Advanced Extravehicular Protective Systems

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Advances in extravehicular life support system technology will directly influence manned space missions of the future. An appraisal of advanced portable life support system and subsystem concepts was conducted to identify required new technology areas. Emphasis was placed on thermal control and combined CO_2 control/O_2 supply subsystems for both primary and emergency systems. As a result of these efforts, candidate primary and emergency life support system baselines were established and new technology recommendations were developed for regenerable thermal storage devices and solid regenerable CO_2 absorbents.

Introduction

THE United States manned space effort planned for the late 1970's and 1980's consists of long duration missions with shuttles, space stations, potential lunar bases and eventually a Mars landing. Extravehicular activity (EVA) is likely to take an increasingly important role in the completion of these future missions. In addition to exploration and experiment conduction, EVA missions may consist of assembly, cargo transfer, inspection, planned and unplanned maintenance, and emergency crew rescue and/or transfer operations. With the potential of two or three EVA missions per man per week, the use of expendables in the portable life support system may become prohibitively expensive and burdensome. For future EVA's to be effective in the total systems context, a portable life support system may need to have a regenerable capability. The objective of this program is to provide a meaningful appraisal of various regenerable and partially regenerable portable life support system concepts for EVA use and to identify required new technology areas.

Study Methodology

The criteria used as a basis for the advanced extravehicular protective system (AEPS) subsystem and system selections are shown in Fig. 1; the criteria used for AEPS emergency subsystem and system selection are shown in Fig. 2.

The go/no go criteria define the minimum acceptable requirements for a concept. If a concept did not meet all of the go/no go criteria, that concept was eliminated. The primary criteria were the principal evaluation criteria for

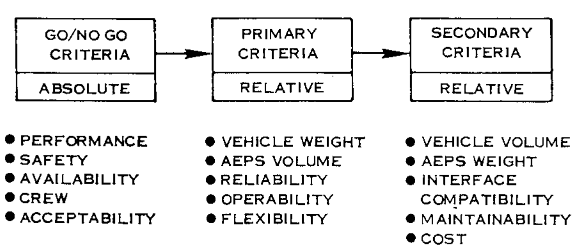

Fig. 1 Primary system evaluation criteria.

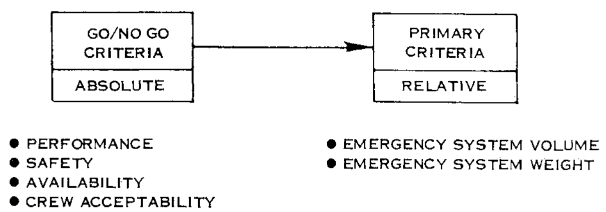

Fig. 2 Emergency system evaluation criteria.

concepts that passed the go/no go evaluation. A candidate concept was selected if its over all rating was clearly the best of the competing concepts. If a clear-cut choice was not evident, the remaining competing concepts were reviewed against the secondary criteria for final selection.

Based upon AEPS specifications for each of the missions being considered, candidate concepts were identified in each of the major subsystem areas (CO_2 control/O_2 supply, trace contaminant control, thermal/humidity control and power). Obvious noncompetitive concepts were eliminated in a preliminary screening evaluation. The remaining subsystems were then compared against the go/no go evaluation criteria. A parametric analysis of the candidate subsystem concepts which passed the go/no go evaluation was then conducted. The candidate subsystems were then compared against the primary and secondary criteria. Based upon the results of the subsystem evaluations, a selection of the best competing subsystems was made for each mission considered.

After completion of the subsystem studies, a systems integration effort was conducted where in the selected candidate subsystem concepts were combined into several candidate baseline shuttle, space station, lunar base and Mars primary AEPS systems and emergency systems. Operating pressure level, oxygen supply pressure level, contaminant control, humidity control, instrumentation, power requirements, and suit and vehicle interfaces were evaluated and defined as part of this effort. Candidate baseline systems were then subjected to a competitive evaluation utilizing the established criteria and the parametric data. After establishment of the baseline concepts, new technology recommendations were made.

Subsystem Studies

To ensure that the results of this study were both meaningful and useful for future related efforts, a broad-based approach to candidate subsystem concept identification was adopted. The whole gamut of concept approaches was investigated with a specific effort to preclude any prejudgment of concept value prior to concept identification. Specific emphasis was placed in the areas of thermal control and CO_2 control/O_2 supply, as they represented the areas where the

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greatest benefits could be derived through reduction of vehicle penalties and AEPS volume and weight.

