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ADVANCED EXTRAVEHICULAR PROTECTIVE SYSTEMS STUDY

James G Sutton, Philip F Heimlich and Edward H Tepper

March 1972

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PREPARED UNDER NASA CONTRACT NO. NAS 2-6021

for

National Aeronautics and Space Administration

Ames Research Center

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FOREWORD

This is the Final Summary Report of the "Advanced Extravehicular Protective System (AEPS) Study". This effort was conducted by Hamilton Standard under contract NAS 2-6021 for the Ames Research Center of the National Aeronautics & Space Administration from July 1, 1970 to November 30, 1971. The AEPS Study was directed by Mr. James G. Sutton, and the principal investigators were Messers. Philip F. Heimlich and Edward H. Tepper.

Special thanks are due to Dr. Alan B. Chambers, Environmental Control Research Branch, Biotechnology Division of the NASA Ames Research Center, Mr. William L. Smith, Chief of Crew Equipment Office for Manned Space Flight, Life Sciences Office of NASA Headquarters, and Mr. Thomas W. Herrala, Space Systems Department of Hamilton Standard for their advice and guidance.

This total report is contained in two volumes as listed below:

Volume I	Final Summary Report
Volume II	Subsystem Studies

1.0 INTRODUCTION

1.0 INTRODUCTION

The United States manned space effort planned for the late 1970's and the 1980's consists of long duration missions with earth-to-orbit shuttles, orbiting space stations, possibly lunar bases, and eventually Mars landings. Extravehicular activity (EVA) is likely to take an increasingly important role in the completion of these future missions. However, with the potential of numerous EVA missions per man per week, the use of expendables in the portable life support system may become prohibitively expensive and burdensome. For future EVA missions to be effective in the total systems context, the portable life support system may need to have a regenerable capability.

The primary objective of the Advanced Extravehicular Protective System (AEPS) study is to provide a meaningful apprisal of various regenerable and partially regenerable portable life support system concepts for EVA use in the late 1970's and the 1980's.

The first phase of the AEPS Study was eleven months in duration and was devoted to an appraisal of portable life support system concepts for Space Station, Lunar Base and Mars EVA missions. The second phase was six months in duration and was devoted to an appraisal of portable life support system concepts for Shuttle EVA missions and emergency life support system concepts for Shuttle, Space Station, Lunar Base and Mars EVA missions.

This volume presents the Final Summary Report. General conclusions and recommendations emanating from this effort are presented in section 2.0. The Space Station, Lunar Base, Mars and Shuttle AEPS specifications and Emergency System specifications are contained in section 3.0. Detailed descriptions of the study methodology utilized in the conduct of both phases one and two of the AEPS Study are found in section 4.0. A summary of the subsystem studies, including schematics and parametric data, are presented in section 5.0. Section 6.0 discusses the systems integration effort and contains schematics, flow chart and pictorial sketches of potential candidate system configurations. New technology requirements and recommendations are discussed in section 7.0. A complete bibliography of the texts and references utilized in the conduction of the AEPS Study is listed in section 8.0.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

General conclusions emanating from the AEPS study effort are:

a. For long duration space missions such as Space Station, Lunar Base and Mars missions, an AEPS configuration incorporating a regenerable CO_2 control subsystem and a thermal control subsystem utilizing a minimum of expendables dramatically decreases the vehicle penalty associated with present configurations (such as the Apollo EMU PLSS) and can be designed to be within an acceptable AEPS volume and weight range.

b. For shorter duration space missions such as Shuttle missions, an AEPS configuration incorporating an expendable water thermal control subsystem is the most competitive subsystem from both a present vehicle and AEPS basis. However, regenerable CO_2 control subsystems, if properly developed, are competitive with their nonregenerable counterparts (such as LiOH) which are being utilized on present day EVA missions.

d. CO_2 reduction and oxygen reclamation, within the parent vehicle, of the CO_2 removed by the AEPS CO_2 control subsystem is only competitive when there are three or more parent vehicle resupply periods (See Section 5.3).

e. For long duration emergency systems of one hour or more, inherent redundancy within the primary AEPS configuration to provide emergency thermal control is the most competitive approach. However, separate and independent equipment are required to provide emergency CO_2 control and O_2 supply, regardless of emergency duration.

2.2 Recommendations

As a result of the AEPS Study Program, the following major areas of new technology were identified and are recommended for future research and development:

a. Thermal Control

1. Thermal Storage - Investigate and develop a thermal storage material(s) whose heat of fusion exceeds 300 BTU/lb. One such candidate material, PH_4Cl, has already been identified and analytically evaluated during conduction of the AEPS study.

2.2 (Continued)

2. Radiation - Investigate and develop radiator surface coatings and treatments to optimize performance and minimize potential surface degradation. In addition, develop a lightweight, deployable radiator concept.

b. CO_2 Control

Develop a solid regenerable CO_2 sorbent that provides the performance, regeneration and life characteristics required for AEPS type applications. Two candidate families of solid regenerable sorbents -- metallic oxides and solid amines -- have already been identified and evaluated during conduct of the AEPS study.

c. O_2 Supply

Develop a high cyclic life (1000 cycles)/high pressure (6000 psi nominal) O_2 supply subsystem that minimizes EVA equipment volume and meets life requirements for AEPS - type applications.

These major areas of new technology, together with other areas having lesser impact, are discussed in Section 7.0.

3.0 AEPS SPECIFICATIONS REVIEW

3.0 AEPS SPECIFICATIONS AND EMERGENCY SYSTEM SPECIFICATIONS REVIEW

This section presents the four (4) AEPS specifications and the four (4) Emergency System specifications (Space Station, Lunar Base, Mars and Shuttle) that the study and final system selections were based on. Since any system result is quite dependent upon the initial requirements established, a review of the specifications is advisable to provide a common understanding of the study results.

The basic specification provided by NASA at the start of the program has been expanded to provide the overall depth required for final systems integration and selection and continually updated to reflect the latest projections of requirements for EVA missions in the 1980's. A series of reviews and discussions, both within Hamilton Standard and with NASA personnel resulted in these final specifications.

3.1 SPACE STATION AEPS SPECIFICATION

SPACE STATION AEPS SPECIFICATION

1.0 SCOPE

This specification defines the basic requirements to be considered for the Space Station AEPS Design Analysis effort.

2.0 DESCRIPTION

The AEPS shall be a portable system capable of supplying the functions of pressurization, ventilation, breathing oxygen supply, contaminant control, humidity control, thermal control and communications. The AEPS shall be a mission regenerable/rechargeable system and/or shall be capable of operating from a vehicle umbilical.

3.0 REQUIREMENTS

3.1 Performance Requirements

3.1.1 EVA Mission Duration - 4 hours nominal

3.1.2 Thermal Control

The AEPS shall maintain crewman thermal equilibrium when subjected to the following conditions.

3.1.2.1 Metabolic Profile

a.	Average	1000 Btu/hr
b.	Peak	2500 Btu/hr
c.	Minimum	400 Btu/hr

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	300 Btu/hr
b.	Maximum outward heat leak	350 Btu/hr
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - None

3.1.3 Pressurization - 6.75 ± 0.2 psia

3.1.4 External Leakage - 200 scc/min (PLSS + suit)

3.1.5 Ventilation

a.	Suit Inlet Flow Rate	6 acfm

b. Suit Inlet Gas Temperature 50-80°F

3.1.6 Humidity Control

a. Nominal Suit Inlet Dewpoint	45°F
b. Maximum Suit Inlet Dewpoint	60°F

3.1.7 Contamination Control

3.1.7.1 CO_2 Control

a. Nominal Suit Inlet CO_2 Level	4 mm Hg
b. Maximum Suit Inlet CO_2 Level	7.5 mm Hg

3.1.7.2 Particulate Contamination - The AEPS shall be capable of removing 100% of all particles 28 microns or larger, 99% of all particles between 7 and 27 microns, and 85% of all particles under 7 microns from the ventilation loop.

3.1.7.3 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.7.4 Odors - The AEPS shall be capable of removing all unpleasant odors from the ventilation loop.

3.1.8 Life Requirements

3.1.8.1 Useful Life - Defined to be that period from the time of delivery until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.8.2 Shelf Life - Defined as that period of time that the AEPS can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the AEPS shall be 5 years.

3.1.8.3 Operational Life - Defined as that period of time for which the AEPS is intended to be used, beginning with acceptance testing, preflight operations and actual usage. Operational life of the AEPS shall be 10 years consisting of 500 EVA missions. Ground maintenance and refurbishment is allowable.

3.2 Design Requirements

3.2.1 Mobility

The AEPS shall not encumber the crewman in the performance of his mission tasks as defined by the EVA/IVA tasks effort.

3.2.2 Controls and Displays

AEPS controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Center of Gravity

The CG of the suit/AEPS and the man shall be as close as possible to the CG of the nude crewman, and shall not shift in excess of 3 inches during conduct of the mission.

3.2.4 Maintainability

a. The AEPS shall be capable of being regenerated/recharged prior to each EVA mission.

b. The AEPS shall permit maximum ease of access to components requiring operational maintenance.

3.2.5 Safety

The AEPS shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.6 Structural Requirements

a. Proof pressure	1.5 x nominal pressure
b. Burst pressure	2.0 x nominal pressure
c. Collapsing pressure	15 psid
d. Cyclic Life	6000 cycles at nominal pressure

3.2.7 Natural Environment

The AEPS shall be compatible with an Earth ambient and Earth orbital environment.

3.2.8 Induced Environment

The AEPS shall be compatible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, operational use and re-entry.

3.2.9 Space Station Resupply Period - 90 days

TABLE 3-1

TRACE GAS CONTAMINATION MODEL

Maximum Concentration and Biological Production Rate of Trace Contaminants

Contaminant	Biological Production Rate, lb/hr	Allowable Concentration mg/m^3
Acetaldehyde	9.16×10^{-9}	360
Acetone	2.02×10^{-8}	2400
Ammonia	2.62×10^{-5}	70
n-Butanol	1.2×10^{-7}	303
Butyric Acid	6.92×10^{-5}	144
Carbon Monoxide	1.43×10^{-6}	115
Ethanol	3.68×10^{-7}	1880
Hydrogen	8.08×10^{-7}	(4.1%)
Hydrogen Sulfide	4.61×10^{-10}	28
Indole	9.18×10^{-6}	126
Methane	1.3×10^{-5}	(5.3%)
Methanol	1.39×10^{-7}	262
Phenol	3.46×10^{-5}	19
Pyruvic Acid	1.92×10^{-5}	9.2

3.2 LUNAR BASE AEPS SPECIFICATION

LUNAR BASE AEPS SPECIFICATION

1.0 SCOPE

The specification defines the basic requirements to be considered for the Lunar Base AEPS Design Analysis effort.

2.0 DESCRIPTION

The AEPS shall be a portable system capable of supplying the functions of pressurization, ventilation, breathing oxygen supply, contaminant control, humidity control, thermal control and communications. The AEPS shall be a mission regenerable/rechargeable system and/or shall be capable of operating from a vehicle umbilical.

3.0 REQUIREMENTS

3.1 Performance Requirements

3.1.1 EVA Mission Duration - 8 hours nominal

3.1.2 Thermal Control

The AEPS shall maintain crewman thermal equilibrium when subjected to the following conditions.

3.1.2.1 Metabolic Profile

a.	Average	1050 Btu/hr
b.	Peak	2500 Btu/hr
c.	Minimum	400 Btu/hr

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	700 Btu/hr
b.	Maximum outward heat leak	350 Btu/hr
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - None

3.1.3 Pressurization - 5.0 to 6.75 psia (dependent on Lunar Base pressure level)

3.1.4 External Leakage - 200 scc/min (PLSS + suit)

3.1.5 Ventilation

a. Suit Inlet Flow Rate 6 acfm

b. Suit Inlet Gas Temperature 50-80°F

3.1.6 Humidity Control

a. Nominal Suit Inlet Dewpoint 45°F
b. Maximum Suit Inlet Dewpoint 60°F

3.1.7 Contamination Control

3.1.7.1 CO_2 Control

a. Nominal Suit Inlet CO_2 Level 4 mm Hg
b. Maximum Suit Inlet CO_2 Level 7.5 mm Hg

3.1.7.2 Particulate Contamination - The AEPS shall be capable of removing 100% of all particles 28 microns or larger, 99% of all particles between 7 and 27 microns, and 85% of all particles under 7 microns from the ventilation loop.

3.1.7.3 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.7.4 Odors - The AEPS shall be capable of removing all unpleasant odors from the ventilation loop.

3.1.8 Life Requirements

3.1.8.1 Useful Life - Defined to be that period from the time of delivery until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.8.2 Shelf Life - Defined as that period of time that the AEPS can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the AEPS shall be 5 years.

3.1.8.3 Operational Life - Defined as that period of time for which the AEPS is intended to be used, beginning with acceptance testing, preflight operations and actual usage. Operational life of the AEPS shall be 10 years consisting of 500 EVA missions.

3.2 Design Requirements

3.2.1 Mobility

The AEPS shall not encumber the crewman in the performance of his mission tasks as defined by the EVA/IVA tasks effort.

3.2.2 Controls and Displays

AEPS controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Center of Gravity

The CG of the suit/AEPS and the man shall be as close as possible to the CG of the nude crewman, and shall not shift in excess of 3 inches during conduct of the mission.

3.2.4 Maintainability

a. The AEPS shall be capable of being regenerated/recharged prior to each EVA mission.

b. The AEPS shall permit maximum ease of access to components requiring operational maintenance.

3.2.5 Safety

The AEPS shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.6 Structural Requirements

a. Proof pressure	1.5 x nominal pressure
b. Burst pressure	2.0 x nominal pressure
c. Collapsing pressure	15 psid
d. Cyclic Life	6000 cycles at nominal pressure

3.2.7 Natural Environment

The AEPS shall be compatible with an Earth ambient, Earth orbital, lunar oribital, and a lunar surface environment.

3.2.8 Induced Environment

The AEPS shall be comptaible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, lunar landing, operational use and re-entry.

3.2.9 Lunar Base Resupply Period - 180 days

TABLE 3-1

TRACE GAS CONTAMINATION MODEL

Maximum Concentration and Biological Production Rate of Trace Contaminants

Contaminant	Biological Production Rate, lb/hr	Allowable Concentration mg/m^3
Acetaldehyde	9.16×10^{-9}	360
Acetone	2.02×10^{-8}	2400
Ammonia	2.62×10^{-5}	70
n-Butanol	1.2×10^{-7}	303
Butyric Acid	6.92×10^{-5}	144
Carbon Monoxide	1.43×10^{-6}	115
Ethanol	3.68×10^{-7}	1880
Hydrogen	8.08×10^{-7}	(4.1%)
Hydrogen Sulfide	4.61×10^{-10}	28
Indole	9.18×10^{-6}	126
Methane	1.3×10^{-5}	(5.3%)
Methanol	1.39×10^{-7}	262
Phenol	3.46×10^{-5}	19
Pyruvic Acid	1.92×10^{-5}	9.2

3.3 MARS AEPS SPECIFICATION

MARS AEPS SPECIFICATION

1.0 SCOPE

This specification defines the basic requirements to be considered for the Mars AEPS Design Analysis effort.

2.0 DESCRIPTION

The AEPS shall be a portable system capable of supplying the functions of pressurization, ventilation, breathing oxygen supply, contaminant control, humidity control, thermal control and communications. The AEPS shall be a mission regenerable/rechargeable system and/or shall be capable of operating from a vehicle umbilical.

3.0 REQUIREMENTS

3.1 Performance Requirements

3.1.1 EVA Mission Duration - 8 hours nominal

3.1.2 Thermal Control

The AEPS shall maintain crewman thermal equilibrium when subjected to the following conditions.

3.1.2.1 Metabolic Profile

a.	Average	1200 Btu/hr
b.	Peak	3000 Btu/hr
c.	Minimum	400 Btu/hr

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	100 Btu/hr
b.	Maximum outward heat leak	700 Btu/hr
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - None

3.1.3 Pressurization - 5.0 to 6.75 psia (dependent on Mars Excursion Module (MEM) pressure level)

3.1.4 External Leakage - 200 scc/min (PLSS + suit)

3.1.5 Ventilation

a.	Suit Inlet Flow Rate	6 acfm
b.	Suit Inlet Gas Temperature	50-80°F

3.1.6 Humidity Control

a.	Nominal Suit Inlet Dewpoint	45°F
b.	Maximum Suit Inlet Dewpoint	60°F

3.1.7 Contamination Control

3.1.7.1 CO_2 Control

a.	Nominal Suit Inlet CO_2 Level	4 mmHg
b.	Maximum Suit Inlet CO_2 Level	7.5 mmHg

3.1.7.2 Particulate Contamination - The AEPS shall be capable of removing 100% of all particles 28 microns or larger, 99% of all particles between 7 and 27 microns, and 85% of all particles under 7 microns from the ventilation loop.

3.1.8.3 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.7.4 Odors - The AEPS shall be capable of removing all unpleasant odors from the ventilation loop.

3.1.8 Life Requirements

3.1.8.1 Useful Life - Defined to be that period from the time of delivered until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.8.2 Shelf Life - Defined as that period of time that the AEPS can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the AEPS shall be 3 years.

3.1.8.3 Operational Life - Defined as that period of time for which the AEPS is intended to be used, beginning with acceptance testing, preflight operations and actual usage. Operational life of the AEPS shall be 3 years consisting of 22 EVA missions.

3.2 Design Requirements

3.2.1 Mobility

The AEPS shall not encumber the crewman in the performance of his mission tasks as defined by the EVA/IVA tasks effort.

3.2.2 Controls and Displays

AEPS controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Center of Gravity

The CG of the suit/AEPS and the man shall be as close as possible to the CG of the nude crewman, and shall not shift in excess of 3 inches during conduct of the mission.

3.2.4 Maintainability

a. The AEPS shall not require in-flight maintenance.

b. The AEPS shall be capable of being regenerated/recharged prior to each EVA mission.

3.2.5 Safety

The AEPS shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.6 Structural Requirements

a. Proof pressure	1.5 x nominal pressure
b. Burst pressure	2.0 x nominal pressure
c. collapsing pressure	15 psid
d. Cyclic Life	6000 cycles at nominal pressure

3.2.7 Natural Environment

The AEPS shall be compatible with an Earth ambient and Earth orbital, Mars orbital and Mars surface environment.

3.2.8 Induced Environment

The AEPS shall be compatible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, Mars landing, operational use and re-entry.

TABLE 3-1

TRACE GAS CONTAMINATION MODEL

Maximum Concentration and Biological Production Rate of Trace Contaminants

Contaminant	Biological Production Rate, lb/hr	Allowable Concentration mg/m^3
Acetaldehyde	9.16×10^{-9}	360
Acetone	2.02×10^{-8}	2400
Ammonia	2.62×10^{-5}	70
n-Butanol	1.2×10^{-7}	303
Butyric Acid	6.92×10^{-5}	144
Carbon Monoxide	1.43×10^{-6}	115
Ethanol	3.68×10^{-7}	1880
Hydrogen	8.08×10^{-7}	(4.1%)
Hydrogen Sulfide	4.61×10^{-10}	28
Indole	9.18×10^{-6}	126
Methane	1.3×10^{-5}	(5.3%)
Methanol	1.39×10^{-7}	262
Phenol	3.46×10^{-5}	19
Pyruvic Acid	1.92×10^{-5}	9.2

3.4 SHUTTLE AEPS SPECIFICATION

SHUTTLE AEPS SPECIFICATION

1.0 SCOPE

This specification defines the basic requirements to be considered for the Shuttle AEPS Design Analysis effort.

2.0 DESCRIPTION

The AEPS shall be a portable system capable of supplying the functions of pressurization, ventilation, breathing oxygen supply, contaminant control, humidity control, thermal control and communications. The AEPS shall be a mission regenerable/rechargeable system and/or shall be capable of operating from a vehicle umbilical.

3.0 REQUIREMEMENTS

3.1 Performance Requirements

3.1.1 EVA Mission Duration - 4 hours nominal

3.1.2 Thermal Control

The AEPS shall maintain crewman thermal equilibrium when subjected to the following conditions.

3.1.2.1 Metabolic Profile

a.	Average	1000 Btu/hr
b.	Peak	2500 Btu/hr
c.	Minimum	400 Btu/hr

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	300 Btu/hr
b.	Maximum outward heat leak	350 Btu/hr
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - None

3.1.3 Pressurization - 6.75 ± 0.2 psia

3.1.4 External Leakage - 200 scc/min (AEPS + suit)

3.1.5 Ventilation

a.	Suit Inlet Flow Rate	6 acfm

b. Suit Inlet Gas Temperature 50-80°F

3.1.6 Humidity Control

a. Nominal Suit Inlet Dewpoint 45°F
b. Maximum Suit Inlet Dewpoint 60°F

3.1.7 Contamination Control

3.1.7.1 CO_2 Control

a. Nominal Suit Inlet CO_2 Level 4 mm Hg
b. Maximum Suit Inlet CO_2 Level 7.5 mm Hg

3.1.7.2 Particulate Contamination - The AEPS shall be capable of removing 100% of all particles 28 microns or larger, 99% of all particles between 7 and 27 microns, and 85% of all particles under 7 microns from the ventilation loop.

3.1.7.3 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.7.4 Odors - The AEPS shall be capable of removing all unpleasant odors from the ventilation loop.

3.1.8 Life Requirements

3.1.8.1 Useful Life - Defined to be that period from the time of delivery until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.8.2 Shelf Life - Defined as that period of time that the AEPS can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the AEPS shall be 5 years.

3.1.8.3 Operational Life - Defined as that period of time for which the AEPS is intended to be used, beginning with acceptance testing, preflight operations and actual usage. Operational life of the AEPS shall be 10 years consisting of 100 Shuttle missions requiring a total of 2400 hours of actual operation. Ground maintenance and refurbishment between Shuttle missions is allowable.

3.2 Design Requirements

3.2.1 Mobility

The AEPS shall not encumber the crewman in the performance of his mission tasks as defined by the EVA/IVA tasks effort.

3.2.2 Controls and Displays

AEPS controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Center of Gravity

The CG of the suit/AEPS and the man shall be as close as possible to the CG of the nude crewman, and shall not shift in excess of 3 inches during conduct of the mission.

3.2.4 Maintainability

a. The AEPS shall not require in-flight maintenance.

b. The AEPS shall be capable of being regenerated/recharged prior to each EVA mission.

c. The AEPS shall be capable of rapid refurbishment during on-the-ground turn-around time.

3.2.5 Safety

The AEPS shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.6 Structural Requirements

a. Proof pressure	1.5 x nominal pressure
b. Burst pressure	2.0 x nominal pressure
c. Collapsing pressure	15 psid
d. Cyclic Life	6000 cycles at nominal pressure

3.2.7 Natural Environment

The AEPS shall be compatible with an Earth ambient and Earth orbital environment.

3.2.8 Induced Environment

The AEPS shall be compatible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, operational use and re-entry.

TABLE 3-1

TRACE GAS CONTAMINATION MODEL

Maximum Concentration and Biological Production Rate of Trace Contaminants

Contaminant	Biological Production Rate, lb/hr	Allowable Concentration mg/m^3
Acetaldehyde	9.16×10^{-9}	360
Acetone	2.02×10^{-8}	2400
Ammonia	2.62×10^{-5}	70
n-Butanol	1.2×10^{-7}	303
Butyric Acid	6.92×10^{-5}	144
Carbon Monoxide	1.43×10^{-6}	115
Ethanol	3.68×10^{-7}	1880
Hydrogen	8.08×10^{-7}	(4.1%)
Hydrogen Sulfide	4.61×10^{-10}	28
Indole	9.18×10^{-6}	126
Methane	1.3×10^{-5}	(5.3%)
Methanol	1.39×10^{-7}	262
Phenol	3.46×10^{-5}	19
Pyruvic Acid	1.92×10^{-5}	9.2

3.5 SPACE STATION EMERGENCY SYSTEM SPECIFICATION

SPACE STATION EMERGENCY SYSTEM SPECIFICATION

1.0 SCOPE

This specification defines the basic requirements to be considered for the Space Station AEPS Emergency System (ES).

2.0 DESCRIPTION

This ES shall be a portable system capable of supplying all the required life support functions in the event of an AEPS failure.

3.0 REQUIREMENTS

3.1 Performance Requirements

3.1.1 Emergency Mode Duration - 20 minutes minimum

3.1.2 Thermal Control

The ES shall maintain crewman thermal equilibrium when subjected to the following conditions:

3.1.2.1 Metabolic Profile

a.	Average	1500 BTU/hr.
b.	Peak	3000 BTU/hr.
c.	Minimum	400 BTU/hr.

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	300 BTU/hr.
b.	Maximum outward heat leak	350 BTU/hr.
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - 200 BTU Maximum

3.1.3 Pressurization - 6.75 ± 0.2 psia

3.1.4 Contamination Control

3.1.4.1 CO_2 Control - Maximum inlet CO_2 level - 15 mm Hg.

3.1.4.2 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.4.3 Odors - Odor level must not adversely affect crewman performance.

3.1.5 Visor Fogging - Visor defogging shall be provided by the ES to ensure crewman visibili'/.

3.1.6 Life Requirements

3.1.6.1 Useful Life - Defined to be that period from the time of delivery until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.6.2 Shelf Life - Defined as that period of time that the ES can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the ES shall be 5 years.

3.1.6.3 Operational Life - Defined as that period of time for which the ES is intended to be used, beginning with acceptance testing, preflight operations and actual usage. Operational life of the ES shall be 10 years. Ground maintenance and refurbishment is allowable.

3.2 Design Requirements

3.2.1 Mobility - ES shall provide minimum encumbrance to the crewman in performance of his mission tasks.

3.2.2 Controls & Displays - All ES controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Maintainability

a. The ES shall not require in-flight maintenance.
b. The ES will not be capable of being regenerated/recharged in-flight.

3.2.4 Safety - The ES shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.5 Structural Requirements

a. Proof pressure	1.5 x nominal pressure
b. Burst pressure	2.0 x nominal pressure
c. Collapsing pressure	15 psid
d. Cyclic Life	2500 cycles at nominal pressure

3.2.6 Natural Environment - The ES shall be compatible with an Earth ambient and Earth orbital environment.

3.2.7 Induced Environment - The ES shall be compatible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, operational use and re-entry.

3.2.8 Space Station Resupply Period - 90 days.

3.6 LUNAR BASE EMERGENCY SYSTEM SPECIFICATION

LUNAR BASE EMERGENCY SYSTEM SPECIFICATION

1.0 SCOPE

This specification defines the basic requirements to be considered for the Lunar Base AEPS Emergency System (ES).

2.0 DESCRIPTION

The ES shall be a portable system capable of supplying all the required life support functions in the event of an AEPS failure.

3.0 REQUIREMENTS

3.1 Performance Requirements

3.1.1 Emergency Mode Duration - 2 hours minimum

3.1.2 Thermal Control

The ES shall maintain crewman thermal equilibrium when subjected to the following conditions:

3.1.2.1 Metabolic Profile

a.	Average	1600 Btu/hr
b.	Peak	3500 Btu/hr
c.	Minimum	400 Btu/hr

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	700 Btu/hr
b.	Maximum outward heat leak	350 Btu/hr
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - 200 Btu Maximum

3.1.3 Pressurization - 5.0 to 6.75 (dependent on lunar base pressure level)

3.1.4 Contamination Control

3.1.4.1 CO_2 Control - Maximum inlet CO_2 level - 15 mm Hg.

3.1.4.2 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.4.3 Odors - Odor level must not adversely affect crewman performance.

3.1.5 Visor Fogging - Visor defogging shall be provided by the ES to ensure crewman visibility.

3.1.6 Life Requirements

3.1.6.1 Useful Life - Defined to be that period from the time of delivery until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.6.2 Shelf Life - Defined as that period of time that the ES can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the ES shall be 5 years.

3.1.6.3 Operational Life - Defined as that period of time for which the ES is intended to be used, beginning with acceptance testing, preflight operations and actual usage. Operational life of the ELSS shall be 10 years. Ground maintenance and refurbishment is allowable.

3.2 Design Requirements

3.2.1 Mobility - ES shall provide minimum encumbrance to the crewman in performance of his mission tasks.

3.2.2 Controls & Displays - All ES controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Maintainability

a. The ES shall not require in-flight maintenance.
b. The ES will not be capable of being regenerated/recharged in-flight.

3.2.4 Safety - The ES shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.5 Structural Requirements

a.	Proof pressure	1.5 x nominal pressure
b.	Burst pressure	2.0 x nominal pressure
c.	Collapsing pressure	15 psid
d.	Cyclic Life	2500 cycles at nominal pressure

3.2.6 Natural Environment - The ES shall be compatible with an Earth ambient, Earth orbital and a lunar surface environment.

3.2.7 Induced Environment - The ES shall be compatible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, lunar landing, operational use and re-entry.

3.7 MARS EMERGENCY SYSTEM SPECIFICATION

MARS EMERGENCY SYSTEM SPECIFICATION

1.0 SCOPE

This specification defines the basic requirements to be considered for the Mars AEPS Emergency System (ES).

2.0 DESCRIPTION

The ES shall be a portable system capable of supplying all the required life support functions in the event of an AEPS failure.

3.0 REQUIREMENTS

3.1 Performance Requirements

3.1.1 Emergency Mode Duration - 1 hour minimum

3.1.2 Thermal Control

The ES shall maintain crewman thermal equilibrium when subjected to the following conditions:

3.1.2.1 Metabolic Profile

a.	Average	2000 Btu/hr
b.	Peak	3500 Btu/hr
c.	Minimum	400 Btu/hr

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	100 Btu/hr
b.	Maximum outward heat leak	700 Btu/hr
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - 200 Btu Maximum

3.1.3 Pressurization - 5.0 to 6.75 psia (dependent on MEM pressure level)

3.1.4 Contamination Control

3.1.4.1 CO_2 Control - Maximum inlet CO_2 level - 15 mm Hg.

3.1.4.2 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.4.3 Odors - Odor level must not adversely affect crewman performance.

3.1.5 Visor Fogging - Visor defogging shall be provided by the ES to ensure crewman visibility.

3.1.6 Life Requirements

3.1.6.1 Useful Life - Defined to be that period from the time of delivery until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.6.2 Shelf Life - Defined as that period of time that the ES can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the ES shall be 3 years.

3.1.6.3 Operational Life - Defined as that period of time for which the ES is intended to be used, beginning with acceptance testing, prelaunch operations and actual usage. Operational life of the ES shall be 3 years.

3.2 Design Requirements

3.2.1 Mobility - ES shall provide minimum encumbrance to the crewman in performance of his mission tasks.

3.2.2 Controls & Displays - All ES controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Maintainability

a. The ES shall not require in-flight maintenance.
b. The ES will not be capable of being regenerated/recharged in-flight.

3.2.4 Safety - The ES shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.5 Structural Requirements

a. Proof pressure	1.5 x nominal pressure
b. Burst pressure	2.0 x nominal pressure
c. Collapsing pressure	15 psid
d. Cyclic Life	2500 cycles at nominal pressure

3.2.6 Natural Environment - The ES shall be compatible with an Earth ambient, Earth orbital, Mars oribtal and Mars surface environment.

3.2.7 Induced Environment - The ES shall be compatible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, Mars landing, operational use and re-entry.

3.8 SHUTTLE EMERGENCY SYSTEM SPECIFICATION

SHUTTLE EMERGENCY SYSTEM SPECIFICATION

1.0 SCOPE

This specification defines the basic requirements to be considered for the Shuttle AEPS Emergency System (ES)

2.0 DESCRIPTION

The ES shall be a portable system capable of supplying all the required life support functions in the event of failure.

3.0 REQUIREMENTS

3.1 Performance Requirements

3.1.1 Emergency Mode Duration - 30 minutes minimum

3.1.2 Thermal Control

The ES shall maintain crewman thermal equilibrium when subjected to the following conditions:

3.1.2.1 Metabolic Profile

a.	Average	1500 BTU/hr
b.	Peak	3000 BTU/hr
c.	Minimum	400 BTU/hr

3.1.2.2 Thermal Loads

a.	Maximum inward heat leak	300 BTU/hr
b.	Maximum outward heat leak	350 BTU/hr
c.	Equipment thermal loads	As required

3.1.2.3 Crewman Thermal Storage - 200 BTU Maximum

3.1.3 Pressurization - 6.75 ± 0.2 psia

3.1.4 Contamination Control

3.1.4.1 CO_2 Control - Maximum inlet CO_2 level - 15 mmHg

3.1.4.2 Trace Contaminants - The maximum allowable concentrations and biological generation rates of trace contaminants are defined in Table 3-1.

3.1.4.3 Odors - Odor level must not adversely affect crewman performance.

3.1.5 Visor Fogging - Visor defogging shall be provided by the ES to ensure crewman visibility.

3.1.6 Life Requirements

3.1.6.1 Useful Life - Defined to be that period from the time of delivery until it is downgraded to an uncontrolled status. The useful life is composed of the shelf life and the operational life.

3.1.6.2 Shelf Life - Defined as that period of time that the ES can be stored under controlled conditions during which it can be removed and put into service without replacement of parts. Routine servicing is allowable. Shelf life of the ES shall be 5 years.

3.1.6.3 Operational Life - Defined as that period of time for which the ES is intended to be used, beginning with acceptance testing, preflight operations and actual usage. Operational life of the ES shall be 10 years consisting of 100 Shuttle missions. Ground maintenance and refurbishment between Shuttle missions is allowable.

3.2 Design Requirements

3.2.1 Mobility - ES shall provide minimum encumbrance to the crewman in performance of his mission tasks.

3.2.2 Controls & Displays - All ES controls and displays shall be located within the sight of and normal reach of the suited crewman.

3.2.3 Maintainability

a. The ES shall not require in-flight maintenance.
b. The ES shall be maintained after each Shuttle mission.
c. The ES will not be capable of being regenerated/recharged in-flight.

3.2.4 Safety - The ES shall minimize the possibility of injury to crewman, service personnel, etc., because of fire, explosion, toxicity, contamination, burns or shock.

3.2.5 Structural Requirements

a.	Proof pressure	1.5 x nominal pressure
b.	Burst pressure	2.0 x nominal pressure
c.	Collapsing pressure	15 psid
d.	Cyclic Life	2500 cycles at nominal pressure

3.2.6 Natural Environment - The ES shall be compatible with an Earth ambient and Earth orbital environment.

3.2.7 Induced Environment - The ES shall be compatible with the vehicle environments and operating fluids and shall be capable of meeting the structural requirements of launch, operational use and re-entry.

4.0 STUDY METHODOLOGY

4.0 STUDY METHODOLOGY

This section describes Hamilton Standard's conduct of the AEPS study. Included in the following discussion are a brief summary of the study approach, the study objectives, guidelines and constraints, the study evaluation criteria, and a description of the study flow.

4.1 Phase One Effort

4.1.1 Study Approach Summary

To ensure that the proper study perspective was established as early as possible in the AEPS study, maximum use was made of prior pertinent studies and discussions with the technical monitor and other NASA personnel to prepare and release a comprehensive AEPS Study Plan and a set of AEPS specifications for the Space Station, Lunar Base, and Mars missions.

The subsystem studies task was initiated by the identification of numerous subsystem concepts in the area of thermal control, humidity control, CO_2 control, O_2 supply, trace contaminant control and power. Utilizing the AEPS specification as a guide to system requirements, these candidate subsystem concepts were analyzed and parametric data generated. Subsystem comparative evaluations were then conducted in accordance with the study evaluation criteria defined in section 4.1.4 of this volume. The subsystems selected were then carried into the system studies task and integrated into several baseline AEPS schematic concepts and, once again, evaluated in accordance with the study evaluation criteria. Based on the results of the systems evaluation, AEPS concepts were selected for each of the three missions--Space Station, Lunar Base, and Mars.

After establishment of the selected AEPS concepts, a prioritized listing of required technology development activity to permit the recommended AEPS concepts to be developed was generated.

4.1.2 Objective

The objective of phase one of the AEPS study was to provide a meaningful appraisal of various regenerable and partially regenerable portable life support system concepts for EVA used in the 1980's.

4.1.3 Guidelines & Constraints

The above objective was accomplished within the following assumptions and guidelines as agreed to with the NASA Ames Research Center:

1. The effort was not to be confined to the conventional techniques of system portability· i.e., backpacks. Rather, in generating concepts for the AEPS, consideration is also to be given to ideas such as:

4.1.3 (continued)

a. Total or partial subsystem integration into the protective suit.
b. Placing of the life support subsystems on a cart or vehicle with umbilical to the suit.
c. Integration of the life support system into a pack or suit with subsystem modules removable for regeneration on a cart or vehicle.

2. The degree of regenerability was an important consideration of this study. A spectrum of system configuration was possible, ranging from totally expendable to completely regenerable. Degrees of regenerability are defined as follows:

   a. A completely regenerative life support system is defined in this study as essentially a closed life support system. It removes exhaled CO_2 for reclamation of the oxygen, and it captures water lost from the astronaut for collection and purification. Furthermore, no water or other material is sublimated or evaporated to space as a mechanism of heat removal. There is no loss of mass from the system as a result of its use except possibly for trace contaminant disposal, or a small amount of external leakage of fluids from the life support system and suit. Moreover, all systems are reuseable and are not discarded after use.
   b. A partially regenerable life support system is defined as a system which has one or more, but not all, subsystems dependent on expendables. For example, a portable life support system may use a space radiator to reject heat rather than subliming water, but it may still use LiOH to remove CO_2, charcoal for adsorption of trace contaminants, etc.
   c. A fully expendable life support system, such as the Apollo EMU Portable Life Support System (PLSS), uses expendables for CO_2 removal, heat rejection, trace contamination control, and power.

3. There was no requirement that recharging or regeneration of the regenerable portions of the system occur specifically within the AEPS; the regeneration may also occur within the parent vehicle. For example, oxygen need not be reclaimed from the CO_2 within the structure of the AEPS, but rather the CO_2 may be collected in the AEPS and returned to the vehicle for reduction. However, if reclamation and recharge are to take place in the vehicle, the necessary vehicle equipment must be considered as part of the AEPS design, and the penalties associated with this approach must be evaluated.

4. The AEPS system(s) concepts selected for earth orbital missions need not necessarily be the system selected for lunar surface or Martian surface operations: however, commonality of subsystems was to be strived for as a design goal.

5. No consideration was to be given to management of the astronaut urine or fecal material.

4.1.3 (continued)

6. Emergency and backup systems were not to be considered as a part of Phase One of this study.

4.1.4 Study Evaluation Criteria

Selection of the most favorable EVA subsystem and system equipment has always posed a difficult problem. This was particularly true for the AEPS study as it dealt with long duration earth orbital, lunar surface, and Martian surface missions, wherein the vehicle penalty for an AEPS configuration has now become increasingly more important than it was for the shorter term Gemini and Apollo programs. This reduces the validity of the traditional heavy emphasis on AEPS equivalent volume and weight within the evaluation criteria. Thus, to fulfill the objective of the AEPS study within the assumptions and guidelines listed previously, it has been necessary to establish criteria reflecting an objective evaluation of not only the EVA crewman and his equipment, but also of the parent vehicle or shelter, and the total mission.

The determination of the AEPS study selection criteria was based on a recognition that some requirements are absolute, others are of primary importance, and still others are secondary in that they represent second order effects. The criteria used as a basis for the AEPS subsystems and system selection are shown in Figure 4-1. The criteria are applied sequentially in the groups shown to eliminate concepts that fail on either an absolute (go/no go) or comparative basis and to provide the basis for selection between surviving candidates. If an eliminated concept still has a potential application if adequately developed, it was identified as a possible candidate for research and development in the pacing technology phase of the study program.

Go/No Go Criteria - Go/No Go criteria define the minimum acceptable requirements for a concept. If a concept does not meet or cannot be modified or augmented to meet all of the go/no go criteria, no further consideration was given in the study and that particular concept was listed as unacceptable and eliminated. The go/no go criteria are listed as follows:

Performance - All concepts must be capable of meeting the entire performance specification to be considered as candidates. To provide a common basis, conceptual designs were adjusted for each competing subsystem, system, or method to meet the same performance requirements.

Safety - Safety of each concept was evaluated with respect to fire, contamination, explosion hazards, hot spots, bacteriological problems, and crew hazards to determine if any of these are present which cannot be eliminated by careful design or inclusion of additional control equipment, different materials, etc. Hazards are investigated during normal operation and off-design operation. If any serious problems were discovered which could not be reasonably avoided, the concept was eliminated.

4.1.4 (continued)

Availability - Availability is a measure of the probability of a concept being fully operational within the required time period (following reasonable development effort). Preliminary screening of concepts eliminates many questionable concepts where feasibility has not been convincingly established. Availability is evaluated by an analysis of the subsystem approach, its interfaces and hardware requirements to define problem areas and design "qualms".

Crew Acceptability - This is a measure of the psychological acceptability of the approach by the eventual user. The equipment must be designed to assure that it includes neither physical nor mental stress on the crew. If a concept was deemed to be unacceptable by the crew and could not be corrected, the concept was eliminated. Examples of potential marginal areas where crew acceptability may be an overriding criteria are the use of a radioactive power source, location of controls and displays, specific EVA operational procedures, etc. If a "marginal" concept did pass the go/no go test, it was highlighted as "marginal" to ensure further consideration of that criterion during later stages of the evaluation.

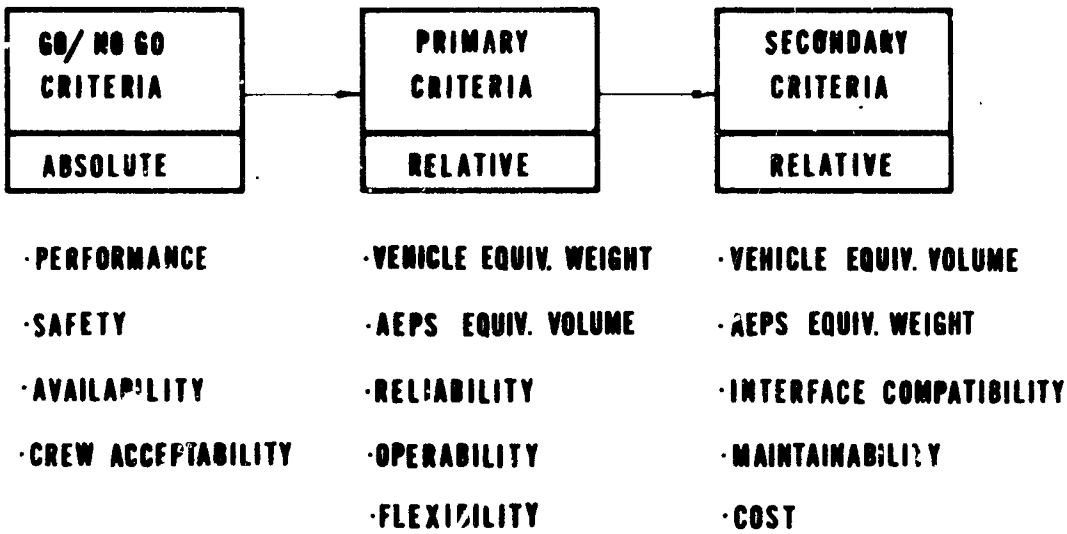


FIGURE 4—1. EVALUATION CRITERIA

4.1.4 (continued)

Primary Criteria - These primary criteria are the principal evaluation criteria for all concepts that passed the go/no go criteria requirements. The ratings applied to a candidate concept are dependent upon the characteristics of the candidate relative to the other candidates. Each candidate concept received a rating of from 0 to 100 for each primary criterion. Each rating was then multiplied by the weighting factors defined in Table 4-1 and these added to obtain a total rating for each candidate concept. If a clear-cut choice was not evident, the remaining competing concepts were reviewed against the secondary criteria. The primary criteria are listed as follows:

Vehicle Equivalent Weight - The physical aspects of any given concept can be converted to an equivalent vehicle launch weight penalty for purposes of comparison. Equivalent vehicle weight consists of subsystem or system fixed weight, expendables, power requirements, heat rejection requirements, recharge and/or regeneration equipment, spares, and special interface equipment.

AEPS Equivalent Volume - AEPS equivalent volume consists of all EVA life support equipment with which the crewman must egress from the vehicle and is an indirect measurement of crewman encumbrance and mobility hindrance. This criterion, as is equivalent vehicle weight, is a tool that provides an objective quantitative basis for evaluation and represents the two most important evaluation criteria for use during the study.

Reliability - Reliability is a measure of the probability that a concept will meet the total mission requirements with a minimum of spares, redundancy and maintenance time. In addition, single point failures and sequential failures are eliminated. Application of these criteria entail objective engineering assessments and do not involve interpolation of numbers representing failure probability estimates.

Operability - Operability is a measure of the concept's ability to be simply used for the mission's various operating modes including: don/doff, startup, checkout, egress/ingress, shutdown, recharge/regeneration, and operational variations during the actual EVA. If the operability of a candidate concept is considered unacceptable, it is eliminated.

Flexibility - Flexibility is a measure of the concept's ability to be used under various conditions at minimum penalty:

a. Different types of EVA missions such as exploration, cargo transfer, assembly operations, etc.
b. Different space programs involving varying gravity environments, thermal environments, etc.
c. Adaptability of incorporating new technology, thus preventing premature technical obsolescence.

PRIMARY CRITERIA WEIGHTING FACTORS

CRITERIA	WEIGHTING FACTORS		
	SPACE STATION	LUNAR BASE	MARS
VEHICLE EQUIVALENT WEIGHT	0.30	0.35	0.35
AEPS EQUIVALENT VOLUME	0.30	0.25	0.25
RELIABILITY	0.15	0.15	0.15
OPERABILITY	0.15	0.15	0.15
FLEXIBILITY	0.10	0.10	0.10

TABLE 4-1

4.1.4 (continued)

Secondary Criteria - These secondary criteria represent a step in depth of competitive evaluation which was taken if no clear-cut selection is available from the primary criteria. Ratings of the candidate concepts against secondary characteristics are relative assessments within each area of consideration and, as in the implementation of the primary criteria, each candidate concept received a rating of from 0 to 100 for each criterion. Each rating was then multiplied by the weighting factors defined in Table 4-2 and these were added to obtain a total rating for each candidate concept. -A concurrent review of both the primary and secondary evaluation results was then conducted. Those concepts which scored relatively high in both evaluations were considered to have passed the secondary evaluation; those that scored relatively low in both evaluations were rejected and elminated from further consideration.

In any event, the secondary criteria were applied against all recommended concepts to provide a systematic review of the overall acceptability of these selected concepts and to ensure that these characteristics would not preclude their use. The secondary criteria are listed as follows:

Vehicle Equivalent Volume - Equivalent vehicle volume is a volumetric measure of the subsystem, expendables, recharge and/or regeneration equipment, power penalty, heat rejection penalty, and special interface equipment, and is a "second-order" tool which provides an objective quantitative basis for evaluation.

AEPS Equivalent Weight - Since this criterion is directly considered in the primary criteria of equivalent vehicle weight, the primary emphasis of weight in the secondary criteria is the limiting factor of ability to handle, service, move, replace, and/or install the equipment and the effect upon the total EVA system (including AEPS, space suit, etc.) center of gravity.

Interface Compability - This is a measure of the ability of the concept to integrate with other subsystems or components, the crew, the space suit and the vehicle without a severe penalty on the other areas. Because of the physical and functional scope of an AEPS, an interface check is necessary to assure that no unreasonable problems are encountered in eventual integration of the AEPS in the total mission/vehicle system.

Maintainability - Maintainability is a measure of the time required for checkout, replacement of expendables, regeneration of components or subsystems, cleaning, and scheduled and unscheduled maintenance where such operations are required. This assessment is made after a satisfactory design concept is evolved with respect to performance, spares, redundancy, and modularity.

Cost - Cost is a secondary criterion since the mission must first be achieved. If two or more competing concepts can achieve the mission, then cost differences are considered as a significant basis for decision.

SECONDARY CRITERIA WEIGHTING FACTORS

CRITERIA	WEIGHTING FACTORS		
	SPACE STATION	LUNAR BASE	MARS
VEHICLE EQUIVALENT VOLUME	0.30	0.30	0.30
AEPS EQUIVALENT WEIGHT	0.15	0.20	0.20
INTERFACE COMPATIBILITY	0.25	0.20	0.20
MAINTAINABILITY	0.20	0.20	0.20
COST	0.10	0.10	0.10

TABLE 4-2

4.1.5 Study Flow

The planned flow of the AEPS study is pertinent as an aid in understanding the material accumulated in this report and the discussion of the parametric data in the subsequent sections and volumes.

The AEPS study program consisted of the following four basic tasks conducted in accordance with the summary study logic diagram presented in Figure 4-2.

a. Study Plan and Specifications - The basic ingredients to a meaningful AEPS study are the study plans and the AEPS specifications. The diverse nature of earth orbital, lunar, and Martian applications required that separate AEPS specifications be generated for each application. However, in the conduct of the study, a greater emphasis was placed on the earth orbital and lunar base AEPS configurations due to the higher probability of the occurrence of these missions and their better near-term schedule prospects. In addition, the technology required for development of a Mars AEPS could be a natural outgrowth of the Space Station or Lunar Base AEPS.

   Some of the obvious design parameters which vary depending upon the type of application and thus affect AEPS concept selection are:

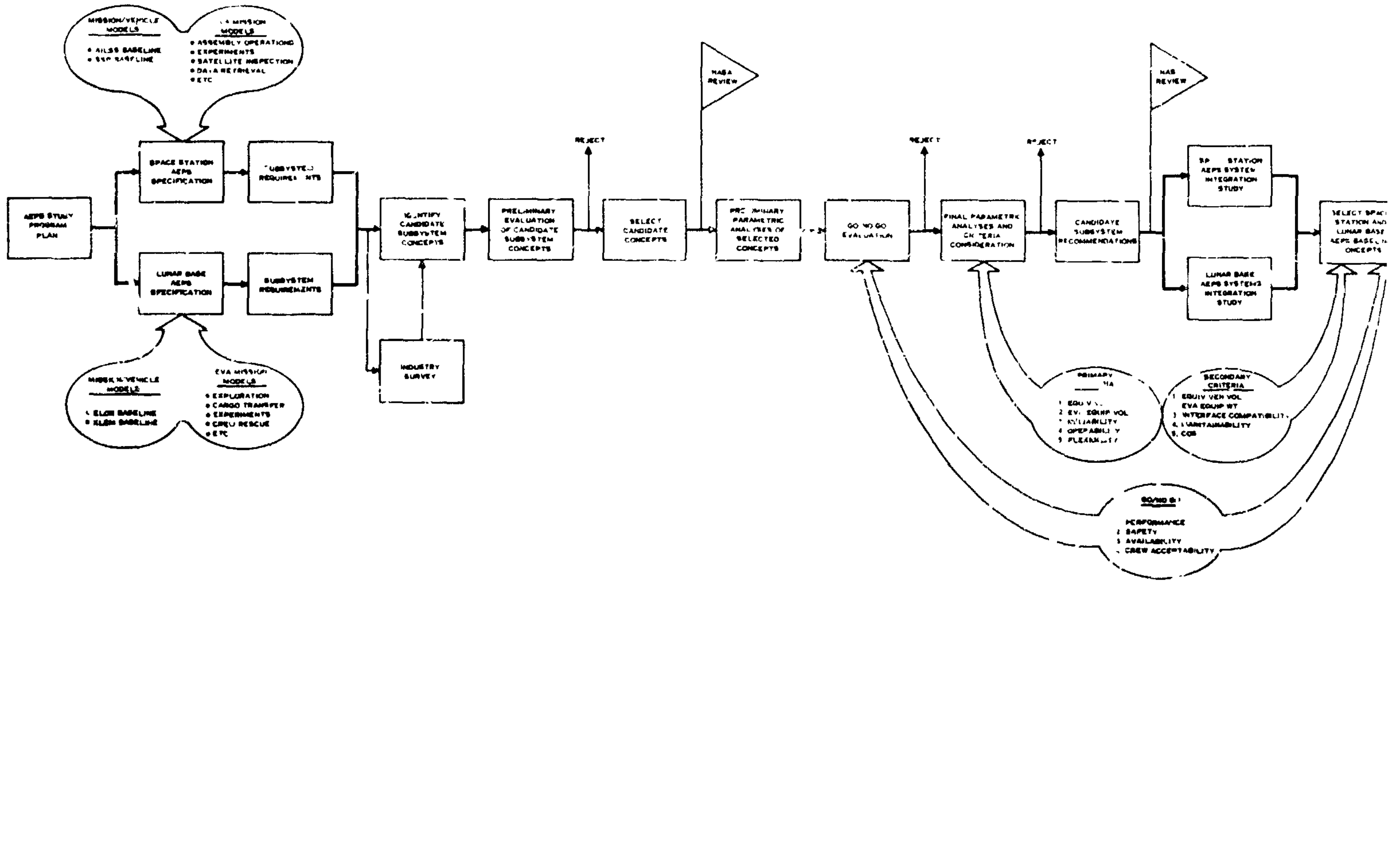
   1. Gravity environment
   2. Ambient pressure
   3. Environmental thermal model
   4. Metabolic work rates
   5. Life requirements
   6. Resupply periods
   7. Mating vehicle EC/LSS configuration
   8. Mating vehicle power source
   9. Specific EVA mission work performance requirements
   10. Number of EVA hours per man per week

   The goal of these specifications was to be general guidelines representing the probable trends for earth orbital, Lunar Base, and Mars landing missions in the 1980's. Efforts were made to remain flexible and to avoid basing the specification on one particular mission concept or one particular vehicle configuration. This approach prevented an ultimate system that is too specific to be used with more than one vehicle or for more than one type of EVA mission. To support the specification generation effort, baseline EVA mission models were established to define work performance tasks and required crew skills; to determine representative time allocations for these tasks; to define operational procedures for donning/doffing, checkout, egress/ingress, recharge/regeneration, etc.; and to define applicable interface areas. In addition, vehicle EC/LSS models were established to serve as guides to determine the AEPS recharge/

FOLDOUT FRAME 1

STUDY PLAN & SPECIFICATIONS

SUBSYSTEM STUDIES



FOLDOUT FRAME 2

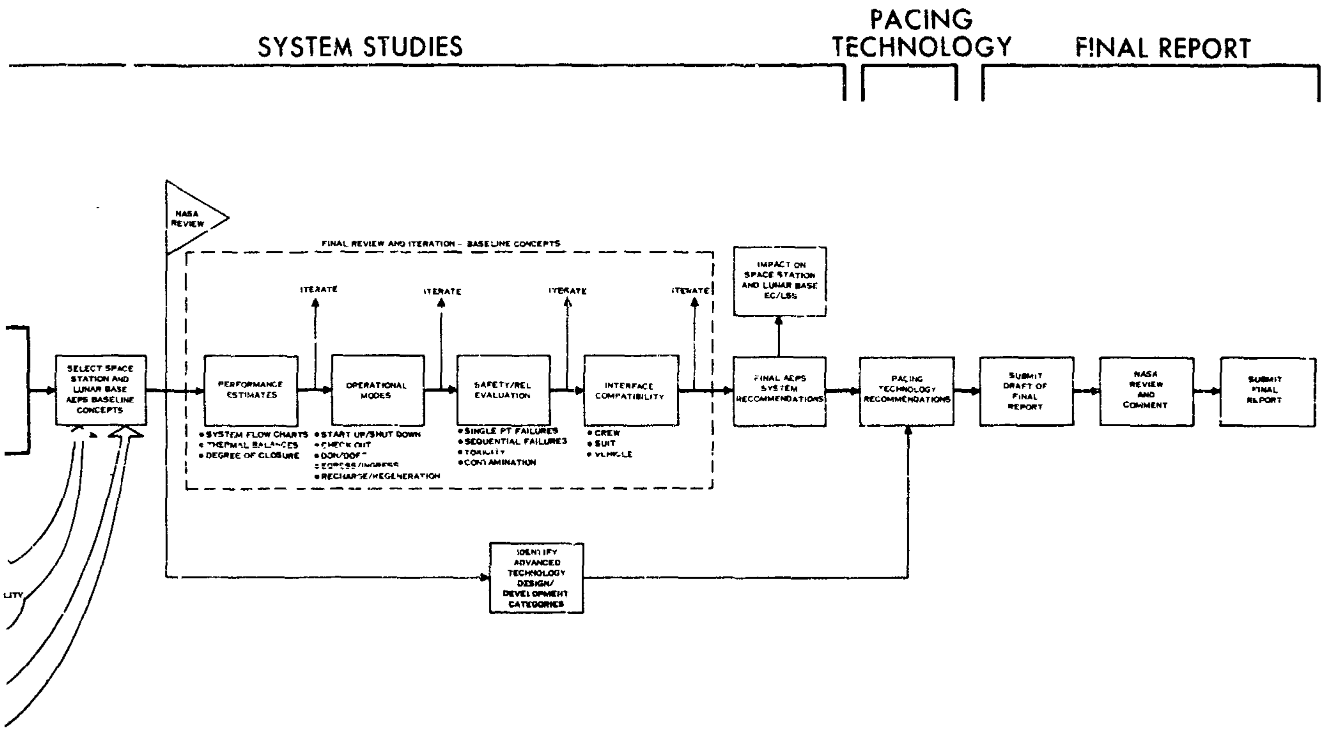


FIGURE 4–2. SUMMARY STUDY LOGIC DIAGRAM

4.1.5 (continued)

regeneration capabilities of the vehicle. The vehicle mission models are based upon Hamilton Standard's past contract efforts such as the Advanced Integrated Life Support System (AILSS) program, and our present contract efforts on the Space Station Prototype (SSP) program and with both of the Space Station Phase B Prime Contractors. These EVA mission models and vehicle EC/LSS models were continually recycled and revised during the study as the influence on the AEPS concepts were determined.

b. Subsystem Studies - The first step in the subsystem definition study was the preparation of subsystem requirements for each of the major functional areas of each configuration. Based upon these requirements, candidate concepts were identified in each of the major subsystem areas (CO_2 control/O_2 supply, trace contaminant control, thermal control/humidity control, and power). In areas where in-house data was not complete, a literature survey was conducted and industry contacts made, as required. Once all data was assembled and candidate subsystem concepts identified, a preliminary evaluation was conducted to screen out the candidates that are obviously noncompetitive. Performance characteristics (such as flow rates, temperature levels and pressure levels) of the selected candidate subsystems were roughly determined and preliminary schematics and component lists generated. The candidate subsystems were then sized to meet the subsystem requirements.

These subsystems were then compared against the go/no go evaluation criteria (performance, safety, availability and crew acceptability). If a concept was found unacceptable, sufficient auxiliary equipment was added, if possible, to that subsystem to meet the go/no go criteria. If a candidate concept could not be made acceptable, it was removed from further consideration at that point.

A parametric analysis of the remaining candidate subsystem concepts was then conducted. The following data was generated as required for comparison purposes among the candidate subsystems:

1. Vehicle launch weight, including expendables, spares, recharge and/or regeneration equipment, and checkout equipment, in addition to the basic subsystem versus total mission duration.
2. EVA equipment volume versus EVA mission duration.
3. Vehicle launch volume versus total mission duration.
4. EVA equipment weight versus EVA mission duration.

4.1.5 (continued)

The remaining candidate subsystems were then compared against the primary criteria (equivalent vehicle weight, AEPS equivalent volume, reliability, operability and flexibility). Further equipment was added or the arrangements modified, as required, to upgrade candidate subsystem concepts that were found to be unacceptable or inferior relative to the reliability and operability criteria. Of course, the associated weight, volume, and power penalties were also reflected in the parametric analyses. If a candidate concept could not be made acceptable, or was still obviously grossly inferior to the other candidates, it was removed from further consideration at that point.

If a clear cut choice still could not be made from the primary criteria evaluation, the remaining candidate subsystem concepts were compared against the secondary criteria (equivalent vehicle volume, AEPS equivalent weight, interface compatibility, maintainability, and cost). As in the primary criteria evaluation, equipment modifications were made to a candidate concept(s) to upgrade it relative to the qualitative criteria (interface compatibility and maintainability) if it appeared inferior to other competing concepts. Again, the associated penalties were reflected in the parametric analyses.

Based upon the results of the subsystem evaluations, a selection of the best competing subsystems were made for each of the AEPS configurations. It is significant to note that several subsystems that perform the same function were recommended for further study on the system level.

In summary, the subsystem comparative evaluations continually attempted to upgrade all candidate concepts to an equivalent level of acceptance as measured by the qualitative criteria and thus permit final subsystem selections to be made on a quantitative basis.

c. System Studies - After completion of the subsystem studies, a systems integration effort was conducted wherein the selected candidate subsystem concepts were combined into several candidate baseline Space Station, Lunar Base, and Mars Base AEPS systems. The systems integration effort evaluated and defined the following elements that could not be fully evaluated on the subsystem level:

1. Subsystem interfaces (both functional and physical)
2. Instrumentation and controls
3. Thermal balance
4. Equipment power requirements
5. Humidity control
6. Method of heat transport to heat rejection system and associated coolant flows
7. Trace contamination requirements
8. Suit and vehicle interfaces

4.1.5 (continued)

The candidate baseline systems were then subjected to a comparative evaluation utilizing the criteria defined in Paragraph 4.1.4 and the parametric results of the subsystem studies. Results of the systems evaluation led to the selection of the Space Station, Lunar Base and Mars Base AEPS baseline concepts. A baseline concept is defined as a competitive AEPS concept for a given set of EVA mission requirements and Mission/Vehicle constraints.

Prior to a final review and iteration of the AEPS baseline concepts, Hamilton Standard reviewed with NASA the general specification and the evaluation criteria to assure that both were still consistent with the objectives of the study and the results to date. Upon satisfactory completion of this task, a detailed performance review and evaluation of the AEPS baseline concepts was performed, as required, to optimize system performance. Components and subsystems were resized, as required, and system arrangements modified, if required.

The operational modes of each baseline concept were reviewed in detail to simplify operational procedures. Specific emphasis was placed on:

1. Startup, checkout, and shutdown procedures
2. Recharge and/or regeneration procedures
3. Maintenance procedures

A safety/reliability evaluation of each baseline concept was conducted and all single point and sequential failures were eliminated. This analysis also formed the basis for the selection of the AEPS instrumentation.

The interface compatibility of each AEPS baseline concept was evaluated with respect to the crew, the space suit, the vehicle and other EVA equipment. Specific emphasis was placed on location of AEPS controls and displays, use of mobile carts, use of the Time Independent Module/Time Dependent Module (TIM/TDM) concept, partial and full integration of the AEPS into the space suit, and compatibility of the AEPS subsystems with vehicle EC/LSS subsystems.

The final AEPS system recommendations resulted from this total effort.

d. New Technology - After establishment of the AEPS baseline concepts, a portion of the study effort was directed toward generation of a priortized listing of required technology development activity to permit the AEPS recommendations to be implemented.

4.1.5 (continued)

The principal objectives of this effort were:

1. To provide confirmation of attractive concepts where, although feasibility may have been demonstrated, development status and confidence is marginal.

2. To define problems and recommend approaches to solve these problems.

4.2 Phase Two Effort

4.2.1 General

The proposed study methodology for phase two was similar to the study methodology used during the initial phase of the AEPS study. The general approach followed consisted of:

a. Establishing the requirements of the systems and the criteria to be utilized in making selections.

b. Conducting subsystem studies to screen, evaluate and select subsystem concepts.

c. Conducting system integration studies and formulating recommendations for Shuttle AEPS configurations.

d. Conducting system integration studies and formulating recommendations for Emergency Systems for:

   Space Station AEPS
   Lunar Base AEPS
   Mars AEPS
   Shuttle AEPS

e. Defining pacing technology areas and recommending approaches to solve problems within these areas.

A detailed summary of each step in the phase two study flow is presented in Figure 4-3.

4.2.2 Shuttle AEPS Systems

A major portion of the phase two AEPS study effort consisted of an evaluation of the AEPS for EVA operations from Shuttle vehicles. This effort included (a) establishment of specification requirements; (b) subsystem studies; and (c) system studies resulting in Shuttle AEPS technology recommendations.

4.2.2.1 Specification - Hamilton Standard initially prepared a Shuttle AEPS specification. This specification served as general guidelines representing the probable trends for earth orbital shuttle missions in the late 1970's and the 1980's. Efforts were made to remain flexible and to avoid basing the specification on one particular mission concept or one particular vehicle configuration. This approach prevents an ultimate system that is too specific to be used with more than one type of vehicle or for more than one type of EVA mission.

As a basis for this effort, Hamilton Standard used NASA's objectives, pertinent published literature, and our EVA equipment and vehicle EC/LSS experience as a guide. Baseline EVA mission models were established to define work performance tasks; to define operational procedures for donning/doffing, checkout, egress/ingress, recharge/regeneration, etc.; and to define applicable interface areas. In addition, vehicle EC/LSS models were established to serve as guides to determine the AEPS recharge/regeneration capabilities of the Shuttle vehicle. The vehicle mission models were based upon Hamilton Standard's Shuttle EC/LSS contract efforts for the NASA Langley Research Center and with both of the Shuttle Phase B Prime Contractors. These EVA mission models and vehicle EC/LSS models were recycled and revised during the study as their influence on the AEPS concepts were determined.

4.2.2.2 Subsystem Studies - The first step in the subsystem definition study was the preparation of subsystem requirements for each of the major functional areas of the Shuttle AEPS. Based upon these requirements, candidate subsystem concepts were identified. In areas where in-house data was not complete, an extensive literature survey was conducted. Once all data was assembled and candidate subsystem concepts identified, a preliminary evaluation was conducted to screen out and reject the candidates that were obviously non-competitive. Performance characteristics (such as flow rates, temperature levels and pressure levels) of the selected candidate subsystems were then roughly determined and preliminary schematics and component lists generated. The candidate subsystems were then sized to meet the subsystem requirements.

These subsystems were compared against the go/no go evaluation criteria (performance, safety, availability and crew acceptability). If a concept was found unacceptable, sufficient auxiliary equipment was added, if possible, to that subsystem to meet the go/no go criteria. If a candidate concept could not be made acceptable, it was removed from further consideration at this point.

4.2.2.2 (continued)

A parametric analysis of the remaining candidate subsystem concepts was then conducted. The following data was generated as required for comparison purposes among the candidate subsystems:

a. Vehicle launch weight (including expendables, spares, recharge and/or regeneration equipment, and checkout equipment, in addition to the basic subsystem) versus total mission duration.

b. EVA equipment volume versus EVA mission duration.

c. Vehicle launch volume versus total mission duration.

d. EVA equipment weight versus EVA mission duration.

The remaining candidate subsystems were compared against the primary criteria (equivalent vehicle weight, EVA equipment volume, reliability, operability and flexibility). Further equipment was added or the arrangement modified, as required, to upgrade candidate subsystem concepts that were found to be unacceptable or inferior relative to the qualitative criteria. Of course, the associated weight, volume and power penalties were reflected in the parametric analyses. If a candidate concept could not be made acceptable, or was still obviously grossly inferior to the other candidates, it was removed from further consideration at this point.

