Although the velocity range considered was small, significant changes in the radiation were observed as velocity was varied. Correlations of the results were attempted in the manner suggested by the equations given previously. It was determined that the results could be well represented in that form. However, in contrast to the correlation with the other parameters in which single values of a, b, and c represented each velocity and location and both the heating rate and total heating, separate values of d for each location and both heating rate and total heating were necessary to correlate the velocity-dependent calculations. These four values and the resulting constants are

$$C_o = 6.17 \times 10^{-26} \qquad K_o = 1.09 \times 10^{-18}$$
$$d = 23.1 \qquad d = 17.2$$
$$C_c = 3.04 \times 10^{-15} \qquad K_c = 1.06 \times 10^{-16}$$
$$d = 13.2 \qquad d = 15.6$$

This necessity for different values of d is not surprising considering the diverse radiative processes occurring during entry in a CO_2–N_2 atmosphere. As seen in Fig. 2 and described earlier, two basic regimes are encountered. As the entry velocity is increased, a larger contribution from the line and continuum processes is encountered. At the lower temperatures away from the stagnation point, the radiation from the molecular band systems remains of major importance to higher entry velocities. As might be expected, the exponents for the total heating for both body locations are nearly equal since the integration tends to average the contributions from the various radiative processes over each trajectory. Because of the extreme sensitivity to entry velocity, care should be taken in using the exponents d outside the velocity range from which they were derived.

The radiative heating results from a series of Venus entry heating calculations have been correlated in terms of the usual trajectory and geometry parameters. The radiation calculation technique employed is an uncoupled one which allows economical consideration of a large number of cases, while still providing reasonable agreement with results of a more elaborate procedure. Within the admittedly small entry velocity range considered, the maximum heating rate and total heating at the stagnation point and at an off-stagnation location were correlated successfully. Single exponents for all velocities represented the variations of nose radius, cone angle, ballistic coefficient, and entry angle. Separate velocity exponents were required for each location and for both heating rate and total heating. With few exceptions, the calculated values could be predicted within 10%. Perhaps the best use of these correlations would be to extrapolate to other shapes, ballistic coefficients, and entry angles from detailed trajectory calculations for one combination of these values at a given entry velocity.

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Shuttle Extra-Vehicular Life Support Equipment

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I. Introduction

THE primary objective of the Space Shuttle Program is to provide a new space transportation capability that will substantially reduce the cost of space operations and provide

Mission Duration	4 Hours
Metabolic loads	
• Average	1000 Btu/hr
• Minimum	400 Btu/hr
• Peak	1600 Btu/hr
O_2 Supply	1.04 lbs
Pressure Control	8.2 ± 0.2 psi
CO_2 Control	7.6 mm Hg maximum
Contaminant Control • Particulate	Debris trap/filter
Thermal Control	
• Heat Loads	1921 Btu/hr average 2559 Btu/hr peak
• Mode of Cooling	Liquid Cooling
• Temperature Control	Manual
Humidity Control	50°F dew point maximum
Ventilation	6 ACFM minimum
Power	220 watt-hours minimum
Communications	
• Primary	Duplex
• Backup	Simplex
Telemetry	As req'd for checkout prior to EVA and status monitoring during EVA
Life	
• Shelf	15 years
• Operational	6000 hours

Fig. 1 PLSS requirements.

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a future capability designed to support a wide range of scientific, defense, and commercial uses. An integral part of this future capability is man. Manned participation will certainly add new dimensions to the useful applications of space technology. EVA operations are a key element of manned participation in the Space Shuttle program. Hamilton Standard, under NASA Contract NAS 9-12506, conducted the Shuttle EVA/IVA Support Requirements Study for the Lyndon B. Johnson Space Center. The primary objectives of the Shuttle EVA/IVA Support Requirements Study were to establish a baseline EVA/IVA approach for Space Shuttle operations and to prepare specific system requirements. This Note specifically addresses itself to the Primary Life Support System (PLSS).

II. PLSS Requirements

The primary functions of a PLSS are to condition and replenish the atmosphere inside the spacesuit and to cool the suited crewman during his EVA mission. In order to accomplish this, the PLSS must provide the basic life support functions of O_2 supply and pressurization, CO_2 control, contaminant control, thermal control, and humidity control.

