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T141RP007

ADVANCED EXTRAVEHICULAR PROTECTIVE SYSTEM (AEPS) STUDY

FINAL REPORT

BY

J. L. WILLIAMS, B. W. WEBBON AND R. J. COPELAND

PREPARED UNDER CONTRACT NO. NAS2-6022 BY
VOUGHT MISSILES AND SPACE COMPANY
LTV AEROSPACE CORPORATION
DALLAS, TEXAS

FOR

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This report summarizes a study of Advanced Extravehicular Protective Systems (AEPS) for future missions beyond Skylab in earth orbit, on the lunar surface, and on the Martian surface. The study concentrated on the origination of regenerable life support concepts for use in portable extravehicular protective systems, and included evaluation and comparison with expendable systems, and selection of life support subsystems. This study was performed by the Vought Missiles and Space Company (VMSC) of LTV Aerospace Corporation during the period of July 1970 through March 1972 for the Environmental Control Branch of the Bio-Technology Division of NASA-Ames Research Center (ARC) under Contract NAS2-6022 supported by NASA-Headquarters Office of Manned Spaceflight (OMSF), Bioenvironmental System Division RTOP No. 970-22-30.

The study was conducted in two phases. In the first phase, subsystem concepts for performing life support functions in AEPS which are regenerable or partially regenerable were originated, and in addition, expendable subsystems were considered. Parametric data for each subsystem concept were evolved including subsystem weight and volume, power requirement, thermal control requirement; base regeneration equipment weight and volume, and expendable requirement. The most favorable subsystem concepts for each life support functional requirement were selected for more detailed study. These candidate concepts were subjected to a preliminary design analysis which refined the parametric data. In addition, system integration factors were considered for the candidate subsystems. Optimum subsystem concepts were selected for each mission, as were optimum total AEPS concepts. The results of this phase of the study were reported in an interim report, NASA CR-114321. The second phase of the study involved an evaluation of the impact of safety considerations involving redundant and/or backup systems on the selection of the regenerable life support subsystems. In addition, the impact of the space shuttle program on regenerable life support subsystem development was investigated. This report incorporates the earlier interim report, and gives a summary of the entire study.

Dr. Alan Chambers of NASA-ARC was the NASA Technical Monitor for this study. Mr. William Smith of the Bioenvironmental System Division of OMSF maintained cognizance of the study for NASA-Headquarters. The study was conducted by the authors of this report.

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1.0 INTRODUCTION AND SUMMARY

Space missions undertaken in the late 1970's and 1980's time frame may involve more ambitious Extravehicular Activity (EVA) than has been attempted on space missions through the Apollo Program. EVA's may be increased in sortie duration, sortie frequency, numbers of personnel involved, and scope. Current EVA equipment performs life support functions through the use of expendable fluids and materials. The Apollo Portable Life Support System (PLSS) is an example of this type of equipment. On some of these future missions, the use of expendables will be prohibitive due to the large mass required. Life support equipment which is regenerable in some measure will be required to make these missions viable.

This study was divided into two phases. The purpose of the first phase was to investigate possible means of accomplishing advanced EVA. Advanced Extravehicular Protective Systems (AEPS) for use in earth orbit, on the lunar surface, and on the Mars surface were considered. The complete range of possible subsystems for performing life support functions was considered, including expendable, partially regenerable, and regenerable techniques. Concepts which had previously been considered or used were included, and new concepts were evolved. The primary emphasis was placed in the areas which require the largest quantity of expendable material in current systems; that is, the thermal control subsystem, and the carbon dioxide control subsystem. Considerable attention was also given to the atmosphere supply subsystem, which may be integrated with the carbon dioxide control subsystem in some instances.

The second phase of the study involved an assessment of the impact of the consideration of emergency requirements for redundant subsystem design or for a complete backup system, on the selection of regenerable life support subsystems. Also, the impact of the space shuttle orbiter, with its short duration missions and possible excess water availability was evaluated. The first phase of the program was documented in an interim report, NASA CR 114321 (Reference [1]); this report is a extension of Reference [1] to include the results of the second phase of the study.

The conclusions reached in this study are:

(1) Regenerable Portable Life Support Systems for use in EVA are feasible

(2) The most promising approach to regenerable portable life support subsystems involves regeneration at the primary base or shelter.

(3) Regenerable portable life support subsystem concepts offer large total launch weight savings at the expense of EVA weight and volume.

(4) Inclusion of an emergency back-up system in the AEPS has only a minimal impact on regenerable life support subsystems, and does not alter any of the subsystem selections.

(5) There is likely to be no advantage for a regenerable carbon dioxide control subsystem for EVA from the space shuttle; there may be an advantage for a fusible heat sink thermal control subsystem, based on fluid dumping restrictions rather than on weight savings considerations.

Specific recommendations made as a result of this study are:

(1) Develop a fusible heat sink, using water as the working fluid, with an evaporative mode capability. This device will reduce total system weight on missions involving a cumulative total of more than 40 hours of EVA time.

(2) Develop a thermally regenerable metallic oxide/hydroxide carbon dioxide control subsystem. This device will be beneficial on missions involving a cumulative total of more than 400 hours of EVA time.

2.0 STUDY OBJECTIVES AND APPROACH

2.1 STUDY OBJECTIVES

The future of manned exploration of space and the planetary bodies will be strongly influenced by the availability of effective and efficient portable life support equipment for use in extravehicular activity (EVA). The development of regenerable or partially regenerable systems for performing life support functions is central to the development of efficient Advanced Extravehicular Protective Systems (AEPS).

The specific objectives of the study were to:

(1) Identify new concepts for providing life support functions in AEPS.

(2) Make a realistic appraisal of regenerable and partially regenerable life support system concepts which are feasible for use in AEPS.

(3) Identify the most promising life support functional concepts and techniques for AEPS, and make recommendations on the priority which should be assigned in the development of these components and techniques.

(4) Assess the impact of the development of the space shuttle, which will significantly reduce the cost of launching a payload into earth orbit, on the selection of regenerable or expendable EVA life support equipment.

(5) Assess the impact of reliability and emergency requirements for either redundant subsystems, or a reduced capacity back-up system on the selection of regenerable life support subsystems.

(6) Evaluate potential space shuttle-based EVA operations, and select life support subsystems for use in this application.

2.2 STUDY APPROACH

The approach taken to accomplish the study objectives was to:

(1) Establish a set of ground rules and contraints which provide a framework which is flexible enough to consider the widest range of potential concepts, but which is specific enough to insure that all selected concepts are practical. There are currently no specific plans for space missions of extended duration beyond the 56 days of Skylab. Therefore, it was necessary to establish guidelines in a somewhat

arbitrary fashion; using prior studies of advanced space missions as a baseline. The design and performance requirements from the AEPS RFP are shown in Table 1. The guidelines and constraints for space shuttle based EVA's can be more firmly established using data from NASA and the shuttle prime contractors.

(2) Review the literature to identify techniques for accomplishing life support functions which have been used previously not only in the space program, but also in commercial and industrial applications.

(3) Review the physical properties and equations governing the fundamental processes involved in heat rejection and carbon dioxide control in order to identify concepts not previously considered.

(4) Perform a preliminary screening process to eliminate those concepts which appear less suitable.

(5) Perform detailed consumables analysis on the candidate concepts. Also perform a preliminary design of the candidate concepts to establish component size and weight, support equipment requirements, and to identify potential operational difficulties.

(6) Select the most promising concepts for each life support function for each specific type of mission considered, including shuttle based operations, and for use on all missions. Also select the most promising concepts considering reliability requirements for redundant subsystems or a backup system.

TABLE 1 DESIGN AND PERFORMANCE REQUIREMENTS

EVA DURATION (AT AVERAGE METABOLIC RATE)	8 + HOURS
FREQUENCY OF MISSIONS	1 PER DAY
MOBILITY	AEPS SHALL PROVIDE MINIMUM ENCUMBRANCE TO THE CREWMAN IN PERFORMANCE OF MISSION TASKS.
CENTER OF GRAVITY	CG OF THE EVA SUIT AND LIFE SUPPORT ELEMENTS ATTACHED TO OR INTEGRATED WITH THE SUIT SHALL NOT SHIFT MORE THAN ± 3 INCHES FROM THE CG OF THE NUDE CREWMAN.
SUIT GAS COMPOSITION	5 – 7.5 PSIA PURE OXYGEN
HUMIDITY CONTROL	
A. NOMINAL SUIT INLET DEW POINT	45°F
B. MAXIMAL SUIT INLET DEW POINT	60°F
VENTILATION (MINIMAL)	
A. INLET FLOW RATE	9 ACFM
B. INLET GAS TEMPERATURE	50 – 70°F
CONTAMINATION CONTROL	
A. NOMINAL INLET CO_2 LEVEL	4 MM Hg
B. MAXIMAL INLET CO_2 LEVEL	7.5 MM Hg
C. ODOR LEVEL MUST NOT ADVERSELY AFFECT CREWMAN PERFORMANCE	
METABOLIC PROFILE	
A. AVERAGE	1600 BTU/HR
B. PEAK (SUSTAINED)	3500 BTU/HR
C. MINIMUM	250 BTU/HR
LIQUID TRANSPORT LOOP FLOW	240 LB/HR
LIQUID INLET TEMPERATURE TO SUIT	40°F
USE WITH VEHICLE OR SHELTER HAVING:	(a) 5 – 14.7 PSIA CABIN PRESSURE (b) 3.5 PSIA OXYGEN WITH DILUENT NITROGEN (c) RELATIVE HUMIDITY 55 ± 5% (d) 65 – 75°F TEMPERATURE
SAFETY	THE SYSTEM SHALL PRECLUDE INJURY TO CREWMAN, SERVICE PERSONNEL, ETC., BECAUSE OF FIRE, EXPLOSION, TOXICITY, CONTAMINATION, AND BURNS OR SHOCK.
OPERATIONAL ENVIRONMENTS	ZERO g, 1/6 g, AND 1 g

3.0 GUIDELINES AND CONSTRAINTS

Studies to establish the configuration of future equipment are profoundly affected by the selection of guidelines and constraints. Very frequently this selection will be the dominant factor in the success with which the study results stand the test of time. However, it is necessary to postulate the missions and mission sequencing which will be undertaken by the United States, so that guidelines and constraints which affect significant trade factors such as power penalty, crew size, mission duration, etc., can be assessed in a reasonable manner. This section discusses the development of guidelines and constraints for use in this study.

3.1 FUTURE SPACE MISSIONS

Several studies have been conducted which indicate the type of missions which might be undertaken in the next two decades. The most comprehensive of these are the NASA report on "America's Next Decades in Space" (Reference [2]) prepared for the Space Task Group and the Bell Comm report on "An Integrated Program of Space Utilization and Exporation for the Decade 1970 to 1980" (Reference [3]). Figure 1 shows a plan for the U. S. Space Program for the 1970-1990 period (Reference [3]). These studies were summarized in a speech (Reference [4]) from which the main thrust of future plans seems to be:

(1) Development of a low cost transportation system

(2) Exploitation of near earth orbit opportunities

(3) Further exploration of the moon

(4) Exploration of Mars

The rate at which this program is conducted is dependent on funding levels granted by Congress; however, the entire program (with the possible exception of the Exploration of Mars) will probably be undertaken within the next two decades. The low cost transportation system seems to be the keystone for all of the other steps, (Reference [4]), and it quite logically seems to have the highest development priority at this time (References [5] and [6]). The low cost transportation system includes a reuseable booster, a reuseable orbiter, and a nuclear-powered tug. The booster and orbiter are used to put payloads into low (up to 260 nm) earth orbit, while the tug is used to transfer payloads to geosynchronous orbit, or to lunar orbit. The space shuttle orbiter will apparently be the first of the vehicles to reach an operational status, and will be developed in two phases, designated Mark I and Mark II, and it will probably be launched initially by a conventional booster (Reference [7]). The exploitation of near-space will probably be undertaken concurrently with the development of the space shuttle booster, to be followed by the development of the nuclear-powered tug, which could ultimately be used as the pro-

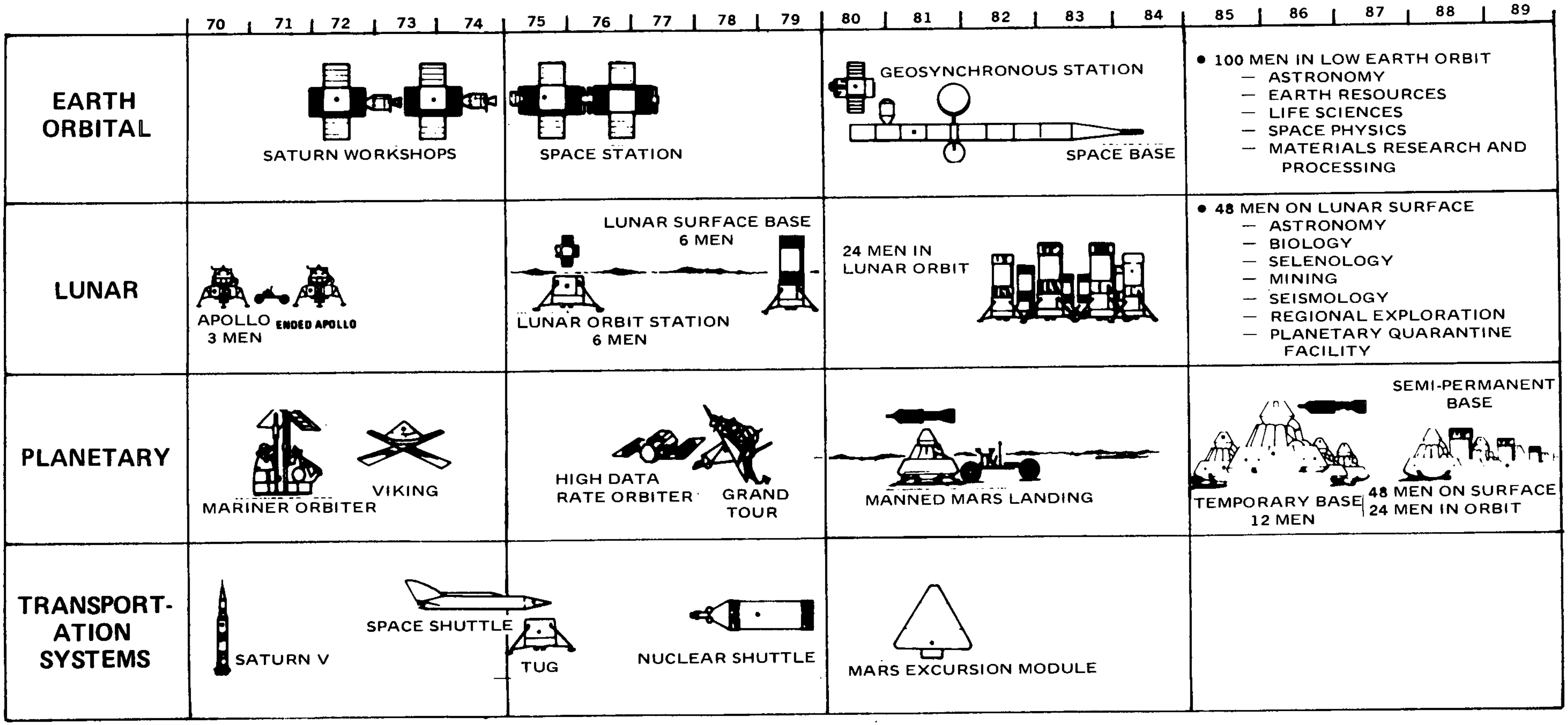


FIGURE 1 INTEGRATED SPACE PROGRAM 1970 – 1990 (REFERENCE 1)

pulsive stage for advanced lunar and Martian exploration expeditions. All of the basic elements of the low-cost transportation system are to be reuseable, including the nuclear-powered tug.

The first manned orbital flight (MOF) for the Mark I shuttle is projected for 1978, and 13 to 15 flights per year are postulated out until 1985 (Reference [8]). The first MOF for the Mark II orbiter is baselined for 1985-1986. These plans are undergoing continual reassessment as the Phase B Shuttle Studies continue. The shuttle is currently planned to be used by both NASA and DOD, with DOD accounting for 36% of the payloads for Mark I (Reference [8]). The DOD applications color the design of the shuttle in many respects, particularly with regard to the cargo bay dimensions, and the ground support requirements.

Numerous studies have been and are now being conducted on the applications and use of the shuttle. Some of the more significant NASA studies include: Shuttle Orbital Applications Requirements (SOAR) and Modular Space Stations by McDonnell-Douglas Corporation; Research and Applications Modules (RAM) and the NASA Blue Book Experiments by General Dynamics - Convair, Inc.; Modular Space Stations, the Payload Sortie System (PSS), and Orbital Operations by North American Rockwell, Inc.; and the Integrated Fleet Study by Aerospace Corporation. There are also studies underway on DOD applications of the Shuttle by Itek Corporation; General Electric Company, TRW Systems, Lockheed Missiles and Space Company, and McDonnell-Douglas Corporation. Based on these studies, and a NASA budget relatively constant at today's level over the next several years, it seems reasonable to expect that the initial shuttle operations will be primarily devoted to earth orbital "sortie" flights (in which an experiment is carried aloft, performed, and returned to earth in the shuttle cargo bay), and in satellite transport, deployment, and servicing. The full spectrum of anticipated shuttle missions is depicted in Figure 2 and includes:

(1) Short Duration Orbital Missions ("sortie" flights, and deployment of free-flying "RAM's")

(2) Placement and Retrieval of Satellites

(3) Service and Maintenance of Satellites

(4) Delivery of Propulsive Stages and Payload (propulsive stages are used to put the payload into higher orbits than the shuttle can achieve)

(5) Space Station buildup and logistics support

(6) Delivery of Propellants (fuel for a conventionally-powered tug for placing payload in different orbit's than that of the shuttle

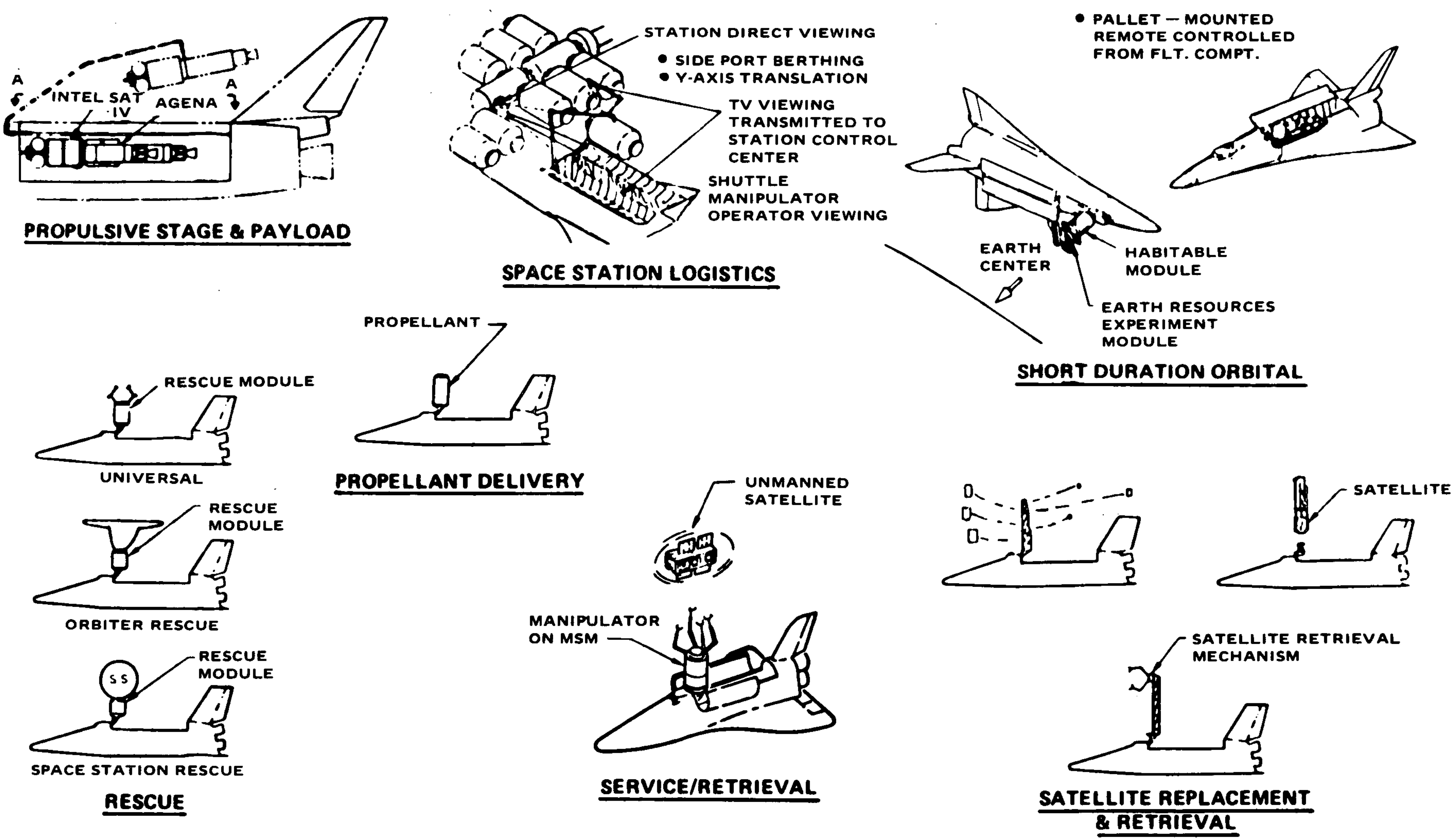


FIGURE 2 TYPICAL SHUTTLE MISSIONS

(7) Space Rescue (the rapid response capability of the shuttle for ground-based rescue missions is identified by Myers (Reference [9]) in the classification of basic shuttle operations)

There are a very large number of experiments which are candidates for use with the shuttle, some of which are more likely to involve EVA than others. There are also many experiments which could involve Intravehicular Activity (IVA) in unpressurized portions of the vehicle, where a life support system including a pressure suit would be required. (The suit would not necessarily require meteroid protection or thermal protection such as are required for EVA suits.) The NASA Blue Book (Reference [10]) lists many of the potential experiments. (NASA is not committed to actually perform the experiments given in Reference [10]; these are presented as typical examples of experiments that might be performed for use in vehicle design). Numerous studies are being conducted on the experiment module, which is typically referred to as the Research and Application Module (RAM). There are several basic RAM configurations under study, each of which is suitable for a specific class of experiments identified in the Blue Book (References [11], [12], and [13]).

The general plans for the future in space involve a substantial number of EVA events, although the Blue Book gives a general recommendation to avoid EVA where possible (Reference [10], p. 3-13). The Blue Book does include experiments with an Astronaut Maneuvering Unit (AMU) and with a Maneuvering Work Platform (MWP). There are 24 EVA experiments on a 60-day flight (Reference [10], p. 3-19). The purposes of the experiments are to:

(1) Demonstrate navigation, docking/anchoring, cargo transfer, astronaut rescue, space structure assembly, maintenance and repair.

(2) Observe and evaluate the maneuverability, stability, control and performance of the maneuvering device.

(3) Evaluate crew physiological factors, personnel equipment limitations, crew hazards, supplementary equipment requirements, mobility and dexterity limitations, and training requirements.

In addition to the EVA experiments, the first 10 shuttle missions involve a considerable amount of EVA and IVA (Reference [14]). Most of these EVA events involve deployment of the "Telefactor", a remote maneuvering vehicle which has manipulator arms. The telefactor contains a television camera which relays pictures to the operator inside the shuttle. The telefactor is unstowed and inspected by an EVA crewman prior to use, and is stowed by an EVA crewman subsequent to use. Cargo in the cargo bay of the shuttle, which is unpressurized, is secured by an EVA crewman prior to any maneuvers which include significant acceleration, such as orbit change or reentry.

The full extent of EVA on future space missions, and particularly on the space shuttle orbiter, is difficult to assess at this time. There is considerable interest in replacing man in EVA with "teleoperators", such as described in Reference [5], or in augmenting man with an Independent Manned Manipulator" (References [5] and [6]). There are also significant efforts being conducted on the performance of man in zero-gravity in EVA or IVA, such as discussed in References [7] and [18]. In the final analysis the choice of man or machine for performance of work external to spacecraft will be decided by experience and actual on-site evaluation and comparison of EVA systems using man, man combined with machines, and teleoperators. Although there may be doubt that man will be the optimum system for effecting crew transfer, cargo transfer, inspection, assembly, etc., there is no doubt that suitable crew equipment will be required for men participating in the evaluation and comparison with other potential systems.

Because of the considerable uncertainty in the direction and sequencing of the space program in the future, an attempt was made to establish guidelines and constraints which cover a broad spectrum of potential programs. There is better definition of the space shuttle program than of potential future programs involving planetary expeditions, but even in the case of the shuttle, there is considerable uncertainty in the amount and nature of EVA which may be employed. For the planetary portions of the study, an ambitious program involving substantial amounts of EVA (compared to the 73-1/2 EVA hours spent on the lunar surface through Apollo 15) has been assumed as the upper extreme because, if the manned space program is to continue, man must be capable of performing useful work in space and on planetary bodies, and undoubtedly, much of that work must be performed outside of the primary vehicle or shelter (Reference [19]).

3.2 AEPS SPECIFICATIONS

The specification used in this study is taken, in part, from the NASA-Ames Research Center Statement of Work (SOW) for AEPS (Table 1) (Reference [20]), and is presented in Table 2. This specification was not regarded as being inviolable, but was considered to be a guideline for use except where it was possible to demonstrate that a significant advantage could be gained by modifying it. The specifications for parameters such as metabolic load are deliberately chosen to be conservative. The intent was to overdesign the AEPS equipment so that the equipment would not limit the man's performance under any reasonable circumstances.

Based on the foregoing discussion of the shuttle program and a review of pertinent documents given in the Bibliography, the following set of basic requirements for shuttle EVA equipment has evolved (it should be noted that the same set of equipment might not satisfy all requirements):

(1) The donning and doffing time for the EVA equipment should be minimal.

TABLE 2 GENERAL AEPS SPECIFICATION

EVA DURATION (AT AVERAGE METABOLIC RATE)	SPACE SHUTTLE – UP TO 4 HOURS OTHER AEPS MISSIONS – UP TO 8 HOURS
FREQUENCY OF MISSIONS	1 PER DAY (MAXIMUM OF 3 – 2 MAN EVA'S IN 24 HOURS)
MOBILITY	AEPS SHALL PROVIDE MINIMUM ENCUMBRANCE TO THE CREW MAN IN PERFORMANCE OF MISSION TASKS, CAPABLE OF NON-UMBILICAL OPERATION WHEN REQUIRED.
CENTER OF GRAVITY	CG OF THE EVA SUIT AND LIFE SUPPORT ELEMENTS ATTACHED TO OR INTEGRATED WITH THE SUIT SHALL NOT SHIFT MORE THAN ± 3 INCHES FROM THE CG OF THE NUDE CREWMAN.
SUIT GAS COMPOSITION	3.7 – 8.0 PSIA PURE OXYGEN OR O_2 – N_2 MIXTURE
HUMIDITY CONTROL a. NOMINAL SUIT INLET DEW POINT b. MAXIMAL SUIT INLET DEW POINT	 45°F 60°F
VENTILATION (MINIMAL) a. INLET FLOW RATE b. INLET GAS TEMPERATURE c. SUIT LEAKAGE	 9 ACFM 50 – 70°F 180 SCCM
CONTAMINATION CONTROL a. NOMINAL INLET TO SUIT CO_2 LEVEL b. MAXIMUM INLET CO_2 LEVEL c. EMERGENCY MAXIMUM d. ODOR LEVEL	 4 MM Hg (NO MIXING IN FACE REGION) 7.5 MM Hg 15 MM Hg MUST NOT ADVERSELY AFFECT CREWMAN PERFORMANCE
METABOLIC PROFILE a. AVERAGE PER SORTIE b. PEAK (SUSTAINED) c. MINIMUM d. AVERAGE OVER ALL SORTIES e. AVERAGE DURING EMERGENCY f. PEAK DURING EMERGENCY	 1600 BTU/HR 3500 BTU/HR 250 BTU/HR 1200 BTU/HR – PLANETARY EVA'S 1500 BTU/HR – SHUTTLE EVA'S 1500 BTU/HR 2000 BTU/HR
LIQUID TRANSPORT LOOP FLOW	4 LB/MIN.
THERMAL STORAGE IN BODY a. NOMINAL b. EMERGENCY	 NONE 400 – 750 BTU
LIQUID INLET TEMPERATURE TO SUIT	40° MINIMUM 60°F MAXIMUM
USE WITH VEHICLE OR SHELTER HAVING:	(a) 10 – 14.7 PSIA CABIN PRESSURE (b) 2.7 PSIA OXYGEN WITH DILUENT NITROGEN (c) RELATIVE HUMIDITY 55 ± 5% (d) 65 – 75°F TEMPERATURE
SAFETY	(a) THE SYSTEM SHALL PRECLUDE INJURY TO CREWMAN, SERVICE PERSONNEL, ETC., BECAUSE OF FIRE, EXPLOSION, TOXICITY, CONTAMINATION, AND BURNS OR SHOCK. (b) FAIL-SAFE AS MINIMUM CAPABILITY
OPERATIONAL ENVIRONMENTS	ZERO g, 1/6 g, 0.37 g AND 1 g
DONNING, DOFFING AND CHECK-OUT TIME	MINIMIZE
EMERGENCY DURATION a. SHUTTLE b. SPACE STATION c. LUNAR AND MARS BASE	 ½ HOUR 1 HOUR 2 HOURS

(2) Pre-oxygenation for removal of nitrogen from the body prior to EVA should be avoided if possible because of the amount of time required; crew time is expensive, and it may not be available in emergency situations.

(3) Overboard venting of gases and vapors should be minimized for EVA in the vicinity of experiments involving astronomy and earth observations.

(4) All systems should be operable in a pressurized environment to simplify pre-EVA checkout.

(5) The EVA life support equipment should be compatible with a separate self maneuvering unit. (This is necessary for personnel rescue and transfer operations).

(6) The EVA equipment should be easily and quickly recharged and serviced.

(7) The EVA equipment should be reusable on many shuttle flights.

(8) Complete reliance on umbilicals should be avoided, particularly for equipment which may be used in emergency situations.

(9) Checkout time for the EVA equipment should be minimal.

(10) Water for use in EVA heat rejection equipment is abundant at little or no penalty.

The missions included in this study involved EVA operations from a space shuttle, a space station in earth orbit, on the lunar surface, and on Mars. With the exception of the shuttle, the primary vehicle life support systems for these missions are not well defined at this time, however, the parameters given in Table 3 were adopted as a guideline. Except for shuttle-based EVA's, it was assumed that a minimum of two men would participate in each sortie , and the number of EVA sorties on a mission was taken to be a study variable with an upper limit as given in Table 3. The specification calls for one sortie per day, so the study baselines the support equipment to meet this requirement; however, less frequent EVA events are also considered. This is significant to the heat rejection system, which is sensitive to the external thermal environment, which varies considerably on the lunar surface and also influences the base penalties required for power, heating, cooling, etc.

The baseline primary vehicle life support systems are also shown in Table 3. The shuttle uses expendables for life support due to the short duration missions. For the other AEPS missions, it was assumed that the primary vehicle or shelter contains a closed life support system. Except for the shuttle, the exact nature of the carbon dioxide collection and reduction equipment was not specified; however, it was assumed that this equipment was sized large enough to accommodate the carbon dioxide which might be released during regeneration of the carbon dioxide sorbent used in the AEPS. It was

TABLE 3 PRIMARY VEHICLE BASELINE LIFE SUPPORT SYSTEM AND ENERGY PENALTIES

	SPACE SHUTTLE	SPACE STATION	LUNAR BASE	MARS BASE
NUMBER OF CREWMEN	4	6 TO 50	6 TO 12	6 TO 12
MAXIMUM NUMBER OF EVA'S (2 MEN PER EVA)	30	500	500	500
MAXIMUM MISSION DURATION (DAYS)	30	365	365	550
RESUPPLY INTERVAL (MO)	NONE	6	12	NONE
POWER PENALTY (LBM/KW)	325 + 1.275 LBM/KWH (1)	500	500	500
PROCESS HEAT UP TO 300°F (LBM/KW) (2)	100 (3)	100	100	100
PROCESS COOLING DOWN TO 40°F (LBM/KW) (2)	100	50	50	50
BASE EQUIPMENT (FT^3/LBM) VOLUME PENALTY (FT^3 KW)	0.025 125	0.025 125	0.025 125	0.025 125
CABIN PRESSURE (PSIA)	10 – 14.7	14.7	14.7	14.7
DILUENT GAS	N_2	N_2	N_2	N_2
OXYGEN PARTIAL PRESSURE (PSIA)	3.0 – 3.35	3.25	3.25	3.25
CO_2 PARTIAL PRESSURE (MM HgA)	5.0	<5.0	<5.0	<5.0
CO_2 CONCENTRATOR	LiOH	REGENERABLE	REGENERABLE	REGENERABLE
CO_2 REDUCTION – O_2 PRODUCTION	NONE	REGENERABLE	REGENERABLE	REGENERABLE
WATER AVAILABILITY	EXCESS WATER MAY BE AVAILABLE	LIMITED	LIMITED	LIMITED

(1) FUEL CELL POWER

(2) SPECIALIZED AEPS EQUIPMENT REQUIRED FOR INCREASED TEMPERATURE RANGE EVALUATED INDIVIDUALLY

(3) WASTE HEAT LESS THAN 150°F AVAILABLE AT NO PENALTY

assumed that this capability was provided in the primary vehicle or shelter. The capacity of this base O_2 reclamation system may have to be increased because the average metabolic rate of a crewman may be greater during an EVA than it is at the base. Therefore, the crewman may generate more CO_2 during the 8 hours of EVA than he would if he remained at the base.

The atmosphere in the primary vehicle or shelter was assumed to be comprised of the proper proportions of oxygen and nitrogen at a pressure of 10 psia to 14.7 psia, as required in the specification. It was assumed that the AEPS uses a pure oxygen atmosphere, after preliminary evaluation of a two-gas system. It was found that a two gas suit would require N_2 to be made up during the EVA since leakage would result in a gradual decrease in the residual N_2 left in the suit from the cabin atmosphere. The only advantage of a high pressure, two gas suit is the elimination of possible difficulty with the "bends" (see Section 4.7) that might be encountered when transitioning from a 14.7 psia, O_2-N_2 cabin atmosphere to a low pressure suit. However, available physiological data indicates that pure O_2 suit pressures up to about 8 psia can be used for EVA equipment with no oxygen toxicity problems. This atmosphere would remove the nitrogen from the crewman's body during the course of the EVA so that the "bends" would not result following an emergency suit decompression. The crewman can thus go directly from a 14.7 psia, O_2-N_2 atmosphere to an 8 psia, O_2, suit with no pre-conditioning time or equipment required for removal of dissolved N_2 from his body. This requires an improvement in suit technology but high pressure suits have been demonstrated (Reference 23) and no technological breakthroughs are required. More detailed physiological data are required to determine the upper and lower limits of suit O_2 pressure that can be used without requiring prebreathing for N_2 removal.

It was assumed that electrical power, process heat, and process cooling were available for use in regeneration of AEPS components. The penalties (References [21] and [22]) assumed for these services are given in Table 3.

With the exception of the shuttle, the same penalty factors are used for all missions, although it is recognized that the exact penalty would depend on the nature of the mission, and the time frame in which it is carried out. The penalties are considered to be representative nominal values, and to be realistic for use in a study such as this.

3.3 ASTRONAUT LOCOMOTION AND MOBILITY

As astronaut requires some means of locomotion in order to function effectively during EVA. In an orbital environment some provisions must be made to enhance mobility. In most instances the distances which must be traversed are small. The means available are:

(1) Handholds on the vehicle (probably with a tether)

(2) Astronaut maneuvering unit (with or without a tether)

(3) Maneuvering Work Platform or Space Taxi (a small one-man vehicle)

Any one or all of these techniques could eventually be used in space. For this study the first two possibilities are considered. The third alternative could support activity of the first two types, and might well include a closed cabin and sophisticated life support system; for this reason it is not considered in this study.

On planetary surfaces the locomotion techniques available to the crewman are:

(1) Walk

(2) Walk supported by an equipment transporter similar to the Modular Equipment Transporter(MET)

(3) Ride a small powered vehicle such as the Lunar Rover on Apollo 15.

The crewman can walk about freely, as was witnessed on the Apollo flights; however, the range which can be covered by a man walking in a space suit over rugged terrain, with no paths or trails, is very limited. For this reason, it was assumed that the astronaut would not operate at a distance of more than a one-hour walk from a support vehicle of some sort. The support vehicle might take the form of a cart, such as the Modular Equipment Transporter (MET) used on the Apollo 14 mission, or it might be a powered vehicle, such as the lunar rover. Support might also be provided by a larger powered vehicle which could contain a relatively sophisticated life support system.

There are two fundamentally different methods of carrying out life support functions with the aid of a supporting vehicle. They are to connect the crewman to the vehicle by means of a part or full-time umbilical, or to carry replaceable modules that can be used during the EVA. The simplest form of umbilical is one that supplies electric power only. A liquid cooling umbilical would be slightly larger and more restrictive, while a gas umbilical is the largest and most difficult to use. Both the umbilical and modular methods were considered and it was found that the choice of which is superior can only be made at the detailed mission planning stage.

The umbilical restricts the EVA mobility for some operations, but this may not be a handicap for activities such as driving a rover, etc. However, it was decided that any umbilical system must retain the capability to operate without the umbilical, since this may be required for emergencies or for some missions. The optimum systems used for non-umbilical operation might use expendables, since proper EVA planning would minimize the time they would be used.

The modular approach does not impose a mobility restriction during normal operation. It is assumed that the crewman can return to his support cart at convenient intervals (every 1-2 hours) and replace spent modules with fresh ones. This would allow concepts such as fusible heat sinks, which might be too large to carry conveniently, to be split into more easily manageable segments. However, this approach does consume EVA time for replacement of the modules and there is a potential reliability problem in the replacement mechanism. It was assumed that any modular system must also retain the capability to operate without the support modules for missions where this may be required. This operation can be done with a penalty in expendables. The modular approach has the advantage that the EVA weight can be optimized for different duration EVA's, by only carrying a sufficient number of modules to satisfy the desired EVA duration.

For purposes of this study, the AEPS life support system supporting equipment is assumed to be limited to that which could be carried on the MET and powered "rover" type of vehicles. The larger powered vehicle life support system is not considered in this study.

The mobility of the astronaut is primarily governed by the local gravitational force, the suit mobility, and the mass, volume and center of gravity (c.g.) of the equipment carried by the man. No control can be exercised over the local gravitational force, and the specification establishes the space suit mobility as being similar to the Apollo A7L suit so that weight, volume and c.g. of the portable equipment are the only mobility parameters over which this study has any influence. The specifications limits c.g. shift of the crewman to less than $\pm$ 3 inches. This requirement is difficult to apply to a study of subsystem operational concepts; however, an attempt was made to insure that concepts considered could reasonably be expected to result in a final hardware configuration that would satisfy this constraint. The mass and volume limitations assumed for the life support system by the crewman or on the support equipment are given in Table 4.

TABLE 4 MAXIMUM MASS AND VOLUME REQUIREMENTS

TRANSPORT TECHNIQUE	MASS LB.	VOLUME IN^3
BACKPACK AND OR CHEST PACK*	200	8,600
"MET" TYPE TRANSPORTER	200	8,600
"ROVER" TYPE POWERED VEHICLE	1000	40,000

*BASED ON THE LTV AEROSPACE/USAF ASTRONAUT MANEUVERING UNIT (AMU)

The assumed maximum allowable mass and volume to be carried by the crewman were deliberately chosen on the high side, to reduce the likelihood that an otherwise attractive subsystem concept would be eliminated from consideration because of excessive mass or volume requirements. The assumption was made that detailed integration of an AEPS could be arranged in such a way as to accommodate attractive subsystems, through reduction in mission capability, selection of other subsystems, and/or improved packaging techniques.

3.4 DESIGN ENVIRONMENTS

The design environments for AEPS are given in Table 5.

TABLE 5 AEPS DESIGN ENVIRONMENTS

	EARTH ORBIT	*LUNAR SURFACE	**MARS SURFACE
SOLAR FLUX (BTU/HR FT^2)	442	442	164 TO 240
ALBEDO	0.35	0.07	0.17
EQUIV. SURFACE TEMP (°R)	–	170–760	POLE: 140–470 EQUATOR: 310–590
MEAN GRAV. CONSTANT (g)	–	0.17	0.38
ROTATIONAL PERIOD (HRS)	–	655	24.61
ATMOS. PRESSURE (MB)	0	0	6

*REFERENCE (41)
**REFERENCES (24) AND (25)

In this study it was assumed that the AEPS design could be optimized for each individual operating environment if this was found to be advantageous. This is a departure from the philosophy which guided the Apollo PLSS, which required the unit to be operational in either an orbital (zero-g) environment, or a lunar surface environment.

A brief study of the thermal environments for AEPS was made so that the heat leak into the AEPS from the external environment could be assessed. For earth orbit and on the lunar surface it was assumed that the AEPS space suit was similar to the Apollo A7L suit. The influence of system heat leak on the capacity of the heat rejection system was considered.

The Mars surface has a significant atmospheric pressure (References [24] and [25]) and has high velocity winds at times so that the convective heat transfer produced by these winds must be considered. The atmospheric pressure on Mars is large enough to greatly increase the thermal conductivity across an Apollo type suit, and thus to increase the heat transfer through the suit. The environment on Mars is relatively low in temperature, so this increased conductivity is primarily manifested in an increase in heat loss from the suit. Increasing the heat loss from the suit is beneficial since it reduces the heat load on the primary heat rejection system. The heat loss or gain through the AEPS space suit and support equipment used in the study is given on Figure 3. The values for lunar operation are variable with sun angle; however, for earth orbit and the Mars surface average values have been used for simplicity. There are potential thermal

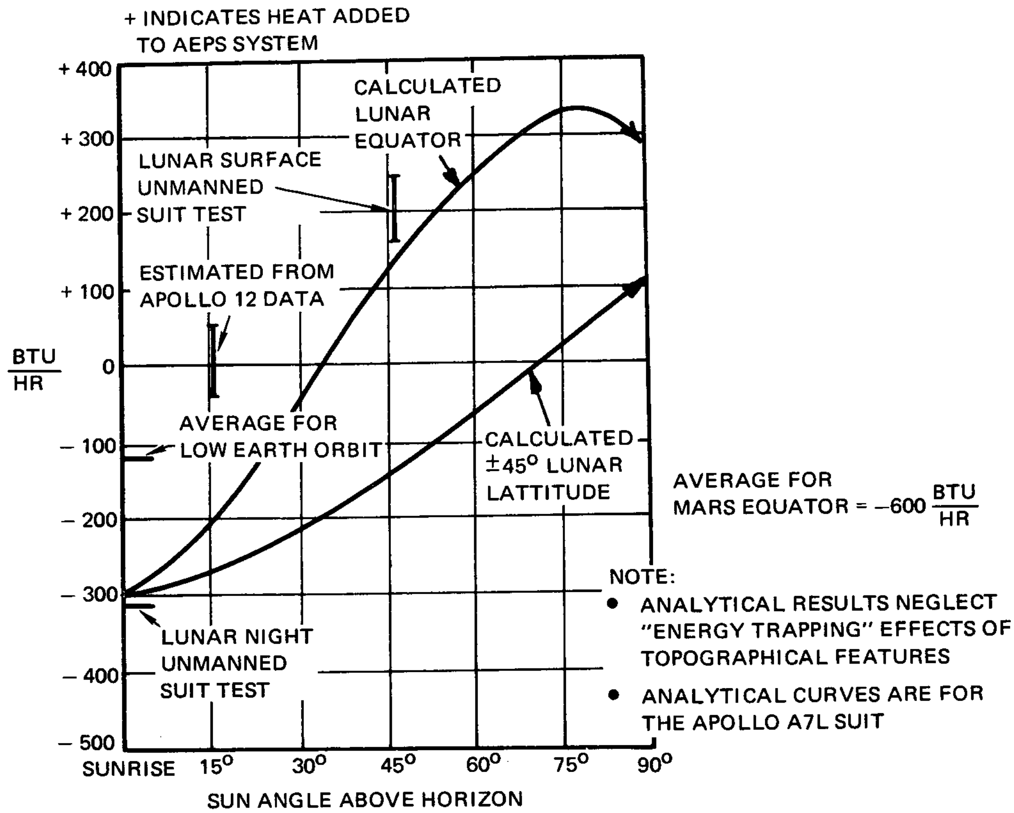


FIGURE 3 AEPS SUIT AND BACKPACK HEAT LEAK

problems with hot and/or cold spots inside the suit; however, these problems were not considered in this study.

The design conditions used for radiator surfaces were as follows: for earth orbit, earth emission, earth albedo, and direct solar radiation were considered; for the lunar surface and for the Mars surface the most severe radiation environment was considered to be the planetary equator. It was found that optical solar reflector (OSR) radiator coatings (α = 0.1, ε = 0.9) would be required for lunar operation of a simple, upward facing radiator. Directional, shielded radiators that would minimize environmental heating were also considered but the size was found to be prohibitive for a portable system. A Mars radiator system could use conventional (α = 0.3) coatings due to the lower sink temperature. No attempt was made to assess the impact of planetary dust on the radiator coating optical properties, although this is recognized as a potential problem area.