If a clear cut choice could not be made from the primary criteria evaluation, the remaining candidate subsystem concepts were compared against the secondary criteria (equivalent vehicle volume, EVA requipment weight, interface compatibility, maintainability, and cost). As in the primary criteria evaluation, equipment modifications were made to candidate concept(s) to upgrade it relative to the qualitative criteria if it appeared inferior to other competing concepts. Again, the associated penalties were reflected in the parametric analyses.

Note that the primary and secondary evaluation criteria referenced above are the same criteria developed during the phase one of the AEPS study.

Based on the results of the primary and secondary evaluations, a selection of the best competing subsystems was made for the Shuttle AEPS. It is significant to note that several subsystems that perform the same function were recommended for further study on the system level.

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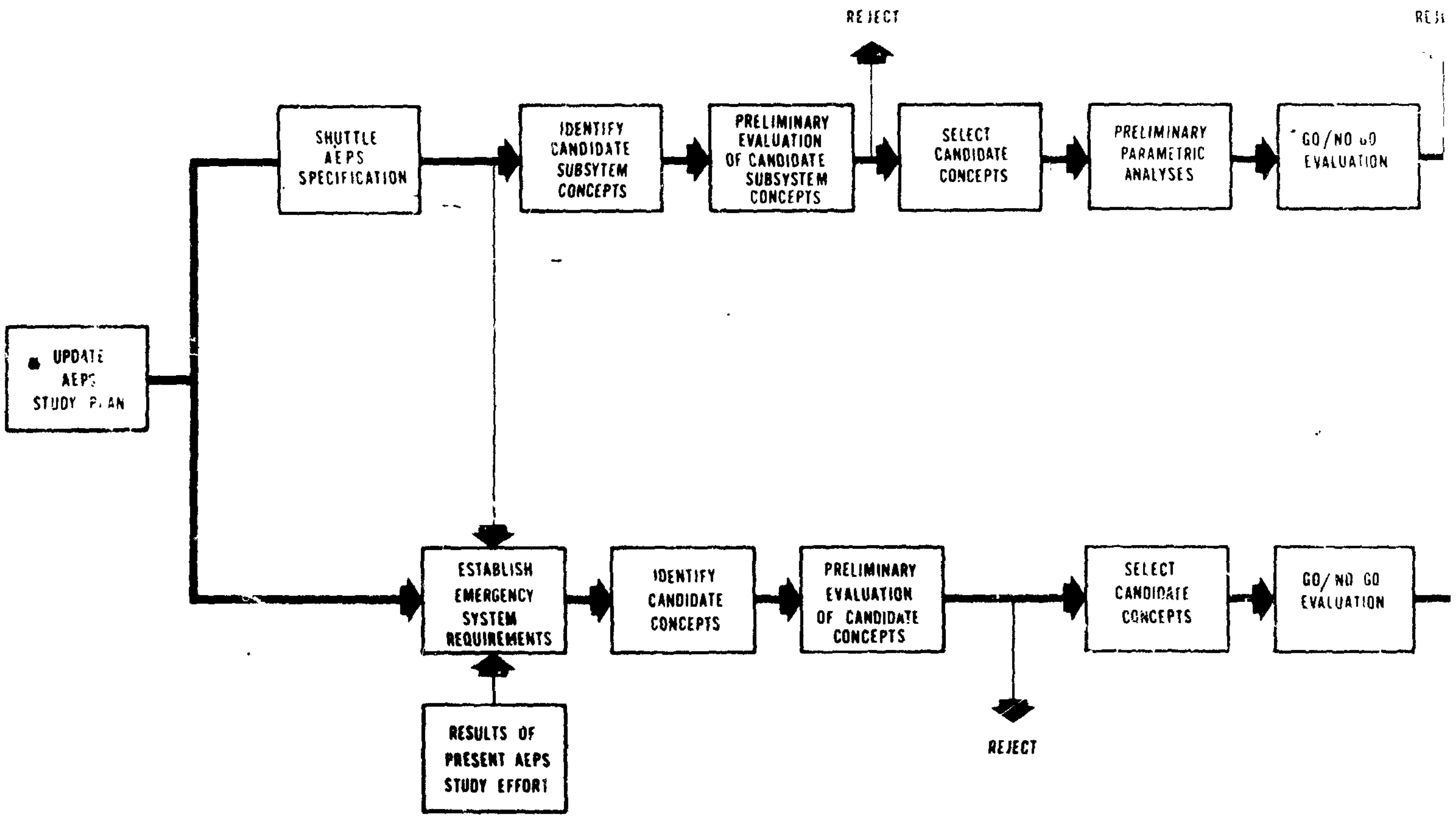

FIGURE 4–3. SUMMARY STUDY LOGI

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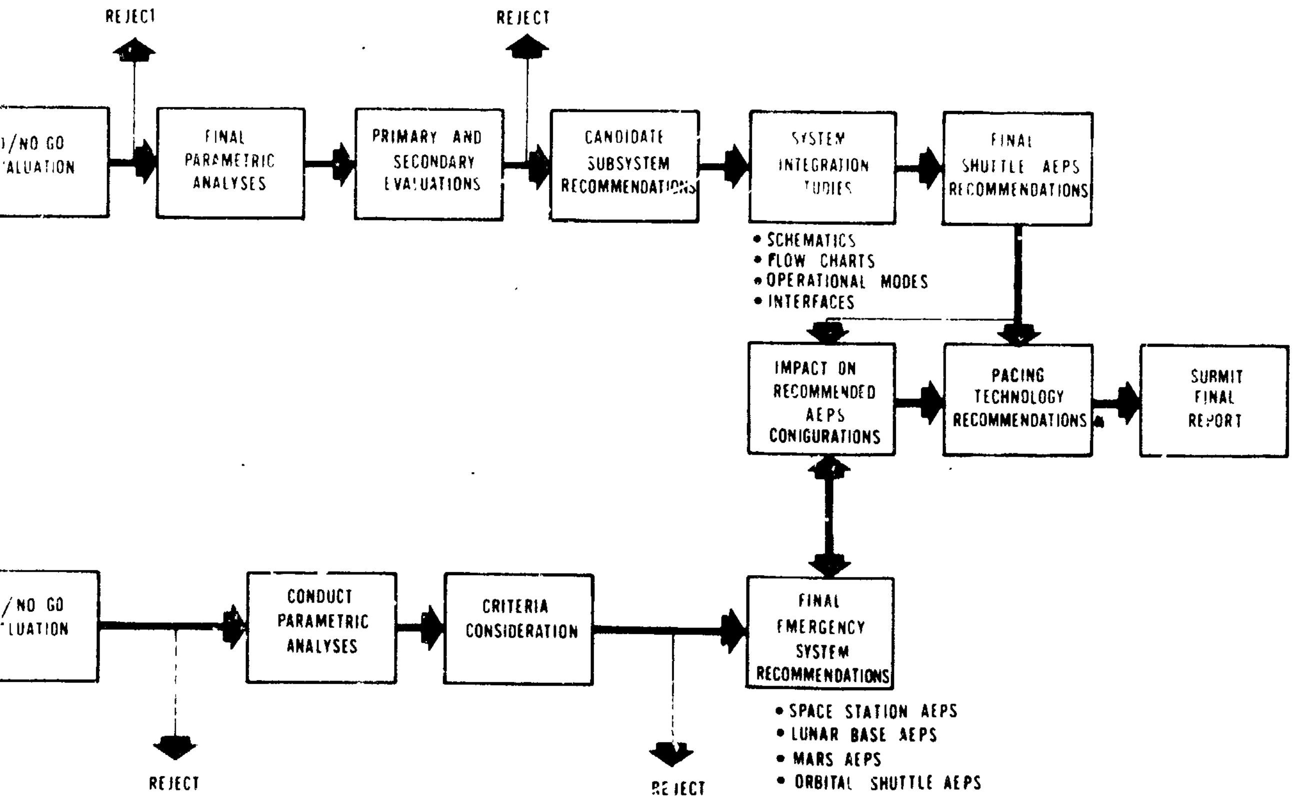

JDY LOGIC DIAGRAM

4.2.2.2 (Continued)

In summary, the subsystem studies continually attempted to upgrade all candidate concepts to an equivalent level of acceptance as measured by the qualitative criteria. Thus, final subsystem selections were made on a quantiative basis.

4.2.2.3 System Studies - After completion of the subsystem studies, a systems integration effort was conducted wherein the selected candidate subsystem concepts were combined into several preliminary baseline Shuttle AEPS systems. The systems integration effort evaluated and defined the following elements that could not be fully evaluated on the subsystem level:

a. AEPS operating pressure level

b. O_2 supply subsystem pressure level

c. Contaminant control

d. Humidity control

e. Equipment power requirements

f. Instrumentation

g. Controls and displays

h. Suit and vehicle interfaces

The candidate baseline systems were subjected to a comparative evaluation utilizing the primary and secondary evaluation criteria and the parametric results of the subsystem studies. Results of this evaluation led to the final baseline schematics.

The operational modes of each baseline concept were reviewed to simplify operational procedures. A safety/reliability evaluation of each baseline concept was conducted to eliminate all single point and sequential failures. The interface compatibility of each baseline concept was evaluated with respect to the crew, the vehicle and other EVA equipment.

The final Shuttle AEPS system recommendations resulted from this total effort.

4.2.3 AEPS Emergency Systems

The remainder of the AEPS study phase two effort consisted of an evaluation of separate emergency backup and/or redundant systems for the AEPS configurations selected for Space Station, Lunar Base, Mars, and the Shuttle missions. This effort included

4.2.3 (Continued)

(a) establishment of the AEPS Emergency System requirements; (b) definition of candidate AEPS Emergency Systems; and (c) determination of the effect of emergency capability on the original AEPS selections and recommendations.

4.2.3.1 Emergency System Requirements - Emergency system requirements were established separately for each of the following AEPS configurations:

Space Station AEPS
Lunar Base AEPS
Mars AEPS
Shuttle AEPS

As a basis for this effort, Hamilton Standard used the results of the phase one AEPS study effort, NASA's emergency philosophy for Apollo EVA missions and our operational EVA experience as a guide. Establishment of the emergency requirements took into consideration the issue of redundancy versus a separate independent back-up system.

4.2.3.2 Subsystem/System Studies - The methodology utilized in the subsystem/system studies resulting in AEPS emergency system recommendations is similar to that used for the Shuttle AEPS Systems. However, a re-evaluation of selection criteria was required at the onset of this effort due to the nature and manner of use of emergency systems (versus a primary life support system). The evaluation criteria are presented in Figure 4-4 and the weighting of the comparative criteria are presented in Table 4-3. The results of this total effort were emergency system recommendations for each of the AEPS configurations referenced in Section 4.2.3.1.

4.2.4 Pacing Technology

After establishment of the Shuttle AEPS and AEPS emergency system recommendations, the study effort was directed toward generation of a priority listing of required technology development activity to permit these recommendations to be implemented.

The principal objectives of this effort were:

a. To provide confirmation of attractive concepts where, although feasibility may have been demonstrated, development status and confidence is marginal.

b. To define problems and recommend approaches to solve these problems.

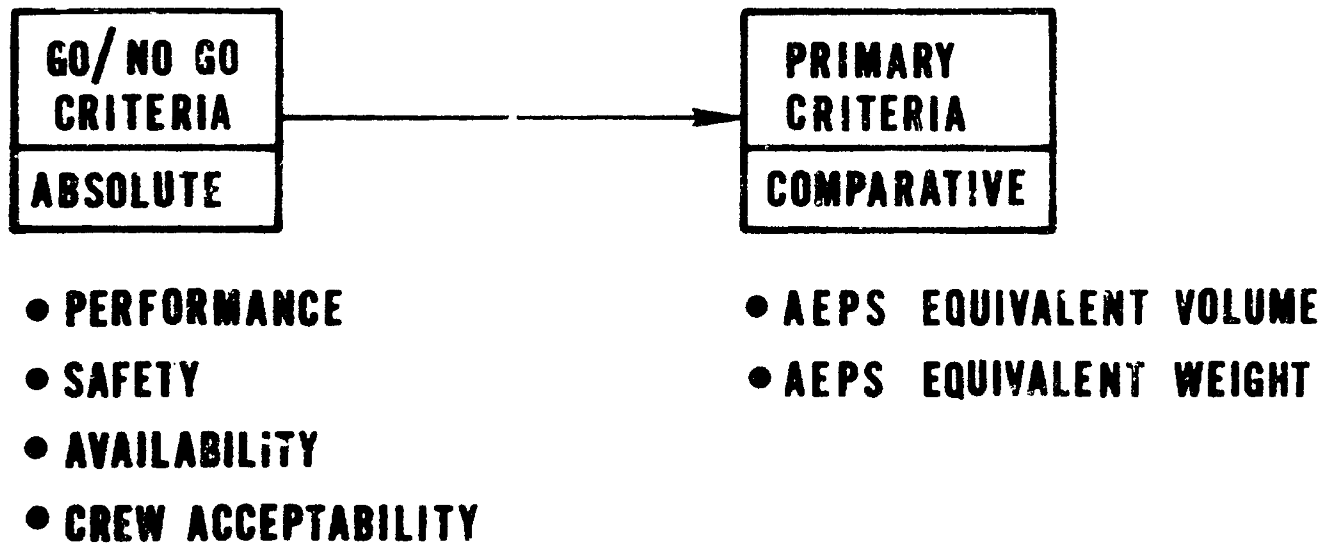

FIGURE 4–4. EMERGENCY SYSTEM EVALUATION CRITERIA

CRITERIA	WEIGHTING FACTORS			
	SHUTTLE	SPACE STATION	LUNAR BASE	MARS
AEPS EQUIVALENT VOLUME	0.70	0.70	0.65	0.60
AEPS EQUIVALENT WEIGHT	0.30	0.30	0.35	0.40

TABLE 4–3. PRIMARY CRITERIA WEIGHTING FACTORS

5.0 SUBSYSTEM STUDIES SUMMARY

5.0 SUBSYSTEM STUDIES SUMMARY

5.1 Phase One Effort

5.1.1 General

To ensure that the results of this study were both meaningful and useful for future related efforts, Hamilton Standard adopted a broad-based approach to candidate subsystem concept identification. The whole gamut of concept approaches was investigated with a specific effort on our part to preclude any pre-judgement of concept value prior to concept identification. Specific emphasis was placed in the areas of thermal control and CO_2 control/O_2 supply, as they represented the areas where the greatest benefits could be derived through reduction of vehicle penalties and AEPS volume and weight.

Initial effort resulted in the identification of 55 candidate thermal control concepts (Table 5-1), 21 candidate CO_2 control concepts (Table 5-2), 14 candidate O_2 supply concepts (Table 5-3), and 3 candidate O_2 generation concepts (Table 5-4). All of these concepts were evaluated on a cursory basis and those that were deemed to be "obviously noncompetitive" were eliminated. Of these original candidate concepts identified and analyzed on a preliminary basis, 25 thermal control concepts and 19 combined CO_2 control/O_2 supply concepts were carried into the go/no go evaluation. These candidate concepts were subjected to the go/no go, primary and secondary evaluations in consecutive order and in accordance with the procedure described in Section 4.1. As a result of these evaluations, the three general thermal control categories selected for further evaluation during the system studies are:

a. Expendable concepts utilizing water
b. Radiation
c. Thermal storage

One general CO_2 control/O_2 supply category was selected for further evaluation during the system studies - a solid regenerable sorbent combined with a high pressure gaseous oxygen supply system. Two families of solid regenerable sorbents were identified as candidate materials:

a. Metallic oxides
b. Solid amines

This section describes each of the subsystems recommended to be carried into the systems studies and presents comparative parametric data.

5.1.2 Subsystem Descriptions

5.1.2.1 Thermal Control - The thermal control subsystem concepts recommended to be carried into the systems integration phase of the AEPS study are:

FOLDOUT FRAME 1

TABLE 5-1
THERMAL CONTROL CON

I. EXPENDABLES

Water
1. Water Boiler
2. Super-Cooled Water Boiler
3. Super-Cooled Water Boiler with Vapor Regenerative Cooling
4. Water Sublimator
5. Super-Cooled Water Sublimator
6. Super-Cooled Water Sublimator with Vapor Regenerative Cooling
7. Plate Fin Flash Evaporator
8. Nonsteady State Pulse Feed Flash Evaporator
9. Static Vortex Flash Evaporator
10. Turbine-Rotary Vortex Flash Evaporator
11. Motor-Rotary Vortex Flash Evaporator
12. Multi-Stage Flash Evaporator
13. Vapor Diffusion Through Suit Pressure Valves
14. Vapor Diffusion Through Water Permeable Membrane

Hydrogen Peroxide (H_2O_2)
15. H_2O_2 Dissociation into H_2O & O_2

Ammonia (NH_3)
16. NH_3 Boiler
17. NH_3 Sublimator

Carbon Dioxide (CO_2)
18. CO_2 Boiler
19. CO_2 Sublimator

Methane (CH_4)
20. CH_4 Sublimator

Cryogenics
21. Cryogenic O_2
22. Cryogenic H_2

Feces/Urine Sludge
23. Evaporation of H_2O From Feces/Urine Sludge

II. CONDUCTION

24. Conduction Via the Lunar or Martian Surface

III. CONVECTION (MARS ONLY)

25. Free Convection
26. Forced Convection
27. Hilsch Tube

FOLDOUT FRAME 2

TABLE 5-1
AL CONTROL CONCEPTS

IV. RADIATION

Direct Cooling

28. LCG
29. Heat Pipe
30. Water Adsorption Utilizing ---
    31. $LiCl \cdot 3H_2O$
    32. $CaCl \cdot 6H_2O$
    33. Molecular Sieve
    34. Silica Gel
    35. $LiBr \cdot 3H_2O$
    36. $Na_2S_e \cdot 16H_2O$

Indirect Cooling

37. Vapor Compression Refrigeration Cycle Using Freon
38. Water Adsorption Cycle Using NH_3
39. Water Adsorption Cycle Using LiBr
40. Brayton Cycle Using Air

V. THERMAL STORAGE

41. Ice
42. Subcooled Ice
43. Thermal Wax - Transit 86
44. Eutectic Salt - Sodium Sulphate ($Na_2SO_4 \cdot 10H_2O$)
45. Phosphonium Chloride (PH_4Cl)
46. Hydrogen (H_2)
47. Lunar or Martian Rock

VI. ENERGY CONVERSION

48. Thermoelectric
49. Thermionic
50. Thermodielectric

VII. HYBRIDS

51. Expendable/Radiation - Direct Cooling
52. Expendable/Radiation - Indirect Cooling
53. Expendable/Thermal Storage
54. Radiation/Thermal Storage
55. Thermal Storage/Water Adsorption

TABLE 5-2

CO_2 CONTROL CONCEPTS

I. EXPENDABLES

Solid Sorbents

1. Hydroxides
2. Superoxides
3. Peroxides
4. Ozonides

Liquid Sorbent

5. Hydroxide Solutions

Open Loop

6. Purge Flow

II. REGENERABLES

Solid Sorbents

7. Activated Charcoal
8. Molecular Sieve
9. Metallic Oxides
10. Solid Amines

Liquid Sorbents

11. Carbonate Solutions
12. Liquid Amines

III. ELECTROCHEMICAL

13. Hydrogen Depolarized Cell
14. Two-Stage Carbonation Cell
15. One-Stage Carbonation Cell
16. Electrodialysis
17. Fused Salt

IV. MECHANICAL

18. Simple Membrane Diffusion
19. Immobilized Liquid Membrane Diffusion
20. Mechanical Freezeout
21. Cryogenic Freezeout

TABLE 5-3
OXYGEN SUPPLY CONCEPTS

I. O_2 STORAGE

1. Gaseous
2. Supercritical Utilizing Thermal Pressurization
3. Subcritical Utilizing Thermal Pressurization
4. Subcritical Utilizing Positive Expulsion
5. Solid

II. SOLID DECOMPOSITION

6. Superoxides
7. Peroxides
8. Ozonides
9. Sodium Chlorate Candles ($NaClO_3$)
10. Lithium Perchlorate Candles ($LiClO_4$)

III. LIQUID DECOMPOSITION

11. Hydrogen Peroxide (H_2O_2)
12. Reactant Storage (N_2H_4/N_2O_4)
13. Reactant Storage (N_2H_4/H_2O_2)

IV ELECTROLYSIS

14. Water Electrolysis

TABLE 5-4
OXYGEN GENERATION CONCEPTS

1. Solid Electrolyte
2. Bosch Reactor/Water Electrolysis
3. Sabatier Reactor/Water Electrolysis

5.1.2.1 (continued)

a. Water Boiler (Figure 5-1) - The water boiler was selected as representative of expendable concepts utilizing the heat of vaporization or heat of sublimation of water to provide thermal control. The water boiler utilizes the heat of vaporization of water to provide direct cooling of the Liquid Cooling Garment (LCG) loop and vent loop. The wick-fed boiler also acts as the storage vessel for the expendable water. The expendable water boiling temperature is controlled by a back pressure valve, which is either a temperature sensing or pressure sensing flow control valve. Crewman comfort is achieved automatically by the temperature control valve which controls LCG loop flow through the water boiler. Water vapor in the vent loop is condensed in the water boiler and removed by the water separator. This separated water is then fed into the water boiler as expendable water, thus providing additional cooling capacity. A relief valve furnishes protection against overpressurization due to storage temperature fluctuations. Recharge is simply accomplished in the vehicle/base utilizing the water fill valve.

Although the water boiler is the lightest and most compact of the recommended thermal control subsystems, its vehicle weight and volume penalties are two to three times that of any of the other recommended thermal control subsystems.

b. Thermal Storage - Phosphonium Chloride (PH_4Cl) - Thermal storage utilizing PH_4Cl is a self-regenerable thermal control concept and is schematically depicted in Figure 5-2. PH_4Cl has the following known properties:

   a. Heat of Fusion - 324 BTU/Lb at 82°F
   b. Specific Gravity - 1.7 to 2.0
   c. Triple Point of 48 atmospheres at 82°F - See Figure 5-3.
   d. Readily decomposes below 20 atmospheres at room temperature to phosphine (PH_3) gas and hydrogen chloride (HCl) gas. Since PH_3 is highly toxic, the thermal storage unit has been concepted to minimize the probability of any failure resulting in external leakage.

PH_4Cl melts at 82°F. Since it is desirable to reject heat from the oxygen ventilation loop and the liquid heat transport loop at approximately 50°F, a heat pump loop is required. The heat pump loop is a vapor compression cycle using Freon as the coolant. Heat from the oxygen ventilation loop and the liquid transport loop is added to the Freon loop at the heat exchanger. The compressor pumps the evaporated Freon up to the saturation pressure equivalent to 82°F.

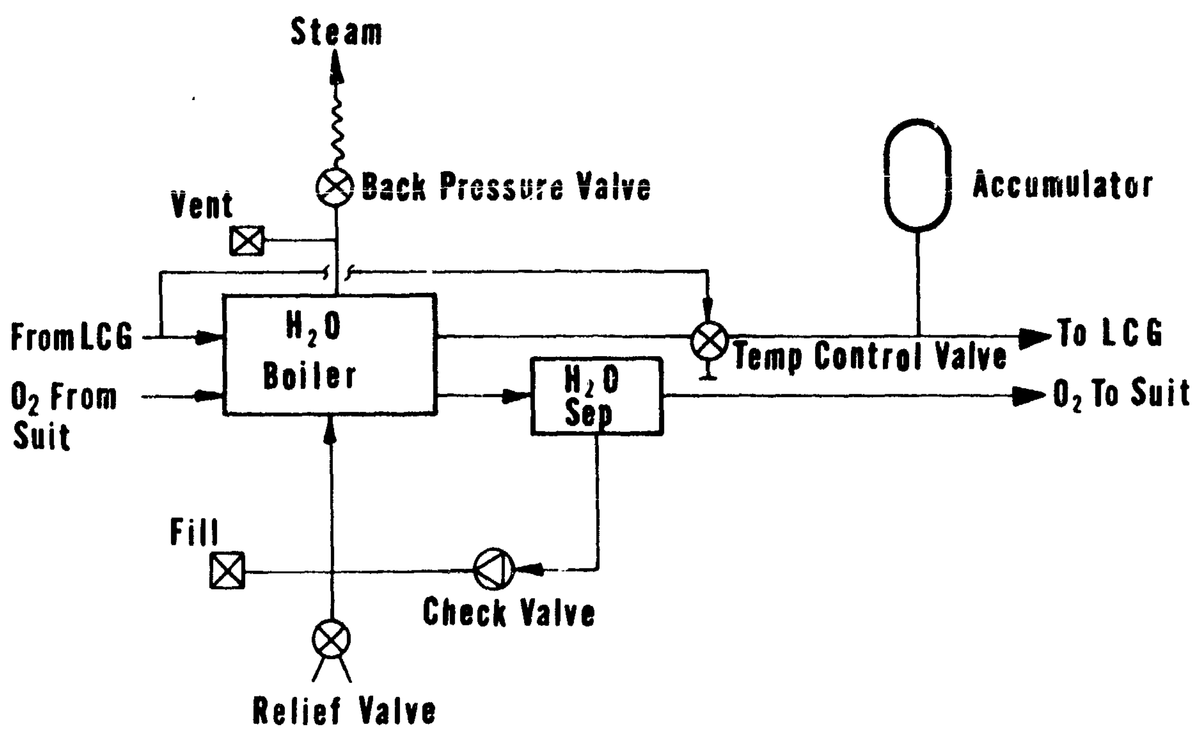

FIGURE 5-1. WATER BOILER

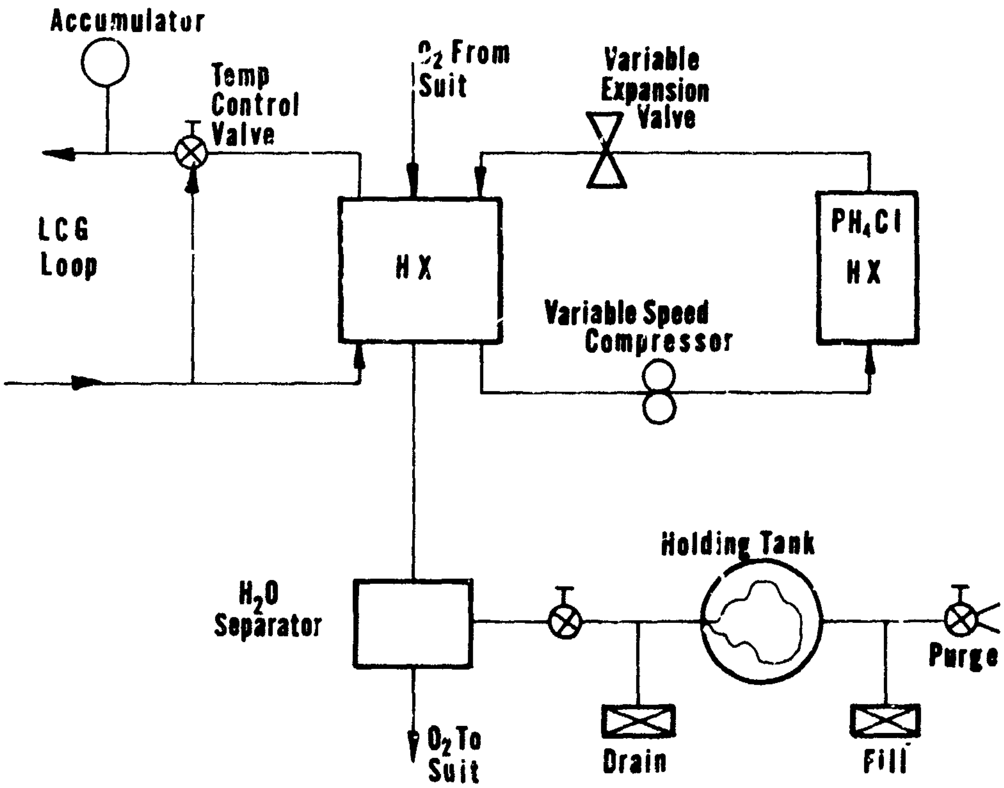

FIGURE 5–2. THERMAL STORAGE–PH_4Cl

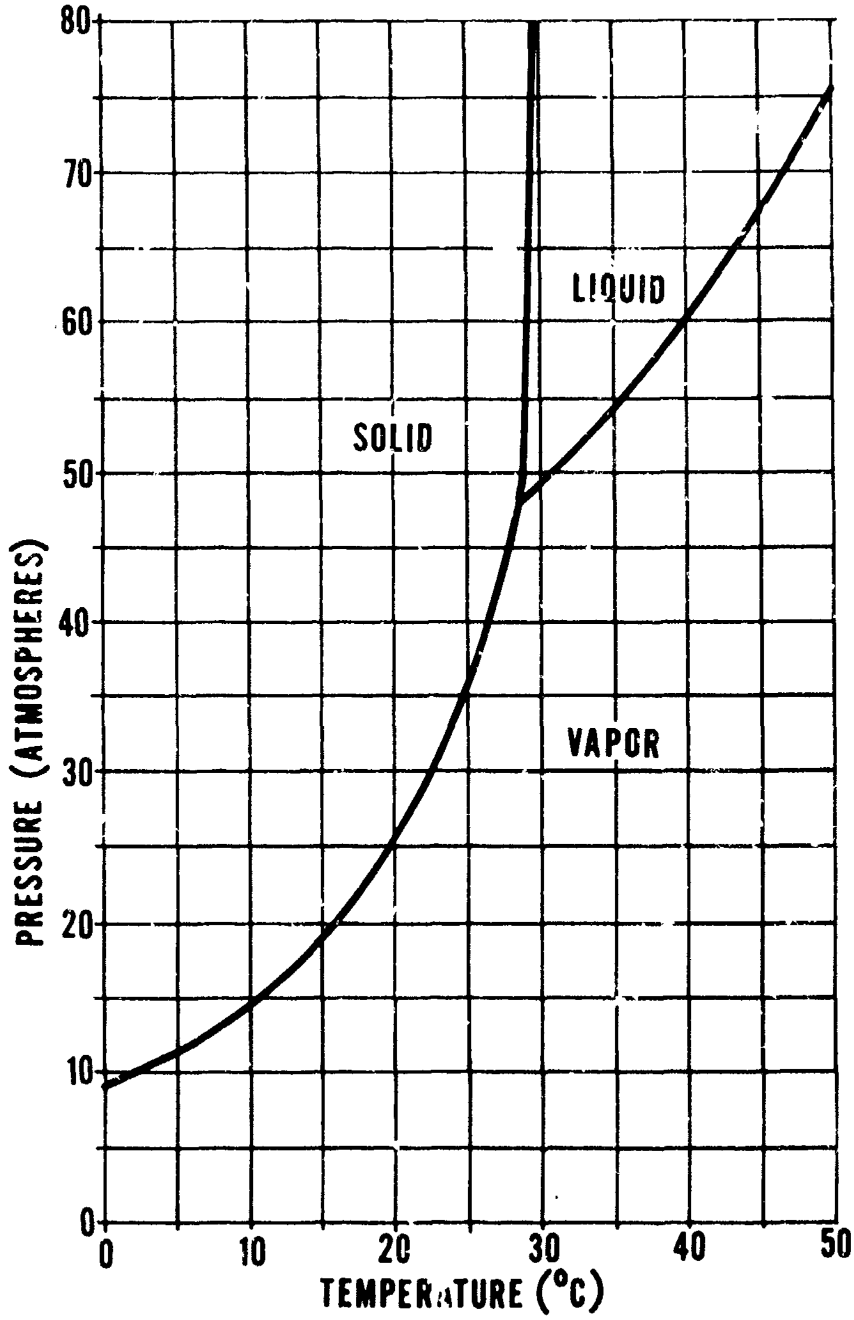

FIGURE 5-3. VAPOR PRESSURES OF PHOSPHONIUM CHLORIDE (PH_4Cl)

5.1.2.1 (continued)

b. A 150°F superheat temperature is actually achieved downstream of the compressor due to compressor efficiency, which for the purposes of this study has been assumed to be constant and equal to 36 percent. A variable speed compressor is utilized to conserve battery power at low load conditions and Freon flow is controlled electronically by feedback from the pressure sensor at the Freon heat exchanger outlet. The Freon is cooled and condensed across the PH_4Cl thermal storage unit by melting of the PH_4Cl. The Freon is then expanded across the variable orifice back to the Freon heat exchanger inlet conditions. The variable orifice back pressures flow as a function of Freon heat exchanger outlet pressure and is electronically controlled by the pressure sensor located at the Freon heat exchanger outlet. The Freon cycle is completed as the Freon passes through the heat exchanger to be re-evaporated.

For the purposes of the AEPS study, two candidate PH_4Cl thermal storage configurations were concepted. A "tube bundle" configuration is shown in Figure 5-4. The brazed tube bundle assembly consists of a fixed head, a floating head, a tube bundle brazed to both heads, and three headers welded to each head to form a closed pressure vessel. A fill port is provided on one of the headers to permit initial PH_4Cl charging. The exterior of the unit consists of a curved rectangular shell with stiffening ribs (not shown), inlet and outlet Freon ports, and a bolt flange and end cap. The fixed head of the tube bundle is clamped to the shell at the bolt flange.

Freon gas enters the thermal storage unit at the inlet and then passes over the tube bundle giving up the AEPS heat load by the heat of condensation and transferring it to the PH_4Cl which in turn melts. Volumetric changes in PH_4Cl are accommodated by the floating feature of the tube bundle which eliminates any damaging stresses due to expansion and contraction.

If leakage of PH_4Cl should occur, it will only leak into the Freon loop. This would create a change in the Freon design point which would be quickly noticed due to a change in performance of the AEPS thermal control subsystem. Corrective action would then be taken immediately.

This configuration has a high packaging efficiency because of its dense tube bundle arrangement and could be utilized for structural integration into the AEPS forming a monocoque construction.

The second concept is pictured in Figure 5-5 and is essentially three (3) "thermos" bottles connected in parallel with helical tubes containing Freon running through the center. The internal pressure vessel contains the PH_4Cl. Not shown, but probably required, are internal fins to maintain uniform heat

5.1.2.1 (continued)

transfer within the melt. A vacuum is maintained between the internal and external vessel. A pressure gage monitors vacuum pressure and would, therefore, sense any leak of PH_4Cl. Expansion clearance at the two end cap mounting bosses permits expansion and contraction of the internal vessel.

Hamilton Standard conducted an extensive literature and industry survey in an attempt to find materials with a heat of fusion greater than that of water and with a melting point between 50 to 150°F. PH_4Cl was the only candidate material identified. After reviewing the pertinent literature and the properties of PH_4Cl specifically, it was concluded that there might be a family of high pressure/high heat of fusion materials. According to the Clapeyron Relation, Johnston's Empirical Rule (JACS, Volume 34, Page 788, 1912), and Othmer's Method (Ind. and Eng. Chem., Volume 32, Page 841, 1940), the heat of fusion of a material is a function of:

a. $\frac{\partial p}{\partial t}$ of the solid/liquid line on the triple point curve

b. ∂v (change in specific volume from solid to liquid)

c. Melting Point Temperature

Utilizing these relationships as a base, synthesis of materials with a high heat of fusion and a melting point within a given temperature range is a distinct possibility. Applied research and development toward this goal is required.

c. Expendable/Thermal Storage - PH_4Cl (Figure 5-6) - This hybrid concept is a combination of the water boiler and the PH_4Cl thermal storage concepts. Hybrid concepts are utilized in an attempt to get the best of two worlds -- the low AEPS volume and weight associated with the expendable water boiler concept and the minimum vehicle penalty associated with the PH_4Cl thermal storage concept. The water boiler is connected in parallel with the thermal storage unit via a temperature control valve. The temperature control valve selects what percentage of the heat load from the liquid heat transport loop is shared by each subsystem, the intention being that the PH_4Cl thermal storage unit can handle the average AEPS heat load and the water boiler handle peak loads. By doing this, compressor power and expendable water are minimized.

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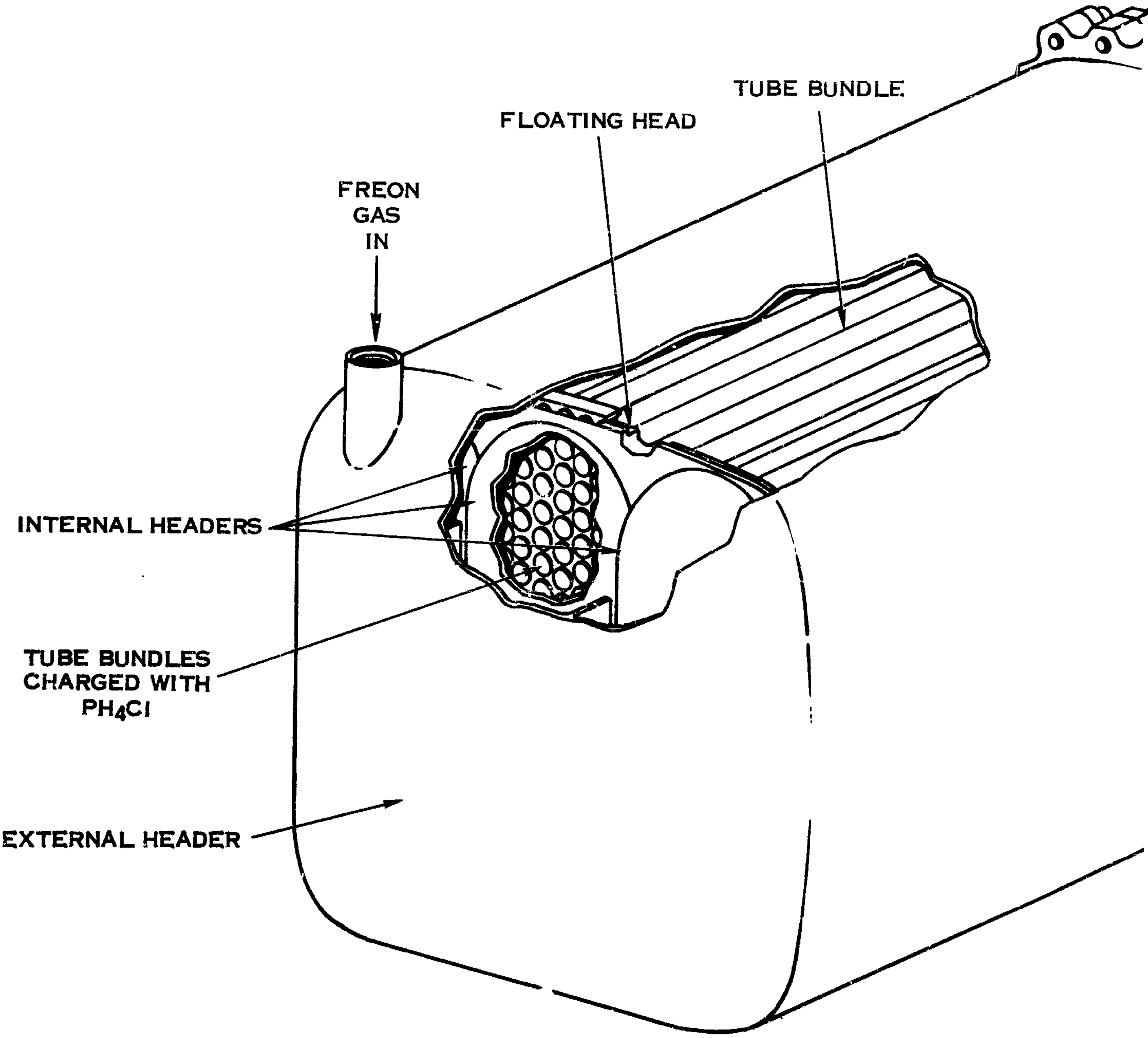

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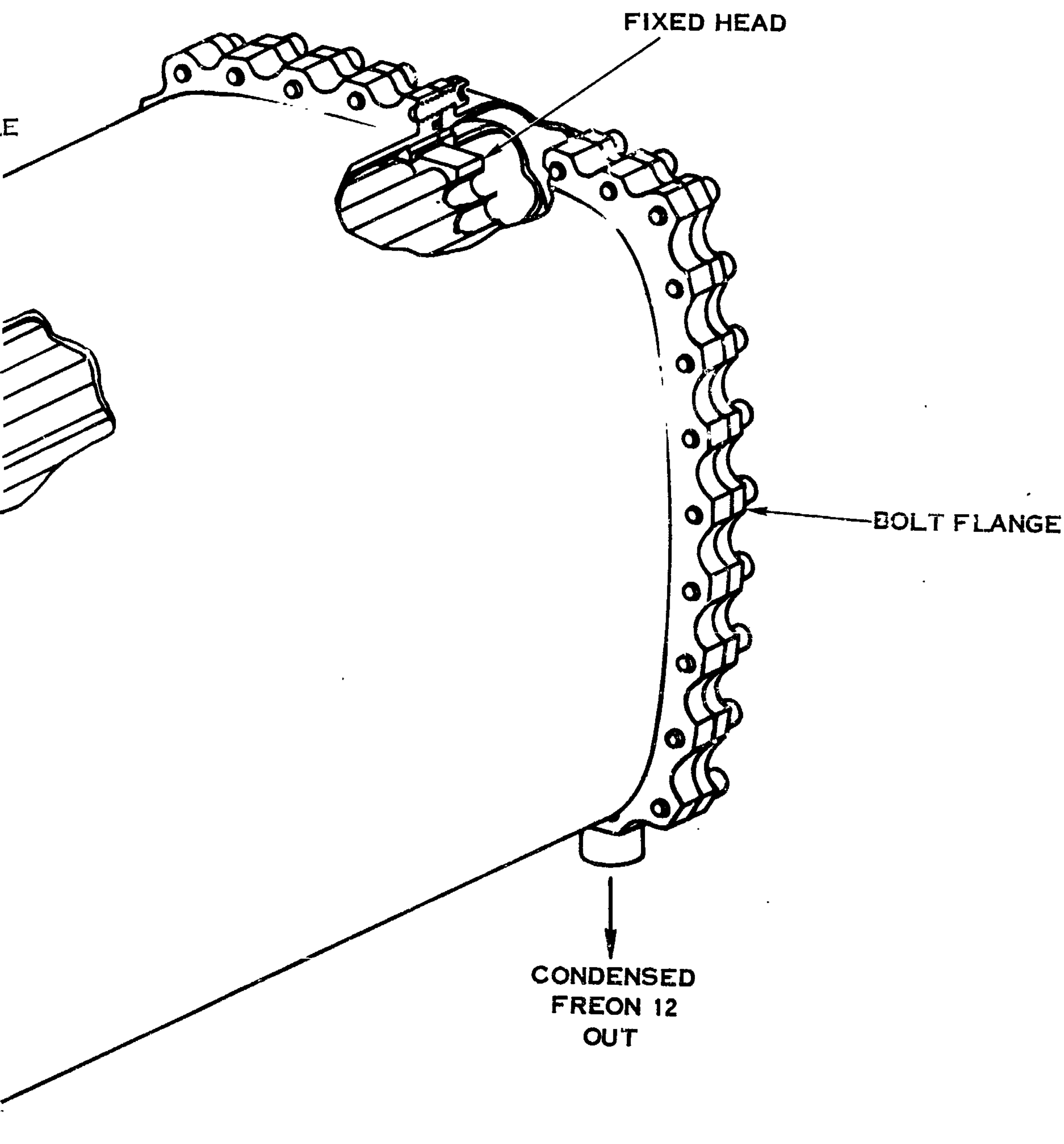


FIGURE 5–4. PH_4Cl THERMAL STORAGE UNIT–TUBE BUNDLE CONFIGURATION

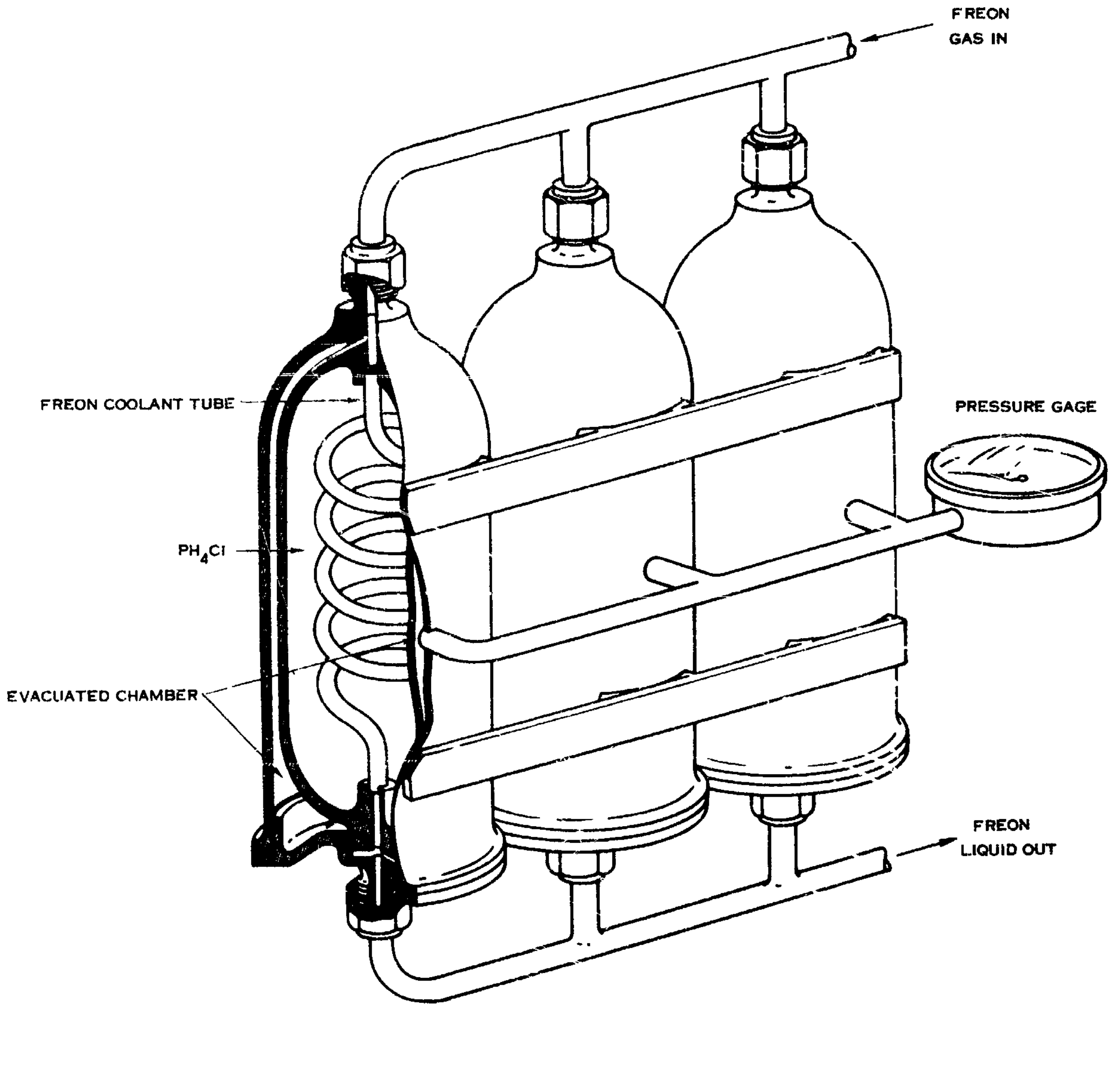


FIGURE 5-5. PH_4Cl THERMAL STORAGE UNIT—
PRESSURE VESSEL CONFIGURATION

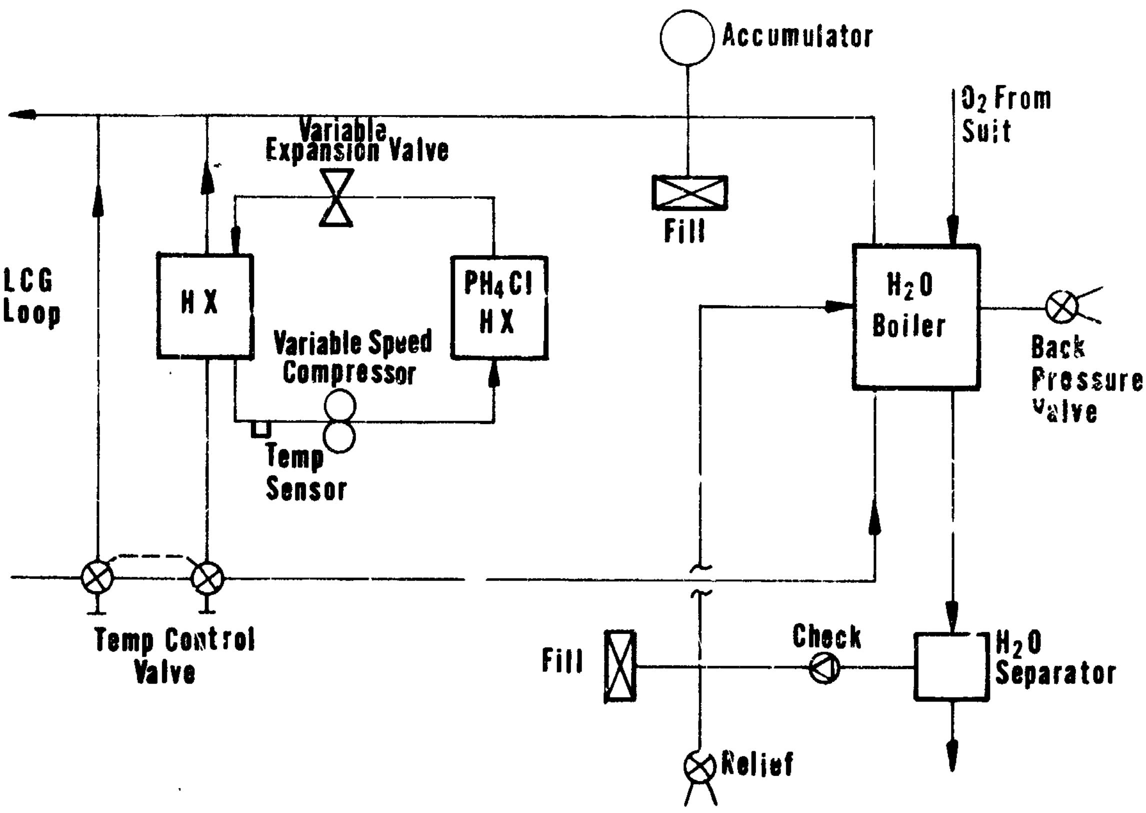


FIGURE 5-6. EXPENDABLE/THERMAL STORAGE—PH_4Cl

5.1.2.1 (continued)

The water boiler provides humidity control by cooling the oxygen vent loop and condensing the entrained moisture. The condensate is then separated from the oxygen vent loop by the water separator and fed back into the water boiler to provide additional cooling capacity. This system is flexible in that it can be sized for a multitude of thermal load sharing combinations.

d. Expendable/Direct Radiative Cooling (Figure 5-7) - This hybrid concept consists of a water boiler and a low temperature radiator connected in parallel through the temperature control valve. The liquid heat transport loop is directly cooled in the radiator. The temperature control valve selects the percentage of the AEPS heat load shared by each subsystem. The radiator is a rate limited thermal control device and is sized to handle the total AEPS thermal load for a "dark side" mission, thus radiator size and water expended in the boiler are minimized. The water boiler handles all excess thermal loads.

Humidity control is provided by a condensing heat exchanger and a water separator which feeds the separated water to the water boiler to provide additional cooling capacity. For low load conditions, a variable area device is utilized to prevent overcooling of the liquid heat transport loop. Since this concept is a low temperature radiation concept, it is more applicable to a Mars application than a Lunar Base application because of the smaller solar constant of Mars -- 192 versus 442 BTU/Hr-Ft^2. Due to the radiator size and configuration, a deployable concept may be required to permit the crewman to egress and ingress from his vehicle or base. To prevent surface degradation of the radiator due to dust, meteorites, and/or operational wear, planned maintenance may be required. This concept is not competitive for Space Station.

e. Expendable/Radiator (Figure 5-8) - This hybrid concept consists of a water boiler and a high temperature radiator connected in parallel through the temperature control valve. The liquid heat transport loop is cooled indirectly by an intermediate vapor compression loop utilizing Freon as a working fluid. The radiator is sized to handle the total AEPS load for a "dark side" mission and the water boiler handles all excess thermal loads. Radiator area is minimized by rejecting heat at 180°F at the expense of compressor power.

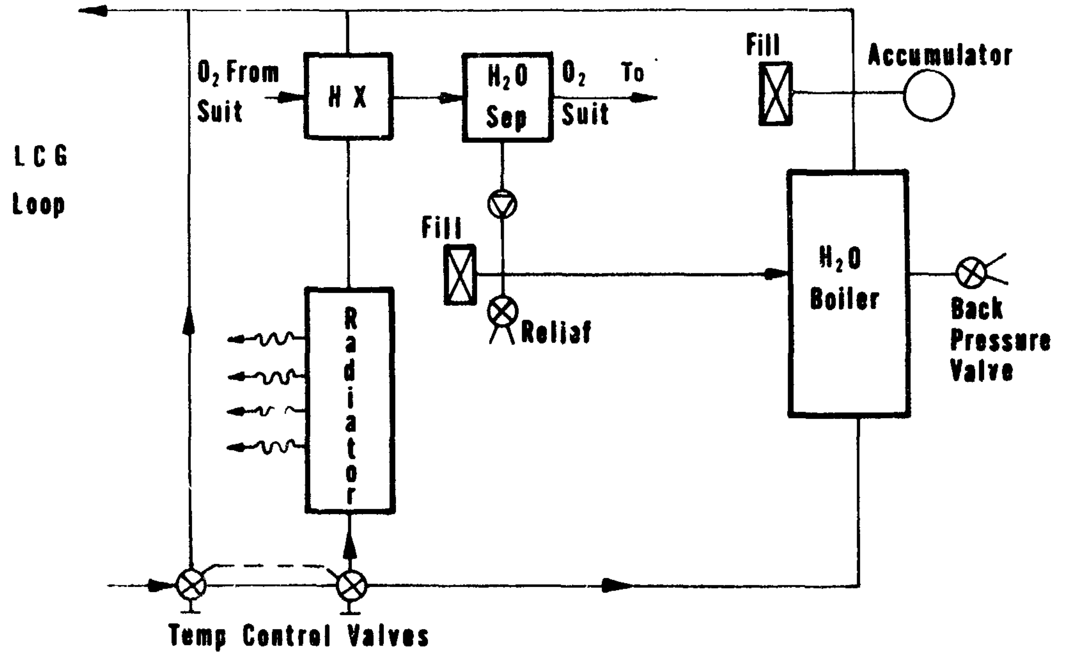


FIGURE 5–7. EXPENDABLE–DIRECT RADIATIVE COOLING

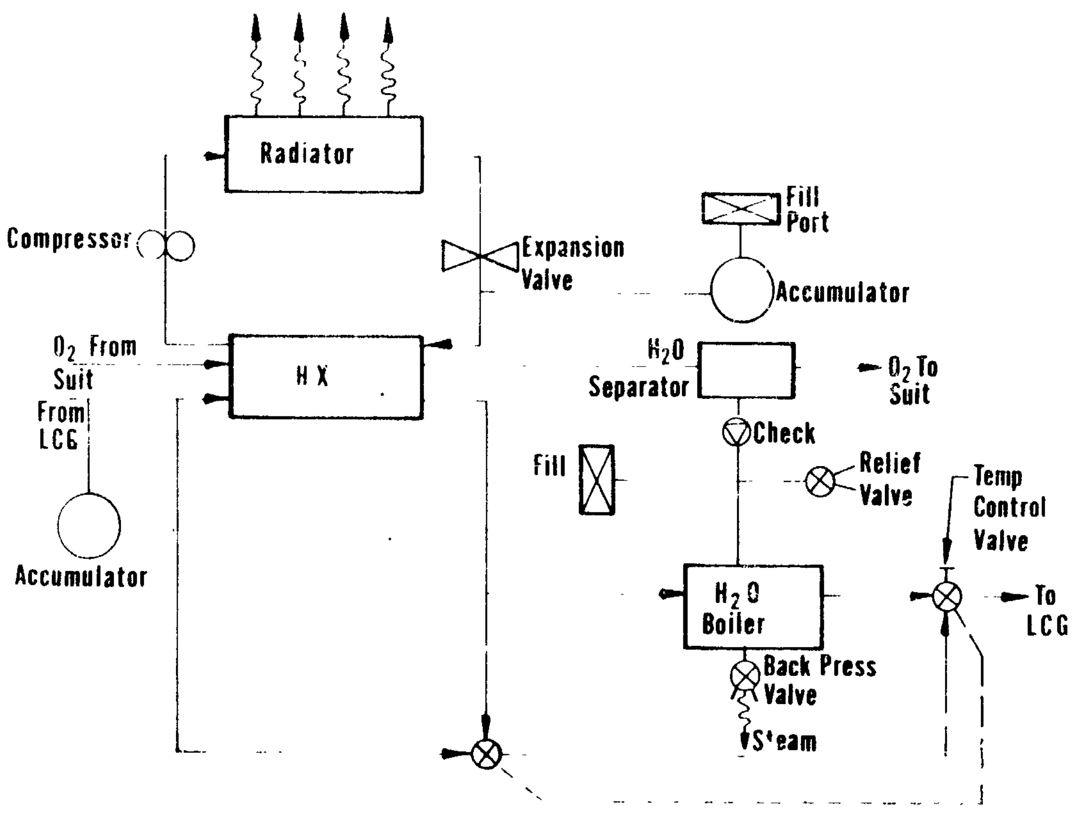


FIGURE 5-8. EXPENDABLE/RADIATION

5.1.2.1 (continued)

Since it is desired to operate the radiator at an outlet temperature of 180°F to minimize radiator area, the vapor compression loop is required to pump the Freon up to the saturation pressure equivalent to 180°F from a Freon evaporator temperature of 50°F. Heat is added to the evaporator by the heat of vaporization of Freon. The compressor then pumps the Freon up to a saturation pressure equivalent of 180°F and a super heat temperature of 350°F. This temperature results from an assumed compressor efficiency of 36%. A variable speed compressor is utilized to conserve battery power at low load conditions and is controlled electronically by feedback from the pressure sensor at the Freon evaporator outlet. The Freon is cooled and condensed across the radiator by radiation to space. The Freon is then expanded across the variable orifice back to the Freon evaporator inlet conditions. The variable orifice back pressures flow as a function of Freon heat exchanger outlet pressure and is electronically controlled by the pressure sensor located at the Freon evaporator outlet. The cycle is completed as the Freon passes through the heat exchanger to be re-evaporated.

Because of its higher radiation temperature and small radiator size, this concept is applicable to Space Station as well as Lunar Base and Mars. However, a deployable radiator configuration may still be required to permit the crewman to egress and ingress from his vehicle or base. Similar to the Expendable/Direct Radiative Cooling concept, planned maintenance may be required to prevent radiator surface degradation due to dust, meteorites and/or operational wear.

In summary, the expendable water boiler concept does not meet the intent of the AEPS study -- to develop regenerable or partially regenerable subsystems to minimize vehicle impact. However, the remaining four concepts discussed in this section are all viable candidate concepts for utilization in an AEPS-type system. To achieve the performance projected in this report, state-of-the-art advancements are required to develop thermal storage materials whose heat of fusion exceeds 300 BTU/Lb and melts between 50 and 150°F. In addition, design/development improvements are required to obtain a lightweight, deployable radiator configuration with optimized surface coatings/treatments to enable it to meet the AEPS requirements.

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

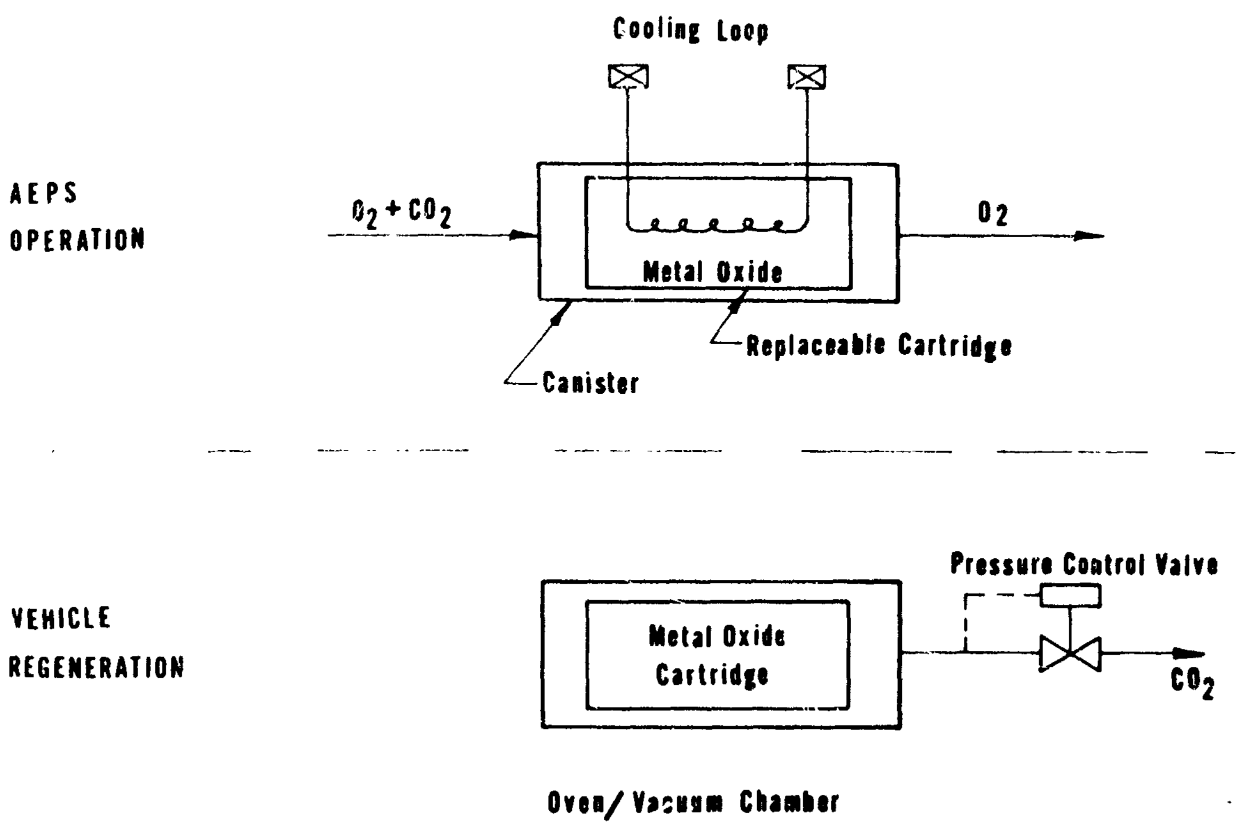


FIGURE 5–9. METALLIC OXIDE–VEHICLE REGENERABLE

5.1.2.2 (continued)

a. Zinc Oxide - Vehicle Regenerable (Figure 5-9) - Metallic oxides such as zinc oxide (ZnO) react with CO_2 according to the following reversible reactions:

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

b. $MO + H_2O \rightleftharpoons M(OH)_2$

c. $M(OH)_2 + CO_2 \rightleftharpoons MCO_3 + H_2O$

Although the adsorption of equation (a) is known to occur, sorbent capacities and rates of reaction are significantly improved in the presence of water vapor thus leading to the possibility of the combined reactions described in equations (b) and (c).

The equilibrium pressure curves shown in Figure 5-10 indicate that the carbonate readily decomposes with increasing temperature and, in some cases, may be solely vacuum regenerable. The reported data in the literature for pure compounds indicate that an activation energy of 300 to 400°F super heat may be required to promote rapid desorption. However, initial work with silver oxide indicates that catalysts are effective in reducing this requirement.

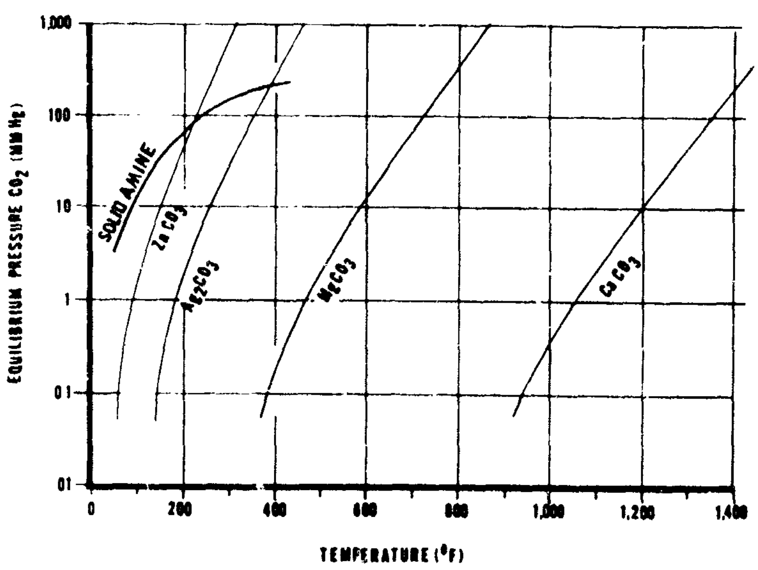


FIGURE 5-10. EQUILIBRIUM PRESSURES — REGENERABLE CO2 SORBENTS

5.1.2.2 (continued)

a. Excessive volume change during the adsorb/desorb cycle affects the chemical's physical stability and is a prime consideration in any future design and development effort. For the purposes of the AEPS study, two candidate vehicle regenerable ZnO canister/cartridge configurations were concepted. One concept shown in figure 5-11 is a "screen pack" configuration and it consists of a rectangular canister into which are inserted four metal oxide screen packs containing the ZnO. The canister has inlet and outlet water headers, an inlet oxygen header, an outlet oxygen header, parallel flow water coolant coils supported by perforated sheets, and ZnO screen pack supports brazed in place. In addition, an access cover for the ZnO screen packs is clamped and hinged to the open side of the canister and is sealed with a "face" seal. The oxygen inlet header is mounted on the access cover. Preload rubber padding holds the screen packs firmly in place.

The screen packs are constructed of a sandwich construction consisting of fine mesh screen, felt padding to prevent dusting, and a channel enclosure to hold the assembly together. A handle is provided to facilitate insertion and removal. Fairly large changes in bed volume can be accommodated with this approach.

The gas flow is both through and around the screen packs. For flow around the screen packs, CO_2 is removed by diffusion into the ZnO bed; for flow through the screen packs, CO_2 is removed by direct contact with the ZnO bed. In this vehicle regenerable configuration, the ZnO is packaged in a screen pack which is replaced and regenerated after each EVA mission. An oven/vacuum chamber is provided within the vehicle/base for regeneration. An advantage of the vehicle regenerable configuration is that it provides the option for either venting the desorbed CO_2 to the ambient environment or collecting the desorbed CO_2 and feeding it into the vehicle/base Environmental Control/Life Support System (EC/LSS) for CO_2 reduction and O_2 reclamation.

Other advantages of this concept include visual inspection of the packed bed before and after each use and simple replacement should it be required; and a long available regeneration period which minimizes the requirement for a desorption catalyst(s) which may be required for the cyclic AEPS regenerable concept.