Initial effort resulted in the identification of 55 candidate thermal control concepts, 21 candidate CO_2 control concepts, 14 candidate O_2 supply concepts, and 3 candidate O_2 generation concepts. Of these original candidate concepts, 25 thermal control concepts and 19 combined CO_2 control/-O_2 supply concepts were carried into the go/no go evaluation. These concepts were subjected to the go/no go primary and secondary evaluations. As a result, three general thermal control categories were selected for further study: expendable water concepts, radiation and thermal storage.

One general CO_2 control/O_2 supply category was selected for further study—a solid regenerable sorbent combined with a high-pressure gaseous oxygen supply system. Two families of solid regenerable sorbents, metalic oxides and solid amines, were identified as candidate materials.

The specific thermal control subsystem concepts recommended to be carried into the systems integration phase of the AEPS study are described as follows.

The water boiler is an expendable thermal control concept that utilizes the heat of vaporization of water to provide direct cooling of the space suit liquid cooling garment (LCG) loop and the suit ventilation loop. The wick-fed water boiler acts as the water storage vessel. The expendable water boiling temperature is controlled by a back pressure valve. Water removed by the water separator is fed into the water boiler, thus providing additional cooling capacity. The water boiler was recommended as a representative concept of all the expendable water concepts.

Thermal Storage (Fig. 3) utilizing phosphonium chloride is a regenerable thermal control concept. PH_4Pl has a heat of fusion of 324 Btu/lb at 82°F and above 48 atm pressure. A vapor compression cycle is utilized to raise the desired coolant temperature of 50°F at the vent loop LCG loop heat exchanger to 82°F at the thermal storage unit. Vehicle penalties associated with this concept are relatively low since PH_4Cl will resolidify of its own accord at normal space cabin temperatures.

PH_4Cl sublimates at pressures below 500 psia at room temperature. As pressure is decreased further, gaseous PH_4Cl dissociates into hydrogen chloride and phosphine (PH_3). PH_3 is highly toxic and, therefore, the thermal storage unit has been concepted so as to minimize the probability of any failure resulting in external leakage.

The expendable/direct radiative cooling subsystem is a hybrid concept which consists of a water boiler and radiator connected in parallel through a temperature control valve. The temperature control valve controls flow thereby controlling of heat load shared by the water boiler and the radiator. The radiator is sized to handle the average heat load while the water boiler handles peak loads; thus radiator size and water expended in the boiler are minimized. Humidity control is provided by a condensing heat exchanger and a water separator which feeds the separated water to the water boiler to provide additional cooling capacity.

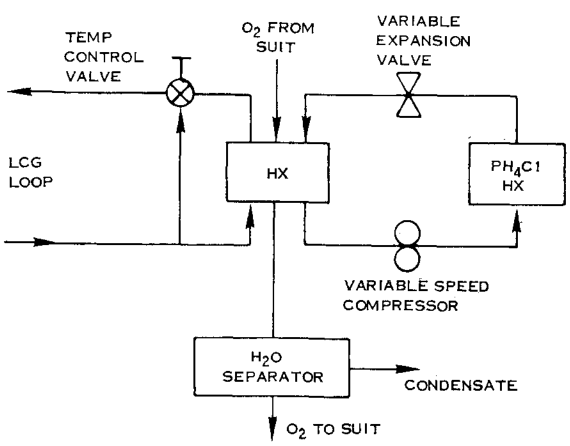

Fig. 3 Thermal storage—phosphonium chloride.

The expendable/radiation subsystem is a hybrid concept which consists of a radiator/vapor compression cycle and a water boiler connected in parallel. The radiator/vapor compression cycle is sized to handle the average LCG heat load plus the heat load from the vent system and the water boiler handles peak loads. This minimizes radiator size, compressor power consumption, and water expended in the boiler.

The expendable/thermal storage subsystem is a hybrid concept which utilizes a water boiler in parallel with the PH_4Cl thermal storage unit. The PH_4Cl thermal storage unit handles the average heat load and the water boiler handle peak loads. By doing this, compressor power and expendable water are minimized.

The CO_2 control/O_2 supply subsystem concepts recommended to be carried into the system integration phase of the AEPS Study are described below. All of the concepts utilize a high pressure gaseous O_2 supply system.

Metallic oxides (i.e., ZnO, MgO) react with CO_2 according to the following reversible reaction

$$MO + CO_2 \rightleftharpoons MCO_3 + Q$$

The carbonate decomposes with increasing temperature and decreasing pressures and in some cases, may be solely vacuum regenerable. However, excessive volume change during the adsorb/desorb cycle affects the chemical's physical stability and is a prime consideration in any future development effort. For this study, the adsorbent was contained between screens with gas flow over rather than through the bed. CO_2 diffusion into the thin oxide bed is sufficient as long as the solid volume transition during adsorb/desorb does not result in an impregnable surface.