Various candidate life support subsystem concepts to perform each of these functions were identified and evaluated to determine the most desirable approaches. The selected concepts were then carried into the system studies where the subsystem concepts were combined into various candidate system concepts. These efforts resulted in the definition of PLSS requirements presented in Fig. 1.

III. PLSS Configurations

As a result of the PLSS subsystems evaluation and selection effort, three candidate PLSS schematic configurations, each containing one of the competitive thermal control sybsystems, were generated.

The PLSS schematic with the flash evaporator option is depicted in Fig. 2 and consists of an oxygen ventilation loop, water heat transport loop, flash evaporator subsystem, high-pressure O_2 subsystem, power supply, communications, remote control unit, and miscellaneous electronics.

The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit enters the atmosphere regeneration subsystem at the suit outlet gas connector (item 31) and first passes through the LiOH canister (item 22). The LiOH canister consists of an activated charcoal bed, an LiOH bed, and a depth filter. Odors and trace contaminants are removed through physical absorption by the activated charcoal bed. CO_2 is removed by chemical absorption utilizing dry LiOH. A depth filter provides dust control. The circulated O_2 then passes through the flash evaporator heat exchanger (item 18) where it is cooled and the entrained moisture is condensed. The cooled O_2 continues to the first stage of the water separator (item 20) where the condensed water and a small quantity of O_2 secondary flow is removed and transported to the second stage of the water separator (item 49). The condensed water is immobilized in a wick in the second stage and the O_2

ITEM	PART NAME
1	MULTIPLE H_2O FEMALE DISCONN
2	SUIT ELEC UMBILICAL
3	MULTIPLE H_2O MALE DISCONN
4	H_2O 'ΔT' TRANSDUCER
5	PUMP MOTOR ASSY
6	ACCUMULATOR
7	CHECK VALVE
8	SOLENOID
9	NOZZLE VALVE
10	TEMP SENSOR
11	S/O VALVE
12	RELIEF VALVE
13	CHECK VALVE
14	PRESS REG
15	FLOW LIMITER
16	H_2O RESERVOIR
17	FILL CONN
18	EVAPORATOR HX
19	DRAIN CONN
20	H_2O SEPARATOR' 1ST STAGE
21	TEMP TRANSDUCER
22	LIOH CANISTER
23	OXYGEN BOTTLE
24	O_2 FILL CONN
25	O_2 REG & S/O ASSY
27	PGA PRESS DIFF SWITCH
28	PGA PRESS DIFF TRANS
29	FAN/MOTOR ASSY
30	CHECK VALVE
31	O_2 CONNECTORS
32	POWER SUPPLY
33	CURRENT SENSOR
34	TERMINAL BOX
35	REMOTE CONTROL UNIT
36	ELECTRONIC CONTROLLER
37	COMMUNICATIONS
39	ORIFICE
40	H_2O CONN STOWAGE CAP
41	ANTENNA
42	GAS SEPARATOR
43	O_2 INLET CONN STOWAGE PLATE
44	O_2 OUTLET CONN STOWAGE PLATE
45	PLSS/PGA ELEC UMBILICAL STWG PLT
46	BATT CABLE STOWAGE PLATE
47	PRESSURE PORT
48	S/O VALVE, DOUBLE BANK
49	H_2O SEPARATOR, 2ND STAGE