Although cooling coils are included in this configuration, the requirement may be minimal because of low heat generation rates. Following are typical heat generation rates. Lithium hydroxide (LiOH) has been included for purposes of comparison.

5.1.2.2 (continued)

a. $ZnO + CO_2 \longrightarrow ZnCO_3 + 696$ BTU/Lb of CO_2

$MgO + CO_2 \longrightarrow MgCO_3 + 1153$ BTU/Lb of CO_2

$2\,LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O\,(g) + 827$ BTU/Lb of CO_2

The increased temperatures that would result by not cooling may actually raise the sorbent capacity by promoting chemisorption. However, the final determination of the interacting effects of bed temperature and water vapor upon sorbent capacity must be determined by test.

Another vehicle regenerable ZnO concept shown in figure 5-12 utilizes a radial flow canister. The canister is a cylindrical assembly consisting of a shell, a bolt flange for mounting the cartridge end cap, and a manifold of water and oxygen inlets and outlets. Flow enters the cartridge through the center perforated tube and flows radially outward through the perforated tube, a particulate filter, the ZnO bed, another particulate filter, a mesh screen and out the canister outlet. The particulate filters provide an even flow distribution as well as preventing dusting. CO_2 is removed in the ZnO bed. Coolant tubes are brazed to the cartridge coolant manifold and bed cooling is provided by a combination of conduction through the bed and gas convection.

Vehicle regeneration of this concept is achieved by exposing the gas passages of the canister to vacuum and flowing superheated steam through the coolant tubes as shown in figure 5-13. This is accomplished without removing the canister or the cartridge from the AEPS by first isolating the gas passages of the canister by closing the isolation valves and exposing these gas passages to vacuum; then a vehicle steam source is connected to the coolant line and steam is circulated throughout the canister. Steam does not flow through the remainder of the liquid heat transport loop because the positive displacement water pump in the liquid heat transport loop dead heads this loop when it is not operating.

For purposes of the AEPS study, both vehicle regenerable metallic oxide concepts were sized based upon a bed loading of 50% of the theoretical capacity.

b. Zinc Oxide - AEPS Regenerable (Figure 5-14) - A variation of the vehicle regenerable metallic oxide concept considers a cyclic or AEPS regenerable configuration. Two beds, similar in design to that described for the vehicle regenerable system, are provided, each containing electrical elements for regeneration and a cooling

FOLDOUT FRAME \

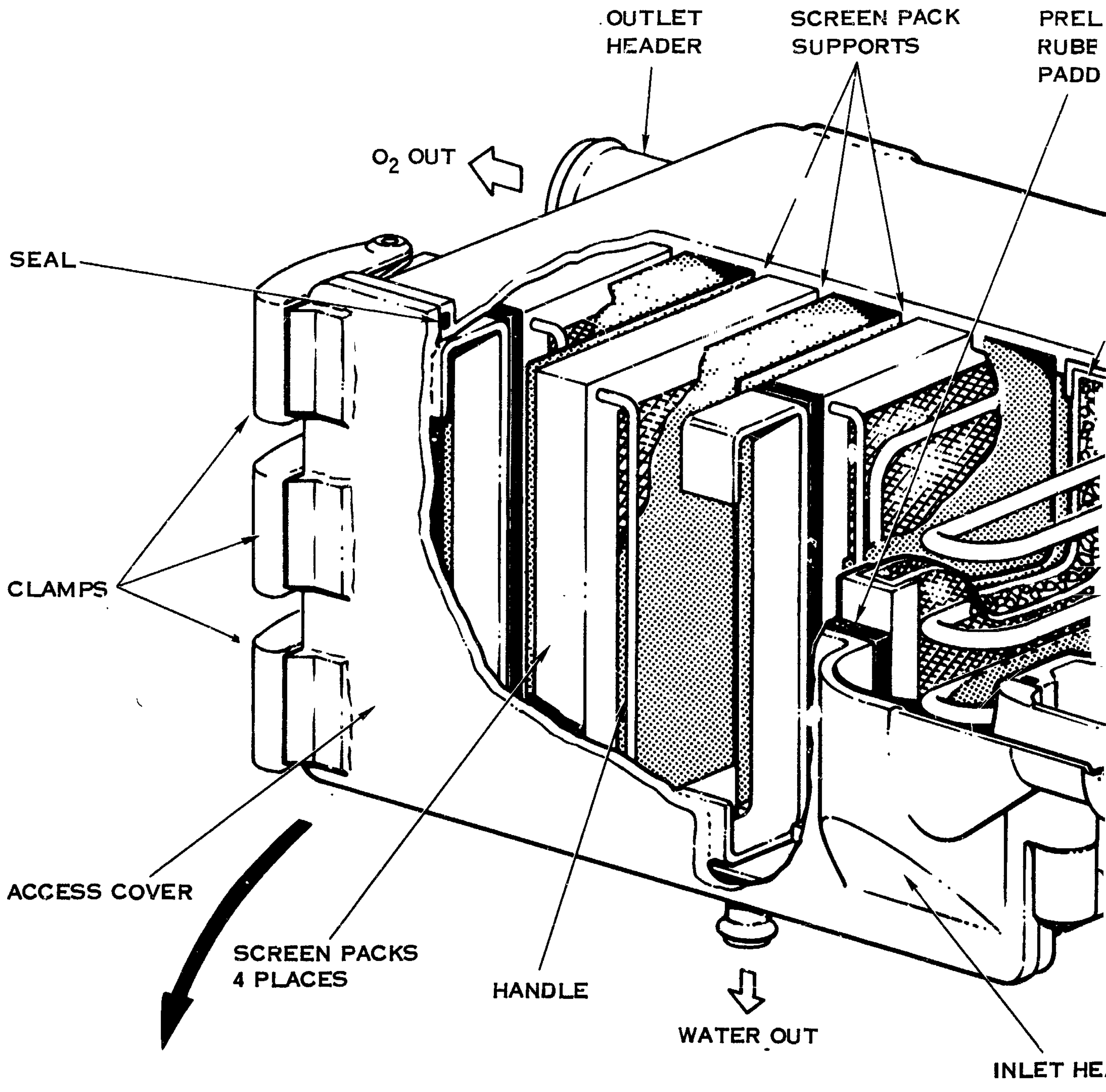


FIGURE 5-11.

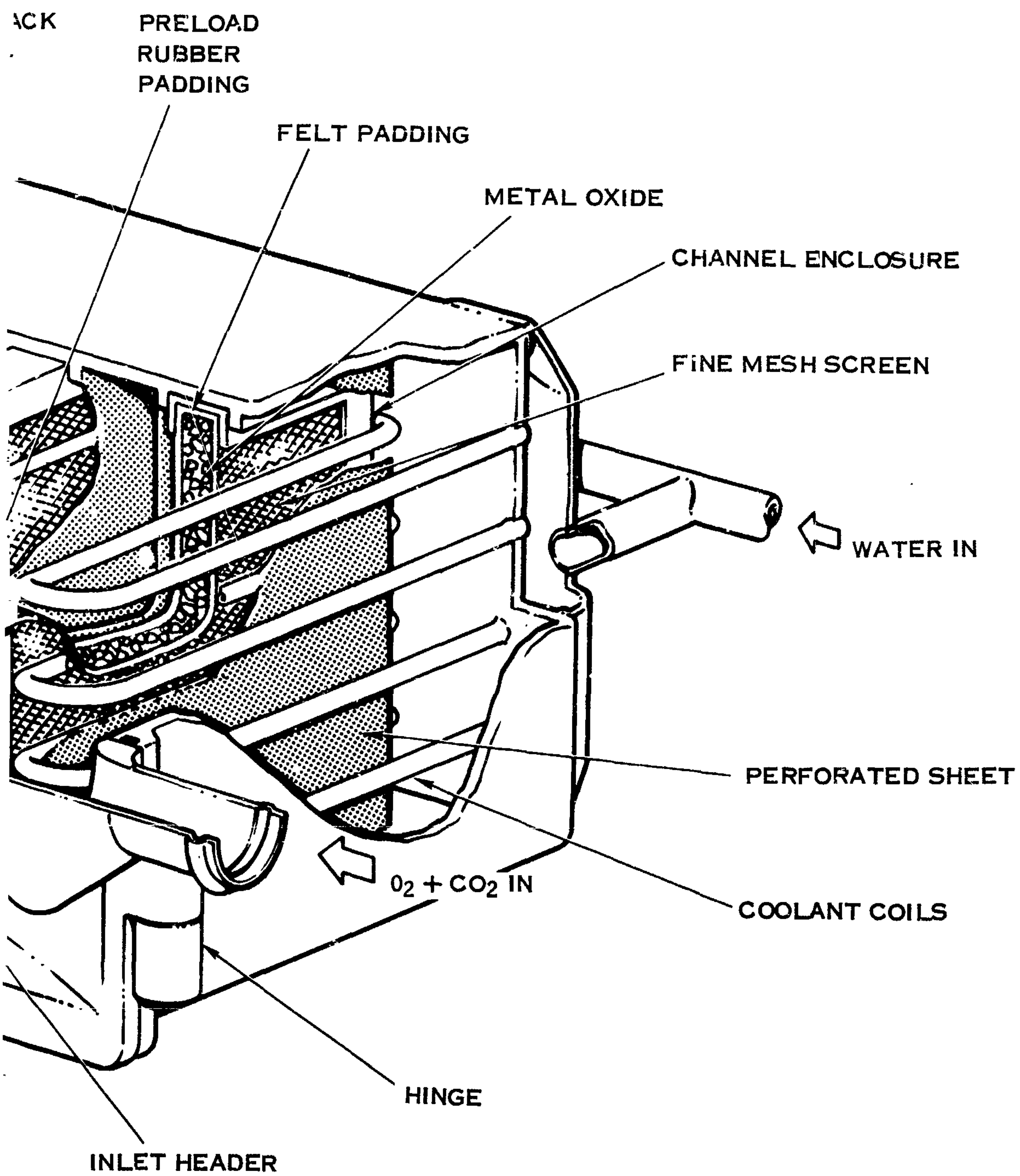


FIGURE 5–11. VEHICLE REGENERABLE METALLIC OXIDE–SCREEN PACK CONFIGURATION

FOLDOUT FRAME 1

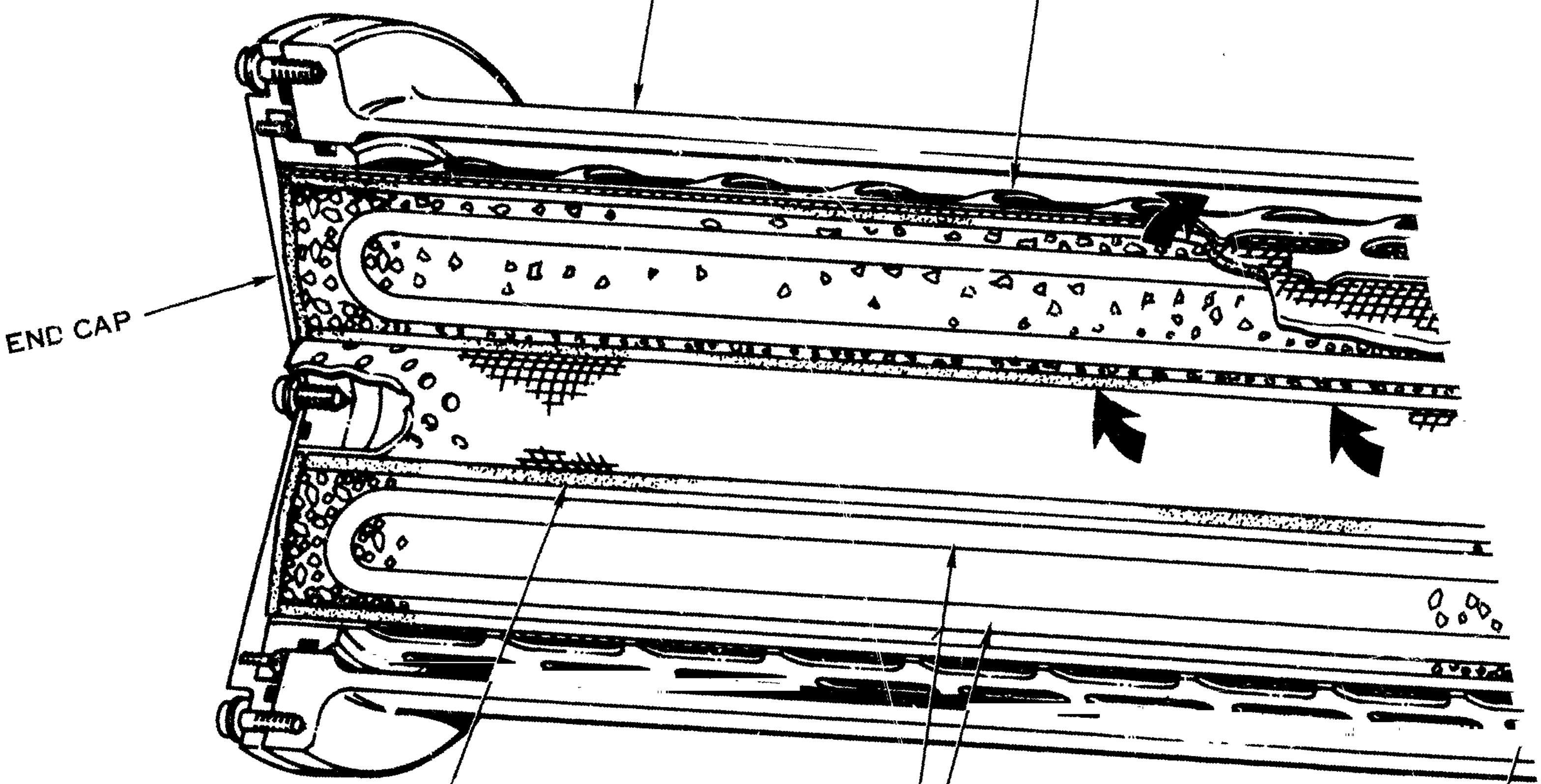


FIGURE 5-12. VE

FOLDOUT FRAME 2

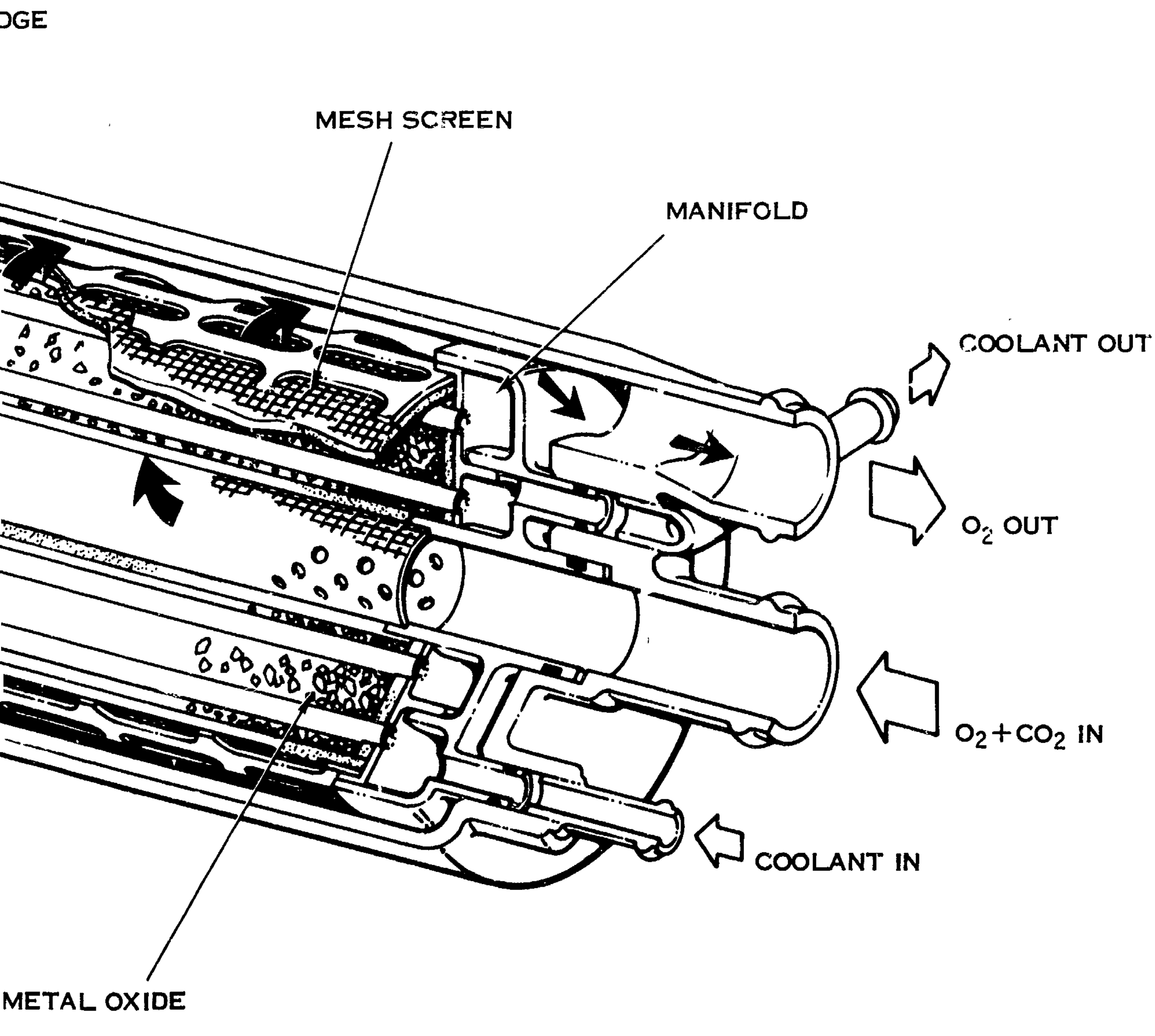


FIGURE 5–12. VEHICLE REGENERABLE METALLIC OXIDE–RADIAL FLOW BED CONFIGURATION

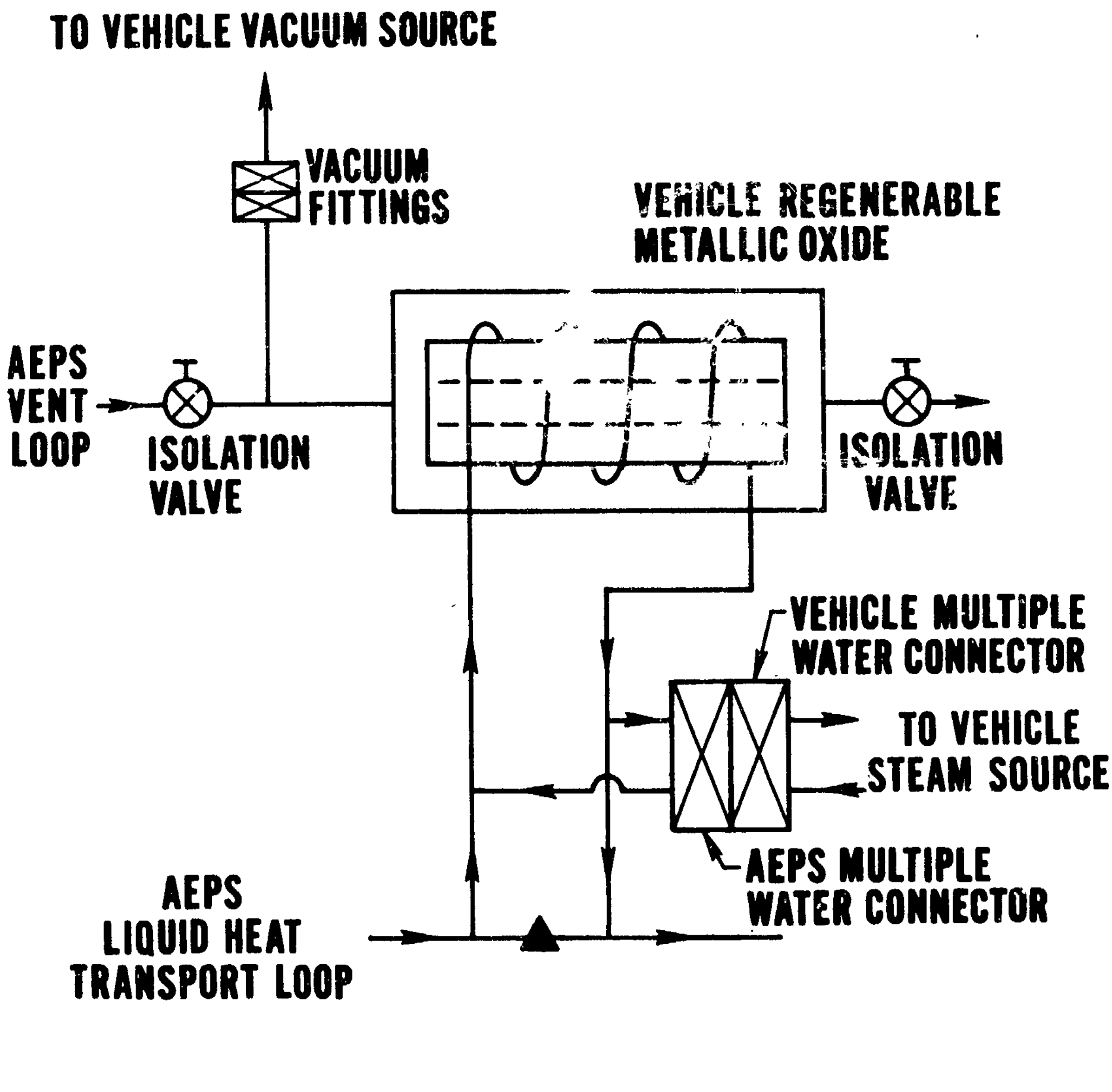


FIGURE 5–13. RADIAL FLOW VEHICLE REGENERABLE METALLIC OXIDE RECHARGE CONCEPT

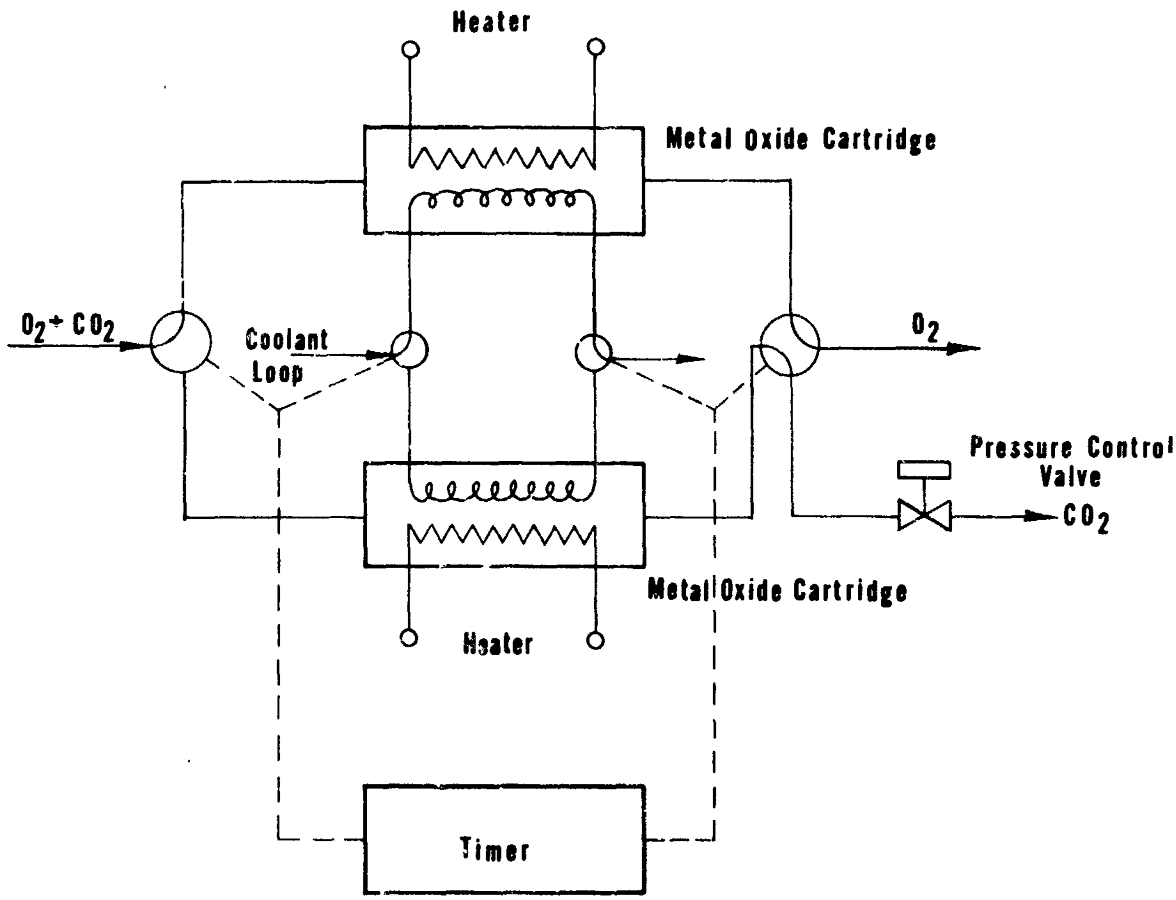


FIGURE 5–14. METALLIC OXIDE–AEPS REGENERABLE

5.1.2.2 (continued)

b. loop to cool the regenerated bed and maintain temperature control during EVA operation. A timer is provided to sequence the vent loop and coolant loop valves to allow the vent loop and coolant loop to flow to the on stream bed and to heat and expose the regenerating bed to space vacuum. This concept operates on a thirty (30) minute half-cycle.

Since the desorbed CO_2 is vented to ambient, this AEPS regenerable concept requires no functional interface with the vehicle/base EC/LSS for regeneration. However, it also does not allow for collection and reduction of the desorbed CO_2 for eventual O_2 reclamation.

For purposes of the AEPS study, each of the AEPS regenerable ZnO beds are sized based upon a bed loading of 25% of the theoretical capacity.

c. Solid Amine - AEPS Regenerable (Figure 5-15) - A thin coating of an amino compound is deposited on an inert carrier to form the stable adsorbent bed used in this concept. Three (3) sets of reactions occur in the adsorbed film:

- Primary Amino Groups

(1) $RNH_2 + H_2O \longrightarrow RNH_3OH$

(2) $RNH_3OH + CO_2 \rightleftharpoons RNH_3 \cdot HCO_3$

- Secondary Amino Groups

(3) $R_2NH + H_2O \rightleftharpoons R_2NH_2OH$

(4) $R_2NH_2OH + CO_2 \rightleftharpoons R_2NH_2 \cdot HCO_3$

- Tertiary Amino Groups

(5) $R_3N + H_2O \rightleftharpoons R_3NHOH$

(6) $R_3NHOH + CO_2 \rightleftharpoons R_3NH \cdot HCO_3$

Experimental effort has shown that equation (1) is not reversed during regeneration and equation (6) does not proceed to any substantial degree.

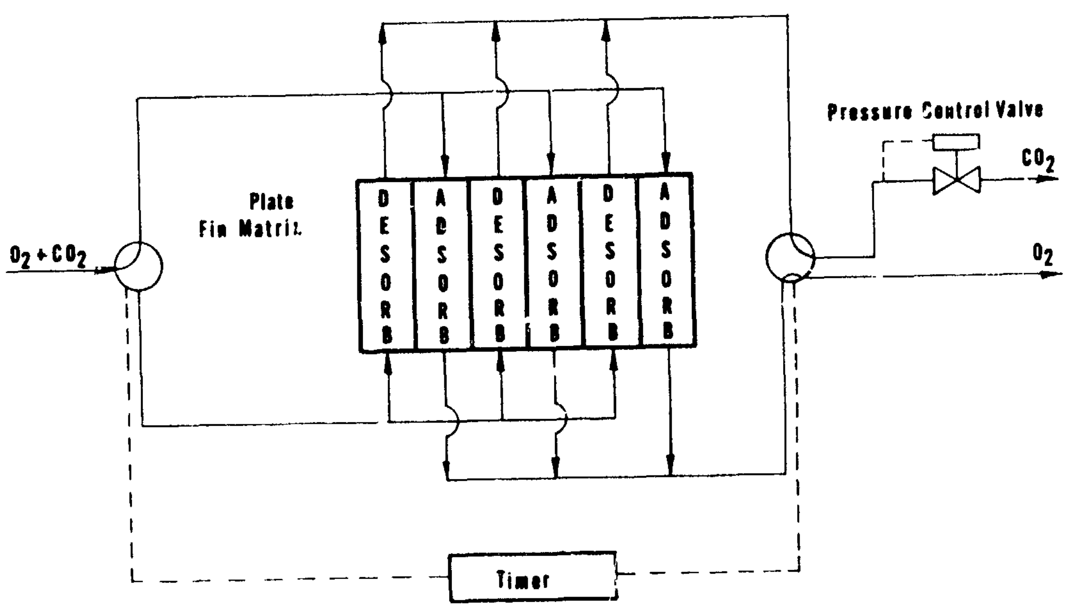


FIGURE 5-15. SOLID AMINE-AEPS REGENERABLE

5.1.2.2 (continued)

c. The current available solid amine CO_2 sorbents possess an affinity for water vapor which is compatible with vehicle or base EC/LSS requirements of one (1) pound of water per pound of CO_2 produced. This level of removal would excessively dehumidify the AEPS ventilation loop since the water generation rate (from exhalation and perspiration) of a suited crewman utilizing a Liquid Cooling Garment (LCG) is approximately one-half (1/2) pound of water per pound of CO_2 produced. Excessive dehumidification could not only cause crewman discomfort, it will also reduce the sorbent's capacity for CO_2 removal.

This problem has been recognized and solutions have been proposed on the Regenerable CO_2 and Humidity Control System Program being conducted by Hamilton Standard for the NASA Manned Spacecraft Center wherein the proper balance and quantity of each of the three (3) amino groups can be determined to obtain the desired ratio of CO_2 and water vapor adsorption as well as total bed capacity.

For the purposes of the AEPS study, two candidate AEPS regenerable solid amine canisters were concepted. One concept in which the solid amine is packaged within the flow passages of a plate-fin matrix (similar in design to an extended surface compact heat exchanger) is pictured in figure 5-16. The brazed plate-fin matrix consists of four alternating flow passages (two adsorbing and two desorbing) separated by closure channels and parting sheets. Heat is transferred from the adsorbing passages to the desorbing passages via sheared rectangular fins which are configured to prevent gas flow channeling. Each header is equipped with a mesh screen and preload padding to facilitate bed charging and to provide a positive preload on the bed.

Utilization of alternate flow passages containing adsorbing and desorbing material results in an isothermal adsorb/desorb process. Energy released from the adsorbing passages is transferred by conduction through the metal matrix to the desorbing material to supply the requirements of the endothermic desorption. This concept neither imposes a thermal load on the AEPS thermal control subsystem nor requires additional energy for regeneration. In addition, it also provides humidity control.

The second concept is the same as the plate-fin matrix concept except the sheared fins are replaced with pins (bent wire) and is pictured in figure 5-17. This pin-fin arrangement improves prevention of gas flow channeling but may be more difficult to charge.

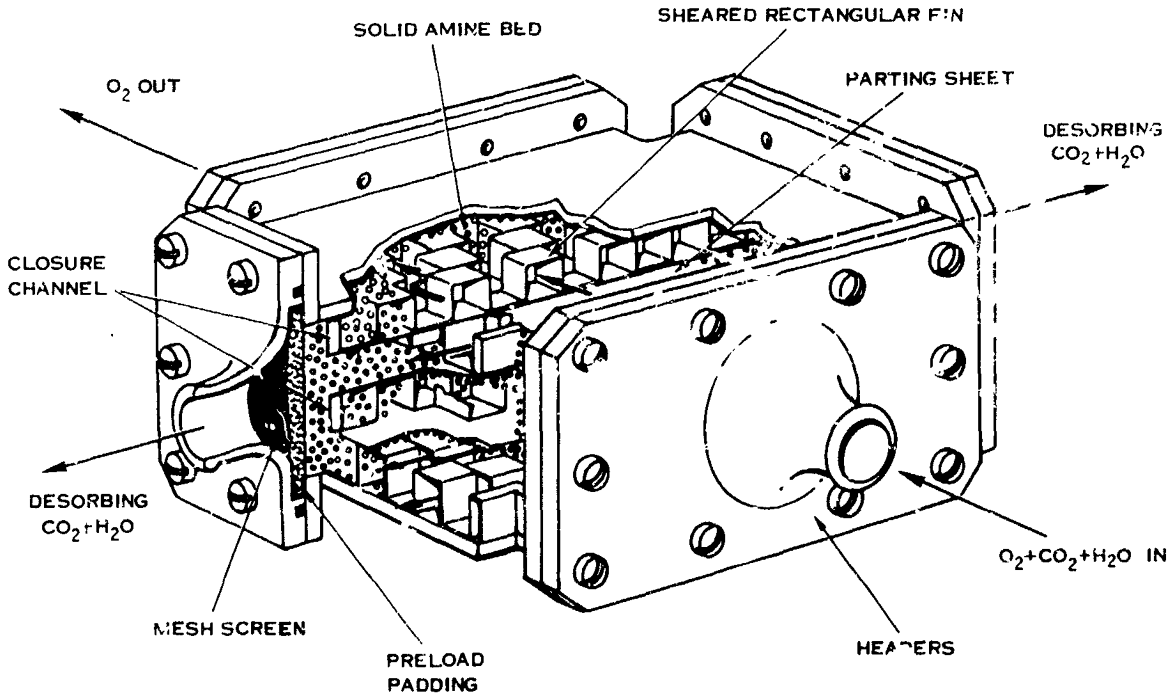


FIGURE 5-16. AEPS REGENERABLE SOLID AMINE-PLATE FIN MATRIX

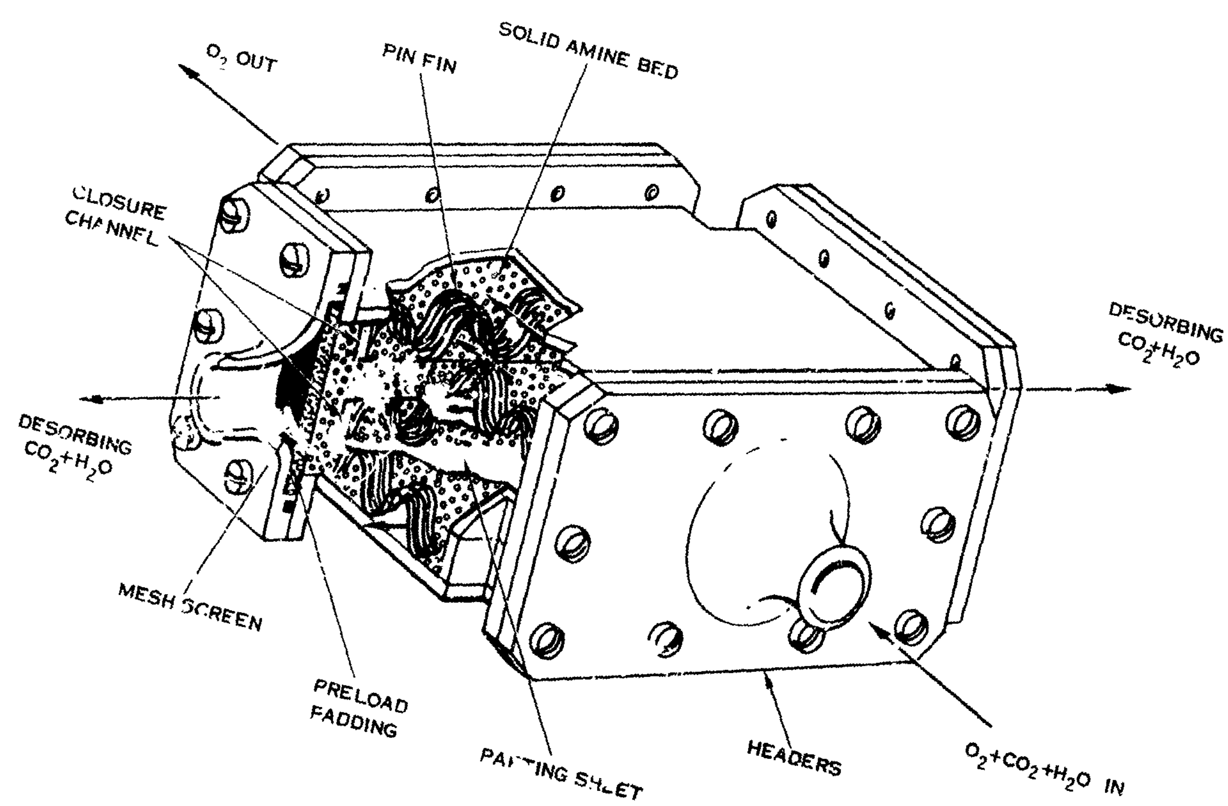


FIGURE 5-17. AEPS REGENERABLE SOLID AMINE-PIN FIN MATRIX

5.1.2.2 (continued)

c. For the purposes of the AEPS study, each of the AEPS regenerable solid amine beds are sized based upon a 2% CO_2 removal capacity by weight (weight of CO_2 removed/weight of amine plus carrier). A timer and valving is provided to cycle the packed beds from the on-line adsorb to the space vacuum desorb cycle. This concept operates on a fifteen (15) minute half-cycle.

   As is the case with the AEPS regenerable ZnO concept, this concept requires no functional interface with the vehicle/base EC/LSS for regeneration. However, it also does not allow for collection and reduction of the desorbed CO_2 for eventual O_2 reclamation.

In summary, the three CO_2 control concepts discussed in this section are all viable candidate concepts for utilization in an AEPS-type system. However, to achieve the performance projected in this report, state-of-the-art improvements through applied research and development are required.

5.1.3 Subsystem Parametric Data

After completion of the primary and secondary evaluations, the AEPS specification requirements for each of the three missions - Space Station, Lunar Base and Mars were reviewed and updated to reflect the latest mission projections. Based upon these updated specification requirements, the original parametric analyses of the recommended subsystem concepts were reviewed and updated, as required. The following parametric data is presented for each of the three missions for all of the recommended thermal control and CO_2 control/O_2 supply subsystems:

a. Vehicle equivalent weight versus total mission duration.

b. Vehicle equivalent volume versus total mission duration.

c. AEPS equivalent volume versus EVA mission duration.

d. AEPS equivalent weight versus EVA mission duration.

e. Accumulated resupply launch weight versus number of resupplies (Space Station and Lunar Base only).

The updated parametric analyses are presented in the following figures.

- Thermal Control for Space Station AEPS - Figures 5-18 through 5-22.

- Thermal Control for Lunar Base AEPS - Figures 5-23 through 5-27.

5.1.3 (continued)

- Thermal Control for Mars AEPS - Figures 5-28 through 5-31.

- CO_2 Control/O_2 Supply for Space Station AEPS - Figures 5-32 through 5-36.

- CO_2 Control/O_2 Supply for Lunar Base AEPS - Figures 5-37 through 5-41.

- CO_2 Control/O_2 Supply for Mars AEPS - Figures 5-42 through 5-45.

Note that the accumulated resupply launch weight versus number of resupplies parametric data indicates that CO_2 reduction only trades off favorably when there are three or more resupplies.

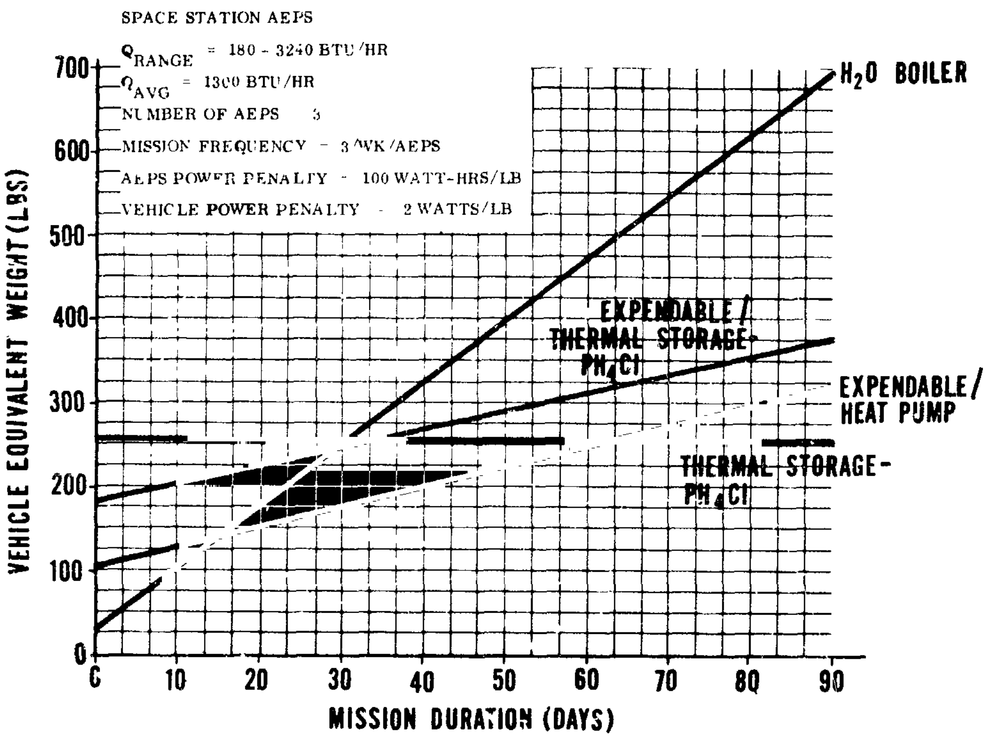


FIGURE 5—18

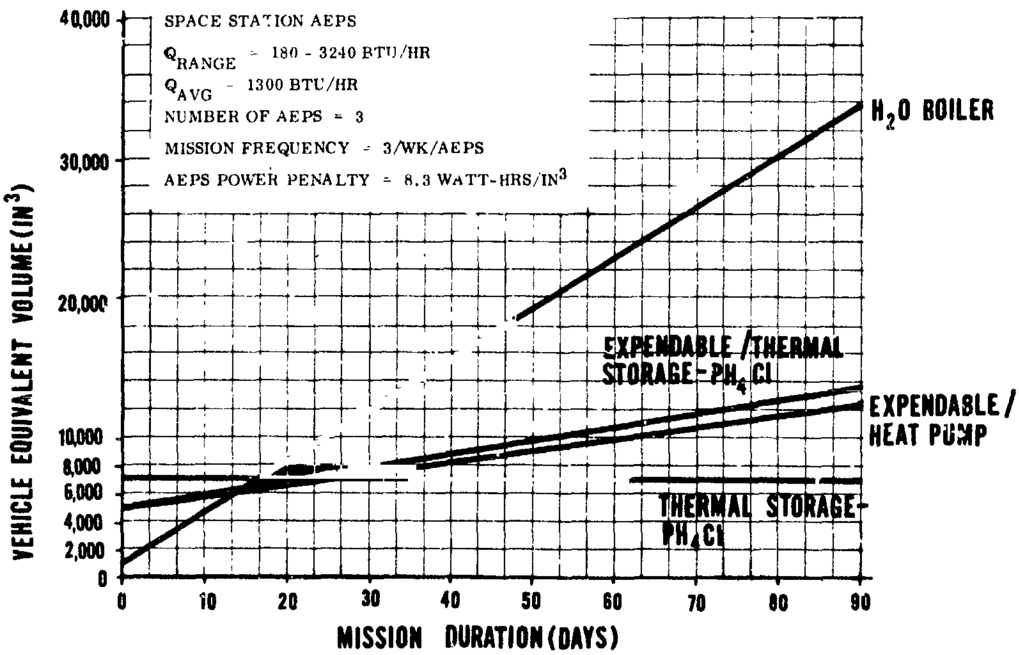


FIGURE 5—19

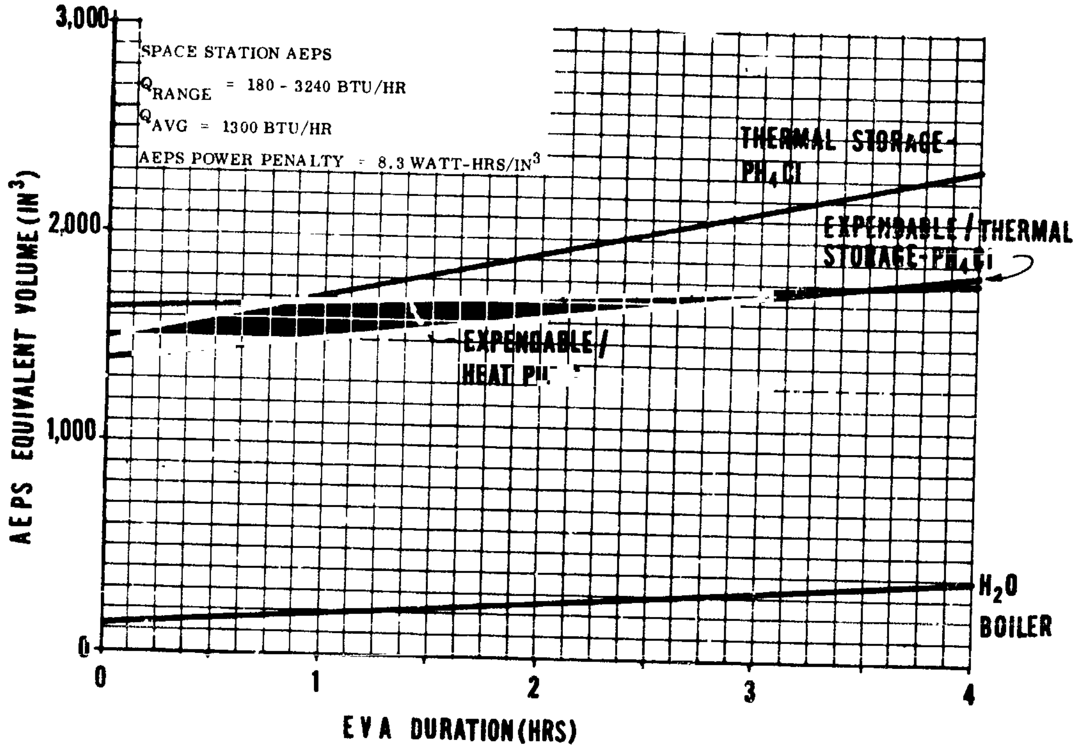


FIGURE 5–20

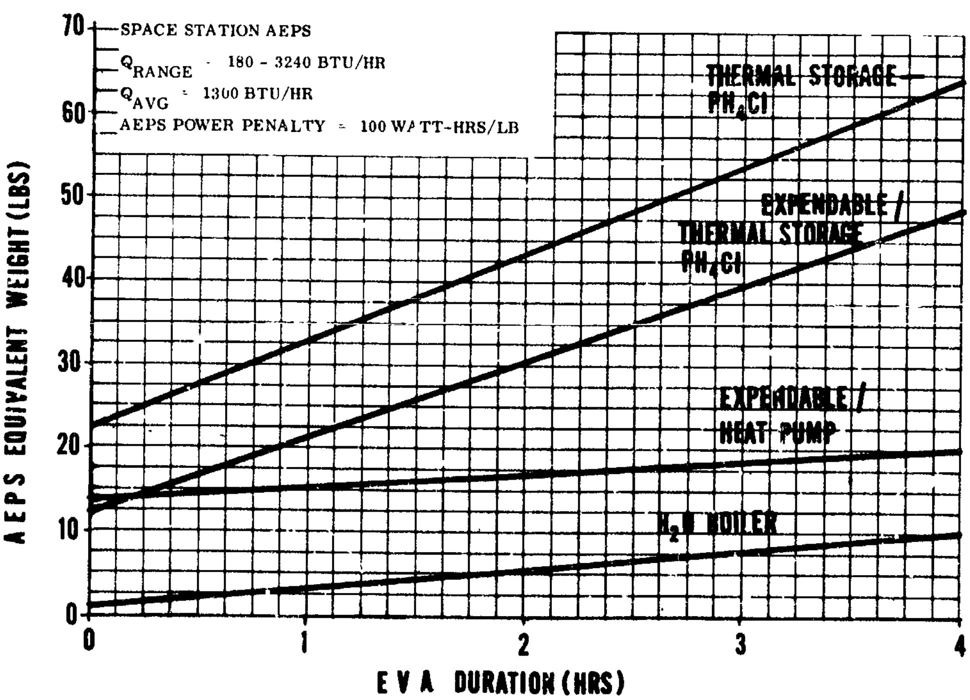


FIGURE 5–21

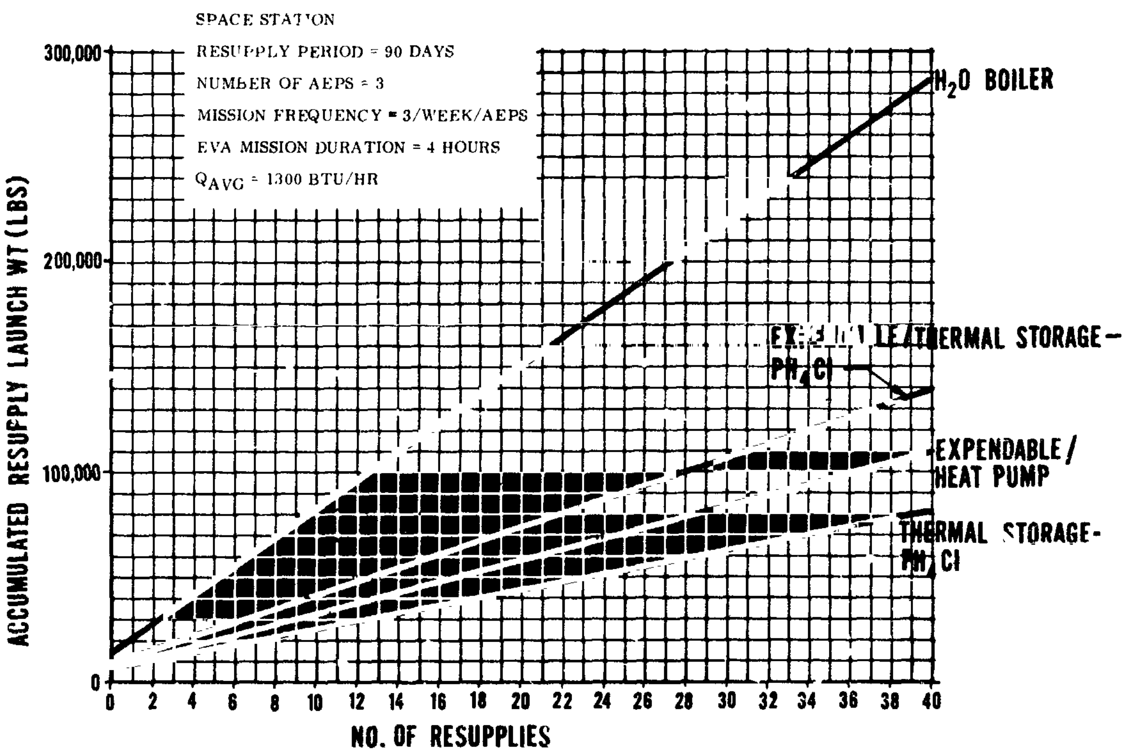

SPACE STATION
RESUPPLY PERIOD = 90 DAYS
NUMBER OF AEPS = 3
MISSION FREQUENCY = 3/WEEK/AEPS
EVA MISSION DURATION = 4 HOURS
Q_{AVG} = 1300 BTU/HR
300,000
200,000
100,000
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
NO. OF RESUPPLIES
ACCUMULATED RESUPPLY LAUNCH WT (LBS)
H_2O BOILER
ERMAL STORAGE-
EXPENDABLE/
HEAT PUMP
RMAL STORAGE-

FIGURE 5–22

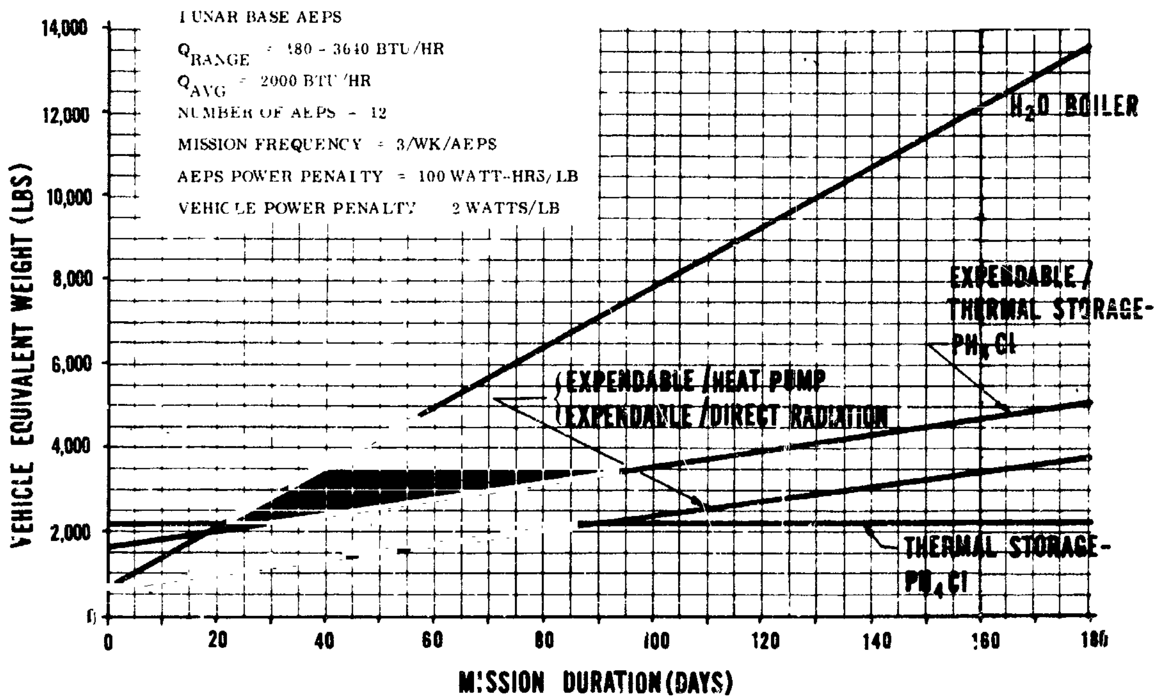


FIGURE 5–23

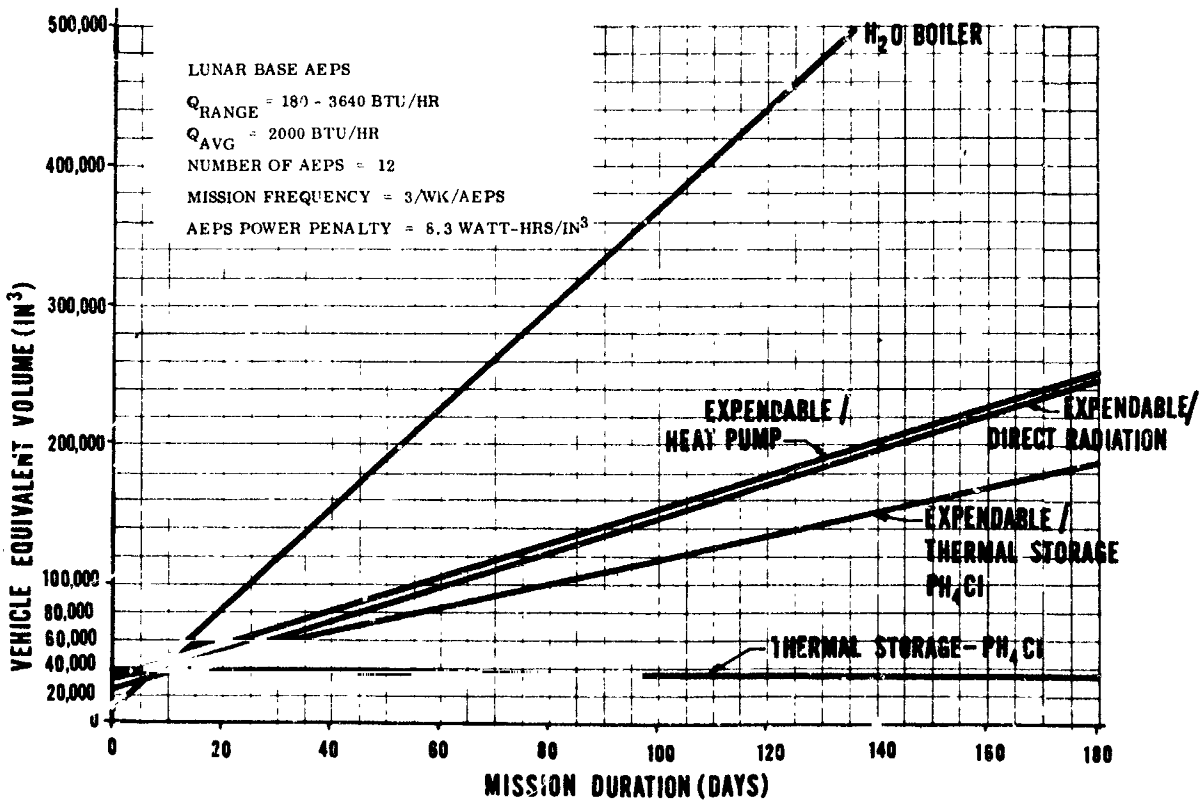


FIGURE 5–24

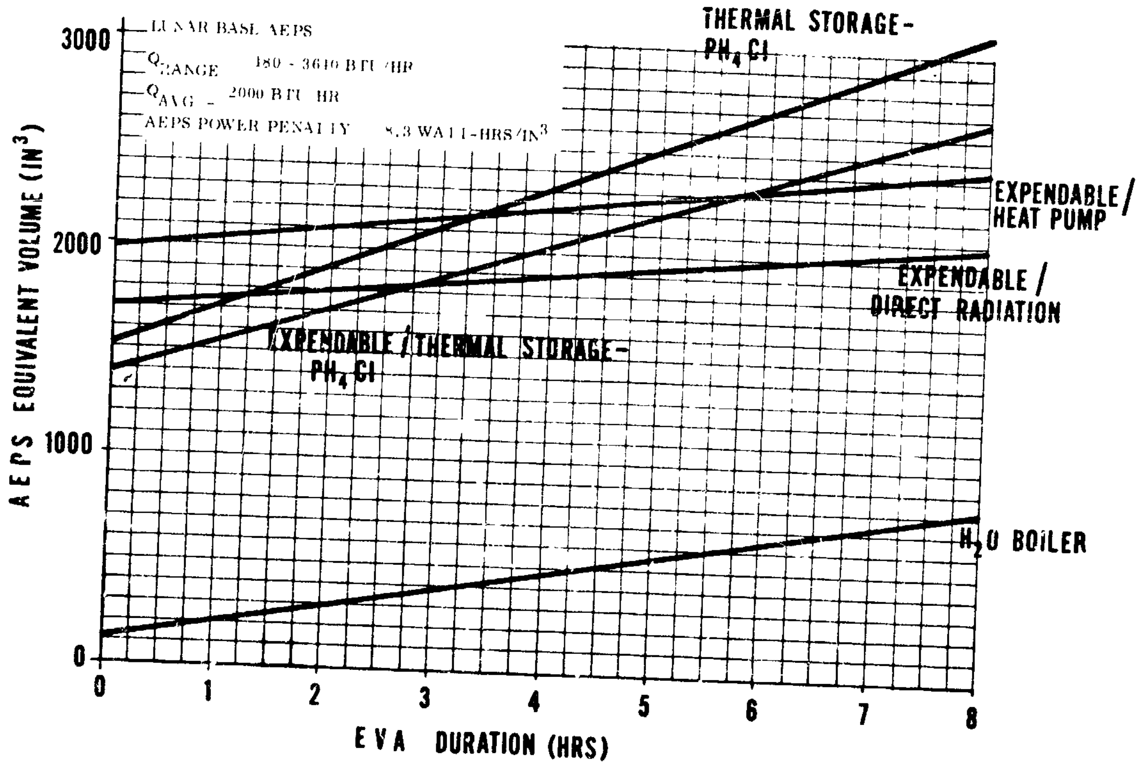


FIGURE 5–25

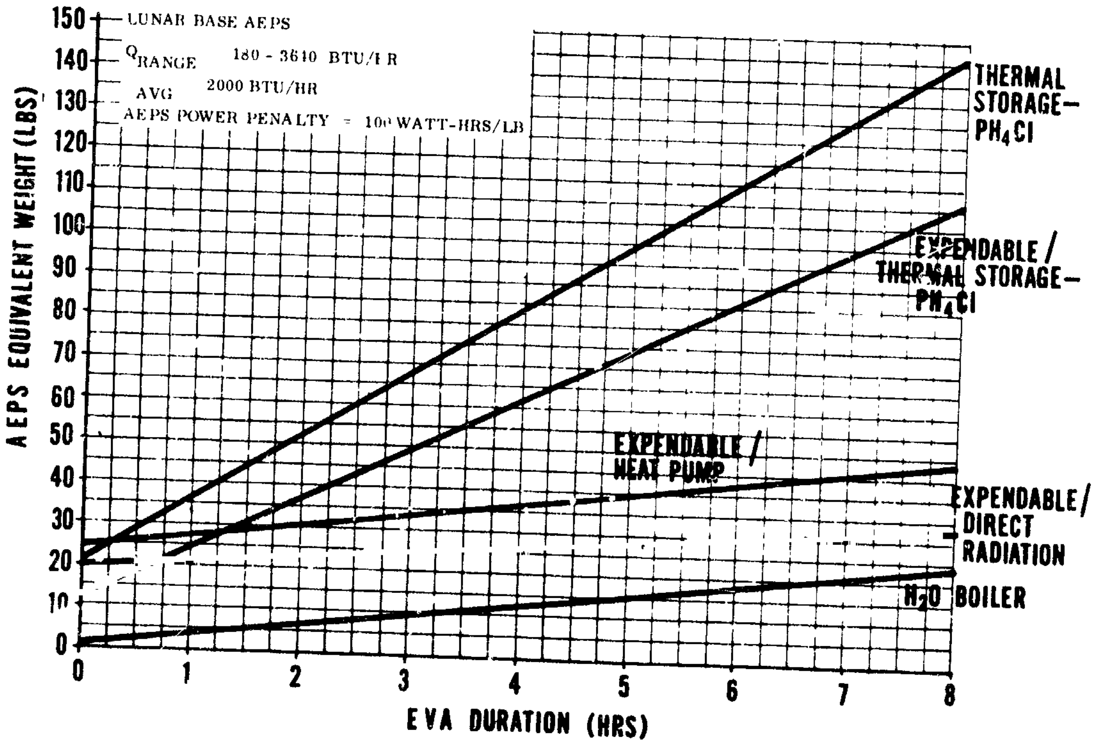
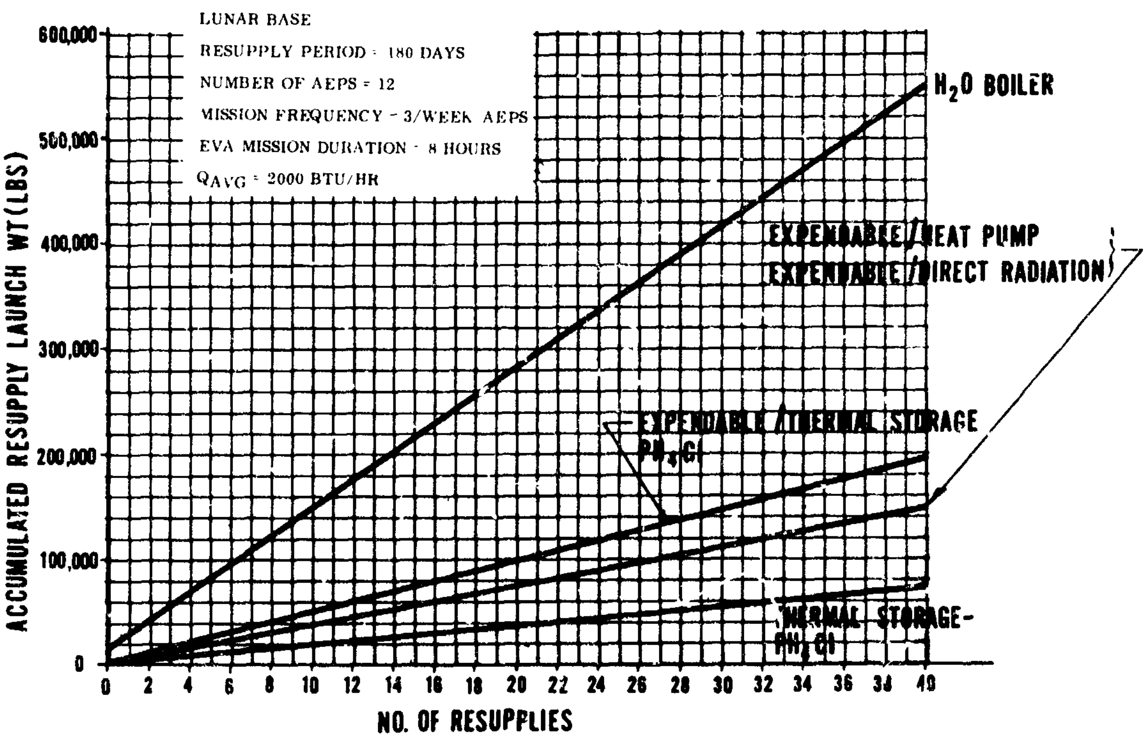


FIGURE 5–26



LUNAR BASE
RESUPPLY PERIOD = 180 DAYS
NUMBER OF AEPS = 12
MISSION FREQUENCY - 3/WEEK AEPS
EVA MISSION DURATION - 8 HOURS
Q_{AVG} = 2000 BTU/HR
600,000
500,000
400,000
300,000
200,000
100,000
0
ACCUMULATED RESUPPLY LAUNCH WT (LBS)
H_2O BOILER
EXPENDABLE/HEAT PUMP
EXPENDABLE/DIRECT RADIATION
EXPENDABLE/THERMAL STORAGE
THERMAL STORAGE-
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
NO. OF RESUPPLIES