3.5 HEAT LOAD

The sources of heat load on the AEPS are:

(1) Crewman metabolic heat

(2) Reactions in the life support system

(3) Suit Heat Leak

(4) Electronic equipment

The crewman is the largest source of heat in the AEPS; the crewman generated heat can range from a basic metabolism rate of around 250 BTU/hr up to the range of 40,000 BTU/hr for short periods (Reference [26]), such as for a man running 100 yards in 10 seconds. The highest measured daily (24 hour) average is about 1300 BTU/hr (Reference [26]). Table 6 presents a summary of the metabolic loads observed to date during the Apollo EVA's.

TABLE 6 APOLLO EVA METABOLIC RATE SUMMARY

		EVA I		EVA II		EVA III		O-g EVA		
		CDR	LMP	CDR	LMP	CDR	LMP	CDR	LMP	CMP
APOLLO 11	AVERAGE (BTU/HR)	800	1100	–	–	–	–	–	–	–
	PEAK (BTU/HR)	1450	1950	–	–	–	–	–	–	–
APOLLO 12	AVERAGE (BTU/HR)	975	1036	672	1042	–	–	–	–	–
	PEAK (BTU/HR)	1680	1380	1710	1510	–	–	–	–	–
APOLLO 14	AVERAGE (BTU/HR)	815	900	907	1070	–	–	–	–	–
	PEAK (BTU/HR)	1175	1560	2490	1885	–	–	–	–	–
APOLLO 15	AVERAGE (BTU/HR)	1097	976	1002	808	1031	810	464	834	940*
	PEAK (BTU/HR)	2200	1700	1200	1500	1900	1700	–	–	2000*

*NOTE CMP PERFORMED ACTUAL EVA, METABOLIC RATE BASED ON HEART RATE ONLY

The AEPS specification calls for a minimum of 250 BTU/hr, an average per sortie of 1600 BTU/hr, and a short-term peak of 3500 BTU/hr.

The crewman performs useful work during EVA; however, a large part of his effort is expended in bending the space suit. Only a fraction of the energy expended by the crewman results in work performed on exterior bodies. For this study, it has been assumed that the crewman performs at an average efficiency of 8% on the basis of work done external to the control volume comprised of the crewman, his suit, and his life support equipment. Typical overall efficiences range from 5 to 35% (Reference [26]). That portion of the crewman's effort which does not go into work outside the suit, is assumed to be converted into frictional heat inside of the control volume. The metabolic heat release inside the control volume is then 92% of the metabolic rate.

Most of the CO_2 control processes which could be used in AEPS produce heat as the CO_2 is removed from the suit atmosphere. This heat is released in the AEPS control volume. For the evaluation of AEPS heat rejection systems, the LiOH heat of reaction in removing CO_2 has been assumed. The equation for this reaction is

$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O(v) + 875\ BTU/lb\ CO_2$$

The water vapor released by this reaction (0.409 lb/lb of CO_2) must be removed in the humidity control system (which requires 438 BTU/lb of CO_2, for simple condensation) so the total heat release is 1313 BTU/lb of CO_2. The CO_2 removal rate can be related to the metabolic rate as follows: For a respiratory quotient of 0.82, the metabolic rate is 4.825 KCal per liter of oxygen consumed (Reference [26]). This is a production of 6081.6 BTU per lb of O_2 consumed, or for a respiratory quotient of 0.82; 5393.7 BTU per lb of CO_2 produced. Thus the ratio of heat release in CO_2 removal to metabolic heat is

$$\text{Ratio} = \frac{1313\ \text{BTU/lb of } CO_2 \text{ reacted}}{5393.7\ \text{BTU/lb of } CO_2 \text{ produced}} = 0.2434$$

For this study, then, the baseline used to evaluate heat rejection systems assumes that an additional amount of energy equal to 24% of the metabolic rate is released in the AEPS carbon dioxide control system.

The heat lost or gained through the suit and the AEPS equipment is given on Figure 3, as discussed previously.

Electrical and electronic equipment heat release was baselined as 50 BTU/hr, a figure similar to that experienced with the Apollo PLSS. This includes the communications equipment, the battery losses, the line losses, the liquid-cooled garment (LCG) pump, and the ventilation fan.

The equation for AEPS heat load is then:

Heat Load = Metabolic Rate (MR) - Useful Work + CO_2 reaction heat release + suit heat leak + electrical equipment heat release

= MR - 0.08 MR + 0.24 MR + Heat Leak (from Figure 3) + 50 BTU/hr

= 1.16 MR + Heat Leak (Figure 3) + 50 BTU/hr

This equation has been plotted parametrically on Figure 4, so that the AEPS

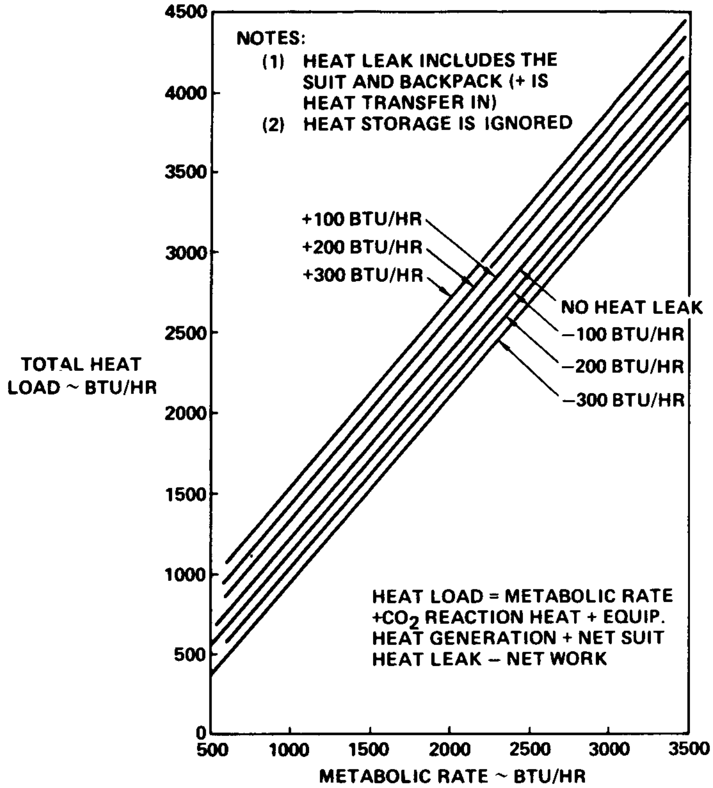


FIGURE 4 ADVANCED EXTRAVEHICULAR PROTECTIVE SYSTEM TOTAL HEAT LOAD

heat load can be read directly from metabolic rate and suit heat leak. The heat rejection system is required to maintain the atmosphere temperature at 60 to 75°F and at a dew point of 45 to 60°F at the inlet to the suit. The specification also requires that the LCG inlet water temperature be as low as 40°F; however, in this study it has been assumed that an improved LCG can be utilized which will allow an inlet temperature of 70°F at the maximum sustained metabolic rate. This assumption allows consideration of some heat rejection techniques which would be impractical if the LCG inlet temperature always had to be 40°F.

3.6 AEPS CONTAMINANTS

The contaminants that must be removed by the AEPS system are primarily products of the crewman's biological processes. The primary contaminants are CO_2, water vapor, and trace gases. All of these substances are produced at sufficiently high rates that they must be removed from the AEPS volume during the course of an EVA. The AEPS subsystems required to maintain these substances within the specifications detailed in Table 1 will be discussed in Sections 4.2, 4.3, and 4.5.

4.0 SUBSYSTEM CONCEPT GENERATION AND ANALYSIS

The life support function subsystems required in an AEPS are shown in the generalized schematic on Figure 5. This section discusses the generation of concepts for the subsystems, and the analysis of those subsystems to establish reasonable weights, volumes, operating characteristics, etc., for use in overall system evaluation. The subsystems considered are:

(1) Atmosphere supply

(2) Carbon dioxide control

(3) Trace contaminant control

(4) Thermal control

(5) Humidity control

(6) Power supply

It is possible that a food and drink supply subsystem and some type of waste management subsystem will be required for a man in an AEPS with an 8-hour sortie duration; however, these subsystems were not considered in this study. New concepts for components such as fans, pumps, valves, etc. were not investigated because the likelihood of substantial improvement in these components is remote. The power supply is included in the study because of the possibility of integration of the power supply with other subsystems, and because there is a high probability that a significant improvement in power supplies can be made in the next decade.

4.1 ATMOSPHERE SUPPLY SUBSYSTEM

The atmosphere for AEPS was specified as pure oxygen at a pressure of 3.7 to 8 psia. The use of a high pressure one or two-gas atmosphere system would reduce the preparation time for EVA, since an oxygen preconditioning period to reduce the nitrogen content in the crewman's body, would not be required. This would also simplify the design and reduce the weight of the parent vehicle or shelter since the oxygen preconditioning equipment would be eliminated. However, the two-gas atmosphere requires higher suit pressures, and greatly increases the risk associated with rapid decompression in the event of a suit gas leak. Some investigation was made into the use of two-gas suits; however, most of the effort concerned only the pure oxygen suit atmosphere. This topic is discussed in more detail in Section 4.7 on emergency backup equipment.

4.1.1 Candidate Subsystem Concepts

In selection of the atmosphere supply subsystem for AEPS it was assumed that a closed circulation system would prove to be most desirable,

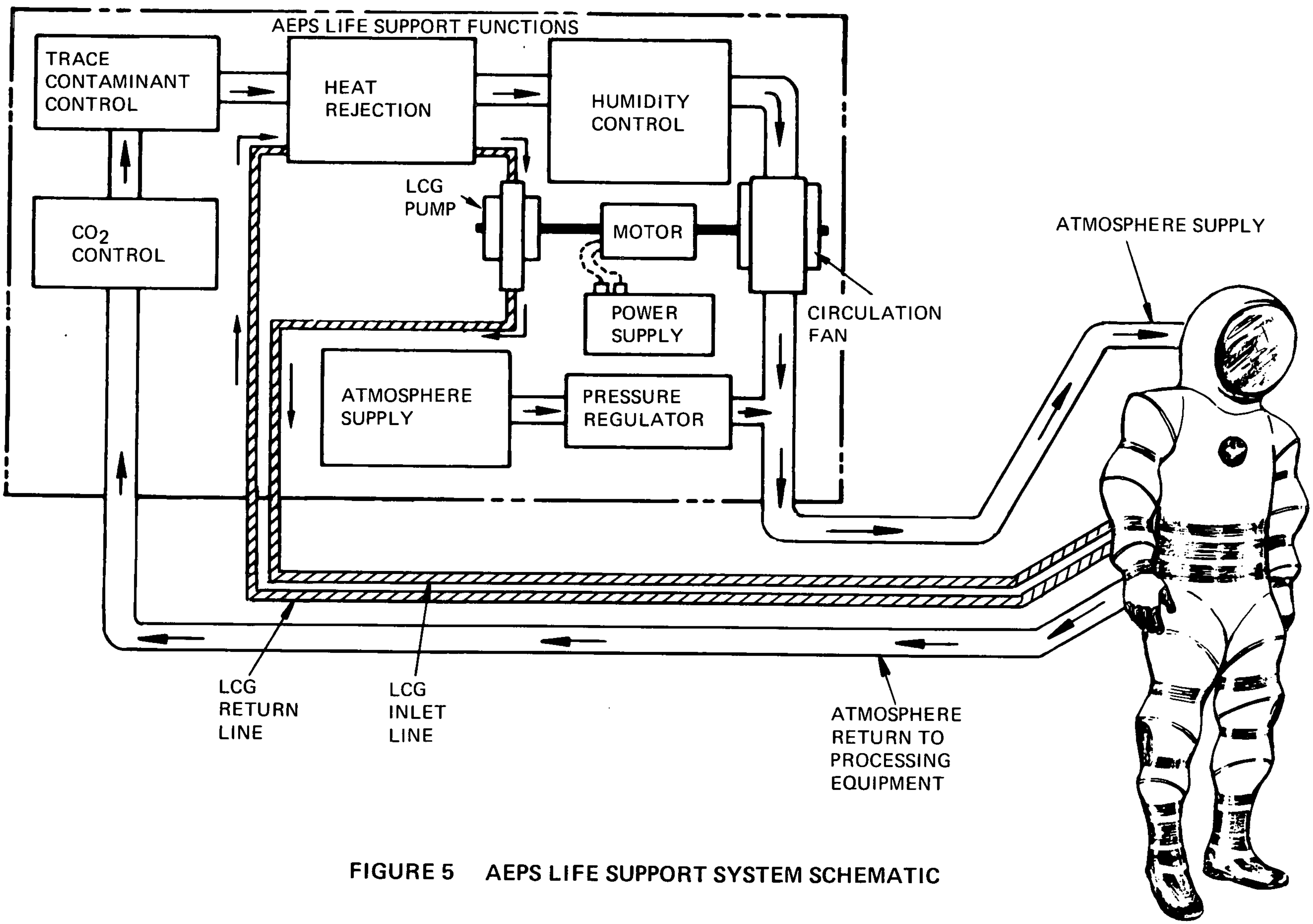


FIGURE 5 AEPS LIFE SUPPORT SYSTEM SCHEMATIC

that is, that the atmosphere supply subsystem must only makeup suit leakage and metabolic oxygen consumption. Open loop systems, which depend on an umbilical to the primary vehicle, were considered at the total system level (Section 5.0). The various methods of providing the atmosphere for AEPS which were considered in this study are listed in Table 7. The basic techniques considered included elemental oxygen storage, chemical storage, and regeneration of oxygen from carbon dioxide. Table 7 shows the results of the preliminary analyses on oxygen supply systems. The regeneration of oxygen from carbon dioxide interfaces with the carbon dioxide control subsystem which is discussed in Section 4.2. However, a carbon dioxide concentrator is required in addition to the oxygen generation device, except for the fused salt technique. All of these CO_2 reduction/O_2 generation systems are large in weight, have large power requirements, and are relatively complex. These factors, coupled with the availability of more suitable approaches, makes the EVA regeneration of oxygen from carbon dioxide in an AEPS an unrealistic approach.

There are some chemical systems which react with carbon dioxide to form oxygen: however, there is a problem in regulation of the oxygen production to match metabolic demand in a space suit. This imposes a requirement for an accumulator, a supplemental oxygen supply or both; the supplemental supply is particularly important if emergency conditions are considered.

The primary vehicle or shelter oxygen supply system has some impact on the AEPS; and it should not be selected without consideration of this interface. The use of high pressure gas storage in AEPS may create a requirement for an oxygen compressor in the primary vehicle or shelter. This approach is compatible with any probable primary vehicle or shelter oxygen supply system. In many possible AEPS designs, the requirement for EVA oxygen will exceed the primary vehicle or shelter make-up oxygen requirement, and the addition of the EVA oxygen to the make-up oxygen supply may have a significant influence on the selection of the primary vehicle or shelter oxygen storage technique.

In addition to the usual methods of storing oxygen, which were discussed in the preceeding paragraphs, there are two additional oxygen supply sources which will have to be considered for the primary vehicle or shelter. These are:

(1) If frozen food is used extensively on future missions, in lieu of freeze-dried foods, then a considerable amount of water will be available from the waste water recovery system after the food is consumed and digested by the crew (Reference [22]). This water can be electrolyzed to generate oxygen.

(2) Studies have shown that oxygen can be generated from the lunar soil (and probably from Martian soil, see References [27] through [30]). The most likely reason for establishing such a process plant would be for production of oxygen for use in propulsion systems. These requirements would be much greater than those

TABLE 7 COMPARISONS OF CANDIDATE OXYGEN SUPPLY TECHNIQUES

STORAGE METHOD	AVAILABLE O_2 (THEORETICAL), WEIGHT %	PURITY	AVAILABLE O_2, LB/LB	SYSTEM DENSITY, LB/CU IN.	HEAT OF REACTION, BTU/LB[2]	O_2 DENSITY, LB/CU IN.
KO_2	33.8	–	0.32	0.0237	415[3]	0.0076
NaO_2	43.6	0.90	0.392	–	635[4]	(0.009)
Li_2O_2	34.8	(1)	0.375	0.0074	– 363[5]	0.029 TO 0.006
NaO_3	56.3	–	–	–	+ 1515	–
$LiNO_3$	23.2	1.00	0.232	0.0861	– 488	0.020
$LiClO_4$	60.1	1.00	0.601	0.0878	– 596	0.053
$NaClO_3$	45.1	–	0.40	0.0815	+ 422	0.032
H_2O	88.8	0.99+	0.89	0.0361	(8)	0.032
90% H_2O_2	47.1	0.90	0.423	0.0502	+ 1106	0.021
98% H_2O_2	47.1	0.98	0.461	0.0515	1214	0.026
GASEOUS	95 +	0.99+	0.50[6][9]	(3000 PSIA) 0.0105	–	0.0115[7]
SUPER-CRITICAL	95 +	0.99+	0.76[6][9]	0.021	–	0.035[7]
SUB-CRITICAL	95 +	0.99+	0.84[6][9]	0.022	– 92	0.041[7]

(1) 10 PERCENT Li_2O_4

(2) + INDICATES EXOTHERMIC REACTION; – INDICATES ENDOTHERMIC REACTION

(3) $2\ KO_2 + 1.23\ CO_2 + 0.23\ H_2O = 0.77\ K_2CO_3 + 0.45\ KHCO_3 + 1.5\ O_2$

(4) $2\ NaO_2 + 1.23\ CO_2 + 0.23\ H_2O = 0.77\ NaO_2CO_3 + 0.46\ NaHCO_3 + 1.5\ O_2$

(5) $Li_2O_2 = Li_2O + 1/2\ O_2$

(6) INCLUDING STORAGE TANK

(7) EXCLUDING STORAGE OR CONTAINING VESSEL

(8) POWER REQUIRED FOR ELECTROLYSIS

(9) BASED ON A SPHERICAL TANK AND 2 LBS OF DELIVERABLE O_2

for metabolic oxygen supply, and so should make EVA oxygen relatively inexpensive.

If either of the above systems were selected for use in a future mission, it might reduce the cost of oxygen (that is, greatly increase the availability), and this could have an impact on subsystem selection for AEPS.

4.1.2 Recommended Subsystem Concept

It was concluded that for the EVA pack, high pressure (3000 - 6000 psia) gaseous oxygen storage is the optimum method for AEPS regardless of the nature of the primary vehicle. This method combines low EVA weight and volume with maximum reliability and ease of integration with base systems; and it offers advantages in emergency situations. It is compatible with any base system since a compressor can be used to fill the EVA tanks directly from the base atmosphere if desired. The construction of such a tank, pressure regulator, and compressor, is well within present technology and improvements in materials, etc., will further reduce the tank weight and volume.

A detailed sizing analysis was performed for a 5000 psia oxygen supply tank. The tank is assumed to be spherical, to be constructed of stainless steel, and ot have a service life of several hundred cycles spread over a number of years. For an 8-hour EVA it contains 2.76 lbm of useable oxygen, weighs 10.5 lbm including mounts, etc., and occupies 213 cu.in. Stainless steel construction at low stress levels was chosen over more exotic techniques because the tank must have a long cycle life, and is in a service where exacting cleanliness procedures cannot be carefully observed. This suggests a design approach such as that described in Reference [40]. The tank also includes an inner shell that functions as a regenerative heat exchanger which insures heat transfer from the tank to the oxygen during rapid gas expulsion in a zero-gravity environment. This regenerator will not be required for many possible system designs. The design approach coupled with the regenerative heat exchanger result in a heavier oxygen supply system than is indicated in Table 7.

For an AEPS used with a long duration primary base which includes a CO_2 reduction facility, the only oxygen expended for most AEPS systems is that due to leakage. This quantity of gas is included in the CO_2 subsystem analysis below. In the case of the space shuttle, the oxygen, which is converted to CO_2 during an EVA, must be considered to be an expendable. Figure 6(a) shows the expendable weight for different storage pressures and oxygen supply sources as a function of EVA time. It should be noted that the mass shown in this figure for supply systems which utilize a compressor to charge EVA tanks from the basic shuttle metabolic oxygen source, is not entirely chargeable to the EVA system since this gas would have been used by the crewman whether he performed an EVA event or not. Figure 6(b) shows a comparison of the mass and volume of oxygen required for open-loop operation, in which CO_2 control is achieved by venting oxygen overboard, and for systems which have a CO_2 absorption subsystem.

4.2 CARBON DIOXIDE CONTROL SUBSYSTEM

As previously mentioned in Section 4.1, the assumption was made that AEPS would have a closed atmosphere in most cases, and thus that carbon

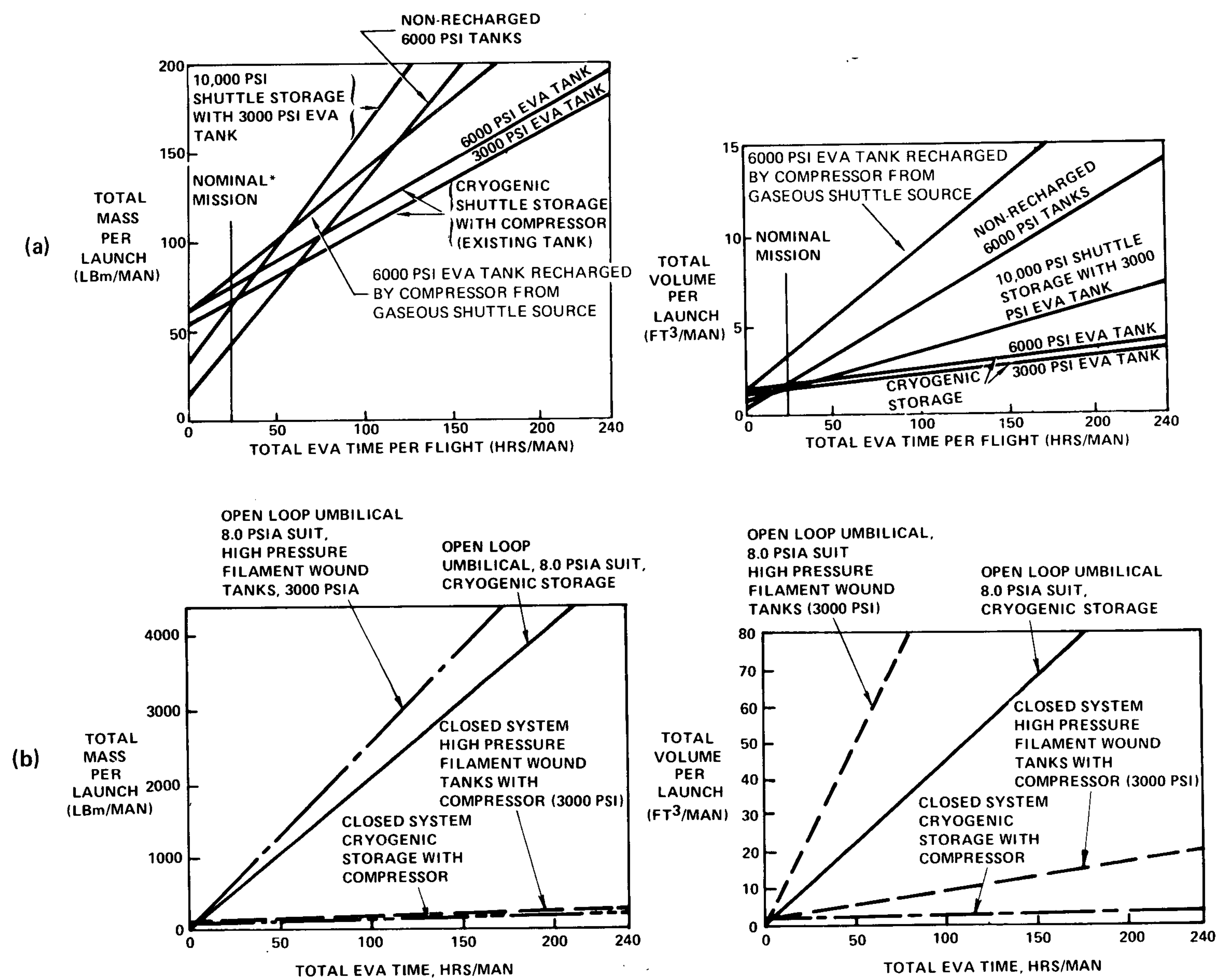


FIGURE 6 COMPARISON OF BASE PENALTIES FOR EVA O_2 SUPPLY SOURCE

dioxide must be removed from the system at a rate proportional to the metabolic rate (since the system volume is too small to provide a significant accumulator or "damping" effect). The alternative to this, which may be attractive for some missions, is an open atmospheric system in which carbon dioxide control is achieved by venting a substantial amount of the atmospheric gas overboard; this system has been used in EVA equipment such as the Astronaut Maneuvering Unit where about 1/4 of the total system flow rate was vented overboard (Reference [31]).. This required about 20 times as much oxygen as the basic suit leakage and metabolic requirements. A more recent open system has been developed (Reference [32]), which uses a breathing vest with a face mask device, and delivers oxygen at the rate it is drawn into the lungs; (approximately 1.8 lb/hr for a metabolic rate of 1600 BTU/hr and a suit pressure of 5 psia).

In this study, as previously noted, it has been assumed that large quantities of oxygen are not readily available, and thus that an open-loop system is undesirable except for very short duration EVA's, or for missions involving few EVA events.

Three levels of regeneration were considered in addition to the expendable system.

(1) A completely EVA regenerable system in which the carbon dioxide is separated from the AEPS atmosphere, and is reduced to generate oxygen by the EVA equipment.

(2) A partially regenerable system in which the carbon dioxide sorbent is regenerated, and the carbon dioxide is vented overboard (the oxygen chemically combined with carbon is thus lost.)

(3) A completely regenerable system in which the carbon dioxide sorbent is regenerated at the parent vehicle or shelter where the carbon dioxide is recovered and is reduced in the parent vehicle life support equipment.

4.2.1 Carbon Dioxide Levels

One of the most significant factors in designing a carbon dioxide control system for a space suit application is the allowable carbon dioxide partial pressure. Early suit designs set the nominal level at 7.5 mm Hg in the oronasal area. This oronasal carbon dioxide partial pressure level is influenced by the helmet design (which influences the removal of the expired gas from the oronasal region), and by the inlet gas carbon dioxide partial pressure which was 4 mm Hg in the early suit designs. Because of controversy surrounding the maximum allowable long term carbon dioxide pressure level, an inlet partial pressure of 2 mm Hg has been used for subsystem sizing when the technique being considered could provide it, without significant penalty. It should be noted that this has some impact on subsystem size in all cases.

The metabolic rate is very significant in sizing the carbon dioxide control system, both from the standpoint of average metabolic rate and maximum metabolic rate, since the rate of CO_2 production is proportional to the metabolic rate and the respiratory quotient.

The respiratory quotient, R.Q., (i.e., volume of CO_2 exhaled/volume of O_2 inhaled) is an indicator of the efficiency of the respiratory and other metabolic processes. Thus, it varies both between individuals and within a given individual as a function of diet and general health. An R.Q. of 0.875 has been recommended for astronauts (Reference [26]), but values ranging from 0.7 to 1.0 have been determined experimentally for a wide range of subjects. A value of 0.97 was assumed for AEPS CO_2 calculations to insure a conservative subsystem design in all cases. The CO_2 production rate is then found to be 0.752 lbm/hr (Reference [26]) at a metabolic rate of 3500 BTU/hr and 0.35 lbm/hr at 1600BTU/hr. At the total mission average metabolic rate of 1200 BTU/hr, 0.26 lbmCO_2/hr are produced. Since the volume of the space suit is relatively small (on the order of 1 cu.ft., or enough volume to contain only 0.0003 lb of CO_2 at a partial pressure of 4 mm Hg), no significant dilution occurs and thus the CO_2 control subsystem must be sized to remove CO_2 at the maximum instantaneous production rate.

The penalty for the oxygen required for an EVA is assigned to the CO_2 control system since, with the assumption of a closed gas circulation system, the bulk of the oxygen required is converted to CO_2. For those systems that collect the CO_2 during the EVA and return it to the base in any chemical form (i.e., carbonates, etc.), a base penalty was assigned for conversion of the CO_2 to the uncombined state.

4.2.2 Gas Separation Ratio

In order to separate two gases, such as oxygen and carbon dioxide, some difference in the physical and/or chemical properties of the two gases must be used to advantage. For the AEPS application the carbon dioxide partial pressure must be reduced to 2 mm Hg while the total pressure is 5-8 psia. The partial pressure ratio of the two gases is then (for the 5 psia case):

$$\frac{P_{CO_2}}{P_{O_2}} = \frac{2\text{mm Hg}}{5\text{ psia}} = \frac{1}{130}$$

The partial pressure ratio represents the mass ratio of the gases; thus the separation potential applied to the system must affect the carbon dioxide by at least a factor of 130 more than it affects oxygen, otherwise as much oxygen as carbon dioxide will be separated out. This is the case with the overboard vent approach.

4.2.3 Recommended Subsystem Concepts

Table 8 shows the most promising CO_2 control methods that were considered for AEPS, along with other concepts which were considered and rejected as being impractical for AEPS. A preliminary screening was used to reduce the number of concepts which were compared by detailed analysis. Concepts discarded at this stage have excessive size or prohibitive regeneration penalties, or no potential for improvement over existing systems. Detailed analysis further reduced these candidates to the following promising candidate subsystems:

- LiOH (expendable)
- Solid Amines (Partially regenerable, i.e., the CO_2 is lost)
- KOH, ZnO, $Mg(OH)_2$ (regenerable at the base)

LiOH is extremely reactive with CO_2 and the LiOH system is the lightest weight and most compact CO_2 control system available. LiOH is thus very satisfactory for missions where a relatively small number of EVA events are required. No other expendable CO_2 control method was found that would be competitive with LiOH from a weight and volume standpoint. It is possible to reverse the CO_2 absorption reaction and recover LiOH from the lithium carbonate (Li_2CO_3) produced during the EVA. However, considerable amounts of energy are required because Li_2CO_3 is relatively insoluble in water, making simple water electrolysis impractical; thermal regeneration is impractical because of the high temperature required. LiOH would absorb 0.92 lb_m CO_2 per lb_m if all of the hydroxide could be converted to carbonate. The actual degree of completion of the reaction is a function of time and other parameters. Approximately 35% completion is typical for a 4 hour Apollo PLSS LiOH canister. The degree of completion can be increased to 50% at 8 hours and 68% after 12 hours. The efficiency consistent with design mission length was used for sizing LiOH canisters.

It was assumed that all of the LiOH required for a given sortie was contained in a single canister which is discarded after the EVA. The utilization efficiency could be increased if the EVA mass were divided into two or three separately replaceable segments. At least one fresh LiOH segment would be installed at the start of each EVA, but each segment would be used for two or more EVA's. This approach could increase the utilization efficiency and thus decrease the LiOH expendable mass by 30 to 40% over a number of EVA's.

Solid amine systems are being researched extensively for use as CO_2 concentrators in primary base life support systems. The most promising solid amine concept for AEPS incorporates a vacuum-vent mode of operation. This concept uses two beds in a cyclic fashion with one bed absorbing CO_2 from the gas stream while the other bed is desorbed to space. The concept is classed as partially expendable because the CO_2 sorbent is reused but the CO_2, along with the water vapor and oxygen contained in the amine bed free volume, is vented to space. Solid amine CO_2 sorbents have a low capacity for CO_2 on a lbm of CO_2 per lbm

TABLE 8 CANDIDATE CO_2 CONTROL METHODS

METHOD	DETAILED ANALYSIS	PRELIMINARY ANALYSIS ONLY	COMMENTS
CHEMICAL EXPENDABLE			
• LiOH	X		GOOD FOR LIMITED NUMBER OF SORTIES
• KO_2, NaO_2		X	NO ADVANTAGE OVER LiOH
• Li_2O_2		X	NO ADVANTAGE OVER LiOH
CHEMICAL, REGENERABLE			
• LiOH	X		HIGH REGENERATION PENALTY
• KOH	X		MODERATE POWER FOR BASE REGENERATION
• ZnO	X		LARGE EVA MASS, LOW REGEN. PENALTY
• KO_2, NaO_2, Li_2O_2		X	EXCESSIVE POWER FOR BASE REGENERATION
• KO_3		X	EXCESSIVE POWER FOR BASE REGENERATION
• $Mg(OH)_2$	X		MODERATE TEMPERATURE FOR REGENERATION
• $Ca(OH)_2$		X	EXCESSIVELY HIGH REGENERATION TEMPERATURE
• Ag_2O		X	LOW CONVERSION EFFICIENCY
ADSORPTION			
• DEAD END MOLE-SIEVES (ZEOLITE)		X	EXCESSIVE EVA MASS AND VOLUME
• VACUUM DESORBED MOLE SIEVES (ZEOLITE)	X		GOOD FOR MODERATE NUMBER OF EVA'S, BUT HAS LARGE EVA MASS AND VOLUME
• VACUUM DESORBED ZEOLITE WITH LiOH "TOP-OFF"	X		EXCESSIVELY LARGE EVA MASS WITHOUT ANY SIGNIFICANT REDUCTION IN EXPENDABLES
• NON-WATER SENSITIVE MOLE-SIEVES		X	NO ADVANTAGE OVER ZEOLITES
ABSORPTION			
• BATCH VACUUM DESORBED SOLID AMINES	X		LARGE EVA MASS; SUITABLE FOR LIMITED NUMBER OF EVA'S
• LIQUID WATER SOLUTION OF AMINES VACUUM DESORBED		X	EXCESSIVE WATER LOSS DURING EVA
• LIQUID WATER SOLUTION OF CARBONATES WITH VACUUM DESORPTION a. LIQUID LOOPS b. MEMBRANES		X	EXCESSIVE WATER LOSS
• DEAD END WATER SOLUTION OF CARBONATES		X	EXCESSIVE EVA SIZE
VACUUM VENT			
• SIMPLE SYSTEM, NO UMBILICAL		X	EXCESSIVE EVA MASS AND EXPENDABLES
• UMBILICAL TO PRIMARY BASE WITH CAPABILITY FOR ONE HR OPERATION OFF OF UMBILICAL	X		SHOWS SOME PROMISE WHEN THE EVA MISSION DOES NOT REQUIRE LONG DURATIONS AT DISTANCES FROM THE SPACE BASE
OTHER			
• CONVERSION OF CO_2 TO WATER BY A BOSCH REACTOR FOR RECOVERY OF O_2 AT BASE		X	VERY HIGH EVA MASS
• H_2-DEPOLARIZED CARBONATION CELL, VACUUM VENT		X	LARGE SYSTEM SIZE, HIGH EXPENDABLES
• VACUUM VENTED SINGLE STAGE CARBONATION CELL		X	HIGH EVA SYSTEM MASS AND POWER, HIGH EXPENDABLES
• Cu/O_2 FUEL CELL CO_2 SORBER		X	LOW CONVERSION EFFICIENCY TO CARBONATE
• ANY SYSTEM CONCENTRATING CO_2 & THEN RECOVERING O_2 DURING THE EVA		X	EXTRAORDINARILY HIGH EVA MASS VOLUMES AND POWER PENALTIES

sorbent basis when compared to chemicals such as LiOH, and they have a lower reaction rate. Thus, the required amine bed size is much larger than a LiOH bed. The amine bed acts as a desiccant so that a separate humidity control system is not required. However, the CO_2 absorption capacity of the bed is critically dependent on the bed's moisture content so that precise control of the bed water content is required for efficient utilization. An operational vacuum desorbed amine unit has not been demonstrated and it is anticipated that bed water management for this type of operation would be difficult. The cyclic operation also requires relatively complex hardware with associated reliability problems. There is no base equipment required for this system since the CO_2 sorbent is regenerated by vacuum venting during the EVA. One potential advantage of this concept is in the adaptation of technology developed for space station applications (which is a steam desorbed rather than a vacuum desorbed system) to reduce development costs. Therefore this concept was retained for consideration at the total, integrated system level. A CO_2 capacity of 0.01 lbm CO_2 per lbm amine was assumed for system sizing calculations, with a delivery CO_2 partial pressure of 4 mm Hg.

The literature survey previously cited provided evidence of some preliminary investigations into the use of other alkaline-earth hydroxides, besides LiOH, as a CO_2 sorbent. All of these materials are very basic and the reaction with the acid gas, CO_2, is basically an acid-base neutralization reaction, with the resulting formation of a carbonate salt and water. These hydroxides all have fairly high CO_2 capacity so that the bed size is comparatively small. LiOH is preferred when the application requires an expendable sorbent because of its low molecular weight and high CO_2 capacity. However, as previously discussed, the chemical properties of the lithium carbonate formed during the EVA reaction are such that regeneration is impractical.

It was found that magnesium carbonate ($MgCO_3$) and zinc carbonate ($ZnCO_3$) are relatively unstable at moderately elevated temperature so that thermal regeneration is possible. The relatively high solubility of potassium carbonate (K_2CO_3) in water suggested the possibility of regeneration by electrolysis of a water solution.

Magnesium and zinc carbonates dissociate into the oxides MgO and ZnO plus CO_2 at elevated temperatures. Thus, if they were used in solid form as a CO_2 sorbent during the EVA, in the same manner that LiOH is presently used, regeneration may be accomplished by simply heating the reacted canisters. The CO_2 will be driven off leaving the metallic oxide, which can then be hydrated to the metallic hydroxide form by circulating wet steam through the bed.

A workable system for the $Mg(OH)_2$ concept is shown in Figure 7. The reactant canister is placed in a heated pressure vessel at the conclusion of the EVA. The system shown uses steam to heat the canister to the required dissociation temperature; however, other types of heat sources could be used. A compressor is used to remove the evolved CO_2 for processing by the base CO_2 reduction system. After all the CO_2 has been driven off, wet steam is introduced into the chamber to hydrate the oxide. The canister can then be

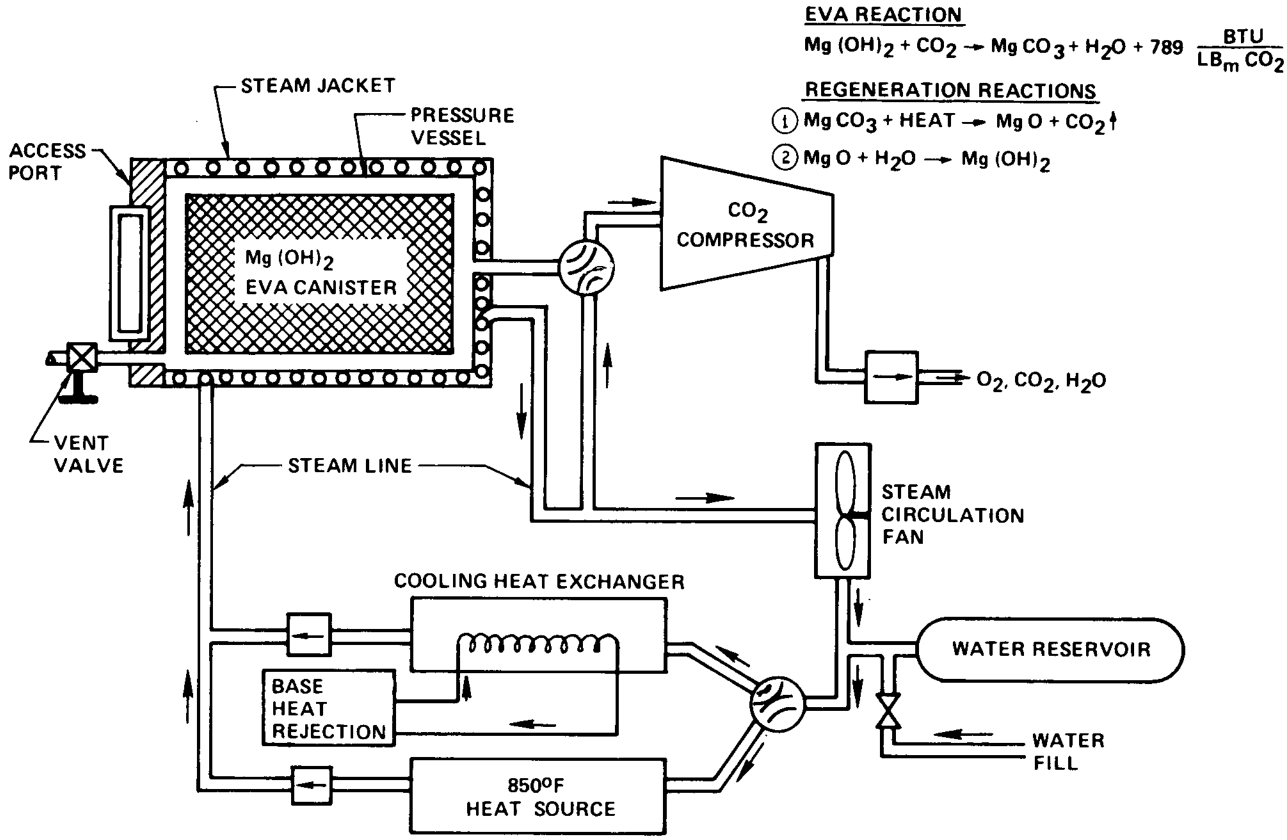


FIGURE 7 MAGNESIUM HYDROXIDE REGENERATION FACILITY

removed and reused. A $Mg(OH)_2$ concept similar to this has been demonstrated (Reference [33]). However, the lifetime of the absorbent pellets after repeated cycling has not been investigated in depth. The pellets may "cake" or disintegrate to powder after a few cycles. Data are needed to determine whether the pellets need to be reformed after each regeneration cycle and to define the conversion efficiency attainable with regeneration within a practical amount of time. A conversion efficiency of 20% was assumed for AEPS sizing calculations. The actual hardware weight required for regeneration of $Mg(OH)_2$ is projected to be about 230 lb_m for a two-man system. The total base penalty calculated for the system is 400 lb_m per two men with the additional weight attributed to energy penalties. Thus, the base weight of the system is strongly dependent on the energy penalties assumed in Table 3.

ZnO is also a candidate for the CO_2 absorbent in this system. Less complete data are available on ZnO than for $Mg(OH)_2$. It appears that active cooling of the ZnO absorbent canister would be required in order to maintain an outlet CO_2 partial pressure of 4 mm Hg (Reference [34]). Thus the EVA weight of the ZnO absorbent may be significantly greater than for the $Mg(OH)_2$ system. However, the low regeneration temperature of ZnO will result in much lower base penalties. For vehicles with waste heat available at 150°F, there may be a minimal penalty for regeneration energy.

During the course of this study, VMSC concieved a different type of metallic hydroxide subsystem which was suggested by a theoretical analysis of energy requirements for regenerable CO_2 absorbents. Figure 8 shows a schematic of this approach, which uses a circulating liquid solution of KOH rather than a solid particle bed.

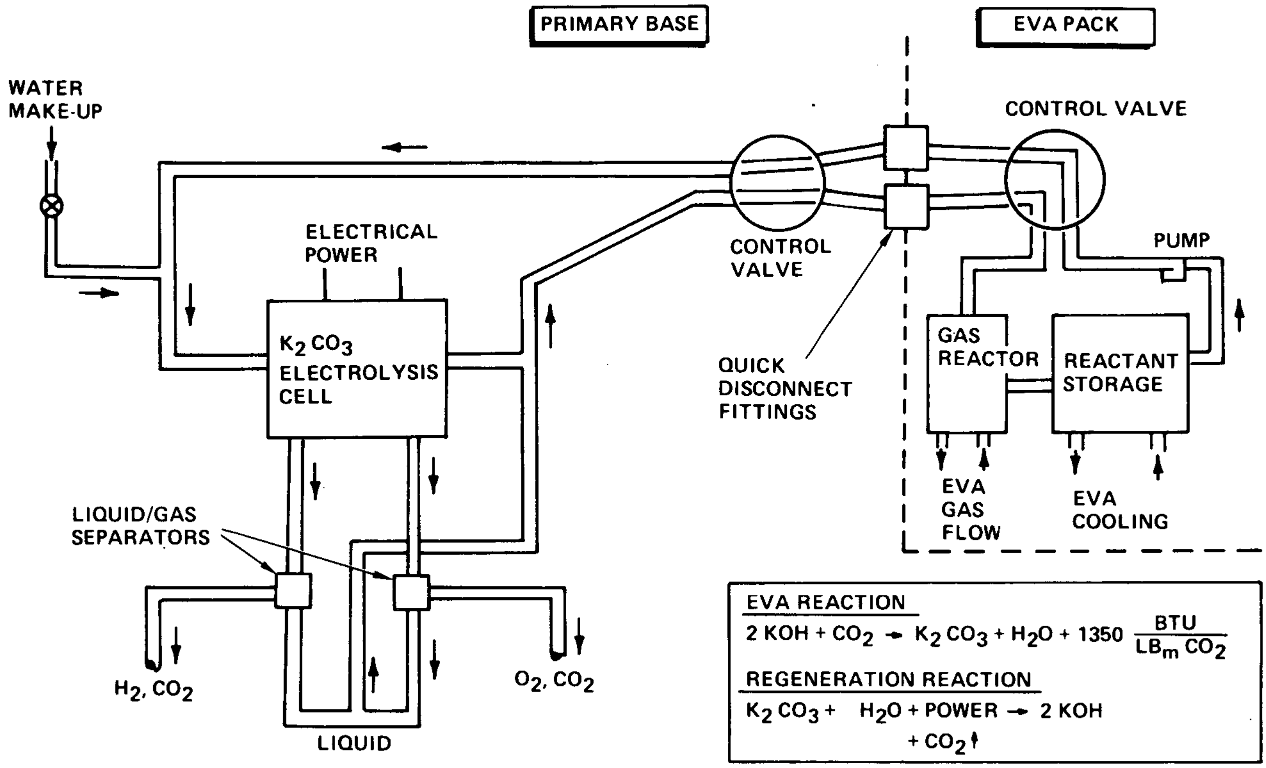


FIGURE 8 LIQUID KOH CO_2 SORBENT REGENERATION FACILITY

This approach overcomes one of the fundamental limitations to efficient utilization of a pelletized sorbent bed, which is the low mass transfer rate of reacted carbonate and unreacted hydroxide inside the pellet.