In the vehicle regenerable configuration (Fig. 4), the adsorbent is packaged in a cartridge which is replaced after each mission. An oven-vacuum chamber is provided within the vehicle for cartridge regeneration. Reclamation of the oxygen is possible with this system by directing the desorbed CO_2 to the vehicle CO_2 reduction system.

A variation of this metallic oxide concept is a cyclic or AEPS regenerable configuration (Fig. 5). This concept provides for regeneration of the metallic oxide subsystem during the actual EVA mission. Two beds, similar in design to that described for the vehicle regenerable system, are provided, each containing electrical elements for regeneration and a cooling loop to cool the regenerated bed and maintain temperature control during operation. A timer is provided to sequence the vent loop and coolant loop valves to allow the vent loop and coolant loop to flow to the on-stream bed and to heat and expose the regenerating bed to space vacuum.

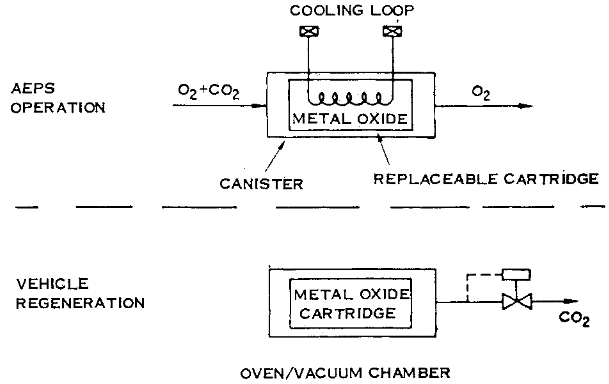

Fig. 4 Metallic oxide—vehicle regenerable.

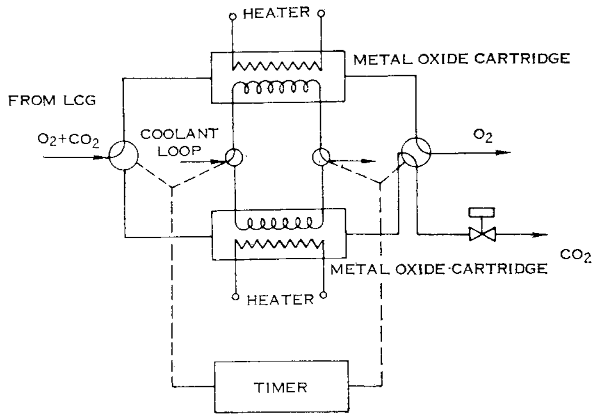

Fig. 5 Metallic oxide—AEPS regenerable.

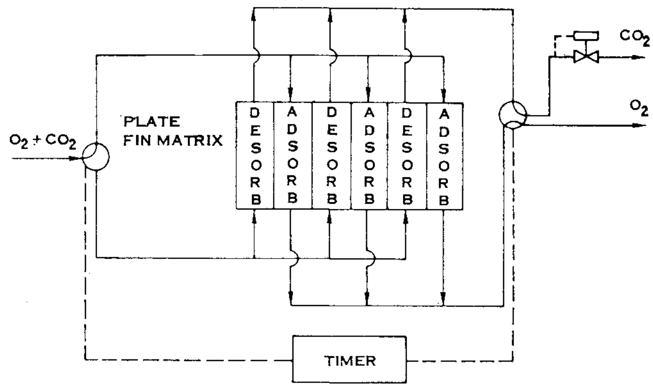

Fig. 6 Solid amine—AEPS regenerable.

The second family of solid regenerable sorbents identified is that of solid amines. An inert carrier is utilized to provide a stable amine adsorbent bed in the concept depicted in Fig. 6. The regenerable solid amine is packaged within the flow passages of a platefin matrix similar in design to an extended surface compact heat exchanger. Alternate flow passages contain adsorbing and desorbing material. Energy released from the adsorbing passages is transferred by conduction through the metal matrix to the desorbing material to supply the requirements of the endothermic desorption. This concept neither imposes a thermal load on the AEPS nor requires energy for regeneration. A timer and valving is provided to cycle the packed beds from the on-line adsorb to the space vacuum desorb cycle.

Systems Studies for the Primary System

The primary system studies combined the selected candidate subsystem concepts into candidate baseline shuttle, space station, lunar base and Mars AEPS schematics. For shuttle and space station, the mission requirement is an average metabolic rate of 1000 Btu/hr for 4 hr; lunar base is 1050 Btu/hr for 8 hr; and Mars is 1200 Btu/hr for 8 hr. The following schematics are representative of potential AEPS configurations which might result if the technology recommendations emanating from the AEPS study are implemented. These schematics are examples of combinations of recommended subsystems and components, and are not necessarily the only competitive combinations.