FIGURE 5-27

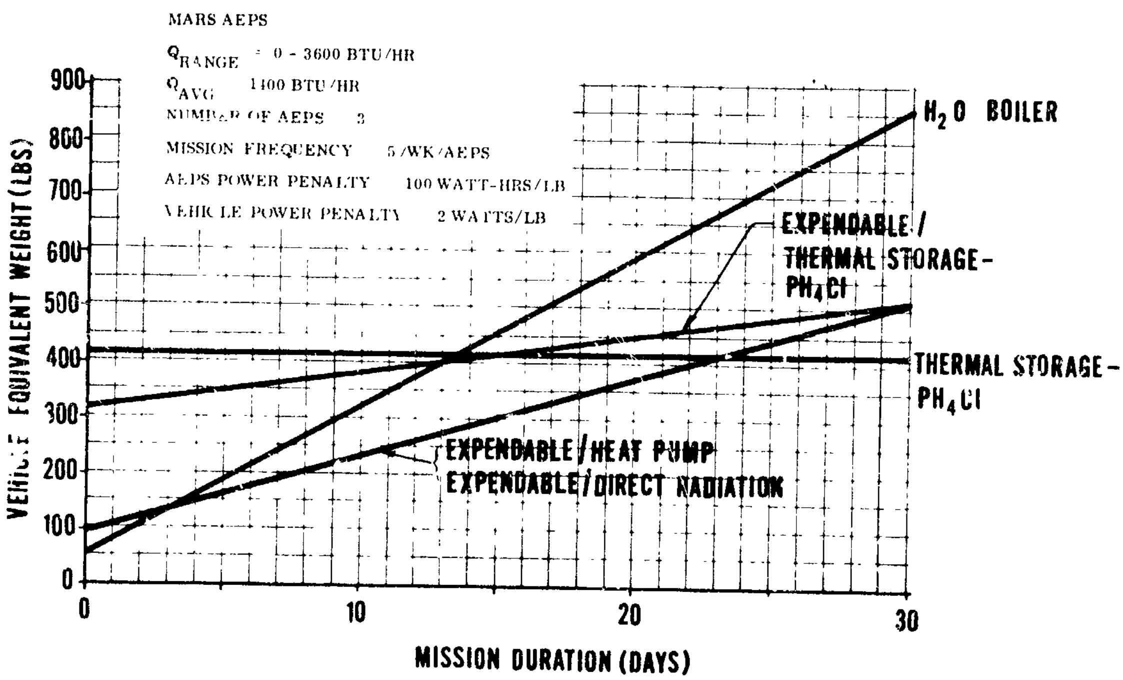


FIGURE 5-28

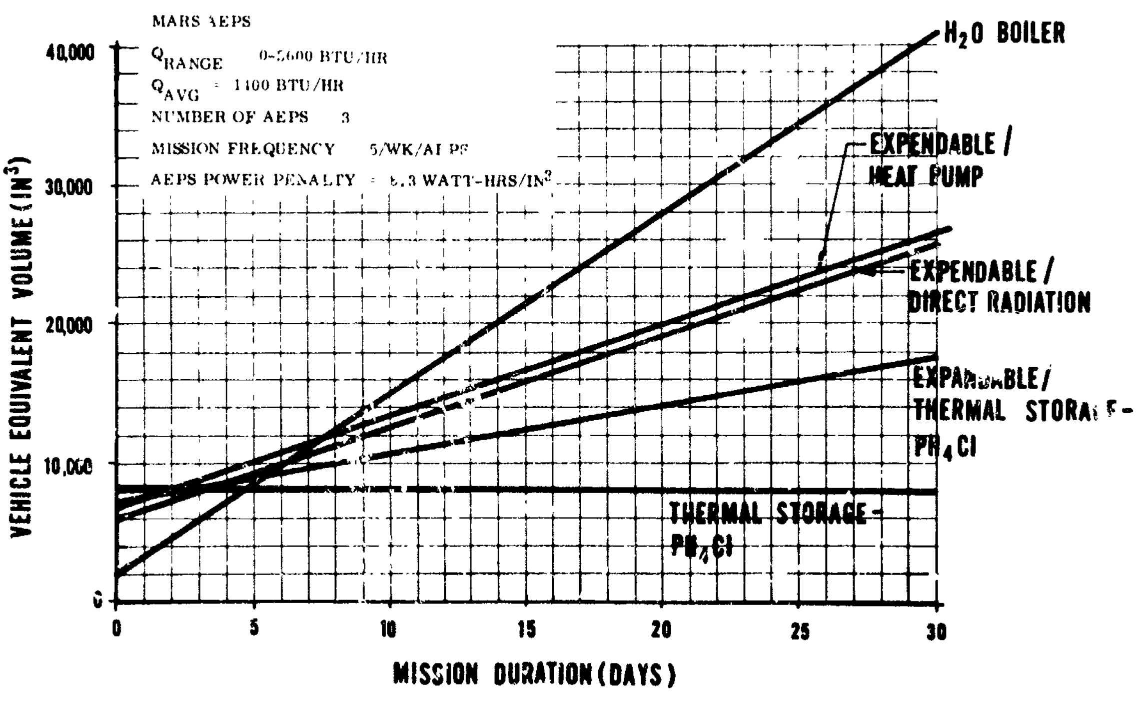


FIGURE 5-29

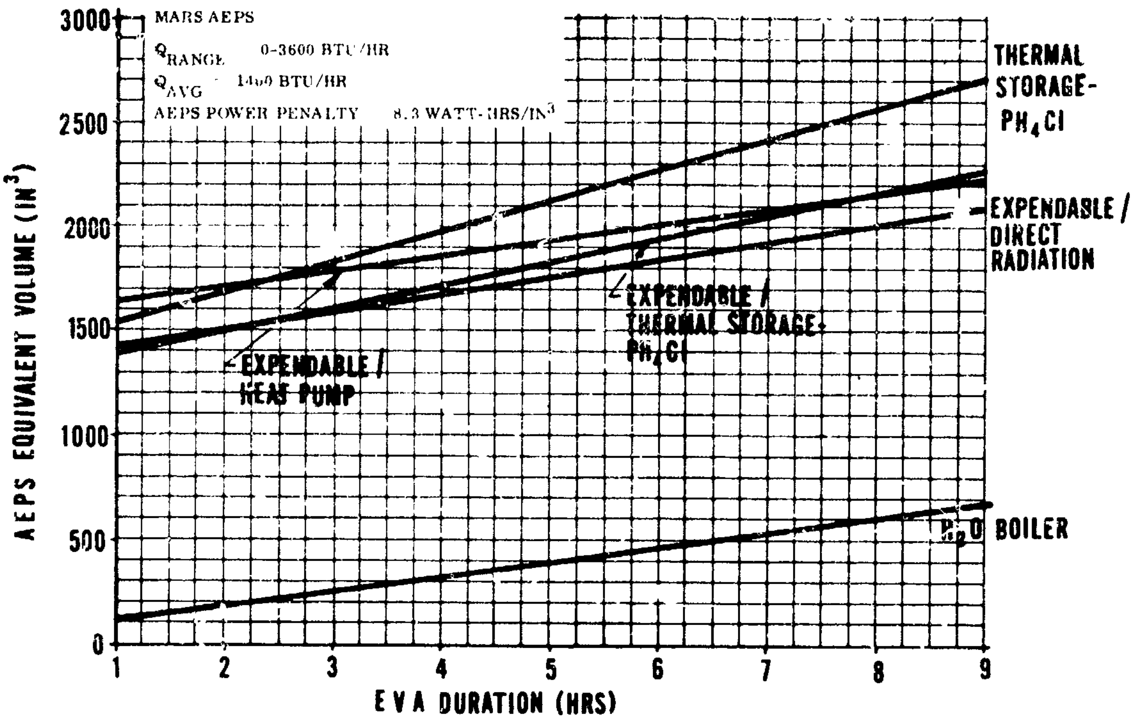


FIGURE 5–30

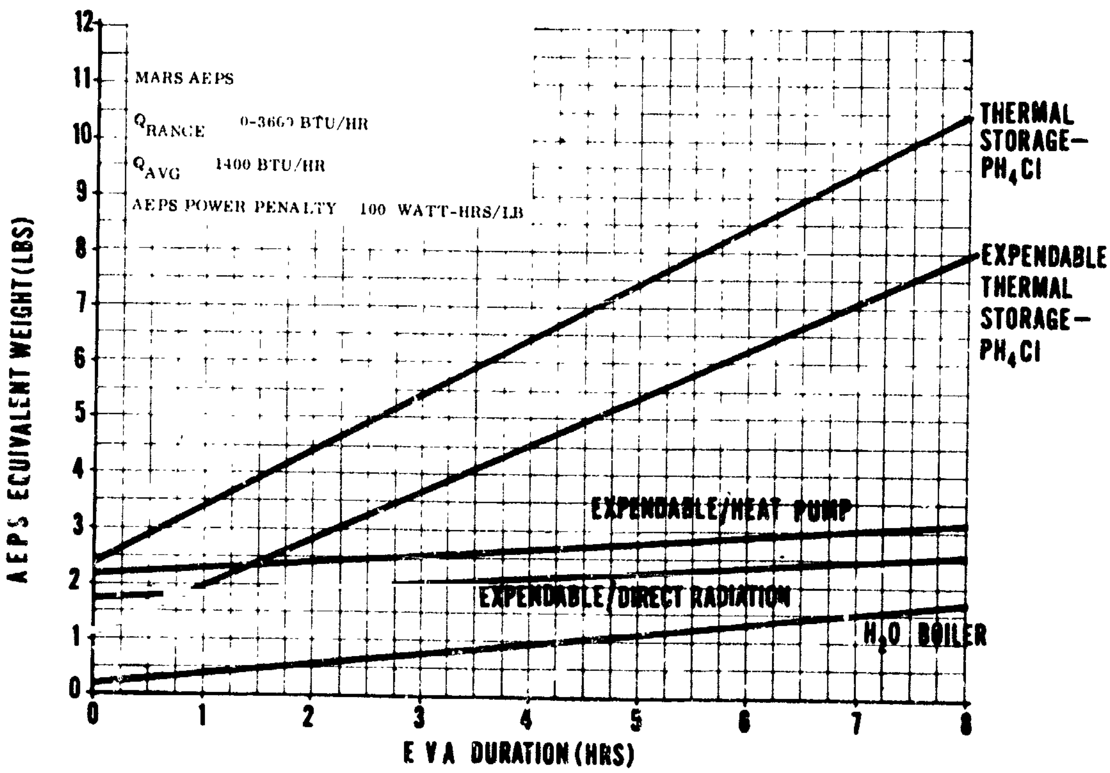


FIGURE 5–31

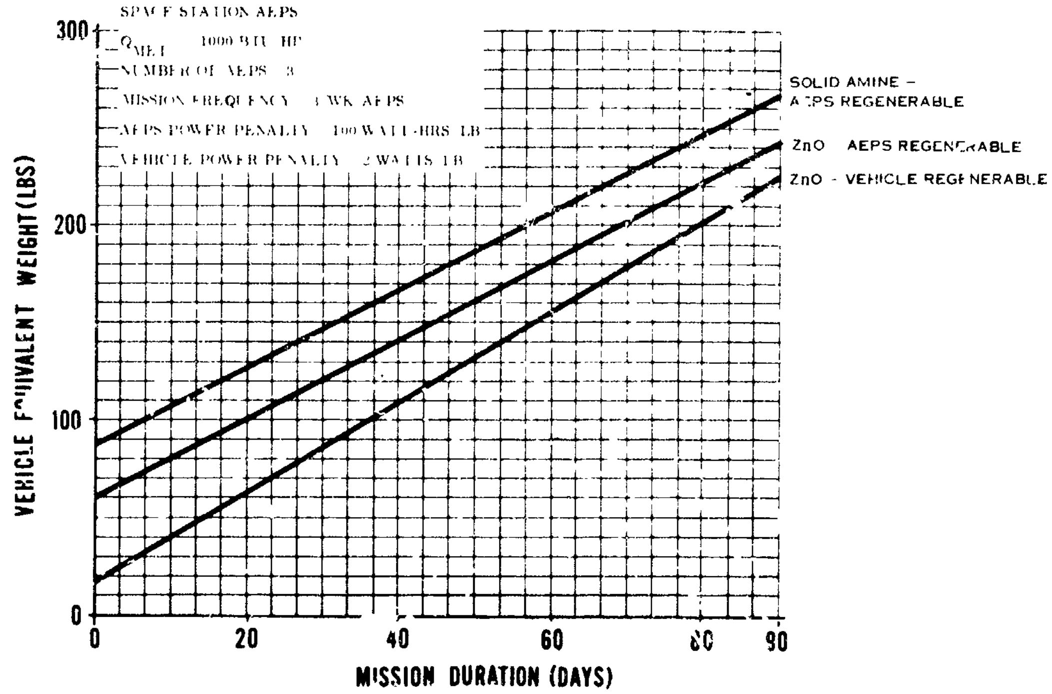


FIGURE 5—32

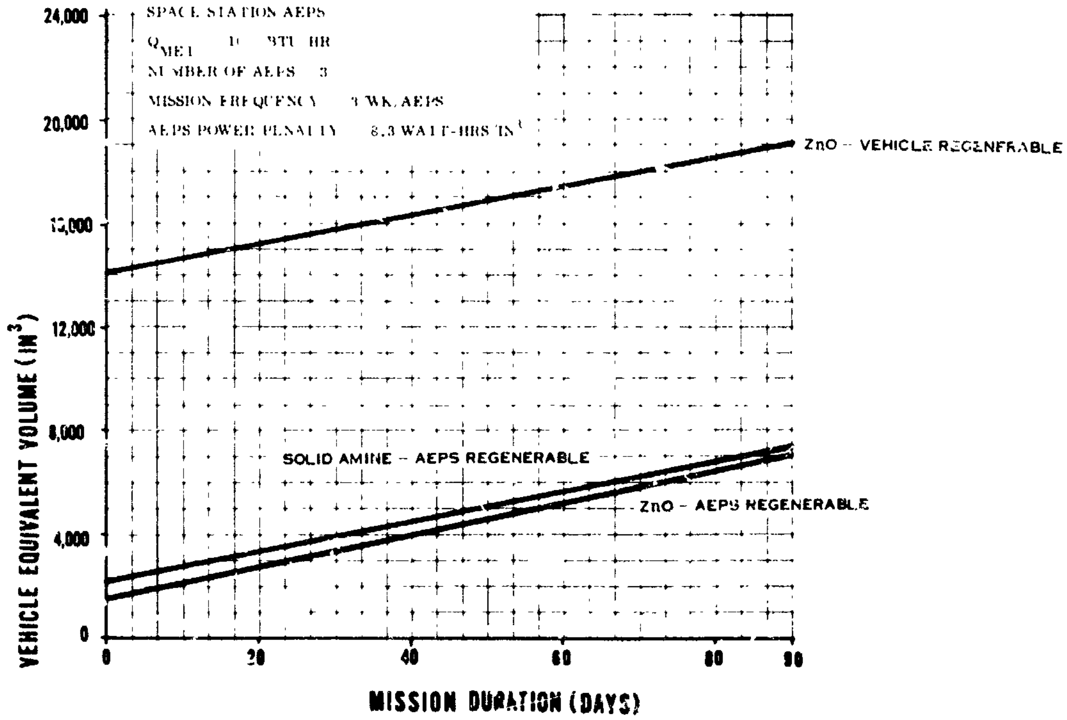


FIGURE 5—33

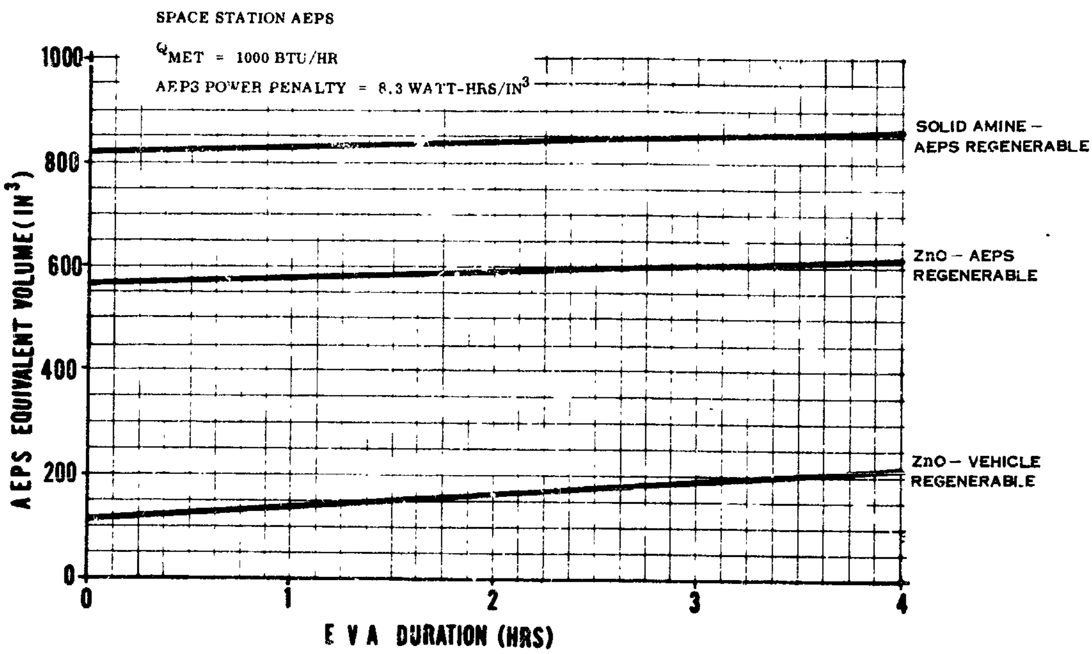


FIGURE 5–34

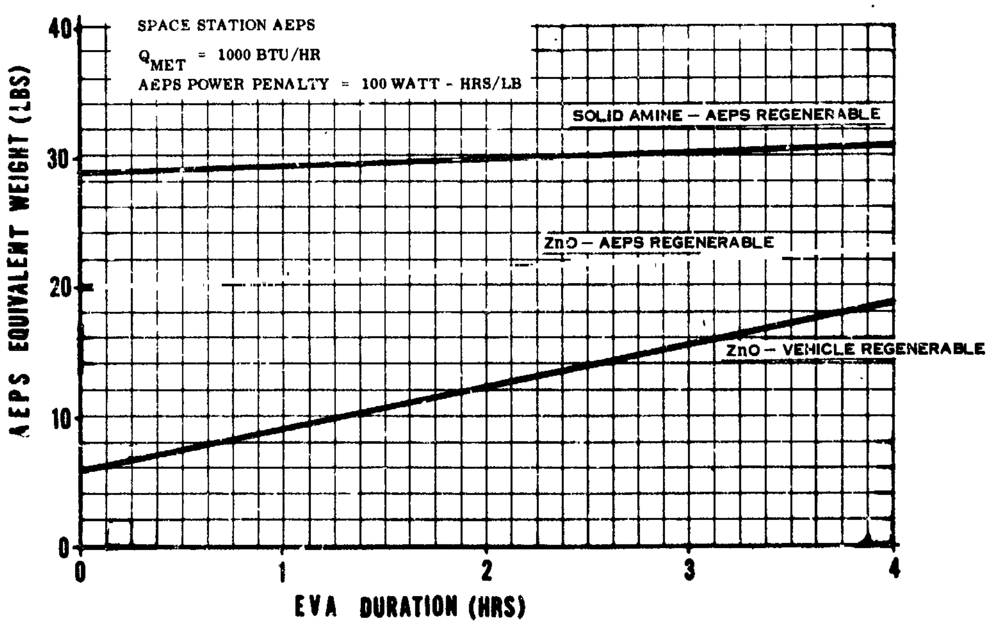
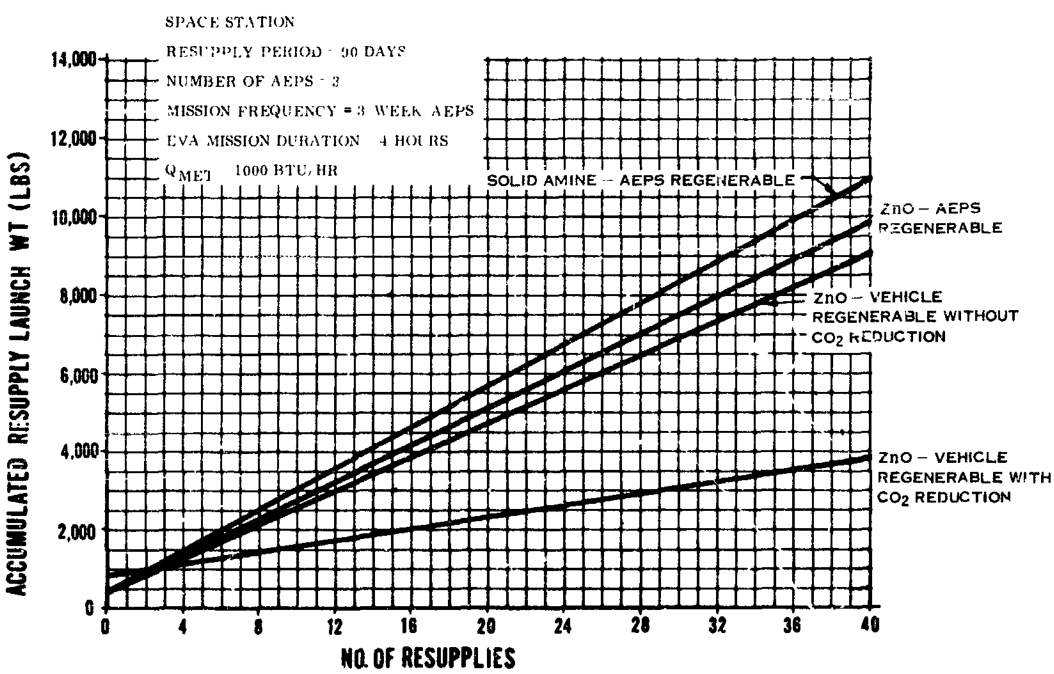


FIGURE 5–35



SPACE STATION
RESUPPLY PERIOD - 90 DAYS
NUMBER OF AEPS - 3
MISSION FREQUENCY = 3 WEEK AEPS
EVA MISSION DURATION 4 HOURS
Q_{MET} 1000 BTU/HR
SOLID AMINE – AEPS REGENERABLE
ZnO – AEPS REGENERABLE
ZnO – VEHICLE REGENERABLE WITHOUT CO_2 REDUCTION
ZnO – VEHICLE REGENERABLE WITH CO_2 REDUCTION
ACCUMULATED RESUPPLY LAUNCH WT (LBS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
4
8
12
16
20
24
28
32
36
40
NO. OF RESUPPLIES

FIGURE 5–36

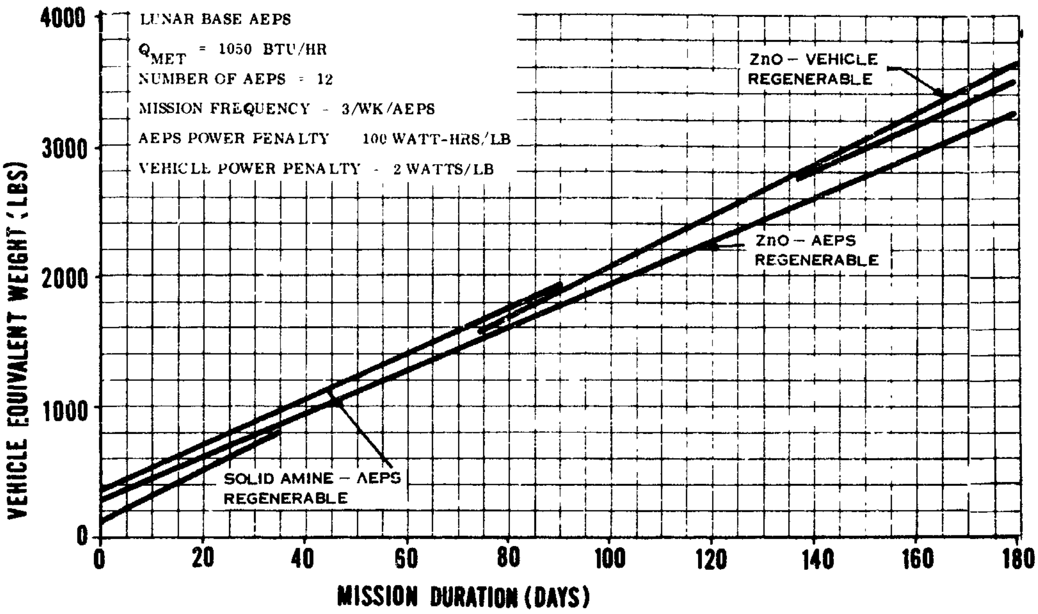


FIGURE 5–37

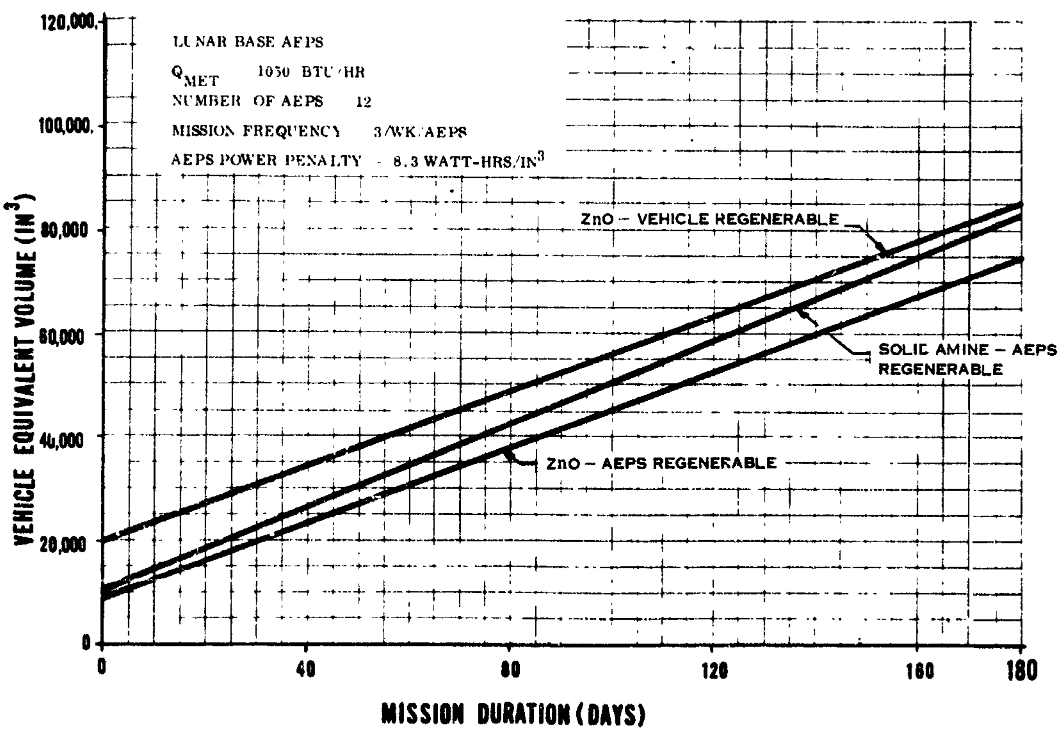


FIGURE 5–38

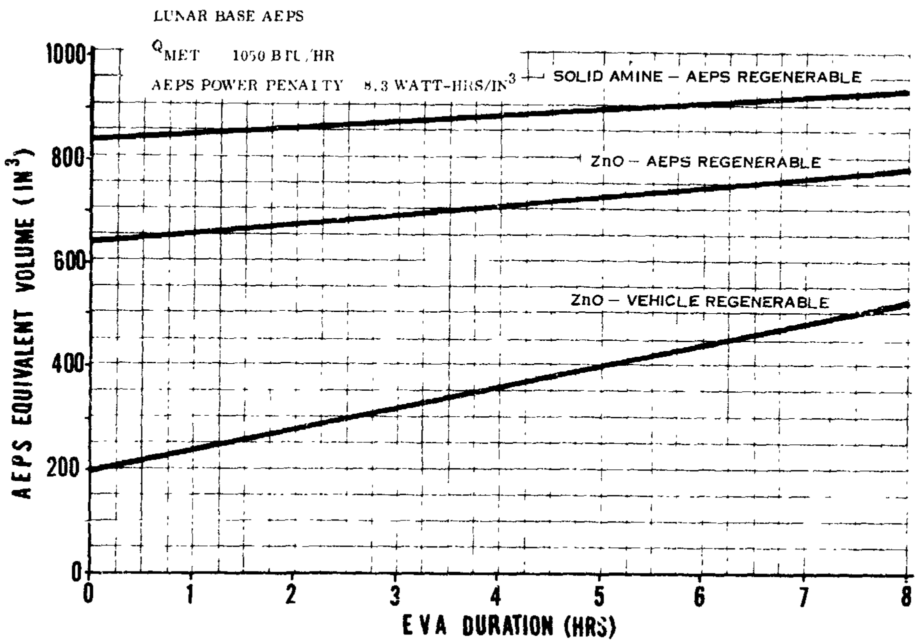


FIGURE 5–39

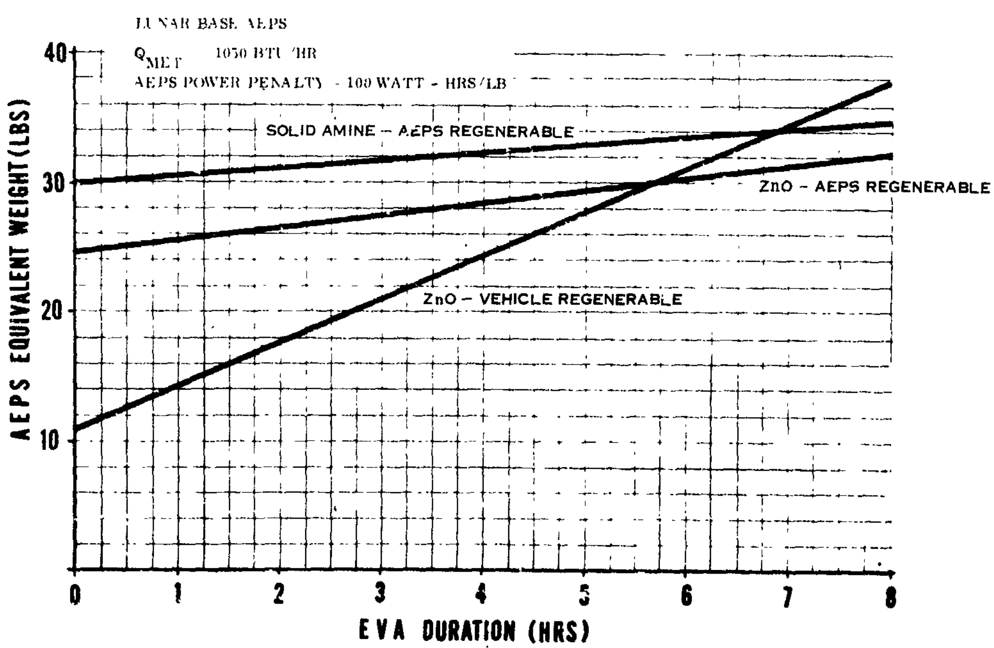


FIGURE 5–40

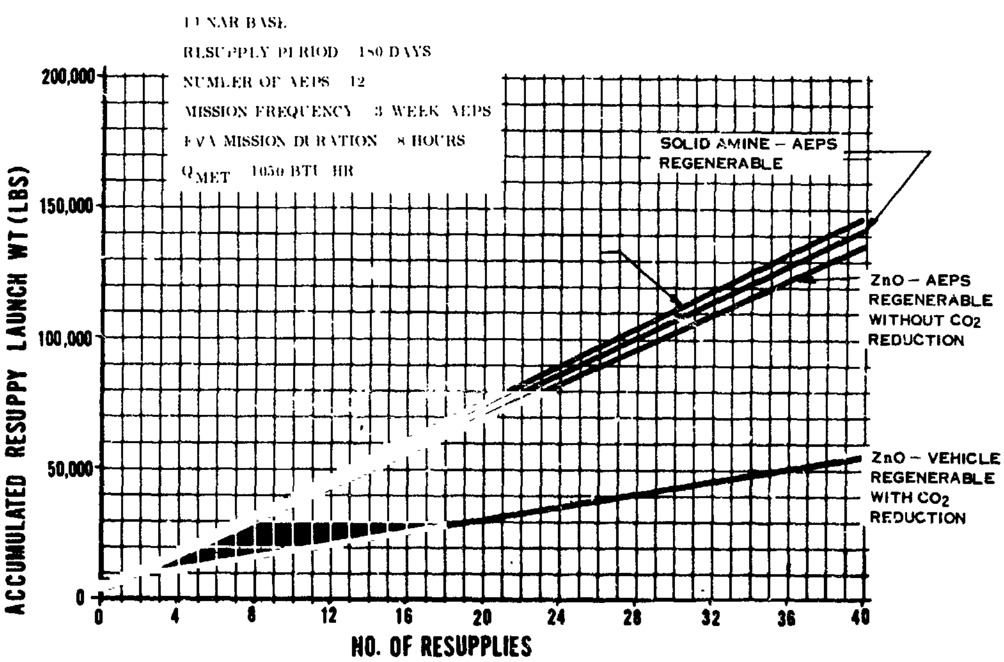

LUNAR BASE
RESUPPLY PERIOD 180 DAYS
NUMBER OF AEPS 12
MISSION FREQUENCY 3 WEEK AEPS
EVA MISSION DURATION 8 HOURS
Q_{MET} 1050 BTU/HR
SOLID AMINE – AEPS REGENERABLE
ZnO – AEPS REGENERABLE WITHOUT CO_2 REDUCTION
ZnO – VEHICLE REGENERABLE WITH CO_2 REDUCTION
ACCUMULATED RESUPPY LAUNCH WT (LBS)
200,000
150,000
100,000
50,000
0
0
4
8
12
16
20
24
28
32
36
40
NO. OF RESUPPLIES

FIGURE 5–41

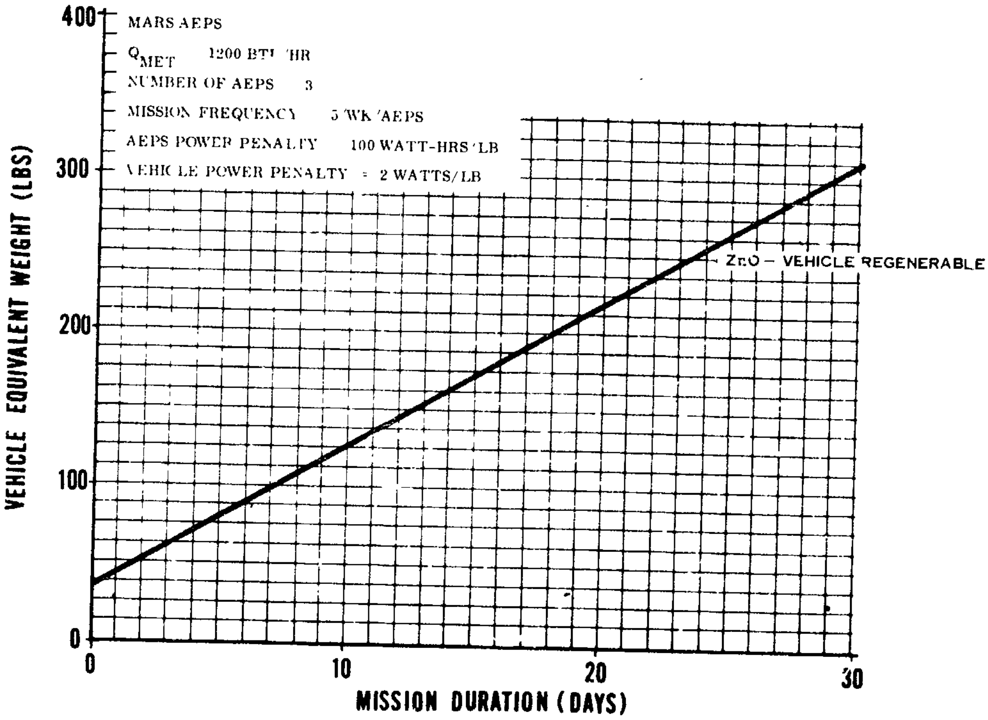


FIGURE 5–42

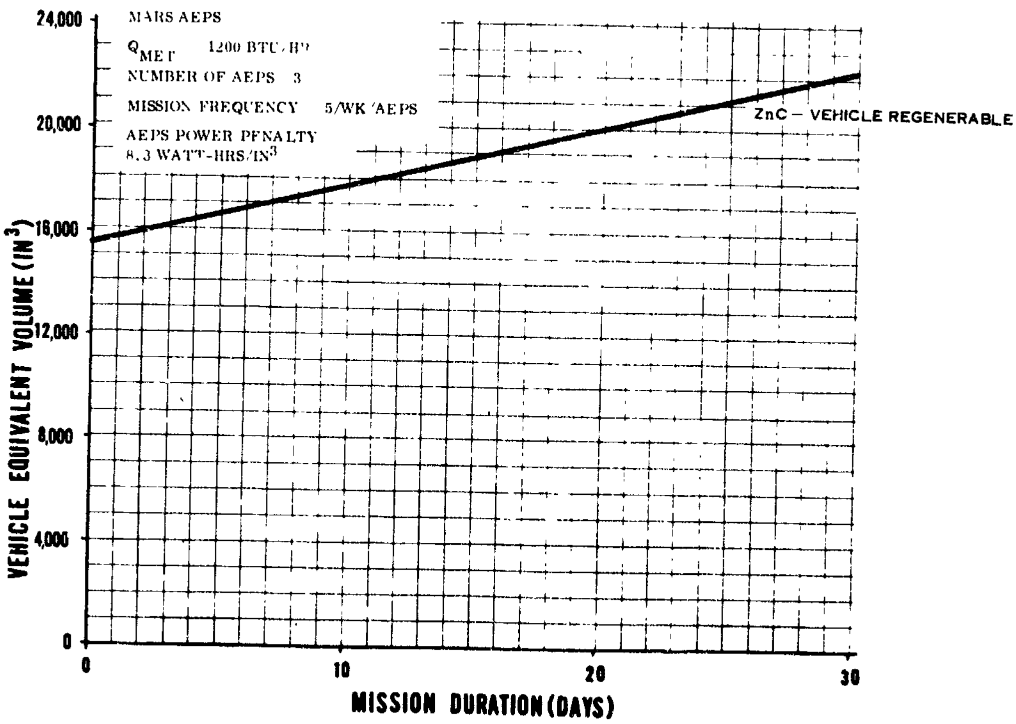


FIGURE 5–43

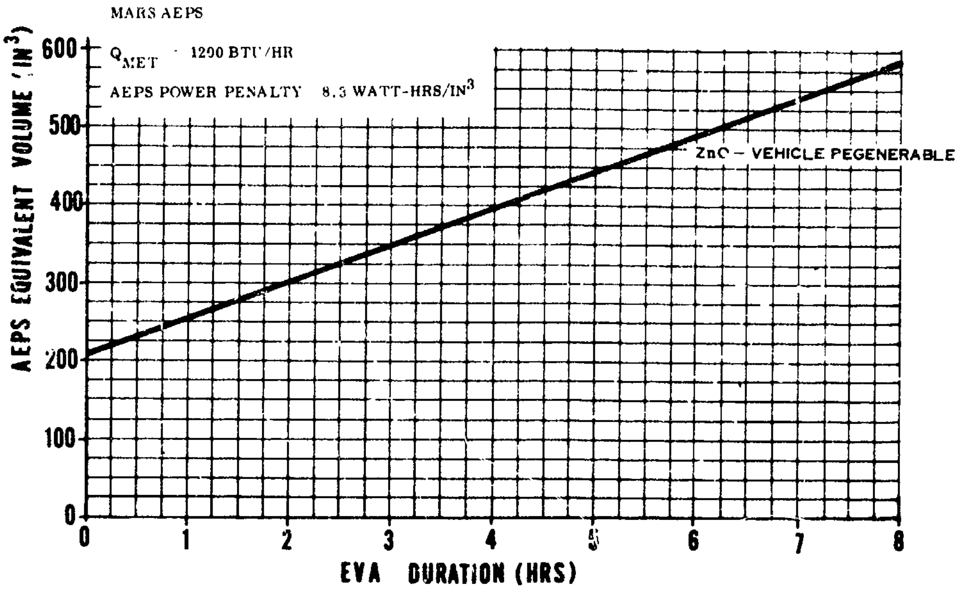


FIGURE 5–44

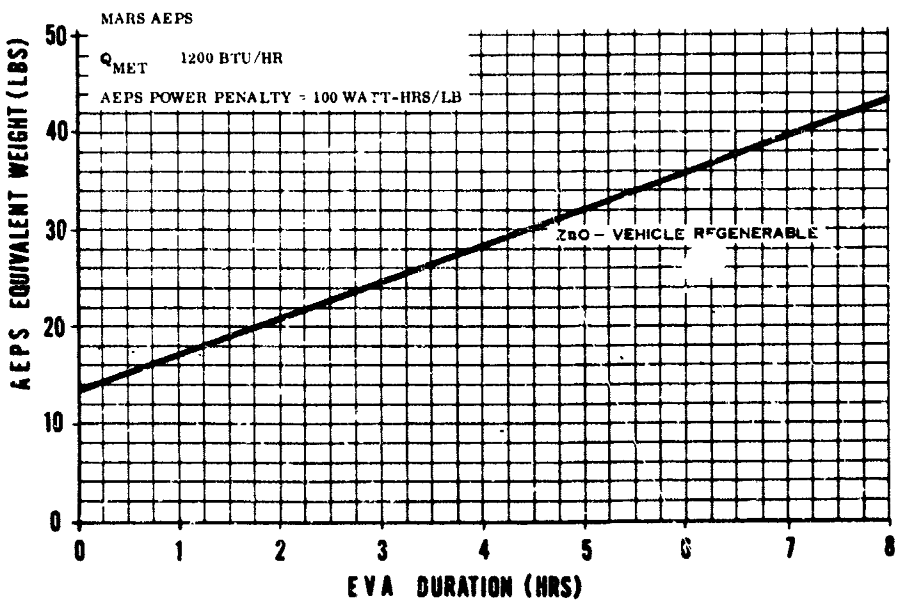


FIGURE 5–45

5.2 Phase Two Effort

5.2.1 General

The subsystem studies effort conducted during phase two utilized the results of the phase one effort as a baseline. Our experience during phase one permitted us to be more discriminating in the selection of candidate subsystem concepts to be carried into the shuttle AEPS and the emergency system go/no go evaluations. This section describes each of the shuttle AEPS subsystems and emergency system subsystems to be carried into the system studies and presents comparative parametric data.

5.2.2 Shuttle AEPS

5.2.2.1 O_2 Supply - The O_2 supply subsystem concept recommended to be carried into the systems integration phase of the shuttle AEPS study effort is a 6000 psi gaseous O_2 storage concept. This concept requires shuttle storage of precharged O_2 supply subsystems. Each subsystem contains a charged 6000 psi O_2 bottle, pressure regulator, pressure gage, fill fitting, shutoff valve and low pressure disconnect. After each AEPS EVA, the expended or partially expended O_2 storage subsystem is removed and replaced with a fresh unit. However, this recommendation will be examined on the systems level and, in the event that O_2 supply subsystem replacement is not acceptable, vehicle rechargeable 900 psi gaseous storage will be considered. Both of these concepts are pictured in Figure 5-46. Other O_2 supply concepts considered include $NaClO_3$ candles (described in section 4.2.1.1 of Volume II) and flush flow and O_2 makeup umbilicals.

5.2.2.2 Thermal Control - The thermal control subsystem concepts recommended to be carried into the systems integration phase of the shuttle AEPS study effort are:

a. Water Boiler - This concept is described in section 5.1.2.1 (a) of this volume.

b. Water Sublimator (Figure 5-47) - The water sublimator is an expendable thermal control concept that utilizes the heat of sublimation to provide direct cooling of the Liquid Cooling Garment (LCG) and ventilation loops. The sublimator is a porous media heat exchanger wherein the downstream side of the porous media is subjected to a hard vacumm and the upstream side is supplied with expendable water. Upon startup, the sudden drop in pressure across the porous media freezes the expendable water within the porous media. The addition of heat from the LCG and vent loops sublimes the ice on the vacuum end of the porous media and thus the thermal load is rejected to space. The sublimator is supplied expendable water from a pressure-fed bladder tank which is pressurized by the vent loop.

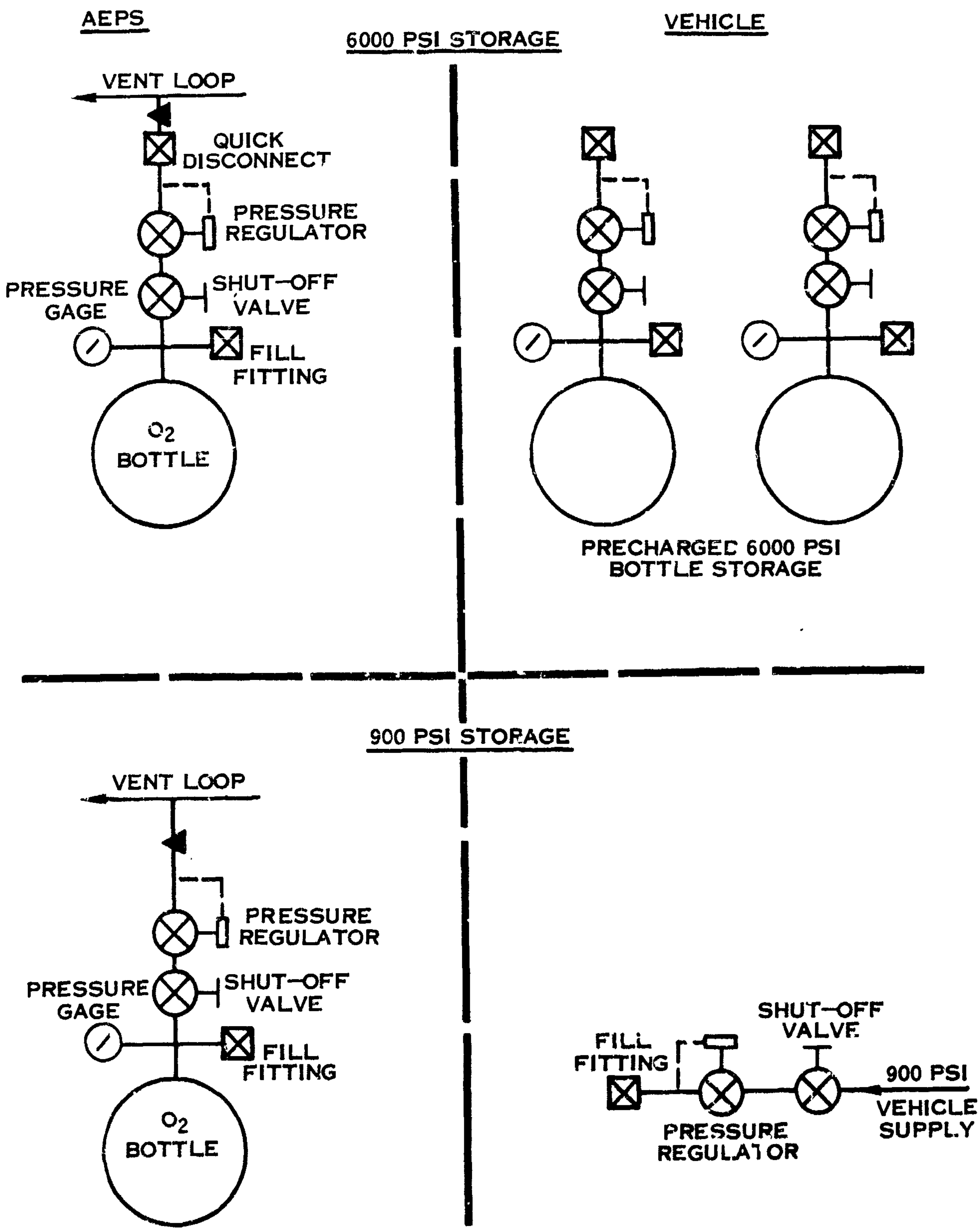


FIGURE 5–46. GASEOUS O_2 SUPPLY

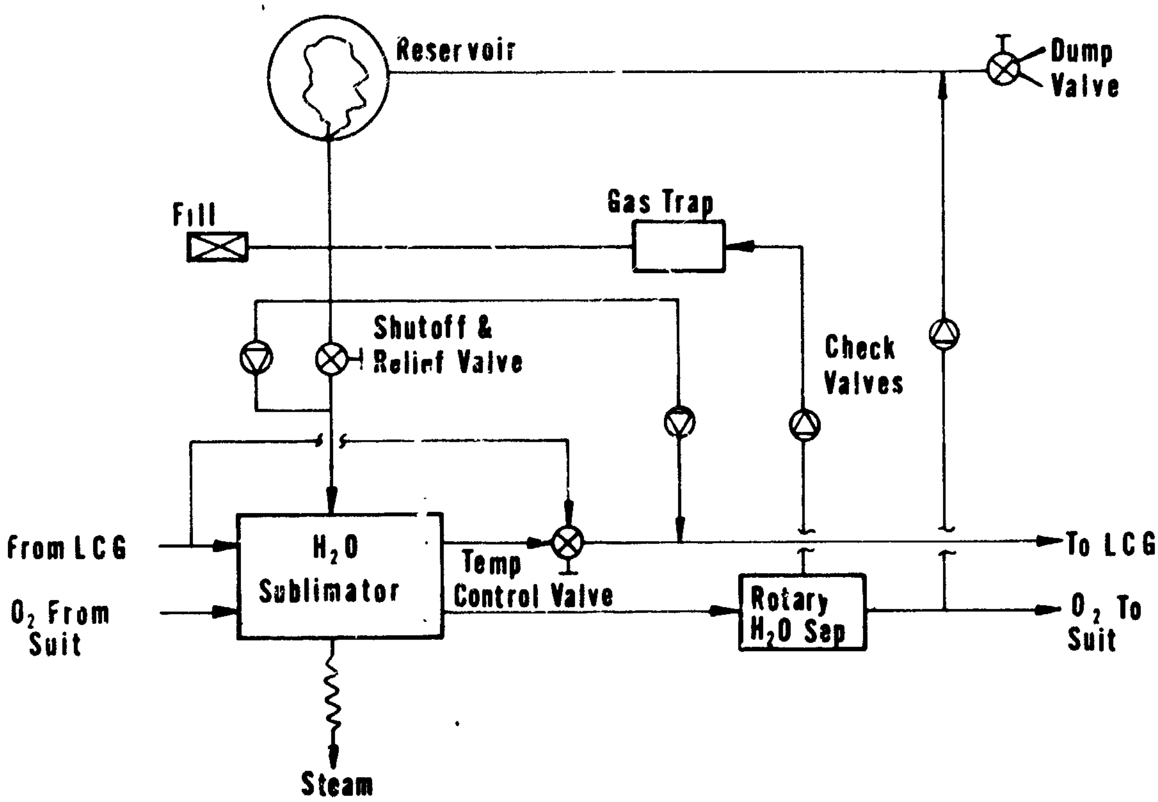


FIGURE 5-47. WATER SUBLIMATOR

5.2.2.2 (Continued)

Although recommendation of both the expendable water boiler and water sublimator concepts does not meet the intent of the AEPS study (...to develop regenerable or partially regenerable subsystem to minimize vehicle impact), those candidate subsystems which are regenerable or partially regenerable are uncompetitive due to the short duration of the projected shuttle missions together with the relatively small number of planned EVA excursions.

5.2.2.3 CO_2 Control/O_2 Supply - The CO_2 control/O_2 supply subsystem concepts recommended to be carried into the systems integration phase of the shuttle AEPS study effort are listed below. All of the concepts utilize a 6000 psi O_2 supply subsystem.

a. Lithium Hydroxide - LiOH (Figure 5-48) - Lithium hydroxide, a non-regenerable solid absorbent, is packaged in replaceable cartridges which also may contain a particulate filter and activated charcoal for trace contaminant control. The LiOH contains 4 to 8% water and must be stored in protective containers in a temperature controlled environment to ensure maximum performance.

After each use, the cartridge is replaced in the canister regardless of the total time or use rate accumulated on the unit. This procedure ensures a fully operational charge for each mission but has a built-in unrecoverable waste which is the unused portion of the absorbent plus the cartridge (unless the used cartridge is then utilized in the vehicle ECS). In use, the vent loop returning from the astronaut is directed to the LiOH where the following reactions occur:

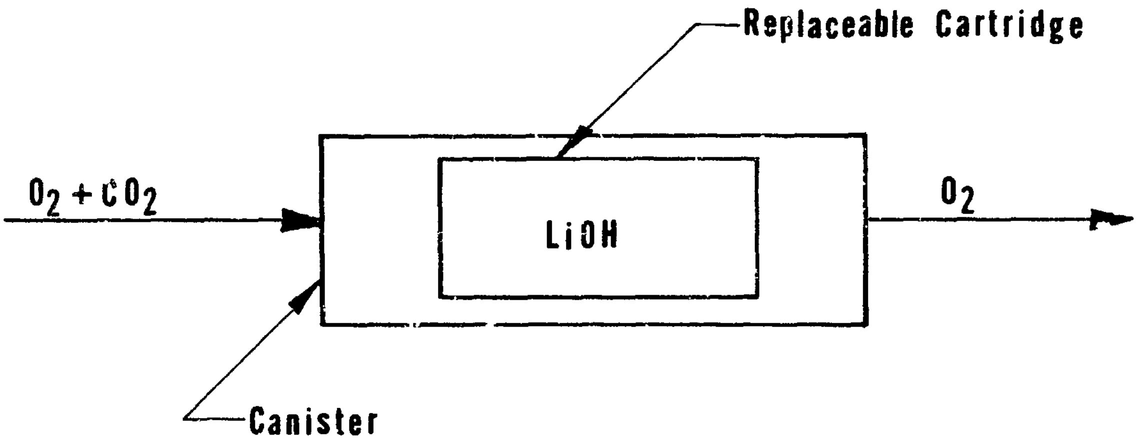
$$LiOH + H_2O(g) \longrightarrow LiOH \cdot H_2O$$

$$2\ LiOH\ H_2O + CO_2 \longrightarrow Li_2CO_3 + 3H_2O(g)$$

$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O(g)$$

As a result of these reactions, energy and water vapor are added to the gas stream and are, in turn, removed by the thermal/humidity control subsystem. Outlet CO_2 concentration remains near zero for almost 80% of the useful life, thus providing the astronaut an extremely low time-averaged CO_2 atmosphere. The curves depicted in Figures 5-61 through 5-64 are based on a LiOH utilization efficiency of 53% at an average metabolic load of 1050 BTU/hr.

b. Metallic Oxide - Vehicle Regenerable - This concept is described in section 5.1.2.2(a) of this volume.



$$2\,LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + Q$$

FIGURE 5–48. LITHIUM HYDROXIDE (LiOH)

5.2.2.3 (Continued)

c. Metallic Oxide - AEPS Regenerable - This concept is described in section 5.1.2.2(b) of this volume.

d. Solid Amine - AEPS Regenerable - This concept is described in section 5.1.2.2(c) of this volume.

5.2.2.4 Shuttle AEPS Subsystems Parametric Data - After completion of the primary and secondary evaluations, the shuttle AEPS specification requirements were reviewed and updated to reflect the latest mission projections. Based upon these updated specification requirements, the parametric analyses were reviewed and updated, as required. The following parametric data is presented for the shuttle mission and contains the recommended O_2 supply, thermal control and combined CO_2 control/O_2 supply subsystems:

a. Vehicle equivalent weight versus total mission duration.

b. Vehicle equivalent volume versus total mission duration.

c. AEPS equivalent volume versus EVA mission duration.

d. AEPS equivalent weight versus EVA mission duration.

The shuttle AEPS subsystems parametric analyses are presented in the following Figures.

- O_2 Supply - Figures 5-49 through 5-52
- Thermal Control - Figures 5-53 through 5-60
- CO_2 Control/O_2 Supply - Figures 5-61 through 5-84

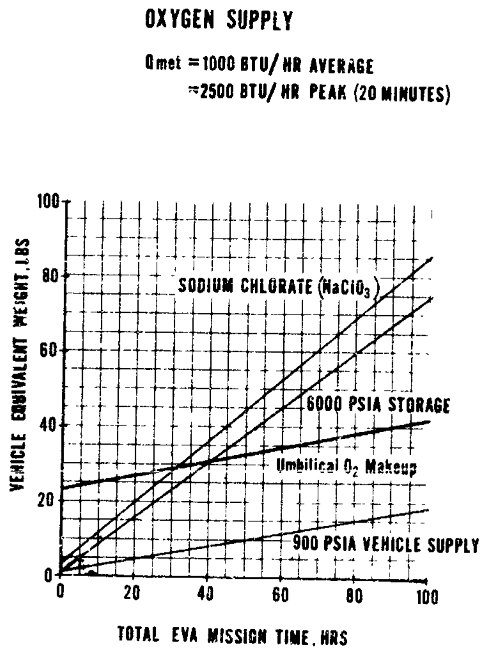


FIGURE 5–49

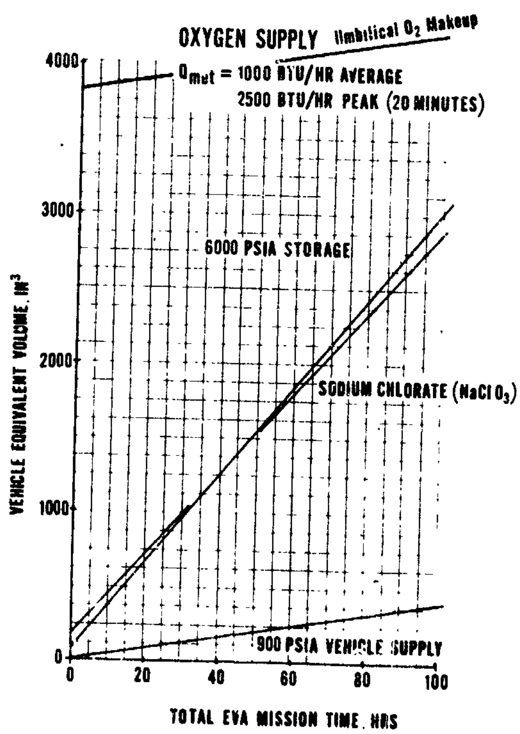


FIGURE 5–50

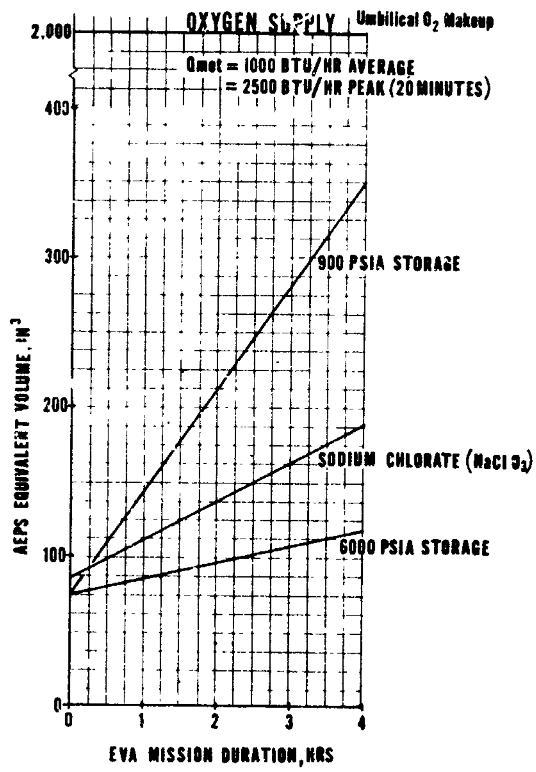


FIGURE 5—51

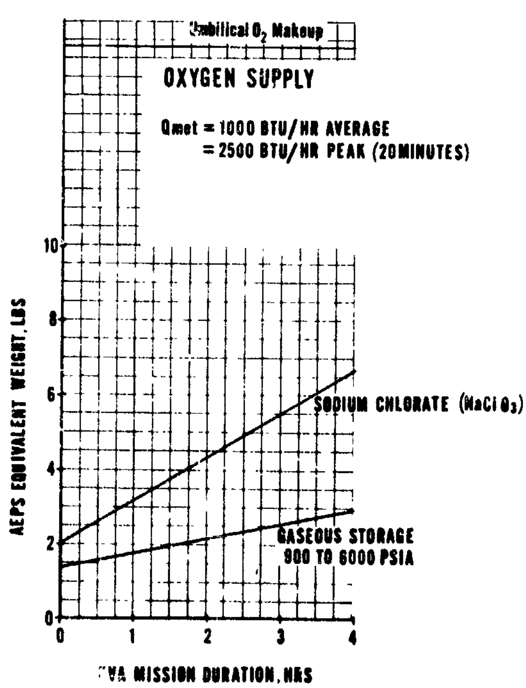


FIGURE 5—52

WATER BOILER

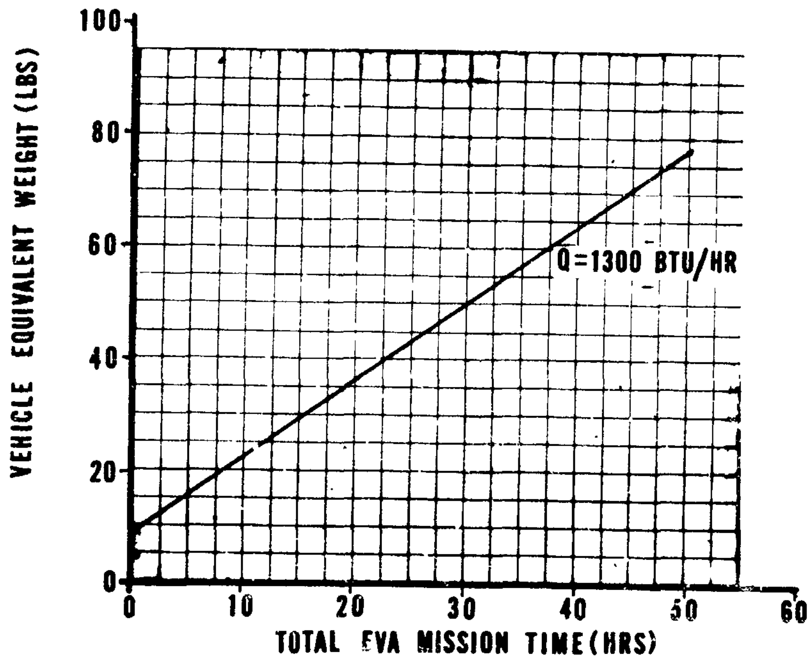


FIGURE 5—53

WATER BOILER

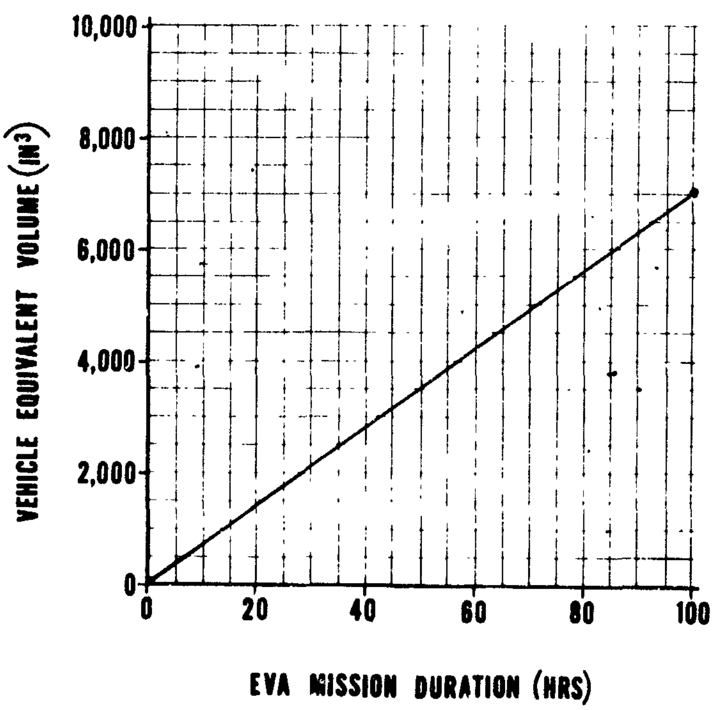


FIGURE 5—54

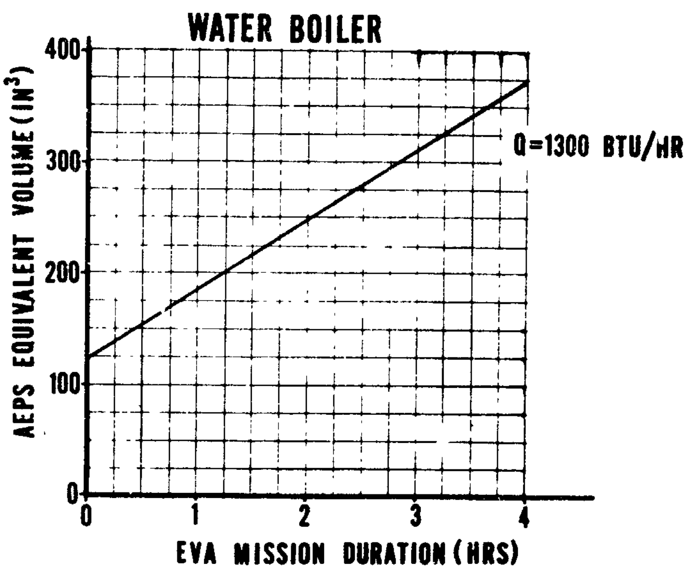


FIGURE 5–55

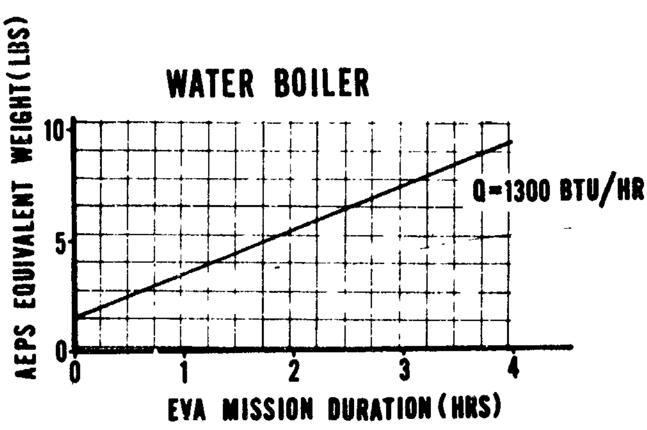


FIGURE 5–56

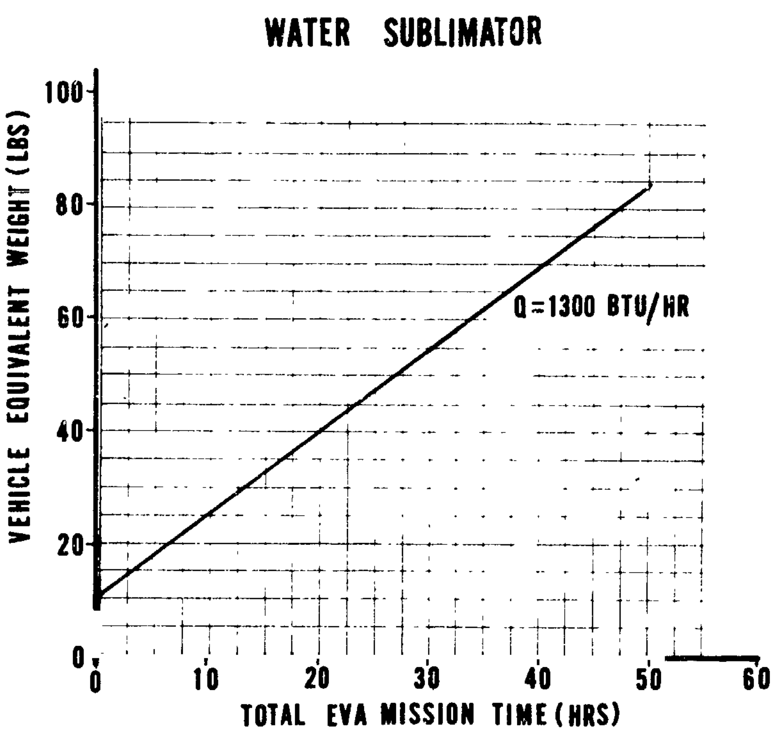


FIGURE 5–57

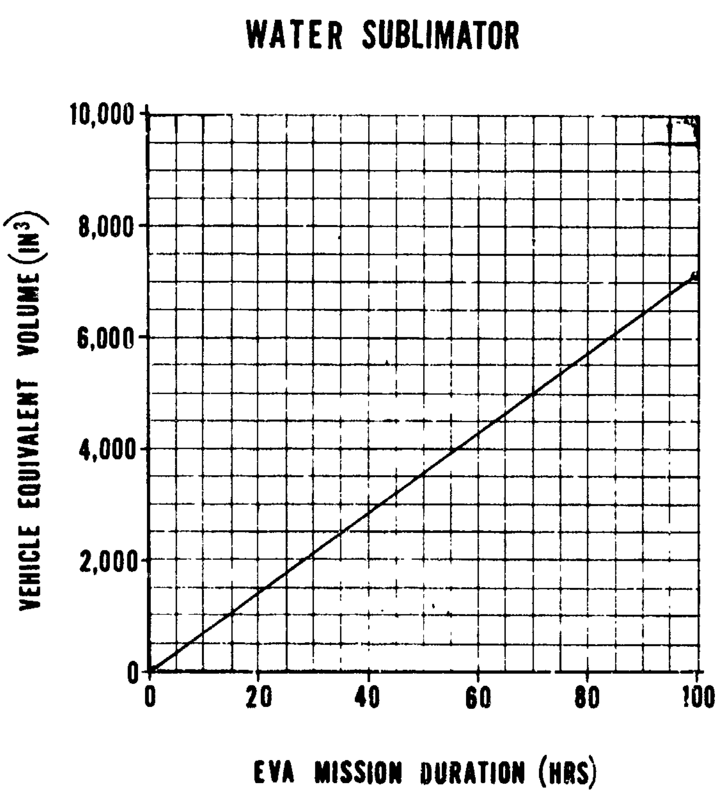


FIGURE 5–58

WATER SUBLIMATOR

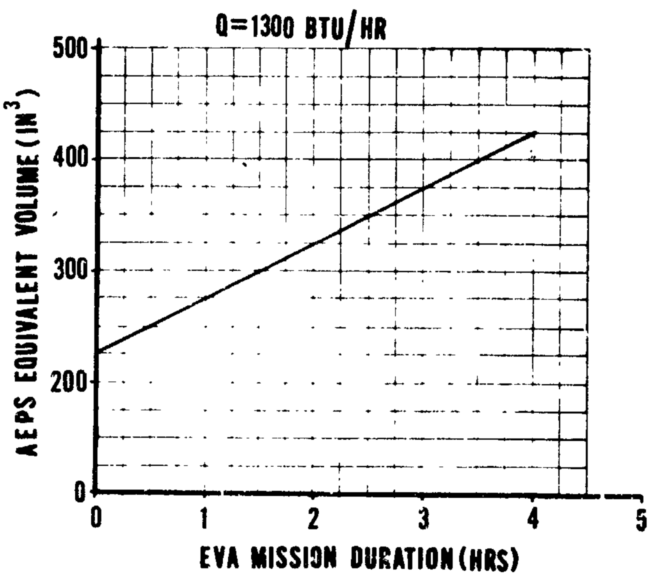


FIGURE 5–59

WATER SUBLIMATOR

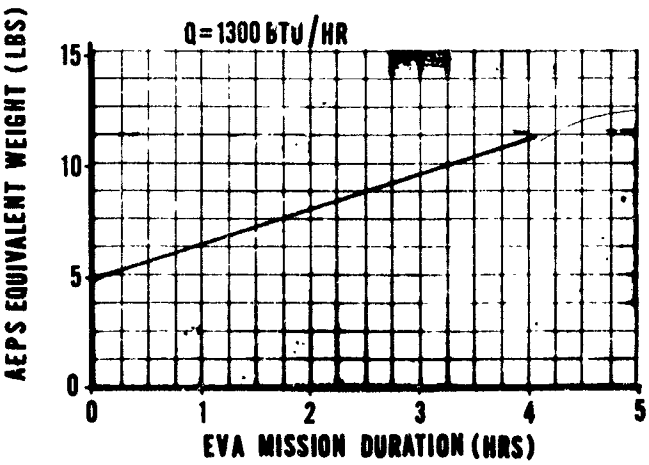


FIGURE 5–60

LITHIUM HYDROXIDE (LiOH)