The circulating liquid approach eliminate this problems since the reacted carbonate is continuously removed from the reaction site by the flowing solvent (water). In operation, the liquid loop is initially filled with a strong solution of KOH in water. The gas, containing CO_2, flows through the gas reactor where it is exposed to the circulating KOH solution. Part of the KOH is reacted to form potassium carbonate (K_2CO_3), which remains in liquid solution, and is circulated to the reactant storage container. There the solution is cooled, decreasing the solubility of the K_2CO_3, so that part of the carbonate is precipitated and can then be filtered out of the solution. The weakened KOH solution is circulated back to the gas reactor. During the EVA the solution strength of the KOH is continually reduced as K+ ions are removed as K_2CO_3 is precipitated out. The concentration of K_2CO_3 in the solution is determined by the solution temperature at the outlet of the reactant storage container and by the efficiency of the filtration process.

Base regeneration, which is also shown in Figure 8, is accomplished by re-dissolving the precipitated carbonate and electrolyzing the resulting solution. The CO_2 is removed in the electrolysis cell and the concentrated solution of KOH is restored; the unit is then ready for reuse.

VMSC has demonstrated the feasibility of this concept by means of a simple experiment. It was found it was not possible to evolve CO_2 at a significant rate without also electrolyzing water. This is not a severe penalty since most advanced base life support systems include a water electrolysis unit for the production of oxygen (Reference [22]). Therefore, a partial credit can be taken for the oxygen produced by this method.

Sizing analyses indicate that the size and weight of the EVA subsystem are comparatively small; however, this is based on very little and incomplete data. There are several significant developmental problems with this concept most notable is the interface between the process gas stream and the KOH solution. The projected total system size for the KOH concept, including all penalties, is comparable to the $Mg(OH)_2$ system previously discussed. Therefore, in order to simplify the discussion at the total system level, these systems were considered to have the same weight and volume. The potential for EVA system size advantage of the KOH system over other regenerable concepts is sufficient to warrant its further investigation.

Figures 9 and 10 show the total launch weight and volume as a function of EVA time for the most promising CO_2 control subsystems. Figure 9 shows that expendable LiOH is the lightest subsystem for less than about 150 EVA hours. The regenerable metallic oxide/hydroxide concepts provide the lightest total systems for more than 150 EVA hours; but as Figure 11 shows, this is accomplished at the expense of the EVA weight. However, this sacrifice is believed to be worthwhile since the regenerable concepts save more than 650 lbm per man over LiOH at 1000 EVA hours. Figure 10 shows total launch weight and volume curves for a primary vehicle with a non-regenerable Atmosphere Revitilization System (ARS), e.g., the space shuttle. It is assumed that the oxygen used during the EVA is an expendable for all systems and this mass and volume are not included in these results. This figure shows that LiOH is the lightest subsystem if less than 35 EVA hours are required on a single flight. For more than approximately 35 hours, the ZnO and solid amine systems, which are regenerable at relatively low temperature, are the lightest. $Mg(OH)_2$, which has a higher regeneration energy penalty, is shown to be somewhat heavier than the other regenerable concepts; this is offset by an advantage in EVA weight as shown in Figure 11. The results presented in these figures were used to prepare similar curves for the total AEPS systems as discussed in Section 5.0.

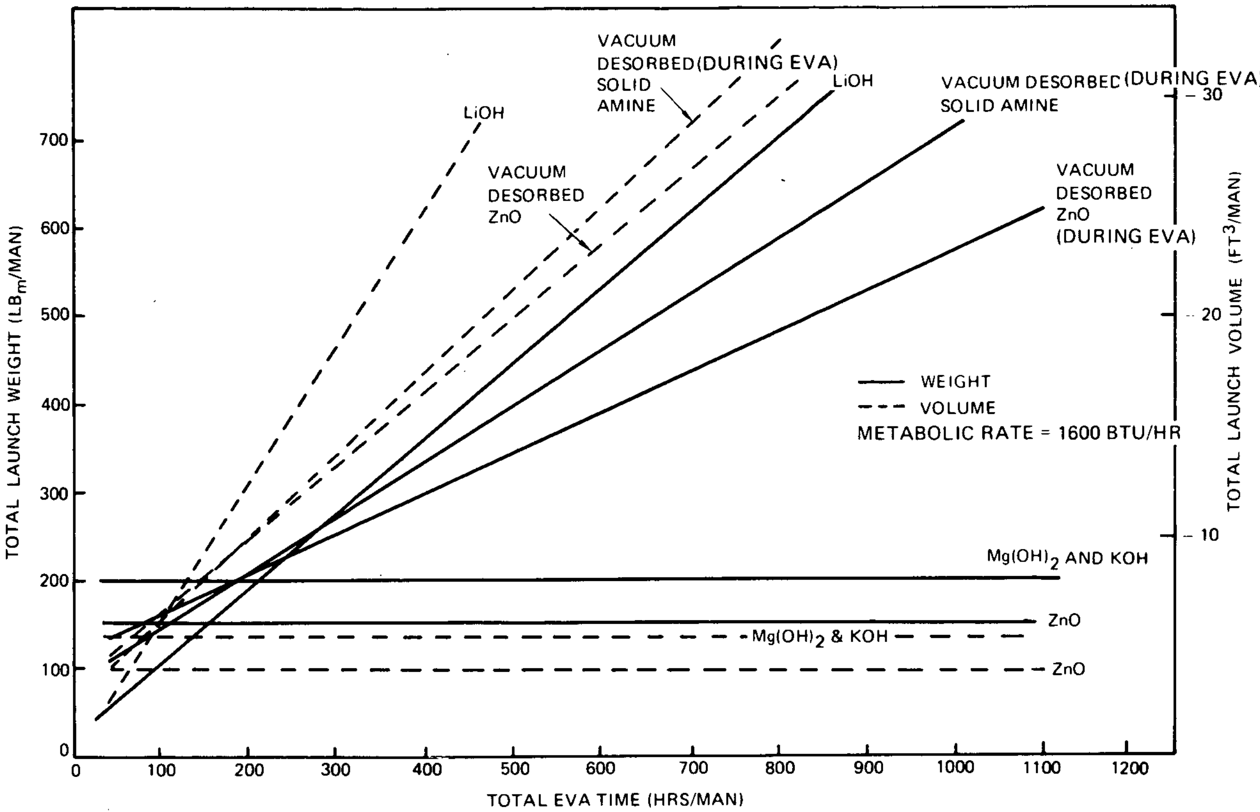


FIGURE 9 COMPARISON OF CANDIDATE CO_2 CONTROL SUBSYSTEMS USED WITH A REGENERABLE BASE ATMOSPHERE REVITALIZATION SYSTEM (ARS)

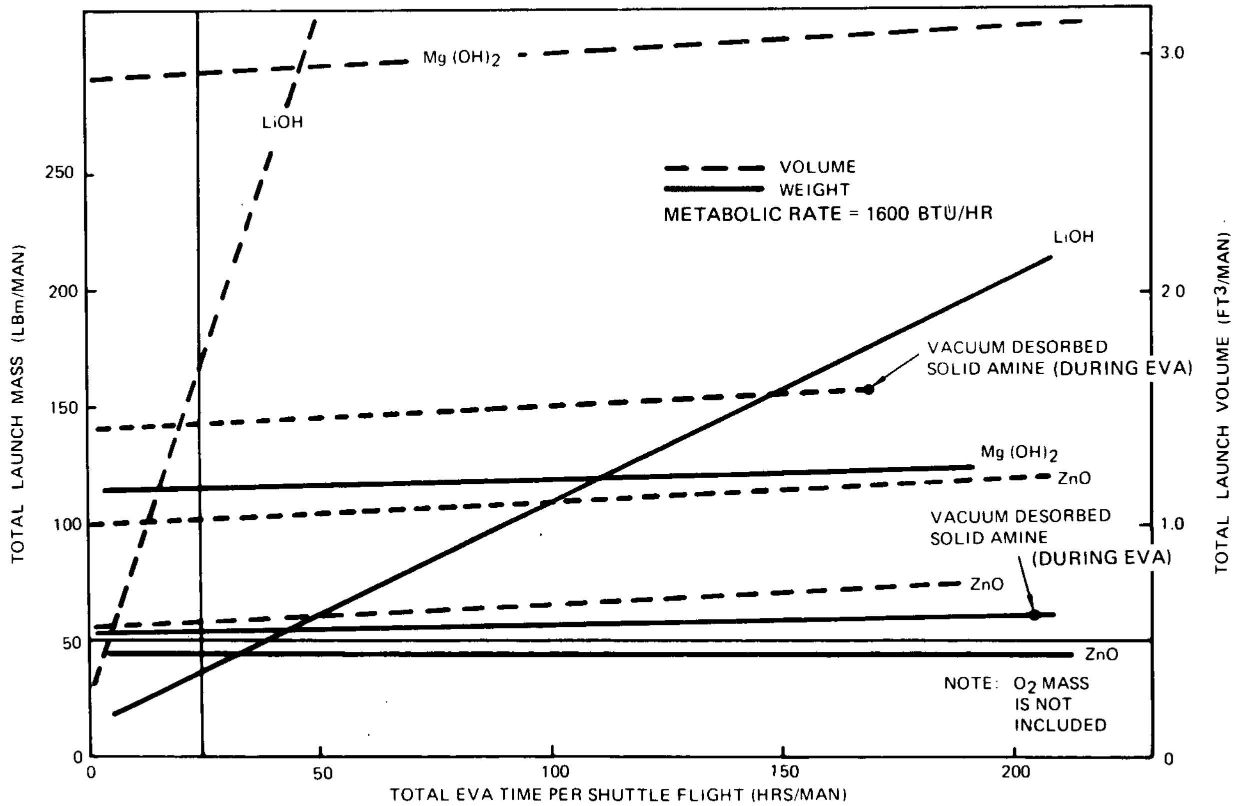
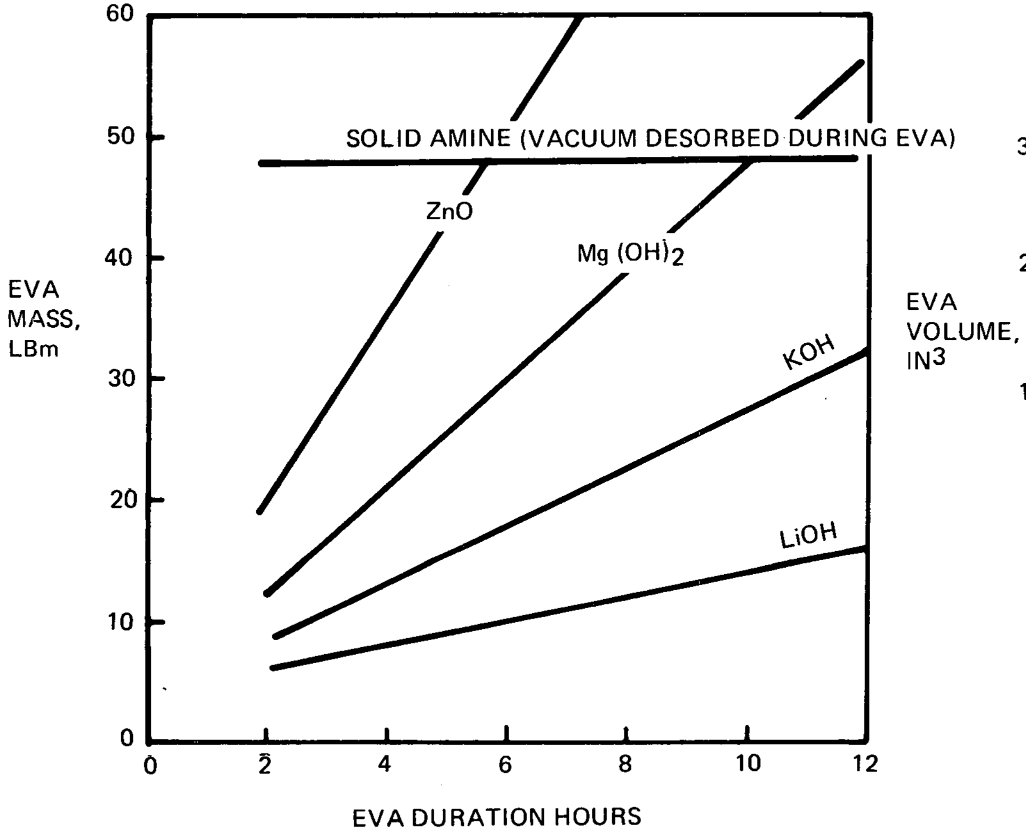
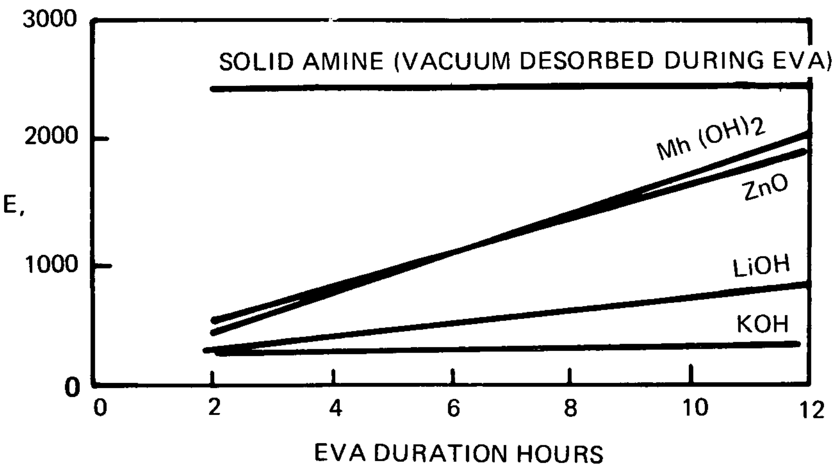


FIGURE 10 COMPARISON OF CANDIDATE CO_2 CONTROL SUBSYSTEMS USED WITH A NON-REGENERABLE ARS, eg. THE SPACE SHUTTLE





NOTE: BASED ON A METABOLIC RATE OF 1600 BTU/HR

FIGURE 11 COMPARISON OF CANDIDATE CO_2 CONTROL SUBSYSTEM EVA WEIGHT & SIZE

4.3 TRACE CONTAMINANT CONTROL SUBSYSTEM

In any inhabited small, closed volume there is a potential problem with odors and toxic gases, and possibly with biological contaminants. The AEPS trace contaminant control system must be designed to eliminate any odors, toxic gases, or biological contaminants which may be generated within the AEPS atmosphere. Considerable investigation has been conducted in this area (References [35] and [37]), and a significant amount of space flight experience has been gained with the Mercury, Gemini, and Apollo spacecraft, and with the Apollo Extravehicular Mobility Unit (EMU). Most of the work done in this field has been directed toward contamination control for long-term occupancy of spacecraft cabins. The AEPS contaminant control problem is similar to the EMU, which is simpler than for the primary base, because of a relatively high leakage rate compared to the suit volume, and a relatively short exposure time. However, the AEPS will be used repeatedly on long duration missions.

There are four primary sources of trace contaminants in a closed life support system:

(1) Volatile materials

(2) Electrical equipment

(3) Chemical processes

(4) Astronaut biological processes

It is assumed that the first two sources can be controlled without an active control system. Careful materials selection will minimize the introduction of odors and toxic vapors into the AEPS environment, and active electrical equipment can be shielded from the pressurized AEPS volume so as to minimize the introduction of ozone and lubricant vapors.

Chemical reactions or processes which may be used to accomplish AEPS functions may also introduce contaminants into the system. For example, chlorate and perchlorate candles, which may be used to supply oxygen, contain fuel (to sustain continuous decomposition), catalysts and binder materials (such as fiberglass). In the relatively simple lithium hydroxide carbon dioxide control system, it is necessary to filter small LiOH particles out of the circulating oxygen. A failure in the gas reactor required for the KOH system could introduce toxic KOH liquid or vapor into the gas stream. These special requirements for trace contaminant control imposed by the life support subsystems will not be considered here; it is assumed that these requirements will be accounted for in the individual component development.

The crewman is the source of a wide variety of noxious and toxic gases; and in addition may be host to a wide variety of micro-organisms. Although these gases are produced by, and the micro-organisms are present in most healthy individuals, they pose a potential hazard in an AEPS. The noxious and toxic gases are treated in this work. The micro-organisms and other bacteriological growths, which may be sustained in the AEPS equipment, particularly in porous plates, filters, and wicks, are not considered in detail. In particular, no attention is given to the possibility of mutation of non-virulent and slightly virulent forms of micro-organisms into species which are much more virulent. It is assumed that in all cases a replaceable biological filter will be used in the circulating oxygen flow; this is the only consideration given to micro-organisms. Biological growths in equipment must be considered on the total AEPS system level. Other problems such as suit and umbilical drying and cleaning are also not considered, although they represent potential problem areas.

A last problem which may be encountered involves cleaning equipment used on planetary surfaces. Dust is known to pose a serious problem on the lunar surface, based on flight experience, and it is difficult to remove from garments and equipment. The full extent and implications of these problems on system design are not known at present; and this was not considered in detail in this study.

The emphasis in this study was placed on the control of trace contaminants generated by the crewman himself, while it is realized that other sources may be present.

4.3.1 Biological Contaminants

Major substances given off by normal human biological processes are presented in Table 9. The most significant of these substances are shown

TABLE 9 TYPICAL BIOLOGICAL CONTAMINANTS

CONTAMINANT	GENERATION RATE (LB/HR)	ALLOWABLE CONC. (P. P. M.)	TOXIC EFFECT	PRINCIPAL SOURCES
AMMONIA	4.15×10^{-5}	10	IRRITANT	FECES, FLATUS, SWEAT
CARBON MONOXIDE	1.15×10^{-6}	20	BLOOD POISON	EXPIRED BREATH
HYDROGEN	8.20×10^{-6}	41,000	ASPHYXIANT	FECES, FLATUS
HYDROGEN SULFIDE	1.79×10^{-8}	2	IRRITANT	FECES, FLATUS
METHANE	7.20×10^{-4}	200 – 50,000	ASPHYXIANT	FECES, FLATUS
METHANOL	4.15×10^{-6}	40	NARCOTIC IRRITANT	EXPIRED BREATH
SULFUR DIOXIDE	4.15×10^{-7}	1	IRRITANT	URINE

along with the generation rate (Reference [35]), the allowable concentration in the AEPS atmosphere, and the probable toxic effect of the contaminant on the human body.

4.3.2 Trace Contaminant Control Techniques

Contaminant control systems for space flight use have been extensively investigated and, for large closed volumes, a system employing a biological filter, charcoal absorbent cartridge and a catalytic burner will maintain all contaminant levels below the recommended maximums. The following control techniques, in order of increasing complexity and size, were considered for the AEPS application:

(1) No active control-leakage only

(2) Periodic suit purge

(3) Biological filter, activated charcoal

(4) Filter, charcoal, and catalytic burner

(5) Chemical control systems

Leakage of the atmosphere out of the spacesuit can be used to control toxic gas concentration, particularly if the generation rate is low. For high generation it may not be feasible to have sufficiently high leakage rates; however, there is preferential leakage for low molecular weight gases.

Contamination control can be achieved in a spacesuit by passive means in some instances. The EVA mission is short, and the generation rate for some toxic gases may be insufficient to raise the toxic gas concentration in the spacesuit free volume above the allowable level. In addition, the normal suit leakage will continually carry some of the toxic gases overboard, so a maximum concentration will be established; for low generation rates this maximum may be below the allowable level. There is also preferential leakage of low molecular weight compounds.

The leakage rate specified for AEPS is 180 sccm which is equivalent to 0.0322 lb_m/hr. This same leakage rate was specified for the Apollo A7L suit. Figure 12 shows the concentration of the various contaminants at the end of 8 hours as a function of active contaminant control system removal efficiency (i.e., removal rate divided by contaminant flowrate; this is 0 for a system based on leakage alone).

These results indicate that methane and ammonia are the only contaminants that may require active control. The other contaminants have sufficiently low generation rates relative to allowable concentrations so that suit leakage only, with about 5% removal efficiency, is adequate to keep the concentrations within allowable limits.

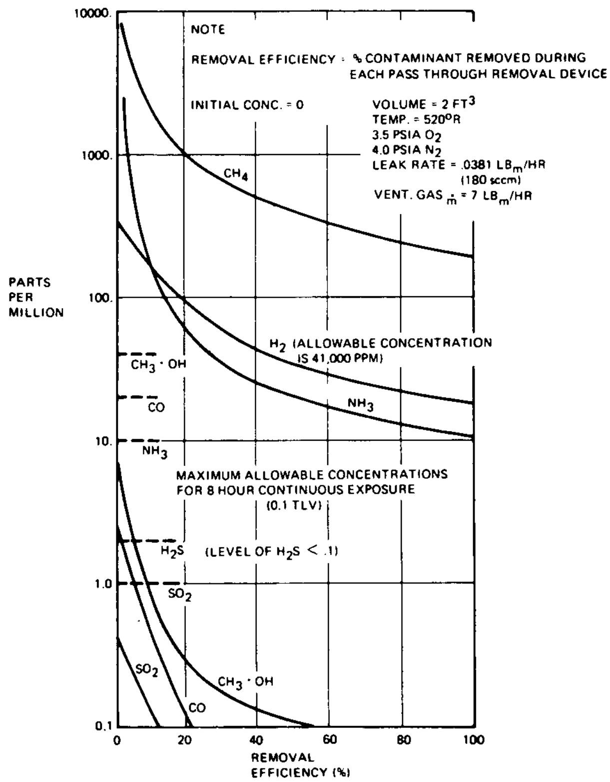


FIGURE 12 TRACE CONTAMINANT CONCENTRATIONS AFTER 8 HOURS AS A FUNCTION OF REMOVAL EFFICIENCY

This result is somewhat misleading since the calculation was made assuming a constant generation rate over the entire EVA. Thus, while substances such as H_2S require little control if only the total mission is considered, the short term odor effects require control consideration. Therefore, suit leakage alone is not sufficient to provide complete control for an AEPS system.

The AEPS space suit could be periodically purged to effectively increase the leakage rate, and thus leakage could provide control for methane and ammonia. However, the required quantity of make-up atmosphere is excessive and safety considerations associated with venting the suit make the purge approach undesirable.

Activated charcoal is widely used for odor removal, and this is very desirable in AEPS. However, charcoal will not effectively adsorb low molecular weight gases such as methane and ammonia. The addition of phosphoric acid (H_2PO_3) to activated charcoal increases the ammonia adsorption capacity, and the addition of potassium hydroxide (KOH) increases the capacity for acid contaminants. Thus, this system is adequate for all contaminants. No other system offers any advantage over this approach and the others were not considered further.

4.3.3 Recommended Concept

A trace contaminant control cartridge containing activated charcoal and biological filters was selected for the AEPS system. The charcoal bed is divided in half with 50% of the charcoal impregnated with a solution of KOH and the remainder with phosphoric acid. The addition of these chemicals improves the adsorption efficiency of acidic and basic contaminants. The cartridge should be located upstream of the humidity control system, since the presence of moisture further improves the adsorption efficiency of the chemically impregnated beds.

The biological filter and the charcoal can be regenerated, however, the expendable weight is only about 0.1 lb_m per man EVA so that regeneration will not be profitable for AEPS unless a great many sorties are undertaken on a mission.

4.4 THERMAL CONTROL SUBSYSTEM

The purpose of the AEPS thermal control subsystem is to maintain the crewman at a comfortable temperature level under all conditions. In addition, other AEPS systems, notably the CO_2 and humidity control systems, may require cooling. The system heat loads were discussed in Sections 3.4 and 3.5.

Gemini experience has shown that gaseous convective cooling of a suited crewman is inadequate when the crewman is working at the high metabolic rates expected during orbital or surface EVA operations. Therefore the AEPS study baselined a circulating water cooling system similar to the Apollo Liquid Cooled Garment (LCG). It has a network of flexible tubes that are held in close contact with the astronaut's skin. Chilled water is circulated through the tubes and heat is removed from the astronaut by conduction from the skin into the tubes. The water is then circulated through a sublimator in the backpack. The low heat exchanger effectiveness of the current LCG requires an inlet temperature of about 40°F in order to remove the maximum metabolic load. This low temperature in close contact with the skin can create physiological and comfort problems for the crewman. A brief investigation showed the feasibility of producing a more effective heat transfer between the heat sink and an LCG that operates with inlet temperatures in the range of 60 to 70°F at the maximum metabolic load. This higher temperature level is beneficial to some heat rejection concepts so that an advanced LCG was assumed to be available for the AEPS thermal control subsystem.

A PLSS-type sublimator heat rejection subsystem expends water at an average rate of 1-2 lb_m per EVA manhour. The water required for heat rejection represents about 3/4 of the total PLSS expendable requirement. Therefore, a fully or partially closed heat rejection system offers a tremendous opportunity to reduce the total launch weight required to support multiple EVA operations.

The AEPS heat rejection systems must be designed to operate without crewman discomfort at the minimum heat load, to have the capacity to reject the nominal heat load as an average over an 8-hour sortie, and to have heat rejection rate capacity sufficient to accommodate the maximum heat load. The average heat load of 1200 BTU/hr is that which the system must be capable of rejecting over all sorties on a mission.

4.4.1 AEPS Heat Loads

The design heat loads for the AEPS were discussed in Section 3.5, and the technique used in this study for calculating the heat load was described. The heat load is a function of the local thermal environment and varies considerably from one mission to another. Table 10 gives the minimum, average, nominal and maximum expected total heat loads for the design missions.

TABLE 10 AEPS DESIGN HEAT LOADS

MISSION	MINIMUM	AVERAGE	NOMINAL	MAXIMUM
EARTH ORBIT { SPACE STATION / SPACE SHUTTLE	525	1330	1800	3950
LUNAR SURFACE	350	1460	1925	4400
MARS SURFACE	350	1160	1650	3825

4.4.2 Definition of Rate Limited and Capacity Limited Systems

Table 10 indicates that while there are significant differences in the heat load on different missions, the variance in heat load on a given sortie may be much greater. The wide variance in heat loads on a given sortie has a significant impact on the selection of the heat rejection system. The systems which might be used for AEPS heat rejection fall into one of two categories; either they are heat transfer rate limited or they are total capacity limited. These characteristics of systems are diametrically opposite, and systems tend to be dominated by one characteristic or the other. For example, a water evaporation system can be designed to operate at the maximum heat load rather than the average heat load with only a slight size and weight increase: the system is primarily limited by the large quantities of water which must be carried to enable the system to reject the total heat load over a sortie. Thus, the evaporation system is said to be capacity limited. A radiator system, on the other hand, grows in size approximately in a linear fashion with the maximum heat load which must be rejected; it is only slightly influenced by the integrated total heat load which must be rejected over a sortie. Thus the radiator system is said to be rate limited.

4.4.3 Top-Off Systems

The expected short transient duration of the peak heat load makes the use of a "top-off" system a potentially attractive concept for AEPS. This would involve the use of a regenerable system to reject some fixed portion of the heat load (probably the nominal or the average) with a separate expendable system to reject any excess heat load when it occurs. This approach may produce the optimum size and weight heat rejection system, and it has some other advantages, namely,

(1) The "top-off" system may also serve as a back-up or emergency system, and

(2) Control problems associated with wide heat load range radiators are circumvented, since the radiator heat load range is reduced.

4.4.4 Candidate Heat Transport Processes

Heat transport processes which were considered for AEPS thermal control are shown in Table 11.

TABLE 11 POSSIBLE APPROACHES TO HEAT REMOVAL FROM AEPS

MECHANISM	MASS & HEAT TRANSFER			PHASE CHANGE			WORK	CHEMICAL REACTION
	CONDUCTION	CONVECTION	RADIATION	EVAPORATION	FUSION	CRYSTALLINE STRUCTURE CHANGE		
GOVERNING EQUATION	$q_L = \frac{KA}{X}(T_L - T_S)$	$q_L = hA(T_L - T_S)$	$q_L = \sigma\epsilon A(T_L^4 - T_S^4)$	$q_L = \dot{m}\lambda$	$q_L = \dot{m}\lambda$	$q_L = \dot{m}\lambda$	$q_L = w\left(\frac{T_L}{T_S - T_L}\right)$	$q_L = m\Delta h_o$
LIMITING FACTOR	RATE	RATE	RATE	CAPACITY	CAPACITY	CAPACITY	RATE	CAPACITY
TYPICAL CANDIDATE SYSTEMS	SUB-SURFACE HEAT SINK	MARS HEAT EXCHANGER	SPACE RADIATOR	SUBLIMATOR	ASTRONAUT HEAT SINK (AHS)*	HEAT SINK DEVICE	VAPOR COMPRESSION REFRIGERATOR	HEAT SINK DEVICE
EXPENDABLE REQUIREMENTS	—	—	NONE	LARGE	NONE	NONE	NONE	NONE
EVA SYSTEM SIZE	—	—	LARGE AREA	SMALL	LARGE	LARGE	MEDIUM	LARGE

* AS DEFINED ON PAGE 50

SYSTEMS SELECTED FOR FINAL SYSTEM INTEGRATION

- SPACE RADIATOR
- SUBLIMATOR
- AHS (WATER SELECTED AS FUSIBLE MATERIAL)
- REFRIGERATOR

AHS SYSTEM USES REPLACEABLE MODULES TO REDUCE PACK WEIGHT

SPACE RADIATOR AND REFRIGERATION SYSTEM USES PART-TIME (70%) UMBILICAL WITH AHS "TOP-OFF"

NOTE:
- T_S = SINK TEMPERATURE
- T_L = SYSTEM HEAT REJECTION TEMPERATURE 40°F
- q_L = SYSTEM HEAT LOAD
- K = THERMAL CONDUCTIVITY
- A = AREA
- X = LENGTH
- h = HEAT TRANSFER COEFFICIENT
- σ = STEFAN-BOLTZMAN CONSTANT
- ϵ = EMITTANCE
- $\dot{m}$ = MASS TRANSFER RATE
- λ = PHASE CHANGE HEAT RELEASE
- w = WORK
- Δh_o = ENTHALPY CHANGE

These processes are discussed below:

Conduction heat transfer into the planetary surface is impractical because of the AEPS mobility requirement. The storage of heat in the planetary surface could be used in the appropriate cases, but a considerable amount of site preparation is required to make this approach operable, and maneuverability would be restricted.

Convection heat transfer is one of the prime mechanisms used for cooling the crewman, by airflow and by coolant flow in the LCG; however, convection is limited as the ultimate heat removal technique in a space application because of the lack of an adequate heat sink. In the Mars application there is sufficient atmosphere (the pressure is about 0.088 psia; 90% CO_2) so that convection is a factor which must be considered; however, it is not adequate to be the primary heat sink at high metabolic rates. A blow-down type of oxygen supply system could marginally provide cooling to the crewman by convection (and the attendant mass transfer associated with sweat evaporation from the crewman's skin); however, this would probably be best applied as a relatively short duration back-up system because of the large expendable atmosphere requirement.

Radiation offers considerable promise as the heat transfer mechanism from an AEPS because it is not dependent on any medium being in contact with the AEPS exterior. There is, of course, a requirement that a line-of-sight relationship with a low-temperature heat sink be maintained. Removal of the maximum allowable heat rate generated by an AEPS system by radiation, without the use of extended area is not physically possible (based on a crewman area of 20 ft^2 and a skin temperature of 80°F). The radiation heat removal rate is reduced in actual practice because of radiation between external suit and equipment surfaces and because the space suit must be insulated to accommodate cold conditions (when the crewman has a low metabolic rate) and extreme hot conditions (when the crewman is in the vicinity of hot objects such as daytime lunar and vehicle surface). This means that, while the space suit surface can be used to reject a portion of the heat load, it cannot reject the maximum heat load, so an alternate means of heat rejection is required. This could be extended radiation area, in the form of a space radiator, or some other suitable heat rejection device. A deployed radiator obviously creates a maneuverability constraint, and there may be difficulty in maintaining proper radiator-orientation in some instances.

Degradation of radiator surface properties due to ultra-violet radiation and high energy particle impingement may pose a significant problem, particularly on the lunar surface where the use of a radiator may be marginal in many locales. Contamination of radiator surfaces by dust may also pose a significant problem on planetary surfaces. Despite these problems, radiation is a promising means for providing the ultimate heat sinks for an AEPS.

Refrigeration systems are widely used in terrestial applications. The function of these systems is to raise the temperature at which the ultimate heat rejection is accomplished, thus reducing the size of the equipment that rejects the heat to the ultimate heat sink. In terrestial applications, the ultimate heat rejection is usually to the atmosphere via a convection process, with evaporation process (cooling towers) also being in wide use. For a space application, the ultimate heat rejection would probably be accomplished by radiation. Work-driven refrigeration systems may be divided into two classifications; vapor cycles and gas cycles. Vapor cycle refrigeration systems are the most widely used in terrestial applications; both shaft-work driven and heat-driven systems enjoy commercial success. Gas cycles are used in turbine-powered aircraft in an open-cycle fashion with the air being supplied in the form of bleed-air from the jet-engine compressor. Heat driven refrigeration systems, including systems where the refrigerant is absorbed in a chemical bed which is regenerated at the base, were considered and found to require much larger weight and volume than mechanically driven systems. The vapor compression cycle is the most probable candidate of refrigeration system for an AEPS application because the system is lighter and more compact than other refrigeration systems, and the driving energy can be conveniently supplied by a battery of reasonable size. Refrigeration is potentially attractive for an AEPS because

(1) The radiation sink temperature for much of the lunar surface is above the desired AEPS metabolic heat sink temperature, and

(2) There is generally an advantage in reducing the required radiator area (which can be accomplished by raising the radiator temperature).

Phase change materials offer considerable promise for the AEPS heat rejection system. Evaporation has been used extensively as a heat sink in space applications; it provides a small, light weight system for relatively short duration EVA sorties. The expendables required over a long mission involving many sorties become prohibitively large, however. Evaporation is very attractive as a top-off system because of the light weight. However, the water vapor vented from an evaporation device may pose a problem in the form of contamination of experiments and sensors that may be serviced by EVA. This contamination can occur both by collection of a contaminant film on a sensor surface and by the tenuous vapor cloud surrounding the EVA crewman. Water vapor poses a particularly difficult problem because it is a strong absorber in several infrared bands and many vehicle surfaces may be cold enough that condensation and freezing can occur on them.

Fusible materials have also been used extensively in space applications, usually to dampen or smooth out temperature excursions where the external environment is cyclic, or where operation (and thus internal heat generation) is intermittent. The capacity of fusible materials is usually inadequate to provide the entire heat sink requirement, except in the case of short duration missions. However, the identification of a fusible material with superior thermal properties, or the potential for marriage of the fusible approach to some other heat rejection technique make the fusible heat sink a strong candidate. Crystalline structure change materials are very similar to fusible heat sink materials, except that the phase change involved is from one solid state to another solid state with a different crystalline structure. This obviously offers a distinct advantage in container and extended heat transfer surface design over fusible materials which go from a solid to a liquid state, with the associated volume change. The primary problem in solid-to-solid phase change systems is the same as for fusible heat sink systems; namely, finding a material with a very high heat of transition and a suitable transition temperature (of approximately 0°F to 50°F). No suitable solid-to-solid phase change materials were found.

Endothermic chemical reactions, which absorb heat, could be used to accommodate AEPS heat rejection. This would be particularly valuable if it could be combined with a chemical reaction already required by the AEPS system such as CO_2 control, humidity control, or power production. No chemical reactions were found that combined the required high heat of reaction in the required temperature range, with non-toxic reactants and products, to allow the construction of a safe, reliable system. Therefore, this approach was not considered further.

4.4.5 Selection of Heat Rejection Subsystem

The primary criteria used for selecting the AEPS heat rejection subsystems were minimum EVA size, mobility restriction, and expendables, combined with reliability and safety for the astronaut in case of failure. As discussed earlier, it was found that the objectives of minimizing EVA size and expendables were contradictory, so that a relatively large EVA system is required for a closed heat rejection system. The most promising candidates are shown in Table 12 below.

TABLE 12 FINAL CANDIDATE HEAT REJECTION SUBSYSTEMS

CONCEPT	SELECTED SYSTEM
1. EXPENDABLE HEAT SINK	SUBLIMATOR, FLASH EVAPORATOR
2. FUSIBLE HEAT SINK	FUSIBLE WATER ASTRONAUT HEAT SINK (AHS)
3. REFRIGERATION MACHINE	VAPOR COMPRESSION CYCLE
4. RADIATOR	PORTABLE RADIATOR PACKAGE
5. COOLANT UMBILICAL	UMBILICAL TO BASE

It was found that no heat rejection system which could operate for 8 hours without expendables was small enough to be integrated entirely into a backpack system. Therefore, some type of a support system, separate from the backpack, is required. This support system could be mounted on a "MET-type" transporter or it could be installed on a powered vehicle.

There are two functionally different methods of supporting the AEPS backpack from a separate system. The AEPS and the support system can be connected by an umbilical or the support system can carry cooling modules which are installed into the AEPS as required. VMSC evaluated both approaches and found that it was not possible to prove one method superior to the other based on the general AEPS guidelines. It was arbitrarily assumed that planetary surface umbilical systems must have the capability to operate without the umbilical for 30% of the EVA duration, in order to allow excursions from the support equipment. Therefore, the radiator and refrigerator systems, which have the capability to operate as completely closed systems, are considered to be supplemented by expendables, since expendables may be used during the non-umbilical portion of the EVA. The coolant umbilical to the base is intended primarily for orbital use.

The expendable heat sink concept has the lowest EVA weight and volume but the highest total weight for a large number of EVA's. However, the space shuttle, which utilizes fuel cells for power production, may generate more water than is needed by the crew and for other purposes on some missions. The fuel cells produce about 0.85 lb_m of water per Kilowatt-hour (KWH) of electricity. Projected shuttle power profiles (Reference [38]) indicate a maximum electrical requirement of approximately 500 KWH yielding 425 lb_m of water generated. The maximum production rate is on the order of 10 lb_m/hr. This water is budgeted for functions such as crew metabolic and wash water, and payload cooling and thus it is not all available to the EVA system without penalty. The actual amount of water available depends on the particular shuttle mission.

The sublimator system, as used in the Apollo PLSS, is a compact, reliable system that is ideally suited to missions where only a few EVA's are required. However, it is not suitable for use as an expendable, "Top-Off", system due to its relatively poor response characteristics from start-up and waste of water during the "dry-out" phase. The flash evaporator is an expendable system being developed by VMSC, under contract to NASA-MSC, for a potential shuttle application. As applied to AEPS, it would offer no expendables advantage over the sublimator when used as the primary cooling system. However, its response to varying heat loads make it ideally suited for use as an expendable "top-off" system. The flash evaporator also has inherent control advantages over conventional devices such as the Apollo Command Module water boiler.

The use of a fusible material allows a completely closed heat rejection system. Water was selected as the fusible material due to its high heat of fusion and the fact that it is completely non-toxic in all forms. In addition, the solid-to-liquid phase change occurs at a temperature and pressure that minimizes hardware design problems. The use of fusible water also allows the system to incorporate a back-up evaporative mode with proper hardware design.

The heat of fusion of ice is roughly 15% of the heat of vaporization so that 6 to 7 times as much water must be transported for use in the fusible as compared to the expendable mode. Approximately 100 lb_m of ice may be required per man, to reject the specified AEPS heat load; this is too heavy and bulky to be carried conveniently in a backpack. In order to minimize mobility constraints, the ice may be modularized into smaller, more manageable portions, with frozen modules carried in an insulated container. The melted ice modules are replaced with frozen ones as required, which will be every 1-2 hours depending on the heat load and the size of the module. However, if for some reason it is not possible to change modules when required, the astronaut could switch to the evaporative mode and continue the full EVA with no restrictions except for the water expended. The ice modules are refrozen at the base between EVA's. This system concept has been designated the Astronaut Heat Sink (AHS) and it is felt to offer considerable promise in reducing the expendables required for EVA heat rejection.

The modular AHS concept is extremely simple. An aluminum pack containing 15 lb_m of ice is mechanically clamped between two heat exchanger modules and heat is rejected by melting the ice. This mechanical interface between the heat sink and the LCG fluid has a reliability advantage since the LCG loop is not broken during routine module replacement. The total subsystem mass is too large to be included in a backpack so the ice is divided into modules with frozen modules carried in an insulated container. A spent (melted) module is replaced with a frozen one from the storage container as required. The AHS is carried in a chest pack to facilitate AHS module replacement.

The heat capacity of each AHS can be increased by sub-cooling the ice during the regeneration mode and heating the melted water above 32°F during use. A total heat sink of 175-200 BTU/lb_m ice can be achieved with only a moderate amount of sub-cooling. Moderate sub-cooling was assumed, since cooling to very low temperatures increases the regeneration penalty and also complicates the subsystem design since freezing of the LCG water must be prevented.

The AHS has a unique contingency mode of operation which is possible because water is used as the heat sink material. At any time when it is not convenient to change AHS modules the AHS in use can be converted to an evaporator simply by opening the manual vent valves. The 15 lb_m of water can then be expended by controlled evaporation. This extends the capability of the AHS system to allow a complete 8-hour EVA without the support modules but with a penalty in water expended. This contingency mode adds considerable flexibility to the AHS concept.

The AHS packs are regenerated at the base simply by refreezing the ice. In some environments, such as the lunar night, the AHS packs can be regenerated without any special equipment by exposing them to the exterior environment. However, the total system weight calculated for the AHS system includes a base freezer system with all associated penalties.

For shorter duration EVA's up to 4 hours, such as may be desirable in earth orbital operations, the entire AHS could be conveniently integrated into the AEPS backpack. This would be desirable in orbital operations because of the difficulty in maintaining a convenient supply of modules, and the potential difficulty in replacing modules in a low gravity environment.

A fusible AHS type heat sink is assumed to be integrated into the backpack for use as the "top-off" system required for the radiator refrigeration systems. This allows 1-2 hours of non-umbilical operation without expending any water and a further 5-6 hours is available by using the expendable mode.

Another approach to using the heat of fusion of ice is to connect the backpack to a large AHS by means of an umbilical. This large AHS could be conveniently mounted on a powered or a " MET-type" transporter. It would provide all AEPS heat rejection when the umbilical could be used but a secondary system would be required in the backpack to allow operation without the umbilical. This system eliminates the requirement for changing modules during the EVA but the umbilical does restrict mobility to some extent. A heat exchanger is included in the backpack to allow a fluid loop separate from the LCG to be circulated through the umbilical.

All of the AHS systems have a relatively large EVA weight per man but they are compact for this weight. This minimizes the transportation difficulty, however, some sort of small transporter is required for an 8 hour system.

Both the simple radiator and the refrigeration systems are rate limited and it was found that they were prohibitively large when designed to reject the maximum heat load. However, this maximum heat load is expected to occur infrequently and for short durations so that a more practical approach is to design the primary system to reject the average heat load with a secondary "top-off" system to accommodate the transient peaks. It was found that for an average metabolic load of 1600 BTU/hr the total system heat load, including equipment cooling and a nominal environmental heat leak, is about 2000 BTU/hr. Therefore, this value was taken as the baseline heat load for the design of the primary system.

A simple radiator system was found to be the lightest weight, closed heat rejection concept available. However, this system suffers several disadvantages that limit its applicability. A large radiator area is required since the radiating temperature is limited to the temperature available from the LCG and will therefore be less than about 70°F. This limits the heat rejection from the radiator to a maximum of 140 BTU/hr ft^2 so that the minimum possible radiator area is about 14 ft^2 for 2000 BTU/hr. The actual area will be considerably greater due to limitations imposed by radiator fin effectiveness, surface optical properties, and the influence of the thermal environment. If a secondary radiator loop is used to avoid circulating the LCG fluid directly through the radiator, the temperature drop across the required heat exchanger will further reduce the radiating temperature. Any thermal radiation incident on the radiator surface will decrease the radiator's net heat rejection per unit area. In some daytime thermal environments, such as inside a lunar crater or near mountains, the infrared radiation from topographical features can render a simple radiator completely useless. The radiator can be shielded or positioned by an orientation system to minimize the incident radiation, but these additions increase the weight and volume of the system so that it is not competitive with several other concepts. However, a radiator would be a very attractive system for a Martian EVA since the thermal environment is much less severe than on the moon.

The problems encountered with the simple radiator can be overcome by using a refrigeration cycle to increase the radiator temperature. A vapor compression refrigeration cycle was selected due to its high coefficient of performance (COP) and compact size. The energy required to drive the system is supplied by a lithium-halide battery.

A conceptual design for an AEPS vapor compression refrigerator was created to allow weight, volume, power, and expendables estimates to be made. It was found that, using conservative estimates for motor and compressor efficiency, a COP of 2.9 could be achieved with an evaporator temperature of 40°F and a condenser temperature of 130°F. The total EVA weight of the system, including power supply and radiator, was found to be about 70 lb_m for a 2000 BTU/hr system. This system employs a 25 foot umbilical with the evaporator built into the AEPS pack. Thus, any failure in the umbilical system would not cause a loss of LCG fluid, since the evaporator acts as a heat exchanger between the LCG loop and the refrigerant. A "top-off" system is also included in the backpack, bringing the total heat rejection system weight to about 95 lb_m. The "top-off" system provides cooling for non-umbilical operations, accommodates transient peak heat loads, and provides a back-up in the event of refrigeration system failure. The only base requirement for this system is recharge of the EVA battery.