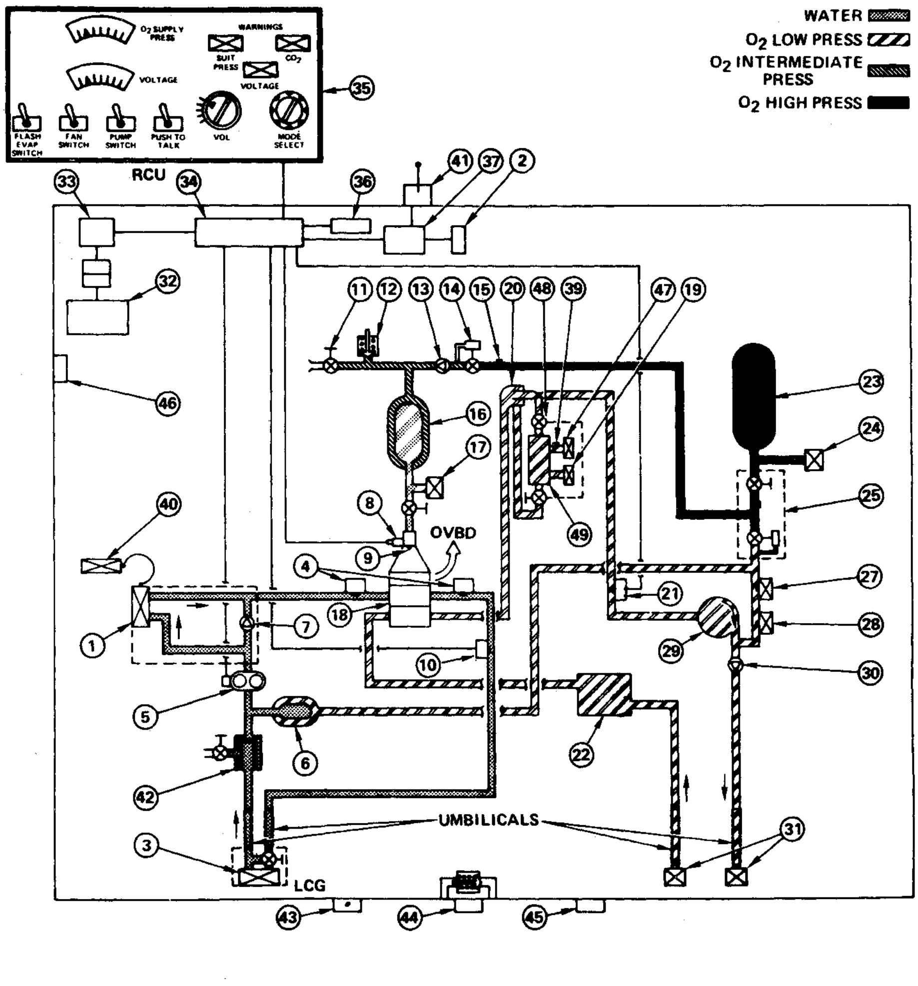

Fig. 2 PLSS schematic (flash evaporator option).

ITEM	PART NAME
1	MULTIPLE H_2O FEMALE DISCONN
2	SUIT ELEC UMBILICAL
3	MULTIPLE H_2O MALE DISCONN
4	H_2O ΔT TRANSDUCER
5	PUMP MOTOR ASSY
6	ACCUMULATOR
7	CHECK VALVE
17	FILL CONN
18	WATER BOILER
19	DRAIN CONN
20	H_2O SEPARATOR, 1ST STAGE
21	TEMP TRANSDUCER
22	LiOH CANISTER
23	OXYGEN BOTTLE
24	O_2 FILL CONN
25	O_2 REG & S/0 ASSY
27	PGA PRESS DIFF SWITCH
28	PGA PRESS DIFF TRANS
29	FAN/MOTOR ASSY
30	CHECK VALVE
31	O_2 CONNECTORS
32	POWER SUPPLY
33	CURRENT SENSOR
34	TERMINAL BOX
35	REMOTE CONTROL UNIT
37	COMMUNICATIONS
39	ORIFICE
40	H_2O CONN STOWAGE CAP
41	ANTENNA
42	GAS SEPARATOR
43	O_2 INLET CONN STOWAGE PLATE
44	O_2 OUTLET CONN STOWAGE PLATE
45	PLSS/PGA ELEC UMBILICAL STWG PLT
46	BATT CABLE STOWAGE PLATE
47	PRESSURE PORT
48	S/0 VALVE, DOUBLE BANK
49	H_2O SEPARATOR, 2ND STAGE