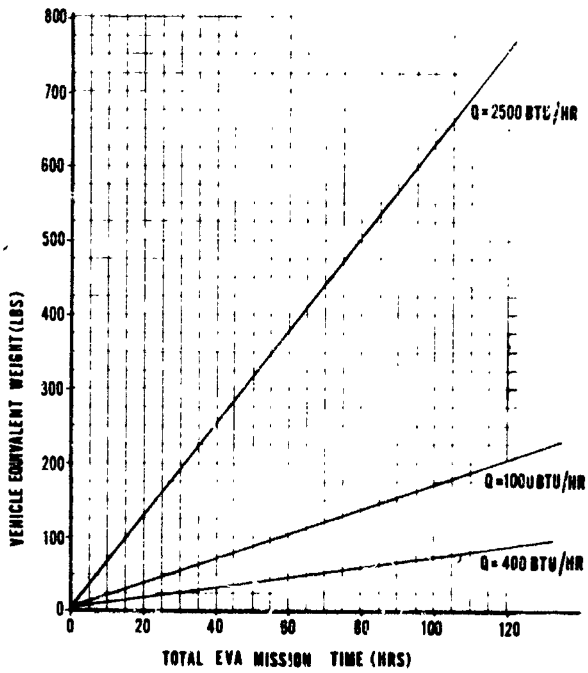


FIGURE 5—61

LITHIUM HYDROXIDE (LiOH)

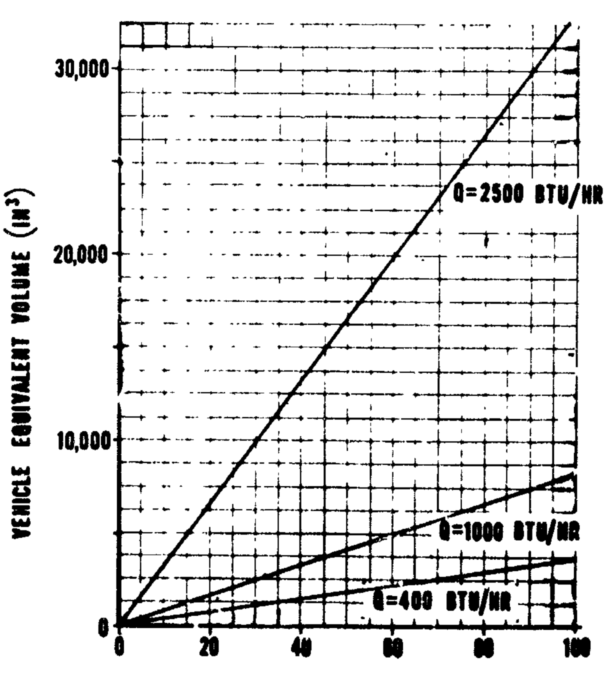


FIGURE 5—62

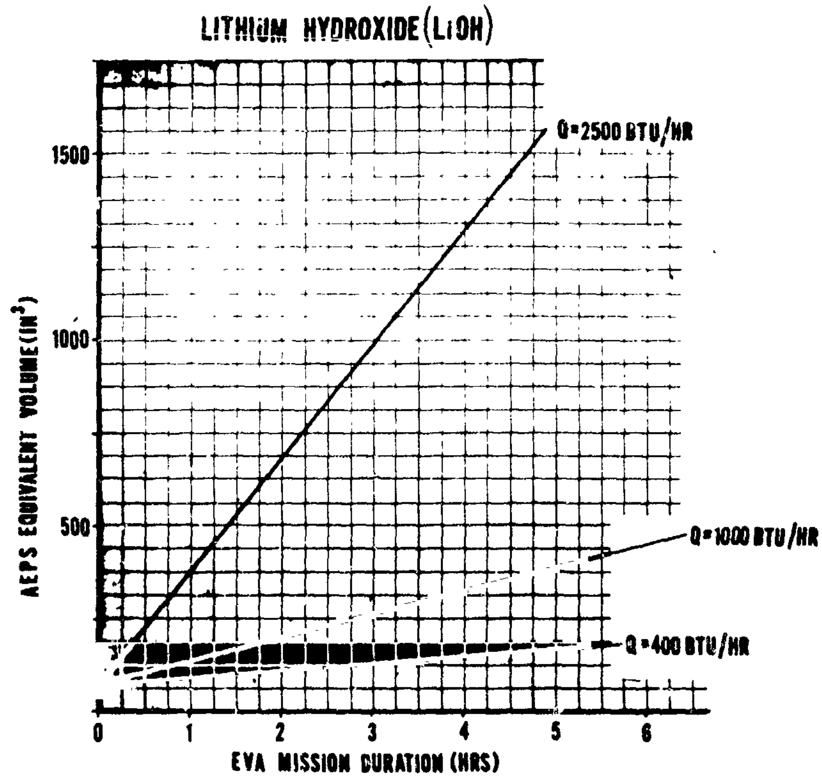


FIGURE 5—63

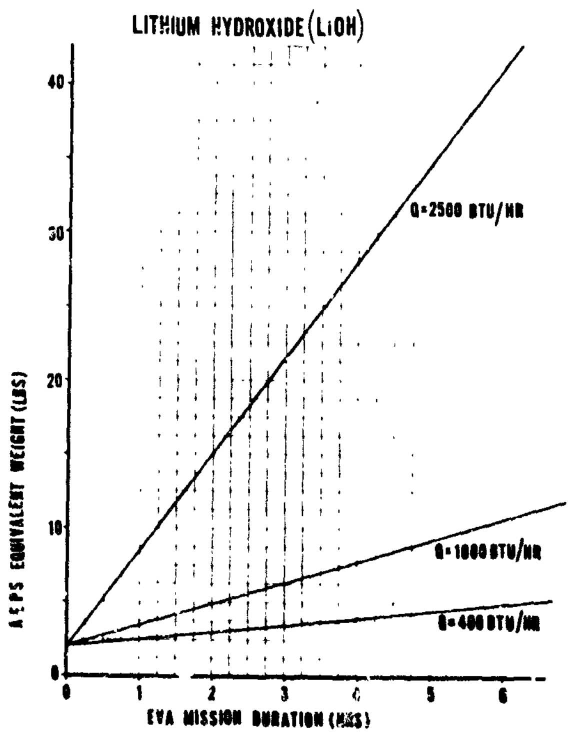


FIGURE 5—64

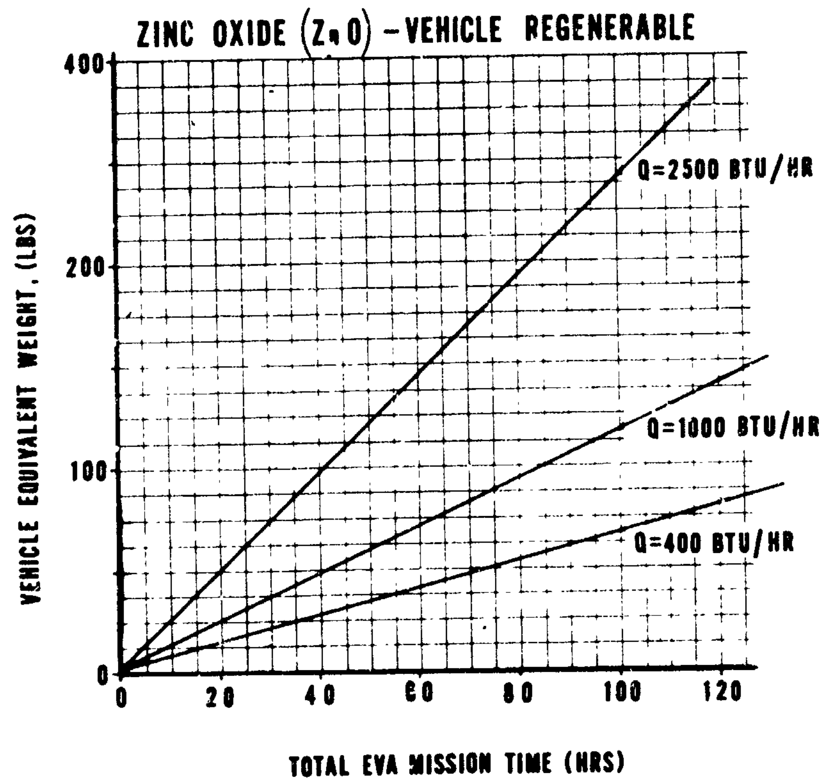


FIGURE 5-65

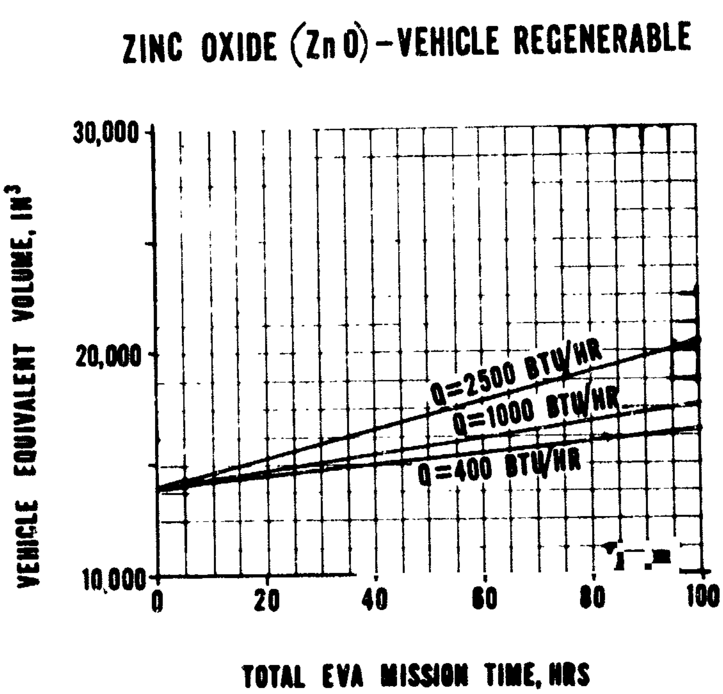


FIGURE 5-66

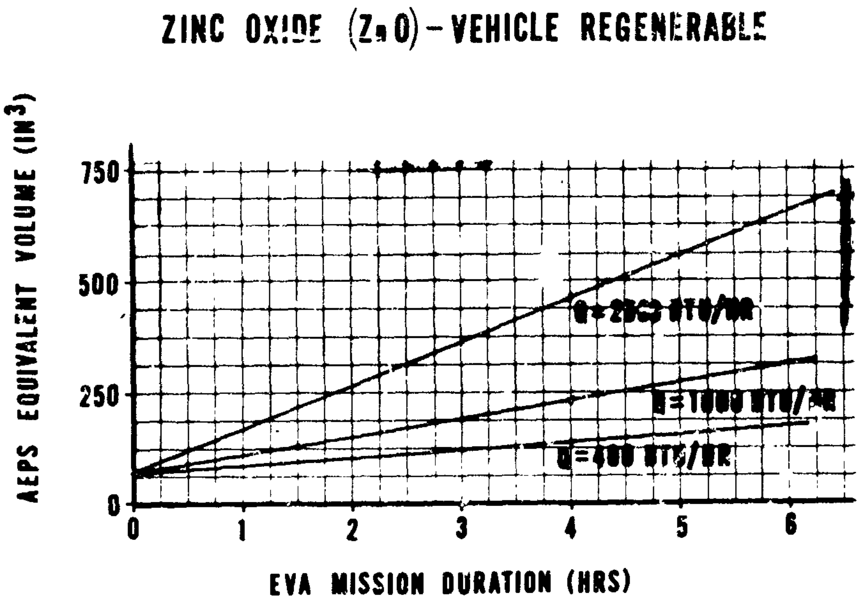


FIGURE 5-67

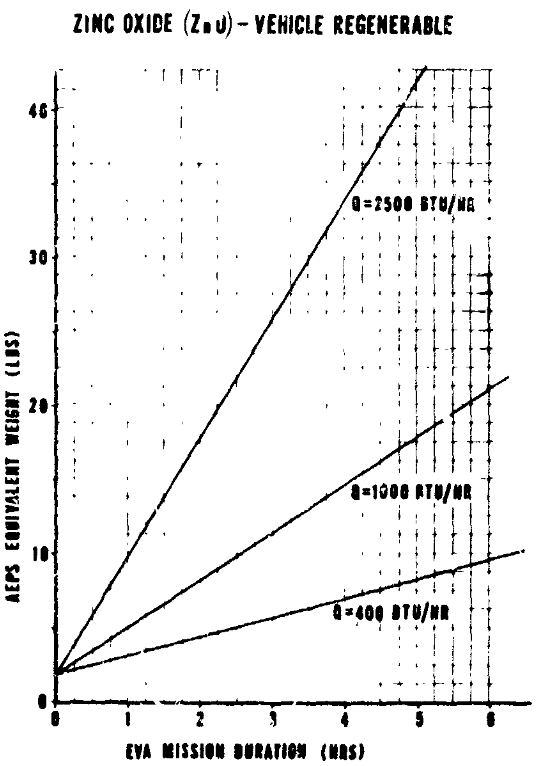


FIGURE 5-68

MAGNESIUM OXIDE (MgO) - VEHICLE REGENERABLE

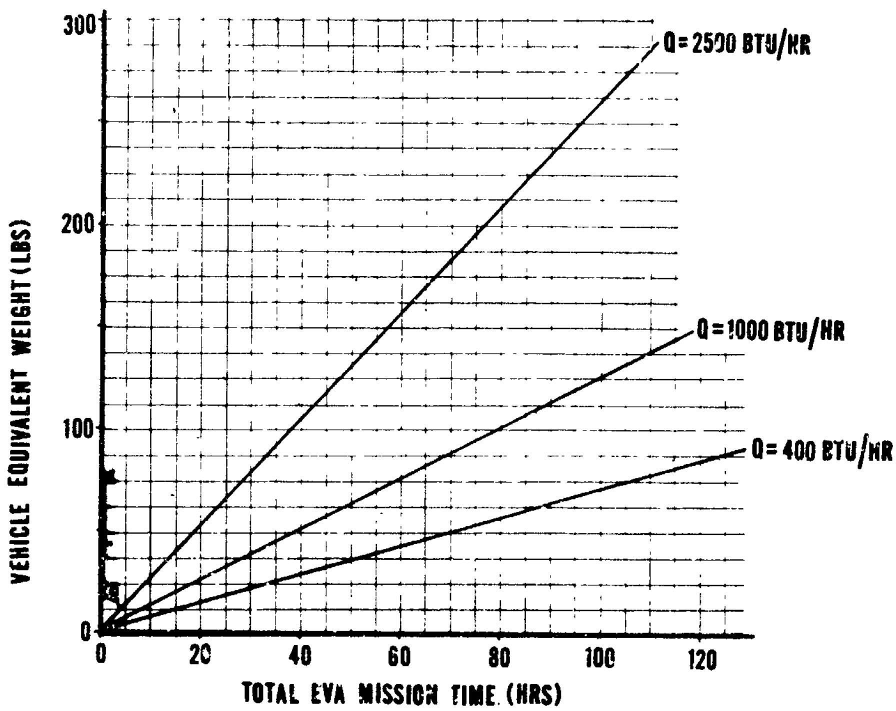
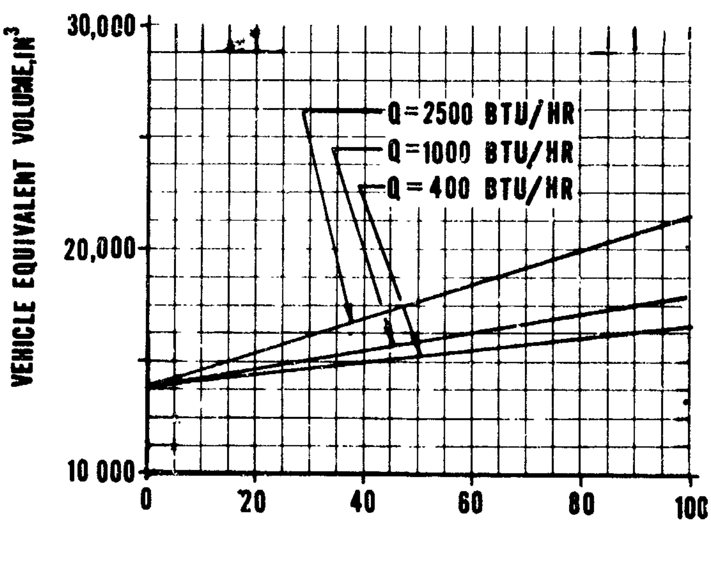


FIGURE 5—69

MAGNESIUM OXIDE (MgO)
—VEHICLE REGENERABLE



TOTAL EVA MISSION TIME, HRS

FIGURE 5—70

MAGNESIUM OXIDE (M_gO) - VEHICLE REGENERABLE

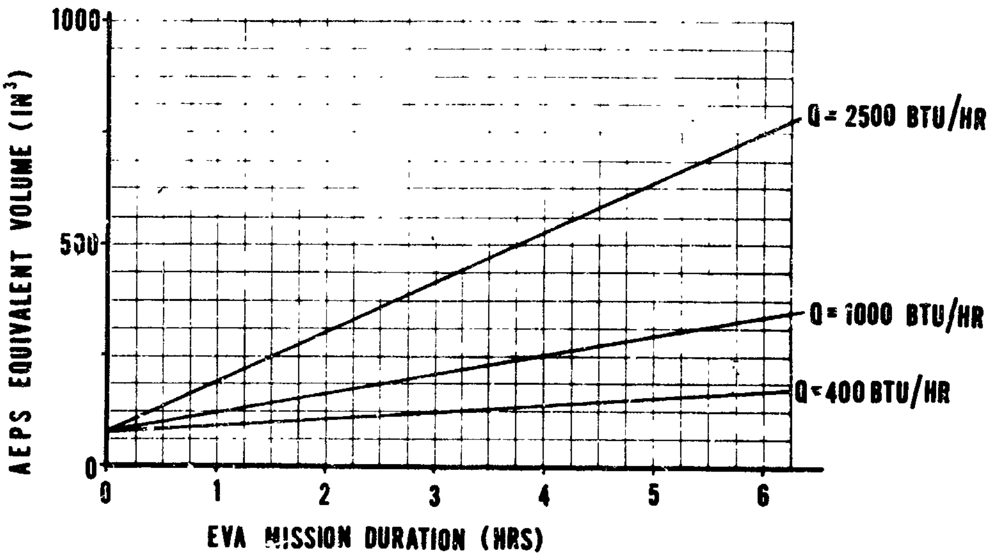


FIGURE 5—71

MAGNESIUM OXIDE (M_gO) - VEHICLE REGENERABLE

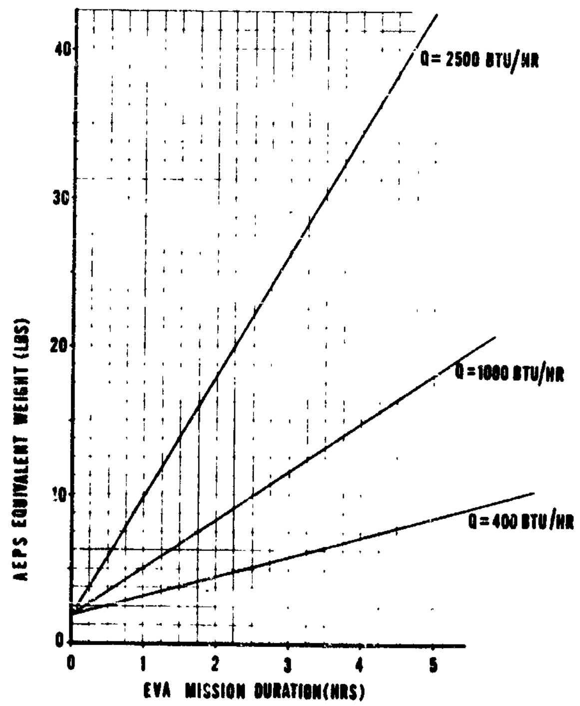


FIGURE 5—72

ZINC OXIDE (ZnO) - AEPS REGENERABLE

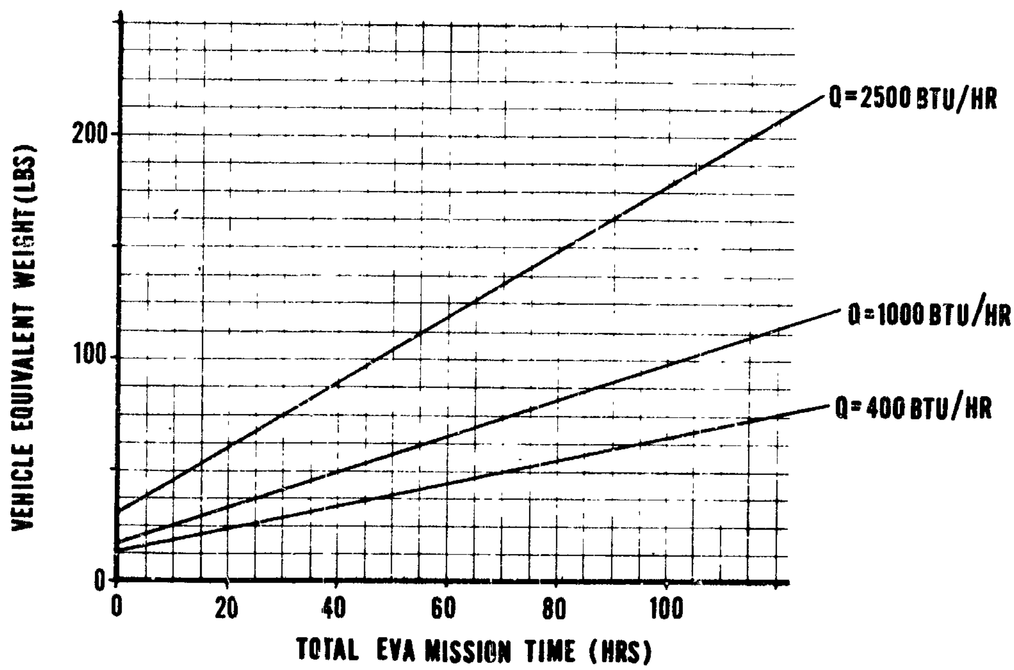


FIGURE 5-73

ZINC OXIDE (ZnO)-AEPS REGENERABLE

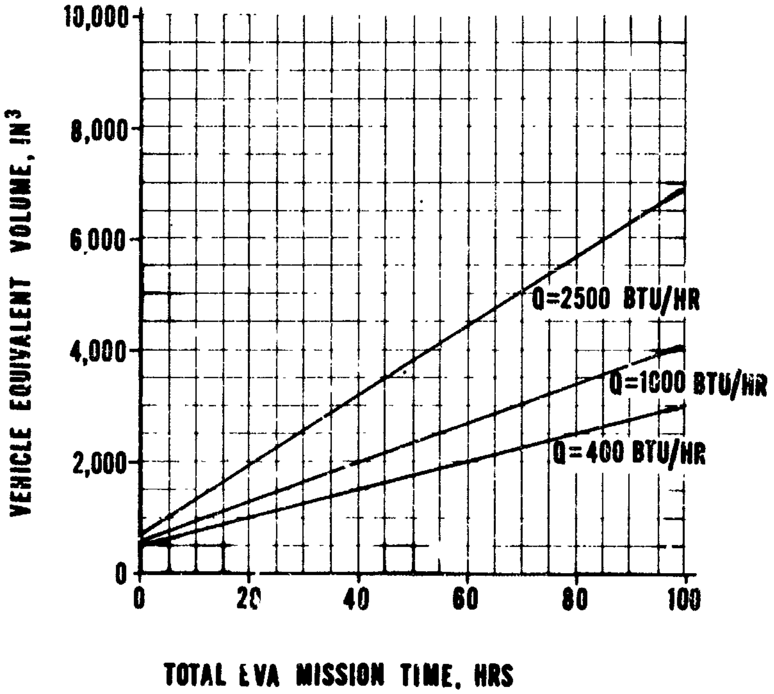


FIGURE 5-74

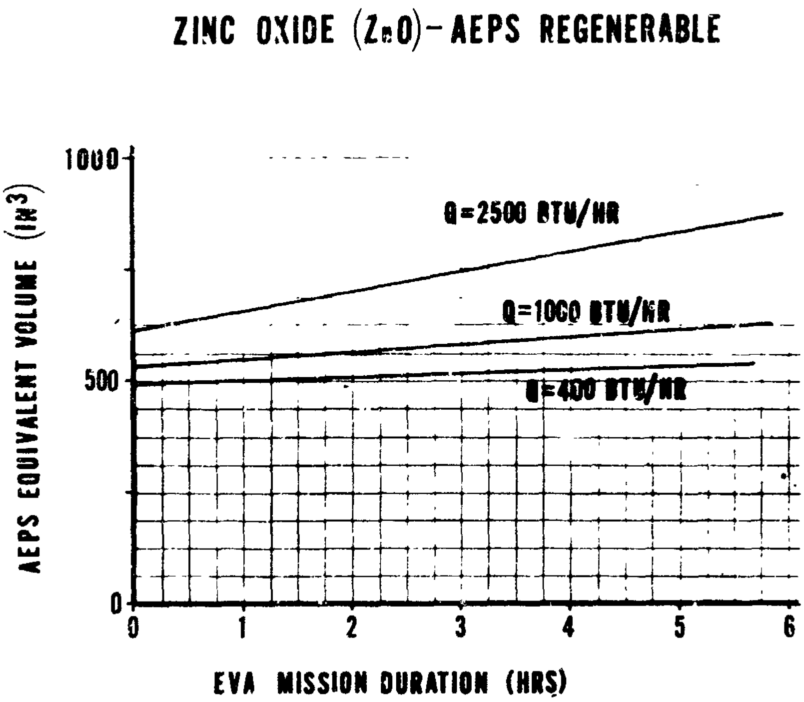


FIGURE 5–75

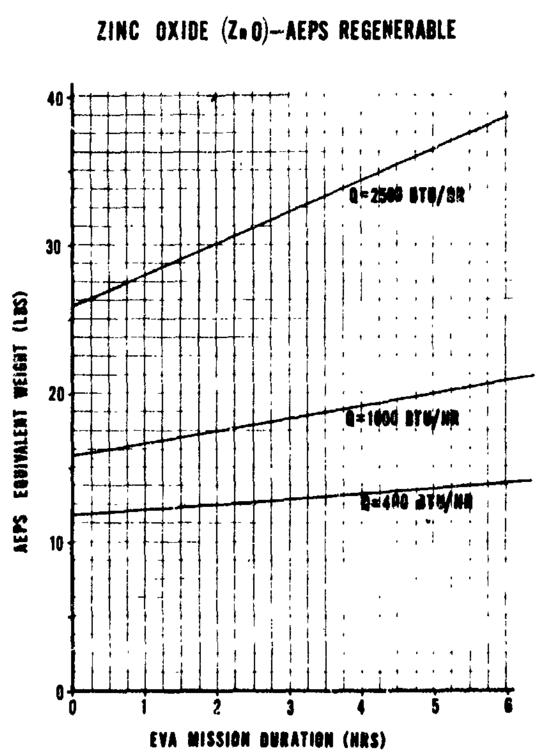


FIGURE 5–76

MAGNESIUM OXIDE (M_gO) - AEPS REGENERABLE

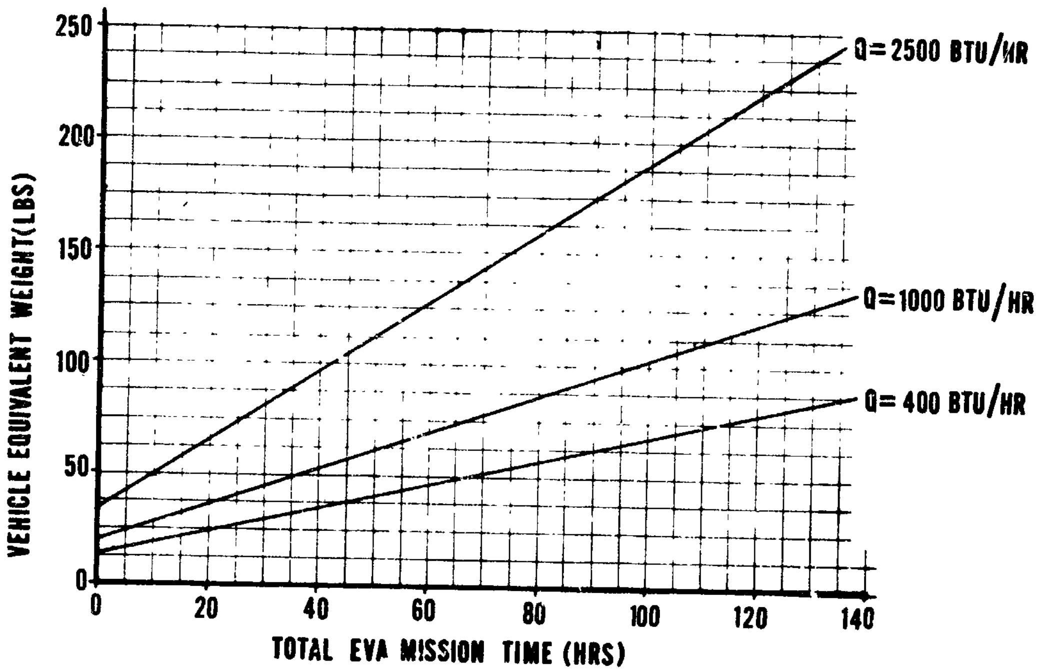


FIGURE 5–77

MAGNESIUM OXIDE (M_g O) –AEPS REGENERABLE

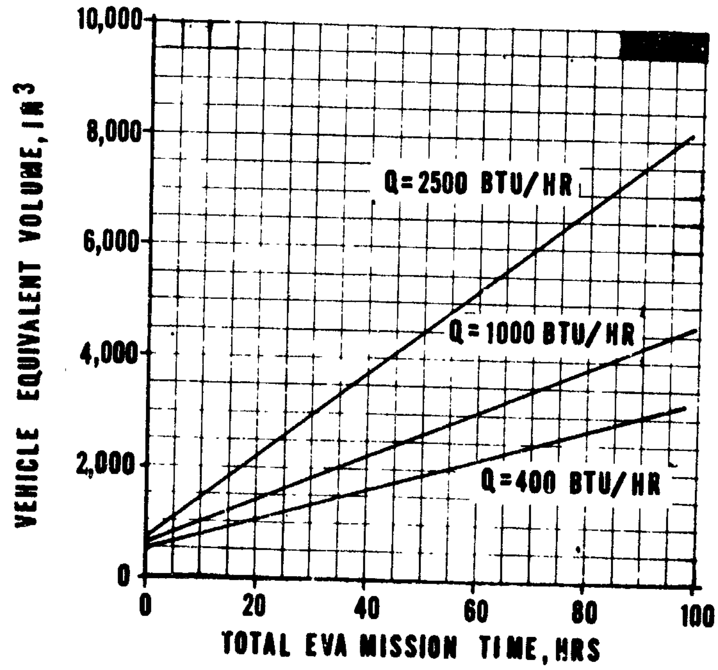


FIGURE 5–78

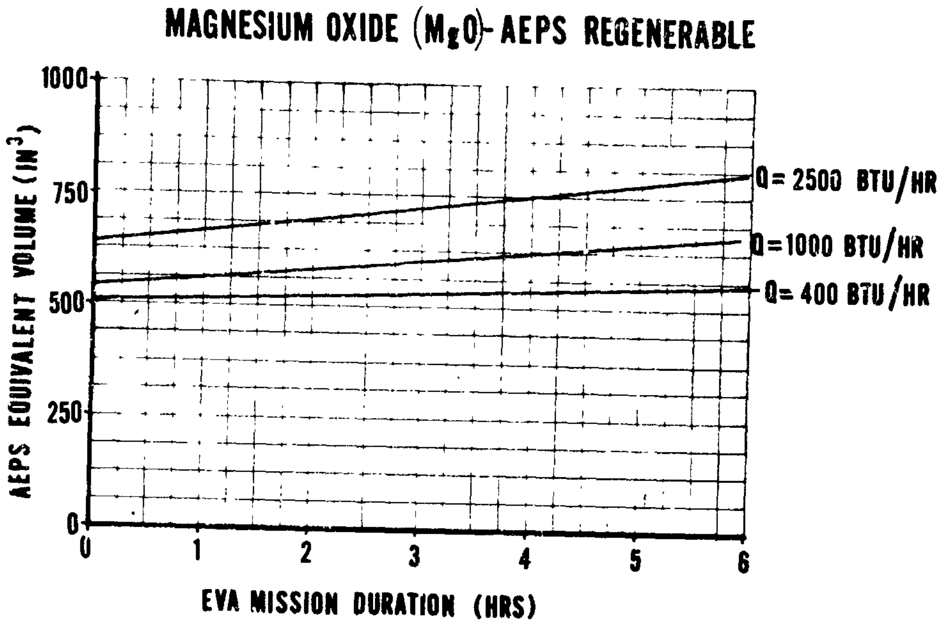


FIGURE 5–79

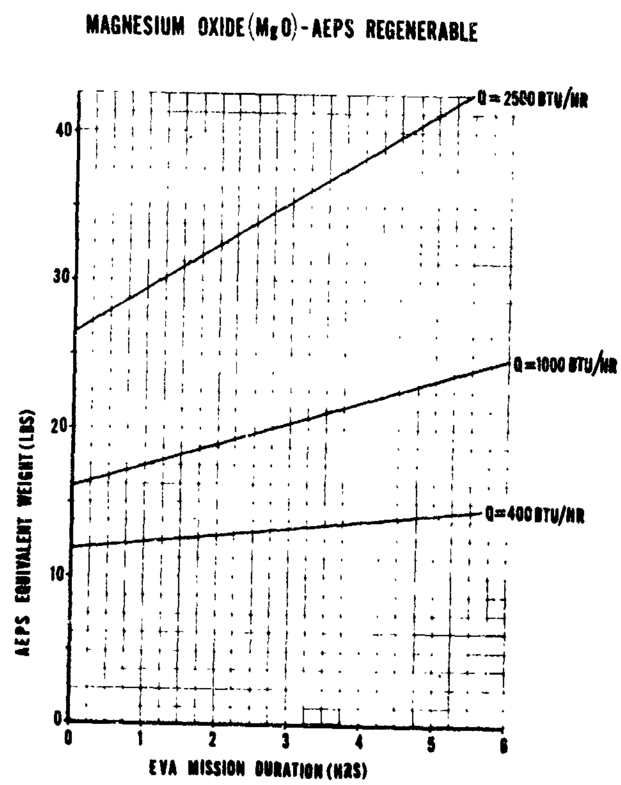


FIGURE 5–80

SOLID AMINE - AEPS REGENERABLE

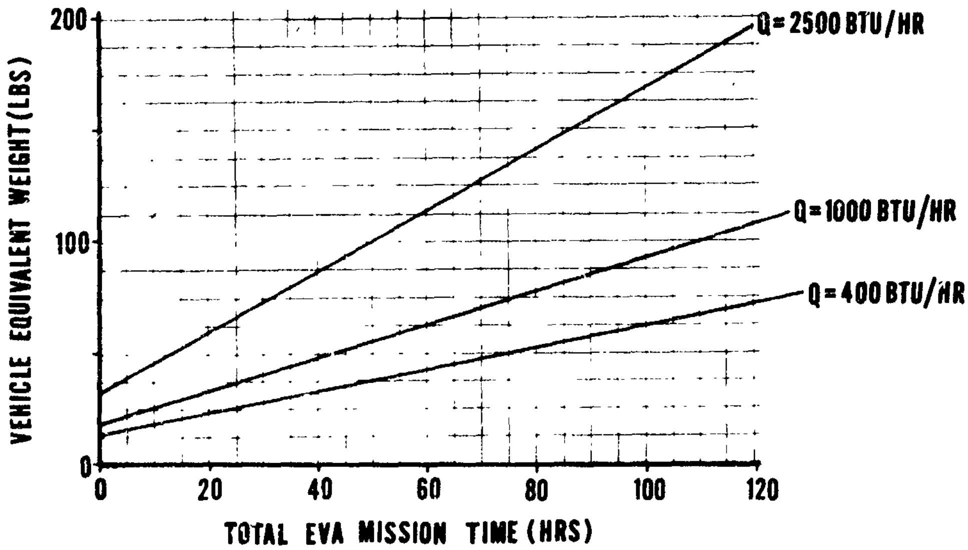


FIGURE 5-81

SOLID AMINE -AEPS REGENERABLE

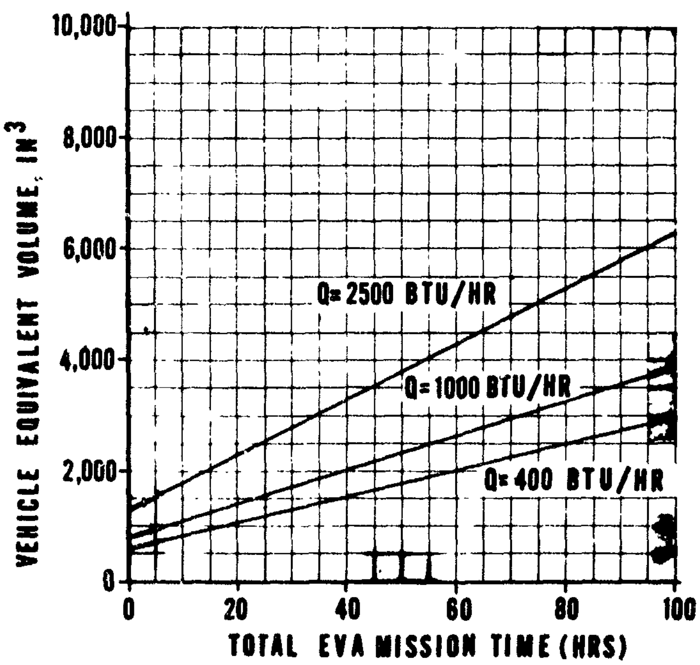


FIGURE 5-82

SOLID AMINE-AEPS REGENERABLE

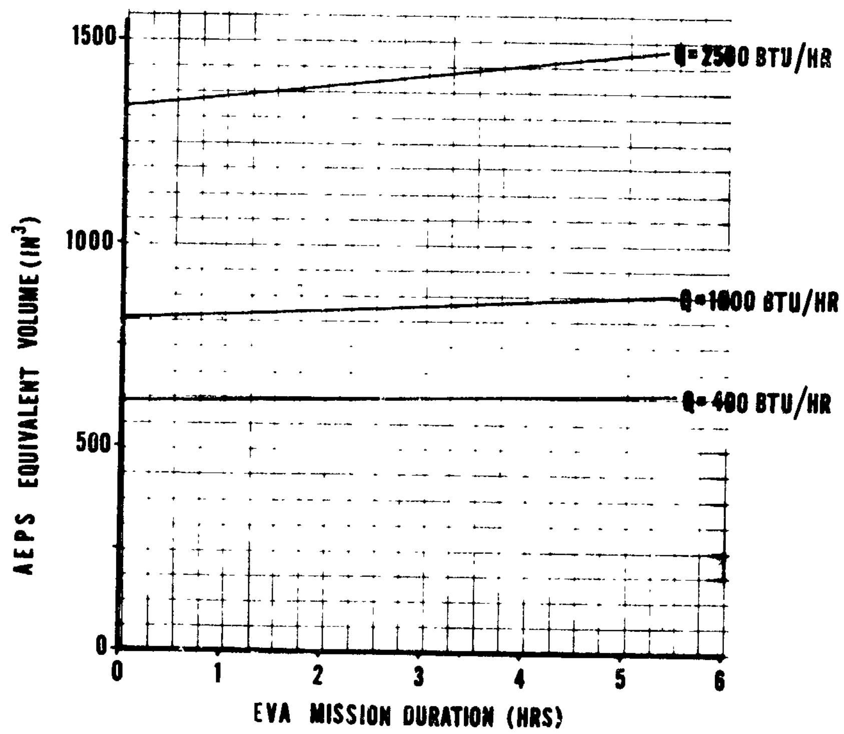


FIGURE 5–83

SOLID AMINE–AEPS REGENERABLE

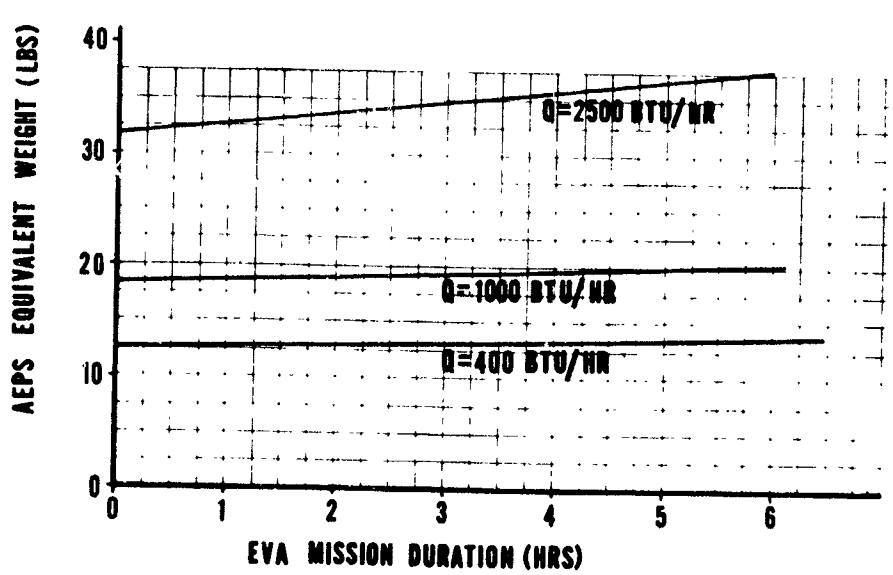


FIGURE 5–84

5.2.3 Emergency Systems

5.2.3.1 Thermal Control - The thermal control subsystem concepts recommended to be carried into the systems integration phase are:

Shuttle/Space Station

a. Water Boiler
b. Water Sublimator

Lunar Base/Mars

a. Water Boiler
b. Water Sublimator
c. Expendable/Thermal Storage-PH_4CI*
d. Expendable/Radiation-Heat Pump*

*Denotes a redundant primary system concept

A parametric analyses containing the above recommended subsystems together with all other candidate concepts considered are presented in the following Figures.

- Thermal control for Space Station/Shuttle Emergency Systems - Figures 5-85 and 5-86

- Thermal Control for Lunar Base Emergency Systems - Figures 5-87 and 5-88

- Thermal Control for Mars Emergency Systems - Figures 5-89 and 5-90

EMERGENCY SYSTEM THERMAL CONTROL
SPACE STATION/SHUTTLE

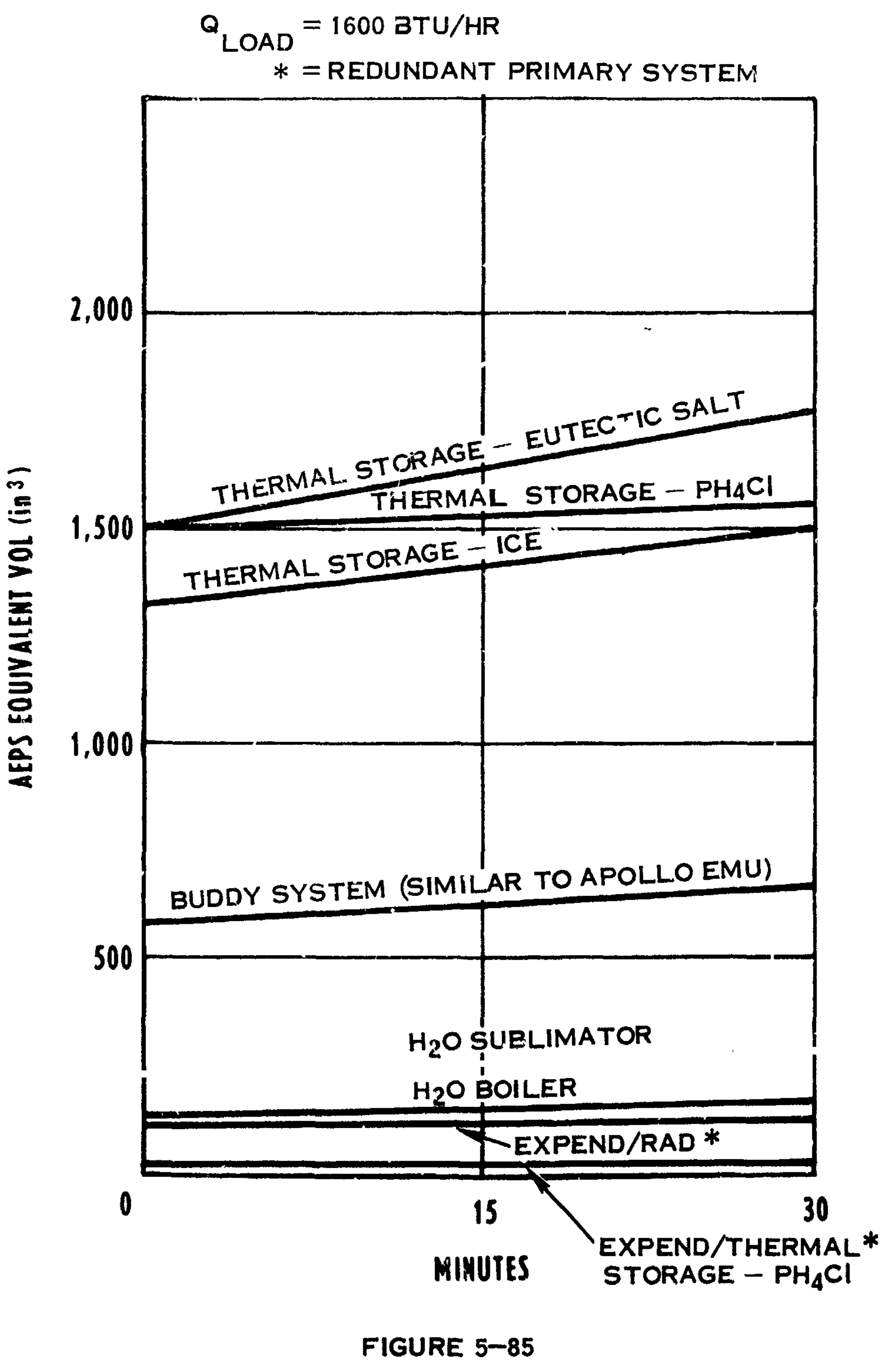


FIGURE 5–85

EMERGENCY SYSTEM THERMAL CONTROL

SPACE STATION/SHUTTLE

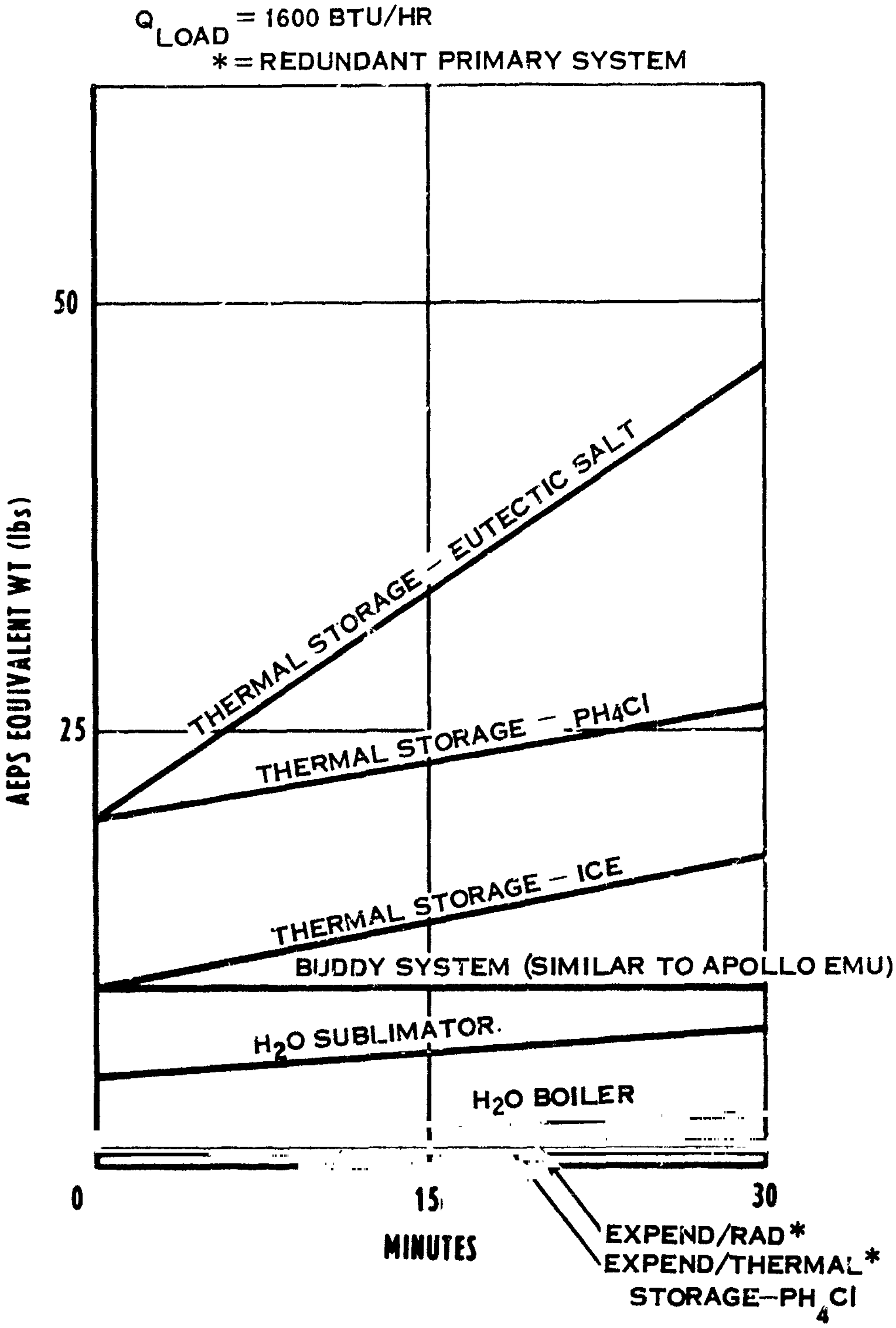


FIGURE 5–86

EMERGENCY SYSTEM THERMAL CONTROL
LUNAR BASE

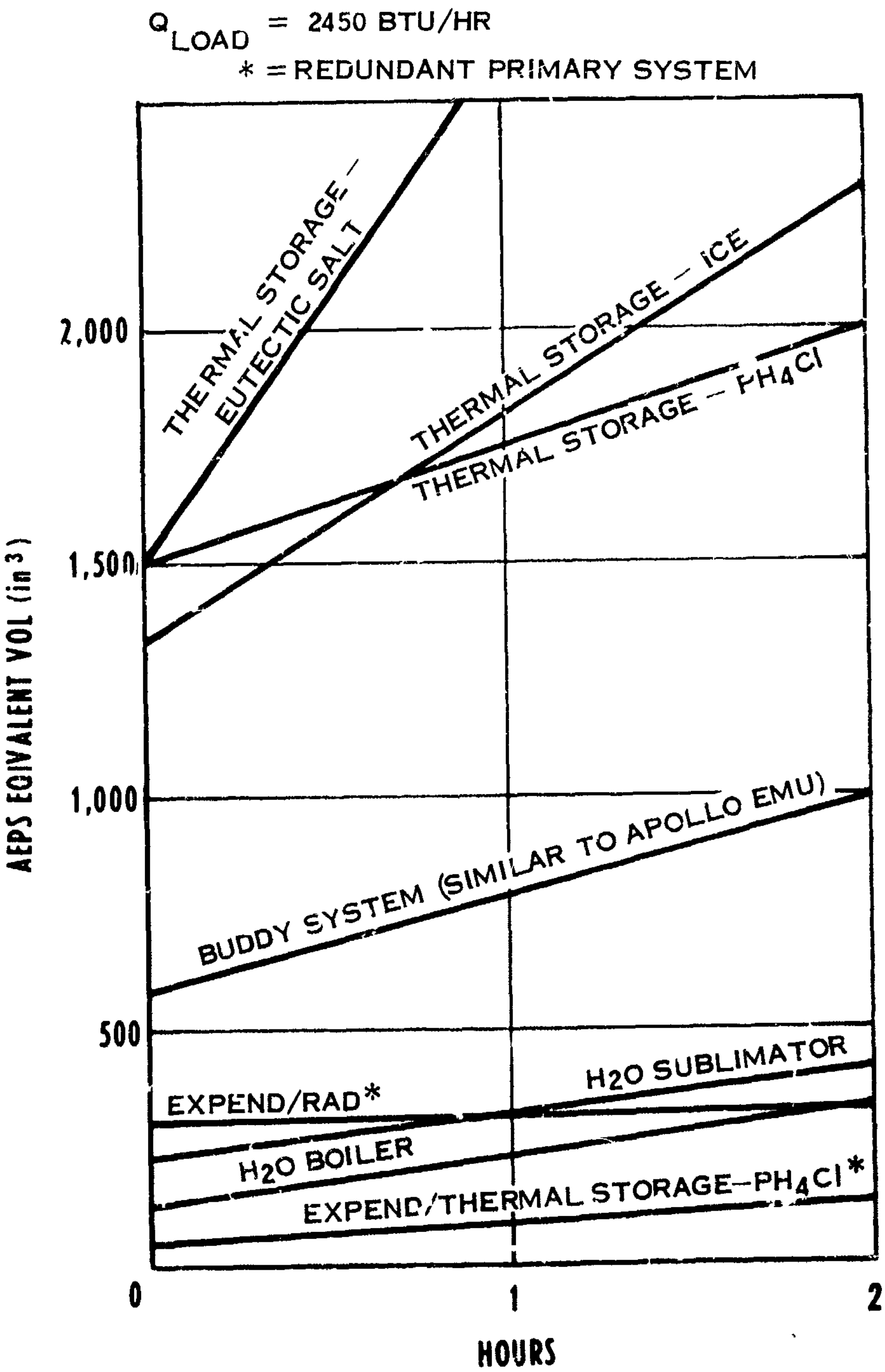


FIGURE 5–87

EMERGENCY SYSTEM THERMAL CONTROL

LUNAR BASE

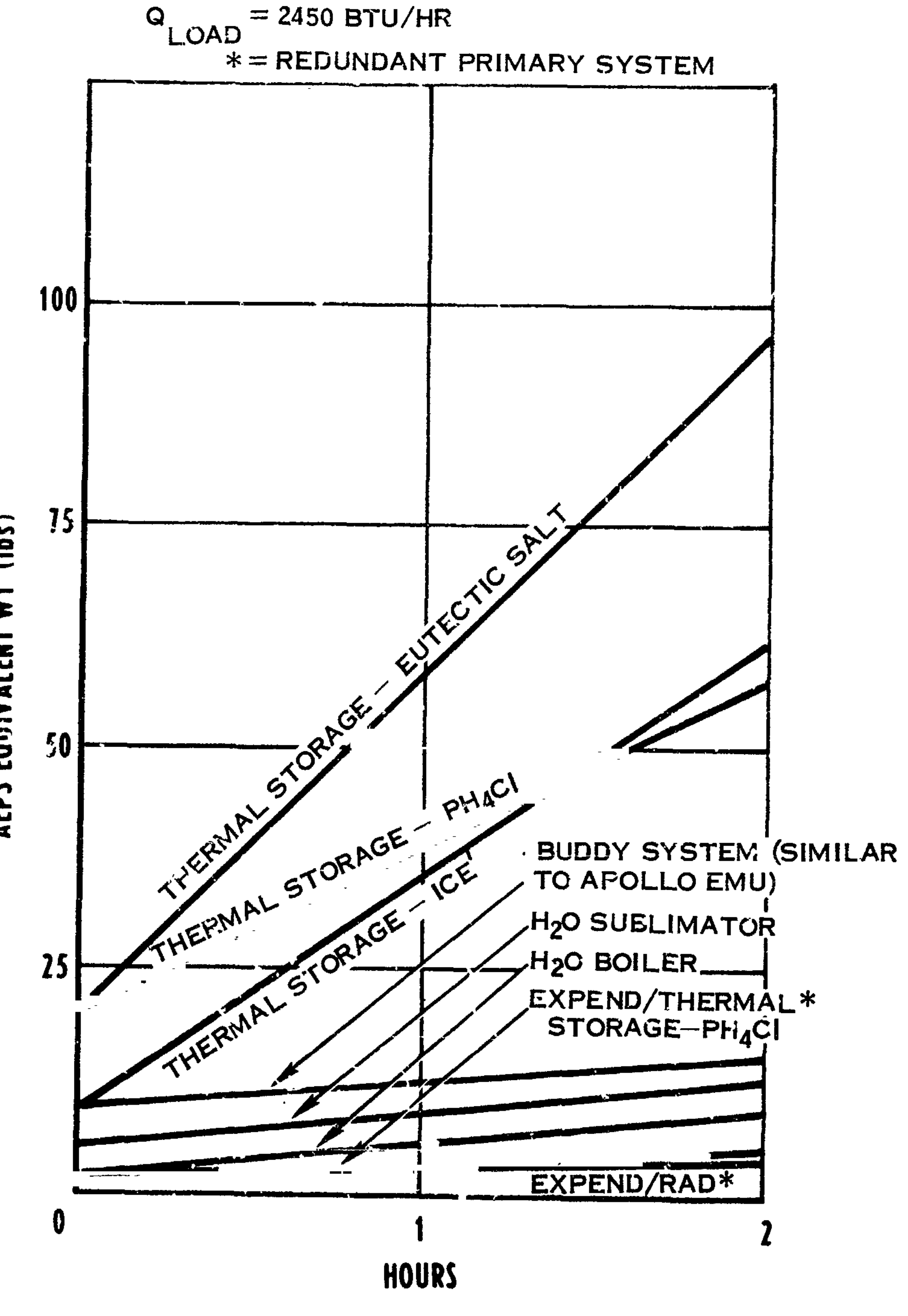


FIGURE 5–88

EMERGENCY SYSTEM THERMAL CONTROL

MARS

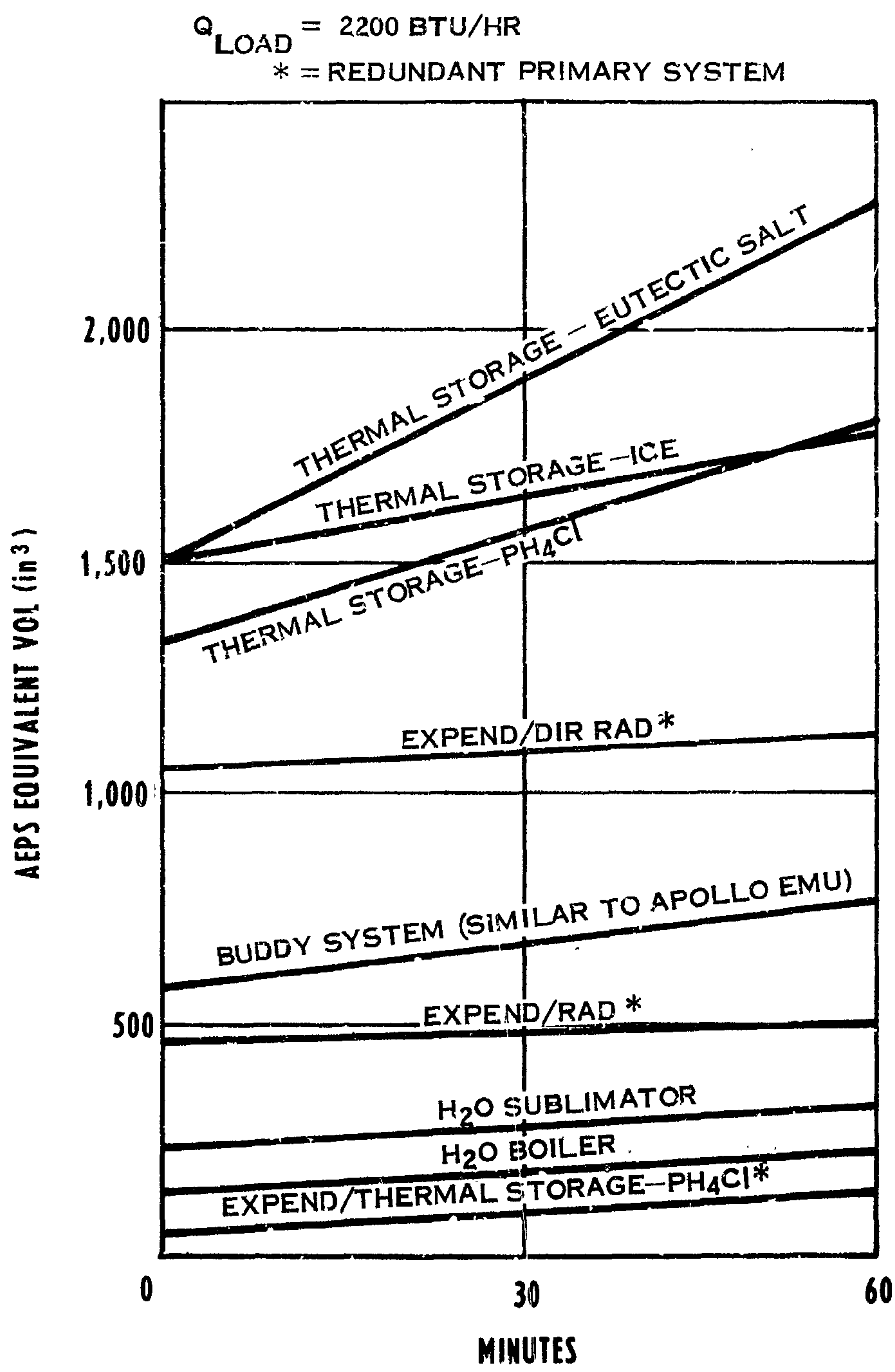


FIGURE 5–89

EMERGENCY SYSTEM THERMAL CONTROL

MARS

Q_{LOAD} = 2200 BTU/HR

* = REDUNDANT PRIMARY SYSTEM

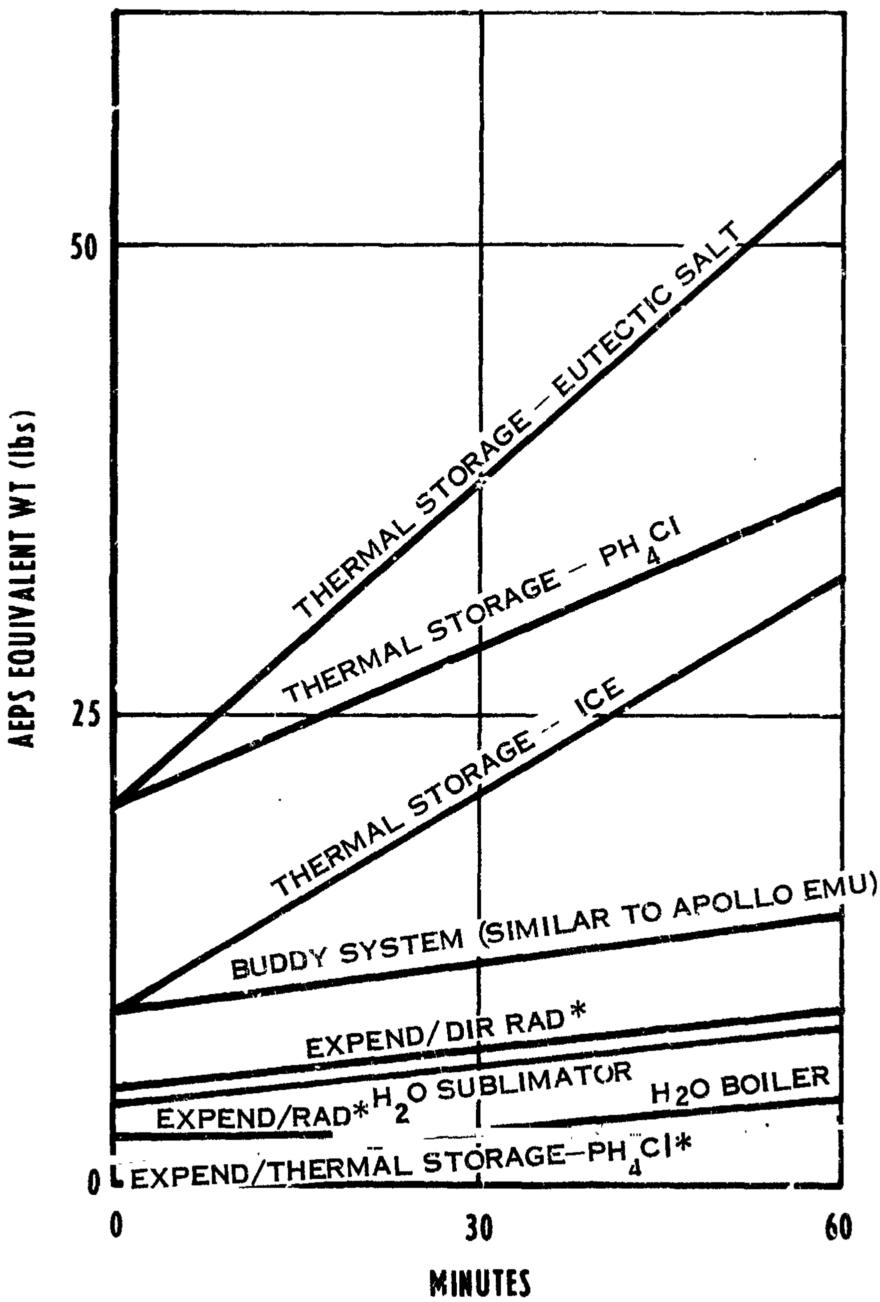


FIGURE 5–90

5.2.3.2 CO_2 Control/O_2 Supply - Due to the overall systems implications of some of the candidate CO_2 control/O_2 supply concepts (specifically the open loop and semi-open loop concepts), final subsystem recommendations were postponed until the systems studies. However, a parametric analyses of the candidate concepts are presented in the following Figures for informational purposes. Those CO_2 control and O_2 supply subsystem which appear in the parametric analyses but are not discussed elsewhere in this volume may be found in Volume II - Subsystem Studies.