The modular and umbilical approaches to AEPS thermal control are illustrated in Figure 13. It shows an AHS chest pack with the insulated storage container integrated into a small "MET-type" equipment transporter. The umbilical refrigeration system is shown mounted on a small, powered transporter. This system could also be mounted on a man-powered equipment transporter or detached from the transporter for use at a work station. Both of these approaches have considerable promise for a wide range of AEPS missions.

The weights and volumes of these promising systems are shown in Figure 14. The figure shows that the expendable weight of the sublimator imposes an extremely large penalty for any mission requiring numerous EVA's. The weight and volume of the AHS/refrigerator system increases with the number of EVA hours, because of the assumption that 30% of the EVA duration is spent off the umbilical, thus requiring the system to expend some water on each EVA. If it were assumed that the umbilical could be used 80% of the time, no water would be expended on a nominal EVA and the AHS/refrigerator would become the lightest weight thermal control system. The simple cooling umbilical to base is shown to be light in weight, but its application is limited to specific missions. No expendable penalty was assigned to the AHS system. Figure 15, which shows weight as a function of individual EVA duration, indicates that the rate-limited refrigeration system size does not change with increased EVA duration while the size of the capacity limited systems increases.

4.4.6 Thermal Control Subsystem Recommendations

On a weight and volume basis, the two most promising regenerable

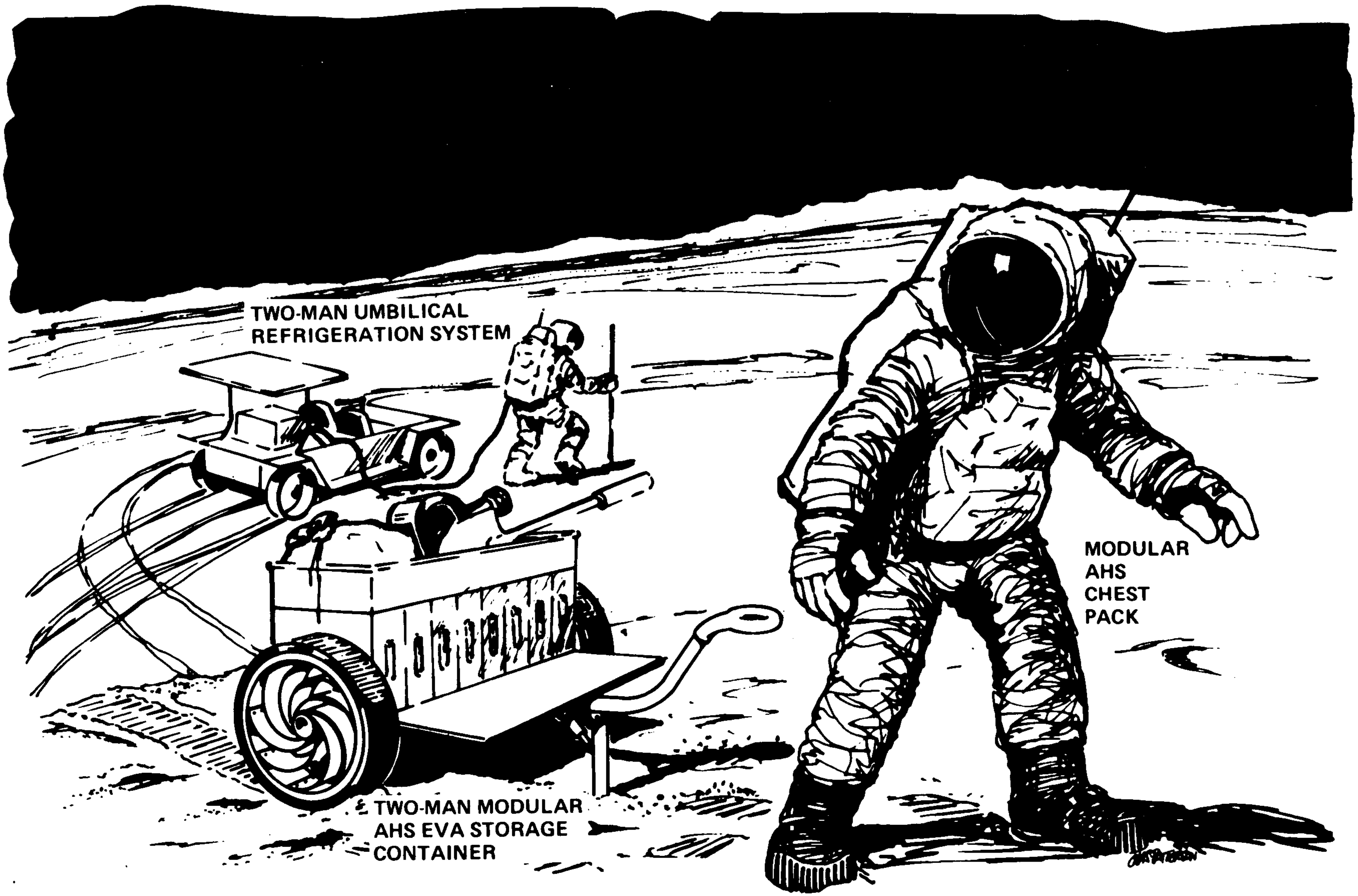


FIGURE 13 MODULAR AND UMBILICAL APPROACHES TO AEPS THERMAL CONTROL

C.2

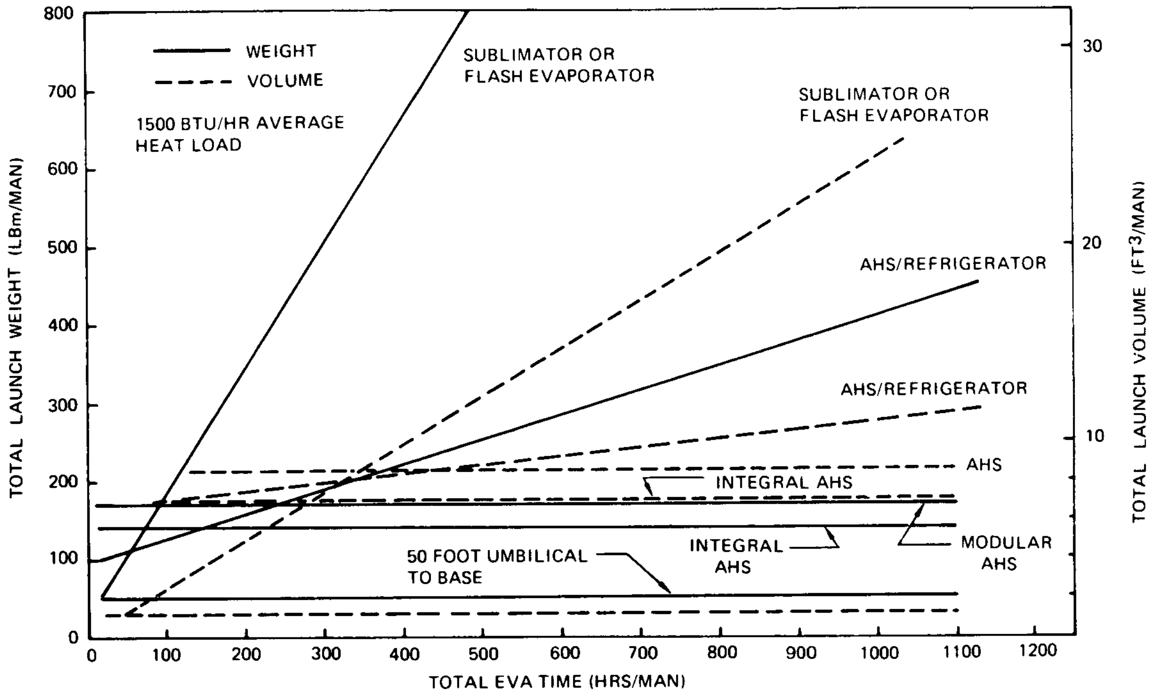


FIGURE 14 AEPS THERMAL CONTROL SUBSYSTEM SIZE – TOTAL LAUNCH WEIGHT AND VOLUME COMPARISON

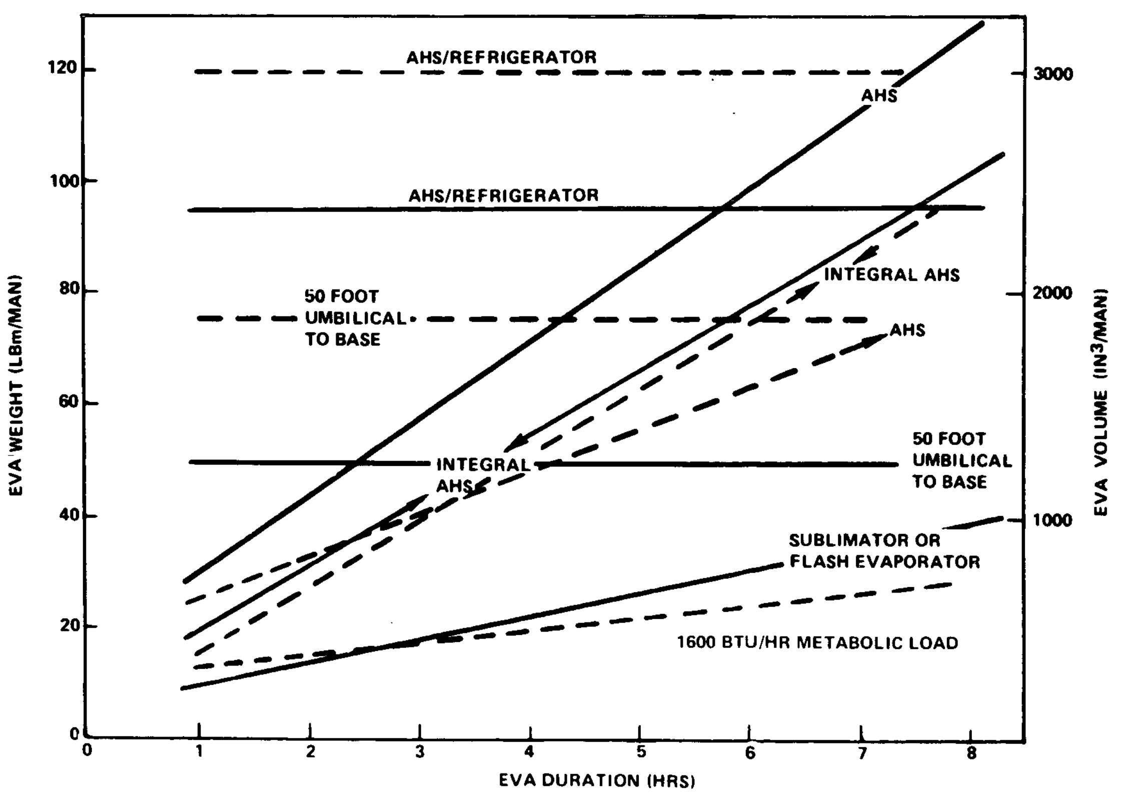


FIGURE 15 AEPS THERMAL CONTROL SUBSYSTEM EVA WEIGHT AND VOLUME

heat rejection subsystems for missions requiring more than 50 EVA hours are the modular AHS system and the refrigerator with AHS "Top-Off". Both systems offer closed heat rejection at a penalty in EVA weight. A fundamental difference between the two is the module vs umbilical approach. The choice of which regenerable approach is optimum for a particular mission can best be made at the detailed mission planning stage. A water sublimator or evaporation system is attractive for short duration missions on which considerable excess water is already available, such as shuttle orbiter missions.

In addition to these primary heat rejection systems, several concepts were identified that would either reduce the AEPS heat load, or improve the primary system performance.

(1) The first is the advanced LCG mentioned in Section 4.4 (page 43). A preliminary analysis indicates that a more comfortable LCG which is a more effective heat exchanger can be produced with a modest development effort. The advantages of this LCG are improved wearer comfort and increased temperature potential for heat rejection.

(2) A second concept is the integration of a fusible material directly into the suit for an orbital EVA. The thermal environment changes rapidly in low earth orbit and a suit incorporating a "Quilt-Like" pattern of paraffin material could be used. Materials are available that would change phase at about 80°F and the use of this suit would tend to stabilize the suit at the phase change temperature. This would increase the net heat leak from the space suit in an orbital environment from about -150 BTU/hr to as much as -1000 BTU/hr. This would significantly reduce the heat load on the primary AEPS system without introducing the problems that accompany similar concepts such as controllable heat pipe suits, etc.

(3) Similarly, for lunar surface EVA, the insulating overcoat principle used for Gemini EVA's can be applied. This would consist of a basic, relatively uninsulated EVA suit that could reject a large fraction of the metabolic heat at night or at low sun angles. An insulating overcoat would cover this suit to minimize the heat transfer into the system for daytime operation.

4.5 HUMIDITY CONTROL SUBSYSTEM

Humidity control is usually achieved with a condensing heat exchanger, both in commercial and aerospace applications. In this technique, the air is brought into contact with a cooling coil which is at or slightly below the desired air dew point temperature. Sufficient moisture is condensed out of the process air to reduce the dew point to the cooling apparatus temperature. In spacecraft, the zero-gravity environment requires that a water separation device be used to remove the water droplets from the air stream. A centrifugal device such as an elbow is normally used for this purpose. A transport system, such as a wick system, is required to remove the water from the separation device to a storage container.

The above system may present two problems in an AEPS.

(1) The wick provides an excellent medium for bacterial growth

(2) Some potential regenerable heat rejection systems may provide a coolant temperature which is not low enough to yield the required atmosphere dew point temperature.

In this latter case a desiccant system can be employed, the most likely candidates being:

(1) Silica Gel

(2) Activated Alumina

(3) Lithium Chloride

(4) Molecular Sieve

The maximum amount of water which must be removed from the AEPS atmosphere is about 3.7 lbs per EVA. This amount is small enough so that regeneration of the system during a mission would not be required, though regeneration by vacuum venting of the dessicants is possible. Any of the systems can be readily regenerated in the primary base or shelter, thus recovering the water.

In this study a condensing heat exchanger was assumed for humidity control when the heat rejection system could supply 40°F cooling to the gas stream, and a silica gel desiccant system was assumed for systems that operate at a higher cooling temperature.

4.6 POWER SUPPLY

The AEPS life support system requires a power system to drive it; in this study an investigation into power systems was accomplished to identify power sources which might be available in the next decade.

4.6.1 AEPS Power Requirements

The anticipated minimum power demands on an AEPS are:

(1) Ventilation gas circulation	25 watts
(2) Liquid coolant circulation	10 watts
(3) Controls, instrumentation and communications	10 watts
(4) Total	45 watts

The power requirement of 45 watts coupled with an 8-hour sortie gives a minimum total energy requirement of 360 watt-hour. This is comparable to the requirements for the current Apollo PLSS. Many potential life support systems, such as a Bosch reactor or a vapor compression rêfrigeration system have power requirements far in excess of the minimum values listed.

4.6.2 Candidate Power Supply Subsystem

Potential power sources for AEPS can be divided into four functional categories:

(1) Battery Systems
(2) Fuel Cells
(3) Nuclear Systems
(4) Solar Cells

Battery systems are usually classified as either primary or secondary; the distinction being that primary batteries are not rechargeable.

Primary batteries provide a large power density for a short duration; however, the nature of most AEPS missions makes the secondary, or rechargeable, battery more promising.

Secondary batteries are regenerated by flowing electric current into the battery to reverse the battery discharge reaction. Since the reaction is not completely reversible, there is a maximum number of discharge cycles before the maximum voltage which the battery can produce falls below the minimum allowable value. In addition, the likelihood of battery failure increases with the number of discharges. The depth of discharge is the significant parameter in the recharge life of the battery; usually sixty percent nominal depth of discharge is taken as a reasonable compromise between battery reliability, and size and weight.

For an AEPS application the most significant battery parameters are the mass and volumetric power densities. Table 13 gives a comparison of these parameters plus cycle lifetime for several batteries, including the common automobile-type lead-acid battery.

TABLE 13 BATTERY SYSTEM PERFORMANCE PARAMETERS

CELL TYPE	POWER DENSITY WATT/LBM	ENERGY DENSITY WATT-HR/LBM	THEORETICAL ENERGY DENSITY WATT-HR/LBM	VOLUMETRIC ENERGY DENSITY WATT-HR/IN^3	LIFETIME NO. CYCLES (60% DISCHARGE, 25°C)
LEAD-ACID	14	10-12	115	2	400
Ni-Fe	18	16	35	1.1	3000
Ni-Cd	20	18	107	1.0	2000
Ag-Zn	70	45	208	5	300
Ag-Cd	60	56	120	3.7	3000
Li-$CuCl_2$	70	160	503	5	–
Li-CuF_2	–	200	750	4	–
Li-Se	–	164	575	3.5	–
Na-S	100	135	543	5.7	–
Na-Bi	36	18	132	1.3	500
Li-Te	127	82	490	5.9	–

The silver-zinc (Ag-Zn) and Silver-Cadmium (Ag-Cd) batteries are commonly used in aerospace applications. The advanced sodium and lithium batteries are currently in development, and improvements in the performance of these batteries should be anticipated.

Battery systems are well suited to the AEPS application since they offer acceptable power levels with low weight and volume and they can be regenerated.

Fuel cells are very similar to batteries in principle in that electrical energy is produced by a chemical reaction. However, fuel cells generally use externally stored reactants which produce a waste product, so the cell will continue to operate as long as reactants are supplied. The tanks, delivery lines, valves, etc. associated with the reactants tend to make the fuel cell more complicated than a battery. The relative complexity of the fuel cell system with the attendant loss of reliability results in the fuel cell having no advantage over batteries for AEPS unless significantly higher AEPS power requirements are defined.

Hybrid fuel cell systems which could be combined with life support functions such as carbon dioxide control are possible, but were found to offer little advantage for an AEPS.

Nuclear Power Systems use nuclear reactions as a heat source and convert the thermal energy to electricity by various means, primarily:

(1) Thermoelectrics

(2) Thermionics

(3) Dynamic machines

The first two of these systems have characteristically low conversion efficiency, and the last involves a considerable amount of rotating machinery. These factors tend to make nuclear systems non-competitive for an application with low power and energy requirements such as AEPS.

Solar cells convert sunlight directly into electrical energy. Usually some sort of power regulation equipment is required with a solar cell system. If the system is shadowed part of the time, such as in earth orbit, then a battery system is required for continual power delivery.

Improvements in solar cell design can be anticipated; and yields of 40 watt/lb, and 8 to 17 watt/ft^2 (at a distance of one astronomical unit from the sun) for cadmium sulfide (CdS) thin film cells and silicon cells, respectively, seem reasonable to expect. This assumes that the cell array is aligned normal to the solar vector; off-alignment will require that the cell array be larger. Efficiency of the cell array is strongly dependent on temperature, and temperature control on the lunar surface, for instance, would be difficult to achieve.

The light weight and no expendable or recharge requirement characteristics of the solar cell make it attractive; however, area and alignment requirements of the cell array make solar cells impractical for a system transported on a man's back. The solar cell is attractive for vehicle power systems.

4.6.3 Power Supply Subsystem Recommendations

Batteries were selected as the power source for AEPS; this is based on the premise that the total energy requirement is no more than 1 kw-hr for an 8-hour mission.

Lithium-halide batteries were selected as the power supply subsystem for the total system weight evaluations: 200 watt-hr/lb and 4 watt-hr/in^3 were assumed for these batteries.

Figure 16 shows the EVA weight and volume of the AEPS power system as a function of power requirement, including the allowance for 60% depth of discharge in a nominal mission. Figure 17 shows the total weight of primary and secondary batteries as a function of total EVA hours. The weight of the secondary batteries includes the recharge regulator and the base power penalty. This figure shows that secondary batteries are desireable on any AEPS mission provided that the recharge power requirement does not require an increase in the capacity of the primary vehicle's power system.

4.7 EMERGENCY CONSIDERATIONS

The backup EVA life support systems used on Gemini and early Apollo missions were designed to provide breathing gas and some measure of convective cooling for a very short period. This was considered to be adequate since the EVA's were conducted in the vicinity of the spacecraft and the crewman was never far from shelter. However, on later Apollo flights and many anticipated AEPS missions, the EVA's take the astronaut far from the primary base and considerable time may be required to return in case of a failure. Therefore, the AEPS system must provide all life support requirements for the time required for the astronaut to return to the base in case of a failure in the primary system. This section summarizes a more detailed discussion of emergency considerations presented in Appendix B.

Primary spacecraft life support systems are generally designed to a "fail operational - - fail safe" requirement. This means that the normal mission can be continued with any single component failure, since the secondary system will provide all required functions without any degradation of performance. Thus, the system is said to have "failed operational". An emergency capability is provided so that a second failure of the same subsystem would not be catastrophic, but it would require termination of the mission. This is the fail-safe condition. The AEPS primary life support subsystems will be assumed to be designed "fail-safe" since including a "fail operational" capability imposes a substantial penalty on a portable system. Therefore, the AEPS life support system would be designed so that a single failure of any component would not be catastrophic, but it would require activation of an emergency system

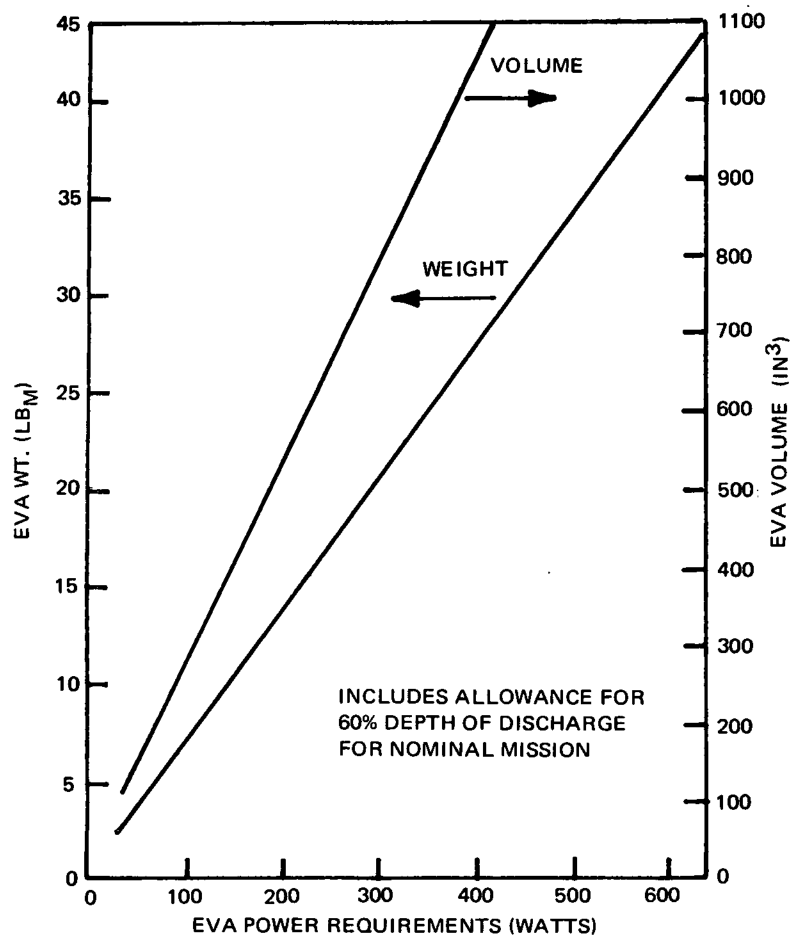


FIGURE 16 POWER SUPPLY EVA WEIGHT AND VOLUME

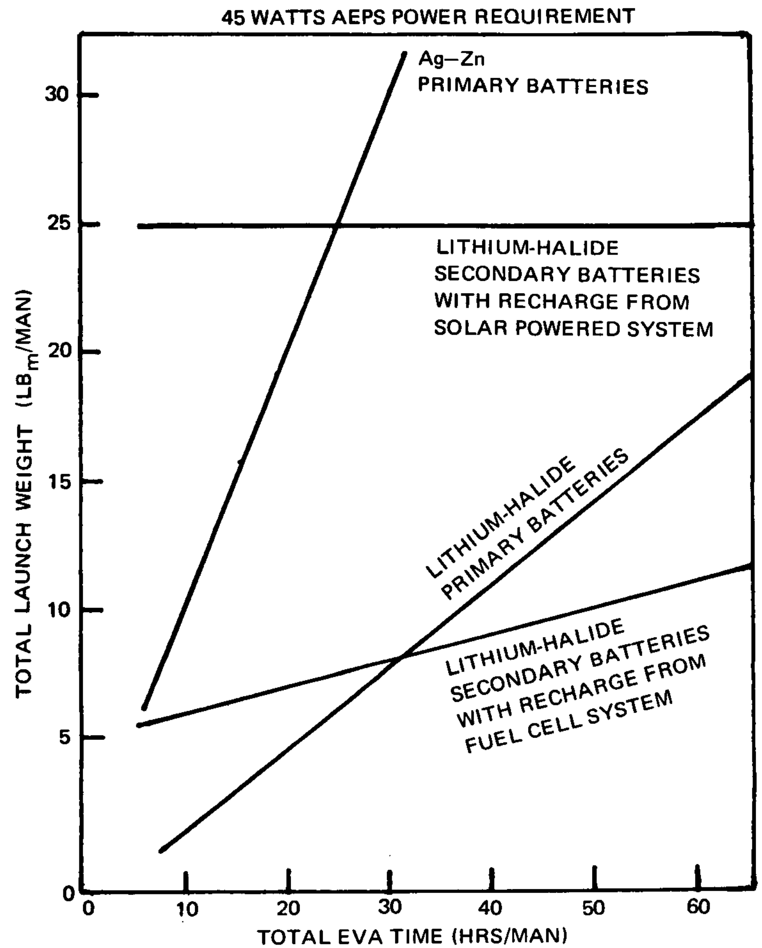


FIGURE 17 POWER SUPPLY TOTAL WEIGHT

and termination of the EVA.

It will be assumed that AEPS structural elements, gas storage bottles, heat exchangers, and flow loop "hard" lines and fittings will be designed with a sufficient safety margin that catastrophic failures will not occur. Dynamic components such as pumps, fans, and valves; flexible seals between joints; and all removeable components such as umbilicals, suit zippers and seals, etc. are subject to failure. It is impossible to accurately, quantitatively assess component reliability for systems in the advanced concept stage. However, it is possible to qualitatively predict possible failure modes that must be accommodated by the emergency system.

The allowable limits for parameters such as CO_2 and trace contaminant partial pressures, total suit pressure, and crewman thermal comfort can be quite different for the AEPS primary and emergency systems. In addition, the time required for the crewman to reach a pressurized shelter following an EVA emergency is expected to be short compared to the nominal EVA duration. The basic physiological reactions of the crewman to variations in these parameters were briefly investigated to attempt to determine reasonable tolerance levels.

4.7.1 Physiological Effects

The physiological effects of most interest are: the effects of total gas pressure and decompression rate in the case of a gas leak, effects of CO_2 and contaminant level on crewman mental and physical performance, and the effects of thermal stress due to cooling system failure.

If a puncture occurs suddenly in the AEPS pressure shell, pressure will decay rapidly as the atmosphere exits through the vent. The time required for the pressure to decay depends on the initial pressure, the configuration of the vent area, and to a lesser degree, on the atmosphere composition and the initial atmosphere temperature. Table 14 shows the characteristic suit volumes, leakage areas, and the volume to area ratio (V/A) for a variety of possible suit failures. Available data (Reference 39) indicate that no lung

TABLE 14 CHARACTERISTICS OF EXPLOSIVE DECOMPRESSION

SOFT SUITS	RESIDUAL SUIT VOLUME (IN^3)	ORIFICE AREA (IN^2)	V/A RATIO (METERS)
NECK SEAL (PLSS)	1585	26.	0.88
WRIST SEAL (PLSS)	1710	9.3	4.67
CHAMBER UMBILICAL HOSE	1555	1.2	32.3
PLSS UMBILICAL HOSE	1710	0.4	100.
FINGERS (PLSS)	1710	0.2	233.
HARD SUITS			
WAIST SEAL (PLSS)	2150	125.	0.435
NECK SEAL (PLSS)	4310	87.	1.25
THIGH (PLSS)	3910	27.	3.6
ANKLE (PLSS)	4580	26.	4.46
WRIST SEAL (PLSS)	4580	8.4	13.9
CHAMBER UMBILICAL HOSE	4330	1.2	89.8
PLSS UMBILICAL HOSE	4580	0.4	268.
FINGERS (PLSS)	4580	0.2	620.

damage will result from decompressions when V/A > 15 meters while decompressions with V/A < 3 meters result in fatal tissue damage.

Decompression also introduces the risk of the crewman suffering from the bends. The "bends" may occur even when the decompression is slow enough to prevent tissue damage. The severity of the bends depends, to some degree, on the amount of de-nitrogenation which the crewman has undergone prior to the decompression event; the risk is greater in a two-gas suit, or in an 8 psia oxygen suit operation out of a vehicle with a two-gas atmosphere. In any event, the time to the onset of bends symptoms is greater than the survival time in a vacuum (Reference 39) so that the bends are not a dominant factor in suit emergencies involving decompression.

Since the AEPS pressurized volume is small relative to the CO_2 production rate of the man, the CO_2 partial pressure will increase rapidly following loss of CO_2 removal capability. The CO_2 partial pressure will increase at a rate of approximately 40 mm Hg/min, resulting in unconsciousness within 3 to 5 minutes (Reference 26). The production rates of other contaminants are low enough (Section 4.3) so that no ill effects will result from a failure of the trace contaminant control subsystem.

In contrast to emergencies involving the gas circulation and suit pressurization systems, the allowable time before crewman collapse and unconsciousness following a cooling system failure is much greater.

Data presented in References 26 and 39 can be used to estimate the crewman's useful survival time following such a failure. These data, which were compiled from various sources, are in fairly good agreement although it should be noted that individual tolerance to heat stress may vary widely.

Crewman incapacitation results from metabolic heat storage in the body, which raises body core temperature producing the same basic effects as a fever due to sickness. The data indicate that a maximum body core temperature of about 105°F can be tolerated without permanent damage. This implies a heat storage of about 750 to 1000 BTU depending on body weight. This is in agreement with other data (Reference 39) indicating incipient collapse after 30-40 minutes of exercise at 1500-2000 BTU/hr in an insulated environment.

Thus it appears reasonable to assume a heat storage of 750 BTU without significant performance degradation under emergency conditions. This value can be used to determine the endurance time for a crewman when his metabolic heat production exceeds the emergency cooling system capacity. Environmental thermal exchange (Section 3.5) can prolong or shorten this time depending on the average environmental sink temperature. Figure 18 shows the expected useful crewman survival time following a cooling system failure for different values of heat storage and emergency cooling. The time shown is that during which the crewman's performance is relatively unimpaired and he can perform useful action to return to shelter without assistance. The emergency durations specified for the various AEPS missions (Table 1) are also

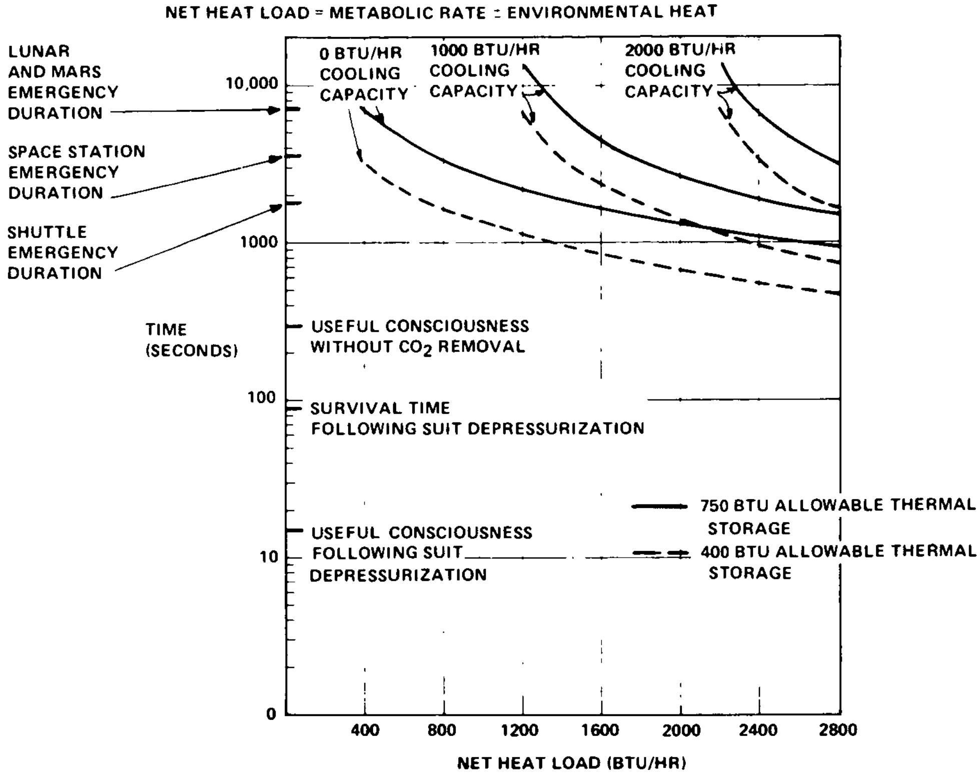


FIGURE 18 AVERAGE UNIMPAIRED PERFORMANCE TIME FOR VARIOUS EVA EMERGENCIES

shown along with the time to collapse following a gas circulation failure and suit depressurization.

These data showing the expected crewman physiological response to different types of emergencies were used along with data on expected failures and failure rates to determine the required types of emergency systems.

4.7.2 Potential Failure Modes

There are many possible equipment failures or accidents that could endanger the life of an EVA crewman. The AEPS emergency system will be designed to specifically accommodate the most credible failures and it will be assumed that this will also be sufficient to handle other, less likely, contingencies.

The most credible failure modes are shown in Table 15, along with the emergency system requirements for each type of failure, and possible approaches that would meet these requirements. The AEPS emergency system must satisfy all of these failure modes for the duration of the EVA emergency.

Figure 19 presents data which are useful in determining the quantity of gas required to maintain suit pressure for different leakage areas. It was

TABLE 15 EVA FAILURE MODES

FAILURE MODE	EMERGENCY SYSTEM REQUIREMENT	POSSIBLE FAILED COMPONENTS
GAS CIRCULATION AND PRESSURIZATION SYSTEM	MAINTAIN SUIT PRESSURE AND PROVIDE FRESH BREATHING GAS	1. SUIT LEAK 2. GAS UMBILICAL FAILURE 3. FAILED GAS REGULATOR 4. FAILED FAN 5. LOSS OF POWER 6. CO_2 CANISTER FAILURE 7. FAILED PRESSURE RELIEF VALVES 8. FAILED HUMIDITY CONTROL SYSTEM
AEPS THERMAL CONTROL SYSTEM	MAINTAIN CREWMAN THERMAL CONFORT WITHIN ACCEPTABLE LIMITS	1. COOLANT UMBILICAL FAILURES 2. PUMP FAILURE 3. LOSS OF POWER 4. FAILED TEMPERATURE CONTROL VALVE 5. FAILED LCG
DEPLETED EVA EXPENDABLES	PROVIDE RESERVE CAPACITY	UNEXPECTEDLY HIGH EXPENDABLE USE RATE

found that the gas flow rate required to maintain suit pressure in case of a leak, is the determining factor for sizing the emergency gas supply system.

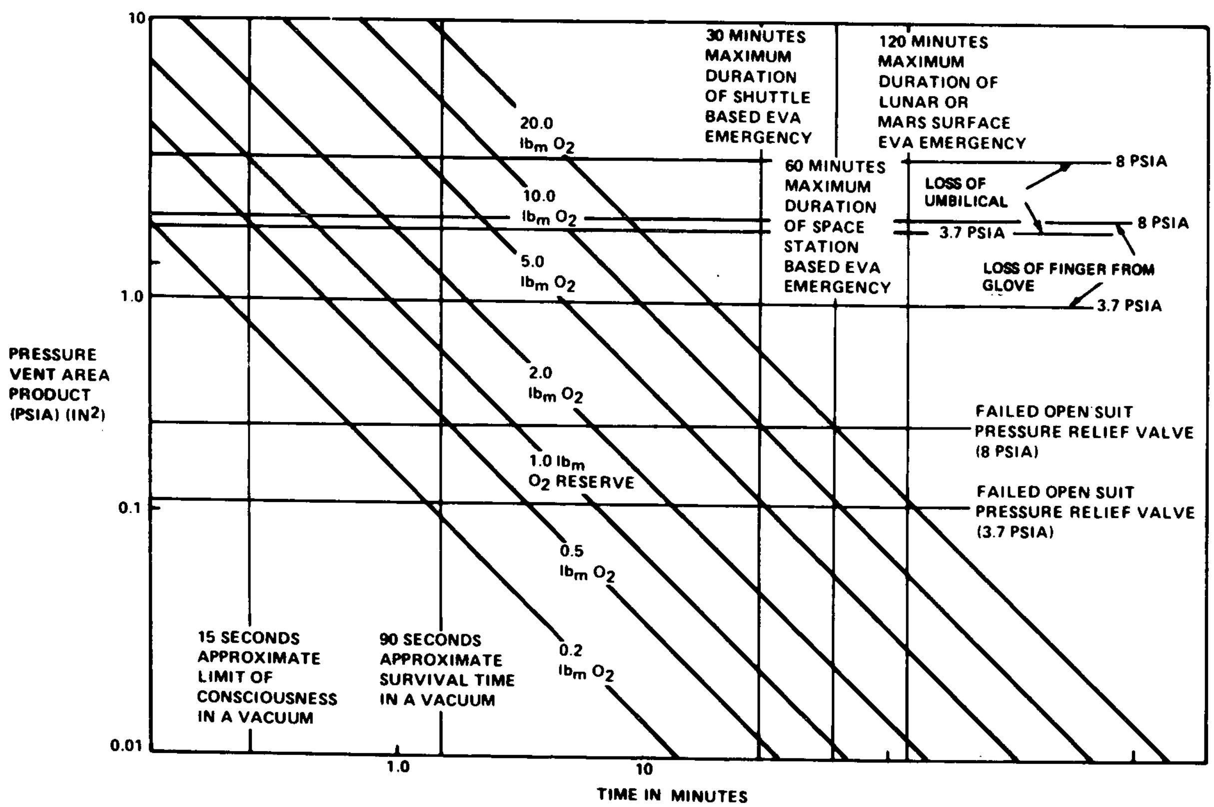


FIGURE 19 EFFECTS OF LEAKAGE AREA AND SUIT PRESSURE ON EMERGENCY GAS REQUIREMENTS

A gas supply system sized to meet credible leakage requirements, will also be capable of supplying gas at the flow rates required for functions such as CO_2 control.

4.7.3 Impact of Emergency Requirements on Primary Systems

It is expected that the AEPS emergency system will only be operated occasionally so that the criteria for system suitability are different than those used to select the AEPS primary subsystems. This infrequent operation allows the use of a completely expendable system since the number of expected uses, even on long duration missions, is insufficient to justify a regenerable capability. The most important factors are long shelf-life with no service required and minimum weight and volume. The emergency system must be capable of being carried on many EVA's involving rugged duty with no service required between EVA's and still be ready for use when required. Since an emergency may occur when the crewman is alone and at a distance from a pressurized shelter, it is necessary to carry an emergency system at all times and, therefore, the weight and volume must be as small as possible.

It was found that high pressure gaseous storage of oxygen is the most practical method of storing elemental oxygen for the primary EVA system because of system simplicity and the fact that other methods such as cryogenic storage have difficulty supplying gas at high flow rates. Since a high flow rate is specified for the emergency system, this is also the only practical elemental O_2 storage method for the back-up O_2 supply. Chemical O_2 storage methods such as potassium superoxide can provide simultaneous CO_2 control and oxygen supply and these would at first appear to be attractive for an emergency system. However, these were found to have no weight or volume advantage over gaseous oxygen storage combined with a separate CO_2 control system. In addition, they cannot easily supply oxygen at the high flow rate required for an emergency repressurization system so that a high pressure O_2 bottle would still be required. A simple high pressure bottle is the only practical method of supplying gas for breathing and suit pressurization for both primary and emergency systems.

CO_2 control subsystems generally fall into one of two categories: passive chemical sorbent beds through which the ventilation gas is continuously circulated or systems such as molecular sieves or solid amine beds where dynamic components are required. The dynamic systems have an obvious reliability problem when compared to passive systems, but it might be possible to include a redundant capability in a primary dynamic system, such as including a third amine bed in a solid amine system. However, this approach is deemed unattractive since the diverter valves and timers in this system are probably more prone to fail than the bed itself. In addition, the weight and volume of a two bed solid amine system are sufficiently large that the addition of redundant components is impractical. The reliability of any dynamic CO_2 subsystem can be increased by including redundancy for critical components, but the overall reliability of the AEPS is increased more by providing a completely separate emergency CO_2 control method. This can be provided by an open-loop system where exhaled CO_2 is vented overboard or by an expendable LiOH cartridge since LiOH was shown to be the most compact CO_2 control method available. If gas umbilicals that link two EVA crewman following a gas system failure, are used, then the CO_2 capacity of the primary system may require an increase to handle the CO_2 produced by two men during such an emergency. Figure 20 shows the influence of employing a buddy gas umbilical on the weight of the AEPS CO_2 control systems. The weight and volume of the regenerable ZnO

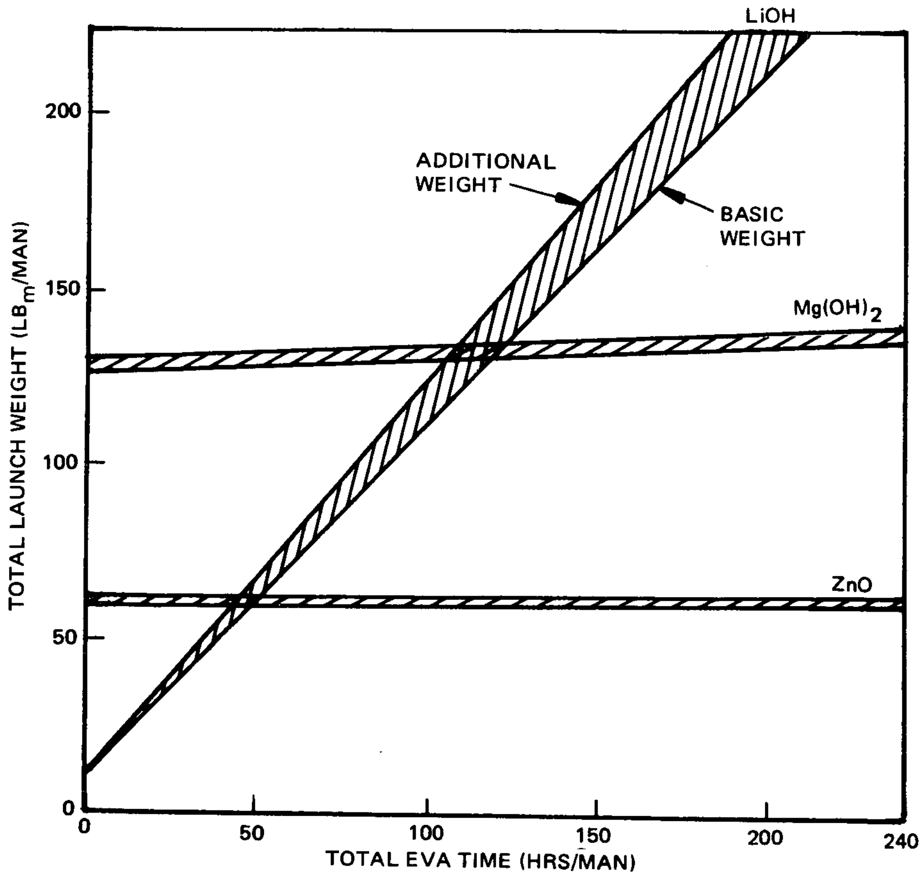


FIGURE 20 IMPACT OF EMERGENCY GAS UMBILICAL ON CO_2 CONTROL SUBSYSTEMS

and $Mg(OH)_2$ systems increases slightly due to the additional penalty required to regenerate the enlarged bed. The LiOH system suffers the largest penalty since the additional mass of the enlarged bed is expended even though no emergency occurs. The solid amine system does not change because the assumed combined emergency metabolic load for two men is lower than the 3500 BTU/hr peak load for which the system was sized.

The fusible Astronaut Heat Sink (AHS) concept discussed earlier has an evaporative contingency mode which enhances the applicability of the concept. No other candidate thermal control system has any inherent advantage when emergency requirements are considered. A failure of the primary AHS could still leave the crewman without cooling so that a secondary cooling method must be provided in case of failure during installation of an AHS or to provide cooling in case of failure of any type of primary heat sink (cracked sublimator plates, refrigerator failure, etc.). Water evaporation devices were shown to be the lightest weight heat sinks available and therfore, they are attractive as an emergency system. Convective cooling by a gas blowdown system could also be used but this method is not capable of removing the required maximum heat load in a practical suit and is therefore not suitable for cooling in an extended emergency situation.

The optimum AEPS power supply was shown to be a secondary (rechargeable) battery. However, as previously stated, there is no requirement that the emergency system be regenerable and therefore, a primary (non-rechargeable) battery will be assumed for a redundant AEPS power supply since non-rechargeable batteries have an advantage in power density.

4.7.4 Emergency Subsystem Approaches

Table 16 shows some of the emergency systems or emergency provisions that have been included in EVA life support systems used, or designed for use, in the past along with the concepts considered in this study. These systems are discussed in more detail in Appendix B. In general, it appears that in the past most systems were designed without the benefit of a careful study of the actual emergency situations and the response of the human body to emergency conditions. The fundamental requirement for the emergency system is to guarantee the survival of the crewman for the specified emergency duration. Crewman comfort is a secondary consideration provided that any discomfort does not interfere with the crewman's performance.