AEPS Concept 1 (Fig. 7) contains all the required life support

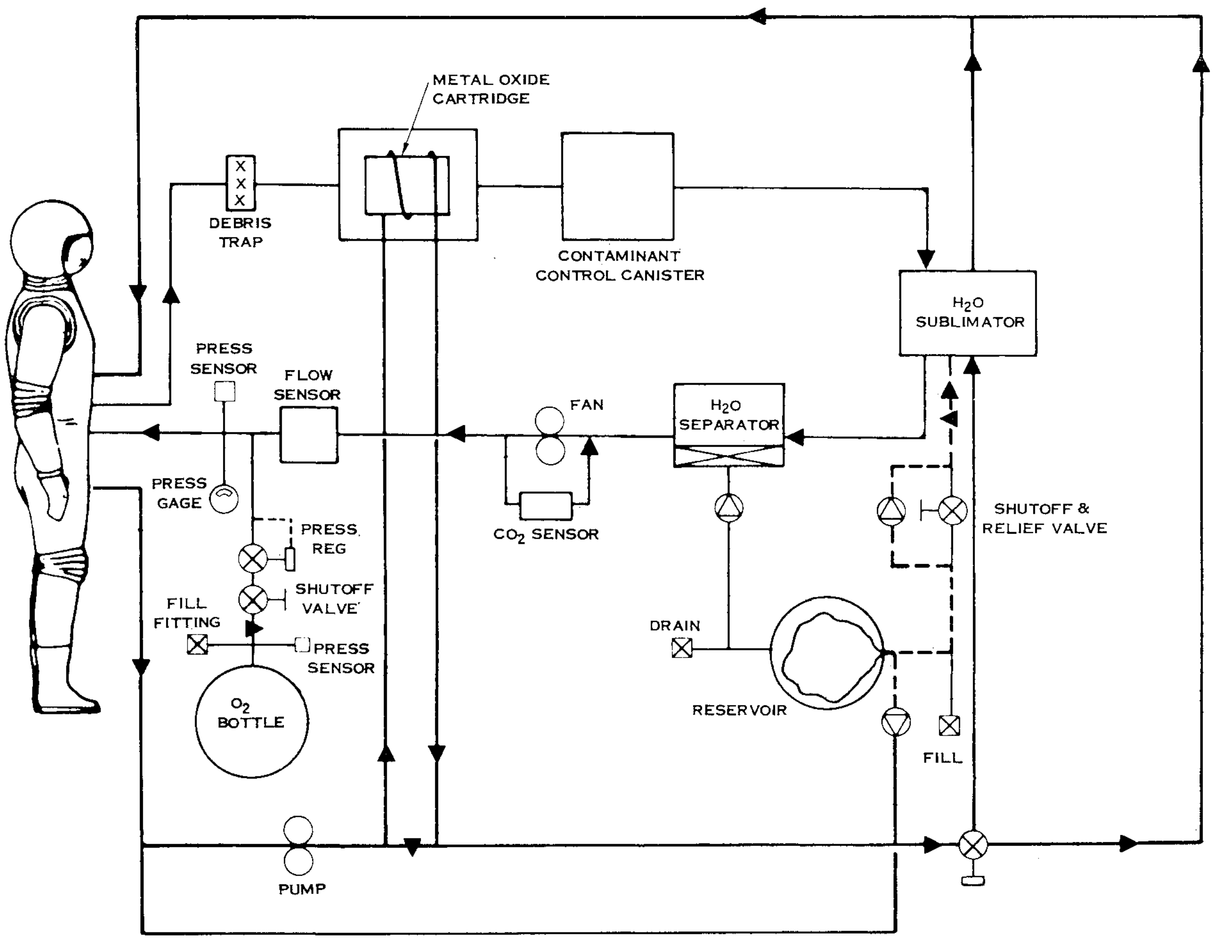

Fig. 7 AEPS concept 1—shuttle.