- CO_2 Control/O_2 Supply for Space Station/Shuttle Emergency Systems - Figures 5-91 and 5-92
- CO_2 Control/O_2 Supply for Lunar Base Emergency Systems - Figures 5-93 and 5-94
- CO_2 Control/O_2 Supply for Mars Emergency Systems - Figures 5-95 and 5-96

EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY

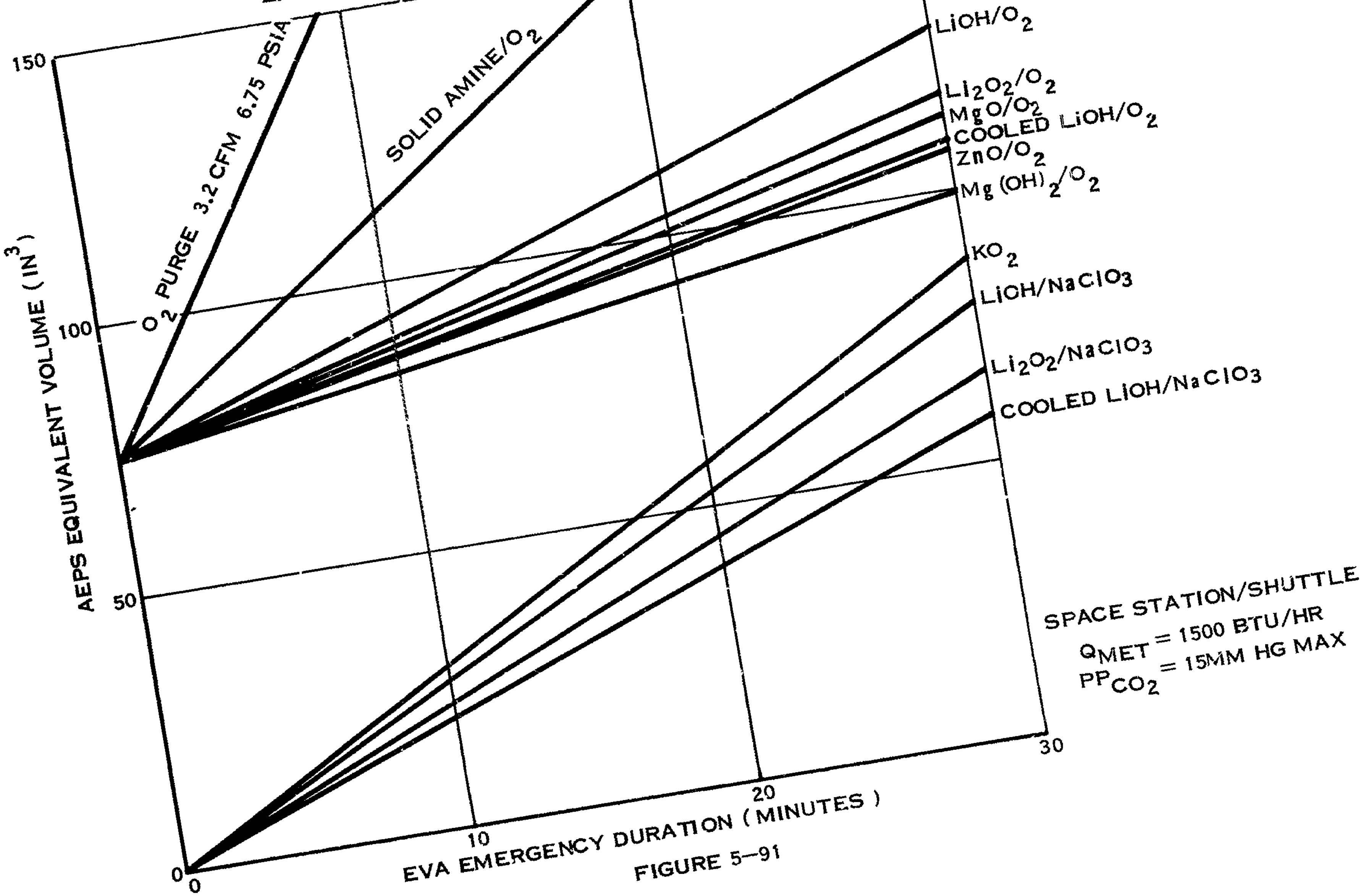
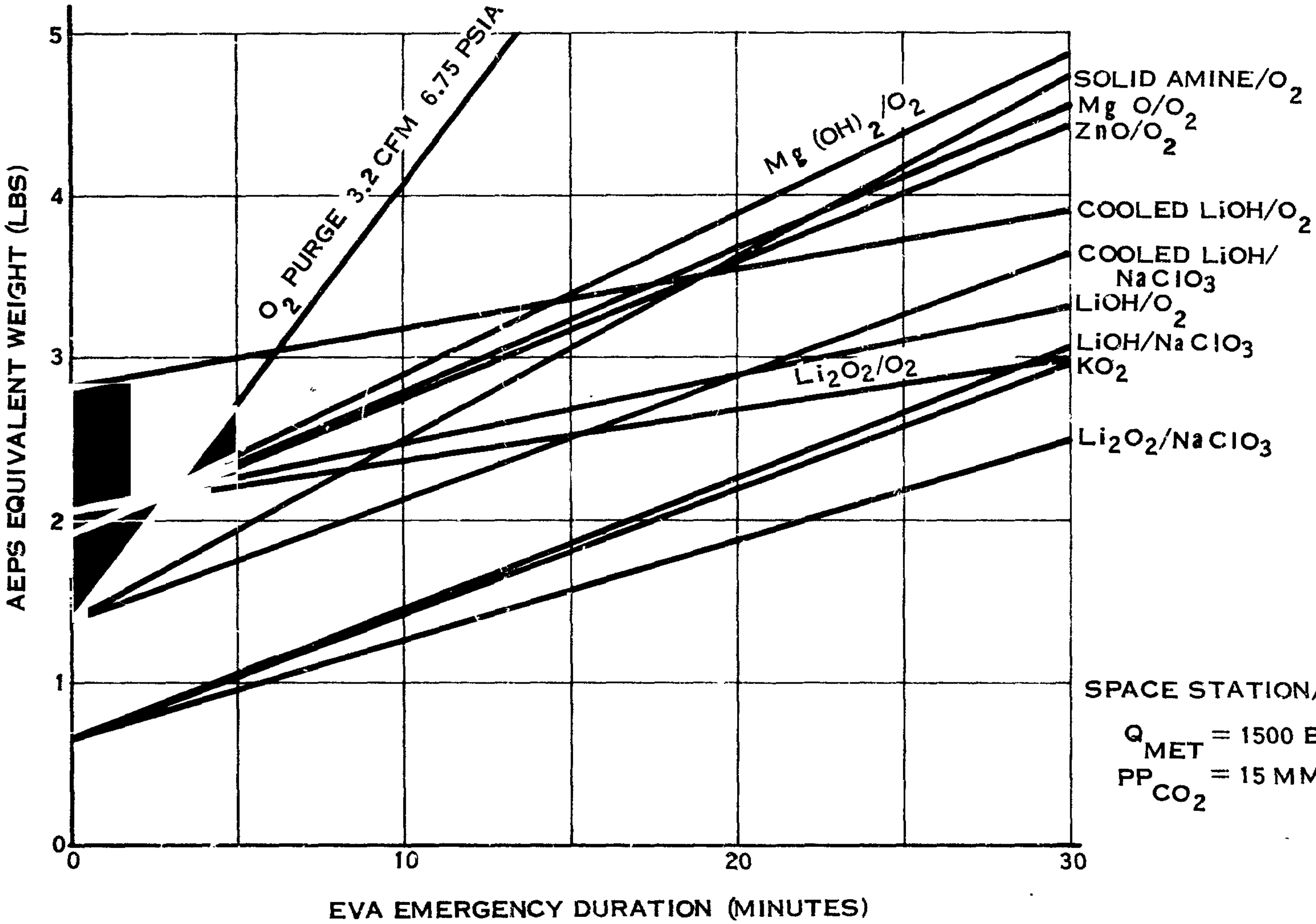


FIGURE 5–91

EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY



SPACE STATION/SHUTTLE

$Q_{MET} = 1500$ BTU/HR

$PP_{CO_2} = 15$ MM HG MAX

FIGURE 5–92

EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY

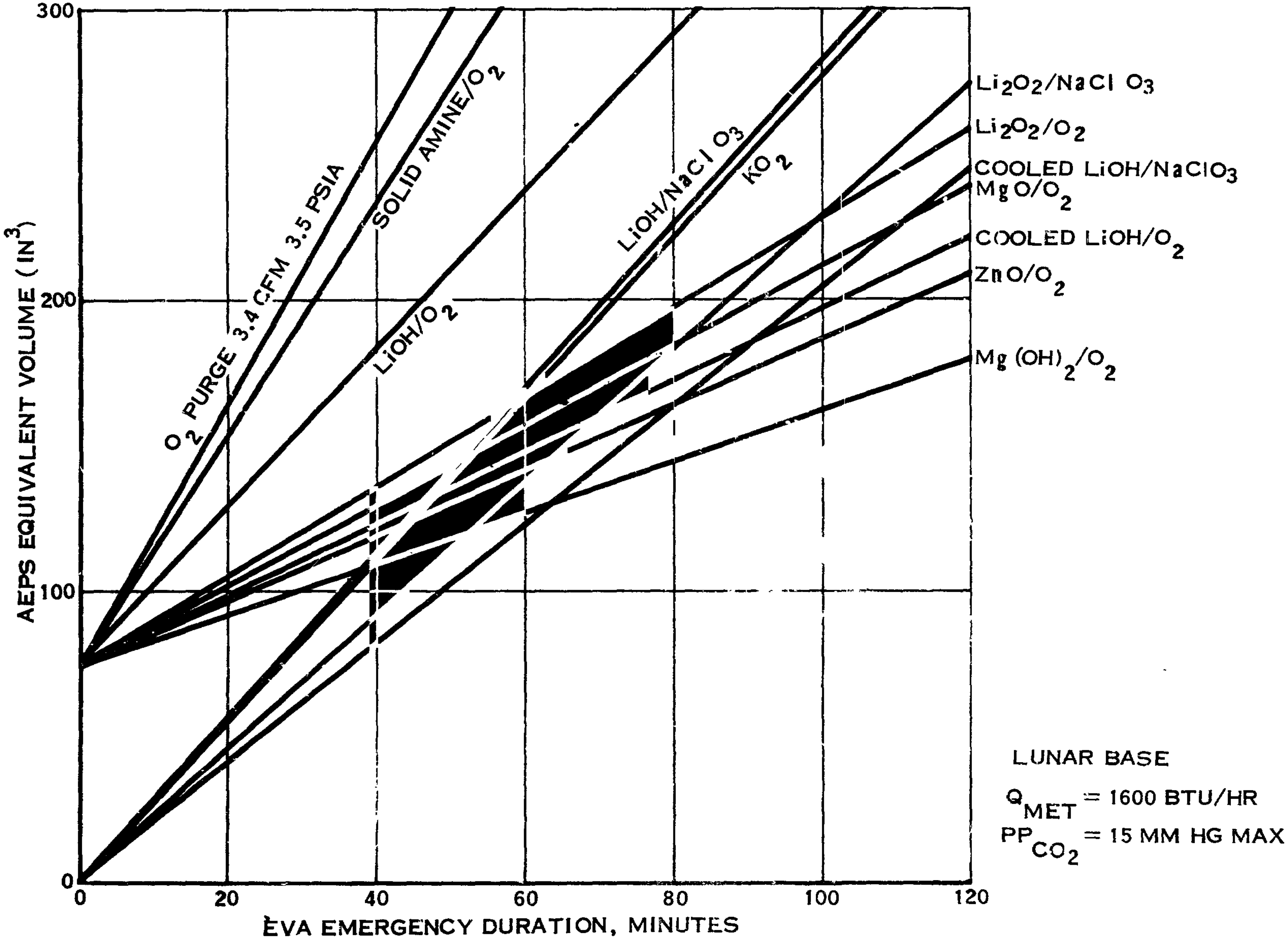


FIGURE 5—93

EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY

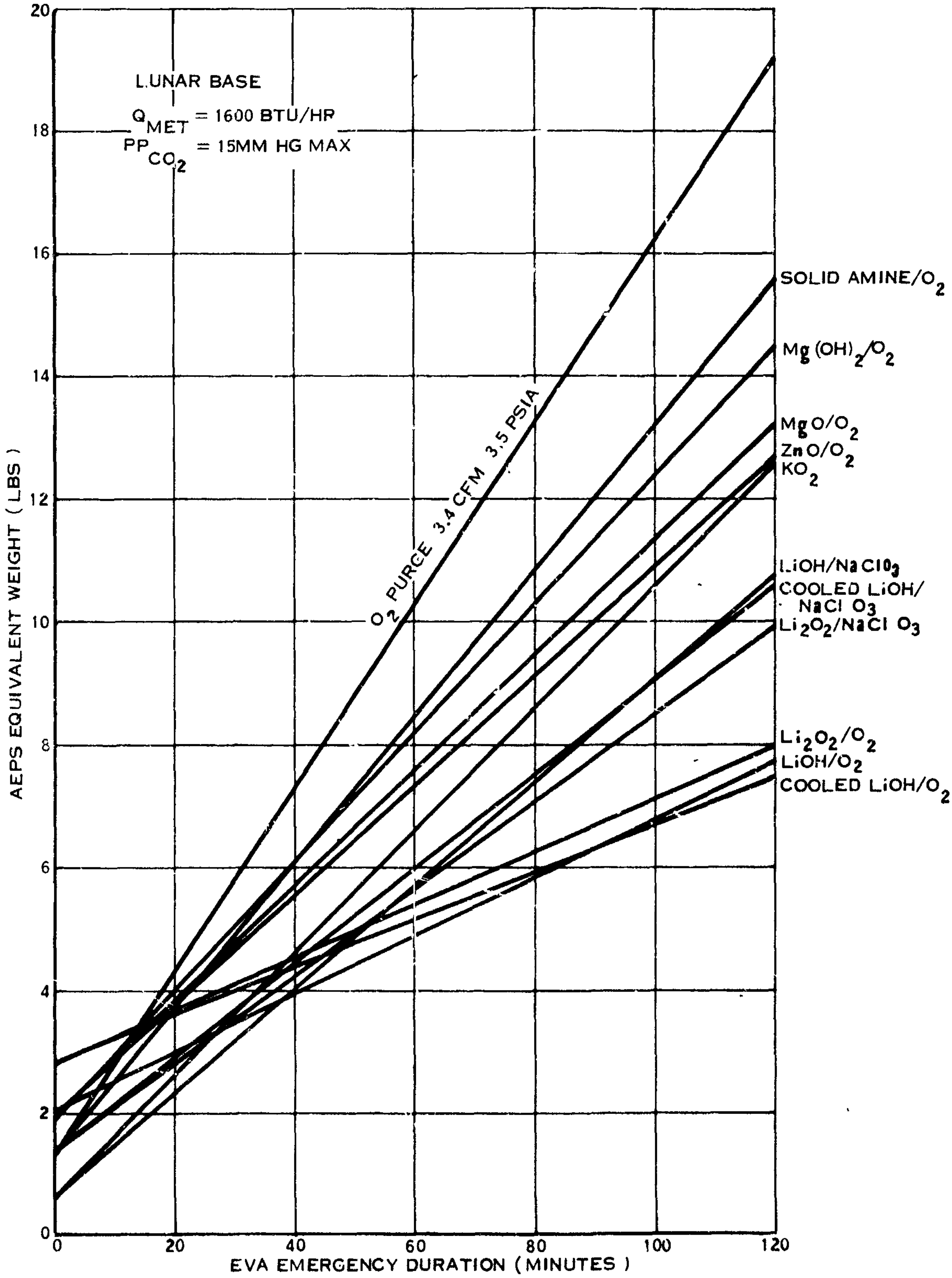


FIGURE 5—94

EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY

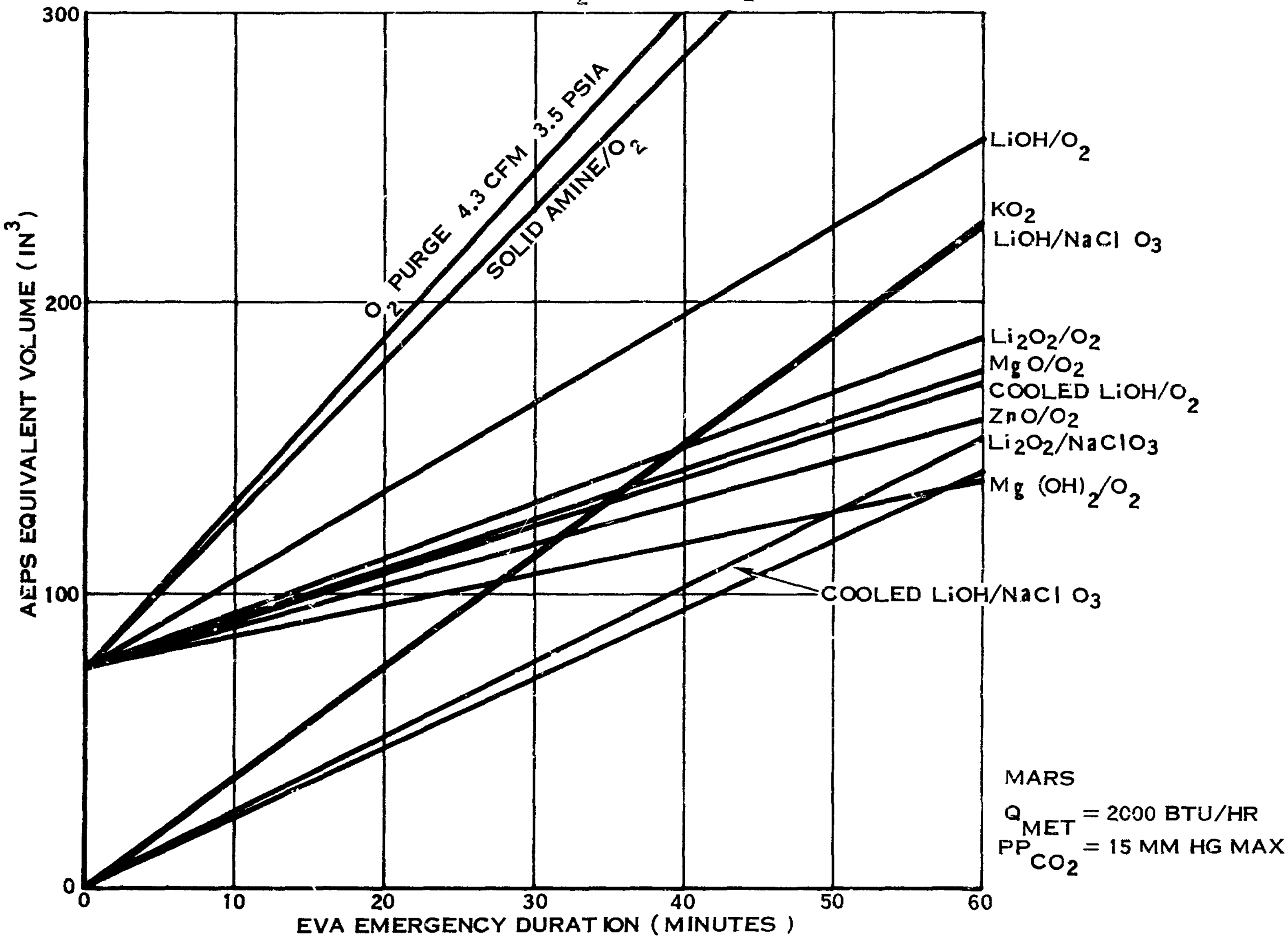


FIGURE 5–95

EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY

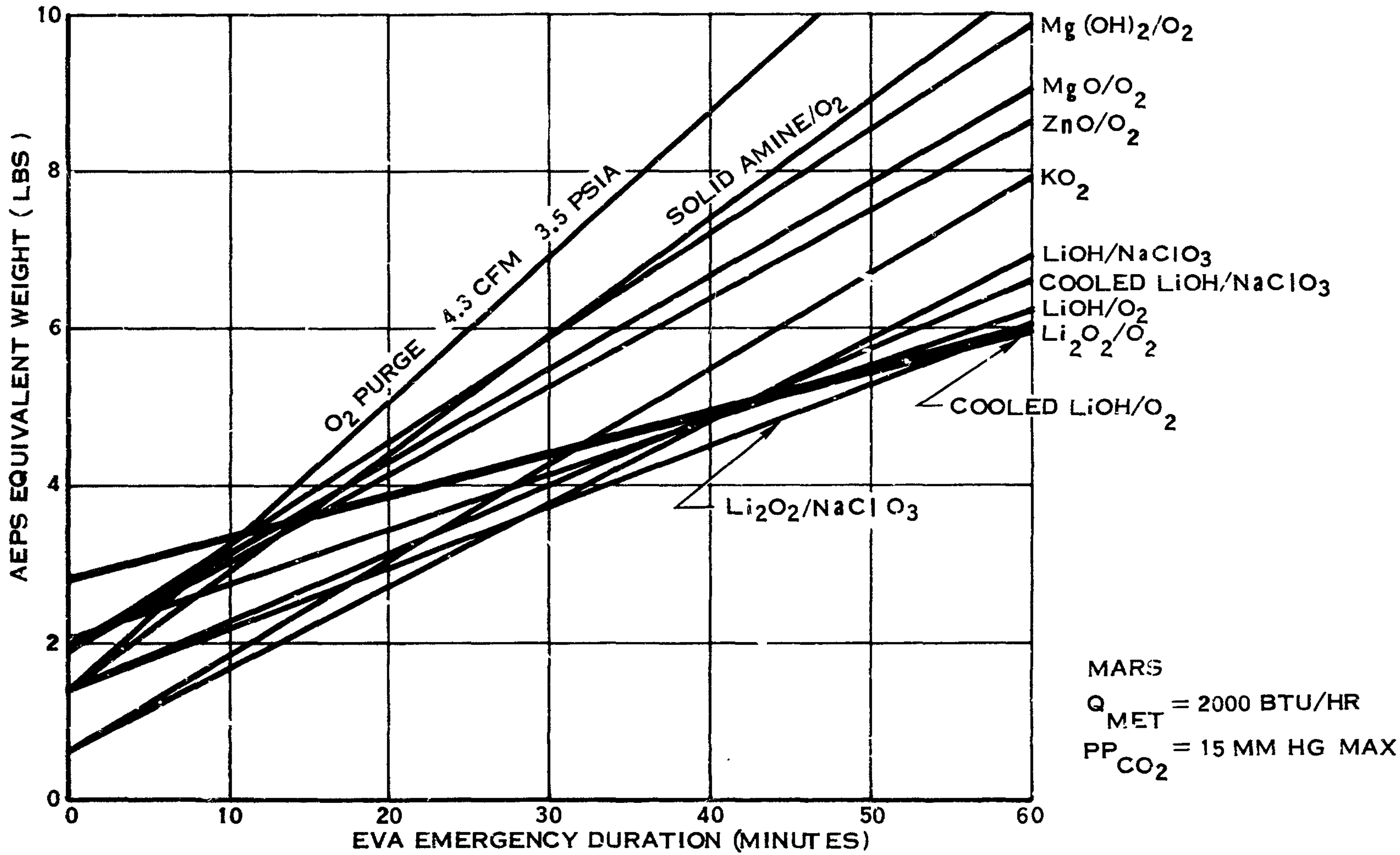


FIGURE 5–96

6.0 SYSTEM SUMMARY

6.0 SYSTEM STUDIES

6.1 General

After completion of the phase one subsystem studies, a systems integration effort was conducted wherein the recommended subsystem concepts were combined into several candidate baseline Space Station, Lunar Base and Mars AEPS configurations. The systems integration effort evaluated the following elements that could not be fully evaluated on the subsystem level:

a. AEPS Operating Pressure
b. Oxygen Storage Pressure Level
c. Contaminant Control
d. Humidity Control
e. Power Supply
f. Instrumentation
g. Controls and displays
h. Suit and vehicle interfaces

In addition, the systems integration effort evaluated the functional and physical interfaces of the recommended thermal control and CO_2 control / O_2 supply subsystems. The candidate AEPS baseline configurations were then subjected to a comparative evaluation utilizing the primary and secondary evaluation criteria defined in Section 4.0. Results of this evaluation led to the selection of the Space Station, Lunar Base and Mars AEPS baseline concepts. A baseline concept is defined as a competitive AEPS concept for a given set of EVA mission requirements and Mission/Vehicle constraints.

The phase two system studies utilized the systems integration effort conducted during phase one as a basis for the determination of a shuttle AEPS baseline concept and the Space Station, Lunar Base, Mars and Shuttle Emergency System baselines.

This section discusses each of the tasks investigated and evaluated in the conduct of the systems integration effort and presents the AEPS baseline concepts and the emergency system baseline concepts.

6.2 Systems Integration

6.2.1 AEPS Operating Pressure

Selection of a suit pressure level is dependent upon the physiological and operational constraints imposed on the crewman and his equipment by:

a. Denitrogenation requirements prior to decompression.

b. Oxygen toxicity.

6.2.1 (Continued)

The objective of this task is to establish an acceptable suit operating pressure level and an EVA mission pressure timeline for the use of a one-gas (pure oxygen) EVA Life Support System operating in conjunction with a two-gas (oxygen: nitrogen) Space System, Lunar Base, Mars Excursion Module or Shuttle vehicle. To be considered acceptable, the selected pressure level should eliminate or require a minimum of prebreathing, yet not adversely affect the crewman or his performance. This section presents a summary discussion of decompression sickness and oxygen toxicity and their potential effect upon EVA. A more detailed discussion of AEPS operating pressure level is found in Volume II.

6.2.1.1 Decompression Sickness - The problems associated with safely transporting man from an area of high ambient pressure to an area of lower ambient pressure have had a significant effect upon both system design and mission performance for caisson workers, divers and aviators for many years. The origin of the problem is tow-fold: (1) trapped gas in body cavities, i.e., middle ear, sinus, intestines, etc.; (2) dissolved gases in body tissues, i.e., fat, muscle, etc. The problems resulting from trapped gases can be minimized via controlled diet; good health, specifically of the ear, nose and throat; and adequate venting of body cavities during the decompression. Trapped gas is not considered of any significance with regard to the AEPS design study. The dissolved gases, however, represent a far more serious problem with regard to the design of the AEPS.

During normal activities, the body becomes saturated with nitrogen (and/or other inert gases), so that in each tissue and fluid of the body sufficient nitrogen is dissolved to produce a partial pressure of gas equal to that in the surrounding atmosphere. If the pressure of the environment is reduced, there will be a nitrogen tension gradient between the body tissues and the pulmonary alveolar (i.e., lung) air and, as a result, surplus nitrogen will be exhaled. However, with a sufficient reduction in environmental pressure, tissues which were saturated at a sea level equivalent pressure and thus are in a state of supersaturation will release these gases to form bubbles. This supersaturation will, for any given rate and magnitude of pressure change, be greatest in those tissues with the least blood supply and with the greatest dissolved nitrogen content. These bubbles, by either direct pressure or indirect action, give rise to the signs and symptoms of decompression sickness. The effects of decompression sickness range from mild discomfort to incapacitation and death.

The various factors which can affect the occurance of nitrogen sickness are age, body type, rate of pressure change, initial pressure level, final pressure level, exercise and equally important, the susceptibility of the particular individual to decompression sickness (bends).

6.2.1.1 (Continued)

Protection from decompression sickness is affected by controlled nitrogen elimination from the body. This can be accomplished in two ways: (1) staged or uniform decompression, which is a very time consuming procedure allowing the body to wash out the nitrogen at a rate which is consistent with the capacities of both the lungs and the blood; (2) accelerating the washout by pre-breathing oxygen at the initial equilibration pressure for a specified time. Of the two choices, only pre-breathing oxygen prior to the decompression is feasible for aerospace missions due to the time involved. One of the most recent approaches to predicting required pre-breathing times is based upon a theoretical correlation with representative physiological test data and is summarized graphically in Figure 6-1. This analyisis is based upon equations derived to explain a theory of the time dependency of the body's nitrogen elimination mechanisms and exhibits a close correlation with actual experience in both military and civilian aviation (i.e., flight and altitude chamber testing).

The application of this pre-breathing data in light of the various physioligical contribution factors mentioned above, and the limitations of the final AEPS working pressure to an equivalent pressure altitude below the "bends-level" (approximately 20,000 feet or 6.75 psia) should minimize the occurrence of decompression sickness during AEPS operations. A reduction in the total base operating pressure from the current 14.7 psia Space Station level to the 10.0 psia level will provide higher confidence and possibly reduce the pre-breathing requirements.

6.2.1.2 Oxygen Toxicity - The problems associated with maintaining man in an environment which includes a higher than normal PO_2, i.e., greater than 3.074 psia (159.0 mm-Hg) are considerably more complex and less quantitative in terms of definite limits than the problem of nitrogen sickness. In general, oxygen toxicity in man has been characterized by various types of symptoms, primarily involving either the central nervous system response, a cardiopulmonary response, or a hematological response (i.e., changes in blood properties), or various combinations of the three. Present information available on the specific signs and symptoms of oxygen toxicity, their relative time of onset, and the net long term effects, is primarily based upon military air crew experience, midical applications, limited space flight data, and a very limited number of controlled manned tests. This data is best summarized graphically in Figure 6-2.

The data shown clearly indicates that symptoms similar to those used clinically to describe oxygen toxicity are observed at partial pressures of oxygen well below the generally accepted toxic level of 425 mm-Hg previously established. This graphic presentation of the data does not truly quantify man's tolerance to the indicated levels,

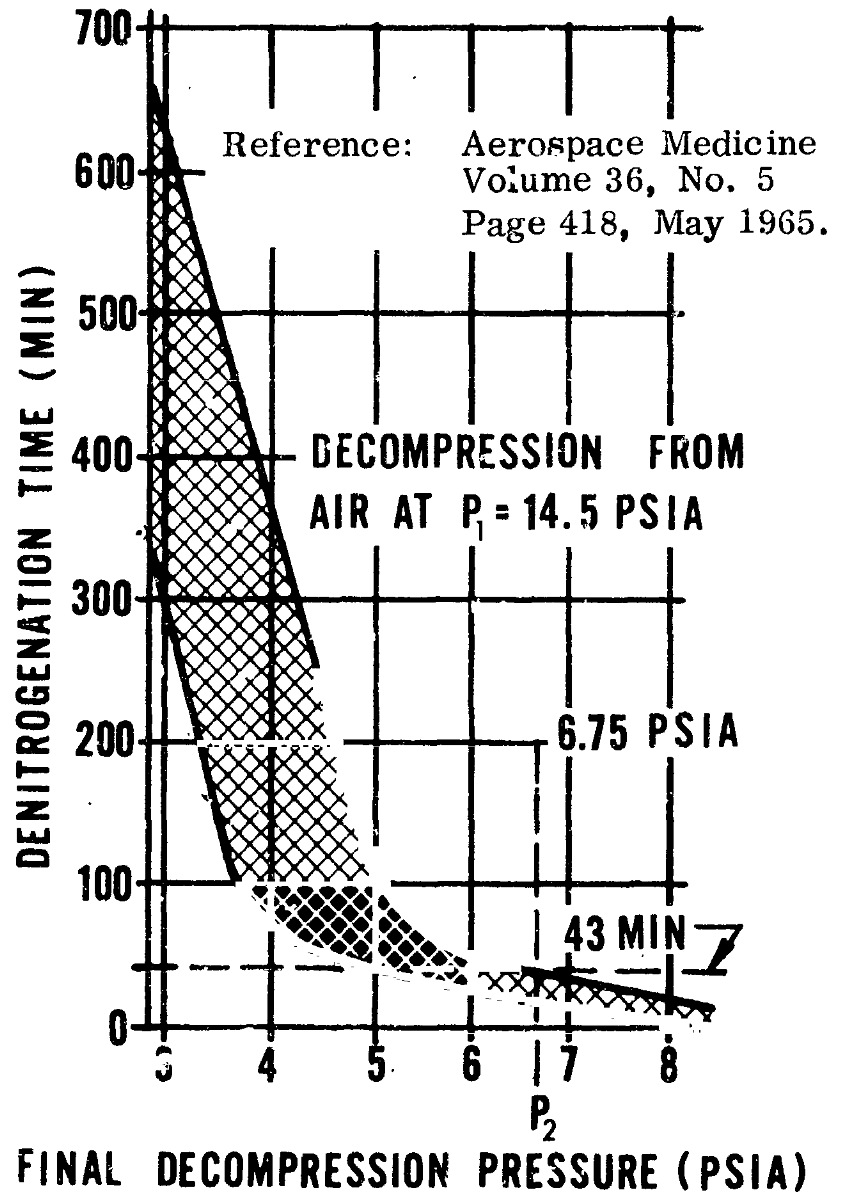


FIGURE 6—1. DENITROGENATION TIME REQUIRED PRIOR TO DECOMPRESSION

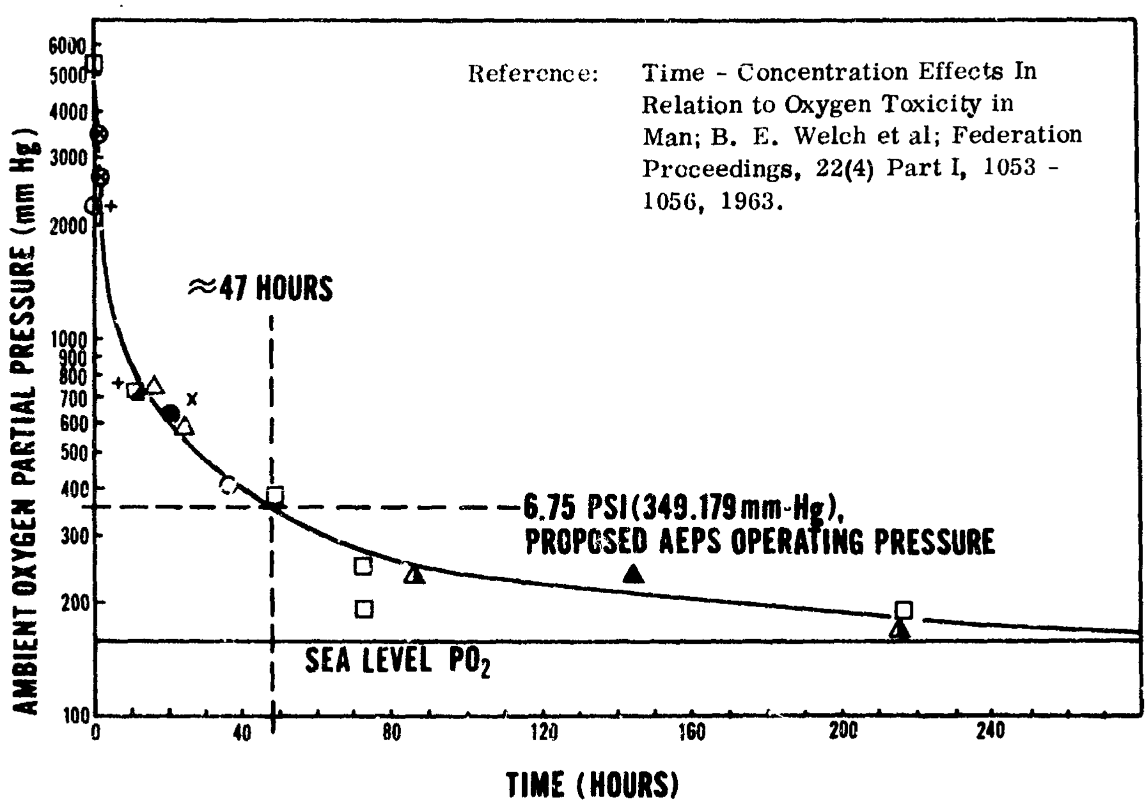


FIGURE 6–2. AVERAGE TIME OF ONSET OF OXYGEN TOXICITY SYMPTOMS AS FUNCTION OF AMBIENT OXYGEN PARTIAL PRESSURE

6.2.1.2 (Continued)

nor does it indicate the impact that repetitive exposure to such pressure levels would have on man. Although this data shows only a physiological trend, it does represent the present "state-of-knowledge" on the subject, and, therefore, should not be exceeded. Based upon military aviation experience, the intermittent exposures of the AEPS crewmen to oxygen pressures below the values shown on the curve should provide a margin of safety, particularly if they are returned to the space station/planetary base atmosphere and allowed to equilibrate for a minimum of 24 hours.

6.2.1.3 Effect on EVA

The present Apollo A-7L-B suit operates at 4.0 psia maximum and would requrie from 3 to 4 hours of oxygen prebreathing if utilized for any future planned EVA missions. This prebreathing requirement is costly both in time and supporting equipment. If suit pressure is increased to approximately 8 to 14.7 psia, the following advantages occur:

a. No prebreathing required.

b. No O_2 purge required for transfer from cabin to EVA equipment.

c. Other crewman may remain in cabin until needed for EVA emergency or rescue.

The disadvantages associated with a higher pressure suit are:

a. Slight weight increase.

b. Some advanced technology required.

Ideally, the optimum suit pressure level is that level which eliminates prebreathing, does not adversely affect the crewman or his performance, and has a minimum impact on the mission vehicle. However, to eliminate prebreathing requirements we must elevate the operating pressure level of the suit to a level (approximately 8 psia) that may or may not adversely affect the crewman due to O_2 toxicity. Therefore, before suit pressure level can be selected, the physiological impact of the following factors must be determined:

6.2.1.3 (Continued)

a. Required versus tolerable O_2 prebreathing time.

b. O_2 partial pressure exposure limitations including frequency and duration.

c. Safe decompression/recompression levels, rates and frequency.

However, for routine exposures over an extended period of time, it appears there is insufficient data available to establish a physiologically safe profile from either a decompression sickness or an oxygen toxicity standpoint. Too little is known about the cumulative effects of frequent exposures to oxygen tension greater than normal sea level values, and even less is known about the effects of frequent exposures to decompression/recompression cycles. Just the daily decompression cycles of crewmen based upon experience with altitude chamber crews may be excessive because of the fatigue resulting from the procedure, compounded by the physical exertion of the planned EVA.

The additive effects of these stresses have never been assessed theoretically or empirically. Therefore, it appears that without a comprehensive test program specifically oriented to the application in question (either Space Station, Lunar Base, Mars or Shuttle), establishment of an acceptable and safe physiological baseline is not possible.

6.2.1.4 Summary

For the purpose of the remainder of the AEPS system studies effort, the following EVA mission baseline requirements are recommended for use with a one-gas (pure oxygen) AEPS in conjunction with a two-gas (oxygen:nitrogen) Space Station, Lunar Base, Mars Excursion Module (MEM) or Shuttle:

a. Space Station - Lunar Base - MEM -Shuttle Atmosphere

- P_T $\doteq$ 10.0 - 14.7 psia
- P_{O_2} = 3.3 psia
- Diluent = Nitrogen

b. Minimum pre-breathing period at total base pressure (10.0-14.7 psia), 100% O_2 is 43 minutes.

c. Decompression rate shall not exceed 1.0 psi per second.

d. AEPS working pressure is 6.75 psia with a maximum exposure time of 8 hours.

6.2.1.4 (Continued)

e. Recompression rate shall not exceed 0.10 psi per second.

f. Minimum off-duty time for crewmen returning from an 8 hour EVA is 24 hours.

The recommended crewman pressure timelines for a Space Station/Shuttle EVA and for a Lunar Base/Mars EVA are presented in Figures 6-3 and 6-4, respectively. Although the Lunar Base/Mars EVA pressure timelines are based on an AEPS pressure of 6.76 psia, the Lunar Base and Mars emergency EVA operating pressures have been set at 5.5 psia as discussed in section 64 of this volume.

6.2.2 Oxygen Supply

Results of the subsystem studies indicated that high pressure gaseous oxygen storage represents the simplest O_2 supply subsystem concept and has the minimum bulk and minimum vehicle impact. In addition, it was the only candidate concept which has the capability to rapidly provide oxygen in the event of an emergency decompression of the AEPS.

An evaluation to optimize the gaseous storage pressure level was conducted during the systems integration effort. In addition, the effects of the selected pressure level upon selection of the O_2 bottle material, design of the O_2 fill fitting, and the procedures and equipment required for AEPS O_2 recharge were investigated.

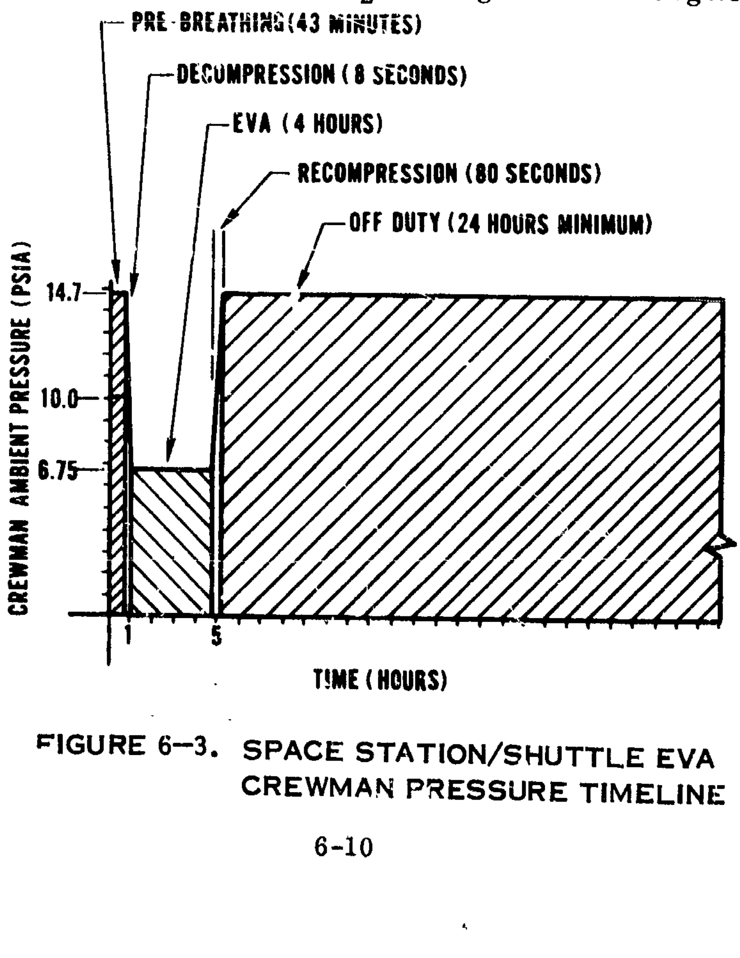


FIGURE 6-3. SPACE STATION/SHUTTLE EVA CREWMAN PRESSURE TIMELINE

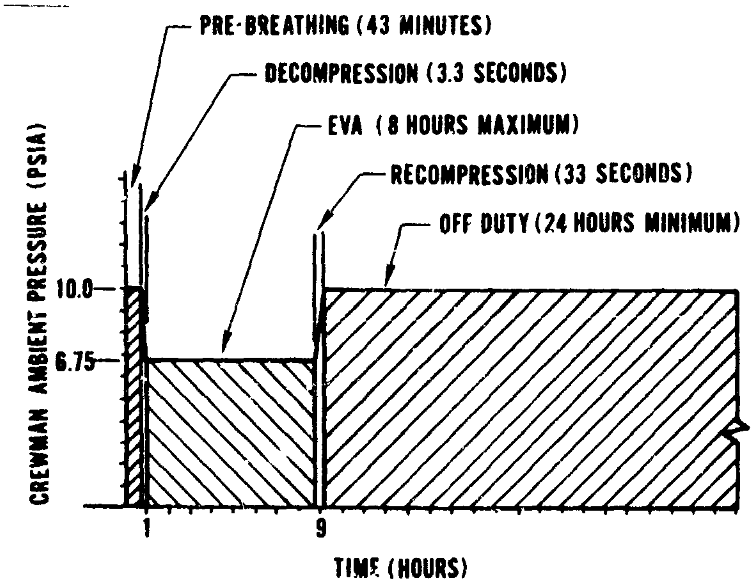


FIGURE 6–4. LUNAR BASE–MARS EVA CREWMAN PRESSURE TIMELINE

6.2.2.1 O_2 Supply Pressure Level - Selection of the AEPS O_2 supply subsystem storage pressure level is primarily dependent upon the following:

a. Vehicle/Base weight impact
b. Vehicle/Base volume impact
c. AEPS weight impact
d. AEPS volume impact
e. Operational and recharge considerations

Variations in O_2 supply subsystem storage pressure level had a relatively small effect upon Vehicle/Base weight or volume and, therefore, both of these evaluation criteria were eliminated from further consideration. Due to the decreased gravity environment of the proposed Space Station, Shuttle, Lunar Base and Mars missions, the importance of AEPS weight as an evaluation criteria was also diminished. However, regardless of gravity environment, AEPS volume remains a direct measure of crewman encumberance and mobility and is the single most important criterion in the determination of the O_2 supply pressure level.

If an evaluation of O_2 supply pressure level is made utilizing weight as the primary criteria, a pressure of approximately 2500 psi would be selected. However, if volume is utilized as the primary criteria, the optimum exists at the highest pressure achievable. These results are depicted graphically in Figure 6-5, which presents

6.2.2.1 (Continued)

bottle weight and volume per pound of stored O_2 versus O_2 supply pressure level. As can be seen, O_2 supply pressure levels above 7500 psi provide a very small volume savings for an attendant large increase in weight and are, therefore, uncompetitive. For instance, a ten (10) percent increase in pressure from 3000 psi reduces volume by 7 in^3 per pound of oxygen while a ten (10) percent increase in pressure from 7500 psi reduces volume by 3 in^3 per pound of oxygen -- all at an ever increasing gain in O_2 bottle weight.

Operational and recharge considerations are complicated by increased O_2 supply subsystem storage pressure level but are certainly not insurmountable and are discussed in more detail in Section 6.2.2.3 and 6.2.2.4.

In summary, a nominal O_2 supply pressure of 6000 psi is recommended for the AEPS applications. Although 7500 psi appears optimum, 6000 psi was chosen to allow for pressure gage inaccuracies and pressure variations due to ambient temperature changes during storage and operation.

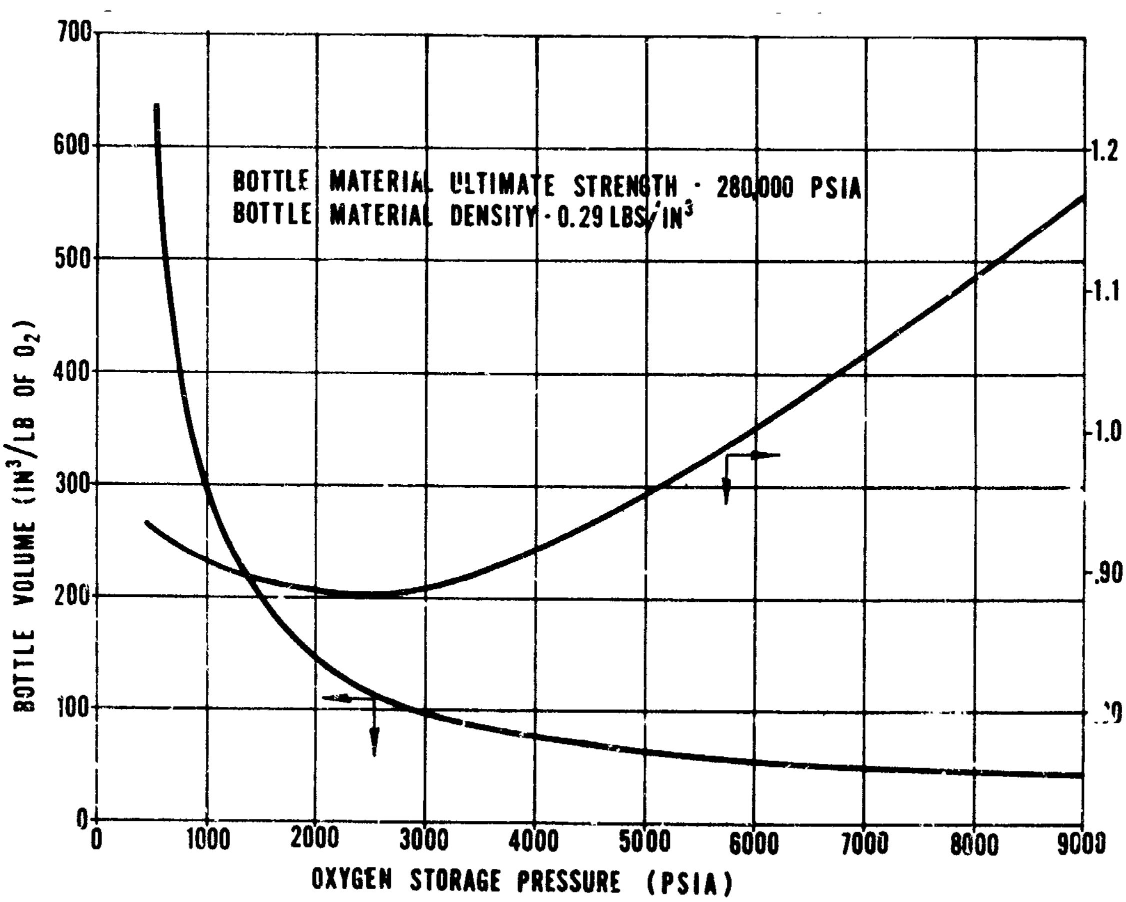


FIGURE 6—5. BOTTLE VOLUME AND WEIGHT VS. OXYGEN STORAGE PRESSURE

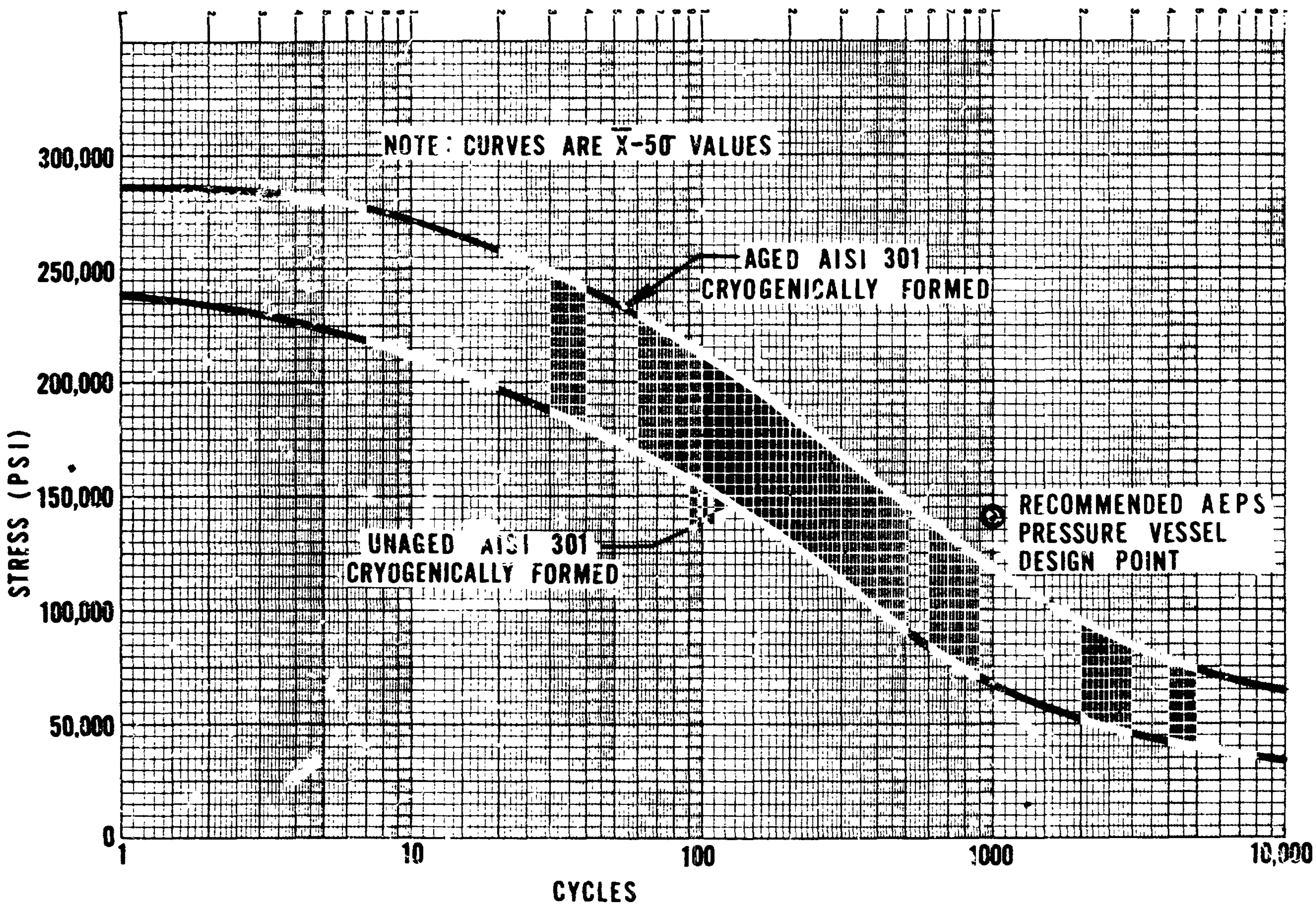


FIGURE 6–6. BOTTLE CYCLE LIFE

6.2.2.2. O_2 Pressure Vessel Material - The multiple EVA excursions planned for the Shuttle, Space Station, Lunar Base and Mars missions of the 1980's, together with the recommended 6000 psi pressure level, requires that a high cyclic life/high static strength O_2 pressure vessel material be utilized. The current Apollo Extravehicular Mobility Unit (EMU) Portable Life Support System (PLSS) utilizes a 1500 psi O_2 supply subsystem pressure vessel fabricated from unaged cryogenically formed AISI 301 with an ultimate strength of 240,000 psi. The present state-of-the-art in the area of stainless steel pressure vessels is represented by aged cryogenically formed AISI 301 which has an ultimate strength of 280,000 psi. For the Shuttle, Space Station and Lunar Base missions, the AEPS O_2 supply subsystem pressure cycle design requirement is of the order of magnitude of 1000 cycles at nominal operating pressure. To be competitive from a weight standpoint, the working stress at the nominal pressure should be set at half the value of the ultimate strength (140,000 psi minimum). As shown in Figure 6-6, neither aged or unaged AISI 301 meets this requirement. Although the aged AISI 301 is relatively close to meeting this requirement, it is highly subject to stress corrosion which would result in a cyclic life far less than that predicted. Therefore, materials research and development in the areas of stainless steels, filament wound materials, etc, to produce a high cyclic life/high static strength pressure vessel material to meet the AEPS requirements is in order.

6.2.2.3 O_2 Fill Fitting - To permit simple and rapid recharge of the AEPS O_2 supply subsystem, a quick disconnect O_2 fill fitting is required. A quick disconnect is defined as a fluid coupling that may be rapidly connected or disconnected while under pressure. A conventional method of connecting and disconnecting a high pressure system is shown schematically in Figure 6-7.

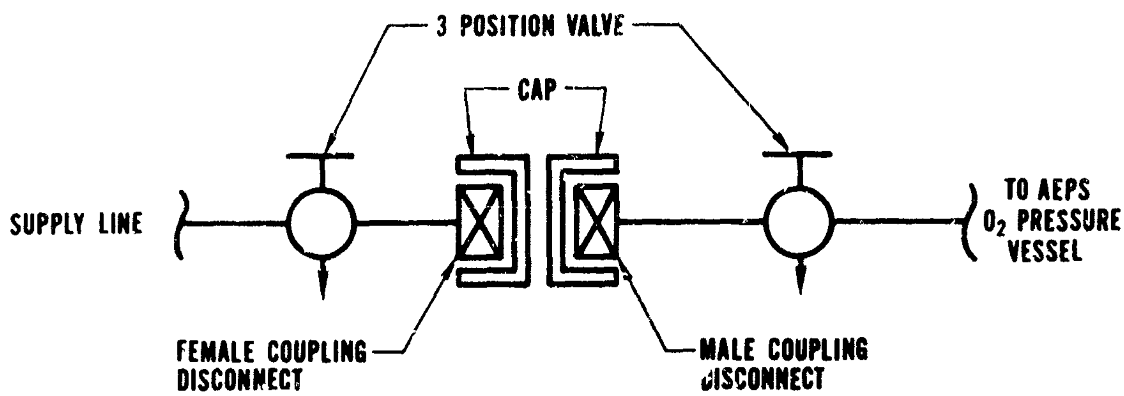


FIGURE 6-7. CONVENTIONAL HIGH PRESSURE DISCONNECT

6.2.2.3 (Continued)

Each shutoff valve is a three-way valve with the following positions:

a. Shutoff position.

b. Vent position to permit gas trapped between disconnect and valve to be vented to ambient.

c. On position with a flow limiting orifice to prevent a rapid pressure buildup.

Both three-way valves are initially closed; they are then vented to permit the gas trapped between the disconnects and the valves to escape and thus decrease the plug load to facilitate connection. The couplings are then connected. The supply line valve is shut off and the A EPS valve is opened. The supply line valve is then opened to charge the A EPS pressure vessel.

One major problem associated with design of a quick disconnect is one of geometry. For a nominal 6000 psi quick disconnect with an effective flow diameter of 0.120 inches, the plug load that must be overcome by the installation load is 85 pounds. A reasonable installation load from a human factors point of view is twenty (20) pounds which would result in an effective seal diameter of 0.037 inches (assuming half the installation loads results from seal friction) thus requiring exceedingly small pieces of hardware designed and manufactured to very close tolerances.

Other problems associated with design and development of a 6000 psi O_2 fill fitting are:

a. Prevent seal extrusion due to high pressure.
b. Prevent seal wear due to mating half sliding over it.
c. Dampen pressure wave during connection to prevent shock.
d. Prevent entrance of contamination.

6.2.2.4 O_2 Recharge - The Space Station, Lunar Base and Mars Excursion Module (MEM) of the 1980's are projected to contain a 3000 psi oxygen supply. Therefore, a method must be developed to step the Vehicle/Base O_2 supply pressure from 3000 psi to 6000 psi to permit O_2 recharge of the AEPS. The following methods are candidate concepts to be considered for future effort:

a. Direct Compression - Electric - The work to compress 1.(pounds of oxygen from 3000 psi to 6000 psi is approximately 32,000 ft-lb with an adiabatic efficiency of 100% If this is accomplished by an electrically driven compressor with an overall efficiency of 10%, the vehicle electrical power penalty is five (5) pounds per A EPS. Vehicle power penalty is 2 watts per pound and recharge time is twelve hours.

6.2.2.4 (Continued)

b. Direct Compression - Manual - If the compressor is a 10% efficient hand pump, ten (10) minutes is assumed as a reasonable time for recharging the AEPS. With the crewman working at 100% efficiency, he would work at a metabolic rate of 2500 BTU/hr in excess of his basal metabolic rate.

c. Night Time Supercritical Storage - The following is a concept to utilize the thermal environment existing during night time or dark side operation to increase the Vehicle/Base O_2 supply storage pressure. The 3000 psi supply is stored in a temperature controlled environment of 530°R. A pressure vessel is placed outside the vehicle and is connected to the vehicle supply by a high pressure line and shutoff valve (Figure 6-8).

   This vessel is designed to a maximum operating pressure of 10,000 psi. During night time operation, this vessel is pressurized to 3000 psi by the vehicle supply.

   Using the cold ambient as the heat sink, the charged gas is allowed to cool to 300°R and then maintained at this level by the insulating enclosure and an internal heater. For night time operations, the AEPS are recharged by drawing cold gas off of the supercritical vessels and allowing the temperature to rise to 530°R in the cabin ambient thus pressurizing the AEPS vessel to 6000 psi. During day time operation, the vehicle vessel supply shutoff valve is turned off and the supercritical cryogenic vessel is allowed to heat up to 530°R where its pressure builds up to 10,000 psi. Oxygen for AEPS recharge is then bled off, as required. If such a concept was utilized in conjunction with a Lunar Base, a 3.5 ft^3 spherical pressure vessel would provide enough oxygen for fourteen (14) days of operation. One lunar day is the equivalent of 28 earth days and, therefore, this size pressure vessel would provide enough oxygen for the fourteen days of sunlight operation.

Regardless of which concept is selected to step up Vehicle/Base O_2 supply pressure from 3000 to 6000 psi, design and development of the subsystem and/or components are required.

6.2.3 Contaminant Control

The contaminant control subsystem maintains the concentration of particulate matter, biological microorganisms, and trace gases at acceptable levels so that the health and comfort of the crewman is safeguarded. To aid in the design conception of a contaminant control subsystem for the AEPS, a model of the contaminant atmosphere was generated and is presented in Table 6-1. The model identifies the contaminants known to be biologically generated and also includes generation rates and maximum allowable concentrations.

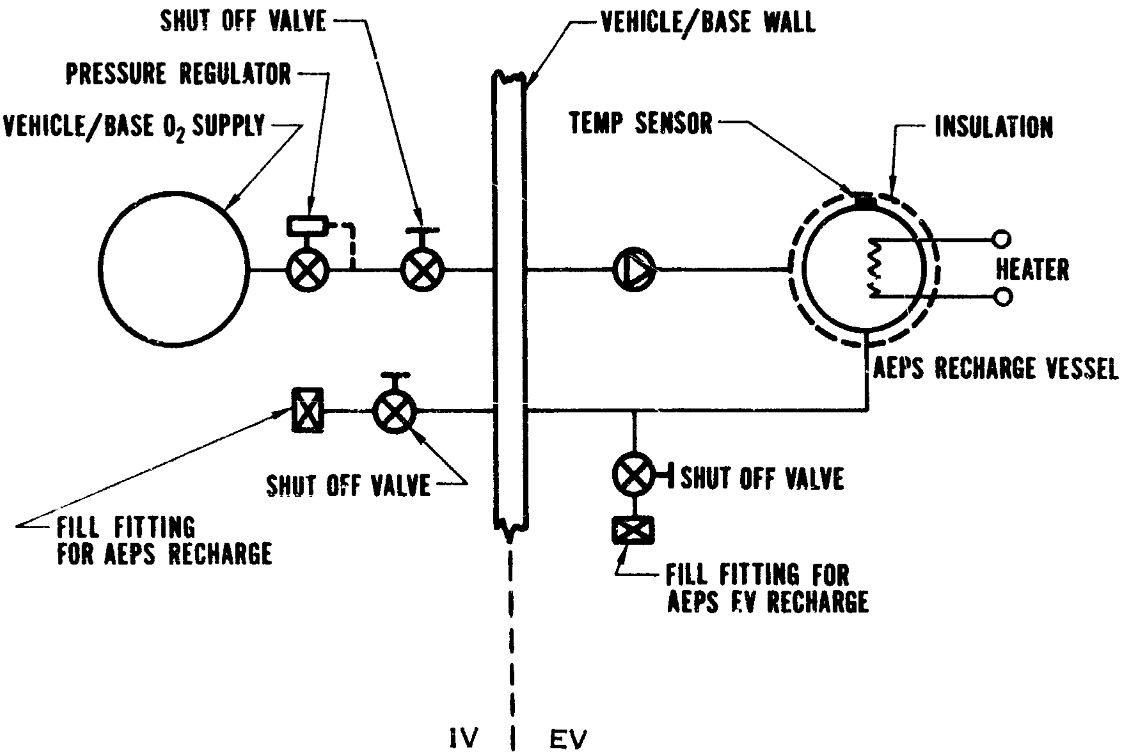


FIGURE 6–8. AEPS HIGH PRESSURE O_2 RECHARGE CONCEPT

TABLE 6-1

TRACE GAS CONTAMINATION MODEL

Contaminant	Biological Production Rate, lb/hr	Allowable Concentration, mg/m^3
Acetaldehyde	9.16×10^{-9}	360
Acetone	2.02×10^{-8}	2400
Ammonia	2.62×10^{-5}	70
n-Butanol	1.2×10^{-7}	303
Butyric Acid	6.92×10^{-5}	144
Carbon Monoxide	1.43×10^{-6}	115
Ethanol	3.68×10^{-7}	1880
Hydrogen	8.08×10^{-7}	(4.1%)
Hydrogen Sulfide	4.61×10^{-10}	28
Indole	9.18×10^{-6}	126
Methane	1.3×10^{-5}	(5.3%)
Methanol	1.39×10^{-7}	262
Phenol	3.46×10^{-5}	19
Pyruvic Acid	1.92×10^{-5}	9.2

6.2.3 (Continued)

An evaluation to determine the contaminant control subsystem configuration was conducted during the systems integration effort and resulted in a subsystem whose functional schematic is shown in Figure 6-9.