4.7.5 Emergency Subsystem Comparison and Conclusions

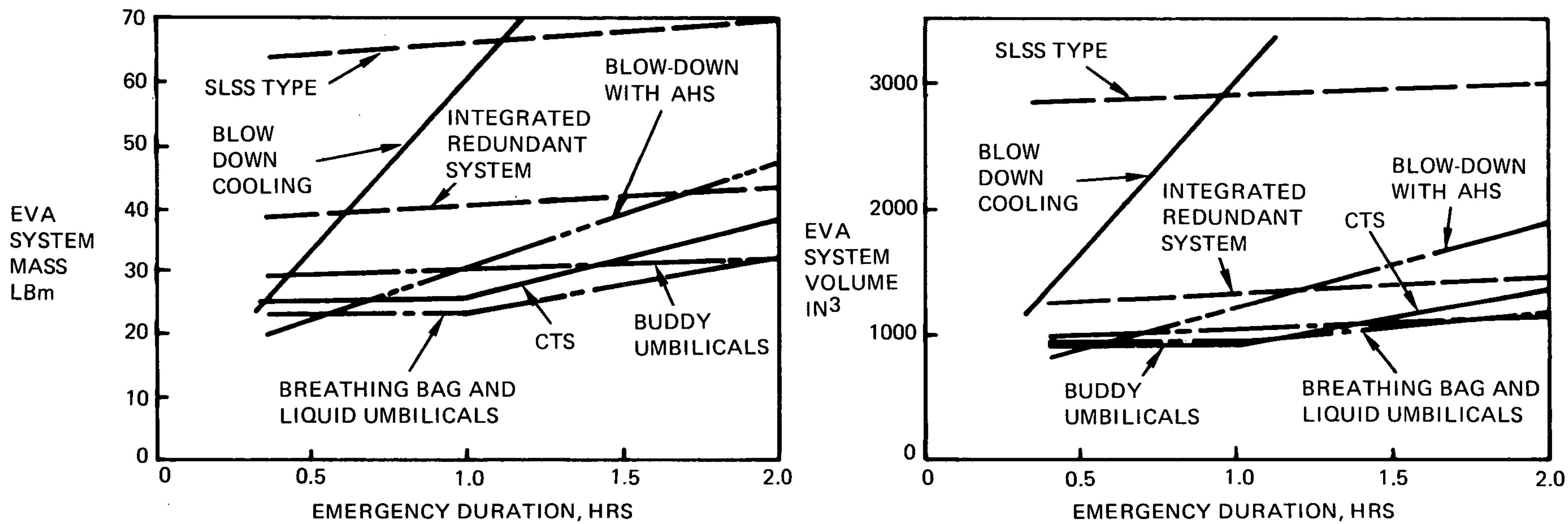
Conceptual designs were created for each of the emergency subsystem approaches shown in Table 16 to allow an estimation of required weight and volume. Figure 21 shows the results of these calculations. All of the systems shown on the figure are designed to meet all the emergency requirements shown in Table 15. All systems also include an oxygen blowdown system containing a minimum of 3-3/4 lb_m of oxygen to meet the emergency suit pressurization requirement. The length of time which this will maintain suit pressure for different leakage areas can be determined from Figure 19.

Figure 21 shows that a blowdown gas system with a breathing bag to reduce the gas flow required for CO_2 control and a buddy cooling umbilical is the smallest volume and lightest weight AEPS emergency system. The other approaches, such as providing a completely redundant, "SLSS-type" system or including redundant components in the primary AEPS, are shown to be heavier and they offer no advantages in additional capability.

Although a decompression of the AEPS pressurized volume is expected to be an unlikely occurrence, it would almost certainly be fatal since no practical system can supply the volumes of gas needed to maintain suit pressure with a large leakage area. Two concepts were identified which would help to increase the chance of survival with very little weight or volume penalty.

TABLE 16 EVA EMERGENCY SYSTEMS AND CONCEPTS

SYSTEM	EMERGENCY PRESSURIZATION SYSTEM	OXYGEN STORAGE SYSTEM	EMERGENCY SUIT VENTILATION	EMERGENCY CO_2 CONTROL SYSTEM	EMERGENCY HUMIDITY CONTROL SYSTEM	EMERGENCY THERMAL CONTROL SYSTEM	EMERGENCY POWER SUPPLY	BASIC SYSTEM OPERATING TIME
ELSS – EMERGENCY LIFE SUPPORT SYSTEM (GEMINI) (UMBILICAL SYSTEM)	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	"BLOW-DOWN" GAS SYSTEM	NONE	23 MINUTES
OPS – OXYGEN PURGE SYSTEM (APOLLO PLSS EMERGENCY BACKUP)	"BLOW-DOWN"		"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	"BLOW-DOWN" GAS SYSTEM	NONE	37 MINUTES MINIMUM
CTS – CONTINGENCY TRANSFER SYSTEM (PROTOTYPE WAS BUILT)	NONE		"BLOW-DOWN" OR BREATHING BAG DEMAND REGULATION	OPEN LOOP (LOW FLOW RATE)	OPEN LOOP	REDUNDANT SUBLIMATOR AND GAS POWERED WATER PUMP	NONE	45 MINUTES MINIMUM
PECS – PORTABLE ENVIRONMENTAL CONTROL SYSTEM (PROTOTYPE WAS BUILT)	"BLOW-DOWN"		GAS EJECTOR	OPEN LOOP	REDUNDANT CONDENSER OR OPEN LOOP	REDUNDANT PUMP AND DUAL SEGMENT EVAPORATOR	REDUNDANT BATTERY	30 MINUTES O_2 WITH EJECTOR, 2 HOURS HEAT REJECTION
ALSA – ASTRONAUT LIFE SUPPORT ASSEMBLY (TO BE USED ON SKYLAB)	"BLOW-DOWN"		"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	"BLOW-DOWN" GAS SYSTEM	NONE	30 MINUTES
SLSS – SECONDARY LIFE SUPPORT SYSTEM (MOCKUP)	NONE		REDUNDANT FAN AND MOTOR	REDUNDANT LiOH CANISTER	REDUNDANT CONDENSER	REDUNDANT SUBLIMATOR AND WATER PUMP	REDUNDANT BATTERY	2 HOURS
AIRS – AEPS INTEGRATED REDUNDANT SYSTEM (CONCEPTUAL)	"BLOW-DOWN"		REDUNDANT FAN AND MOTOR	REDUNDANT LiOH CANISTER	NONE OR OPEN LOOP	REDUNDANT HEAT SINK AND PUMP	REDUNDANT BATTERY	–
OPS AND REDUNDANT HEAT SINK	"BLOW-DOWN"		"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	REDUNDANT HEAT SINK AND PUMP	NONE	–
OPS AND BUDDY UMBILICALS	"BLOW-DOWN"		BUDDY GAS UMBILICAL	BUDDY GAS UMBILICAL	BUDDY GAS UMBILICAL	BUDDY WATER UMBILICAL	NONE	–
OPS AND BUDDY COOLANT UMBILICAL	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	GAS EJECTOR	OPEN LOOP	OPEN LOOP	BUDDY WATER UMBILICAL	NON	–



NOTE: (1) 8 PSIA SUIT

(2) AT LEAST 3.75 LBm OF O_2 ARE AVAILABLE FOR EMERGENCY SUIT PRESSURIZATION

FIGURE 21 COMPARISON OF AEPS EMERGENCY SUBSYSTEMS

The first of these is the collar and wrist seal concept shown in Figure 22. These seals would allow gas flow under normal conditions but the gas flow rate resulting from a large leak would cause the seal to extend and thus greatly reduce the leakage area. The areas of the body downstream of the seal would be exposed to a near vacuum, but preliminary physiological data (Reference 39) indicate that a crewman might survive without suffering permanent ill effects for some time if 1.5 to 2.0 psia O_2 pressure could be maintained in the helmet even though the rest of the body was exposed to vacuum.

Better data are needed to determine the physiological feasibility of the concept. If shown to be practical, this concept would greatly extend the crewman's survival time allowing him to return to the primary base or to erect the portable shelter shown in Figure 23.

This concept simply consists of a cylindrical bag made of flexible plastic with a zippered entrance. The crewman could zip the bag around him following a large suit leak and the bag would be pressurized from the leak. The crewman can continue to breath from his primary O_2 supply and he can either attempt to fix the leak or he could be carried home on a transporter.

The conclusions and recommendations resulting from the review of emergency requirements for AEPS are summarized in Table 17.

TABLE 17 SUMMARY OF EMERGENCY SYSTEMS CONCLUSIONS

CONCEPT	COMMENTS
BLOW-DOWN "OPS-TYPE" SYSTEM	INSUFFICIENT COOLING CAPACITY FOR SOME EMERGENCY SITUATIONS, PROVIDES FOR ALL CRITICAL FUNCTIONS
BLOW-DOWN "OPS-TYPE" SYSTEM WITH BREATHING BAG AND BUDDY COOLING UMBILICALS	MEETS ALL REQUIREMENTS WITH MINIMUM WEIGHT
EMERGENCY GAS AND COOLING UMBILICALS COMBINED WITH BLOW-DOWN SYSTEM	SUITABLE FOR EVA'S CONDUCTED BY TWO OR MORE MEN
COMPLETELY REDUNDANT EMERGENCY SECONDARY LIFE SUPPORT SYSTEM	EXCESS WEIGHT, VOLUME, AND RELIABILITY SERVICING REQUIREMENTS
AEPS INTEGRATED REDUNDANT SYSTEM (AIRS)	SUITABLE FOR ALL AEPS MISSIONS, MAY PROVIDE MORE REDUNDANCY THAN ACTUALLY NEEDED
COMPLETE SPARE AEPS PACK	EXCESS WEIGHT, VOLUME, AND RELIABILITY/ SERVICING REQUIREMENTS
COLLAR/WRIST SEAL	EXTENDS SURVIVAL TIME IN CASE OF MASSIVE SUIT LEAK
RECOMMENDED SYSTEM:	BLOW-DOWN SYSTEM INCLUDING BREATHING BAG AND BUDDY COOLANT UMBILICALS; COLLAR AND WRIST SEALS INTEGRAL WITH SUIT; PORTABLE SHELTER FOR EACH PAIR OF EVA CREWMAN

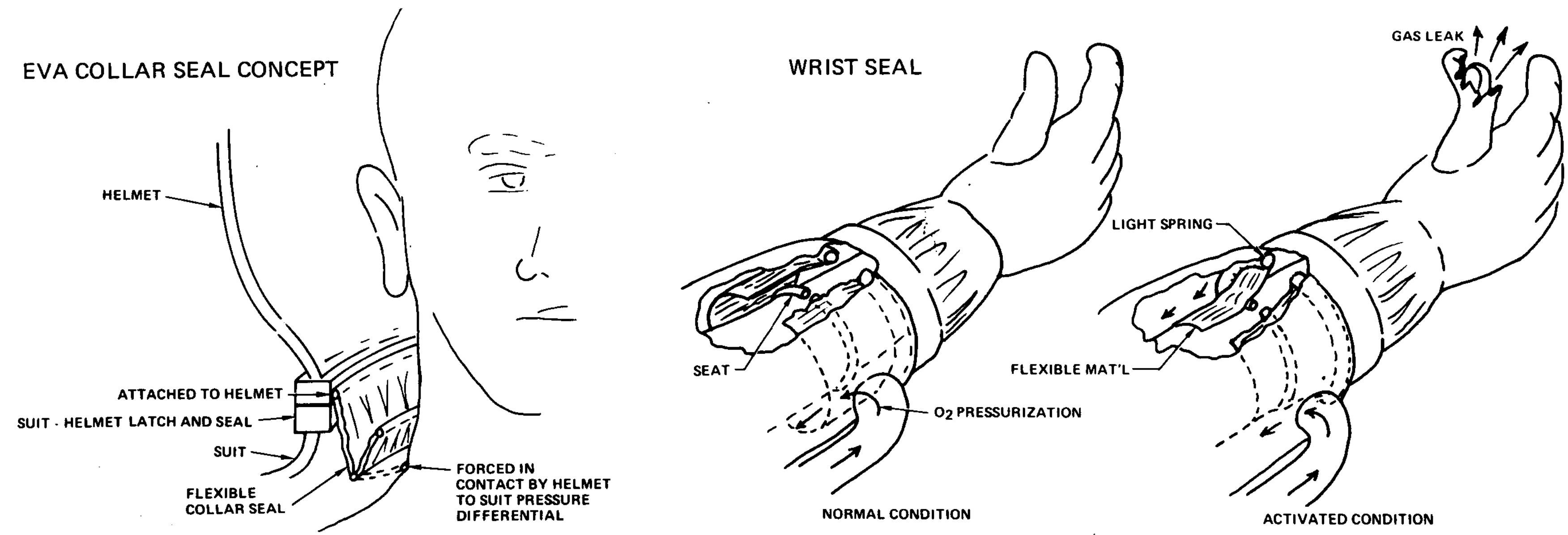


FIGURE 22 EVA COLLAR AND WRIST SEAL CONCEPT

WEIGHT SUMMARY

PRESSURE SHELL	5.0 LB_m
ZIPPER	0.5
STORAGE BAG	0.5
PRESSURE RELIEF VALVE	1.0
TOTAL	7.0 LB_m

STOWED VOLUME
APPROXIMATELY 150 IN^3

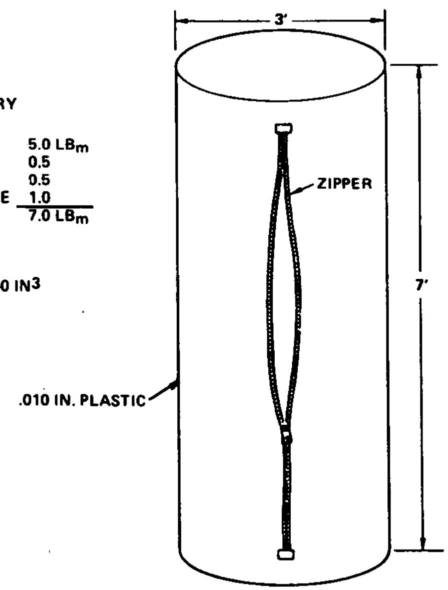


FIGURE 23 LIGHTWEIGHT EMERGENCY SHELTER

5.0 SUBSYSTEM CONCEPT INTEGRATION

The most promising subsystems for performing the AEPS life support functions can now be combined for consideration at the total system level. The selections of activated charcoal for trace contaminant control, either a desiccant or a condensing heat exchanger for humidity control (depending on the selection of the heat rejection system), and a lithium-halide battery for power supply were made as discussed previously in Sections 4.3, 4.5, and 4.6, respectively. The remaining candidate subsystems for oxygen supply, CO_2 control, and thermal control are given, for each application, in Table 18.

TABLE 18 FINAL CANDIDATE SUBSYSTEMS

MISSION	OXYGEN SUPPLY	CO_2 CONTROL	THERMAL CONTROL
ORBITAL EVA	• HIGH PRESSURE GAS • UMBILICAL TO BASE	• LiOH • VACUUM DESORBED SOLID AMINE • $Mg(OH)_2$ • ZnO • KOH • UMBILICAL TO BASE	• EVAPORATOR • AHS WITH UMBILICAL TO LARGE AHS • UMBILICAL TO BASE
LUNAR EVA	• HIGH PRESSURE GAS	• LiOH • VACUUM DESORBED SOLID AMINE • $Mg(OH)_2$ • ZnO • KOH	• EVAPORATOR • AHS • AHS WITH UMBILICAL TO REFRIGERATOR
MARS EVA	• HIGH PRESSURE GAS	• LiOH • $Mg(OH)_2$ • KOH • ZnO	• EVAPORATOR • AHS • AHS WITH UMBILICAL TO RADIATOR

The suitability for each of the concepts to the various applications was based on the following rationale:

(1) The umbilical to the base for oxygen supply was considered to be applicable only to orbital operations. It could be used in the planetary surface applications, but it would be limited to use near the primary vehicle or base. Thus it would not be capable of supporting long range excursions which will almost certainly be required.

(2) The vacuum-desorbed solid amine system for CO_2 control is not suitable for use on Mars surface missions, because of the high CO_2 partial pressure of the Mars environment ($\approx$ 3.5 mm Hg). The LiOH, $Mg(OH)_2$, ZnO, and KOH concepts could be used on any AEPS mission.

(3) Regarding thermal control subsystems, it was assumed that a large AHS with an umbilical to the man would probably not be used for surface operations due to its mass. This system is relatively compact, however, and it would be well suited for mounting on a small, powered surface transporter (LRV-type) or an orbital maneuvering work platform.

The modular AHS system may be limited in orbital use because of potential difficulty in replacing AHS modules in "zero-g". However, it may be possible to alleviate this difficulty by storing modules at a crew station on the vehicle exterior. For cases where the expected EVA duration is 4 or less hours, the required fusible heat sink could easily be integrated entirely into the backpack and/or suit thus eliminating the requirement for heat sink module replacement during an EVA.

The refrigeration and/or radiator systems were not considered for orbital use because of potential problems with manually maneuvering any system that required a deployed radiator. If this system were integrated with a maneuvering work platform, this difficulty would be avoided; there might still be orientation problems with these systems, however.

Table 19 lists the total systems which were considered in detail, and identifies them by a number which is used in later discussions and on figures. The table also summarizes the AEPS EVA weight and volume for each total system concept for design sortie durations of 4-hours and 8-hours. All possible combinations of subsystems are not included in Table 19, or in subsequent trade curves. Preliminary analysis indicated that some combinations were not competitive for any number of EVA's in any application; these were excluded from further consideration.

Figure 24 shows the total launch weight for AEPS systems suitable for use with vehicles having a non-regenerable ARS, such as the space shuttle. The appropriate power, heating, and cooling penalties for the shuttle were used in the calculation of the weight of the regenerable systems. Since the basic

TABLE 19 INTEGRATED AEPS EVA WEIGHT AND VOLUME SUMMARY

SYSTEM NO. AND DESCRIPTION	PACK WT. (LB_m/MAN)	PACK VOL. (IN^3/MAN)	EVA SUPPORT WEIGHT[4] (LB_m/2 MEN)	EVA SUPPORT VOLUME[4] (IN^3/2 MEN)	TOTAL EVA WEIGHT (LB_m/2 MEN)	TOTAL EVA VOLUME (IN^3/2 MEN)
1 – IMPROVED PLSS	120 (100)[1]	2650 (2210)	0 (0)	0 (0)	240 (200)	5,300 (4,420)
2 – AMINE/AHS WITH UMBILICAL TO LARGE AHS	150 (150)[2]	4940 (4940)	294 (175)	7020 (4175)	594 (475)	16,900 (14,055)
3 – $Mg(OH)_2$/AHS WITH UMBILICAL TO LARGE AHS	144 (128)[2]	3900 (3470)	294 (175)	7020 (4175)	582 (431)	14,820 (11,115)
4 – AMINE/AHS/ REFRIGERATOR "TOP-OFF"	150 (150)[2]	4940 (4940)	131 (131)	4370 (4370)	431 (431)	14,250 (14,250)
5 – $Mg(OH)_2$/AHS	134 (158)	3600 (4125)	203 (0)[2]	4750 (0)	471 (316)	11,950 (8,250)
6 – $Mg(OH)_2$/AHS REFRIGERATOR "TOP-OFF"	144 (128)[2]	3900 (3470)	131 (131)	4370 (4370)	419 (387)	12,170 (11,310)
7 – LiOH/AHS	106 (144)	2500 (3360)	203 (0)	4750 (0)	212 (288)	9,750 (6,720)
8 – LiOH/AHS/ RADIATOR "TOP-OFF"	117 (113)[2]	2820 (2725)	76 (76)	2990 (2990)	310 (302)	8,630 (8,440)
9 – $Mg(OH)_2$/AHS/ RADIATOR "TOP-OFF"	144 (128)[2]	3900 (3470)	76 (76)	2990 (2990)	364 (332)	10,790 (9,910)
10 – ZnO/AHS	161 (171)	3420 (3860)	203 (0)	4750 (0)	525 (342)	11,590 (7,720)
11 – ZnO/AHS/ REFRIGERATOR "TOP-OFF"	171 (157)[2]	3800 (3570)	131 (131)	4370 (4370)	473 (445)	11,970 (11,510)
12 – ZnO/AHS/ RADIATOR "TOP-OFF"	171 (157)	3800 (3570)	76 (76)	2990 (2990)	418 (390)	10,590 (10,130)
13 – "ALSA TYPE" UMBILICAL SYSTEM	108 (108)[3]	–	–	–	216	–
14 – ZnO/EVAPORATIVE HEAT SINK	173 (127)	3550 (2710)	0 (0)	0 (0)	346 (254)	7,100 (5,420)

1. DATA FOR 4 HOUR EVA SYSTEM GIVEN IN BRACKETS
2. AHS INTEGRATED INTO BACK PACK
3. INCLUDES UMBILICAL WEIGHT
4. NOT INCLUDING ITEMS COMMON TO ALL SYSTEMS SUCH AS THE EVA STATION

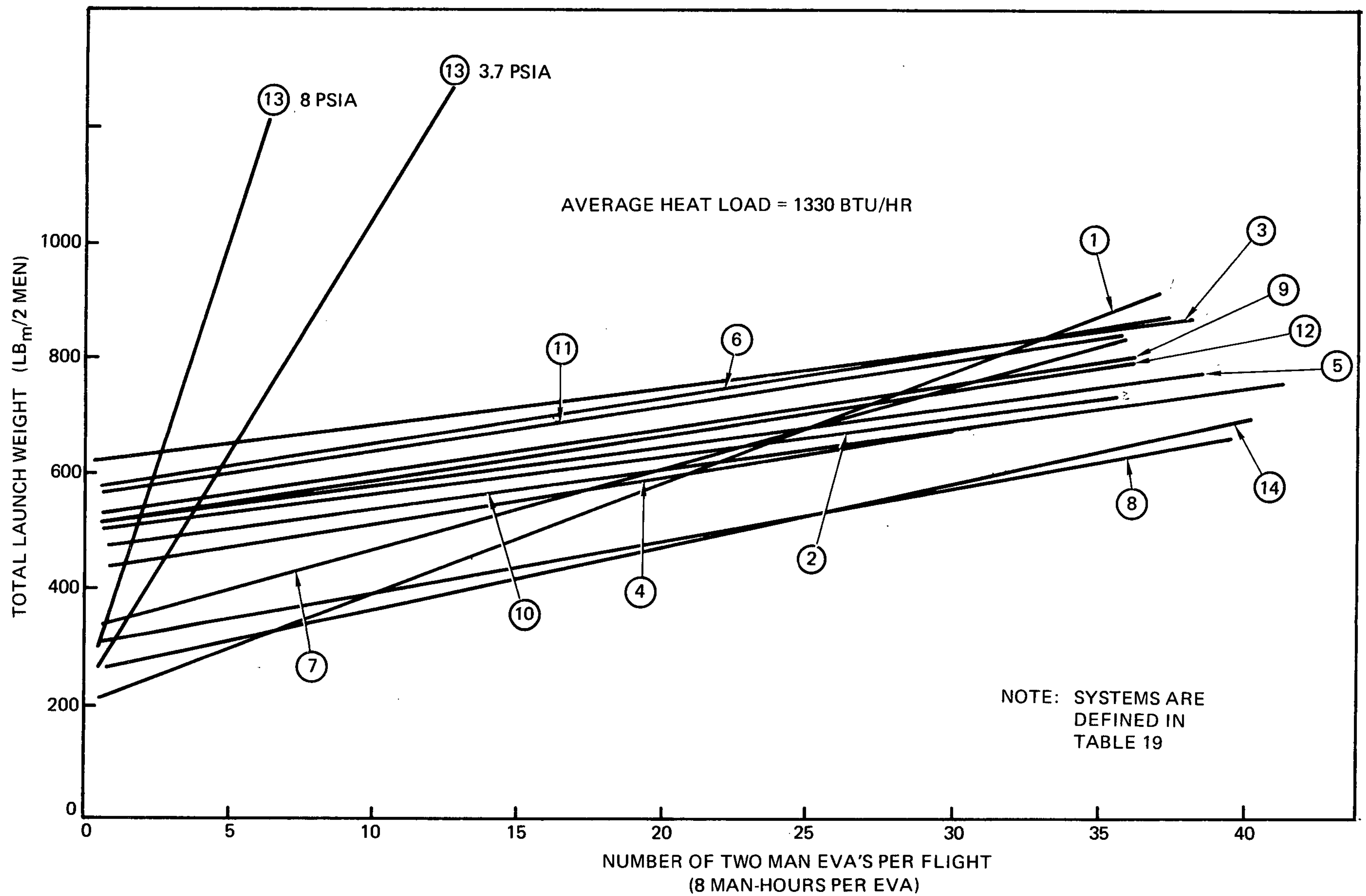


FIGURE 24 COMPARISON OF AEPS TOTAL SYSTEM WEIGHT FOR A VEHICLE WITH A NON-REGENERABLE ARS, SUCH AS THE SPACE SHUTTLE

shuttle does not include equipment to regenerate O_2 from CO_2; All regenerable CO_2 control subsystems, for shuttle use,vent the CO_2 produced during the EVA. This venting can occur during the EVA or during regeneration of the sorbent in the shuttle. Figures 25 and 26 show similar curves calculated for long duration base penalties with a total AEPS heat load of 1200 BTU/hr and 2000 BTU/hr respectively.

These total system heat loads correspond to metabolic rates of 1000 BTU/hr and 1700 BTU/hr, respectively, with no heat leak; or higher metabolic rates with negative heat leak, etc. The total system heat load is used as a parameter rather than metabolic rate since this is the factor that determines the heat rejection expendables. The total heat load includes waste metabolic heat, CO_2 control heat release, equipment waste heat, and environmental heat load. The use of total heat load allows these curves to be independent of the environment so long as the total heat load equals the assumed values.

In Figures 24-26, the completely regenerable systems show a weight increase with total EVA time because of suit gas leakage. Also, the closed heat rejection systems which require an umbilical may show a further increase in weight with total EVA time because of the arbitrary assumption that only 70% of each EVA would be spent on the umbilical; the remaining 30% would be spent on a supplemental, or "top-off" heat rejection system which may require some expendables.

The ordinate intercept of these curves, which is identified as the total system weight, includes all base equipment and penalties unique to each concept, plus EVA packs and spares, etc.; but excludes EVA expendables and common equipment such as the EVA station. The slope of each curve gives the system expendable weight in lbm per 2 man EVA.

The system weights were based on 2 man EVA events because of the ground rule that safety requirements would dictate that at least two men be involved in each EVA event. Increasing the number of men participating in an EVA event reduces the amount of support equipment needed for regenerable portable life support equipment on a per man basis. Thus planned one-man EVA's would be somewhat more costly, while those EVA's planned for more than three men would cost somewhat less per man.

Although the cross-over points are not the same for regenerable and non-regenerable ARS's at the base, the general trend shown by the figures is that the expendable Apollo PLSS type system is lightest for less than about 3 EVA's (involving 2 men). Between approximately 3 and 20 EVA's an expendable or partially regenerable CO_2 control system, with a closed or semi-closed heat rejection system is superior, while a closed CO_2 system is advantageous for more than 20 EVA's.

The remaining systems must now be compared on a more detailed basis. Table 19 gave some of the required parameters for each of the systems. $Mg(OH)_2$ and ZnO were chosen for final system integration over KOH because of uncertainty about the technical feasibility of the KOH concept. The KOH concept has a potential advantage in pack weight and volume so it could ultimately prove to be the superior concept.

Some of the candidate subsystems have specific mission applications and total system combinations employing them are not applicable to all AEPS missions.

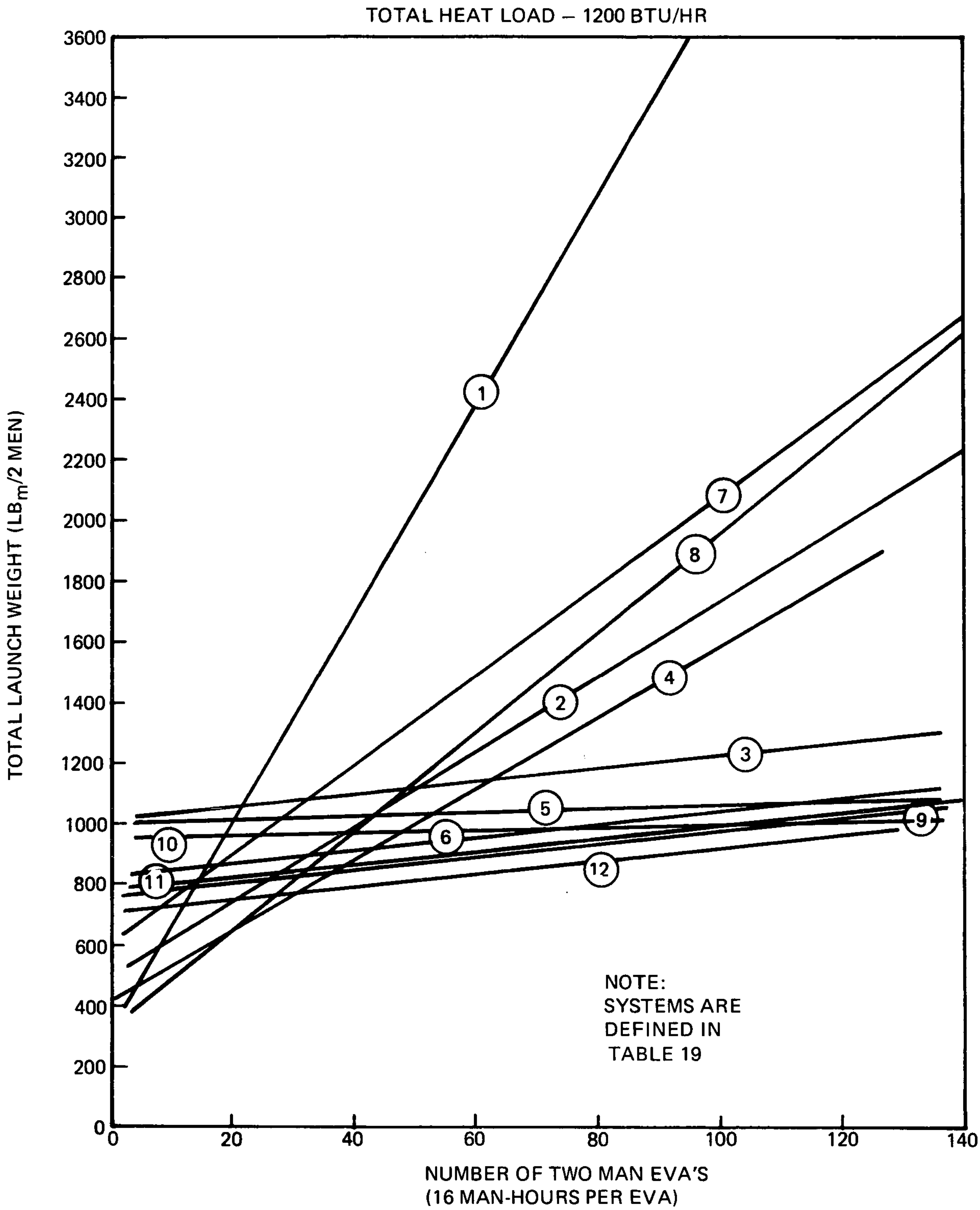


FIGURE 25 LONG DURATION BASE AEPS TOTAL SYSTEM LAUNCH WEIGHT VS. NUMBER OF EVA'S – 1200 BTU/HR HEAT LOAD

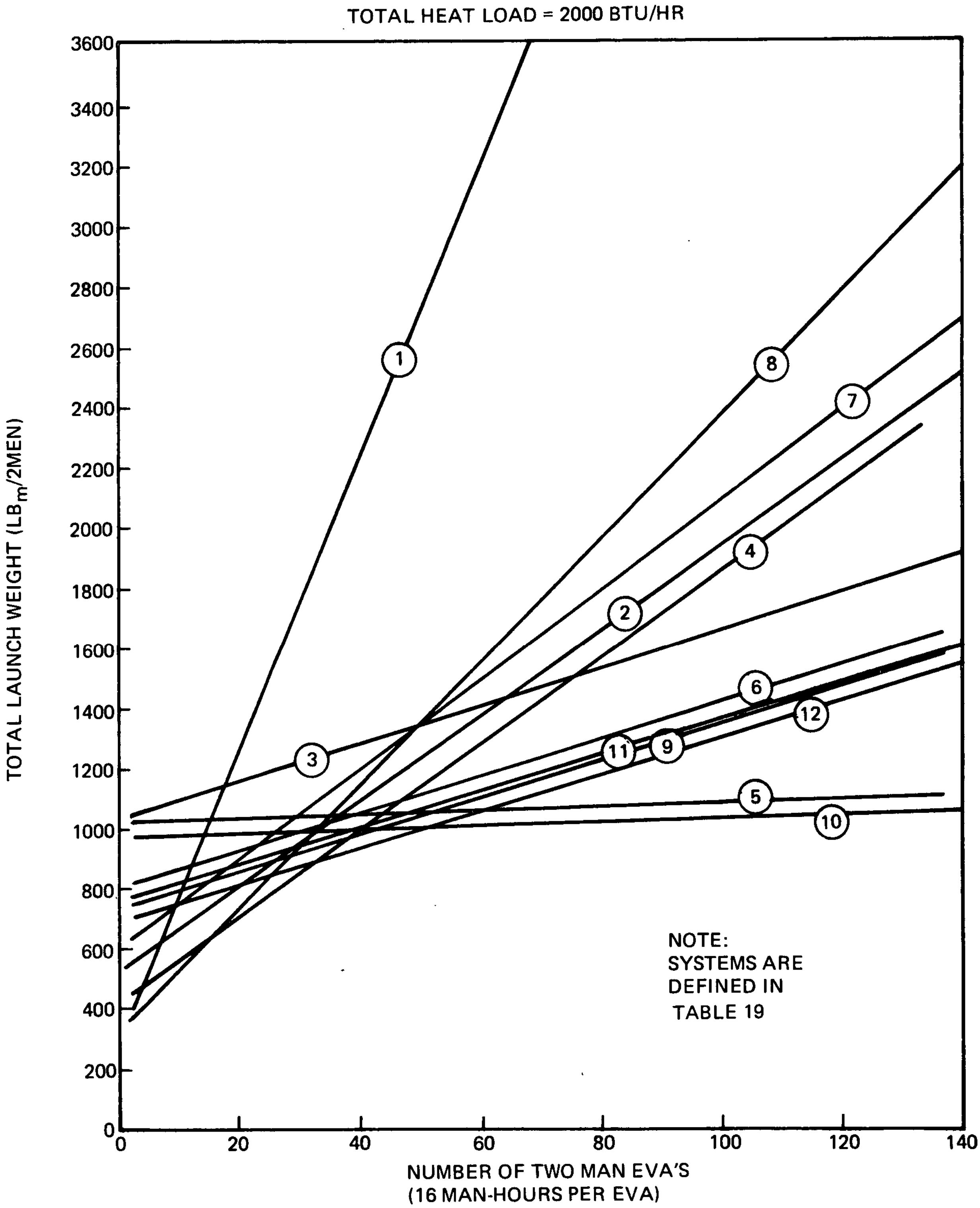


FIGURE 26 AEPS TOTAL SYSTEM LAUNCH WEIGHT VS. NUMBER OF EVA'S – 2000 BTU/HR HEAT LOAD

An Apollo PLSS-type system with improved LiOH utilization and reusability is suitable for all potential AEPS missions. However, this system is only competitive for less than about 5 EVA's so that it would not be used for longterm lunar or Mars missions involving many EVA's. The large AHS/umbilical support system could be used on any mission. It was assumed that it would not be used for surface EVA due to its large mass but if a powered transporter was assumed, it would be an attractive system due to its compact size.

Systems 2 and 4 are the least desirable of the remaining systems, due to the large pack weight and volume required for the amine system. This method of CO_2 control has inherent reliability problems when applied to an AEPS size unit. These problems are sufficient to make this system undesirable unless it can be shown that considerable advantage can be taken of the development effort already expended on solid amine systems for space station use.

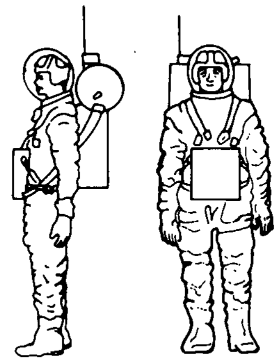
Table 19 and Figures 24 - 26 illustrate that a decrease in total system weight, by reducing expendables, can only be accomplished by an increase in the EVA mass and volume. It is possible to integrate non-expendable life support systems within the weight and volume constraints of a backpack, with the exception of the heat rejection system if a nominal 8 hour EVA duration is required.

The two methods of using a small transporter for AEPS support, i.e., modular or umbilical approach, were discussed earlier. It was found, that the modular AHS system is heavier than the refrigerator, umbilical system, 203 lb_m per 2 men vs 131 lb_m per 2 men and that EVA time is required to change modules. However, the system is more compact, since no radiator is required, and therefore, it may be easier to transport. In addition, no mobility is sacrificed by requiring an umbilical and the system has the capability to operate for the full EVA duration, without support, by employing the expendable mode of operation. The refrigeration system has an EVA weight of 131 lb_m per 2 men and the only base requirement is a battery charger and the recharge power penalty.

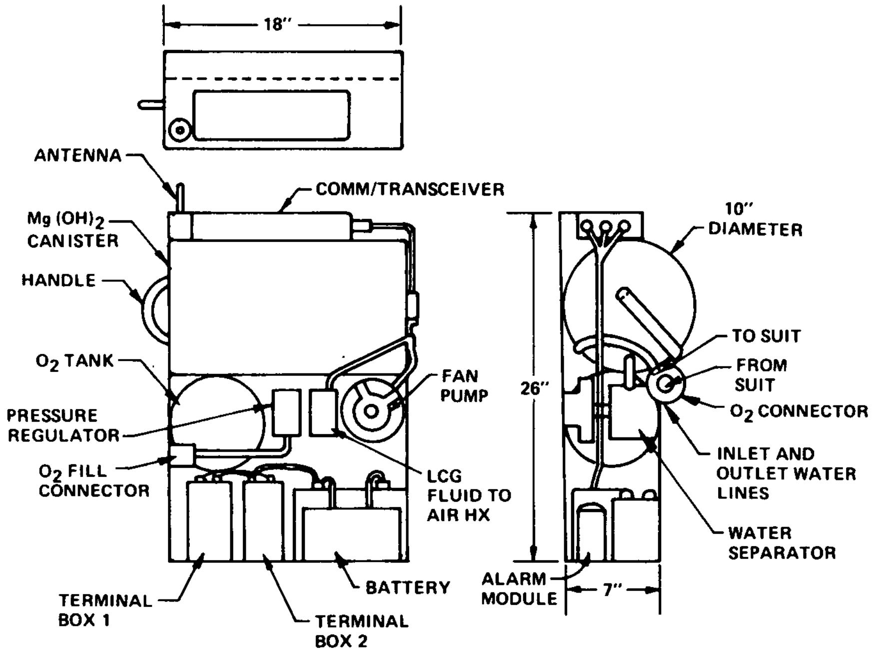
A heat exchanger is included between the LCG loop and the umbilical fluid to preclude the possibility of an umbilical failure causing a loss of all cooling. This system is probably best suited for applications where a powered transporter is assumed. The refrigerator/radiator could be easily integrated with the transporter and it could be used while riding on the transporter and for operations in its immediate vicinity. The inclusion of a fusible AHS heat sink into the pack allows 1-2 hours operation, without the umbilical, with no water consumption. If more nonumbilical time is required, the EVA can be continued with no loss in capability simply by switching the AHS to the expendable mode.

Several conceptual backpack designs were produced to demonstrate that the regenerable thermal control and CO_2 control subsystems could be integrated with the other AEPS subsystems into a practical pack system.

Figure 27 illustrates a system using a metallic oxide/hydroxide canister for CO_2 control with a modular AHS carried in a chest pack. This



	WT (LB)
BACKPACK	
OXYGEN BOTTLE	10.40
$Mg(OH)_2$	38.90
TRACE CONTAMINANT	0.30
BATTERY	10.50
REMAINDER	47.82
CHEST PACK	
RCU	5.64
AHS	30.00
TOTAL	143.56



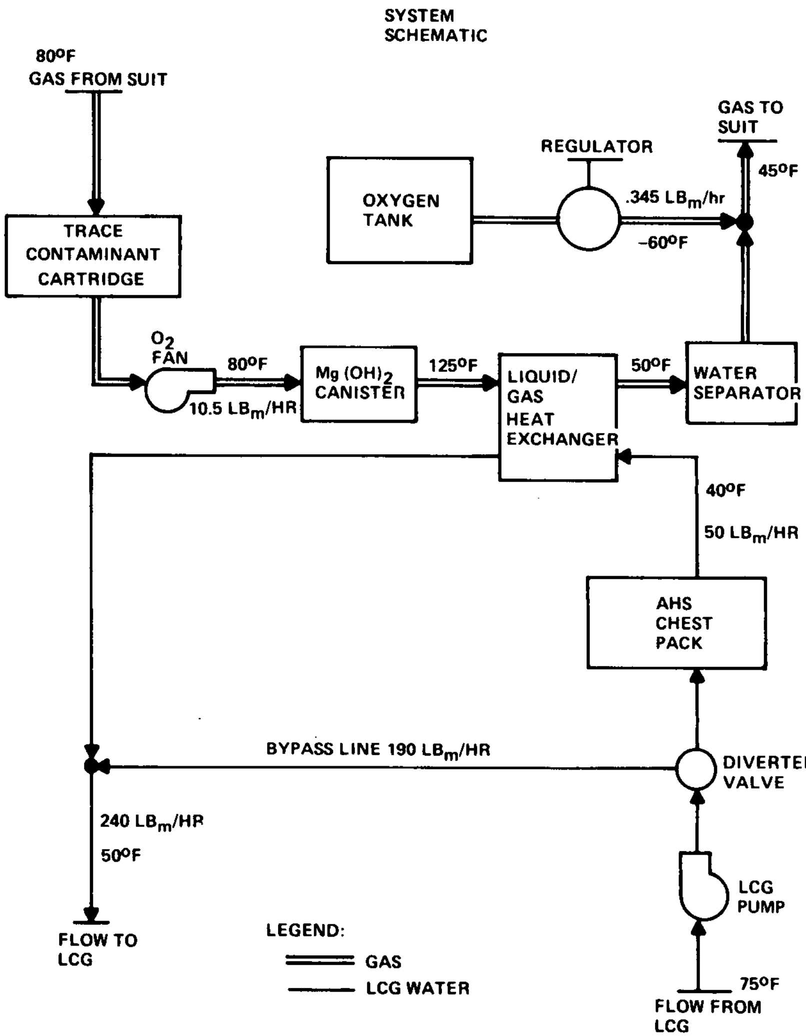


FIGURE 27 BACKPACK WITH MAGNESIUM HYDROXIDE CARBON DIOXIDE CONTROL AND CHEST PACK AHS HEAT REJECTION SYSTEM

chest pack also contains the backpack controls, quantity indicators, and warning lights similar to the PLSS Remote Control Unit (RCU). The chest mounting of the modular AHS was chosen because it facilitates module replacement. The large volume of the $Mg(OH)_2$ canister is primarily responsible for the large bulk of the backpack. However, the total weight of the system is only about 25 lbm greater than the -7 PLSS. This system has the capability to operate for 1-2 hours without requiring any expendables or replacement modules and a full 8 hours by utilizing the AHS evaporation mode.

System No. 6 is shown in Figure 28; it is similar to system No. 5 described above, but includes a heat exchanger and an umbilical to connect to a refrigeration system. An AHS chest pack is also included to allow 1-2 hours of non-expendable operation without the umbilical. Since the AHS is not replaced during the EVA with this system, it could be integrated into the backpack. This pack weighs more than the modular AHS pack because of the requirements for a heat exchanger and umbilical quick-disconnects.