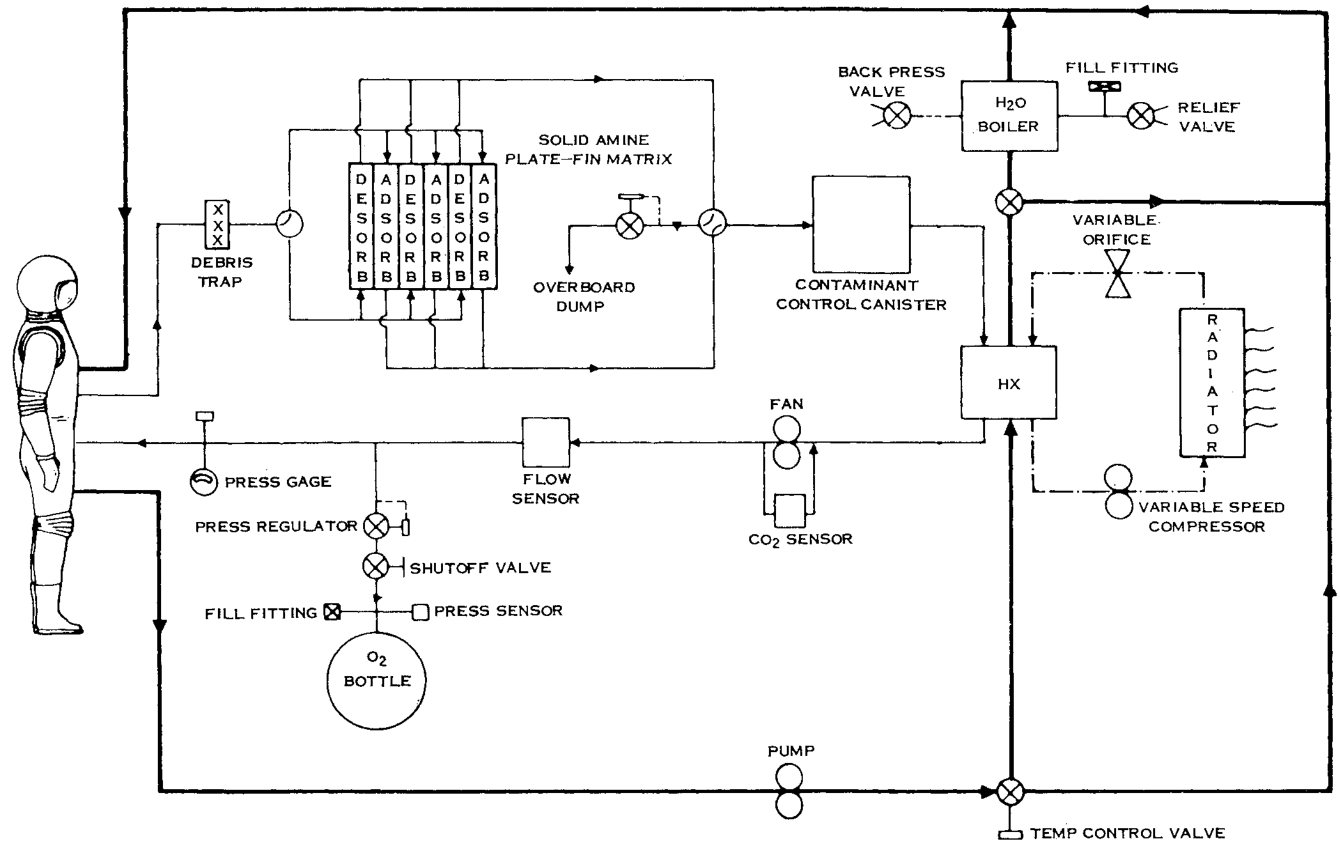

Fig. 8 AEPS concept 2—space station.