This section discusses the main constituents of the proposed contaminant control subsystem.

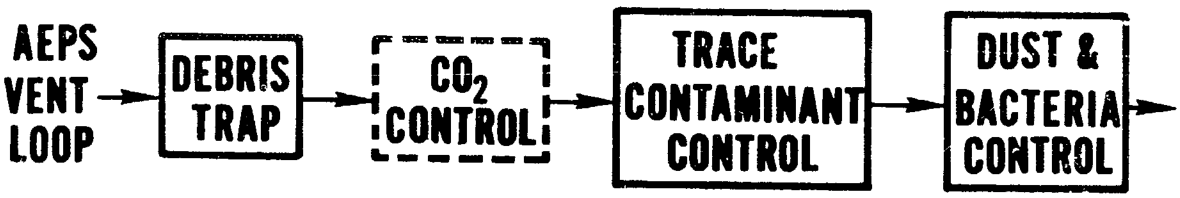


FIGURE 6-9. CONTAMINANT CONTROL SUBSYSTEM

6.2.3.1 Debris Trap - A debris trap was selected to control gross particulate matter such as hair, skin flakes, fabric particles, vomitus, etc., which may enter the AEPS ventilation loop. The debris trap is concepted as an in-line conical configuration consisting of a 100 mesh teflon-coated screen with a hydrophilic sponge on its outer diameter to serve as a sump. Located at the inlet to the AEPS ventilation loop, a clean debris filter will have a maximum pressure drop of 0.25 inches of water at a flow of 6 acfm. This pressure drop should be constant throughout the mission, only rising when subjected to gross contamination such as vomitus. Maintenance is limited to post EVA inspection and replacement, if required. Minimal replacement is expected due to the low generation rates of such gross particulate matter.

6.2.3.2 Trace Contaminant Control - Trace gases considered in this effort are presented in Table 6-1 and are limited to those which are biologically generated. An optimistic assumption is made utilizing this procedure since compounds contributed by the AEPS equipment are not considered. Justification for this approach is based upon future materials development leading to surface coatings and treatments allowing minimal outgassing.

The exposure limits presented are based on threshold limit values (TLV). These limits generally apply to eight (8) hour exposures for an industrial worker subject to a five (5) day work week with the recovery or non-work time taking place in a relatively contaminant-free atmosphere. Space maximum allowable concentrations (SMAC) are normally utilized for space vehicle applications. However, these are defined for continuous exposure and were considered too restrictive for the AEPS application. A realistic set of constraints will only be defined after test data are obtained on man subjected to a small closed system (i.e., 2 ft^3) with a gradual

6.2.3.2 (Continued)

buildup of contaminants rather than a steady concentration. Other factors requiring evaluation include repetitive exposure to the operational atmosphere with recovery time subject to SMAC limits.

Based upon the defined model, the following trace gases build up in the AEPS beyond the allowable concentration during the eight (8) hour EVA mission:

a. Ammonia
b. Butyric Acid
c. Indole
d. Phenol
e. Pyruvic Acid

All other trace gases generated remain within acceptable limits during an eight (8) hour EVA.

Utilization of the following adsorbents to control the above trace gases was evaluated:

a. Sorbead - Silica gel modified by Hamilton Standard with a $CuSO_4$ coating; primarily used for ammonia control; nonregenerable.

b. Purafil-Controls CO, H_2S, acid gases, SO_2, O_3 and NO; nonregenerable.

c. Activated Charcoal - Wide range sorbent; will not control CO, H_2, CH_4 and NH_3; regenerable.

d. Phosphoric Acid Impregnated Charcoal - Primarily utilized for NH_3; nonregenerable.

e. Catalytic Oxidizer (including pre- and post-sorbers) - Controls CO, H_2 and CH_4.

Results indicated that use of activated charcoal for control of butyric acid, indole, phenol and pyruvic acid and the use of purafil for control of ammonia presents the optimum arrangement from both the vehicle and AEPS standpoints. The activated charcoal cartridge is removed and regenerated after each EVA mission in a Vehicle/ Base oven/vacuum chamber. One concept presently under consideration combines the vehicle regenerable metallic oxide with the activated charcoal to permit removal and vehicle regeneration as a combined assembly.

6.2.3.2 (Continued)

Approximately 0.02 pounds (or 1 in^3) of purafil are required to provide ammonia control for an eight (8) hour AEPS mission. Since this is such a small amount, the purafil could be packaged in a multimission cartridge and replaced by the crewman, as required.

6.2.3.3 Dust and Bacteria Control - Any dust generated by the CO_2 control unit or the trace contaminant control unit must be prevented from being recirculated to the suited crewman. In addition, bacteria control may be required within the AEPS itself due to the long term duration of future space missions and the extensive planned use for the AEPS. A depth filter can be utilized to control both dust and bacteria generation.

As a design model for loading of the depth filter, a class 100,000 clean room with a limit of 1.5×10^{-6} g/ft^3 was selected as representative of the AEPS atmosphere. Loading during one 8 hour EVA mission would be approximately 5 mg at a design flow of 6 acfm.

The following filters were considered for dust and bacteria control:

a. Flanders Econocell
b. Flanders Airpore J Series
c. Mott Series A Porous Stainless Steel
d. Pall Rigimesh
e. Millipore UG and VH

The Flanders Airpore J series appears to be the optimum selection based on pressure drop and performance characteristics. It has an initial pressure drop of 0.3 inches of water rising to a maximum of 0.8 inches of water at the end of the 8 hour mission. It is capable of removing 95 percent of all contaminants 0.3 microns or larger. It will, however, require periodic replacement to prevent excessive pressure drop.

6.2.3.4 Summary - The contaminant control subsystem concepted in this section will maintain adequate contaminant control within the AEPS. It should be noted that the contaminant control subsystem has not been concepted as a regenerative subsystem due to the extremely small chemical bed weight involved. However, further effort is required to confirm (or modify) the AEPS contaminant model selected and to determine the effect of long term intermittent exposure upon the suited crewman.

6.2.4 Humidity Control

The humidity control subsystem maintains the relative humidity within the space suit at a comfortable level for the suited crewman. Water vapor enters the gas stream as a product of crewman respiration and sweating and must be continually removed.

6.2.4 (Continued)

Selection of a humidity control subsystem is greatly dependent upon the CO_2 control or thermal control subsystem selected. The solid amine subsystem provides both CO_2 and humidity control and AEPS configurations containing a solid amine subsystem require no additional humidity control. However, AEPS configurations containing a metallic oxide subsystem for CO_2 control may require a humidity control subsystem.

The following candidate humidity control concepts were identified during the subsystem studies and were evaluated during the system studies:

a. Condensing heat exchanger combined with any of the following "change-of-momentum" type devices:

    1. Elbow wick separator
    2. Elbow scupper separator
    3. U-shaped gravity separator
    4. Vortex gravity separator
    5. Motor driven rotary separator
    6. Turbine driven rotary separator

b. Water vapor adsorption utilizing a desiccant such as silica gel.

c. Water emulsion formation and storage.

d. Freezeout.

    1. Mechanical
    2. Cryogenic

e. Condensing heat exchanger in series with a hydrophobic/hydrophyllic screen separator.

f. Water vapor diffusion through permeable membrane.

g. Condensation and separation utilizing a Hilsch tube.

h. Utilization of electrical energy to provide separation by:

    1. Electrolysis
    2. Electrophoresis
    3. Electroosmosis

i. Vapor dump.

    1. Open loop vent system
    2. Semi-open loop vent system

6.2.4 (Continued)

Results indicate that a condensing heat exchanger in series with either an elbow wick separator or a hydrophobic/hydrophyllic screen separator are the optimum choices. Both concepts are relatively simple, small, light, require no electrical power for operation, and are not gravity sensitive. However, due to the long useful life requirements of the proposed Shuttle, Space Station, Lunar Base and Mars missions, these subsystems are subject to contamination build-up which would steadily decrease their performance. In the case of the elbow wick separator, bacterial and fungus growth is also a possibility. Therefore, research and development is required in these areas to develop a humidity control subsystem with long life characteristics.

6.2.5 Power Supply

Selection of an AEPS power supply is heavily dependent upon the required power capacity for a given mission duration. The AEPS subsystems and components which require electrical power are:

a. Communications and Telemetry
b. Instrumentation
c. Displays
d. O_2 Vent Loop Prime Mover
e. Liquid Heat Transport Loop Prime Mover
f. CO_2 Control Subsystem (AEPS Regenerable Metallic Oxide only)
g. Thermal Control Subsystem (Thermal Storage - PH_4Cl, Expendable/ Thermal Storage - PH_4Cl, and Expendable/Radiation only)

The above subsystems and components have a total power consumption of 30-180 watts, depending upon which CO_2 control and thermal control subsystems are selected.

For this range of power consumption, the electric storage battery represents the lightest, smallest and most reliable concept. The present Apollo EMU PLSS utilizes a silver oxide-zinc battery which has a capacity of 40 to 50 watt-hours per pound. Laboratory tests by Gulton Industries with a lithium-nickel halide battery were reported to have achieved a capacity of 100 watt-hours per pound. Based on these results, a lithium-nickel halide battery with a capacity of 100 watt-hours per pound was assumed as the AEPS power supply and incorporated into all AEPS concepts. However, operational development of this battery (or any other battery demonstrating a similar or greater capacity) is still required through research and development.

6.2.6 Instrumentation

Instrumentation is required to provide status monitoring of the crewman and his equipment for the following purposes:

a. Operational safety.
b. To be able to perform an adequate analysis of circumstances should a mission abort be required.

Instrumentation utilized to provide the above functions must meet the following operational requirements:

a. Crewman comfort.
b. Reliability.
c. System compatibility with AEPS, vehicle, etc.
d. Mission non-interference.

In accordance with the above guidelines and constraints, instrumentation for the following parameters were incorporated into the AEPS concepts:

a. High Pressure Oxygen Storage Pressure - Telemetered to central receiving station; electrically drives a gage visible to the AEPS crewman. This parameter is an indirect measure of crewman metabolic rate and aids in the determination of O_2 remaining.

b. Suit Pressure - Telemetered to central receiving station, triggers audible and visual warning signals when pressure decreases below a pre-determined level.

c. Suit Inlet CO_2 Partial Pressure - Telemetered to central receiving station. This parameter is a measure of CO_2 control subsystem performance.

d. O_2 Vent Loop Flow Sensor - Triggers audible and visual warning signals when O_2 vent loop flow decreases below a pre-determined level.

e. Liquid Heat Transport Loop Inlet and Outlet Temperatures - Telemetered to central receiving station. These parameters are a measure of thermal control subsystem performance.

f. Freon Evaporator Outlet Pressure - Telemetered to central receiving station; provides electrical signal to control both the variable-speed compressor and the variable orifice. This parameter is a measure of thermal control subsystem performance and is only measured for thermal control subsystems utilizing a vapor compression cycle.

6.2.6 (Continued)

g. Battery Voltage - Telemetered to central receiving station; triggers audible and visual warning signals when battery voltage falls below a pre-determined level.

h. Fan Current - Telemetered to central receiving station; triggers audible and visual warning signals when fan current rises above a pre-determined level.

i. Pump Current - Telemetered to central receiving station; triggers audible and visual warning signals when pump current rises above a pre-determined level.

j. Compressor Current - Telemetered to central receiving station; triggers audible and visual warning signals when compressor current rises above a pre-determined level. This parameter is only measured for thermal control subsystems utilizing a vapor compression cycle.

6.2.7 Displays

The following displays are recommended for AEPS operation and must be easily visible to the suited crewman:

a. High Pressure Oxygen Storage Pressure Gage
b. Suit Pressure Gage
c. Visual Warning Displays for -
    1. Low suit pressure
    2. Low O_2 vent flow
    3. Low battery voltage
    4. High fan current
    5. High pump current
    6. High compressor current (only for thermal control subsystems utilizing a vapor compression cycle)

6.2.8 Controls

The following manual controls are required for AEPS operation and must be readily accessible to the suited crewman:

a. Oxygen Supply Shutoff Valve
b. Fan On-Off Switch
c. Pump On-Off Switch
d. Compressor On-Off Switch (only for thermal control subsystems utilizing a vapor compression cycle)
e. Communication System Controls

6.2.8 (Continued)

In addition, each AEPS is concepted to contain an automatic temperature control valve with a readily accessible manual overrride. Automatic temperature control provides the following benefits:

a. Improved crewman comfort.
b. Decreased number of crewman manual operations.
c. More efficient use of expendable water.

Several signal parameters, many of which are a function of metabolic rate, have been suggested to provide accurate temperature control:

a. Heart Rate
b. Deep Body Temperature
c. Skin Temperature
d. Oxygen Consumption
e. CO_2 Generation
f. Water Generation
g. LCG Differential Temperature

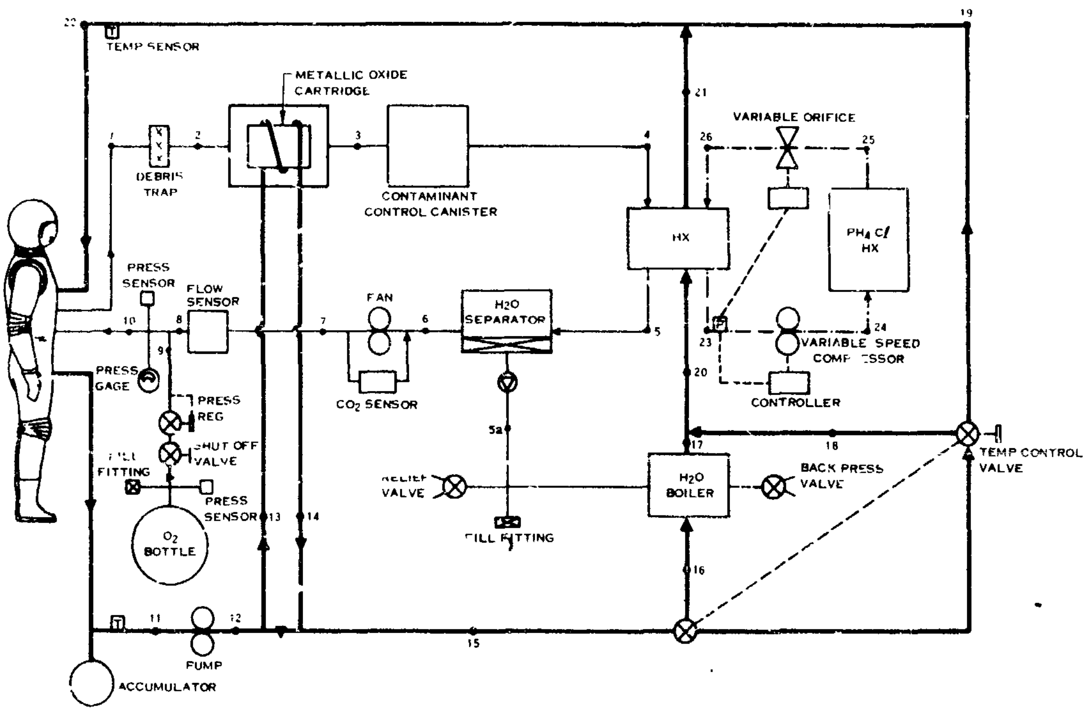
Heart rate is inaccurate; measurement of both deep body and skin temperature is uncomfortable and in some cases, pychologically unacceptable; and oxygen consumption is impractical to measure within a space suit. CO_2 generation, water generation, LCG differential temperature, or any combination of the three, appear to have promise. Further research and development is required to determine the signal parameters that provide accurate automatic temperature control and to develop the required hardware.

6.3 AEPS Baseline Concepts

Upon completion of the systems integration effort, the selected subsystems and components were combined into baseline Space Station, Lunar Base, Mars and Shuttle AEPS concepts. This section discusses six (6) potential AEPS configurations which might result if the technology recommendations emanating from the AEPS study are implemented. The schematics discussed are examples of combinations of recommended subsystems and components, and are not necessarily the only competitive combinations. In the same vein, the packaging configurations presented are intended only as examples of potential approaches.

6.3.1 AEPS Concept 1 - Space Station (Figure 6-10)

6.3.1.1 System Description - This AEPS concept contains all required life support equipment for extravehicular operation including an O_2 ventilation loop, a high pressure O_2 subsystem, a water heat transport loop, a Freon heat transport loop, a power supply, instrumentation, communications, and operating controls and displays. The



VENT LOOP		STATION										
		1	2	3	4	5	5a	6	7	8	9	10
Temperature	°F	79	79	79	79	50	--	50	72	72	72	72
Volume Flow Rate	CFM	6.315	6.32	[illegible]	[illegible]	5.90	--	5.93	5.96	[illegible]	.072	[illegible]
Total Pressure	psia	6.9	6.89	6.86	6.82	6.78	--	6.76	6.99	6.987	6.987	6.987
Total Weight Flow	lb/hr	14.225	14.225	14.030	14.030	13.898	--	13.898	13.898	[illegible]	.169	[illegible]
O_2 Weight Flow	lb/hr	13.531	13.531	[illegible]	13.531	13.531	--	13.531	13.531	13.531	.169	[illegible]
CO_2 Weight Flow	lb/hr	357	[illegible]	[illegible]	162	162	--	162	162	162	--	[illegible]
H_2O Weight Flow	lb/hr	337	337	337	337	205	132	205	.205	.205	-	[illegible]
O_2 Partial Pressure	psia	6.49	6.48	6.51	6.48	[illegible]	--	6.52	6.75	[illegible]	6.987	[illegible]
CO_2 Partial Pressure	psia	[illegible]	[illegible]	.056	.056	[illegible]	--	.059	.06	.06	-	.059
H_2O Partial Pressure	psia	.28	.28	.294	.285	.176	--	.175	.181	.181	--	.170
Dew Point	°F	[illegible]	63	64	63	56		50	50	50	--	[illegible]

LIQUID LOOP		STATION											
		11	12	13	14	15	16	17	18	19	20	21	22
Weight Flow	lb/hr	240	240	40	[illegible]	240	18.2	18.2	[illegible]	0	240	240	240
Temperature	°F	64.7	64.8	64.8	68.2	65.5	65.5	45	[illegible]	--	64.7	60	60
Pressure	psia	[illegible]	[illegible]	[illegible]	22.1	22.1	22.0	21.7	21.7	[illegible]	21.7	[illegible]	[illegible]

FREON LOOP		STATION			
		23	24	25	26
Weight Flow	lb/hr	18	18	18	18
Temperature	°F	50	150	82	45
Pressure	psia	61.4	[illegible]	102	[illegible]

FIGURE 6-10. AEPS CONCEPT 1 – SPACE STATION

6.3.1.1 (Continued)

O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit enters the atmosphere regeneration subsystem and first passes through the debris trap where solid particles and/or droplets are removed; next CO_2 is removed by both physical adsorption and chemical absorption using a vehicle regenerable metallic oxide -- zinc oxide; odors and trace contaminants are removed through physical adsorption by the activated charcoal in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The O_2 then passes to a Freon evaporator heat exchanger which cools the circulated O_2 and condenses the entrained moisture. The cooled O_2 continues to the water separator where the condensed water vapor is removed and transferred to the water boiler to provide additional cooling capacity. The cool, dry O_2 then passes to the fan which circulates a ventilation flow of 6 acfm to the suit.

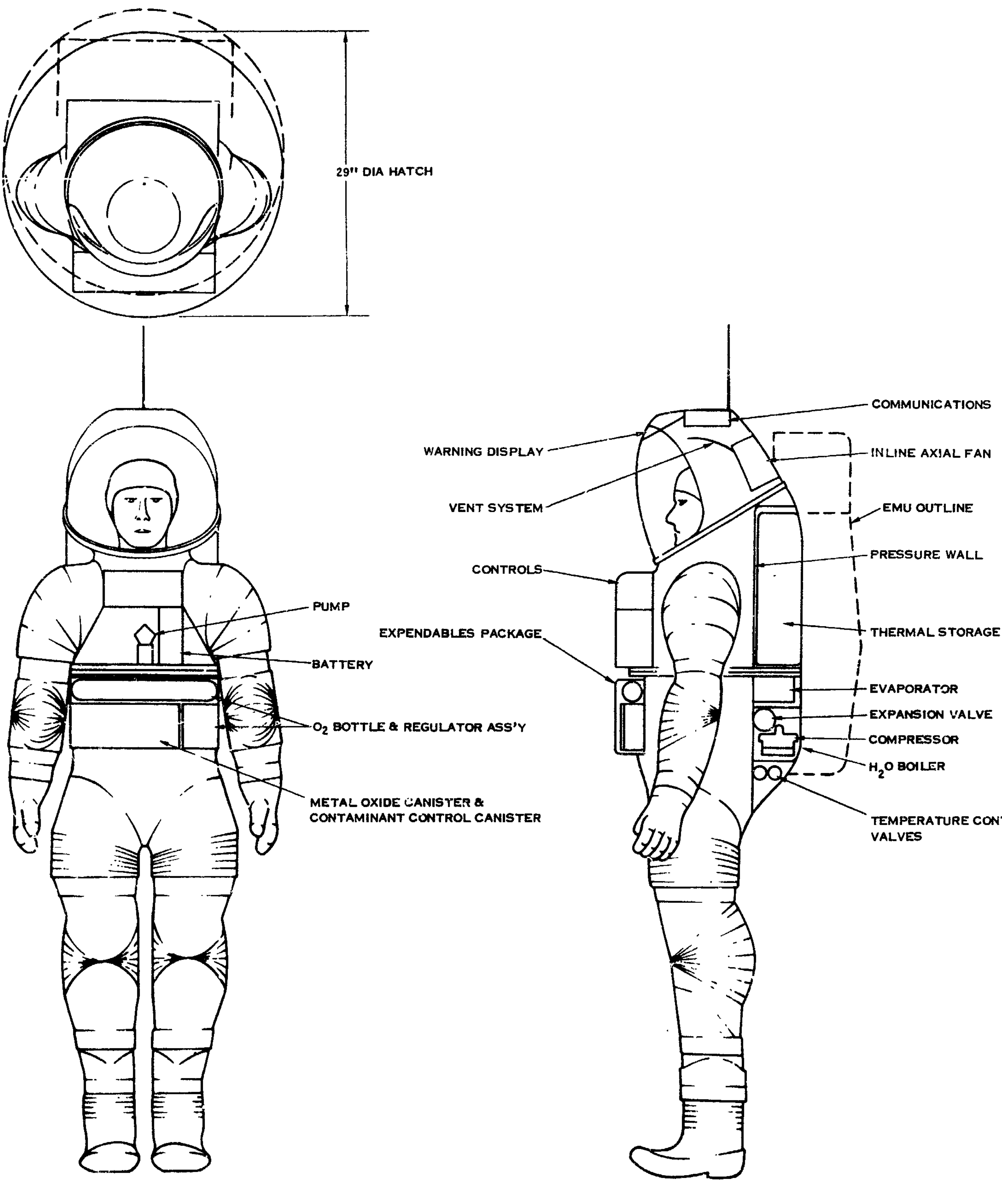
The high pressure O_2 subsystem contains 0.75 pounds of usable O_2 at 6000 psia and 65°F and regulates the pressure in the O_2 ventilation loop to 7.0 ± 0.1 psia. This subsystem consists of an O_2 bottle, fill fitting, pressure sensor, shutoff valve and pressure regulator.

The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to a level where little, if any, perspiration occurs. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. Flow through the thermal control subsystem is regulated by an automatic temperature control valve.

The thermal control subsystem is a hybrid expendable/thermal storage concept which consists of a water boiler and phosphonium chloride (PH_4Cl) thermal storage unit. A Freon heat transport loop consisting of a Freon evaporator, a variable speed compressor and a variable orifice is utilized to transfer heat added at the evaporator to the phase change thermal storage unit. Average thermal loads are handled by the Freon evaporator. However, as the heat load increases above average levels, an increasing quantity of flow is precooled in the water boiler to prevent overloading of the evaporator and resultant loss of humidity control.

6.3.1.2 System Configuration - A potential packaging configuration for AEPS Concept 1 is shown in Figure 6-11. The configuration shown integrated the life support equipment into a hard center torso section. Since a waist joint is not necessarily required for zero gravity operation, some equipment has been packaged in the lower torso area. The thermal storage unit is a PH_4Cl tube bundle configuration which is packaged external to the suit pressure wall. The metallic oxide unit is a multiple screen pack configuration which is readily accessible for removal, regeneration and replacement.

FOLDOUT FRAME 1



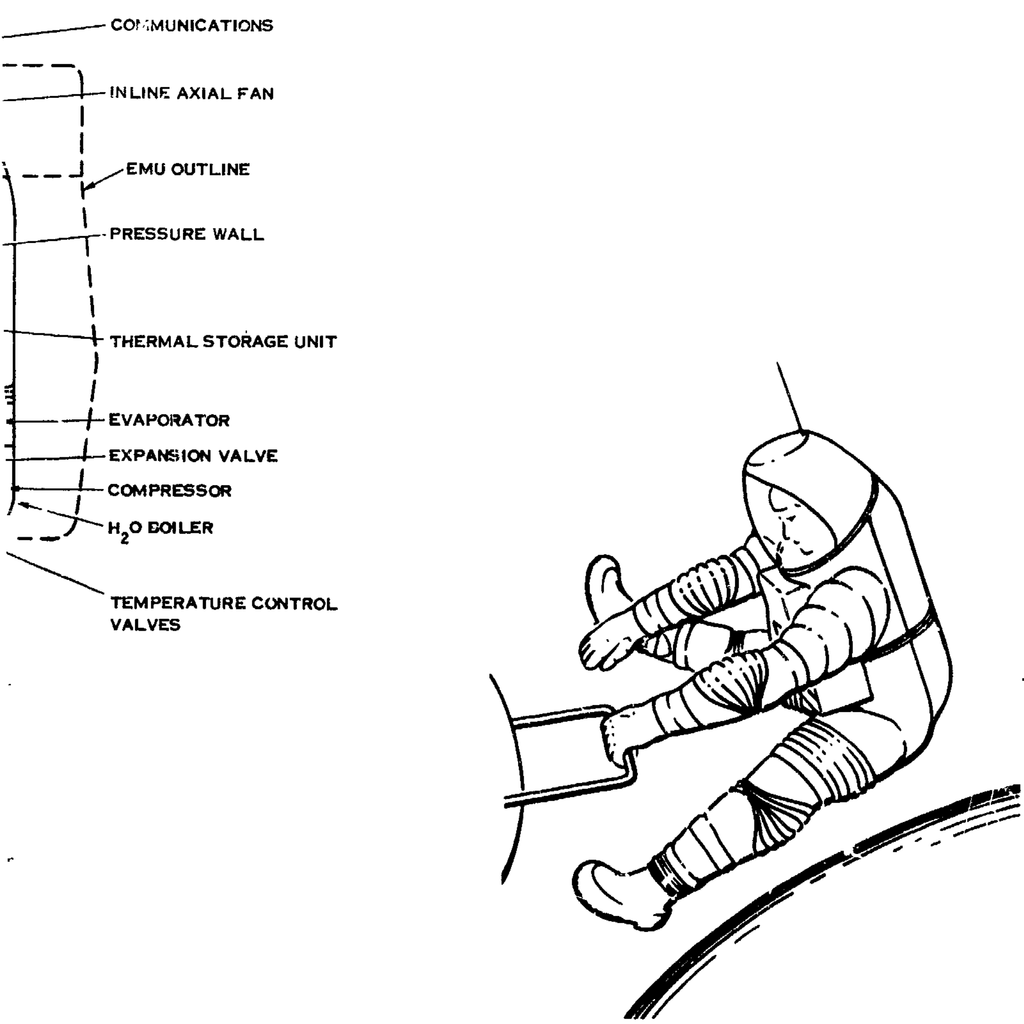


FIGURE 6—11. AEPS CONCEPT 1—SPACE STATION

6.3.1.3 System Operational Modes - This section presents an example of the operational procedures a crewman might follow in the conduct of his EVA mission. Detailed operational procedures are dependent upon the final AEPS configuration and the final vehicle configuration selected.

Step 1. Unstow AEPS

Step 2. Initial Checkout

- Visually inspect AEPS
- Verify O_2 supply subsystem pressure
- Verify PH_4Cl deep core temperature to be below 81°F
- Verify water boiler is fully charged

Step 3. Don AEPS in Donning Station

Step 4. Enter Airlock

- Close air lock to cabin hatch
- Connect vehicle oxygen and multiple water connectors
- Attach prebreathing face mask
- Prebreath pure O_2 for 43 minutes

Step 5. Final Checkout and Startup

- Depress automatic checkout switch to verify fan, pump, compressor and battery performance
- Check mission plan
- Doff face mask; don helmet and gloves
- Purge AEPS of diluent (nitrogen) by manually opening vehicle O_2 supply shutoff valve and the suit purge valve
- After 60 seconds, close the vehicle O_2 supply shutoff valve and then close the suit purge valve
- Activate the air lock compressor and depressurize the air lock at a maximum rate of 2 psi per minute. Open the AEPS O_2 supply subsystem shutoff valve when the air lock pressure decreases to 1.5 psia.
- Verify AEPS pressure regulation is normal
- Actuate air lock dump and open air lock to ambient hatch
- Disconnect vehicle multiple water connector and activate AEPS pump
- Activate AEPS compressor and verify freon evaporator outlet pressure is normal
- Verify CO_2 partial pressure is within allowable limits
- Manually override temperature control valve and verify water boiler performance. Switch temperature control valve back to automatic operating mode.

6.3.1.3 (Continued)

Step 6. Egress Airlock

Step 7. Perform EVA Mission

Step 8. Ingress Airlock

Step 9. Shutdown

- Attach vehicle multiple water connector
- Deactivate AEPS pump and compressor
- Close airlock to ambient hatch
- Attach vehicle O_2 supply umbilicals; do not open shutoff valve
- Start airlock repressurization
- When airlock pressure reaches 4 psia, turn off AEPS O_2 supply subsystem shutoff valve and turn on vehicle O_2 shutoff valve; turn off AEPS fan
- When airlock pressure reaches 10 psia, depressurize suit; turn off vehicle O_2 shutoff valve; purge suit to equalize pressure; remove helmet and vehicle O_2 umbilicals
- Open airlock to cabin hatch

Step 10. Ingress Cabin

Step 11. Doff AEPS in Donning Station

- Visually inspect AEPS

Step 12. Recharge/Regeneration/Maintenance

- Water Boiler - Connect vehicle quick disconnect from potable water supply to water boiler fill fitting. Recharge until water flow through the vehicle potable water flow meter ceases. Detach vehicle quick disconnect.
- Liquid Heat Transport Loop - Check the liquid heat transport loop accumulator level indicator. If the level is within an acceptable range, the liquid loop is topped off by adding water through a fill fitting. If the level is not within an acceptable range, corrective maintenance is performed to determine the source of the leak and to correct it. Then the liquid loop is topped off by adding water through a fill fitting.
- Oxygen Supply - Ensure O_2 supply subsystem shutoff valve is in closed position. Connect vehicle high pressure O_2 supply to AEPS O_2 fill fitting. Monitor AEPS O_2 bottle to specified level, remove

6.3.1.3 (Continued)

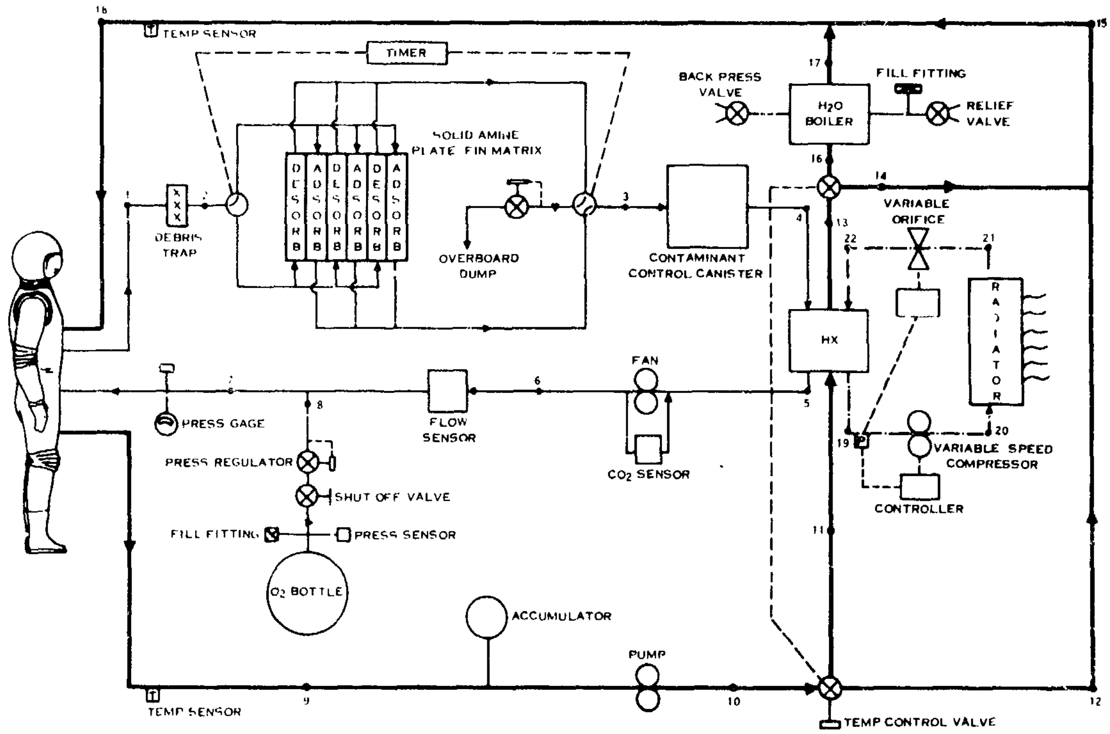
vehicle connector. Confirm pressure level with AEPS pressure gage and pressure sensor.

- Metallic Oxide/Charcoal Bed - Unclamp and rotate canister access cover out of way. Remove spent metallic oxide screen packs and visually inspect for signs of damage and/or malfunction. Place used screen packs in regenerating oven and actuate pressure/temperature controller. Place fresh screen packs (from storage) in the AEPS canister and close and reclamp the canister access cover.
- Debris Trap - Remove from AEPS and visually inspect for signs of moisture and contaminants. If excessive contaminants are present, replace debris trap in AEPS. Contaminated units are bagged and transferred to the maintenance area.
- Depth Filter - Remove used filter and transfer to sterilization area. Inspect and clean filter housing. Install new filter in AEPS.
- Battery - Connect the vehicle electrical connector to the AEPS battery recharge connector. Recharge for 12 hours. Battery circuit voltage is then checked across a known resistance against acceptable limits. If the minimum acceptable voltage level cannot be achieved, the battery is replaced.

Step 13. Stow AEPS

6.3.2 AEPS Concept 2 - Space Station (Figure 6-12)

6.3.2.1 System Description - This AEPS concept contains all required life support equipment for extravehicular operation including an O_2 ventilation loop, a high pressure O_2 subsystem, a water heat transport loop, a Freon heat transport loop, a power supply, instrumentation, communications, and operating controls and displays. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit enters the atmosphere regeneration subsystem and first passes through the debris trap where solid particles and/or droplets are removed; next the flow enters an AEPS regenerable solid amine plate-fin matrix which removes both CO_2 and water vapor from the O_2 ventilation loop thus providing CO_2 and humidity control. This is a cyclic concept using a 30 minute full cycle. Energy released during the adsorb cycle is conducted to the regeneration portion of the subsystem thus supplying the endothermic heat of desorption. Odors and trace contaminants are then removed through physical adsorption by the activated charcoal in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The O_2 then passes to a Freon evaporator heat exchanger which cools the circulated O_2 and passes it to the fan which circulates a ventilation flow of 6 acfm to the suit.



VENT LOOP		STATION 1	2	3	4	5	6	7	8
Temperature	°F	79	79	79	79	50	72	72	72
Volume Flow Rate	CFM	6.31	6.32	6.18	6.22	5.92	5.97	6.037	072
Total Pressure	psia	[illegible]	6.84	6.84	6.80	6.76	6.99	6.987	6.987
Total Weight Flow	lb/hr	[illegible]	[illegible]	13.898	13.898	13.898	13.898	14.067	.169
O2 Weight Flow	lb/hr	[illegible]	[illegible]	[illegible]	13.531	13.531	13.531	13.7	.169
CO2 Weight Flow	lb/hr	[illegible]	[illegible]	162	.162	162	162	162	-
H2O Weight Flow	lb/hr	[illegible]	337	205	.205	205	205	205	--
O2 Partial Pressure	psia	[illegible]	[illegible]	[illegible]	[illegible]	6.51	6.75	6.75	6.987
CO2 Partial Pressure	psia	[illegible]	[illegible]	[illegible]	[illegible]	057	059	059	-
H2O Partial Pressure	psia	[illegible]	[illegible]	178	177	175	182	179	--
Dew Point	°F	[illegible]	[illegible]	60	60	60	61	50	--

LIQUID LOOP		STATION 9	10	11	12	13	14	15	16	17	18
Weight Flow	lb/hr	210	210	[illegible]	0	210	202	202	[illegible]	[illegible]	210
Temperature	°F	64.7	[illegible]	64.8		62.3	62.3	62.1	62.3	45	60
Pressure	psia	18	22.1	22.2	20.1	21.7	20.4	20.4	21.1	20.4	20.1

FREON LOOP		STATION 19	20	21	22
Weight Flow	lb/hr	11	11	11	11
Temperature	°F	[illegible]	110	180	15
Pressure	psia	[illegible]	[illegible]	119	[illegible]

FIGURE 6-12. AEPS CONCEPT 2 – SPACE STATION

6.3.2.1 (continued)

The high pressure O_2 subsystem contains 0.75 pounds of usable O_2 at 6000 psia and 65°F and regulates the pressure in the O_2 ventilation loop to 7.0 ± 0.1 psia. This subsystem consists of an O_2 bottle, fill fitting, pressure sensor, shutoff valve and pressure regulator.

The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to a level where little, if any, perspiration occurs. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. Flow through the thermal control subsystem is regulated by an automatic temperature control valve.

The thermal control subsystem is a hybrid expendable/radiation heat pump subsystem and consists of a water boiler and a Freon refrigeration system. The Freon refrigeration system consists of a Freon evaporator, a variable speed compressor, a high temperature radiator and a variable orifice. The Freon system is sized to reject average heat loads at night time conditions. Heat in excess of this amount is rejected by the water boiler. The automatic temperature control valve maintains the correct flow split between the two thermal control subsystems as well as conditioning the water heat transport loop.

6.3.2.2 System Configuration - A potential packaging configuration for AEPS Concept 2 is shown in Figure 6-13. The configuration shown integrates most of the life support equipment into a hard center torso section. Since a waist joint is not necessarily required for zero gravity operation, some equipment has been packaged in the lower torso area. The thermal control subsystem, including the radiator assembly, Freon evaporator, and water boiler, is packaged in the upper back portion of the torso. The radiator assembly and the suit pressure wall form a monocoque construction. The high temperature radiator is a fixed area device and is insulated on the suit-facing side to prevent radiating back to the AEPS. The solid amine CO_2 control subsystem is a plate-fin matrix configuration and is packaged in the lower front torso section.

Similar to AEPS Concept 1, the cross-section of this configuration is less than that for the Apollo EMU PLSS. However, this suit is also approximately four inches higher than the present Apollo suit due to the increased helmet size required to facilitate packaging of the communications and warning display. The center of gravity for this configuration is very close to that of the nude crewman.

The estimated total volume and weight for this AEPS configuration (less the suit) are 3100 in^3 and 65 pounds based on an average metabolic rate of 1000 BTU/hr for an EVA duration of 4 hours.

6.3.2.3 System Operational Modes - This section presents an example of the operational procedures a crewman might follow in the conduct of his EVA mission. Detailed operational procedures are dependent upon the final AEPS configuration and the final vehicle configuration selected.

Step 1. Unstow AEPS

Step 2. Initial Checkout

- Visually inspect AEPS
- Verify O_2 supply subsystem pressure
- Verify water boiler is fully charged

Step 3. Don AEPS in Donning Station

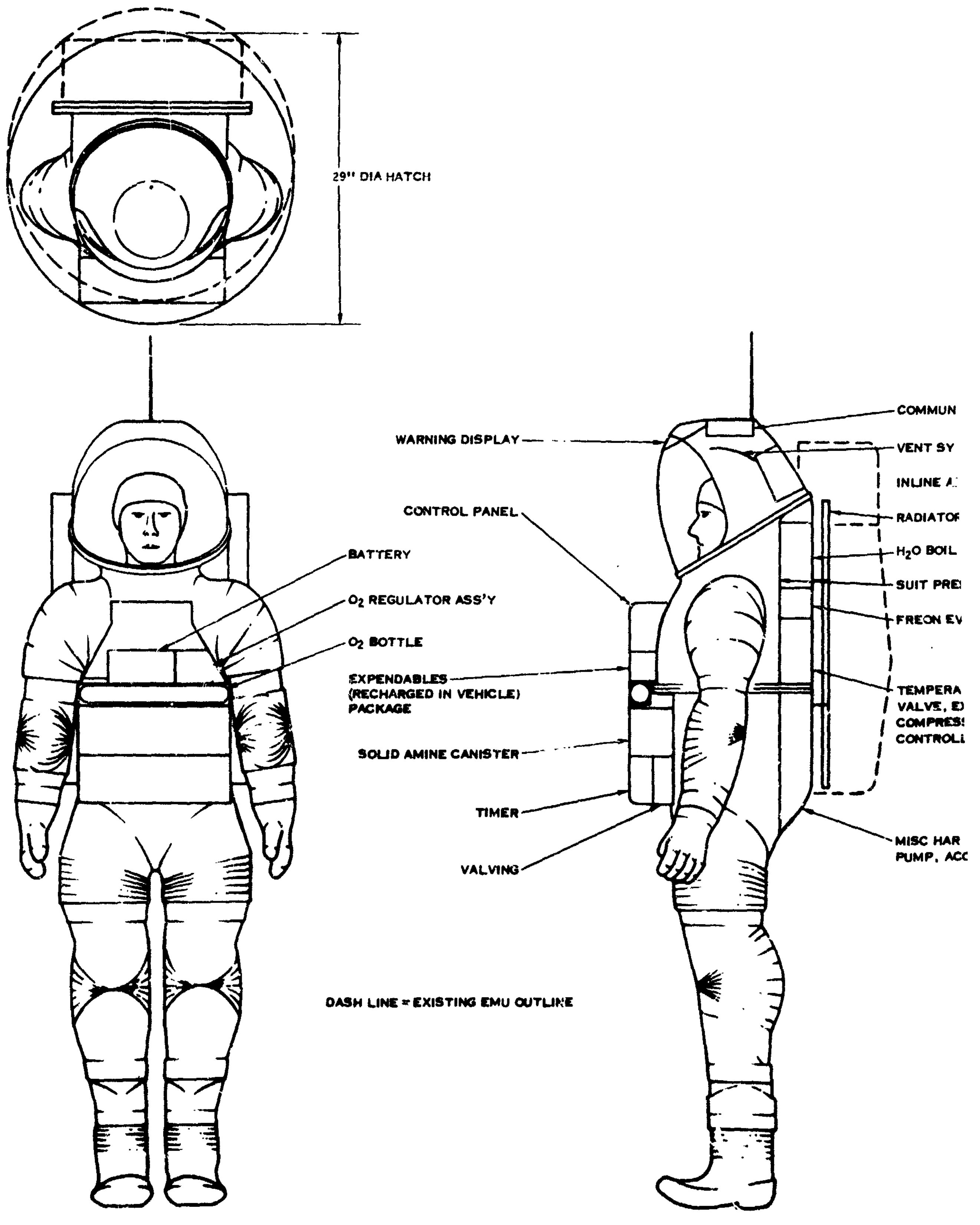
Step 4. Enter Airlock

- Close air lock to cabin hatch
- Connect vehicle oxygen and multiple water connectors
- Attach prebreathing face mask
- Prebreath pure O_2 for 38 minutes

Step 5. Final Checkout and Startup

- Depress automatic checkout switch to verify fan, pump, compressor and battery performance
- Check mission plan
- Doff face mask; don helmet and gloves
- Purge AEPS of diluent (nitrogen) by manually opening vehicle O_2 supply shutoff valve and the suit purge valve
- After 60 seconds, close the vehicle O_2 supply shutoff valve and then close the suit purge valve
- Activate the air lock compressor and depressurize the air lock at a maximum rate of 2 psi per minute. Open the AEPS O_2 supply subsystem shutoff valve when the air lock pressure decreases to 1.5 psia.
- Verify AEPS pressure regulation is normal
- Actuate air lock dump and open air lock to ambient hatch
- Disconnect vehicle multiple water connector and activate AEPS pump
- Verify CO_2 partial pressure is within allowable limits
- Manually override temperature control valve and verify water boiler performance

FOLDOUT FRAME 1



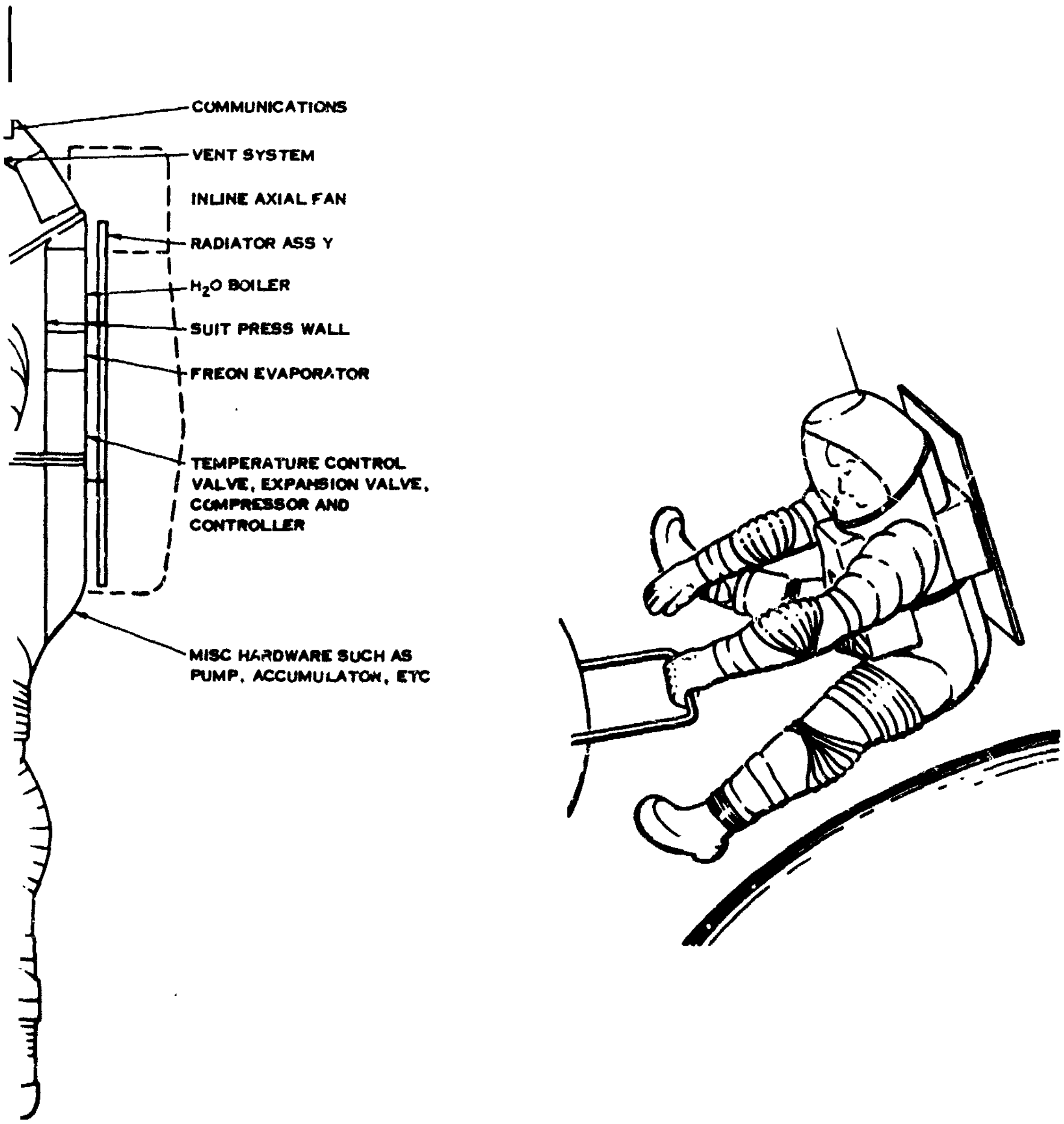


FIGURE 6–13. AEPS CONCEPT 2–SPACE STATION

6.3.2.3 (continued)

Step 6. Egress Airlock

- Activate AEPS compressor and verify freon evaporator outlet pressure is normal
- Switch temperature control valve back to automatic operating mode

Step 7. Perform EVA Mission

Step 8. Ingress Airlock

Step 9. Shutdown

- Deactivate compressor
- Attach vehicle multiple water connector
- Deactivate AEPS pump
- Close airlock to ambient hatch
- Attach vehicle O_2 supply umbilicals; do not open shutoff valve
- Start airlock repressurization
- When airlock pressure reaches 10 psia, depressurize suit; turn off vehicle O_2 shutoff valve; purge suit to equalize pressure; remove helmet and vehicle O_2 umbilicals
- Open airlock to cabin hatch

Step 10. Ingress Cabin

Step 11. Doff AEPS in Donning Station

- Visually inspect AEPS

Step 12. Recharge/Regeneration/Maintenance

- Water Boiler - Connect vehicle quick disconnect from potable water supply to water boiler fill fitting. Recharge until water flow through the vehicle potable water flow meter ceases. Detach vehicle quick disconnect.
- Liquid Heat Transport Loop - Check the liquid heat transport loop accumulator level indicator. If the level is within an acceptable range, the liquid loop is topped off by adding water through a fill fitting. If the level is not within an acceptable range, corrective maintenance is performed to determine the source of the leak and to correct it. Then the liquid loop is topped off by adding water through a fill fitting.

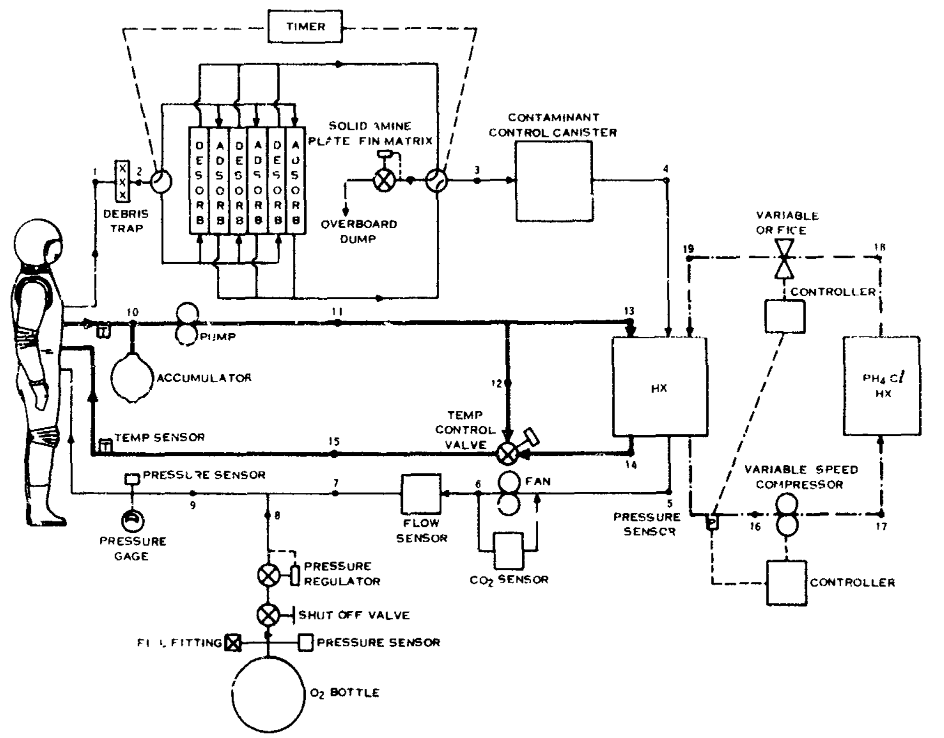
6.3.2.3 (continued)

- Oxygen Supply - Ensure O_2 supply subsystem shutoff valve is in closed position. Connect vehicle high pressure O_2 supply to AEPS O_2 fill fitting. Monitor AEPS O_2 bottle pressure to ensure fill is taking place. Two hours after pressurizing O_2 bottle to specified level, remove vehicle connector. Confirm pressure level with AEPS pressure gage and pressure sensor.
- Charcoal Cartridge - Unclamp and rotate canister access cover out of way. Remove spent charcoal cartridge and visually inspect for signs of damage and/or malfunction. Place used charcoal cartridge in regenerating oven and actuate pressure/temperature controller. Place fresh cartridge (from storage) in the AEPS canister and close and reclamp the canister access cover.
- Debris Trap - Remove from AEPS and visually inspect for signs of moisture and contaminants. If excessive contaminants are present, replace with space from storage. If contaminants are not present, replace debris trap in AEPS. Contaminated units are bagged and transferred to the maintenance area.
- Depth Filter - Remove used filter and transfer to sterilization area. Inspect and clean filter housing. Install new filter in AEPS.
- Battery - Connect the vehicle electrical connector to the AEPS battery recharge connector. Recharge for 12 hours. Battery circuit voltage is then checked across a known resistance against acceptable limits. If the minimum acceptable voltage level cannot be achieved, the battery is replaced.

Step 13. Stow AEPS

6.3.3 AEPS Concept 3 - Lunar Base (Figure 6-14)

6.3.3.1 System Description - This AEPS concept contains all required life support equipment for extravehicular operation including an O_2 ventilation loop, a high pressure O_2 subsystem, a water heat transport loop, a Freon heat transport loop, a power supply, instrumentation, communications, and operating controls and displays. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit enters the atmosphere regeneration subsystem and first passes through the debris trap where solid particles and/or droplets are removed; next the flow enters an AEPS regenerable solid amine plate-fin matrix which removes both CO_2 and water vapor from the O_2 ventilation loop thus providing CO_2 and humidity control. This is a cyclic concept using a 30 minute full cycle. Energy released during the adsorb cycle is conducted to the regeneration portion of the subsystem thus supplying the endothermic heat of desorption. Odors and contaminants are removed through physical adsorption by the activated charcoal in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The O_2



VENT LOOP		STATION 1	2	3	4	5	6	7	8	9
Temperature	°F	79	79	79	79	50	72	72	72	72
Volume Flow Rate	CFM	6.31	6.31	6.21	6.25	5.94	6.00	6.00	.066	6.08
Total Pressure	psia	6.9	6.89	6.84	6.80	6.7[illegible]	6.99	6.987	6.987	6.987
Total Weight Flow	lb/hr	14.224	14.224	13.887	[illegible]	[illegible].887	13.887	13.887	.178	14.067
O_2 Weight Flow	lb/hr	13.52	13.52	13.52	[illegible]	13.52	13.52	[illegible]	.178	13.7
CO_2 Weight Flow	lb/hr	.367	.367	.162	.162	.162	.162	.162		.162
H_2O Weight Flow	lb/hr	.337	.337	.205	.205	.205	.205	.205	-	.205
O_2 Partial Pressure	psia	6.46	6.46	6.60	[illegible]	[illegible]52	6.75	6.75	6.987	6.75
CO_2 Partial Pressure	psia	.11	.13	.057	.057	.057	.058	.058	--	.058
H_2O Partial Pressure	psia	.29	.29	.18	.18	.18	.18	.18	-	.18
Dew Point	°F	64	61	50	50	50	50	50		50

LIQUID LOOP		STATION 10	11	12	13	14	15
Weight Flow	lb/hr	210	210	167	[illegible]	73	210
Temperature	°F	66	66.8	66.8	66.8	45	60
Pressure	psia	18	21.[illegible]	21.3	21.[illegible]	20.[illegible]	20.[illegible]

FREON LOOP		STATION 16	17	18	19
Weight Flow	lb/hr	27	27	27	27
Temperature	°F	50	150	82	45
Pressure	psia	61.4	104	102	61.8

FIGURE 6–14. AEPS CONCEPT 3 – LUNAR BASE

6.3.3.1 (continued)

then passes to a Freon evaporator heat exchanger which cools the circulated O_2 and passes it to the fan which circulates a ventilation flow of 6 acfm to the suit.

The high pressure O_2 subsystem contains 1.5 pounds of usable O_2 at 6000 psia and 65°F and regulates the pressure in the O_2 ventilation loop to 7.0 ± 0.1 psia. This subsystem consists of an O_2 bottle, fill fitting, pressure sensor, shutoff valve and pressure regulator.

The water heat transport loop cools the suited crewman by supplying the circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to a level where little, if any, perspiration occurs. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. Flow through the thermal control subsystem is regulated by an automatic temperature control valve.

The thermal control subsystem is a thermal storage subsystem utilizing PH_4Cl and is composed of a PH_4Cl thermal storage unit and a Freon refrigeration cycle consisting of a Freon evaporator, a variable speed compressor and a variable orifice. Heat is added at the evaporator and stored at the thermal storage unit by the melting of PH_4Cl.

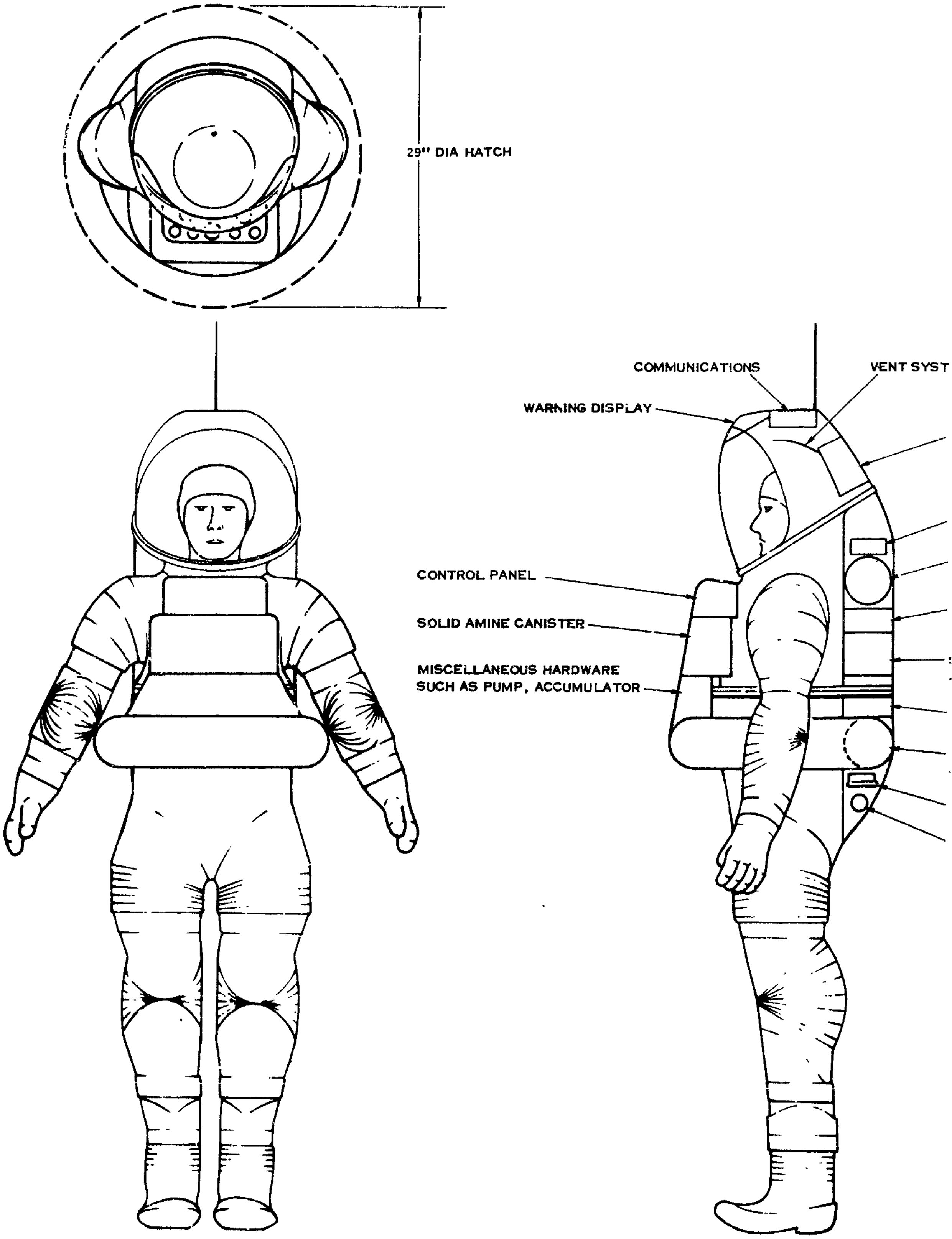
6.3.3.2 System Configuration - A potential packaging configuration for AEPS Concept 3 is shown in Figure 6-15. The configuration shown integrates the life support equipment into a hard center torso section. This concept combines the highest AEPS volume

CO_2 control subsystem (AEPS regenerable solid amine) with the highest AEPS volume thermal control subsystem (PH_4Cl thermal storage unit). Although this configuration can still pass through a 29 inch diameter batch, the extended profile of the thermal storage unit may slightly impair arm mobility. In addition, this concept does not have a waist joint. To solve both of these problems, the thermal storage unit could be repackaged in the upper torso area, with an attendant increase in suit cross-section.

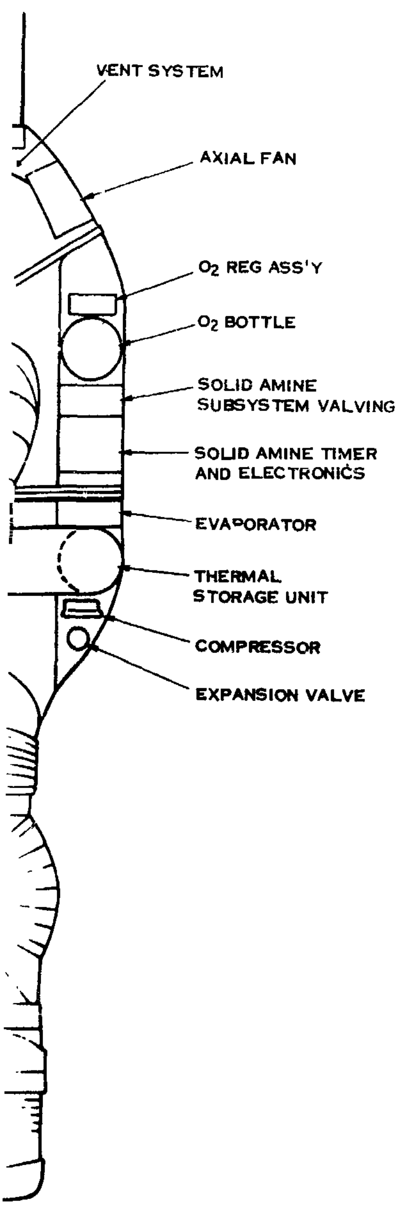
The estimated total volume and weight for this AEPS configuration (less the suit) is 4500 in^3 and 193 pounds based on an average metabolic rate of 1050 BTU/hr for an EVA duration of 8 hours. This configuration has been presented because it requires no vehicle interface for recharge or regeneration of the CO_2 control or thermal control subsystems.

6.3.3.3 System Operational Modes - This section presents an example of the operational procedures a crewman might follow in the conduct of his EVA mission. Detailed operational procedures are dependent upon the final AEPS configuration and the final base configuration selected.