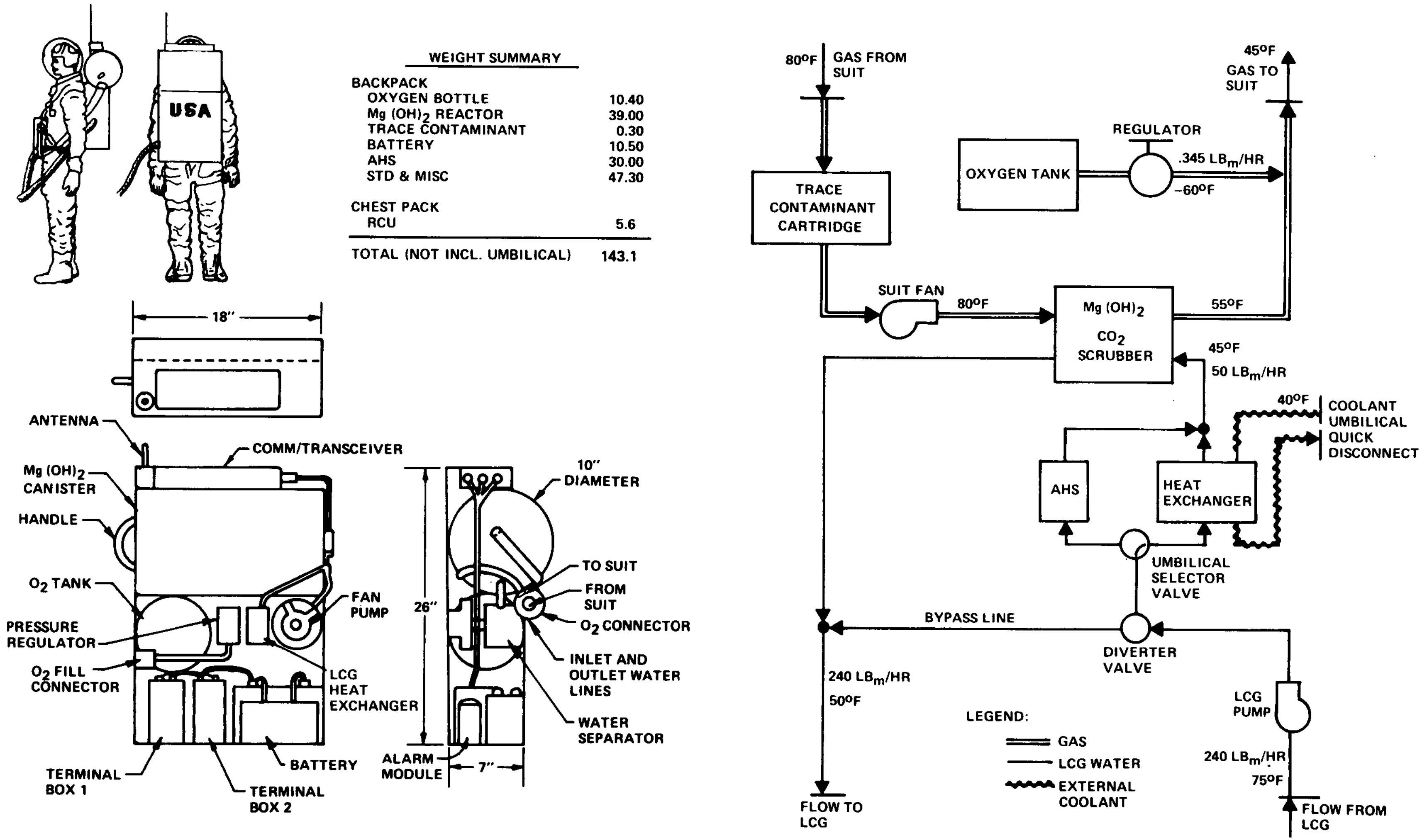
Figure 29 presents System No. 7, which utilizes expendable LiOH for CO_2 control with a fusible/evaporative AHS for thermal control. Since this system is designed for a 4 hour maximum EVA duration the AHS is integrated entirely within the backpack. No separate EVA support equipment is required.

Figure 30 summarizes the weight requirements for the most promising AEPS total systems for use with a long duration orbital or surface base. The improved Apollo PLSS (System No. 1) is shown to have the smallest total launch weight and volume for less than about 20 EVA's (involving 2 men each). Completely regenerable systems show large weight savings beyond this point.

Figure 31 presents similar results consistent with the space shuttle energy penalties and life support system outlined in Table 3. This figure shows that an ALSA system (System No. 13) is never competitive on a weight basis regardless of the number of EVA hours. An expendable closed loop system shows a slight weight advantage over most of the range. The greater weight of the fusible heat sink systems may be more than offset by their operational advantage of not venting water vapor during the EVA. The AHS also includes the capability to operate as an evaporative heat sink so that this mode could be used on EVA's which had no venting constraints in order to save the power required for freezing.

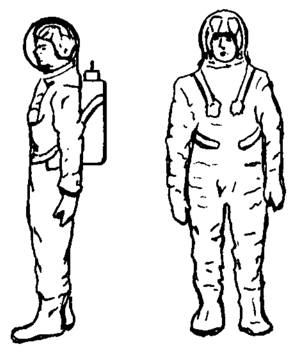
Figure 32 shows the EVA weight for the above systems plus the Amine/AHS/Refrigerator System (No. 4) as a function of EVA duration. The weight carried by the man is shown in the upper plot, while the lower plot shows the total EVA weight. This weight includes frozen AHS modules with their storage container or a refrigeration system along with the pack weight. This figure shows that the pack weight is relatively independent of the EVA duration while the total EVA weight of a system using AHS thermal control changes considerably since about 10 lbm of ice are required per EVA hour.

These figures illustrate the conclusion that a large saving in total system weight by utilizing regenerable subsystem is possible only by increasing

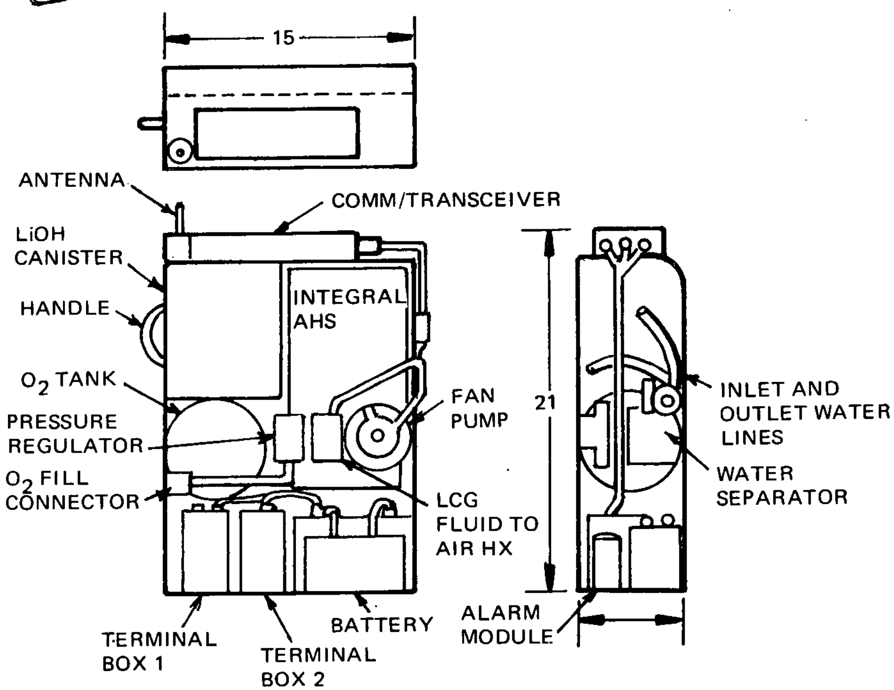


WEIGHT SUMMARY	
BACKPACK	
OXYGEN BOTTLE	10.40
$Mg(OH)_2$ REACTOR	39.00
TRACE CONTAMINANT	0.30
BATTERY	10.50
AHS	30.00
STD & MISC	47.30
CHEST PACK	
RCU	5.6
TOTAL (NOT INCL. UMBILICAL)	143.1

FIGURE 28 BACKPACK WITH MAGNESIUM HYDROXIDE CARBON DIOXIDE CONTROL AND AHS/REFRIGERATOR HEAT REJECTION SYSTEM



WEIGHT SUMMARY	
INTEGRAL AHS	45.0
OXYGEN SUPPLY	6.0
LiOH	8.0
TRACE CONTAMINANT	0.3
BATTERY	2.0
EMERGENCY SYSTEM	20.0
MISCELLANEOUS	25.3
TOTAL	106.6



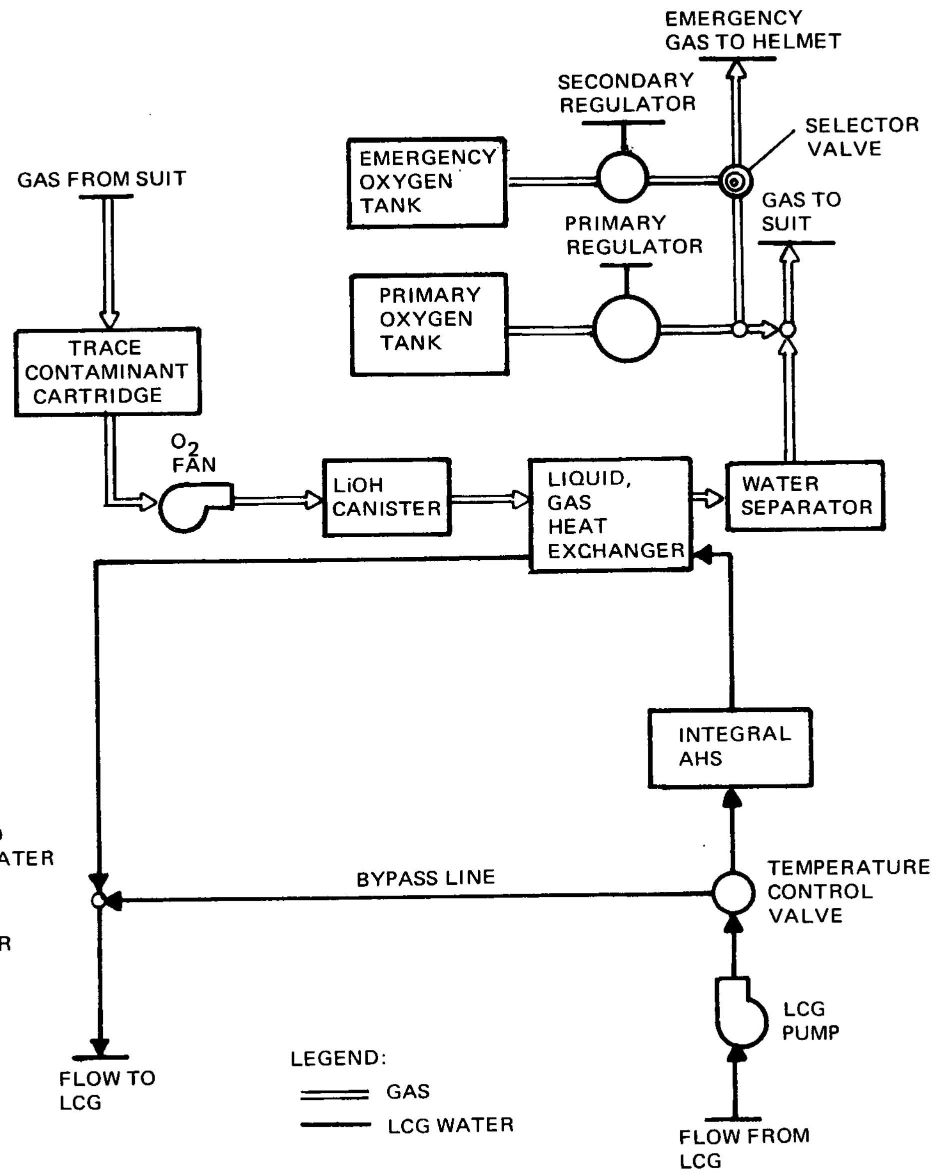


FIGURE BACKPACK WITH LITHIUM HYDROXIDE CARBON DIOXIDE CONTROL AND INTEGRAL AHS HEAT REJECTION SYSTEM (4 HOUR CAPACITY)

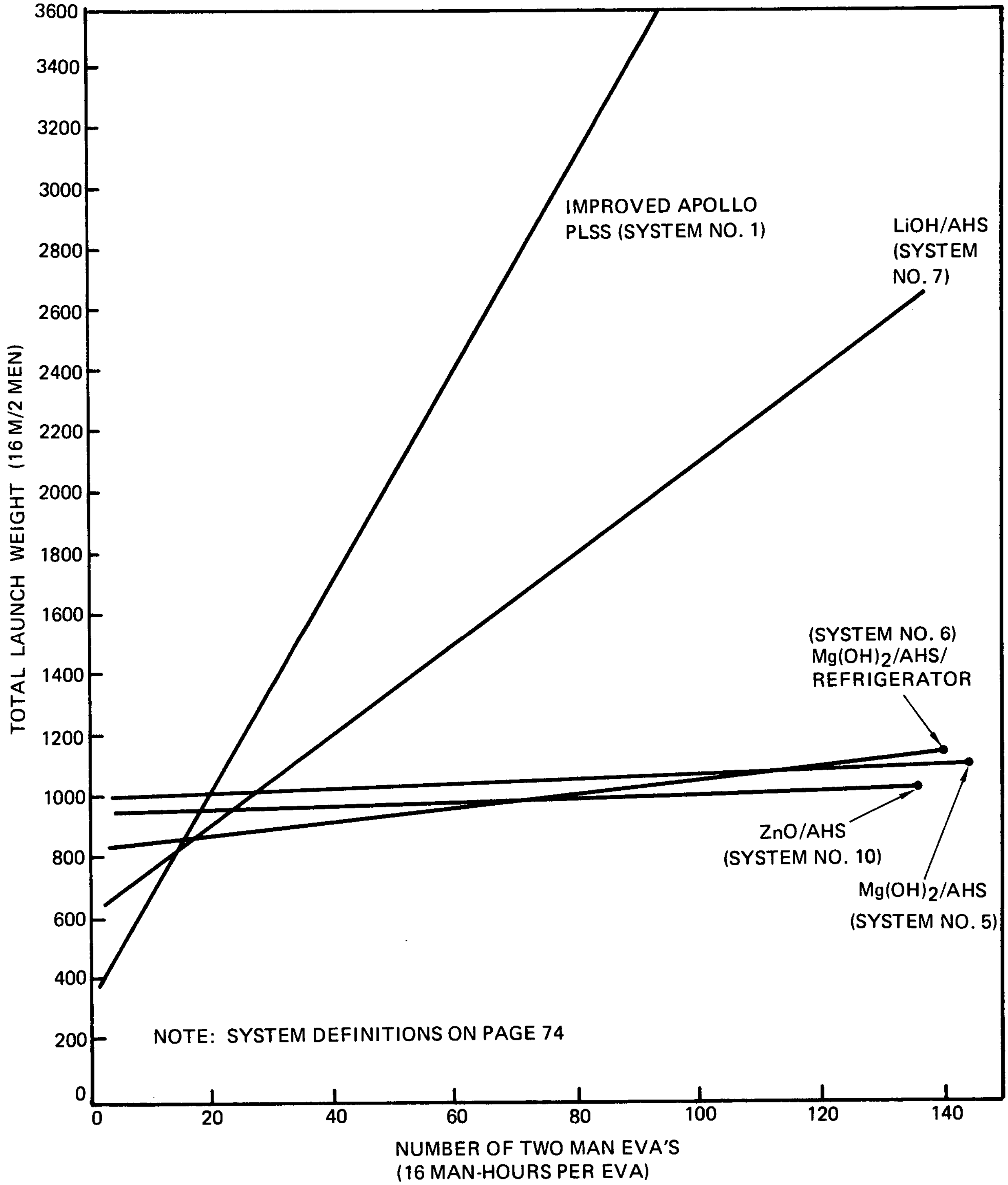


FIGURE 30 SUMMARY OF AEPS FOR PERMANENT BASE EVA (WITH A REGENERABLE ARS)

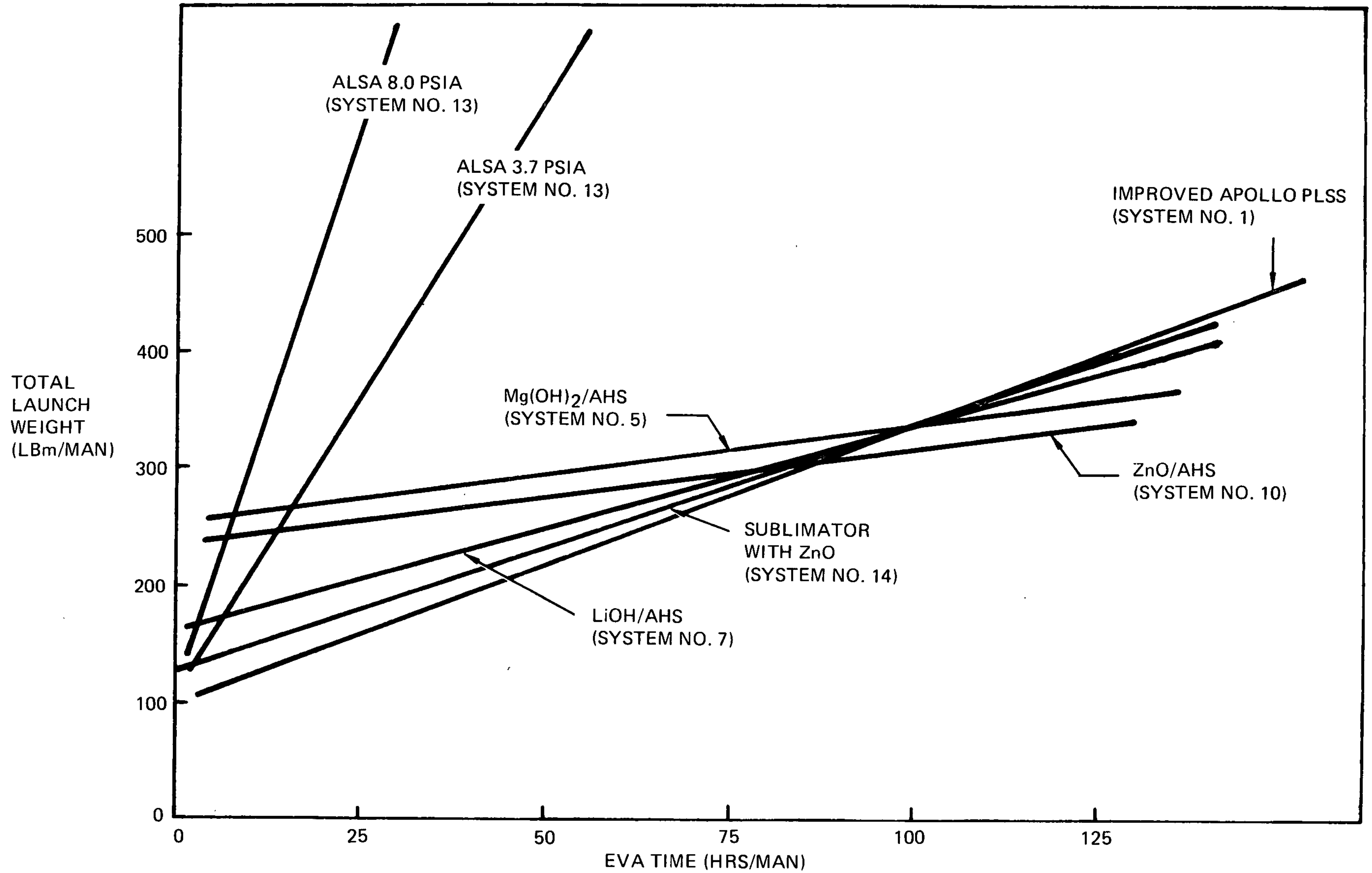


FIGURE 31 COMPARISON OF CANDIDATE AEPS TOTAL LAUNCH WEIGHT VS EVA TIME FOR BASE WITH NON-REGENERATIVE ARS, e.g., THE SPACE SHUTTLE

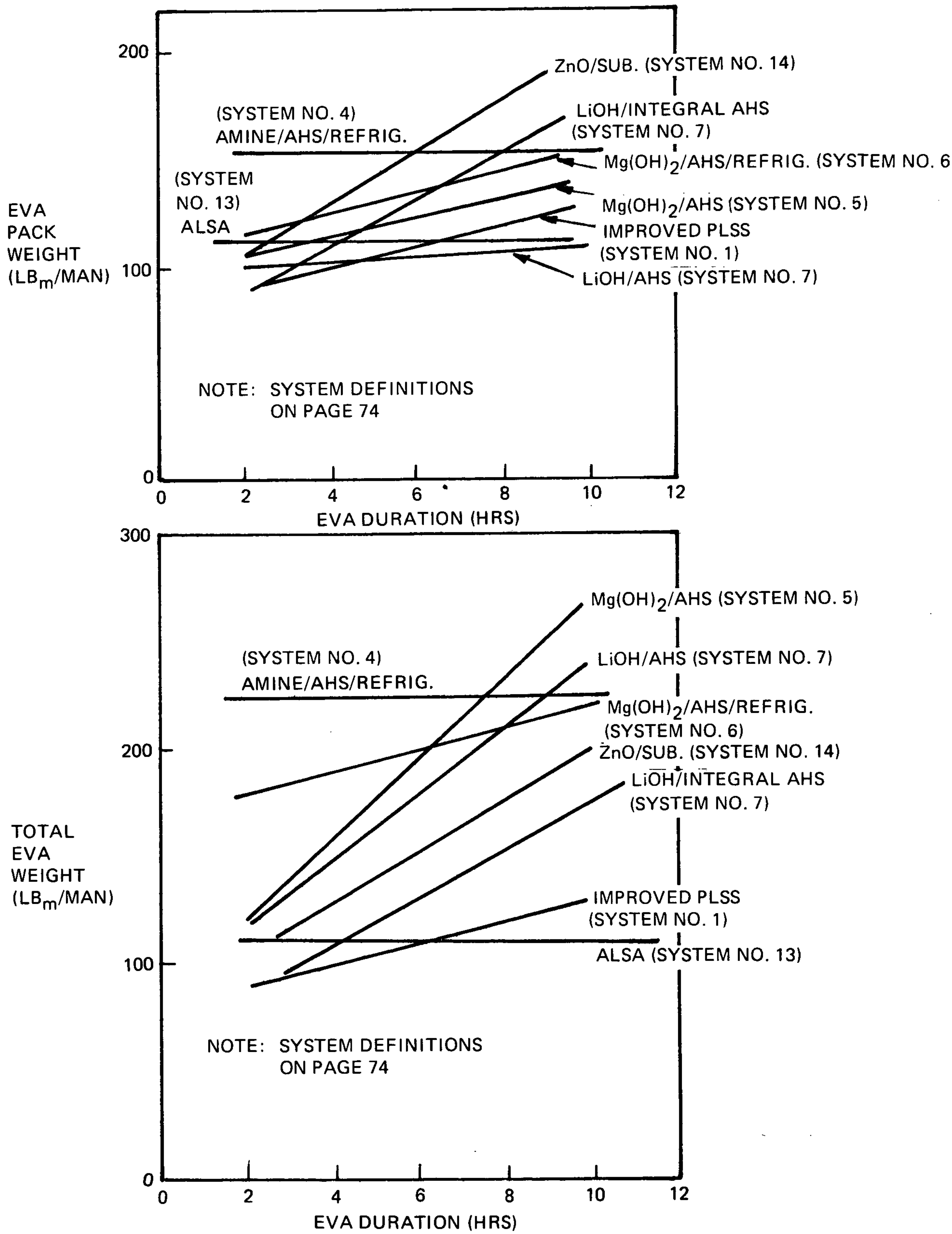


FIGURE 32 SUMMARY OF AEPS EVA WEIGHT

the weight of the EVA system. In order to minimize the EVA transportation difficulties, a large part of this weight is separate from the man and he is supported by means of a cooling umbilical or with replaceable AHS modules. Thus, the weight of the pack that the man must carry is only slightly increased over the weight of an expendable "PLSS-type" system. This is considered to be the most promising approach to providing a fully regenerable EVA life support system with minimum encumbrance.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Lithium Hydroxide (LiOH) for carbon dioxide control is best for missions involving up to about 200 hours each of EVA time for two crewman. Beyond this point the thermally regenerable metallic oxide/hydroxides are favored. The trade point is significantly influenced by the base power penalty since slightly over 50% of the $Mg(OH)_2$ total launch weight is power penalty for reducing the carbon dioxide which is produced during the EVA to recover the oxygen; 25% is for energy penalty associated with regeneration of the $Mg(OH)_2$; and only the remaining 25% is actual hardware weight.

The water evaporator expendable thermal control concept is the best choice for missions involving up to 20 hours of EVA time each for two crewman. Beyond this point the regenerable thermal control systems are superior from a total launch system standpoint; although they do involve the use of a transporter to support the AEPS design mission. The most favorable concept is the AHS in some form; it has simplicity and low total launch weight. For planetary and surface missions a transporter to supply additional AHS modules is required for the AEPS design mission. The crewman has complete freedom of movement, since he is not tied to the transporter by an umbilical but some useful EVA time is sacrificed in replacement of AHS modules. It is not mandatory that the crewman remain near the transporter, or that he replace AHS modules, since he can use the AHS in the water evaporator mode, in which case there is an ample supply of expendable water to accomplish the AEPS design mission. For use in orbital operations the design mission duration will probably be less than the AEPS design mission duration of 8 hours, thus a single, large fusible heat sink device may be attractive. It is also possible that the design metabolic rate used for planetary missions will be less than the 1600 BTU/hr used for the AEPS design EVA, and this will make the AHS more attractive since less frequent replacement of AHS modules would be required, and fewer AHS modules would be carried.

The thermal control concept of the refrigeration machine with an AHS for "top-off" is attractive for lunar surface operations. It has the disadvantages of a requirement for a coolant umbilical, and relatively high subsystem complexity. For Mars surface operation the refrigeration machine could be replaced by a simple space radiator subsystem. In orbital operations or on Mars the space radiator mounted on the transporter could be replaced by an integral suit radiator, with a "top-off" system to provide the additional heat rejection capacity necessary during periods with higher-than-normal heat loads.

The emergency or backup system has a mandatory requirement for a "blow-down" oxygen supply capability; this is the only effective approach for maintaining suit pressurization in the event of suit failure. Rapid decompression is the most lethal of the more probable types of AEPS failures or contingency conditions, so some protection against it is required. The emergency "blow-down" oxygen supply inherently provides ventilation and thermal control. This makes the use of redundant components in the primary subsystems less attractive; except for the emergency oxygen supply itself, which may be in a separate container. It could also be in an enlarged primary oxygen supply tank with redundant pressure regulators. Under the constraints set in this study, the amount of oxygen which can be carried for use in the blow-down system is limited to about 20 minutes of high flow. Therefore, an additional form of protection is needed to handle high suit leakage rates on planetary EVA's which involve travel to points as much as two hours from the parent vehicle; the Lightweight Emergency Shelter (LES) will satisfy this need. For failures of the ventilation subsystem at a considerable distance from the parent vehicle, a CTS-type of "blow-down" technique which uses a low flowrate can easily be used. Thermal control is marginal in this circumstance, so an additional means of thermal control may be required; the "buddy umbilical" system is the most attractive in this application.

The impact of the emergency back-up system on the selection of regenerable primary subsystems is minimal. This is primarily a consequence of the expendable nature of the "blow-down" emergency system. The "buddy umbilical" technique for thermal control will require each AEPS system to have more heat rejection capacity. This has little impact on heat rejection subsystem selection, but does favor the AHS slightly, since it has an inherent excess water boiling capacity.

Based on the relatively small number of EVA hours which seem likely to occur on the shuttle, purely expendable AEPS subsystems are favored. If it is assumed that a larger number of EVA events will be accomplished from the shuttle, then the AHS heat rejection subsystem becomes attractive, although it is probable that an ample amount of water will be generated by the shuttle fuel cells to support EVA requirements. However, there is a strong possibility that many missions will prohibit the venting of fluids into space in the vicinity of the vehicle. Thus the most favorable shuttle AEPS heat rejection is the fusible AHS, which also has an evaporation mode.

The following general conclusions were reached in this study:

(1) Regenerable Portable Life Support Systems for use in EVA are feasible.

(2) The most promising approach to regenerable portable life support subsystems involves regeneration at the primary base or shelter.

(3) Regenerable portable life support subsystem concepts offer large total launch weight savings at the expense of EVA weight and volume.

(4) Inclusion of an emergency back-up system in the AEPS has only a minimal impact on regenerable life support subsystems, and does not alter any of the subsystem selections.

(5) There is likely to be no advantage for an AEPS regenerable carbon dioxide control subsystem on the space shuttle; there may be an advantage for a fusible heat sink thermal control subsystem,

based on fluid dumping restrictions rather than on weight savings considerations alone.

Recommendations for future study and development are given in Table 28 for both primary and secondary efforts. The highest priority subsystem concept recommendations are:

(1) Develop the AHS concept to provide a regenerable thermal control subsystem which will be beneficial on missions involving more than 20 hours of EVA time or for EVA's which are restricted to no vapor venting.

(2) Develop the thermally regenerable metallic oxide/hydroxide carbon dioxide control system, which will be beneficial on missions involving more than 200 hours of EVA time.

The following recommendations for future work, while not relating to regenerable life support systems, results from the study and are thought to warrant identification:

(1) Develop the Lightweight Emergency System for use in contingency situations involving rapid suit decompression.

(2) Investigate the concept of seals in the wrist and neck regions which preclude extremely rapid decompressions in the bulk suit and helmet regions, respectively, in the event of suit failure.

(3) Perform a study to determine the optimum means of executing EVA from a vehicle with a 14.7 psia, two-gas atmosphere.

TABLE 28 RECOMMENDED AEPS DEVELOPMENT ITEMS

	PRIMARY ITEMS	RECOMMENDATION
(1)	ASTRONAUT HEAT SINK (AHS)	DEMONSTRATE FEASIBILITY OF THE AHS CONCEPT AND DETERMINE OPTIMUM METHOD OF INTEGRATION WITH AEPS
(2)	ZnO AND Mg $(OH)_2$ CO_2 CONTROL SYSTEM	DEMONSTRATE FEASIBILITY OF AEPS DESIGN AND BASE REGENERATION FACILITY
(3)	LiOH CO_2 CONTROL SYSTEM	IMPROVE UTILIZATION EFFICIENCY
(4)	KOH CO_2 CONTROL SYSTEM	INVESTIGATE THE CONCEPT FEASIBILITY
(5)	PORTABLE REFRIGERATION SYSTEM	DEVELOP HARDWARE FOR PORTABLE LUNAR REFRIGERATION SYSTEM
	SECONDARY ITEMS	
(a)	LES	PERFORM DETAILED DESIGN AND TESTING
(b)	WRIST AND COLLAR SEAL	PERFORM DETAILED DESIGN AND TESTING AND INVESTIGATE PHYSIOLOGICAL RESPONSE OF CREWMAN
(c)	EMERGENCY THERMAL CONTROL REQUIREMENTS	DETERMINE CREWMAN RESPONSE TO EMERGENCY THERMAL STRESS
(d)	LCG DESIGN	DEVELOP MORE EFFECTIVE AND COMFORTABLE LCG
(e)	HEAT SINK SUIT	INVESTIGATE POTENTIAL BENEFITS AND DESIGN FOR ORBITAL EVA
(f)	IMPROVED PLSS	INCREASED REUSABILITY, RELIABILITY, AND EVA DURATION
(g)	PORTABLE RADIATOR SYSTEM	DEVELOP HARDWARE FOR PORTABLE MARS RADIATOR SYSTEM
(h)	UMBILICAL DESIGN	INVESTIGATE DESIGN OF LIGHTWEIGHT FLEXIBLE COOLING UMBILICALS AND DETERMINE MOBILITY RESTRICTIONS
(i)	VACUUM QUICK-DISCONNECTS	DEVELOP HARDWARE FOR RELIABLE VACUUM QUICK-DISCONNECTS
(j)	HIGH PRESSURE O_2 COMPRESSOR	DEVELOP LIGHT-WEIGHT COMPRESSOR FOR REFILLING EVA O_2 TANKS AT BASE
(k)	EVA THERMAL CONTROL OVERCOAT	INVESTIGATE FEASIBILITY AND POTENTIAL WEIGHT SAVINGS FOR LUNAR EVA
(l)	BIOLOGICAL CLEANING	INVESTIGATE METHODS OF STERILIZATION AND CLEANING OF EVA EQUIPMENT FOR LONG TERM, REPEATED USE

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APPENDIX A

SPACE SHUTTLE EVA

APPENDIX A

SPACE SHUTTLE EVA

This appendix discusses the shuttle orbiter life support system, current shuttle baseline EVA equipment, and the rationale behind the Shuttle AEPS specification given in Table 2 of the main body of this report.

1.0 SHUTTLE ENVIRONMENTAL CONTROL/LIFE SUPPORT SYSTEM

1.1 CABIN ENVIRONMENT

The Space Shuttle Orbiter is intended to have a nominal mission duration of 7 days (References [1]* and [2] and [3]). The mission duration may be as short as 2 days or as long as 30 days (Reference [3]). There is basically a 4 man crew, although as many as 14 men and women as passengers and crew are considered for study purposes (Reference [3]). The significant requirements for the orbiter cabin are given in Table A-1 (from References [4] and [5]). Table A-2 gives the techniques chosen for the various life support functions by the shuttle study contractors. Food is nominally of the canned or dehydrated variety, although a food freezer may be used to provide whole food on the longer missions (Reference [2]). Some potable water is carried on the shuttle, but the primary source of potable water is the hydrogen-oxygen fuel cells which produce water as a by-product. The electrical requirements are high, and so water production exceeds demand by a significant amount. The excess water is either stored for transfer to another space vehicle such as a space station or is dumped overboard (References [2] and [3]). Human waste products are not processed to recover water, but are simply stored for return to earth.

1.2 ENVIRONMENTAL CONTROL/LIFE SUPPORT SYSTEM (EC/LSS) RELIABILITY

The baseline EC/LSS Reliability requirements are that the failure sequence will be fail operational, fail safe. That is, the system must be capable of continued operation with no degradation in performance, or impact on mission goals, after a single failure, and it must be capable of operating in an adequate fashion to allow a safe return to earth after a second failure. The specified emergency operation period is 48 hours (Reference [3]).

1.3 EVA CAPABILITY

Regarding EVA, the space shuttle orbiter must not be designed so as to preclude EVA (Reference [3]). This requires that an airlock be provided for egress purposes. The airlock must be large enough to accommodate two men plus EVA equipment; this means that the volume must be at least 210 cu.ft. (Reference [8]) and the baseline nominal volume is 337 cu.ft. The vehicle life support system must be capable of replenishing the atmosphere lost during egress, and it may be advantageous for the vehicle to contain a pumping system to recover the atmosphere in the airlock prior to egress. The current shuttle baseline calls for all EVA equipment except the airlock to be charged to the payload.

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* Reference numbers refer to the reference list at the end of this appendix.

TABLE A-1

BASIC SHUTTLE EC/LSS CABIN

DESIGN CRITERIA (REFERENCE [4])

Parameter	Minimum	Maximum	Nominal
Total Pressure (psia)	10	14.7	-
Oxygen Partial Pressure (psia)	3.15 @ 10 3.00 @ 14.7	3.35 @ 10 3.25 @ 14.7	3.15 @ 10 3.10 @ 14.7
Atmosphere Diluent		Nitrogen	
CO_2 (mm Hg)	0	7.6	5.0
Cabin Temperature (°F)	70	75	72
Cabin Temperature Control Range (°F)	-	-	±2
Cabin Dew Point (°F)	47	57	50
Cabin Wall Temperature (°F)	65	80	72
Cabin Volume (Ft^3)	-	-	526
Airlock (Ft^3)	-	-	337
Tunnel Volume Retracted (Ft^3)	-	-	74
Tunnel Volume Extended (Ft^3)	-	-	121
Pressurized Compartment Leakage (Lb/Day)	0	3.5	-
Repressurizations	0	1	-
Gravitational Force (g) (Any Direction)	0	3	-
Cabin Ventilation (fpm)	15	40	25
Cabin Airborne Bacteria (Microbes/Ft^3)	-	TBD	-

TABLE A-2 SUMMARY OF SHUTTLE LIFE SUPPORT SYSTEMS

Life Support Function	Selected Concept Grumman(1)	MDAC(2)	NAR(3)
CO_2 Control	LiOH	LiOH	LiOH
Humidity Control	Condensing Heat Exchanger	Condensing Heat Exchanger	Condensing Heat Exchanger
Trace Contaminants	Activated Charcoal	Activated Charcoal	Activated Charcoal
Primary O_2 Storage	1200-350 psi Gas From Attitude Control Storage Tank	Liquid Oxygen(4) from Orbital Maneuvering System Storage Tank	3000 psi Gas
Emergency O_2 Storage	High Pressure Gas	3000 psi Gas	900 psi Gas
Primary N_2 Storage	3000 psi Gas	3000 psi Gas	3000 psi Gas
Thermal Control	Optical Solar Reflector Radiators	Radiators With Expendable "Top-Off"	Radiators With Expendable "Top-Off"
Power Supply	Fuel Cells	Fuel Cells	Fuel Cells

(1) Reference [6]

(2) Reference [4]

(3) Reference [7]

(4) Cryogens have been removed from Orbiter since Phase B reports

2.0 SHUTTLE LIFE SUPPORT EQUIPMENT BASELINE

Phase B shuttle studies have been conducted by McDonnell-Douglas Corp. and North American Rockwell, Corp. for NASA. Both of these studies have considered the use of EVA equipment with the shuttle, as required in the Shuttle Study Guidelines. In addition, NASA has funded work on IVA pressure suits for use in the shuttle program.

2.1 EVA/IVA EQUIPMENT

North American Rockwell (Reference [9]) and McDonnell-Douglas (Reference [5]) have baselined Apollo PLSS technology for use in the Shuttle Orbiter. Soft suits similar to the Apollo A7L suit are baselined with an atmosphere of pure oxygen at a pressure level of 3.75 psia. According to Reference [9] the crewmen pre-breathe pure oxygen at 14.8 psia for denitrogenation purposes prior to an EVA event. (The adequacy of a 4 hour pre-oxygenation period prior to a reduction in pressure from 14.7 psia to 3.75 psia might be questioned; Reference [5] indicates that there would be some risk in this procedure).

The equipment baselined for use in the shuttle is identified below:

(1) Pre-Breathing Apparatus

(2) Suits

(3) PLSS

(4) Consumables storage (or interconnects to orbiter gas storage)

(5) Airlock

Additional equipment which might be carried includes:

(6) Scavenging pumps (to recover atmosphere from the airlocks prior to depressurization.)

(7) Open-loop operation support equipment

(8) Umbilicals (for use in open-loop operation)

The EVA mission definition is:

(1) The number of EVA/IVA events per flight varies with mission; however, EVA is the backup for the manipulator system; therefore, a capability for two 4-hour EVA events is provided for each flight.

(2) Two crewmen will participate in each specific EVA mission.

(3) Airlock pressurization time and depressurization time are 10 minutes each.

(4) EVA/IVA duration is an average of 4 hours.

2.2 FLIGHT TEST PRESSURE SUIT

McDonnell-Douglas has proposed to provide an emergency pressure suit for use in the Shuttle Orbiter Flight Test Program (Reference [5]). The shirtsleeve atmosphere in the cabin is used; however, the crewmen are suited with Apollo A7L suits and breathe pure oxygen through a face mask. If the total cabin pressure drops below 8 psia, the crewmen don helmets and the suits are pressurized by a mini-suit circuit. The suit pressure level is 3.7 psia. The Apollo liquid-cooled garment (LCG) is used to provide cooling to the crewmen. The mini-suit circuit is essentially an Apollo PLSS which has been repackaged to fit under the crewman's seat.

2.3 LIGHTWEIGHT, CONSTANT WEAR PRESSURE SUIT

Hays has recommended that a lightweight, constant wear pressure suit, weighing less than 12 lbs., be developed for use in the shuttle to replace the Flight Test Pressure Suit discussed above (Reference [10]). NASA has contracts underway with International Latex Corporation (References [11] and [12]) and Space-Age Controls to produce concepts and prototypes of this suit. This suit is to be worn at all times and so needs to have greater comfort, and to be more aesthetically pleasing. The suit is intended only for intravehicular use, and so has no meteroid or thermal protection. This allows greater flexibility in design to reduce bulk without sacrificing mobility. There is greater flexibility in selection of materials and fabric textures than was available with Apollo because the cabin atmosphere is air rather than pure oxygen. The unit has a soft helmet which is stowed within the suit so that it can be quickly activated in an emergency. The suits are currently designed for operation at a pressure level of 5 psia, so a period of pre-oxygenation would be required prior to use in a depressurization emergency in the shuttle (with its 14.7 psia two-gas atmosphere). There will be an attempt to raise the suit's operating level to 8 psia, to eliminate the necessity for pre-oxygenation. There may be difficulty in obtaining adequate mobility at a pressure level of 8 psia with a suit with no joints. The ILC suit weighs 9-1/2 lbs. (Reference [12]).

3.0 SPECIFICATION

The rationale used in establishing the quantities given in the shuttle EVA specification in Table II of the main body of this report is discussed below.

3.1 EVA DURATION

EVA performed in an orbital environment should involve much less translation time than is usually involved in planetary EVA, thus reducing total sortie duration. In orbital EVA the crewmen will spend most of the time in the immediate vicinity of the parent vehicle. References [1], [5], [7], and [13] all indicate that the orbital EVA duration should be about 4 hours at the most.

3.2 FREQUENCY OF SORTIES

It is assumed that all EVA's will involve two crewmen, although in some instances only one crewman will actually be involved in the EVA, while another crewman is suited and is prepared to go to the assistance of the crewman who is involved in the EVA if required. The maximum frequency of EVA is specified at 3 events per 24 hours. This is predicated on 2 planned EVA events plus one emergency EVA event.

3.3 ORBITER MISSION LENGTH

It has been assumed that an orbiter mission length of 30 days might be involved in a "shuttle sortie" mission.

3.4 MOBILITY

The EVA equipment should allow the crewman freedom-of-movement sufficient to allow easy accomplishment of all required tasks. This primarily relates to manipulator backup and emergency situations since planned EVA events would be based on actual system capability. The use of an umbilical seems questionable in the backup and emergency situations, and also in situations involving crew translation across distances of more than 50 feet.

3.5 CENTER OF GRAVITY

The center of gravity (CG) shift of $\pm$ 3 inches was adopted from the original AEPS specification without any investigation or evaluation.

3.6 SUIT GAS

The specification calls for an 8 psia pure oxygen atmosphere in the pressure suit. This eliminates the need for pre-oxygenation when transferring from the shuttle orbiter with a 14.7 psia atmosphere comprised of 3.2 psia oxygen plus diluent nitrogen to the pressure suit. This also assumes that a suitable high pressure suit with adequate mobility and manual dexterity is available. The high pressure suit system was baselined because (1) there would be no time for pre-oxygenation in emergency situations, (2) the cost of pre-oxygenation in manpower, equipment, and expendables is significant, and (3) a satisfactory high pressure suit is within the current state of suit technology.

3.7 VENTILATION

The nominal suit gas flow rate is 5 acfm with a suit inlet temperature of 50 to 70°F. In emergency situations with a loss of liquid cooling flow, a gas flow rate of 9 acfm with a 50°F inlet temperature would be desirable.

3.8 HUMIDITY CONTROL

In normal operation the LCG will provide adequate cooling to the crewmen;

however, it is desirable to maintain humidity in a moderate range to insure crewman comfort. It is specified that the inlet gas dewpoint temperature be about 5°F colder than the inlet gas dry bulb temperature. This then makes the dewpoint temperature range 45-50°F.

3.9 CONTAMINATION CONTROL

The nominal CO_2 partial pressure level was established as 4 mm Hg at the inlet to the helmet, while the maximum level was set at 7.5 mm Hg for high metabolic load conditions. The CO_2 partial pressure level for the space shuttle orbiter is specified as 5 mm Hg (Reference [5]), while for the space station it is 3.0 mm Hg (Reference [14]). The maximum CO_2 partial pressure of 7.5 mm Hg during high metabolic loads seems reasonable due to the relatively short duration of this type of exposure. The short duration of the EVA event coupled with the relatively large leakage rate of the system compared to the suit volume make a trace contaminant control system unnecessary. Strong odors may have an adverse or disconcerting effect on the crewman, and these should be eliminated.

3.10 METABOLIC LOAD

Crewman metabolic loads during the performance of EVA events are subject to considerable debate, particularly for zero-g events. It is difficult to establish the metabolic rate of an individual under laboratory conditions, and it is more difficult to determine accurate metabolic rates under actual EVA conditions. In addition, it is difficult to extrapolate laboratory experience to actual flight conditions. For this study the average metabolic rate for the 4 hour mission has been specified at 1500 BTU/hr. This gives a total energy expenditure of 6000 BTU/hr over the EVA event, the same value as recommended in Reference [15]. The maximum metabolic rate to be sustained for a long period of time, such as one hour, is specified as 3500 BTU/hr. This is the maximum heat removal rate required for the system. Higher metabolic rates may be experienced for shorter periods of time; it is assumed that the excess heat above the 3500 BTU/hr will be absorbed by the crewman temporarily. The minimum metabolic rate is 280 BTU/hr; it is assumed that this low rate would not be sustained for periods longer than one hour so that a peak heat leak from the system of larger than 280 BTU/hr could be accepted.

3.11 LIQUID TRANSPORT LOOP

It is specified that liquid cooling will be used as the primary means for transporting heat away from the crewman. The flow rate is nominally specified as 4 lb/min of water. It is assumed that the LCG used by the crewman has a higher heat exchanger effectiveness than the Apollo LCG, so an inlet temperature of 60°F is adequate to reject the maximum metabolic load plus equipment heat load. The inlet coolant temperature is required to be no more than 60°F.

3.12 OPERATIONAL ENVIRONMENT

This system is intended for use only in a zero-gravity vacuum environment.

This has impact on the system design in that EVA equipment volume and envelope are more significant than weight per se. The orbital environment, or possibly a free space environment, allows reliance on the rejection of heat from the system by thermal radiation which cannot be counted on in planetary surface environments (which have a substantial amount of incident infared thermal radiation at times). At times the system may have to operate without venting large quantities of water vapor overboard, such as when in the vicinity of astronomy or earth observation experiments. Also, there may sometimes be a need to reject heat inside a pressurized compartment where cooling by water evaporation is not feasible.

3.13 DONNING, DOFFING, AND CHECKOUT

Time required for the crewman to don and checkout, or to doff the EVA equipment should be minimal. The donning time for the suit should be 5 minutes or less, and the time for donning and checking out the portable life support equipment should be 5 minutes or less. In addition, the manhours needed for servicing and maintaining the equipment should be minimized.

3.14 SAFETY

The EVA system should be designed in a fail-safe manner. That is, the EVA event will be aborted after any system failure, and the system will provide an adequate "get home" capability. The safety system is discussed in detail in Appendix B.

APPENDIX A REFERENCES

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[3] Herrala, W. (HSD) and Kleiner, G. N. (HSD), "Space Shuttle Environmental Control and Life Support System", ASME Paper No. 71-Av-16, SAE/ASME/AIAA Life Support and Environmental Control Conference, San Francisco, California, 12-14 July 1971.

