 10.4 psia cabin pressure with a 4.3 psia EMU to eliminate the POS and prebreathe. This status will not harm payloads or orbiter electronics, yet still requires that the cabin remain at 10.4 psia for 6 hours prior to EVA.

However, raising the EMU pressure to 8.0 psia will permit use of 14.7 psia cabin pressure even during EVA support. This would lift current constraints and resolve conflicts in assigning pressure sensitive payloads to flight with planned or backup EVA. An 8.0 psia EMU will provide mission flexibility as EVA events increase.

Additionally, an 8 psia EMU will provide "quick reaction" EVA and additional crewmember safety. NASA has been directing 8 psia soft goods assembly CR&D programs to provide alternates and evaluate technologies for the necessary SSA mobility for 8 psia.

Non-Venting Thermal Control Subsystems

The only significant alteration of the free space environment caused by the EMU is due to the venting of the steam used for cooling. Specifics concerning water contamination have already been described in the payload interface section. NASA has conducted many programs to develop non-venting thermal control subsystems, with the most recent being an on-going program to provide a 4-hour non-venting thermal control subsystem. This regenerative system will have the dual benefit of eliminating potential payload EMU H_2O contamination and reduce the expendable mass required by the EMU system.

Enhanced Glove Development

NASA is also developing technology which will significantly improve the mobility of the EMU glove. This effort comes from the realization that hand mobility is the key to effective EVA work.

Summary

The EMU will serve as an important tool for both planned and contingency EVA. The EMU is capable of performing the standard satellite servicing tasks (e.g., module replacement, appendage retraction, override of latches and release mechanisms). However, satellite servicing tasks need not be constrained by current capabilities, since the EMU is flexible enough to adjust to a myriad of satellite servicing operating conditions.

The technology used in the EMU system is by no means static. The technical solutions to manned utilization of space are dependent on the vehicle services available, the understanding of the needs, and the resources available. Payload designers in planning for satellite servicing should not presuppose EMU operating conditions and capabilities, but be advised to contact appropriate NASA personnel before solidifying payload design concepts. None of the technology elements of the EMU are static and continued refinement of EMU technology shall proceed in concurrence with satellite servicing demands.