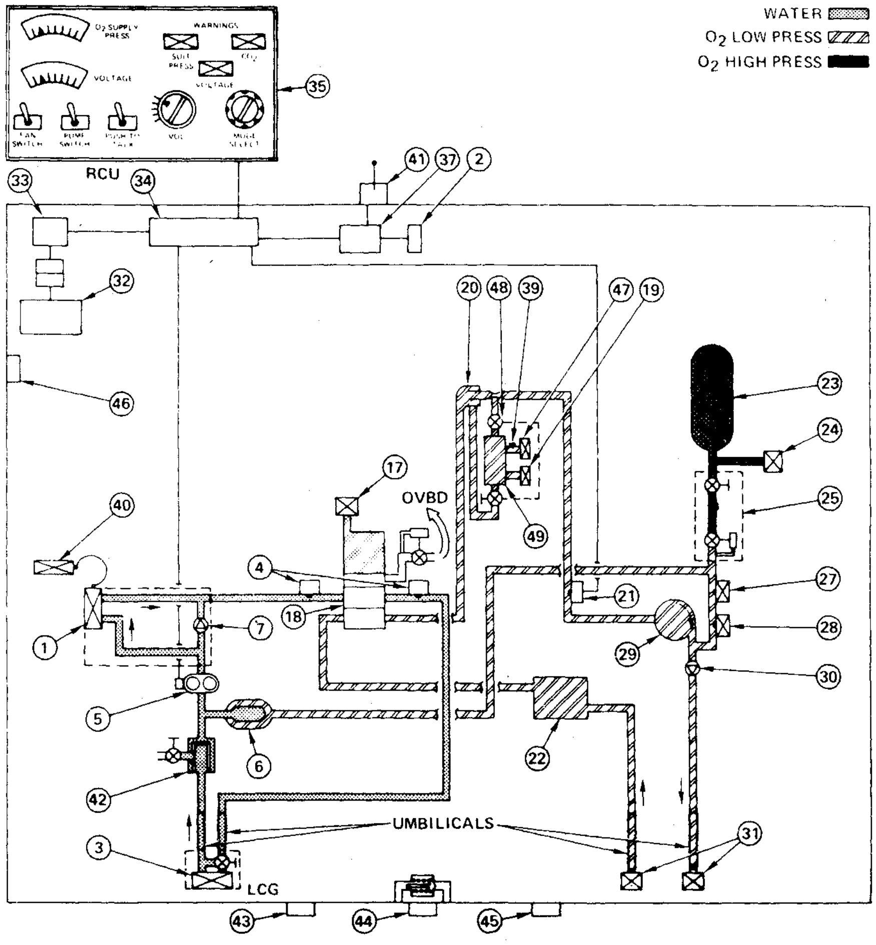

Fig. 3 PLSS schematic (water boiler option).

secondary flow is returned to the main gas stream at the venturi which provides the pressure differential necessary to split the flow between the main and secondary gas streams. The cool, dry O_2 then passes to the fan (item 29) which circulates a ventilation flow of six (6) acfm to the suit and superheats the gas stream above the dew point to prevent visor fogging.

The high-pressure O_2 subsystem contains 1.04 lb of usable O_2 at 900 psia and regulates the pressure in the O_2 ventilation loop to 8.2 ± 0.2 psia downstream of the fan. This subsystem consists of an O_2 bottle (item 23), fill fitting (item 24), shutoff valve, flow limiting orifice and pressure regulator assembly (item 25), and pressure sensors (items 27 and 28). Additionally, this subsystem provides pressurization for the flash evaporator subsystem (to be discussed later) and the liquid heat transport loop via the bladder tank accumulator (item 6).

The water heat transport loop cools the suited crewman by supplying and circulating cool water through the crewman's LCG. There are two modes of operation: active PLSS thermal control and umbilical operation.

During the active PLSS thermal control mode, the flash evaporator subsystem provides thermal control for both the O_2 ventilation loop and the liquid heat transport loop in the three fluid evaporative heat exchanger (item 18). The water connector stowage cap (item 40) is stowed in the multiple H_2O female disconnect (item 1) to provide redundant sealing. Water returning from the LCG enters the loop at the multiple water connector (item 3).