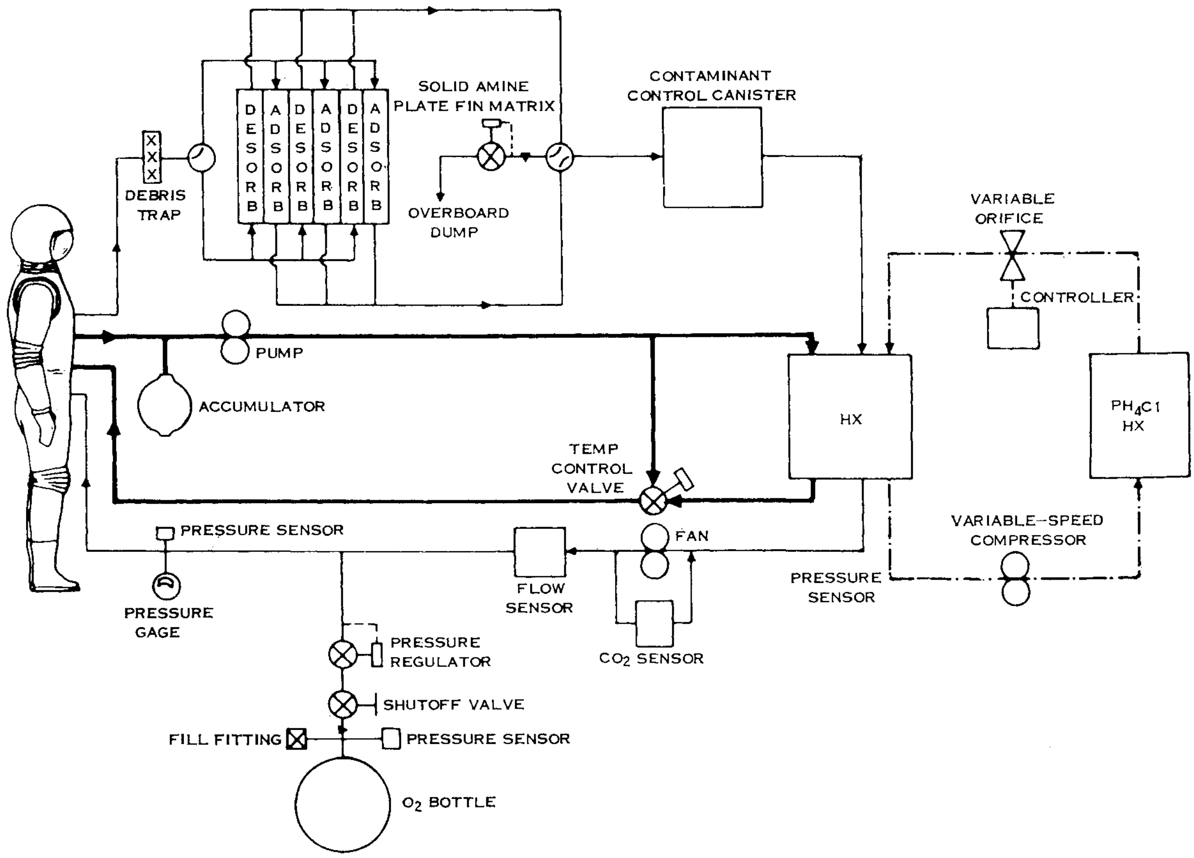

Fig. 9 AEPS concept 3—lunar base.

equipment for extra-vehicular operation including a ventilation loop, a high-pressure O_2 supply subsystem, a water heat transport loop, a power supply, instrumentation, communications, and operating controls and displays. The ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit first passes through the debris trap where solid particles and/or droplets are removed; next CO_2 is removed using a vehicle regenerable metallic oxide subsystem; odors and trace contaminants are removed by the activated charcoal in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The water sublimator cools the circulated O_2 and condenses entrained moisture. The water separator removes condensed water vapor and transfers it to the water reservoir for condensate storage and water reservoir pressurization. The fan circulates a ventilation flow of 6 acfm to the suit. The high pressure O_2 supply subsystem contains 0.75 lb of usable O_2 at 6000 psia and 65°F, and regulates the pressure in the ventilation loop to 6.75 ± 0.2 psia. This subsystem consists of an O_2 bottle, fill fitting, pressure sensor, shut-off valve and pressure regulator. The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to a level where little, if any, perspiration occurs. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. Flow through the thermal control subsystem is regulated by an automatic temperature control valve. The estimated volume and weight for this AEPS concept 1 (less the suit) are 1100 in.^{3} and 38 lb, based on an average metabolic rate of 1000 Btu/hr for an EVA duration of 4 hr. AEPS Concept 2 (Fig. 8) consists of a ventilation loop, a high pressure O_2 supply subsystem, a water heat transport loop, a Freon 12 heat transport loop, a power supply, instrumentation, and operating controls and displays. O_2 from the suit first passes through the debris trap where solids particles and/or droplets are removed; CO_2 and water vapor are removed using an AEPS solid amine plate fin-matrix; odors and trace contaminants in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The Freon evaporator cools the circulated O_2 and condenses the entrained moisture. The thermal control subsystem is a hybrid expendable/radiation subsystem and consists of a water boiler and a Freon refrigeration system. The estimated volume and weight for this configuration are 3100 in.^{3} and 65 lb, based on an average metabolic rate of 1000 Btu/hr for an EVA duration of 4 hr.

AEPS Concept 3 (Fig. 9) is similar to Concept 2 except the thermal control subsystem is a PH_4Cl thermal storage unit. Heat is added at the evaporator and stored at the thermal storage unit by the melting of PH_4Cl. The estimated volume and weight for this AEPS configuration are 4500 in.^{3} and 193 lb, based on an average metabolic rate of 1050 Btu/hr for an EVA duration of 8 hr.

AEPS Concept 4 (Fig. 10) is similar to Concept 1 except the thermal control subsystem is a hybrid expendable/direct radiative cooling subsystem and consists of a water boiler and a radiator. Water in the heat transport loop exiting the radiator is the coolant in the humidity control condensing heat exchanger. The estimated volume and weight for this AEPS conguration are 3100 in.^{3} and 84 lb, based on an average metabolic rate of 1200 Btu/hr for an EVA duration of 8 hr.

Systems Studies for the Emergency System

The emergency system studies combined the selected subsystem concepts into candidate baseline shuttle, space station, lunar base and Mars emergency systems. The mission requirements for shuttle and space station are an average metabolic rate of 1500 Btu/hr for an emergency duration of 30 min; lunar base is 1600 Btu/hr for 2 hr; Mars is 2000 Btu/hr for 1 hr.