[4] "Space Shuttle Phase B System Study Final Report, Part II, Technical Summary", McDonnell-Douglas Report No. MDC-E0308, Dated 30 June 1971.

[5] "Space Shuttle Data: Environmental Control and Life Support", McDonnell-Douglas Report No. MDC-E0393, dated 30 June 1971.

[6] "Alternate Space Shuttle Concepts Study Final Report, Part II, Technical Summary", MSC-03810, Grumman Report No. B35-43RP-12, dated 6 July 1971.

[7] "Space Shuttle Program - Phase B Final Report, Volume II, Technical Summary", MSC-03307, North American Rockwell Space Division Report SD71-1142, dated 25 June 1971.

[8] Canetti, G., "Systems Safety for Manned Operation in Earth Orbital Missions", AIAA Paper No. 71-826, AIAA Space Systems Meeting, Denver, Colorado, 19-20 July 1971.

[9] Stoll, O. T., "Space Shuttle Orbiter EVA System", Space Division, North American Rockwell Corporation, May 1971.

[10] Hays, E. L., "Space Shuttle Vehicle-Environmental-Thermal Control and Life Support Technology", Space Transportation System and Technology Symposium - VII Biotechnology, NASA TMX-52876 Volume VII, NASA Lewis Research Center, Cleveland, Ohio, dated 15-17 July 1970.

[11] "Emergency Spacesuit for Lightweight Protection", Industrial Research, August 1971, p. 18.

[12] Durney, G., "Intravehicular Space Suit Assembly (ISSA) Phase C, Final Report", ILC Report No. 8829200877, dated 23 June 1971.

[13] "Extravehicular Engineering Activities (EVEA) Program Requirements Study", Final Report, North American Rockwell Report No. SD-68-304-7 under contract NAS8-18128, dated September 1968.

[14] NASA-MSC-03696, Rev. 7, "Phase B Program Definition Study Modular Space Station Guidelines and Constraints Document" dated 30 July 1971.

[15] NASA CR-94705, "Extravehicular Engineering Activities (EVEA) Program Requirements Study, Volume I - Summary Technical Report", North American Rockwell Report No. SD 68-304-1, 6 May 1968.

APPENDIX B

AEPS EMERGENCY CONSIDERATIONS

1.0 INTRODUCTION

The backup EVA life support systems used on Gemini and early Apollo missions were designed to provide breathing gas and some measure of convective cooling for a very short period. This was considered to be adequate since the EVA's were conducted in the vicinity of the spacecraft and the crewman was never far from shelter. However, on later Apollo flights and many anticipated AEPS missions, the EVA's will take the astronaut far from the primary base and considerable time may be required to return in case of a failure. Therefore, the AEPS system must provide all life support requirements for the time required for the astronaut to return to the base in case of a failure in the primary system.

Primary spacecraft life support systems are generally designed to a "fail operational - - fail safe" requirement. This means that the normal mission can be continued with any single component failure, since the secondary system will provide all required functions without any degradation of performance. Thus, the system is said to have "failed operational". An emergency capability is provided so that a second failure of the same subsystem would not be catastrophic, but it would require termination of the mission. The AEPS primary life support subsystems will be assumed to be designed "fail safe" since including a "fail operational" capability imposes an unnecessary penalty on a portable system. Therefore, a single failure of any primary component would not be catastrophic, but it would require activation of an emergency system and termination of the EVA. It will be assumed that AEPS structural elements, gas storage bottles, heat exchangers, and flow loop "hard" lines and fittings will be designed with a sufficient safety margin that catastrophic failures will not occur. Dynamic components such as pumps, fans, and valves; flexible seals between joints; and all removeable components such as umbilicals, suit zippers and seals, etc., are subject to failure. It is impossible to accurately, quantitatively assess component reliability for systems in the advanced concept stage. However, it is possible to qualitatively predict possible failure modes that must be satisfied by the emergency system.

The allowable limits for parameters such as CO_2 and trace contaminant partial pressures, total suit pressure, and crewman thermal comfort can be quite different for the AEPS primary and emergency systems. The time required for the crewman to reach a pressurized shelter following an EVA emergency is expected to be short compared to the nominal EVA duration. The basic physiological reactions of the crewman to variations in these parameters were briefly investigated to attempt to determine reasonable tolerance levels.

2.0 PHYSIOLOGICAL CONSIDERATIONS

The physiological effects of most interest are: the effects of total gas pressure and decompression rate in the case of a gas leak, effects of CO_2 and contaminant level on crewman mental and physical performance, and the effects of thermal stress due to cooling system failure.

If a puncture occurs suddenly in the AEPS pressure shell, pressure will decay rapidly as the atmosphere exits through the vent. The time required for the pressure to decay depends on the initial pressure, the configuration of the vent area, and to a lesser degree, on the atmosphere composition and the initial atmosphere temperature. Rapid decompressions will occur adiabatically, while slow decompressions will tend to be isothermal. Figure B-1 presents generalized curves (from Reference B-1) which may be used for calculating the time required for decompression from one pressure level to another.

The physiological effect of rapid decompression on human beings most commonly known is in relation to deep sea diving accidents where divers rise to the surface too rapidly, and suffer from spontaneous pneumothorax, dysbarism, or decompression sickness; "the bends". In the case of divers, the pressure change may be from several atmospheres down to one atmosphere. The same phenomena can occur when the pressure level is reduced from near one atmosphere to a fraction of an atmosphere.

Spontaneous pneumothorax is caused by the trapping of gases in body cavities such as the sinuses and the chest. If this gas is not removed as the ambient pressure is reduced, it will expand and it can rupture internal organs if the pressure differential is large. The cause of the bends is inert gases, primarily nitrogen, which are dissolved in body fluids and fat, and which come out of solution when the pressure level is reduced. They are released as bubbles in the blood, body tissue, and fat. Oxygen, water vapor, and carbon dioxide diffuse rapidly into the bubbles causing them to grow. When the bubbles form in tissue, they may produce pain, particularly around the joints. The bubbles may rupture the fat cells, causing fat to enter the bloodstream. In addition, the bubbles in the bloodstream may lodge in the terminal vessels of the lungs or the brain, thus cutting off the blood supply to some tissue in those regions. Gases formed in the stomach and intestines cause severe abdominal distress. Aeroembolism frequently produces severe pulmonary distress, a condition which is often called "the chokes".

It is very difficult to predict the onset of the symptoms of dysbarism, or the severity of the symptoms. "Many factors, among them temperature, muscular work, age, body build, etc., influence susceptibility to decompression sickness." (Reference B-2).

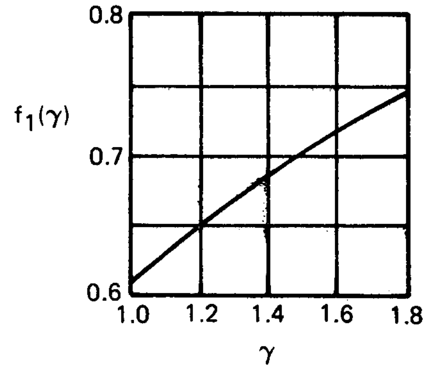
The change in pressure level without encountering aeroembolism symptoms is uncertain but it is generally accepted that the majority of healthy people can withstand a pressure decrease from 14.7 psi air to 7.3 psi air without being

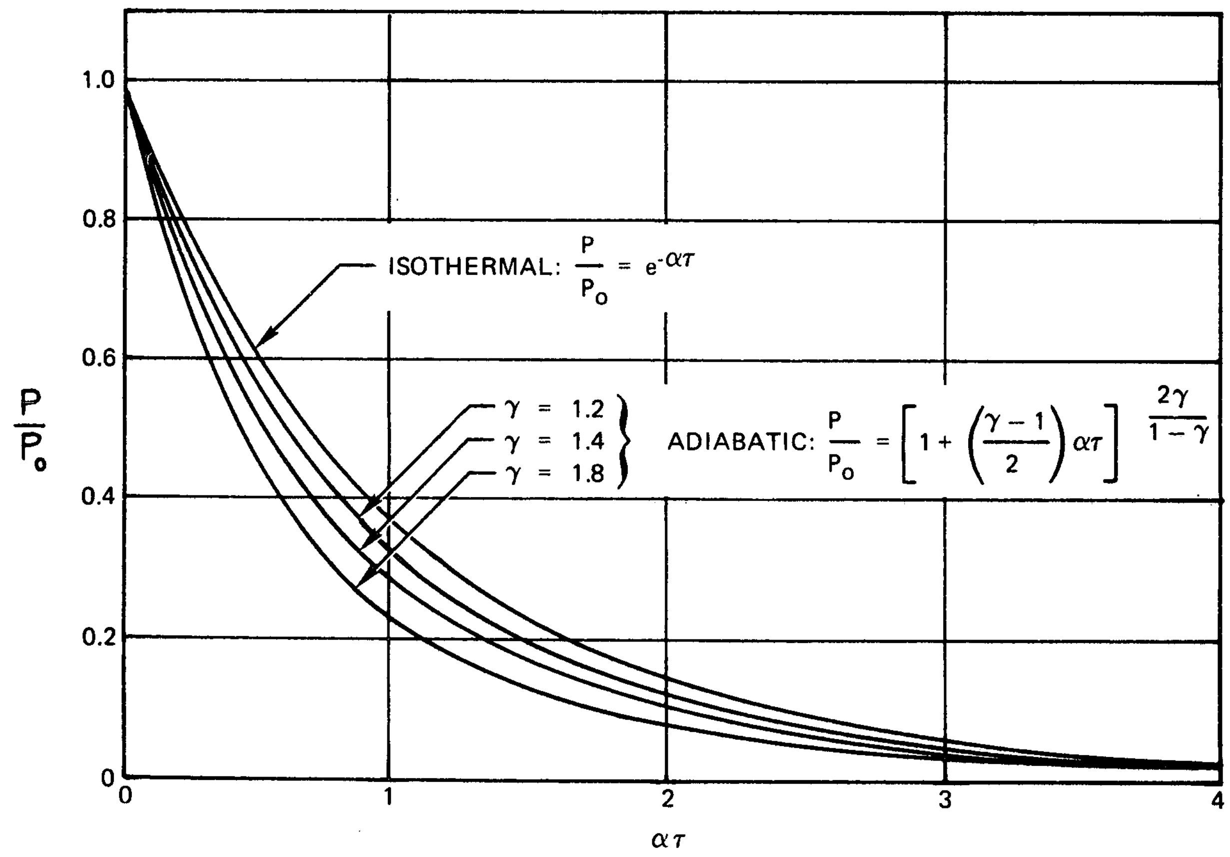
$$\alpha = 223 \left(\frac{C_d A}{V}\right)\sqrt{\frac{T_o}{m}}\; f_1(\gamma) \text{ [UNITS: SEC}^{-1}\text{]}$$

$$f_1(\gamma) = \sqrt{\gamma \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma + 1}{\gamma - 1}}}$$

where:

- C_d = DISCHARGE COEFFICIENT, DIMENSIONLESS
- T_o = INITIAL GAS TEMPERATURE °R
- A_s = VENT AREA, FT^2
- V = VOLUME, FT^3
- γ = RATIO OF SPECIFIC HEATS, C_P/C_V
- m = MOLECULAR WT. OF GAS
- τ = TIME, SEC





REFERENCE: B-1

FIGURE B-1 GENERALIZED DECOMPRESSION CURVES FOR SPACE COMPARTMENTS (NO MAKE-UP GAS)

subject to symptoms (Reference B-2). Actually, this is a rule of thumb that should be used with caution due to the many uncertainties associated with decompression sickness.

There is also considerable uncertainty associated with the time required for onset of symptoms. Reference B-2 indicates a range in time until on-set of symptoms of from 5 minutes to 40 minutes associated with a pressure decrease from 14.7 psia to 3 psia.

Protection from the bends may be obtained by washing the inert gases out of the system by prebreathing pure oxygen. Five hours is usually sufficient for pressure reductions of from 14.7 psia air to 3.5 psia oxygen, and as little as 3 hours may be sufficient for many people. This time may vary from one event to another for a given individual. Also, it appears that susceptibility to decompression sickness may increase rather than decrease with repeated decompressions.

In a space flight situation which involves rapid decompression, it would appear that the crew would have a significant amount of time to react prior to onset of decompression sickness symptoms. Symptoms may generally be relieved by repressurization to the original pressure and breathing pure oxygen. The problems associated with decompression sickness are applicable to EVA events operating from a spacecraft with two-gas atmosphere at a pressure of 14.7 in contrast to vehicles, such as Apollo, with a low-pressure pure oxygen atmosphere: virtually the same atmosphere that is used in the space suit during EVA

If decompression takes place in a time on the order of 0.01 seconds, the crew may be subject to mechanical damage. This occurs when the suit pressure falls faster than the gas pressure in the lungs and airways of the body. A transthoracic pressure difference of 1.5 to 2.0 psia could result in lung rupture, depending upon where in the breathing cycle the subject is when the decompression occurs (Reference B-2). Smaller pressure differentials can cause severe ear pains.

The partial pressure of the oxygen and carbon dioxide is reduced along with the total pressure. However, the mixed venous blood entering the lungs will contain the same amount of oxygen and carbon dioxide as immediately prior to the decompression. This gives rise to a situation where the oxygen diffuses out of the lungs into the air. Exposure to a near vacuum pressure for longer than 6 to 7 seconds will result in unconsciousness even if the pressure is then increased; however, the subject will have 10-15 seconds before he actually becomes unconscious. This time becomes shorter if the subject is exercising (Reference B-2). There is some question as to how much time he would have to take corrective action or signal for help if the decompression took place over a period of several seconds because he might not recognize the problem. Experiments have exposed primates to a vacuum for as long as 180 seconds without sustaining permanent injury, although they remained unconscious for 2-30 minutes after recompression (Reference B-2). Denitrogenation increases the survival time, apparently because it permits the vital brain tissues and fluids to be saturated with oxygen prior to decompression. It also reduces the possibility that evolved nitrogen bubbles might disrupt the vital neural pathways in the central nervous system.

Mild hypoxia can also occur, resulting from a drop in the oxygen partial pressure to less than 1.9 psia. This can result in mild confusion and loss of visual acuity.

An additional effect of reduced ambient pressure is the fact that blood reaches its boiling point at a temperature of 37°C at a pressure of 47 mm Hg. It does not vaporize in the body when the body is exposed to a pressure of 47 mmHg because there are hydrostatic and tensile forces in blood vessels and tissues which retard vaporization (Reference B-2). Experiments with animals decompressed to less than 30 mm Hg have shown that blood circulation comes to a standstill in 10-15 seconds due to "vapor lock" resulting from blockage of capillaries with bubbles (Reference B-2). This time may be longer in humans; however, it appears that ebullism would not be a factor in exposure to vacuum since the subject would already be unconscious due to hypoxia prior to circulatory arrest. However, ebullism may retard the subjects recovery after recompression because, while water vapor may disappear rapidly on repressurization due to condensation, gases such as O_2, CO_2, and N_2 which have diffused into the vapor bubbles will not be absorbed immediately, and may persist for some time (Reference B-2).

Reference B-3 presents data on an unprotected human hand exposed to low pressures. This data suggests that pressures on the order of 5 to 10 mm Hg are required to produce swelling (indicating ebullism) within a few minutes. Reference B-2 suggests that a survival time of 90 seconds under vacuum conditions should be possible provided that other problems such as the bends and explosive decompression can be avoided. Thus an emergency repressurization system must act within this time to assure survival of the crewman.

A loss of gas circulation or CO_2 removal capability in the AEPS will cause the partial pressure of CO_2 in the helmet to increase rapidly. The body's initial reaction is to increase both the respiratory rate and volume in an attempt to decrease the CO_2 partial pressure in the lungs. The heart rate is also increased somewhat (Reference B-2). However, since the respiratory system volume is comparable to the free volume in the helmet and suit, the CO_2 level will increase at a rate of about 40 mm Hg/min. At this rate, most crewmen will become unconscious in 3 to 5 minutes. Gas circulation must be restored within this time for the crewman to remain conscious and save himself without assistance.

As previously discussed, the AEPS suit will be insulated to protect the crewman from environmental extremes but this also has the effect of trapping the crewman generated metabolic heat.

In contrast to emergencies involving the gas circulation and suit pressurization systems, the allowable time before crewman collapse and unconsciousness following a cooling system failure is much greater.

Data presented in References B-2 and B-4 can be used to estimate the crewman's useful survival time following such a failure. These data, which were compiled from various sources, are in fairly good agreement although it should be noted that individual tolerance to heat stress may vary widely.

Crewman failure occurs due to the raising of body temperature that results from a metabolic heat production rate that is greater than the total heat removal rate. The excess heat is stored in the body producing the same basic effects as a fever due to sickness. The data indicate that a maximum body core temperature of about 105°F can be tolerated without permanent damage. This implies a heat storage of about 750 to 1000 BTU depending on body weight. This is in agreement with other data (Reference B-4) indicating incipient collapse after 30-40 minutes of exercise at 1500-2000 BTU/hr in an insulated environment.

Thus it appears reasonable to assume a heat storage of 750 BTU without significant performance degradation under emergency conditions. This value can be used to determine the endurance time for a crewman when his metabolic heat production exceeds the emergency cooling system capacity. Environmental thermal exchange (Section 3.5) can prolong or shorten this time depending on the average environmental sink temperature. Figure B-2 shows the expected useful crewman survival time following a cooling system failure. The time shown is that during which the crewman's performance is relatively unimpaired and he can perform useful action to return to shelter without assistance. The emergency durations specified for the various AEPS missions are also shown along with the time to collapse following a gas circulation failure and suit depressurization.

These data showing the expected crewman physiological response to different types of emergencies can now be used along with data on expected failures and failure rates to determine the required types of emergency systems.

C.3

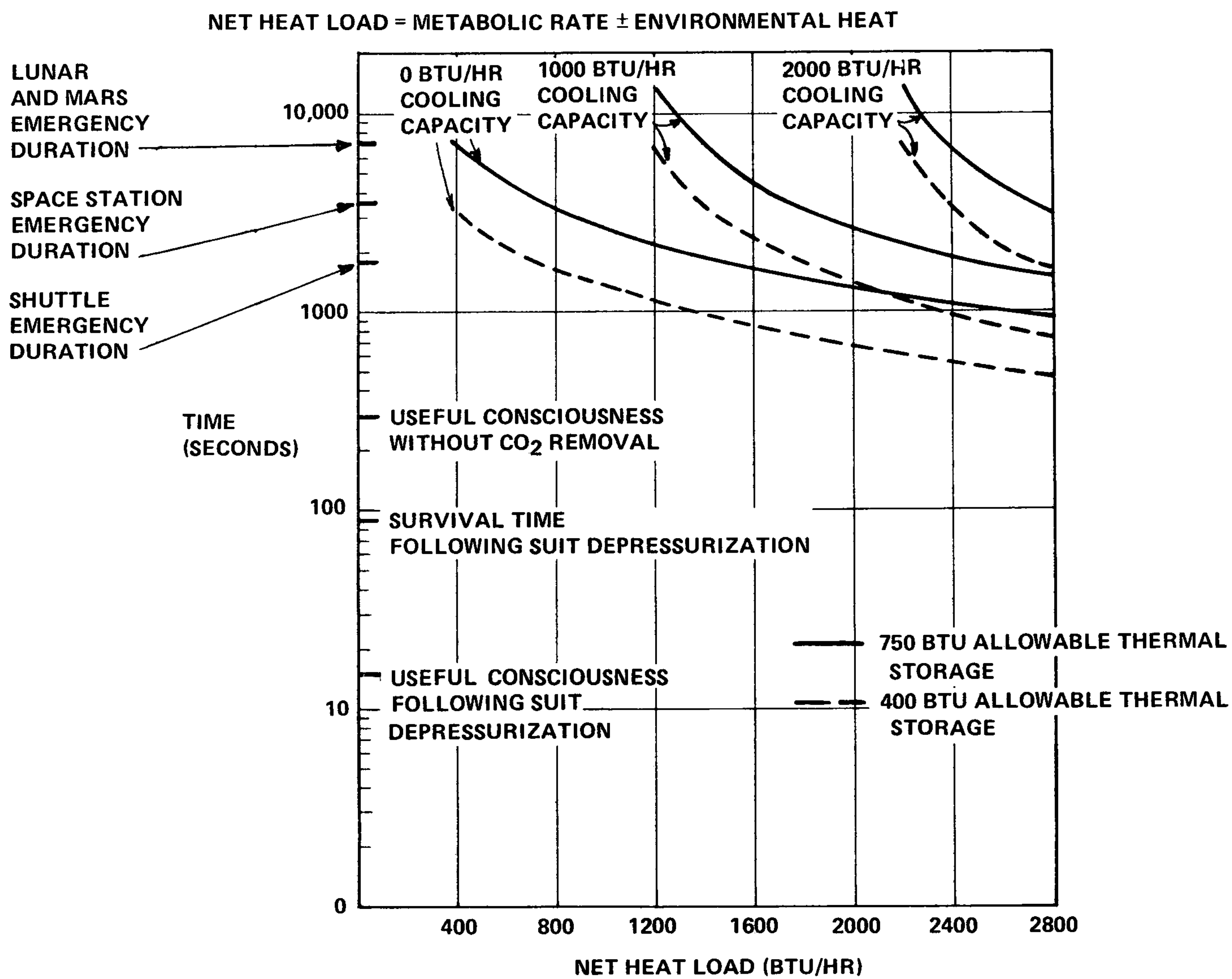


FIGURE B-2 AVERAGE UNIMPAIRED PERFORMANCE TIME FOR VARIOUS EVA EMERGENCIES

3.0 POTENTIAL FAILURE MODES

There are many possible equipment failures or accidents that could endanger the life of an EVA crewman. The AEPS emergency system will be designed to specifically accommodate the most credible failures and it will be assumed that this will also be sufficient to handle other, less likely, contingencies.

The most credible failure modes are shown in Table B-1 along with the emergency system requirements for each type of failure, and possible approaches that would meet these requirements. Running out of oxygen or other

TABLE B-1 FAILURE MODES

FAILURE	CAUSE	REACTION TIME	REQUIREMENTS TO PROVIDE
Excessive Gas Leakage	Seal Umbilical Suit Rip Regulator Pressure Relief Valve	Short	Pressurization
Ventilation	Fan/Motor Umbilical CO_2 Bed Line Blockage	A Few Minutes	Atmosphere Circulation & Purification
Heat Rejection	Sublimator Umbilical LCG Leak LCG Line Blockage Temp. Control Valve Pump	Several Minutes	Cooling
Power	Battery Fuse Terminal Board Short	A Few Minutes	All Life Support Functions
Expendables Depleted Prematurely	High Metabolic Rate	Long	All Life Support Functions As Required

consumables before the end of the EVA and a leaking suit are probably the most likely types of EVA emergency. The consumables problem can be solved by providing a reserve capacity that is manually activated. Stopping a leak is more difficult since the leak could be anything from a leaking zipper to a torn suit. Small leaks could be handled by the primary oxygen system and would merely require the EVA duration to be reduced due to the increased gas usage rate. Large leaks are potentially catastrophic since no practical system could keep the suit pressurized for long if a large rip occurred. Therefore, it is necessary to arbitrarily specify a maximum leakage rate and duration that the emergency system can accommodate.

The Apollo command module has a specified emergency flow rate of 40 lb_m/hr, which is sufficient to maintain 4.5 psia cabin pressure for a minimum of 5 minutes with a 0.50 inch hole. This is intended to provide sufficient time for the crew to don their suits and activate the ECS suit loop. Such a specification must be assigned for the AEPS emergency pressurization system in order to define the quantity of emergency pressurization gas that must be carried. Figure B-3 shows the effect of suit pressure and vent area on the quantity of gas required to maintain suit pressure for a given time. Table B-2 indicates the actual leakage area and volume/leak area ratio (V/A) expected for different types of failures of the AEPS pressure garment. Reference B-2 indicates that no lung or other damage is expected from rapid decompression when $V/A > 15m$. When V/A is in the range from 3 to 15m some mechanical damage is expected and potential fatalities can occur. This indicates that failure of the neck seal or any leak on the order of 10 in^2 or greater will probably be fatal regardless of the emergency system.

A similar credible failure mode would be a failure in the AEPS gas plumbing loop. This could be caused by mechanical damage to the gas circulation lines, fittings, or gas umbilicals between the suit and AEPS pack. The result of this failure would also be system depressurization, but in this case, the suit would retain pressure integrity. Therefore, EVA operations could be continued for a considerable time if a means is provided to isolate the suit from the AEPS pack and maintain gas circulation through the helmet by an auxiliary method.

A failure of the gas circulation fan would cause a loss of CO_2, trace contaminant, and humidity control unless another means of gas circulation was provided. This could be accomplished by a redundant fan, a "blow-down" system, or a hybrid "blow-down" system that incorporates a gas ejector to provide gas circulation.

Failures in the primary cooling system, which is specified to be a water circulation loop consisting of a pump, a heat sink, and a Liquid Cooling Garment (LCG) are less serious than most gas system failures since the EVA crewman can survive for some time without active cooling while system depressurization would be fatal within minutes.

Loss of electrical power could occur for many reasons and could cause a loss of both gas and water circulation since the pumps are electrically powered.

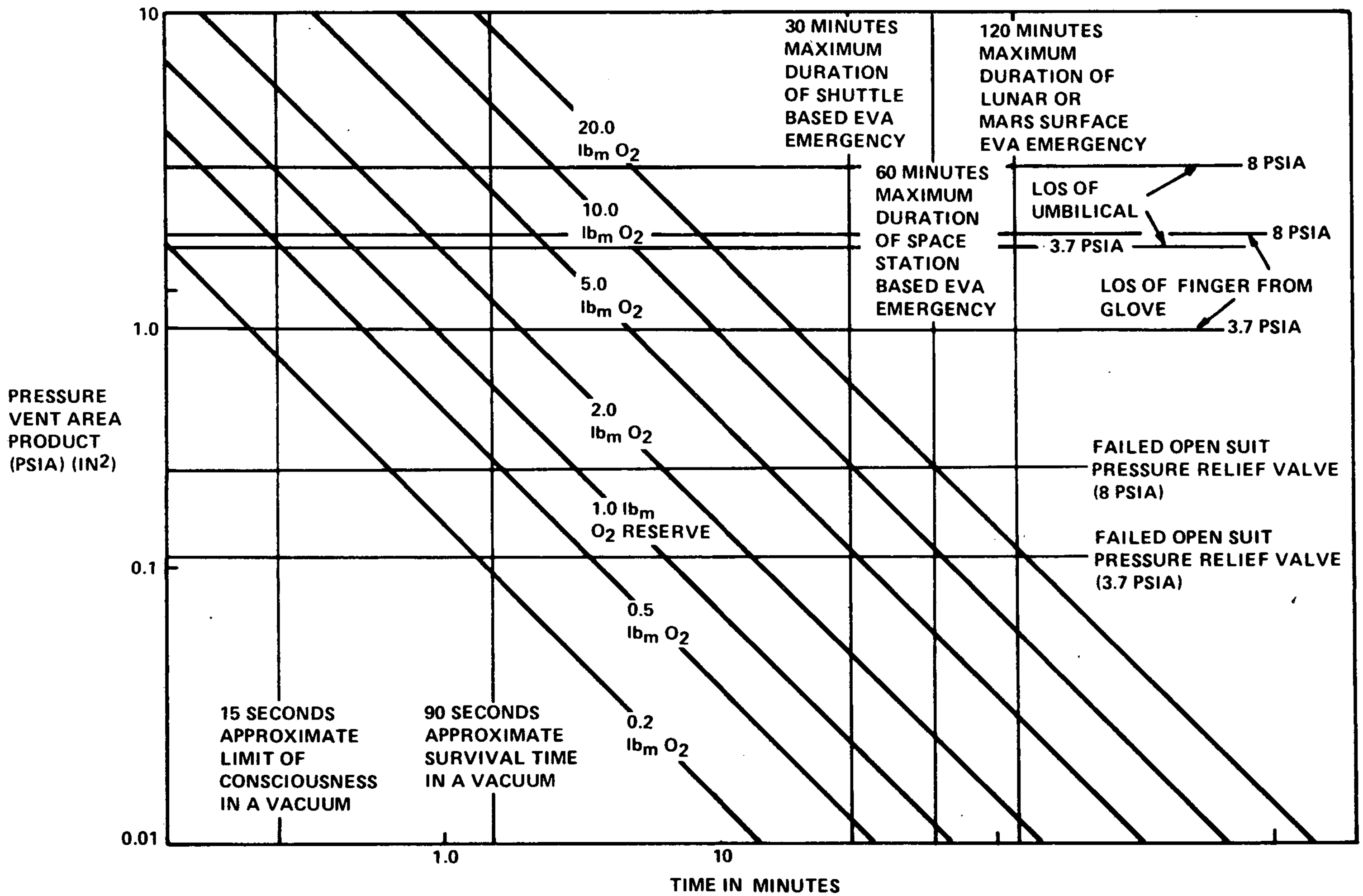


FIGURE B-3 EFFECTS OF LEAKAGE AREA AND SUIT PRESSURE ON EMERGENCY GAS REQUIREMENTS

Secondary methods of providing these functions have been discussed, but a loss of electrical power would also cause a loss of communication which might be vital in an emergency. Therefore, a redundant power supply should be provided. The simplest means of providing auxiliary power is with a non-rechargeable, primary battery.

The last credible EVA failure mode is for the crewman to run out of consumables during the EVA. This can occur because of a longer than planned EVA, excess O_2 use due to leakage, or high average metabolic rate, excess water expended due to hot environment, etc. This contingency can be accommodated by using a reserve capability built into the system.

TABLE B-2 CHARACTERISTICS OF EXPLOSIVE DECOMPRESSION

SOFT SUITS	RESIDUAL SUIT VOLUME (IN^3)	ORIFICE AREA (IN^2)	V/A RATIO (METERS)
NECK SEAL (PLSS)	1585	26.	0.88
WRIST SEAL (PLSS)	1710	9.3	4.67
CHAMBER UMBILICAL HOSE	1555	1.2	32.3
PLSS UMBILICAL HOSE	1710	0.4	100.
FINGERS (PLSS)	1710	0.2	233.
HARD SUITS			
WAIST SEAL (PLSS)	2150	125.	0.435
NECK SEAL (PLSS)	4310	87.	1.25
THIGH (PLSS)	3910	27.	3.6
ANKLE (PLSS)	4580	26.	4.46
WRIST SEAL (PLSS)	4580	8.4	13.9
CHAMBER UMBILICAL HOSE	4330	1.2	89.8
PLSS UMBILICAL HOSE	4580	0.4	268.
FINGERS (PLSS)	4580	0.2	620.

4.0 IMPACT OF EMERGENCY REQUIREMENTS ON PRIMARY SYSTEMS

It is expected that the AEPS emergency system will only be operated occasionally so that the criteria for system suitability are different than those used to select the AEPS primary subsystems. This infrequent operation allows the use of a completely expendable system since the number of expected uses, even on a long duration mission, is insufficient to justify a regenerable capability. The most important factors are long shelf life with no service required and minimum weight and volume. The emergency system must be capable of being carried on many EVA's and subjected to a rugged environment with no service required between EVA's and still be ready for use when required. Since an emergency may occur when the crewman is alone and at a distance from a pressurized shelter, it is necessary to carry an emergency system at all times and therefore, the weight and volume must be as small as possible.

It was found that high pressure gaseous storage of oxygen is the most practical method of storing elemental oxygen for the primary EVA system because of system simplicity and the fact that other methods such as cryogenic storage have difficulty supplying gas at high flow rates. Since a high flow rate is specified for the emergency system, this is also the only practical elemental O_2 storage method for the back-up O_2 supply. Chemical O_2 storage methods such as potassium superoxide can provide simultaneous CO_2 control and oxygen supply and these would at first appear to be attractive for an emergency system. However, these were found to have no weight or volume advantage over gaseous oxygen storage combined with a separate CO_2 control system. In addition, they cannot easily supply oxygen at the high flow rate required for an emergency repressurization system so that a high pressure O_2 bottle would still be required. A simple high pressure bottle is the only practical method of supplying gas for breathing and suit pressurization for both primary and emergency systems.

CO_2 control subsystems generally fall into one of two categories: passive chemical sorbent beds through which the ventilation gas is continuously circulated or systems such as molecular sieves or solid amine beds where dynamic components are required. The dynamic systems have an obvious reliability problem when compared to passive systems, but it might be possible to include a redundant capability in a primary dynamic system; for example, by including a third amine bed in a solid amine system. However, this approach is deemed unattractive since the diverter valves and timers in this system are probably more prone to fail than the bed itself. In addition, the weight and volume of a two bed solid amine system are sufficiently large that the addition of redundant components is impractical. The reliability of any dynamic CO_2 subsystem can be increased by including redundancy for critical components, but the overall reliability of the AEPS is increased more by providing a completely separate emergency CO_2 control method. This can be provided by an open-loop system where exhaled CO_2 is vented overboard or by an expendable LiOH cartridge since LiOH was shown to be the most compact CO_2 control method available. If gas umbilicals that link two EVA crewman following a gas system failure, are used, then the CO_2 capacity of the primary system may require an increase to handle the CO_2 produced by two men during such an emergency.

The fusible Astronaut Heat Sink (AHS) concept discussed earlier has an evaporative contingency mode which enhances the applicability of the concept. No other candidate thermal control system has any inherent advantage when emergency requirements are considered. However, the evaporative capability of the AHS would only be useful for contingency situations where it is not possible to replace a melted AHS module. A failure of the primary AHS could still leave the crewman without cooling so that a secondary cooling method must be provided in case of failure during installation of an AHS or to provide cooling in case of failure of any type of primary heat sink (cracked sublimator plates, refrigerator failure, etc.). Water evaporation devices were shown to be the lightest weight heat sinks available and therefore, they are attractive as an emergency system. Convective cooling by a gas blow-down system could also be used but this method is not practically capable of removing the required maximum heat load and is therefore not suitable for cooling in an extended emergency situation.

The optimum AEPS power supply was shown to be a secondary (rechargeable) battery. However, as previously stated, there is no requirement that the emergency system be regenerable and therefore, a primary (non-rechargeable) battery will be assumed for a redundant AEPS power supply since non-rechargeable batteries have an advantage in power density.

The various concepts for AEPS emergency systems will be discussed in the following section. It should again be noted that all concepts are assumed to be "fail safe" so that a failure in a primary AEPS subsystem and subsequent activation of the emergency system will cause the EVA to be terminated as soon as possible. Some of the concepts have an inherent "fail operational - fail safe" capability for certain types of emergencies thus providing an extra safety margin.

5.0 EMERGENCY SUBSYSTEM APPROACHES

Table B-3 shows some of the emergency systems or emergency provisions that have been included in EVA life support systems used, or designed for use, in the past. In general, it appears that most of these systems were designed without the benefit of a careful study of the actual emergency situations and the response of the human body to emergency conditions. The fundamental requirement for the emergency system is to guarantee the survival of the crewman for the specified emergency duration. Crewman comfort is a secondary consideration provided that any discomfort does not interfere with the crewman's performance. The emergency system must satisfy all of the EVA failure modes shown in Table B-1.

A blow-down high pressure system, similar to the OPS, is shown in Figure B-4. This system is basically the same as the OPS, with the addition of the mode select and suit isolation valves. These valves allow the suit to be isolated from the rest of the AEPS O_2 system with a direct gas feed from the emergency gas storage bottle. This could be used in case of failure of an umbilical or seal in the gas plumbing system while a simple gas circulation failure would not use the isolation valves and the emergency gas flow would augment the normal makeup gas. The flow is taken directly to the helmet area by an independent gas umbilical. Crewman survival time would be increased if a collar seal was provided to isolate the helmet from the suit. This would allow 1.5-2.0 psia helmet pressure to be maintained for some time even with a totally depressurized suit. Preliminary data indicate that the crewman could survive in this mode although lung and other tissue damage might result. If useful consciousness could be maintained for 5-10 minutes by this method, it would provide time for the crewman to actuate an emergency pressurized shelter system.

Some degree of convective cooling would be provided by the gas flow and this along with thermal storage by the crewman should satisfy cooling system failures. The mode select valve is used to divert the flow through an ejector, which would maintain gas circulation in case of a fan failure. The flow rate in the system would be reduced in this case because an ejector could not easily produce as much flow through the system as the fan. This mode could also be used to supply make-up oxygen in case of simple expendables depletion.

The collar seal concept shown in Figure B-4 could also be used at the wrists to partially maintain suit pressure integrity in case of failure of a wrist seal or loss of a glove. The effect of such a seal is to reduce the leakage area and conserve the emergency gas supply. The parts of the body that are exposed to vacuum might suffer painful swelling and hemorrhaging, but the alternative is certain death in most cases; since, as shown on Figure B-3, the quantity of gas required to maintain suit pressure for any significant length of time with a large leak, is impractically large.

The figure shows a separate emergency O_2 bottle, but the emergency O_2 supply could also be stored in the primary bottle if its size was increased and a redundant regulator provided. Increasing the size of the primary bottle

TABLE B-3 SUMMARY OF EMERGENCY SYSTEMS

SYSTEM	EMERGENCY PRESSURIZATION SYSTEM	OXYGEN STORAGE SYSTEM	EMERGENCY SUIT VENTILATION	EMERGENCY CO_2 CONTROL SYSTEM	EMERGENCY HUMIDITY CONTROL SYSTEM	EMERGENCY THERMAL CONTROL SYSTEM	EMERGENCY POWER SUPPLY	BASIC SYSTEM OPERATING TIME
ELSS (UMBILICAL SYSTEM)	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	"BLOW-DOWN" GAS SYSTEM	NONE	23 MINUTES
OPS	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	"BLOW-DOWN" GAS SYSTEM	NONE	37 MINUTES MINIMUM
CTS	NONE	REDUNDANT TANK AND REGULATOR	"BLOW-DOWN" OR BREATHING BAG DEMAND REGULATION	OPEN LOOP (LOW FLOW RATE)	OPEN LOOP	REDUNDANT SUBLIMATOR AND GAS POWERED WATER PUMP	NONE	45 MINUTES MINIMUM
PECS	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	GAS EJECTOR	OPEN LOOP	REDUNDANT CONDENSER OR OPEN LOOP	REDUNDANT PUMP AND DUAL SEGMENT EVAPORATOR	REDUNDANT BATTERY	30 MINUTES O_2 WITH EJECTOR, 2 HOURS HEAT REJECTION
ALSA	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	"BLOW-DOWN" GAS SYSTEM	NONE	30 MINUTES
SLSS	NONE	REDUNDANT TANK AND REGULATOR	REDUNDANT FAN AND MOTOR	REDUNDANT LiOH CANISTER	REDUNDANT CONDENSER	REDUNDANT SUBLIMATOR AND WATER PUMP	REDUNDANT BATTERY	2 HOURS
AIRS	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	REDUNDANT FAN AND MOTOR	REDUNDANT LiOH CANISTER	NONE OR OPEN LOOP	REDUNDANT HEAT SINK AND PUMP	REDUNDANT BATTERY	–
OPS AND REDUNDANT HEAT SINK	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	"BLOW-DOWN"	OPEN LOOP	OPEN LOOP	REDUNDANT HEAT SINK AND PUMP	NONE	–
OPS AND BUDDY UMBILICALS	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	BUDDY GAS UMBILICAL	BUDDY GAS UMBILICAL	BUDDY GAS UMBILICAL	BUDDY WATER UMBILICAL	NONE	–
OPS AND BUDDY COOLANT UMBILICAL	"BLOW-DOWN"	REDUNDANT TANK AND REGULATOR	GAS EJECTOR	OPEN LOOP	OPEN LOOP	BUDDY WATER UMBILICAL	NON	–

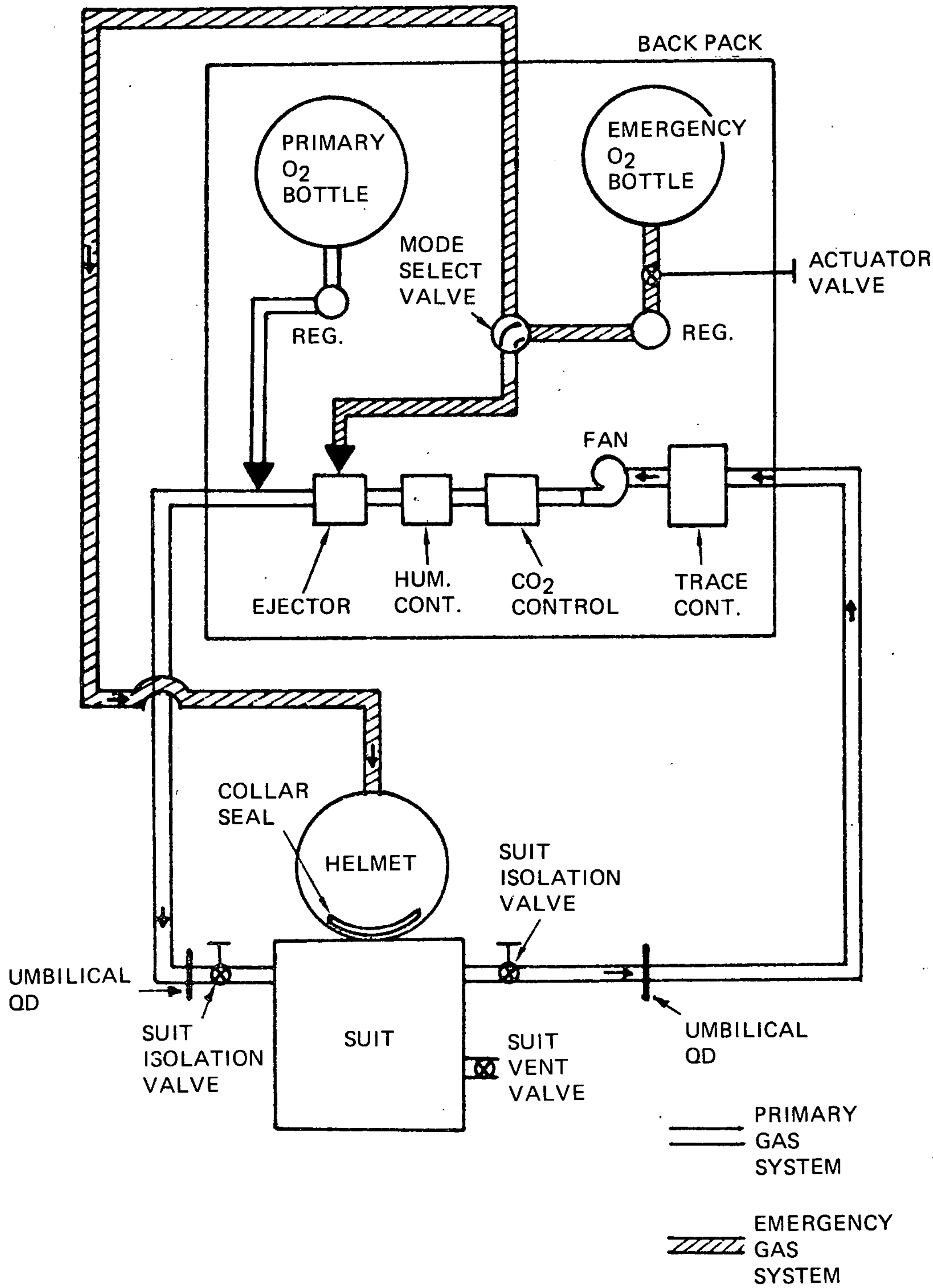


FIGURE B-4 AEPS "BLOWDOWN" EMERGENCY SYSTEM would result in a somewhat lighter system but a separate emergency supply could provide a higher emergency flow rate if a leak occurred near the end of an EVA when the primary bottle pressure was reduced.

The contingency transfer system (CTS), (Reference B-5), is a modification to the simple "blow-down" system. The CTS uses a breathing bag and face mask to supply fresh oxygen on demand and thus reduce the required gas flow rate. The CTS includes a breathing bag bypass valve to increase the flow rate for emergency suit pressurization and a sublimator for cooling. The system capacity and size are given in Table B-3. A schematic is shown in Figure B-5.