A portion of the flow is immediately returned to the LCG by the temperature control valve which is an integral part of item 3. The remainder of the flow passes into the subsystem through a water umbilical, the gas separator (item 42), the pump (item 5), the evaporative heat exchanger (item 18), and back to the LCG via item 3. The pump circulates the water at 4 lb/min.

During umbilical operation, a vehicle umbilical is attached to the multiple water connector (item 1). During this mode of operation, the flash evaporator subsystem and the pump are shut down. The system heat load is dissipated at the vehicle via the vehicle liquid heat transport loop umbilical which directly cools the liquid heat transport loop. The O_2 ventilation loop is cooled by the liquid heat transport loop in the evaporative heat exchanger (item 18).

The flash evaporator subsystem consists of an evaporative heat exchanger (item 18), nozzle valve (item 9), solenoid (item 8), fill fitting (item 18), water reservoir (item 16), shutoff valve (item 11), relief valve (item 12), check valve (item 13), pressure regulator (item 14), flow-limiting orifice (item 15), and a temperature sensor (item 4). This subsystem is designed to maintain a constant liquid heat transport loop temperature downstream of the evaporator. This temperature is sensed by item 4. The nozzle valve (item 9) is pulsed by the solenoid (item 8) which is energized by an electronic controller (item 36). This controller modulates the power signal to the solenoid as a function of the signal from the temperature sensor. Since this type of system requires a short thermal response time to operate properly, all of the liquid heat transport water flows through the heat exchanger. The water reservoir (item 16) stores 8.3 lb of expendable water and supplies it to the nozzle valve (item 9) at 80–100 psig. Subsystem pressurization is provided by pressurizing the back side of the water reservoir bladder with high pressure O_2 regulated by the pressure regulator (item 14). The power supply (item 32) is a rechargeable, silver-zinc battery. The remote control unit (item 35) consists of the warning displays and controls as shown.

ITEM	PART NAME
1	MULTIPLE H_2O FEMALE DISCONN
2	SUIT ELEC UMBILICAL
3	MULTIPLE H_2O MALE DISCONN
4	H_2O ΔT TRANSDUCER
5	PUMP MOTOR ASSY
7	CHECK VALVE
11	S/0 VALVE
15	FLOW LIMITER
16	H_2O RESERVOIR
17	FILL CONN
18	WATER SUBLIMATOR
19	DRAIN CONN
20	H_2O SEPARATOR, 1ST STAGE
21	TEMP TRANSDUCER
22	LiOH CANISTER
23	OXYGEN BOTTLE
24	O_2 FILL CONN
25	O_2 REG & S/0 ASSY
27	PGA PRESS DIFF SWITCH
28	PGA PRESS DIFF TRANS
29	FAN/MOTOR ASSY
30	CHECK VALVE
31	O_2 CONNECTORS
32	POWER SUPPLY
33	CURRENT SENSOR
34	TERMINAL BOX
35	REMOTE CONTROL UNIT
37	COMMUNICATIONS
39	ORIFICE
40	H_2O CONN STOWAGE CAP
41	ANTENNA
42	GAS SEPARATOR
43	O_2 INLET CONN STOWAGE PLATE
44	O_2 OUTLET CONN STOWAGE PLATE
45	PLSS/PGA ELEC UMBILICAL STWG PLT
46	BATT CABLE STOWAGE PLATE
47	PRESSURE PORT
48	S/0 VALVE, DOUBLE BANK
49	H_2O SEPARATOR, 2ND STAGE