An example of a candidate emergency system which was concepted for the space shuttle application is depicted in Fig. 11. This concept contains all required life support

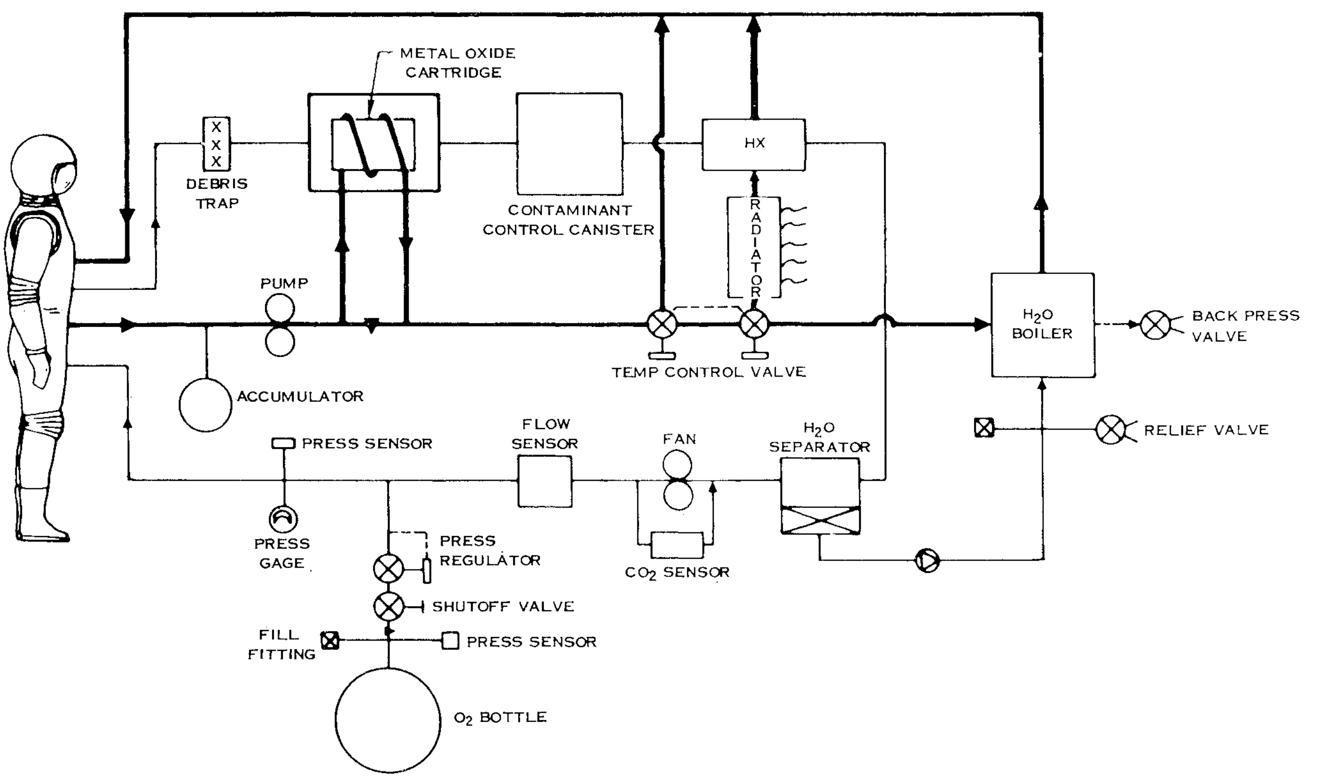

Fig. 10 AEPS concept 4—Mars.

equipment for extravehicular operation during an emergency. The ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. CO_2 and humidity control are accomplished by the addition of a fresh supply of oxygen at the ejector, which circulates the ventilation system at 6 acfm, and the purging of suit outlet ventilation flow at the dump valve. The dump valve maintains a back pressure of 6.75 ± 0.2 psia. The high pressure O_2 supply subsystem contains 1.9 lb of usable O_2 at 6000 psia and 60°F, and regulates the ejector upstream pressure to 200 ± 10 psia. In addition, this subsystem drives the gas-powered pump and regulates pump flow at 4.0 ± 0.2 lb/min and pump inlet water pressure to 6.9 ± 0.2 psia via a pressure accumulator. The temperature of the water heat transport loop is controlled by a water sublimator. A bladder water reservoir, pressurized by the ventilation loop, supplies the sublimator with expendable water. The thermal control subsystem consists of a water sublimator, a water reservoir, fill and drain fittings, and a shut-off and relief valve. The estimated volume and weight for this emergency system concept are 512 in.^{3} and 14.5 lb, based on an average metabolic rate of 1500 Btu/hr for an emergency EVA duration of 30 mins.