An umbilical system, somewhat similar to the one used on the later Apollo flights, can be used to interconnect two AEPS packs so that one pack could support two astronauts. The primary AEPS subsystems were sized for a maximum metabolic rate of 3500 BTU/hr but the average rate experienced on lunar EVA's to date has been on the order of 1000 BTU/hr (Table 6, p. 20). Therefore, a single AEPS primary system has more than enough capacity to support two men under

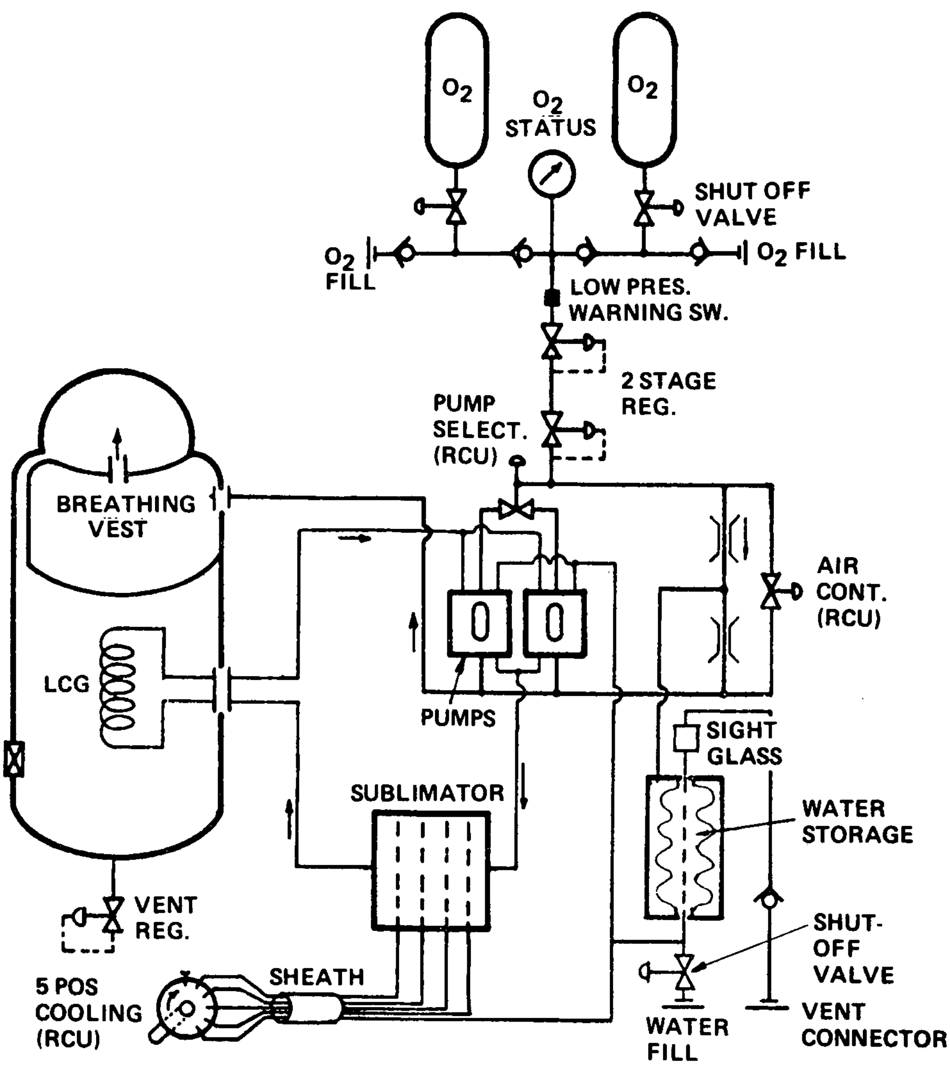


FIGURE B-5 BREATHING VEST EMERGENCY SYSTEM ordinary conditions.

The Apollo emergency umbilical system allows two EVA astronauts to share the cooling capability of a single PLSS. The gas system is not shared so that the OPS must be actuated for failures in this system. The umbilical system concept for the AEPS would allow both the gas and water subsystems to be shared. An OPS type blow-down system would also be required to supply breathing gas in the interval between the time of the emergency and the connection of the umbilical. A schematic of this system is shown in Figure B-6.

The gas and water umbilicals can be used separately so that either or both subsystems can be shared independently. Check and selector valves are included to allow the failed backpack to be completely bypassed. Since this system uses the primary AEPS consumables (except for the emergency O_2 supply), the length of time it can be used during an emergency will depend on the EVA elapsed time when the emergency occurs. If the emergency occurred near the end of the EVA, when the consumables were nearly depleted, the functional pack could only supply both men for a short time. However, the emergency O_2 supply from both packs would still be available and the crewman would probably already be returning to the base so that the system should be adequate for any condition. The primary life support system incorporates redundant components for critical components that may be prone to fail. Such a system is shown in Figure B-7.

This system includes redundant paths for both the O_2 and water loops and a separate, emergency O_2 supply. The umbilicals between the AEPS pack and the suit are shared by both primary and secondary systems so that an umbilical failure would eliminate both systems. This type of failure is unlikely; but if it occurred; the secondary oxygen supply, which has a separate umbilical, can be activated. A redundant power supply, not shown in the figure, is also included.

The system is designed to be "fail-safe" so that redundancy is only included for those functions that are required for survival. Thus, redundant trace contaminant and humidity control are not provided since these functions are not required for a minimum, survival system. The redundant gas system bypasses the primary trace contaminant and humidity control subsystems so that leaks in these components can be isolated. However, a detailed reliability analysis of the actual hardware might show that the probability of failure of these components is sufficiently low that they need not be bypassed. The selector valve could then be placed downstream of the trace contaminant subsystem with the return line upstream of the humidity control subsystem. This would be the preferred location since, if it is feasible from a component reliability standpoint, it would retain humidity and trace contaminant control for the emergency system. Similarly, flow from the secondary heat sink should be routed through the humidity control system if possible.

The secondary CO_2 control subsystem is assumed to use expendable LiOH since this is the lightest, most compact CO_2 control method available. The secondary heat sink is assumed to be a self-contained water boiler similar to the AHS concept. This consists of a sealed water container with an internal fin and tube network to allow the secondary transport loop to be circulated directly through the heat sink as shown in Figure B-8.

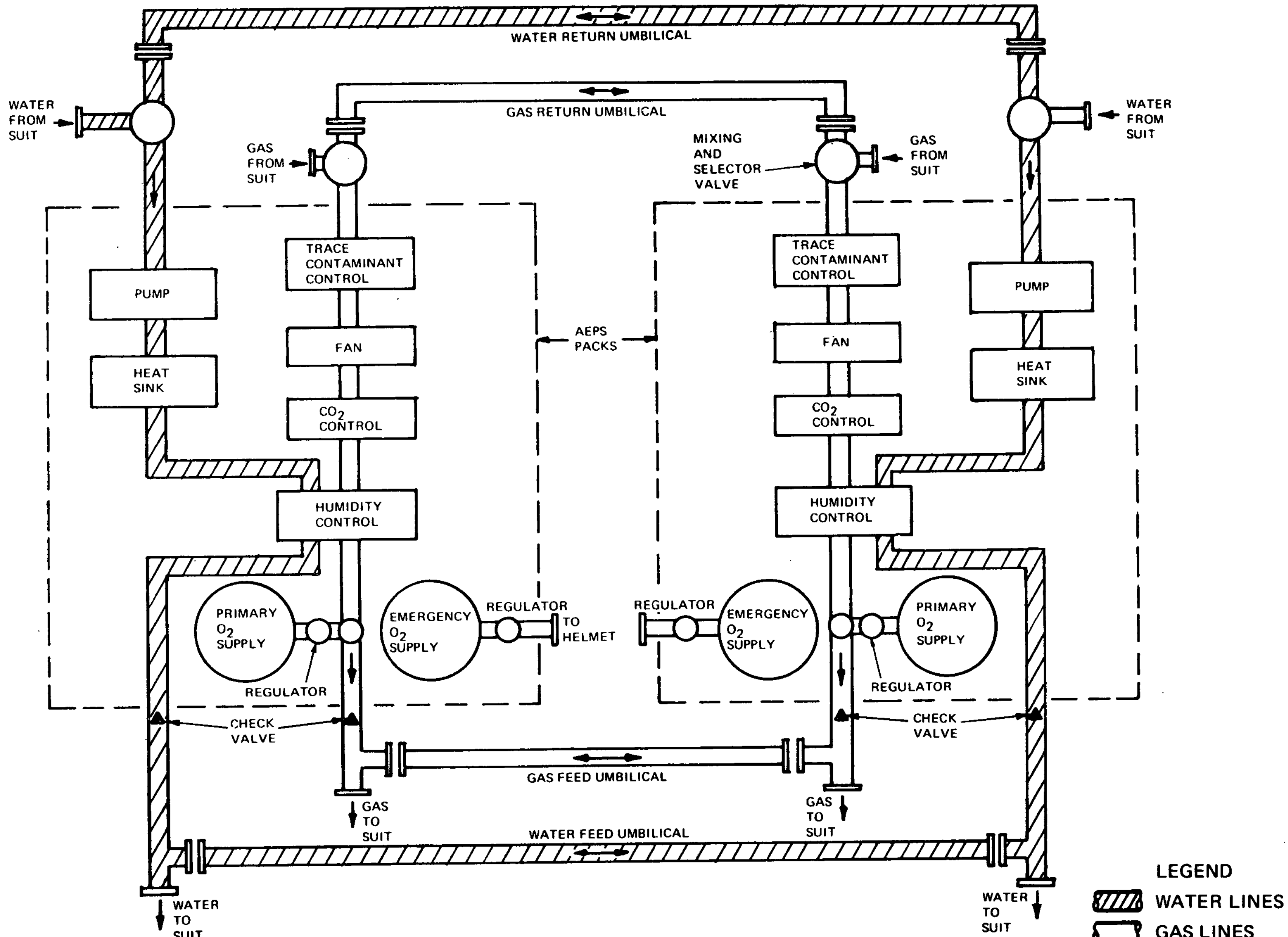


FIGURE B-6 EMERGENCY UMBILICAL SYSTEM

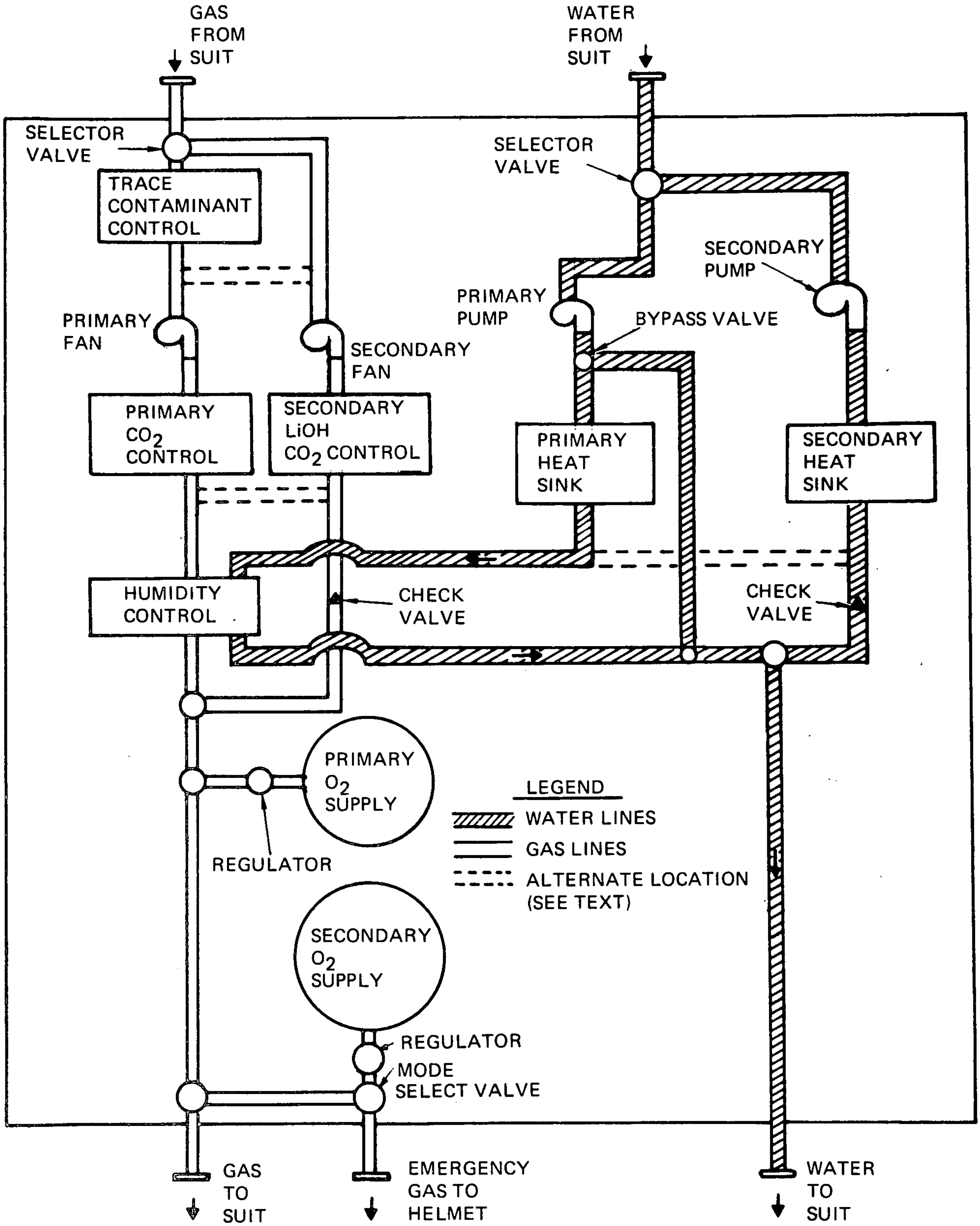


FIGURE B-7 AEPS INTEGRATED REDUNDANT SYSTEM

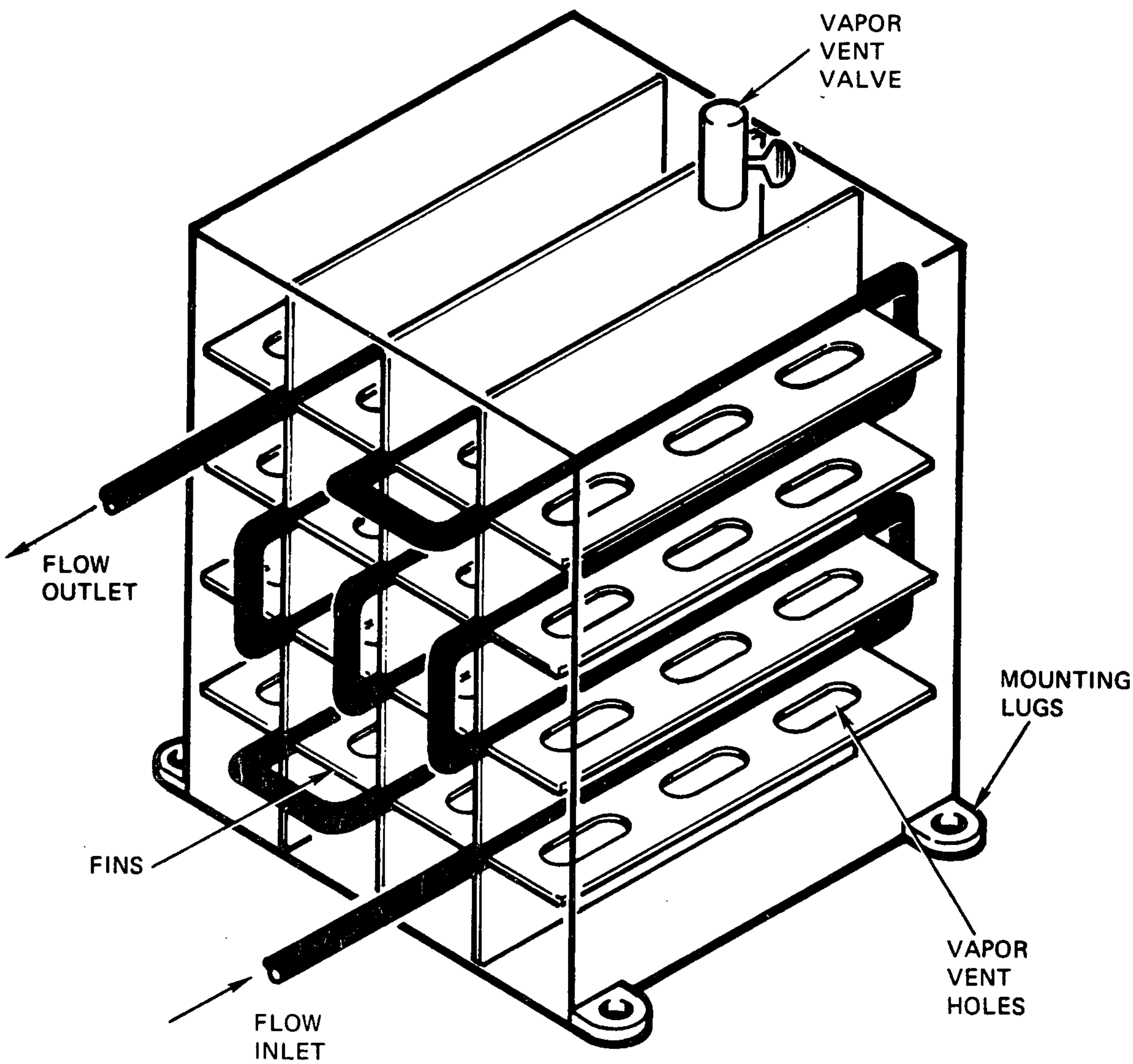


FIGURE B-8 AEPS SECONDARY HEAT SINK

The water can be exposed to vacuum by opening a valve, thus allowing the water to boil by absorbing heat from the transport loop. This device would be sealed until use so that no routine service would be required. It has a weight and volume advantage over conventional systems, e.g., sublimator, wick water boiler, flash evaporator, etc., since the water storage and evaporation functions are integrated.

This redundant approach would satisfy all the emergency requirements in Table B-1, but the capabilities of the system would be further enhanced if the umbilical sharing capability shown in Figure B-6 were added. This would give the emergency system greater flexibility if two astronauts were present because it would allow a "fail-operational, fail-safe" capability. That is, a failure and consequent secondary system activation in either of the primary AEPS packs would not require termination of the EVA if another crewman was in the vicinity, because the secondary O_2 supply and umbilicals would still be available if required.

The SLSS, which was considered for use on Apollo flights as a replacement for the OPS, used a somewhat similar approach. This emergency system was essentially a completely separate, short duration portable life support system. This approach is also applicable to AEPS, however, in the case of AEPS it may be advantageous for the secondary system to use expendable systems such as LiOH for CO_2 control, and an evaporative heat sink for thermal control. This is because the secondary system is rarely used so there is little penalty associated with the use of expendables. However, it is always carried, so fixed weight and volume are very significant.

A schematic of the Apollo SLSS is shown in Figure B-9. It provides all life support requirements for up to 2 hours with a metabolic load of 1600 BTU/hr. The maximum emergency gas flow rate is specified as 2.65 lbm/hr and this is sufficient to maintain suit pressure for two minutes with the suit pressure relief valve failed open. The maximum CO_2 level is 15 mm HgA. The system baselined a sublimator for thermal control and expendable LiOH as a CO_2. Additionally, 0.886 lbm of oxygen is stored in a high pressure, 7500 psi, bottle.

Another method of satisfying the AEPS emergency requirements is to provide a completely separate, spare backpack that could be installed during the EVA in place of a failed unit. Apollo EVA experience has shown the desirability of utilizing an auxiliary transporter, either powered or unpowered, to help carry tools and equipment needed during an EVA and this transporter could be used to carry an additional backpack. The umbilicals between the pack and suit would require vacuum quick-disconnect fittings so that the spare pack could be installed during the EVA if required. A separate OPS type system would be needed to supply breathing gas during the change over.

This approach has several inherent difficulties, in addition to the large weight which makesit unattractive for most missions. The requirement for operating quick-disconnects in a vacuum introduces further reliability problems since a failure of a disconnect fitting could prevent the crewman from installing the spare pack and could also cause a serious leak that would rapidly deplete his emergency oxygen supply. In addition, the primary AEPS system will probably be designed to accept some fixed EVA weight and/or volume

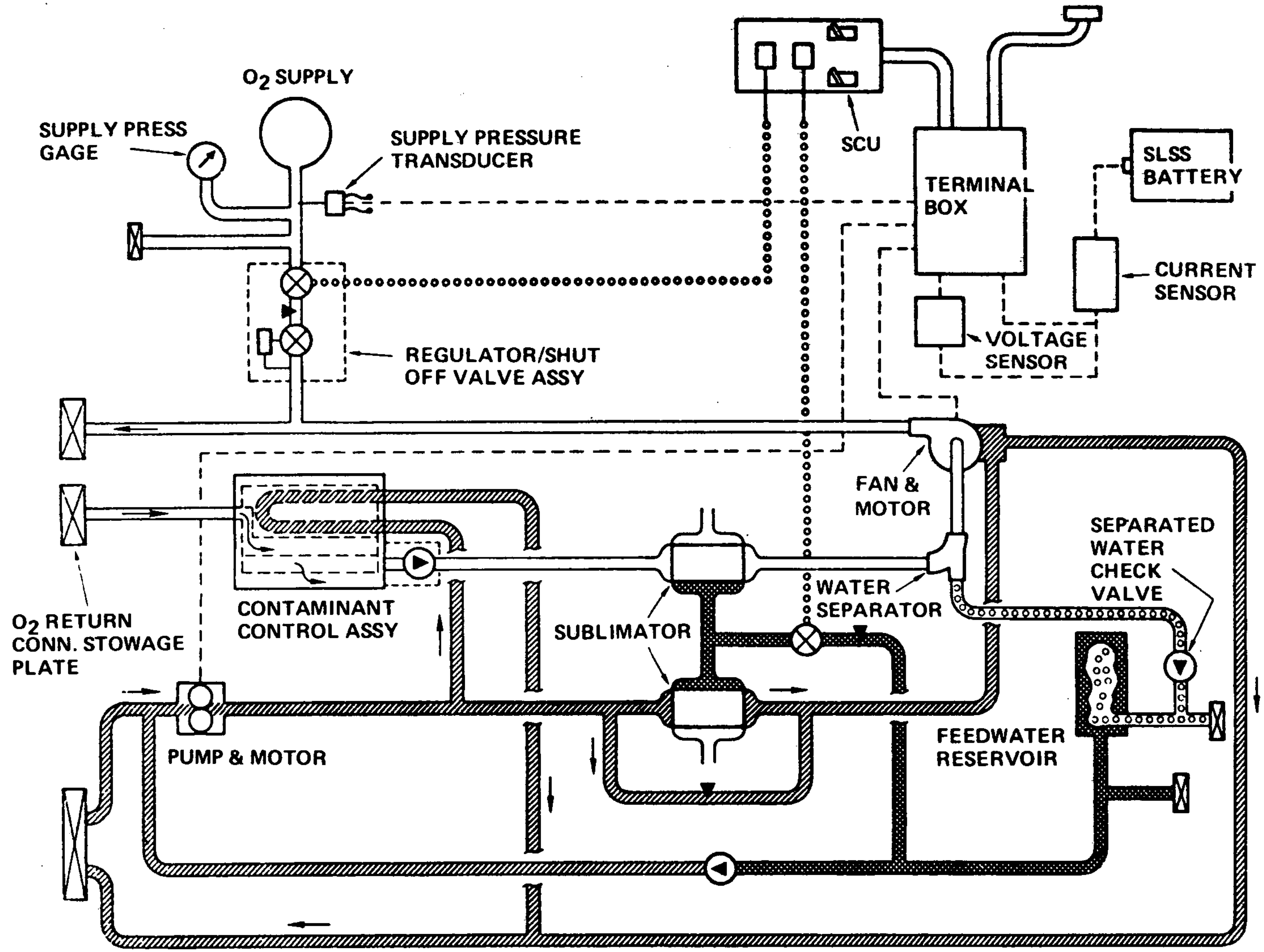


FIGURE B-9 REDUNDANT LOOPS EMERGENCY SYSTEM SLSS SCHEMATIC penalties in the interest of reducing expendables. Thus, this approach would be inefficient when used as a back-up system since the emergency system will be used infrequently, and therefore can profitably use expendables for some functions in the interest of reducing EVA weight and volume. The primary AEPS pack would probably also not be designed for long-term, charged, but inactive, use and therefore it would require some checkout and servicing prior to each EVA even when carried as a spare.

The spare AEPS approach is therefore considered to be an inefficient method of providing an emergency capability.

The possibility of a massive suit rip is probably remote; but, it if occurred, it would almost certainly be fatal, since no practical man-carried system can supply the large volume of gas required to maintain suit pressure for more than 5-10 minutes. For this contingency, a concept designated the Lightweight Emergency Shelter (LES) could be used as an emergency shelter to protect the crewman until he could be returned to the primary base. The LES, shown in Figure 23 (p. 71 of the main text), is simply a closed, balloon like cylinder made of flexible plastic with a sealed zipper on one side. It can be folded into a small package for transporting during a normal EVA. If the LES is required, it is removed from the storage bag and the crewman with the torn suit zips it over him. The balloon will be inflated by the gas leaking from the suit and the crewman can continue to breath from his normal AEPS oxygen supply. The LES can be prevented from overpressurization by leakage through the zipper or by providing a simple pressure relief valve. The device acts simply as an easily transportable, last resort pressurized shelter to protect a crewman with a badly ripped suit. The collar and wrist seals could keep the crewman conscious long enough to erect the LES.

The concept, as shown in Figure 23 (p.71), would not allow the crewman to walk so that he must depend on outside help with a powered vehicle or "MET-type" transporter to return him to the primary base. This is assumed to be an acceptable approach since there seems to be no other practical solution to protect a crewman in this contingency situation. There is also a high probability that a crewman involved in an accident severe enough to rip his suit, will also be injured and thus, may be physically incapable of getting to shelter without assistance. The crewman might also be provided with patches, that could be applied to the pressure suit while inside the LES, to effect a temporary suit repair. The LES could then be deflated and the crewman could walk to the base without assistance.

The LES is a simple, compact solution to an unlikely, but probably fatal, contingency and it could easily be carried in addition to any other AEPS emergency system. One LES unit for each EVA excursion party of 2-3 men should be sufficient, since the probability of more than one man being involved in the type of accident that would require LES activation on a single EVA, is assumed to be extremely low.

6.0 EMERGENCY SUBSYSTEM WEIGHT AND VOLUME ANALYSIS

The weight and volume estimates for the candidate concepts were based largely on analogy with similar equipment and components.

The effect of leakage area and suit pressure on emergency oxygen requirements was shown in Figure B-3. It was arbitrarily assumed that the blow down system must maintain a suit pressure of 3.7 psia for 5 minutes following the loss of a finger from the glove. This should be sufficient time to allow the crewman to erect the LES portable shelter without assistance. The use of the collar and wrist seals could increase this time considerably. The weight of this system is summarized in Table B-4.

TABLE B-4

AEPS EMERGENCY BLOW-DOWN SYSTEM COMPONENT ANALYSIS

Component	Weight (lb_m)	
Oxygen	3.7	
Oxygen Tank	10.35	
Regulator	3.7	Total Volume = 935 in^3 by analogy with OPS
Actuator	0.8	
Mode Select Valve	0.25	
Ejector	0.25	
Oxygen Hose	1.25	
Frame and Misc.	12.0	
Collar Seal	1.5	
TOTAL	33.8	

The total weight and volume of this system concept is very similar to the Apollo OPS currently in use. The system operation, is also similar to the OPS, with the addition of the mode select valve, ejector, and collar seal. This system should have good long term shelf life with no service required unless the unit has been activated.

The only service that should be required after the unit has been used, is replenishment of the oxygen supply. There are two methods of accomplishing this requirement. The tank could be refilled from the base oxygen supply by using a compressor to pump the gas from the base storage pressure to the 10,000 psi required, or the empty tank could be replaced with a pre-charged tank that was filled on Earth before the mission. A base weight of 30 lb_m was calculated for the compressor and power penalty required to compress oxygen from 50 to 10,000 psi for a similar size tank. Thus, a compressor that was supplied only to recharge emergency O_2 bottles would have a weight approximately equivalent to 3 spare tanks. The optimum recharge method would probably be to have the primary and emergency oxygen supply bottles designed so that they could be filled from the same compressor. However, it is expected that the emergency system would be used so seldom that supplying several spare, charged tanks would not present a large penalty. The weight penalty for any one of the recharge methods is small and it is not possible to define the optimum method at this time.

The SLSS weight breakdown is given in Table B-5. This system is con-

TABLE B-5

SLSS DESIGN FLIGHT WEIGHTS (REFERENCE B-6)

NAME	FLIGHT WT
Canister/Reservoir	10.40
Sublimator	6.50
O_2 Bottle	4.99
Regulator Assy.	2.40
Power Supply	3.90
Control Unit	2.88
Fan Motor Assy.	2.72
O_2 Umbilical	2.56
Thermal Cover	1.93
H_2O Umbilical	1.38
Pump Motor Assy.	1.35
Terminal Box	.34
O_2 Stowage Plates	.73
H_2O Separator	.55
Pressure X'Ducer	.32
Antenna Assy.	.25
Oxygen	1.30
Water	6.00
Structure and Cover	6.20
Msg. Packaging	4.30
	61.00

siderably more complicated than the simple blow-down system and therefore some servicing and checkout would probably be required before each use even though the system had not been activated on the previous EVA. If the emergency system had been used, then servicing would include recharging the oxygen bottle, replacement of the contaminant control cartridge (LiOH and charcoal), filling of the feedwater reservoir, and recharging or replacement of the battery.

Table B-5 shows the weight to be greater than 60 lb_m and based on an assumed density of 40 lb_m/ft^3, the volume is projected to be approximately 1-1/2 ft^3.

The emergency umbilical system is similar to the Apollo B-SLSS umbilical currently in use, with the addition of gas flow passages. The weight of the B-SLSS water umbilical is given as 10.65 lb_m (Reference B-7), including storage bag and contained water. The dry weight is 9.62 lb_m. It was found that 1.0 lb_m per foot is a reasonable weight for an umbilical containing two oxygen lines (supply and return) and this is in good agreement with the weight of the umbilical designed for Skylab. The Skylab umbilical contains cooling water feed and return lines, a gas feed line, electrical cable, a tether and insulation; while the anticipated AEPS emergency umbilical would not have the electrical cable but it would include a gas return line. Therefore, a representative weight of 1.0 lb_m/foot, including connectors, was assumed for the AEPS emergency umbilical system.

The mobility requirements, etc., for this system are assumed to be similar to these for the B-SLSS system and therefore the length of the umbilicals was also assumed to be similar. A length of 6 ft. was assumed so that the dry weight is 6.0 lb_m. The storage bag weight, again by analogy with the B-SLSS bag at 2.57 lbm, is assumed to weigh 4.0 lbm. The umbilical water inventory is about 1.0 lbm so that the total weight of the system is approximately 11.0 lb_m. The weights and volumes are summarized in Table B-6.

COMPONENT	WEIGHT (lb_m)	VOLUME (IN^3)
umbilical	6.0	256 (coiled volume)
storage bag	4.0	-
contained water	1.0	28
TOTAL	11.0	284

plus blow-down system at 33.8 lb_m and 935 in^3 per man

TABLE B-6

AEPS Emergency Umbilical System Component Analysis

This system requires no routine servicing between EVA's unless it has been used. The B-SLSS umbilical is stored "wet", i.e., full of water, but this would probably create a problem of corrosion and other deterioration over a long period. Therefore, the AEPS umbilical system will be assumed to be stored dry with the 1.0 lbm of water required to fill the umbilical carried in the LCG loop accumulator already in the AEPS backpack. Service after use would simply require emptying and drying the umbilical and replacement in the storage bag.

A conceptual secondary heat sink was shown in Figure B-8. It is simply a can containing water, with finned tubes, through which the transport water is circulated. The can is sealed during normal operation, but if the heat sink is required a vapor vent line is opened to expose the liquid to vacuum. The pressure in the can will then drop to a value determined by the minimum vent area and the heat load and the device will operate as a pool boiler using the heat of vaporization as a heat sink. The device shown in the figure is intended for operation in a gravity field and would require modification for operation in zero-g.

There are several other redundant heat sink concepts that could alternatively be used. The AHS concept discussed in Section 4.4 could be modified by increasing the number of separate ice modules and providing a redundant clamping mechanism so that two modules could be used at once. Another approach would be to use a light weight sublimator such as that used in the CTS (Reference B-5). The weight and volume of any of these approaches is expected to be comparable to that of the redundant heat sink as shown in Table B-7.

COMPONENT	WEIGHT (lb_m)	VOLUME (in^3)
blow-down system	33.8	935
fan	2.7	50
LiOH canister	5.0	130
pump	1.4	25
redundant heat sink	7.5	150
battery	1.0	20
misc.	5.0	200
	56.1	1.510

TABLE B-7

AIRS COMPONENT ANALYSIS

The size of the redundant LiOH CO_2 control canister, taken from Reference B-7, is approximately 5 lbm and 130 in^3 for a two hour life. A complete size analysis of this AEPS emergency system concept is shown in Table B-7. The weight estimates of components such as the pump, fan and battery are taken from Table B-5.

This emergency concept is shown to be only slightly lighter than the completely redundant emergency system approach. However, the capability of the system is greater, primarily because of the inclusion of a large capacity, oxygen blow-down system.

In the study of primary AEPS subsystems and integrated systems it was found that a weight of 140 lbm and a volume of 3600 in^3 are reasonable for several different types of backpacks that could be expected to be used on different AEPS missions. Therefore, these values will be assumed for a spare pack to be carried on a transporter without specifying the particular subsystems in the pack. It is assumed that one spare pack will be carried for every two men since two men are unlikely to experience simultaneous failures.

An approximate weight analysis of the LES system shown in Figure 23 on page 71 of the main text was performed by assuming the balloon was a cylindrical tank constructed of polyethylene plastic. It can be easily shown that a polyethylene film 0.010 inches thick can provide the required strength when pressurized to 3 psig over-pressure. This material may not be used but the strength is conservatively representative of a wide range of plastic film materials that might be used.

7.0 EMERGENCY SUBSYSTEM COMPARISON AND CONCLUSIONS

The weight and volume estimates generated earlier can now be used to compare the candidate emergency system concepts. These results are given on a per man basis so that, for systems such as the buddy umbilicals and the LES, 1/2 of the total penalty will be assigned to each man. These results are summarized in Table B-8.

Concept	Emergency System Weight (lb_m/man)	Emergency Sys. Vol. (in^3/man)	Total Man-* Carried Wt. (lb_m/man)	Total Man-* Carried Vol. (in^3/man)
Blow-down System	33.8	935	173.8	4535
Emergency Secondary Life Support System	62.4	2600	202.4	6200
Emergency Umbilical	5.5	142	179.3**	4677
AIRS	56.1	1510	196.1**	5110
Spare Pack ***	70.0	1800	173.8**	4535
LES	3.5	75	-	-

* includes primary backpack
** includes blow-down system
*** carried on transporter

TABLE B-8

EMERGENCY SYSTEM WEIGHT SUMMARY

The simple blow-down system is seen to be the lightest weight candidate and it is also a basic element of most of the other concepts. However, it provides a more limited capability than any of the other systems since activation of the emergency high flow rate mode would rapidly deplete the gas supply. Thus the crewman might be left with insufficient gas to reach the primary base, even if the leak could be quickly repaired. Therefore, this system is only recommended for use near a shelter or primary vehicle.

The completely redundant ESLSS concept can provide all emergency functions for a considerable period but it requires the largest man carried weight and volume. This system provides a completely redundant life support system, but this is not required since many components of the primary system can be assumed to be sufficiently reliable that redundancy is not required. Therefore, this system is not recommended.

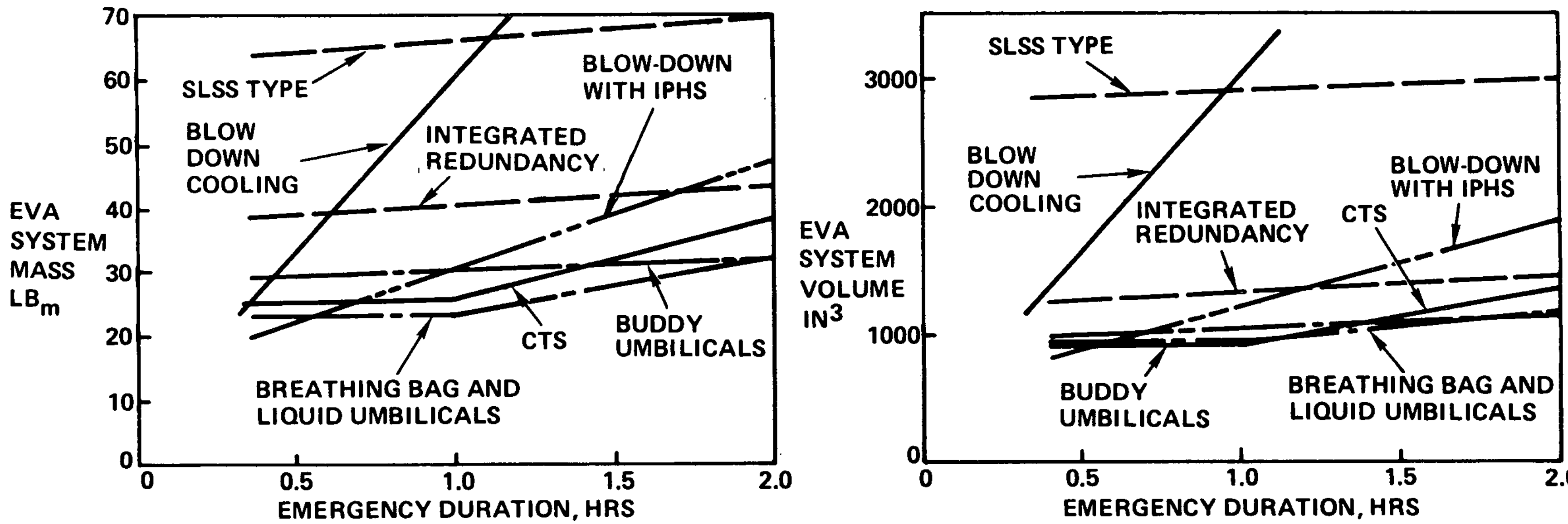
The emergency umbilical is primarily a supplement to the blow-down system and it greatly increases the emergency capabilities of that system with only a small increase in weight and volume. This is an attractive approach but it does have the drawback that it requires two men for operation. Most lunar and Mars surface EVA sorties in the AEPS time frame (1978-1990) will be conducted by a minimum of two men, but many orbital EVA's will only require one man so that this approach is not applicable. Therefore, the umbilical/blow-down approach is well suited for surface EVA's but not for all orbital EVA operations. It is recommended that all primary backpacks be provided with the fittings necessary to accept the emergency umbilicals and that these umbilicals be provided on every EVA undertaken by two or more crewmen. Provision of this emergency umbilical capability in the primary backpack would also allow the primary AEPS system to be used as a backup to an umbilical-to-base system used in the vicinity of a shuttle or space station, thus maximizing the utility of the primary AEPS system.

The AEPS Integrated Redundant System (AIRS) concept is similar to the ESLSS, but redundancy is provided only for those components that are most likely to fail. The weight and volume of this system also includes a blow-down system and no allowance was made for any reduction that could be made by integration of the primary and blow-down system. The weight of the included blow-down system contains a 12 lbm allowance for a separate support frame and it seems certain that this could be reduced considerably if the primary and emergency systems were fully integrated. Thus, the 17 lbm weight penalty of this system over the umbilical/blow-down system might also be reduced. However, the principal advantage of the AIRS is that it provides maximum emergency capability without requiring assistance from another backpack. Provision of an emergency umbilical capability to the AIRS would allow the system to be extended to a "fail-operational" mode on any two-man mission, since a primary system failure could be handled by the built-in redundancy while only a second failure would require activation of the emergency umbilical and termination of the EVA mission.

The spare pack approach requires a blow-down system to provide life support while the failed pack is being replaced and it also requires some type of auxiliary transporter to carry the spare pack. This approach has no advantages over other, significantly lighter systems and is therefore not recommended.

The LES system is intended to supplement any of the other systems and its use is recommended on all EVA's.

The primary influence of emergency duration on system weight and volume is on the quantity of expendable gas, water, and oxygen. The weight of hardware such as redundant pumps, regulators, and umbilicals is not affected. Based on the oxygen tankage calculations given in Section 4.2.1, an oxygen tank penalty factor of 3 lb total per lb of oxygen was used, along with the information in Figure B-3 and Table B-2, to estimate the size of the emergency pressurization system. The weight of such a system, assuming the same leakage area discussed in Section 4.7, is shown plotted as a function of emergency duration in Figure B-10.



NOTE: (1) 8 PSIA SUIT

(2) AT LEAST 3.75 LB_m OF O_2 ARE AVAILABLE FOR EMERGENCY SUIT PRESSURIZATION

FIGURE B-11 COMPARISON OF AEPS EMERGENCY SYSTEMS

The figure also shows the weight of the other emergency subsystem approaches.

The influence of emergency requirements on the total AEPS system weight is shown in Figure B-11. The CO_2 control system is the only one affected and this only in the case of using buddy gas umbilicals. The figure shows the weight of expendable LiOH is increased slightly if gas umbilicals are used. This occurs because the size of the primary CO_2 sorbent bed must be increased slightly to handle the load of an additional man if the emergency occurs near the end of the EVA. In the case of an expendable sorbent bed, this extra weight is discarded after each EVA. The regenerable bed must also be increased in size but since the extra weight is not expended the only real increase is in the base penalty for regenerating the increased mass. The figure shows that this increase is negligible.

The conclusions of the emergency study are presented in Table B-9.

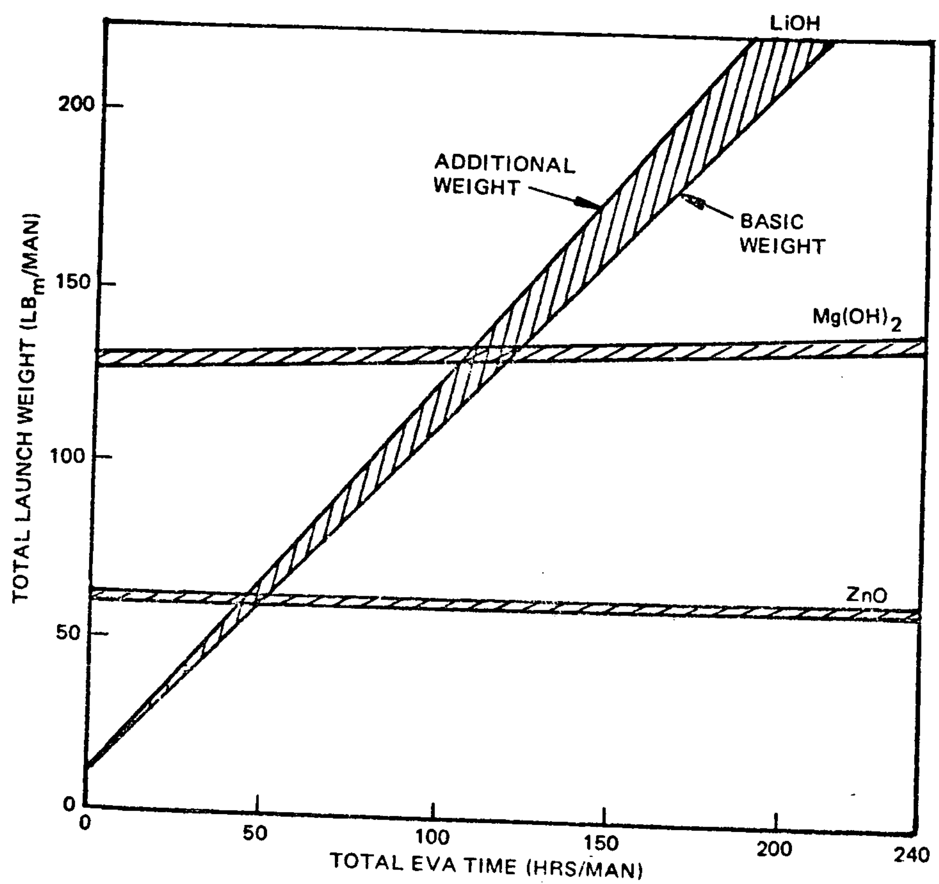


FIGURE B-11 IMPACT OF EMERGENCY GAS UMBILICAL ON CO_2 CONTROL SYSTEMS

A blow down gas system is required in all cases since, as shown in Figure B-2, failures of the suit pressurization or CO_2 removal systems will incapacitate and kill the crewman within minutes. Failure of the cooling system could be tolerated for a considerable length of time, especially if the gas blowdown system was designed to provide some measure of convective cooling.

Thus, the AEPS emergency system must provide for emergency suit pressurization and CO_2 removal. Both of these functions can be provided by the blowdown system shown in Figure B-4. The addition of redundant components such as fans, pumps, heat sinks, and CO_2 sorbent canister may be warranted if a detailed reliability analysis of actual AEPS hardware shows that this is desirable. A set of buddy umbilicals would provide essentially the same capability if two crewman were assumed to be present. The LES and collar/wrist seal concepts provide additional protection against suit leaks and seal failures.

TABLE B-10

SUMMARY OF EMERGENCY SYSTEMS CONCLUSIONS

Concept	Comments
Blow-down "OPS-type" System	insufficient capacity for some emergency situations, provides for most critical functions
Completely Redundant Emergency Secondary Life Support System (ESLSS)	excessive weight, volume, and reliability/ servicing requirements
Emergency Umbilical Combined With Blow-down System	suitable for EVA's conducted by two or more men
AEPS Integrated Redundant System (AIRS)	suitable for all AEPS missions, may provide more redundancy than actually needed
Complete Spare AEPS Pack	excessive weight, volume, and reliability/ servicing requirements
Lightweight Emergency Shelter (LES)	recommended as complement to other systems for use in case of large suit leak
Collar/Wrist Seal	extends survival time in case of massive suit leak

APPENDIX B REFERENCE LIST

B-1 "Analytical Methods for Space Vehicle Atmosphere Control Processes", ASD-TR-61-162 Part II, Airesearch Manufacturing Company, July 1962.

B-2 NASA CR 1205, "Compendium of Human Responses to the Aerospace Environment" November 1968.

B-3 Webb, P., "The Space Activity Suit: An Elastic Leotard for Extravehicular Activity", Aerospace Medicine, April 1968.

B-4 NASA SP-3006, "Bioastronautics Data Book", 1964.

B-5 Curtis, D. L., "Open-Loop Portable Life Support System Lightens Crew Load", Space/Aeronautics, December 1969.

B-6 Hamilton-Standard Document SP10T69, "Design Review Meeting - SV706100-7 Portable Life Support System and Secondary Life Support System", presented to NASA, 15-16 September 1969.

B-7 "B-SLSS Critical Design Review" Hamilton-Standard Presentation to NASA at Windsor Locks, Connecticut on 20-22 May 1970.