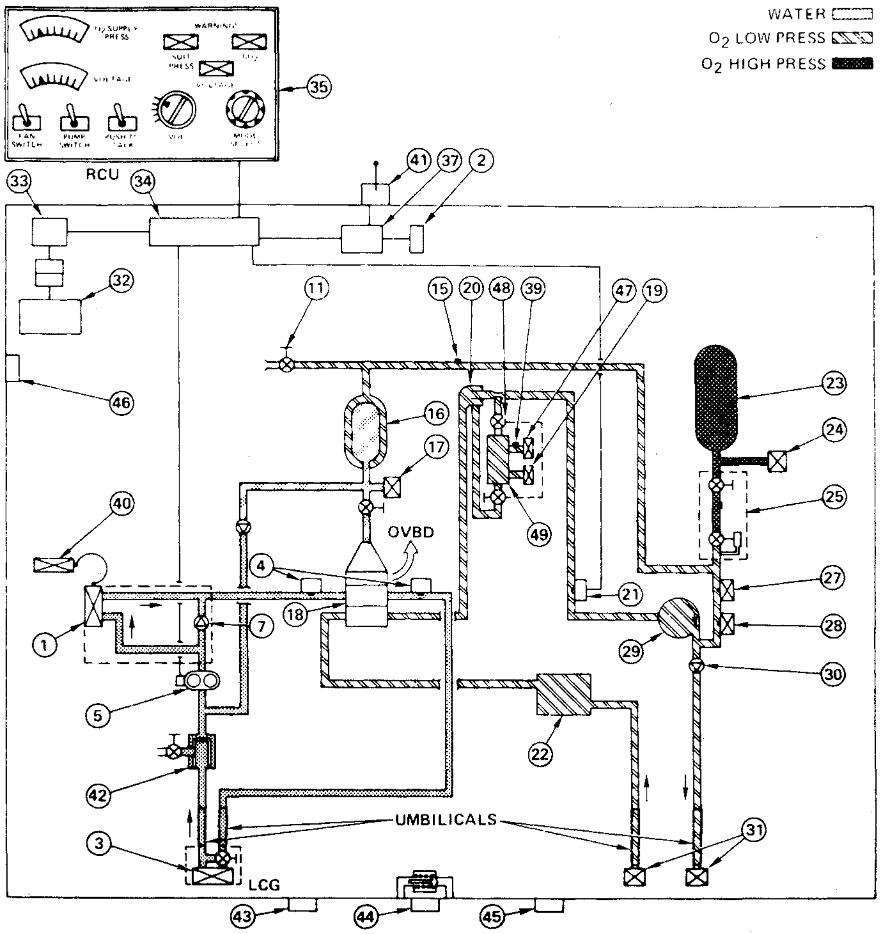

Fig. 4 PLSS schematic (water sublimator option).

The PLSS schematic with the water boiler option is depicted in Fig. 3 and is the same as the flash evaporator system except that the flash evaporator subsystem is replaced with an integral wick-fed water boiler. The sink temperature is controlled by the back pressure control valve which is a temperature sensing device. Notice that full flow of the liquid heat transport loop through the boiler is maintained to allow for cooling of the O_2 ventilation loop during umbilical operation.

The PLSS schematic with the water sublimator option is depicted in Fig. 4 and is the same as the flash evaporator system except that the flash evaporator subsystem is replaced with the water sublimator subsystem. The water reservoir (item 16) is pressurized to 8.0 psia by the O_2 ventilation loop and acts as the accumulator for the liquid heat transport loop as well as supplying expendable water to the sublimator. Again, full flow through the sublimator is maintained to allow for cooling of the O_2 ventilation loop during umbilical operation.

IV. Conclusions

General conclusions emanating from the Shuttle EVA/IVA Support Requirements Study in the area of EVA life support equipment are as follows.

1) The PLSS should be a closed-loop, self-contained system with the capability for liquid-loop umbilical operation.

2) The PLSS and the Emergency Life Support System (ELSS) should be structurally integrated to minimize weight and volume and to eliminate functional interfaces, and thus reduce the operational time required to stow, don/doff, and recharge the equipment.

Time Requirements for Multiple Intersatellite Transfers

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Nomenclature

k = ft/naut mile, constant
N = total number of revolutions required in all transfer ellipses
n = number of revolutions in transfer ellipse
Q = represents result of a calculation
r = radius of circular orbit, naut miles
T = time, days
$\Delta\lambda$ = phase (position) change in a circular orbit, deg
ΔV = change in velocity, fps
τ = period of an orbit, days or sec as required
μ = Earth's gravitational constant, naut miles^3

Subscripts
c = original circular orbit
i = ith transfer ellipse
j = jth transfer ellipse
1 = first transfer
2 = second transfer
3 = third transfer

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