New Technology Recommendations

As a result of the AEPS Study Program, two major new technology areas were identified and recommended for future research and development. In the area of thermal control, it is recommended that a research and development program be initiated to identify, evaluate and develop candidate thermal storage materials possessing a heat of fusion greater than 300 Btu/lb and melting between 50°F and 150°F. One such candidate material (PH_4Cl) has been identified and analytically evaluated during conduct of the AEPS study and is recommended for further study. In addition, an investigation to determine the characteristics that contribute to high heat of fusion, synthesis of promising materials, and test characterization of any such materials are recommended.

In the area of CO_2 control, it is recommended that a research and development program be initiated to develop a solid regenerable CO_2 sorbent and associated hardware. Two candidate families of solid regenerable sorbents—metallic oxides and solid amines—have been identified and analytically evaluated during conduct of the AEPS study, and are recommended for further research and development.

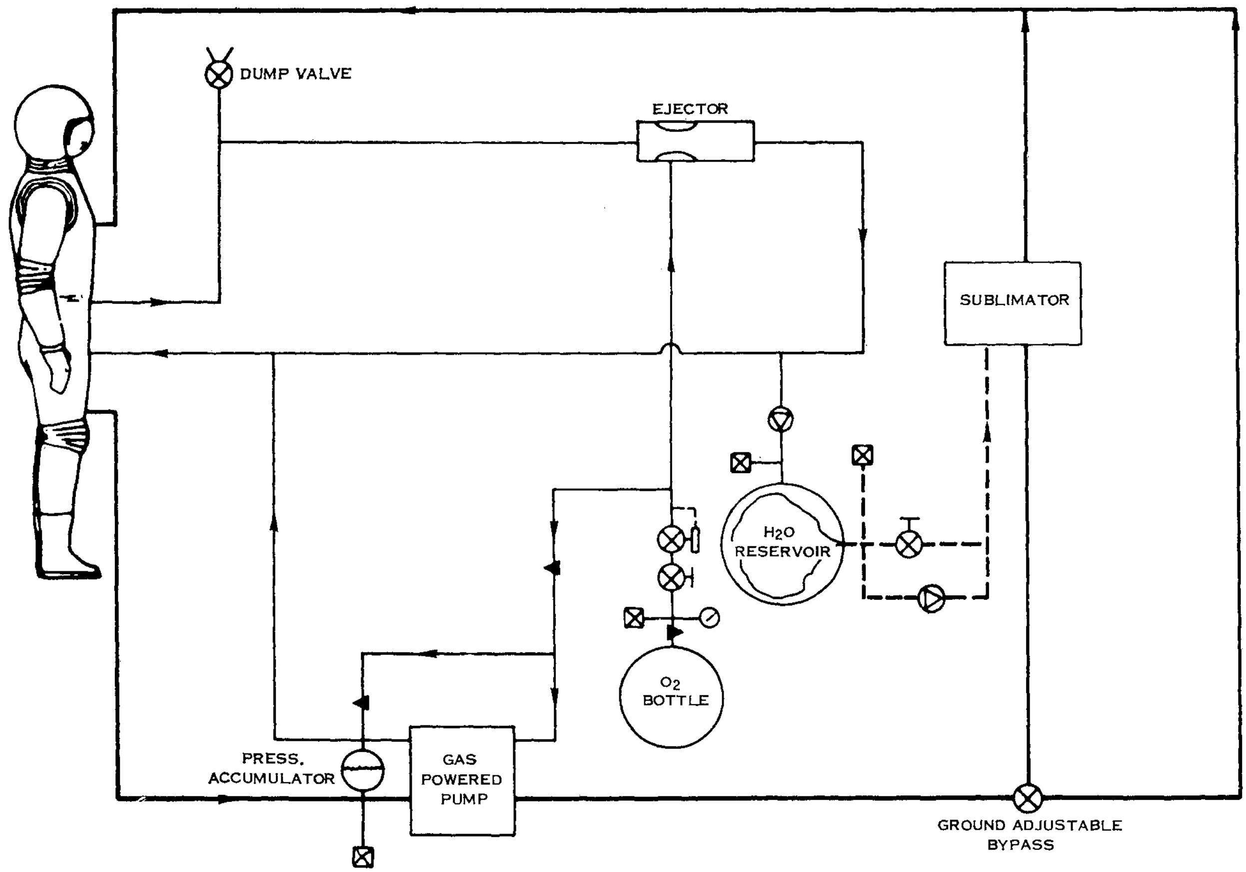

Fig. 11 AEPS emergency concept 1—space shuttle.