FOLDOUT FRAME 1



FOLDOUT FRAME 2



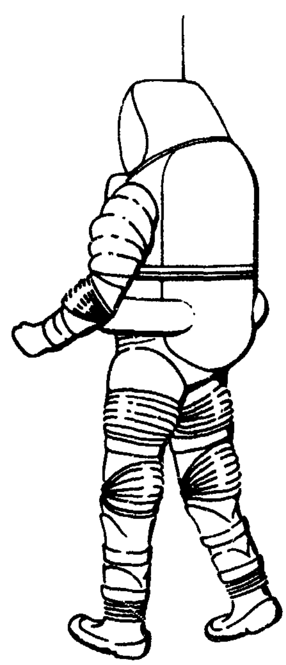


FIGURE 6–15. AEPS CONCEPT 3—LUNAR BASE

6.3.3.3 (continued)

Step 1. Unstow AEPS

Step 2. Initial Checkout

- Visually inspect AEPS
- Verify O_2 supply subsystem pressure
- Verify PH_4Cl deep core temperature to be below 81°F

Step 3. Don AEPS in Donning Station

Step 4. Enter Airlock

- Close airlock to cabin hatch
- Connect base oxygen and multiple water connectors
- Attach prebreathing face mask
- Prebreath pure O_2 for 38 minutes

Step 5. Final Checkout and Startup

- Depress automatic checkout switch to verify fan, pump, compressor and battery performance
- Check mission plan
- Doff face mask; don helmet and gloves
- Purge AEPS of diluent (nitrogen) by manually opening base O_2 supply shutoff valve and the suit purge valve
- After 60 seconds, close the base O_2 supply shutoff valve and then close the suit purge valve
- Activate the airlock compressor and depressurize the airlock at a maximum rate of 2 psi per minute. Open the AEPS O_2 supply subsystem shutoff valve when the airlock pressure decreases to 1.5 psia.
- Verify AEPS pressure regulation is normal
- Actuate airlock dump and open air lock to ambient hatch
- Disconnect base multiple water connector and activate AEPS pump
- Activate AEPS compressor and verify freon evaporator outlet pressure is normal
- Verify CO_2 partial pressure is within allowable limits

Step 6. Egress Airlock

Step 7. Perform EVA Mission

Step 8. Ingress Airlock

6.3.3.3 (continued)

Step 9. Shutdown

- Attach base multiple water connector
- Deactivate AEPS pump and compressor
- Close airlock to ambient hatch
- Start airlock repressurization
- When airlock pressure reaches 4 psia, turn off AEPS O_2 supply subsystem shutoff valve and turn on vehicle O_2 shutoff valve; turn off AEPS fan
- When airlock pressure reaches 10 psia, depressurize suit; turn off vehicle O_2 shutoff valve; purge suit to equalize pressure; remove helmet and vehicle O_2 umbilicals
- Open airlock to cabin hatch

Step 10. Ingress Cabin

Step 11. Doff AEPS in Donning Station

- Visually inspect AEPS

Step 12. Recharge/Regeneration/Maintenance

- Liquid Heat Transport Loop - Check the liquid heat transport loop accumulator level indicator. If the level is within an acceptable range, the liquid loop is topped off by adding water through a fill fitting. If the level is not within an acceptable range, corrective maintenance is performed to determine the source of the leak and to correct it. Then the liquid loop is topped off by adding water through a fill fitting.
- Oxygen Supply - Ensure O_2 supply subsystem shutoff valve is in closed position. Connect base high pressure O_2 supply to AEPS O_2 fill fitting. Monitor AEPS O_2 bottle pressure to ensure fill is taking place. Two hours after pressurizing O_2 bottle to specified level, remove base connector. Confirm pressure level with AEPS pressure gage and pressure sensor.
- Charcoal Cartridge - Unclamp and rotate canister access cover out of way. Remove spent charcoal cartridge and visually inspect for signs of damage and/or malfunction. Place used charcoal cartridge in regeneration oven and actuate pressure/temperature controller. Place fresh cartridge (from storage) in the AEPS canister and close and reclamp the canister access cover.

6.3.3.3 (continued)

- Debris Trap - Remove from AEPS and visually inspect for signs of moisture and contaminants. If excessive contaminants are present, replace with spare from storage. If contaminants are not present, replace debris trap in AEPS. Contaminated units are bagged and transferred to the maintenance area.
- Depth Filter - Remove used filter and transfer to sterilization area. Inspect and clean filter housing. Install new filter in AEPS.
- Battery - Connect the base electrical connector to the AEPS battery recharge connector. Recharge for 12 hours. Battery open circuit voltage is then checked across a known resistance against acceptable limits. If the minimum acceptable voltage level cannot be achieved, the battery is replaced.

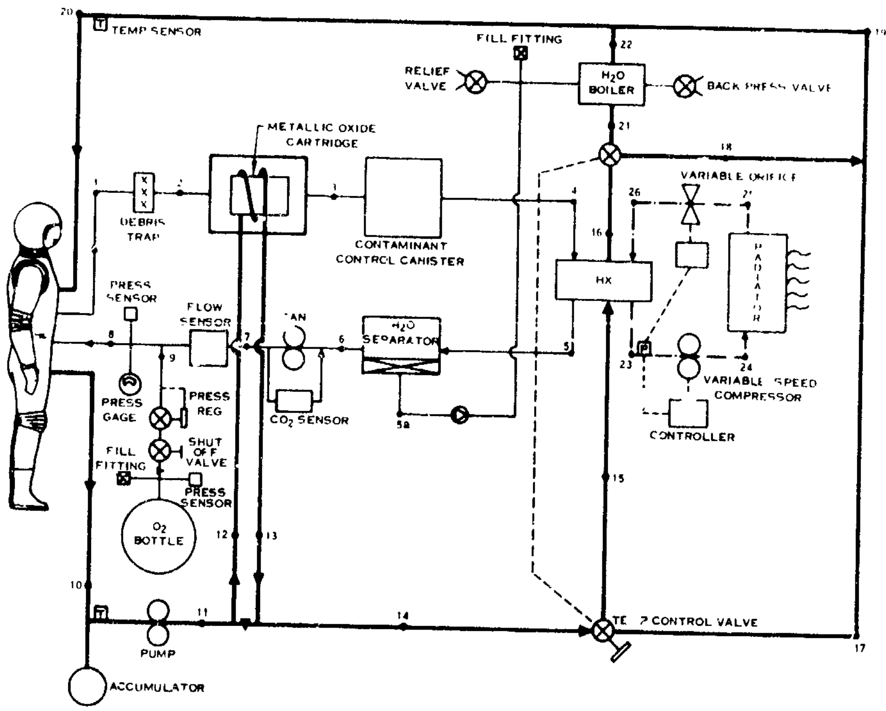
Step 13. Stow AEPS

6.3.4 AEPS Concept 4 - Lunar Base (Figure 6-16)

6.3.4.1 System Description - This AEPS concept contains all required life support equipment for extravehicular operation including an O_2 ventilation loop, a high pressure O_2 subsystem, a water heat transport loop, a Freon heat transport loop, a power supply, instrumentation, communications, and operating controls and displays. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit enters the atmosphere regeneration subsystem and first passes through the debris trap where solid particles and/or droplets are removed; next CO_2 is removed by both physical adsorption and chemical absorption using a vehicle regenerable metallic oxide--zinc oxide; odors and trace contaminants are removed through physical adsorption by the activated charcoal in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The O_2 then passes to a Freon evaporator heat exchanger which cools the circulated O_2 and condenses the entrained moisture. The cooled O_2 continues to the water separator where the condensed water vapor is removed and transferred to the water boiler to provide additional cooling capacity. The cool, dry O_2 then passes to the [illegible], which circulates a ventilation flow of 6 acfm to the suit.

The high pressure O_2 subsystem contains 1.5 pounds of usable O_2 at 6000 psia and 65°F and regulates the pressure in the O_2 ventilation loop to 7.0 ± 0.1 psia. This subsystem consists of an O_2 bottle, fill fitting, pressure sensor, shutoff valve and pressure regulator.

The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to a level where little, if any, perspiration occurs. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. Flow through the thermal control subsystem is regulated by an automatic temperature control valve.



VENT LOOP		STATION 1	2	3	4	5	5a	6	7	8	9
Temperature	°F	79	79	79	79	60	-	50	72	72	72
Volume Flow Rate	CFM	6.3	6.3	6.25	6.29	5.91		5.93	.99	6.09	.066
Total Pressure	psia	6.9	6.89	6.86	6.82	6.78		6.76	6.90	6.987	6.987
Total Weight Flow	lb/hr	14.221	14.12	14.019	14.016	14.987	-	14.887	14.987	14.067	.178
O_2 Weight Flow	lb/hr	13.52	13.52	13.52	13.52	13.52		13.52	13.52	13.7	.178
CO_2 Weight Flow	lb/hr	.167	.16	.162	.162	.162		.162	.162	.162	
H_2O Weight Flow	lb/hr	.137	.137	.137	.137	.206	.132	.205	.205	.205	
O_2 Partial Pressure	psia	6.49	6.48	6.52	6.48	6.55		6.51	6.75	6.75	6.987
CO_2 Partial Pressure	psia	.13	.1	.056	.056	.056	-	.056	.059	.059	
H_2O Partial Pressure	psia	.28	.28	.29	.29	.176		.17	.181	.179	
Dew Point	°F	63	63	64	63	60	-	50	50	50	

LIQUID LOOP		STATION 10	11	12	13	14	15	16	17	18	19	20	21	22
Weight Flow	lb/hr	240	240	40	40	240	240	240	0	186	186	240	54	54
Temperature	°F	61.7	68.8	66.8	70.4	62.5	61.5	64.7		64.7	64.7	60	64.7	4[illegible]
Pressure	psia	18	22.4	22.4	22.3	22.3	22.2	21.4	20.4	20.4	20.4	20.4	21.3	20.4

FREON LOOP		STATION 23	24	25	26
Weight Flow	lb/hr	14.8	14.8	14.8	14.6
Temperature	°F	50	140	180	45
Pressure	psia	61.1	150	149	61.8

FIGURE 6–16. AEPS CONCEPT 4 – LUNAR BASE

6.3.4.1 (Continued)

The thermal control subsystem is a hybrid expendable/radiation heat pump subsystem and consists of a water boiler and a Freon refrigeration system. The Freon refrigeration system consists of a Freon evaporator, a variable speed compressor, a high temperature radiator and a variable orifice. The Freon system is sized to reject average heat loads at night time conditions. Heat in excess of this amount is rejected by the water boiler. The automatic temperature control valve maintains the correct flow split between the two thermal control subsystems as well as conditioning the water heat transport loop.

6.3.4.2 System Configuration - Two potential packaging configurations for AEPS Concept 4 are shown in Figures 6-17a nad 6-17b. Both configurations shown are composed of a separate suit and life support systems. The main difference between the two configurations is the location of the life support system on the suit and its resultant effect upon radiator deployment. The mid-back mounted configuration requires that the variable area radiator assembly be telescoped into a position above the crewman while the higher mounted configuration is already in that position. However, the higher mounted configuration may be too "top-heavy".

This approach has the disadvantages of umbilicals and a large cross-section dimension (similar to the Apollo EMU) and the advantage of being able to integrate with a highly mobile suit. The estimated total volume and weight for this AEPS configuration (less the suit) is 3500 in^3 and 100 pounds based on an average metabolic rate of 1050 BTU/hr for an EVA duration of 8 hours.

6.3.4.3 System Operational Modes - This section presents an example of the operational procedures a crewman might follow in the conduct of his EVA mission. Detailed operational procedures are dependent upon the final AEPS configuration and the final base configuration selected.

Step 1. Unstow AEPS

Step 2. Initial Checkout

- Visually inspect AEPS
- Verify O_2 supply subsystem pressure
- Verify water boiler is fully charged

Step 3. Don AEPS in Donning Station

Step 4. Enter Airlock

- Close airlock to cabin hatch
- Connect base oxygen and multiple water connectors

6.3.4.3 (Continued)

- Attach prebreathing face mask
- Prebreath pure O_2 for 38 minutes

Step 5. Final Checkout and Startup

- Depress automatic checkout switch to verify fan, pump, compressor and battery performance
- Check mission plan
- Doff face mask; don helmet and gloves
- Purge AEPS of diluent (nitrogen) by manually opening base O_2 supply shutoff valve and the suit purge valve
- After 60 seconds, close the base O_2 supply shutoff valve and then close the suit purge valve
- Activate the air lock compressor and depressurize the air lock at a maximum rate of 2 psi per minute. Open the AEPS O_2 supply subsystem shutoff valve when the air lock pressure decreases to 1.5 psia.
- Verify AEPS pressure regulation is normal
- Actuate air lock dump and open air lock to ambient hatch
- Disconnect base multiple water connector and activate AEPS pump
- Verify CO_2 partial pressure is within allowable limits
- Manually override temperature control valve and verify water boiler performance.

Step 6. Egress Airlock

- Activate AEPS compressor and verify freon evaporator outlet pressure is normal
- Switch temperature control valve back to automatic operating mode

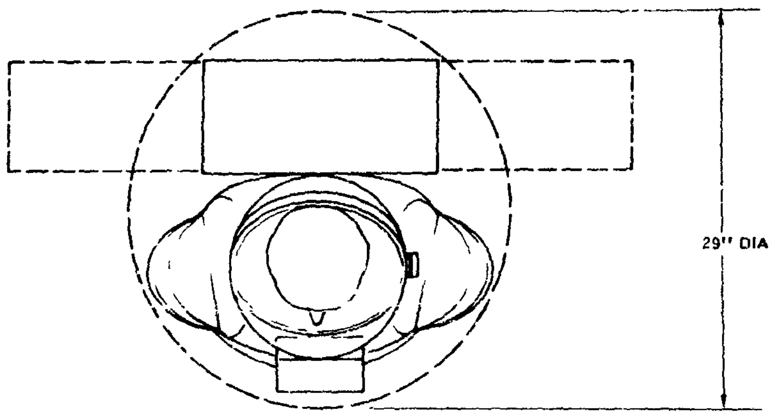
Step 7. Perform EVA Mission

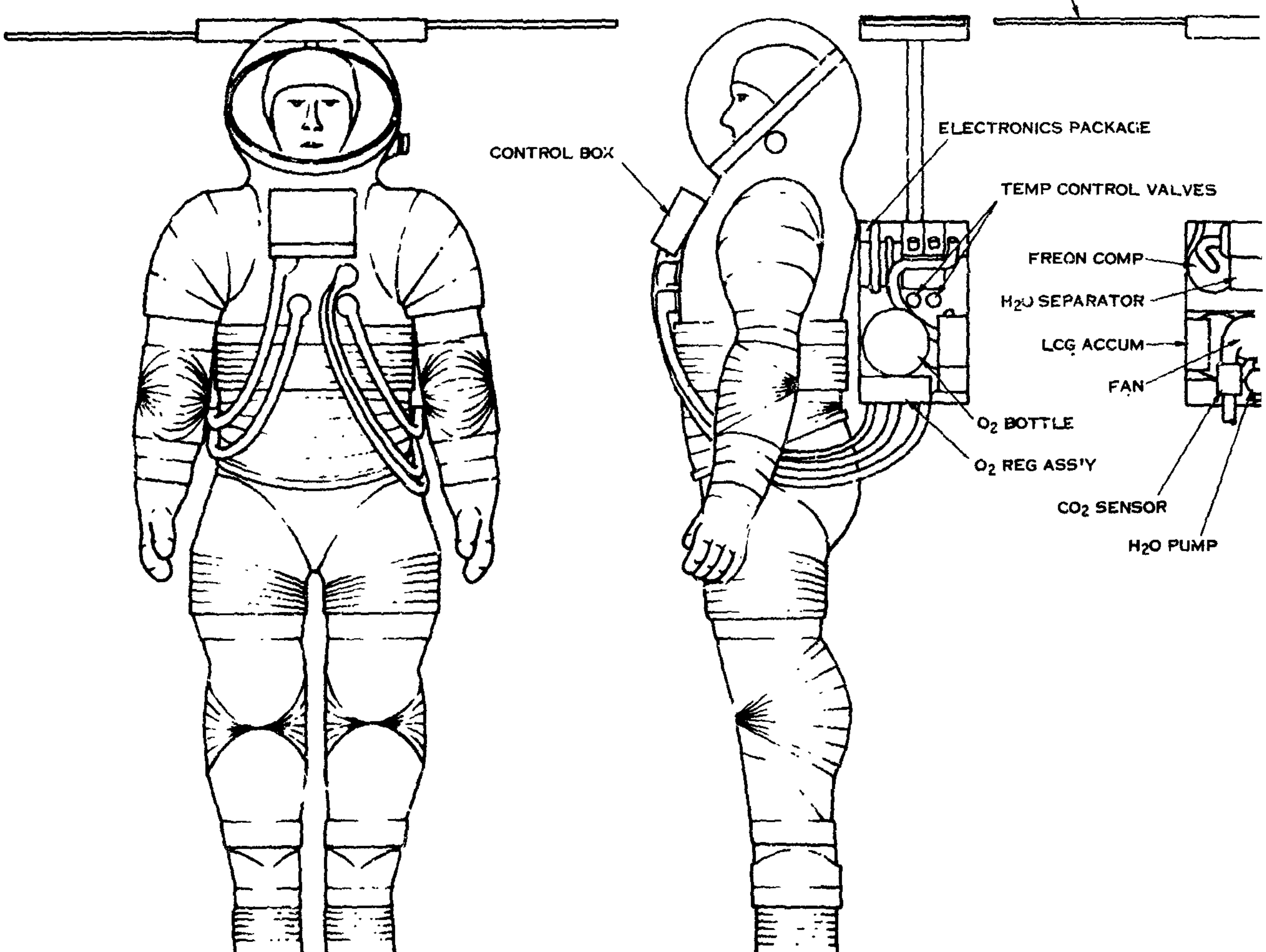
Step 8. Ingress Airlock

Step 9. Shutdown

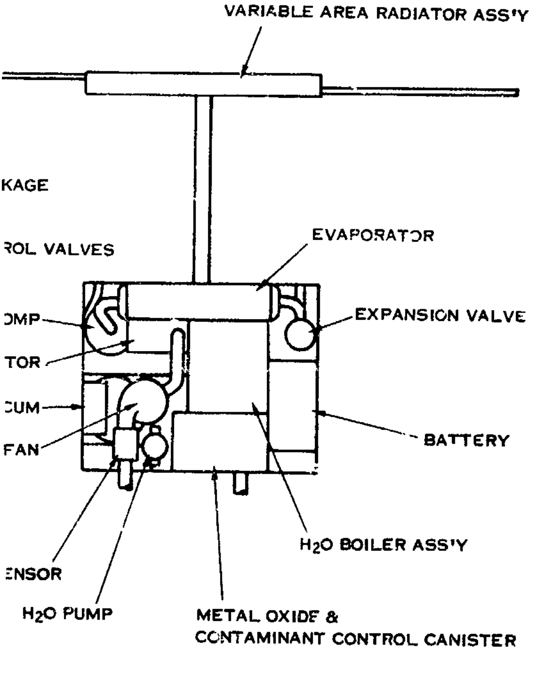
- Deactivate compressor
- Attach base multiple water connector
- Deactivate AEPS pump
- Close airlock to ambient hatch
- Attach base O_2 supply umbilicals; do not open shutoff valve
- Start airlock repressurization

FOLDOUT FRAME 1





FOLL-OUT FRAME 2



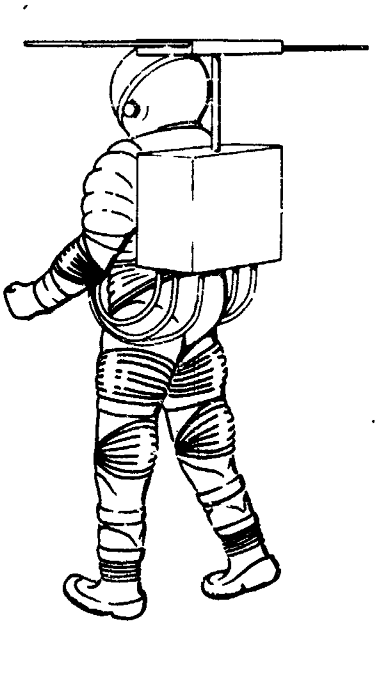
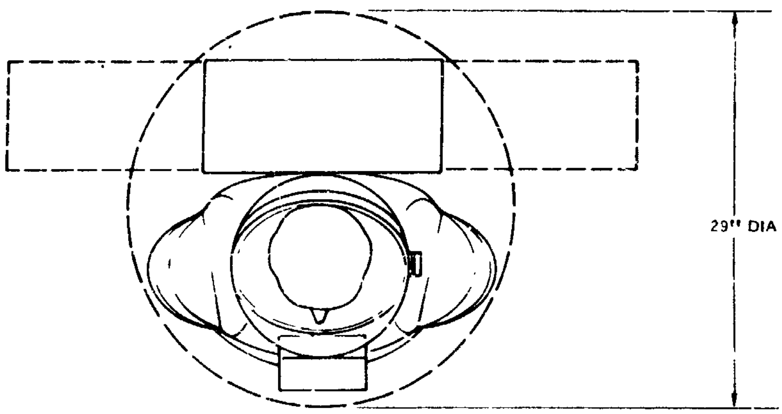
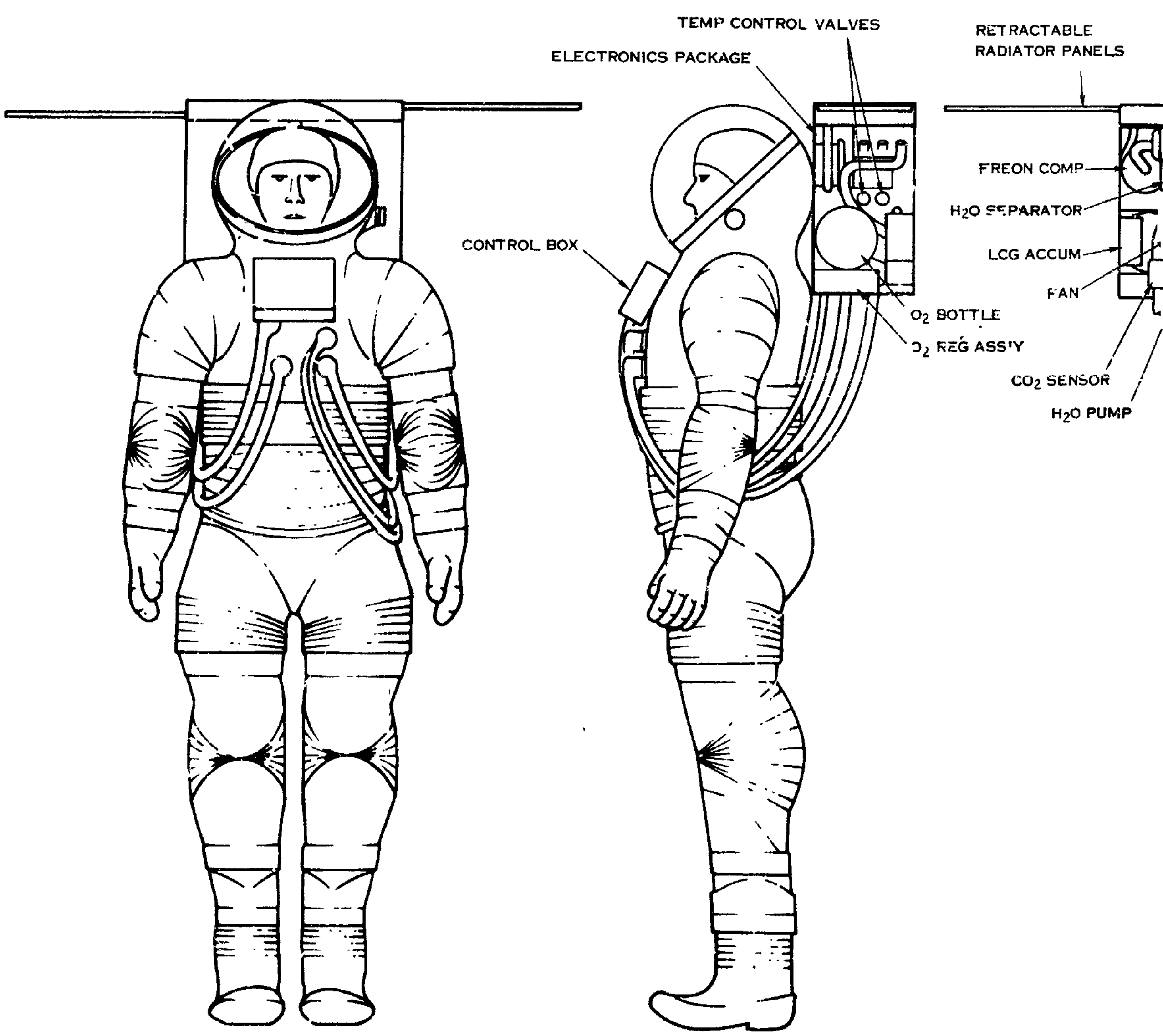


FIGURE 6—17A. AEPS CONCEPT 4—LUNAR BASE

FOLDOUT FRAME 1





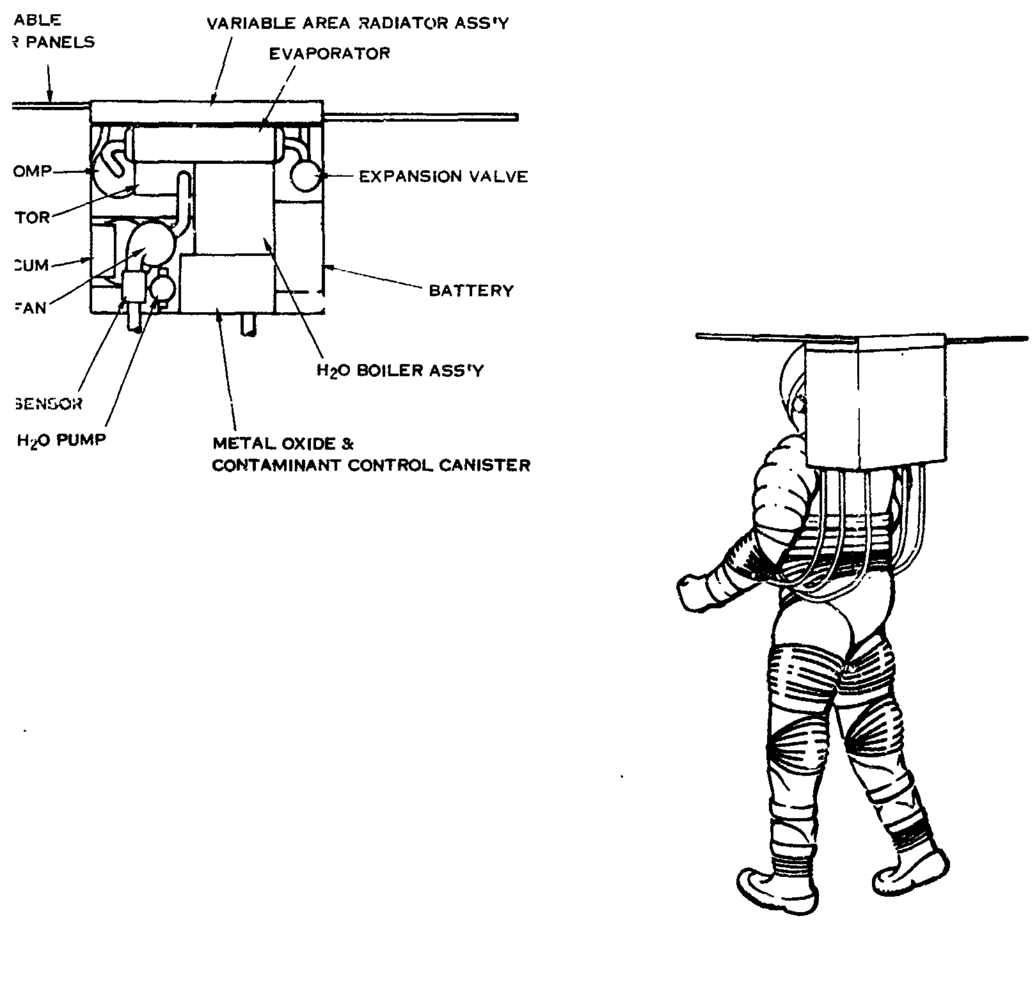


FIGURE 6–17B. AEPS CONCEPT 4–LUNAR BASE

6.3.4.3 (Continued)

- When airlock pressure reaches 4 psia, turn off AEPS O_2 supply subsystem shutoff valve and turn on base O_2 shutoff valve; turn off AEPS fan
- When airlock pressure reaches 10 psia, depressurize suit; turn off base O_2 shutoff valve; purge suit to equalize pressure; remove helmet and base O_2 umbilicals
- Open airlock to cabin hatch

Step 10. Ingress Cabin

Step 11. Doff AEPS in Donning Station

- Visually inspect AEPS

Step 12. Recharge/Regeneration/Maintenance

- Water Boiler - Connect vehicle quick disconnect from potable water supply to water boiler fill fitting. Recharge until water flow through the base potable water flow meter ceases. Detach base quick disconnect.
- Liquid Heat Transport Loop - Check the liquid heat transport loop accumulator level indicator. If the level is within an acceptable range, the liquid loop is topped off by adding water through a fill fitting. If the level is not within an acceptable range, corrective maintenance is performed to determine the source of the leak and to correct it. Then the liquid loop is topped off by adding water through a fill fitting.
- Oxygen Supply - Ensure O_2 supply subsystem shutoff valve is in closed position. Connect base high pressure O_2 supply to AEPS O_2 fill fitting. Monitor AEPS O_2 bottle pressure to ensure fill is taking place. Two hours after pressurizing O_2 bottle to specified level, remove base connector. Confirm pressure level with AEPS pressure gage and pressure sensor.
- Metallic Oxide/Charcoal Bed - Unclamp and rotate canister access cover out of way. Remove spent metallic oxide screen packs and visually inspect for signs of damage and/or malfunction. Place used screen packs in regenerating oven and actuate pressure/temperature controller. Place fresh screen packs (from storage) in the AEPS canister and close and reclamp the canister access cover.
- Debris Trap - Remove from AEPS and visually inspect for signs of moisture and contaminants. If excessive contaminants are present, replace with spare from storage. If contaminants are not present, replace debris trap in AEPS. Contaminated units are bagged and transferred to the maintenance area.

6.3.4.3 (Continued)

- Depth Filter - Remove used filter and transfer to sterilization area. Inspect and clean filter housing. Install new filter in AEPS.
- Battery - Connect the base electrical connector to the AEPS battery recharge connector. Recharge for 12 hours. Battery open circuit voltage is then checked across a known resistance against acceptable limits. If the minimum acceptable voltage level cannot be achieved, the battery is replaced.

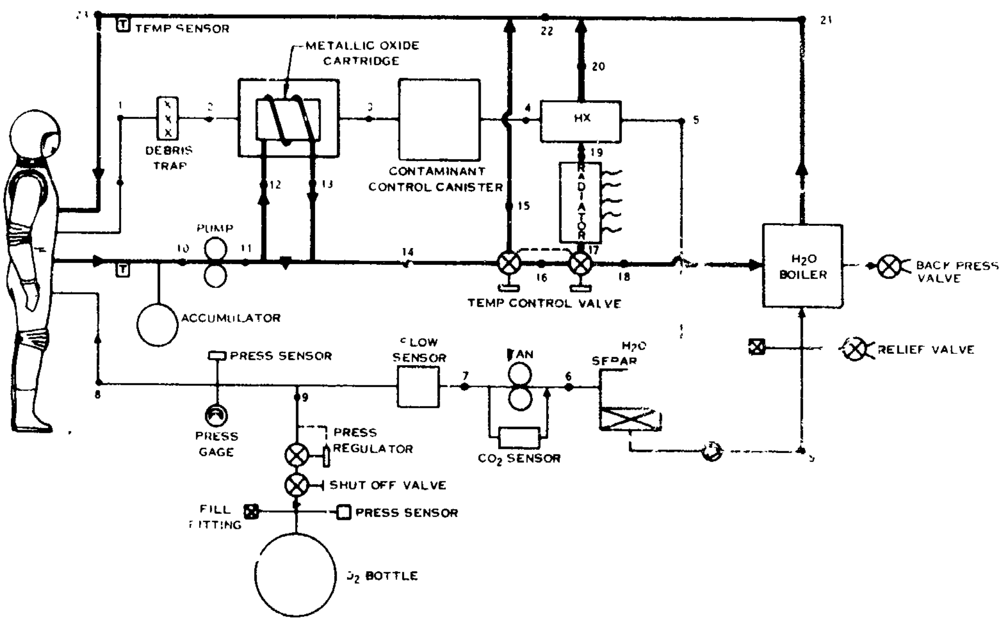
Step 13. Stow AEPS

6.3.5 AEPS Concept 5 - Mars (Figure 6-18)

6.3.5.1 System Description - This AEPS concept contains all required life support equipment for extravehicular operation including an O_2 ventilation loop, a high pressure O_2 subsystem, a water heat transport loop, a Freon heat transport loop, a power supply, instrumentation, communications, and operating controls and displays. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit enters the atmosphere regeneration subsystem and first passes through the debris trap where solid particles and/or droplets are removed; next CO_2 is removed by both physical adsorption and chemical absorption using a vehicle regenerable metallic oxide--zinc oxide; odors and trace contaminants are removed through physical adsorption by the activated charcoal in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The O_2 then passes to a Freon evaporator heat exchanger which cools the circulated O_2 and condenses the entrained moisture. The cooled O_2 continues to the water separator where the condensed water vapor is removed and transferred to the water boiler to provide additional cooling capacity. The cool, dry O_2 then passes to the fan which circulates a ventilation flow of 6 acfm to the suit.

The high pressure O_2 subsystem contains 1.7 pounds of usable O_2 at 6000 psia and 65°F and regulates the pressure in the O_2 ventilation loop to 7.0 ± 0.1 psia. This subsystem consists of an O_2 bottle, fill fitting, pressure sensor, shutoff valve and pressure regulator.

The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to a level where little, if any, perspiration occurs. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. Flow through the thermal control subsystem is regulated by an automatic temperature control valve.



VENT LOOP		STATION 1	2	3	4	5	5a	6	7	8	9
Temperature	°F	70	70	70	70	50	-	50	72	72	72
Volume Flow Rate	CFM	[illegible]	6.29	[illegible]	6.26	[illegible]		5.92	[illegible]	6.01	[illegible]
Total Pressure	psia	[illegible]	[illegible]	6.87	[illegible]	6.79		[illegible]	7.02	7.02	7.02
Total Weight Flow	lb/hr	[illegible]	[illegible]	14.01	14.01	13.87	-	13.87	13.85	14.07	.20
O_2 Weight Flow	lb/hr	[illegible]	[illegible]	[illegible]	[illegible]	13.5	-	[illegible]	13.5	13.7	.203
CO_2 Weight Flow	lb/hr	[illegible]	[illegible]	.162	.162	.162		.162	.162	[illegible]	
H_2O Weight Flow	lb/hr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.141	.205	[illegible]	[illegible]	
O_2 Partial Pressure	psia	[illegible]	6.49	[illegible]	6.48	[illegible]		[illegible]	6.76	[illegible]	7.0[illegible]
CO_2 Partial Pressure	psia	.11	.11	[illegible]	[illegible]	.057	-	[illegible]	[illegible]	.058	
H_2O Partial Pressure	psia	[illegible]	[illegible]	[illegible]	[illegible]	.18		.18	.17	.17	
Dew Point	°F	64	64	64	64	60	-	60	60	60	

LIQUID LOOP		STATION 10	11	12	13	14	15	16	17	18	19	20	21	22	23
Weight Flow	lb/hr	[illegible]	240	40	40	240	167	240	[illegible]	28	[illegible]	[illegible]	28	240	240
Temperature	°F	[illegible]	[illegible]	[illegible]	68.5	[illegible]	65	[illegible]	65	[illegible]	45	[illegible]	[illegible]	60	60
Pressure	psia	18	[illegible]	[illegible]	21.4	21.4	20.4	21.4	21.2	20.8	20.8	20.4	20.4	20.4	20.4

FIGURE 6-18. AEPS CONCEPT 5 - MARS

6.3.5.1 (Continued)

The thermal control subsystem is a hybrid expendable/direct radiative cooling subsystem and consists of a water boiler, direct radiator and a condensing heat exchanger. As the radiator load increases and exceeds design values, a portion of the water heat transport loop flow bypasses to the water boiler, thus maintaining a constant radiator outlet temperature.

6.3.5.2 System Configuration - A potential packaging configuration for AEPS Concept 5 is shown in Figure 6-19. The configuration shown integrates the life support equipment into the upper hard torso section and helmet assembly, thus permitting incorporation of a waist joint into this configuration. The low temperature radiator is helmet mounted to minimize the view factor with the Martian surface. This radiator is foldable to permit egress/ingress through the Mars Excursion Module (MEM) hatchways. The metallic oxide unit is a multiple screen pack configuration which is readily accessible for removal, regeneration and replacement.

The estimated total volume and weight for this AEPS configuration (less the suit) is 3100 in^3 and 84 pounds based on an average metabolic rate of 1200 BTU/hr for an EVA duration of 8 hours.

6.3.5.3 System Operational Modes - This section presents an example of the operational procedures a crewman might follow in the conduct of his EVA mission. Detailed operational procedures are dependent upon the final AEPS configuration and the final vehicle configuration selected.

Step 1. Unstow AEPS

Step 2. Initial Checkout

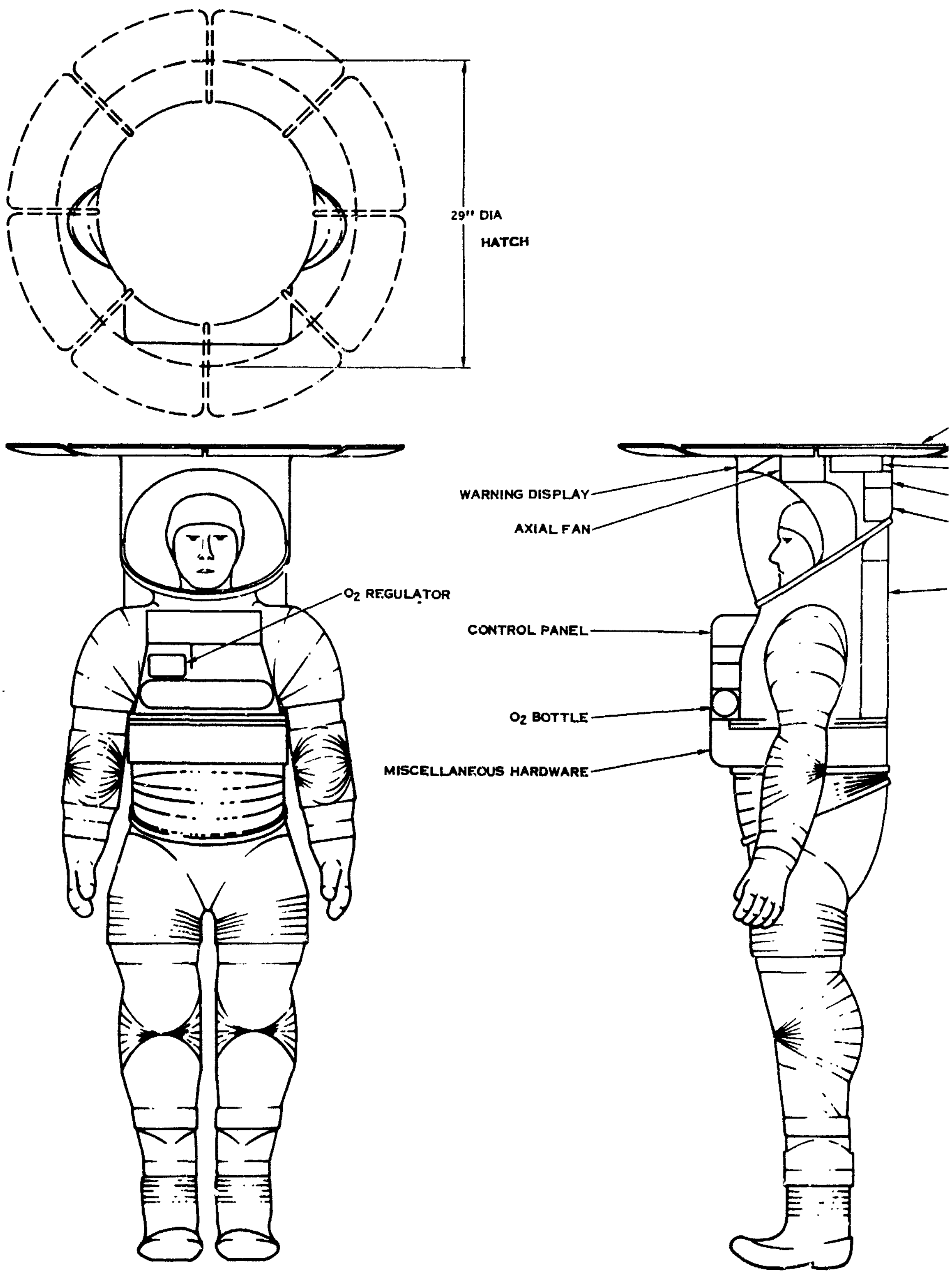
- Visually inspect AEPS
- Verify O_2 supply subsystem pressure
- Verify water boiler is fully charged

Step 3. Don AEPS in Donning Station

Step 4. Enter Airlock

- Close air lock to cabin hatch
- Connect vehicle oxygen and multiple water connectors
- Attach prebreathing face mask
- Prebreath pure O_2 for 38 minutes

FOLDOUT FRAME 1



FOLDOUT FRAME 2

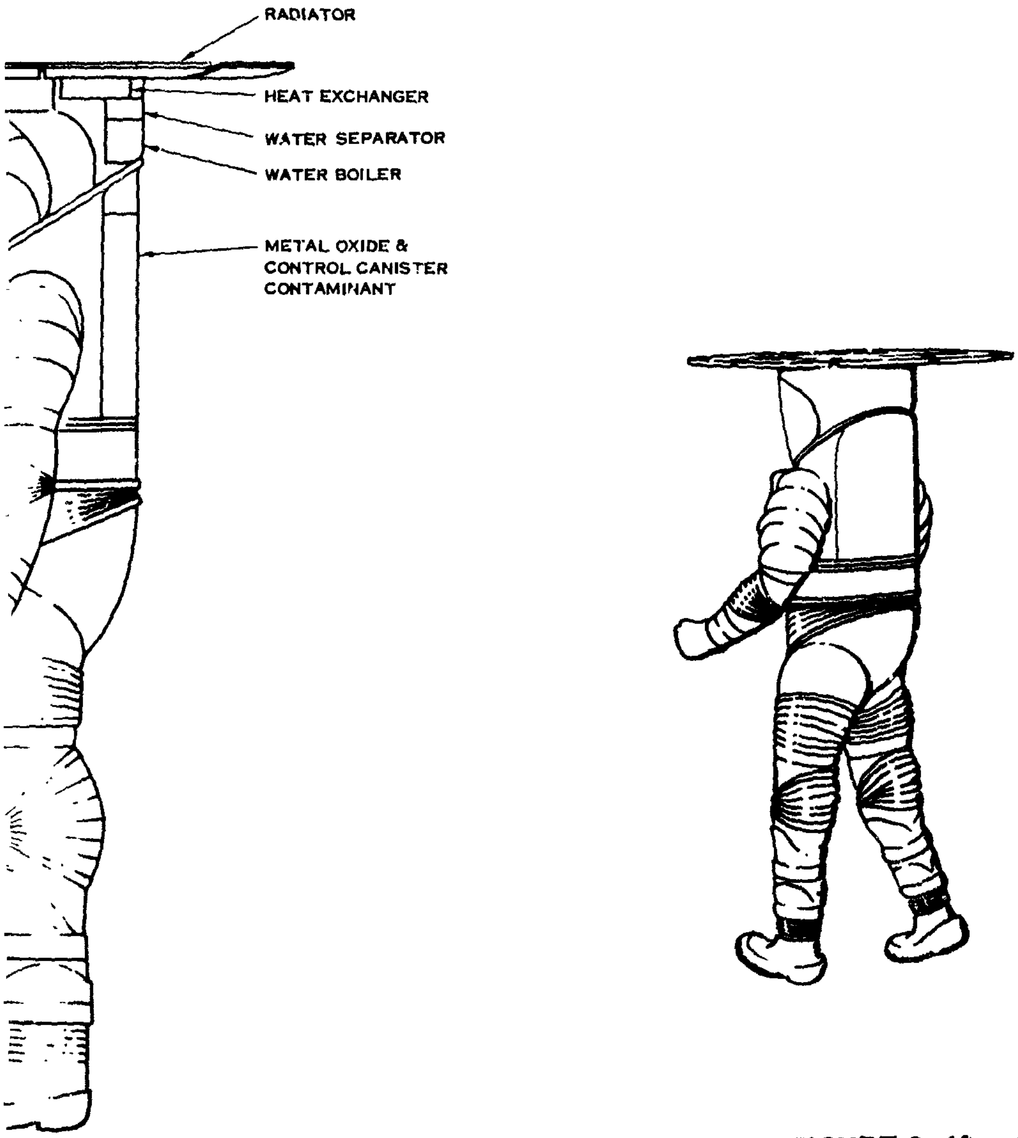


FIGURE 6–19. AEPS CONCEPT 5–MARS

6.3.5.3 (Continued)

Step 5. Final Checkout and Startup

- Depress automatic checkout switch to verify fan, pump and battery performance
- Check mission plan
- Doff face mask; don helmet and gloves
- Purge AEPS of diluent (nitrogen) by manually opening vehicle O_2 supply shutoff valve and the suit purge valve
- After 60 seconds, close the vehicle O_2 supply shutoff valve and then close the suit purge valve
- Activate the air lock compressor and depressurize the air lock at a maximum rate of 2 psi per minute. Open the AEPS O_2 supply subsystem shutoff valve when the air lock pressure decreases to 1.5 psia.
- Verify AEPS pressure regulation is normal
- Actuate air lock dump and open air lock to ambient hatch
- Disconnect vehicle mulitple water connector and activate AEPS pump
- Verify CO_2 partial pressure is within allowable limits
- Manually override temperature control valve and verify water boiler performance

Step 6. Egress Airlock

- Switch temperature control valve back to automatic operating mode.

Step 7. Perform EVA Mission

Step 8. Ingress Airlock

Step 9. Shutdown

- Attach vehicle multiple water connector
- Deactivate AEPS pump
- Close airlock to ambient hatch
- Attach vehicle O_2 supply umbilicals; do not open shutoff valve
- Depressurize airlock to remove any vestiges of the Martian atmosphere
- Start airlock repressurization
- When airlock pressure reaches 4 psia, turn off AEPS O_2 supply subsystem shutoff valve and turn on vehicle O_2 shutoff; turn off AEPS fan

6.3.5.3 (Continued)

- When airlock pressure reaches 10 psia, depressurize suit; turn off vehicle O_2 shutoff valve; purge suit to equalize pressure; remove helmet and vehicle O_2 umbilicals
- Open airlock to cabin hatch

Step 10. Ingress Cabin

Step 11. Doff AEPS in Donning Station

- Visually inspect AEPS

Step 12. Recharge/Regeneration/Maintenance

- Water Boiler - Connect vehicle quick disconnect from potable water supply to water boiler fill fitting. Recharge until water flow through the vehicle potable water flow meter ceases. Detach vehicle quick disconnect.
- Liquid Heat Transport Loop - Check the liquid heat transport loop accumulator level indicator. If the level is within an acceptable range, the liquid loop is topped off by adding water through a fill fitting. If the level is not within an acceptable range, corrective maintenance is performed to determine the source of the leak and to correct it. Then the liquid loop is topped off by adding water through a fill fitting.
- Oxygen Supply - Ensure O_2 supply subsystem shutoff valve is in closed position. Connect vehicle high pressure O_2 supply to AEPS O_2 fill fitting. Monitor AEPS O_2 bottle pressure to ensure fill is taking place. Two hours after pressurizing O_2 bottle to specified level, remove vehicle connector. Confirm pressure level with AEPS pressure gage and pressure sensor.
- Metallic Oxide/Charcoal Bed - Unclamp and rotate canister access cover out of way. Remove spent metallic oxide screen packs and visually inspect for signs of damage and/or malfunction. Place used screen packs in regenerating oven and actuate pressure/ temperature controller. Place fresh screen packs (from storage) in the AEPS canister and close and reclamp the canister access cover.
- Depris Trap - Remove from AEPS and visually inspect for signs of moisture and contaminants. If excessive contaminants are present, replace with spare from storage. If contaminants are not present, replace debris trap in AEPS. Contaminated units are bagged and transferred to the maintenance area.

6.3.5.3 (Continued)

- Depth Filter - Remove used filter and transfer to sterilization area. Inspect and clean filter housing. Install new filter in AEPS.
- Battery - Connect the vehicle electrical connector to the AEPS battery recharge connector. Recharge for 12 hours. Battery circuit voltage is then checked across a known resistance against acceptable limits. If the minimum acceptable voltage level cannot be achieved, the battery is replaced.

Step 13. Stow AEPS

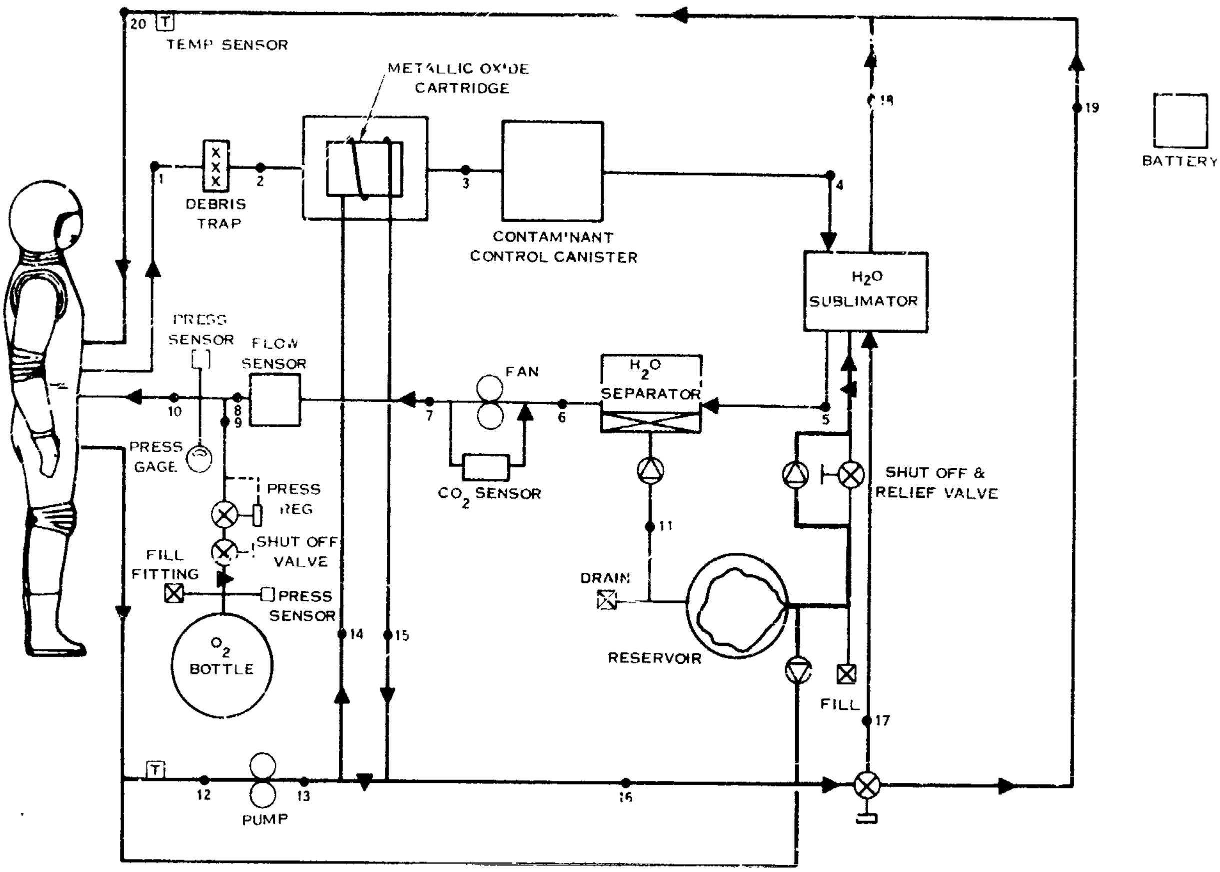
6.3.6 AEPS Concept 6 - Shuttle (Figure 6-20)

6.3.6.1 System Description - This AEPS concept contains all required life support equipment for extravehicular operation including an O_2 ventilation loop, a high pressure O_2 subsystem, a water heat transport loop, a power supply, instrumentation, communications, and operating controls and displays. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. O_2 from the suit enters the atmosphere regeneration subsystem and first passes through the debris trap where solid particles and/or droplets are removed; next CO_2 is removed by both physical adsorption and chemical absorption using a vehicle regenerable metallic oxide; odors and trace contaminants are removed through physical adsorption by the activated charcoal in the contaminant control canister; and finally, an absolute filter provides dust and bacteria control. The O_2 then passes to a water sublimator which cools the circulated O_2 and condenses the entrained moisture. The cooled O_2 continues to the water separator where the condensed water vapor is removed and transferred to the reservoir for condensate storage. The cool, dry O_2 then passes to the fan which circulates a ventilation flow of 6 acfm to the suit.

The high pressure O_2 subsystem contains 0.75 pounds of usable O_2 at 6000 psia and 65°F and regulates the pressure in the O_2 ventilation loop to 6.75 ± 0.1 psia. This subsystem consists of an O_2 bottle, fill fitting, pressure sensor, shutoff valve and pressure regulator.

The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to a level where little, if any, perspiration occurs. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. Flow through the thermal control subsystem is regulated by an automatic temperature control valve.

6.3.6.2 System Configuration - A potential packaging configuration for AEPS Concept 6 is shown in Figure 6-21. The configuration shown integrates the life support equipment into a hard center torso section. Since a waist joint is not necessarily required

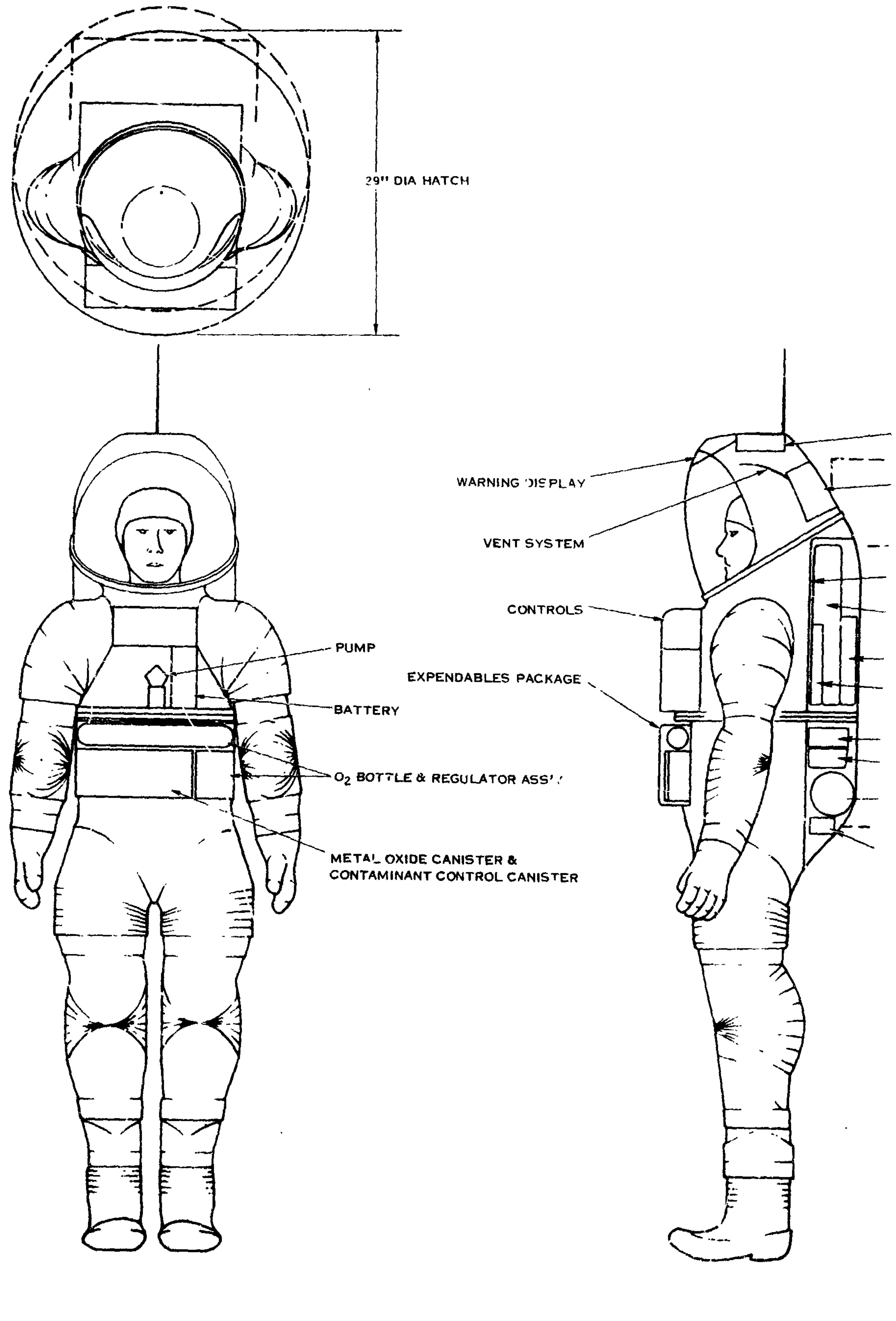


VENT LOOP	UNITS	STATION 1	2	3	4	5	6	7	8	9	10	11
TEMPERATURE	°F	79	79	79	79	50	50	72	72	72	72	
VOLUME FLOW RATE	CFM	6.28	6.29	6.25	6.29	5.95	5.97	5.98	5.98	.075	6.0	
TOTAL PRESSURE	PSIA	6.662	6.642	6.582	6.532	6.482	6.462	6.752	6.75	6.75	6.75	6.46
TOTAL WEIGHT FLOW	LB/HR	13.756	13.758	13.563	13.563	13.431	13.431	13.431	13.431	.169	13.6	
O_2 WEIGHT FLOW	IB/HR	13.064	13.064	13.064	13.064	13.064	13.064	13.064	13.064	1169	13.233	
CO_2 WEIGHT FLOW	IB/HR	.337	[illegible]	.162	.162	.162	.162					
H_2O WEIGHT FLOW	IB/HR	.337	.337	.337	.337	.205	.205	.205	.205		.205	.132
O_2 PARTIAL PRESSURE	PSIA	6.248	6.229	6.235	6.237	6.299	6.231	6.513	6.511	6.75	6.512	
CO_2 PARTIAL PRESSURE	PSIA	.126	.125	.057	.058	.057	.057	.059	.059		.059	
H_2O PARTIAL PRESSURE	PSIA	.288	.288	.290	.288	.175	.174	.180	.180		.179	
DEW POINT	°F	63	63	63	63	50	50	50	50		50	

LIQUID LOOP	UNITS	STATION 12	13	14	15	16	17	18	19	20
WEIGHT FLOW	IB/HR	240	240	40	[illegible]	240	55	55	185	240
TEMPERATURE	°F	64.7	64.8	64.8	68.2	65.5	65.5	45	65.5	60
PRESSURE	PSIA	6.46	9.76	9.76	9.56	9.56	9.46	8.86	8.86	8.86

FIGURE 6-20. AEPS CONCEPT 6 - SHUTTLE

FOLDOUT FRAME 1



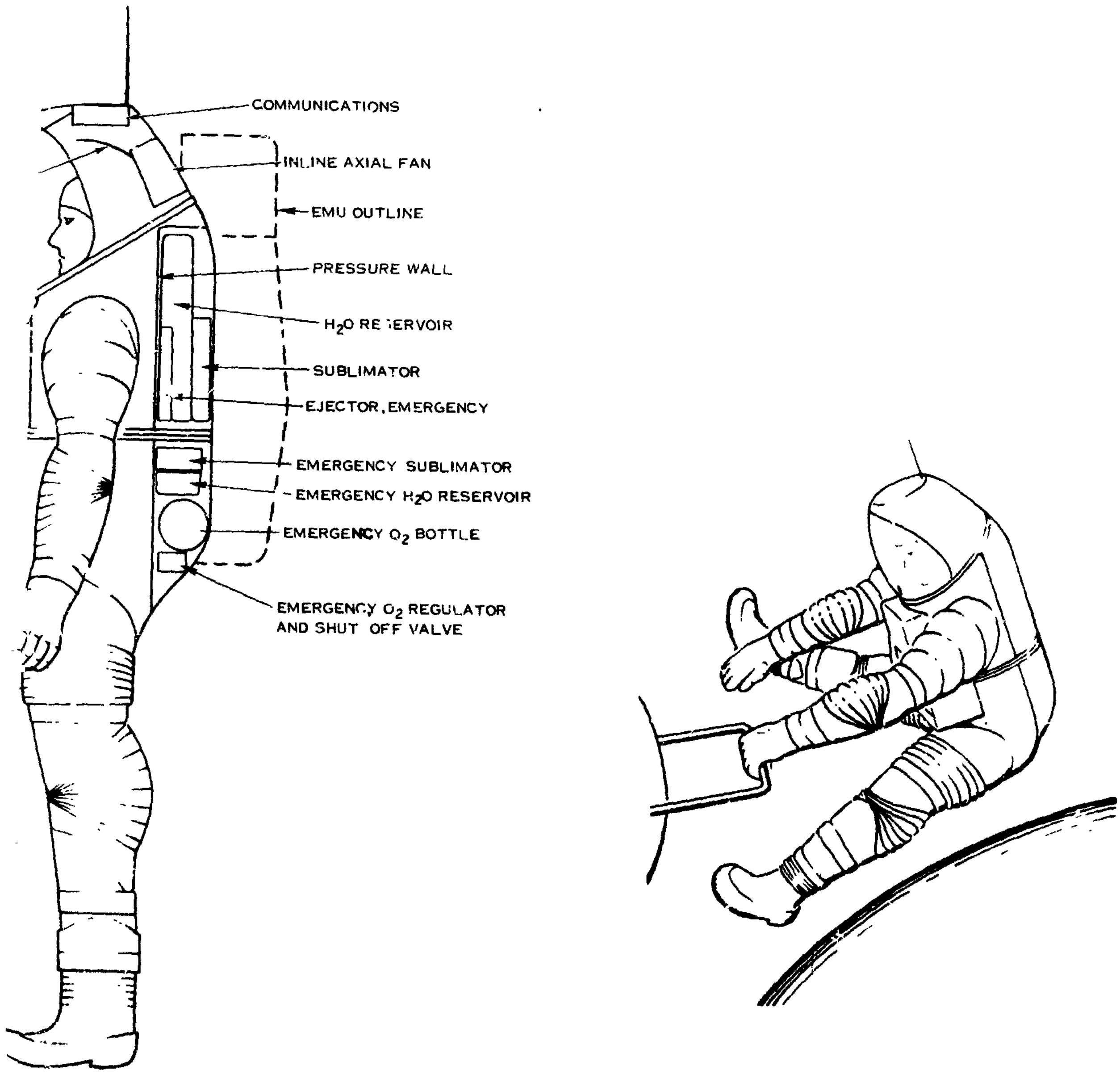


FIGURE 6–21. AEPS CONCEPT 6

6.3.6.2 Continued

for zero gravity operation, some equipment has been packaged in the lower torso area. The metallic oxide unit is a multiple screen pack configuration which is readily accessible for removal, regeneration and replacement. An ejector-type emergency system is packaged in the back of the lower torso area. This emergency system concept is discussed in detail in section 6.4.

As shown by the dotted outline, the cross-section of this configuration is less than that for the Apollo EMU PLSS. However, this suit is approximately four inches higher than the present Apollo suit due to the increased helmet size required to facilitate packaging of the communications and the warning display. The center of gravity for this configuration is very close to that of the nude crewman.

The estimated total volume and weight for this AEPS configuration (less the suit and the emergency system) are 1100 in^3 and 38 pounds based on everage metabolic rate of 1000 B[illegible]/hr for an EVA duration of 4 hours.

6.3.6.3 <u>System Operational Modes</u> - This section presents an example of the operational procedures a crewman might follow in the conduct of his EVA mission. Detailed operational procedures are dependent upon the final AEPS configuration and the final vehicle configuration selected.

Step 1. <u>Unstow AEPS</u>

Step 2. <u>Initial Checkout</u>

- Visually inspect AEPS
- Verify O_2 supply subsystem pressure
- Verify water reservoir is fully charged

Step 3. <u>Don AEPS in Donning Station</u>

Step 4. <u>Enter Airlock</u>

- Close air lock to cabin hatch
- Connect vehicle oxygen and multiple water connectors
- Attach prebreathing face mask
- Prebreath pure O_2 for 43 minutes

Step 5. <u>Final Checkout and Startup</u>

- Depress automatic checkout switch to verify fan, pump and battery performance

6.3.6.3 (Continued)

- Check mission plan
- Doff face mask; don helmet and gloves
- Purge AEPS of diluent (nitrogen) by manually opening vehicle O_2 supply shutoff valve and the suit purge valve
- After 60 seconds, close the vehicle O_2 supply shutoff valve and then close the suit purge valve
- Activate the airlock compressor and depressurize the airlock at a maximum rate of 2 psi per minute. Open the AEPS O_2 supply subsystem shutoff valve when the airlock pressure decreases to 1.5 psia.
- Verify AEPS pressure regulation is normal
- Actuate airlock dump and open airlock to ambient hatch
- Disconnect vehicle multiple water connector and activate AEPS pump
- Activate AEPS compressor and verify freon evaporator outlet pressure is normal
- Verify CO_2 partial pressure is within allowable limits
- Manually override temperature control valve and verify water sublimator performance. Switch temperature control valve back to automatic operating mode.

Step 6. Egress Airlock

Step 7. Perform EVA Mission

Step 8. Ingress Airlock

Step 9. Shutdown

- Attach vehicle multiple water connector
- Deactivate AEPS pump
- Close airlock to ambient hatch
- Attach vehicle O_2 supply umbilicals; do not open shutoff valve
- Start airlock repressurization
- When airlock pressure reaches 4 psia, turn off AEPS O_2 supply subsystem shutoff valve and turn on vehicle O_2 shutoff valve; turn off AEPS fan
- When airlock pressure reaches 10 psia, depressurize suit; turn off vehicle O_2 shutoff valve; purge suit to equalize pressure; remove helmet and vehicle O_2 umbilicals
- Open airlock to cabin hatch

Step 10. Ingress Cabin

6.3.6.3 (Continued)

Step 11. Doff AEPS in Donning Station

- Visually inspect AEPS

Step 12. Recharge/Regeneration/Maintenance

- Water Reservoir - Connect vehicle quick disconnect from potable water supply to water reservoir fill fitting. Attach vehicle drain fitting to the reservoir drain fitting. Recharge until water flow through the vehicle potable water flow meter ceases. Detach vehicle quick disconnects.
- Oxygen Supply - Ensure O_2 supply subsystem shutoff valve is in closed position. Disconnect low pressure disconnect and remove spent O_2 supply subsystem. Replace with fresh O_2 supply subsystem. Confirm proper AEPS O_2 supply pressure with AEPS pressure gage.
- Metallic Oxide/Charcoal Bed - Unclamp and rotate canister access cover out of way. Remove spent metallic oxide screen packs and visually inspect for signs of damage and/or malfunction. Place used screen packs in regenerating oven and actuate pressure/temperature controller. Place fresh screen packs (from storage) in the AEPS canister and close and reclamp the canister access cover.
- Debris Trap - Remove from AEPS and visually inspect for signs of moisture and contaminants. If excessive contaminants are present, replace with spare from storage. If contaminants are not present, replace debris trap in AEPS. Contaminated units are bagged and transferred to the maintanance area.
- Depth Filter - Remove used filter and transfer to sterilization area. Inspect and clean filter housing. Install new filter in AEPS.
- Battery - Connect the Vehicle electrical connector to the AEPS battery recharge connector. Recharge for 12 hours. Battery open circuit voltage is then checked against acceptable limits. If the minimum acceptable voltage level cannot be achieved, the battery is replaced.

Step 13. Stow AEPS

6.4 Emergency System Baseline Concepts

Due to the overall system implications of some of the candidate CO_2 control/O_2 supply concepts (specifically the open loop candidate concepts), the CO_2 control/O_2 supply subsystems evaluation was conducted on the system level. Maximum allowable CO_2 partial pressure level and total suit pressure level directly affect the overall emergency system concept and design. Figure 6-22 depicts required ventilation rate (as measured with the Apollo helmet configuration) versus metabolic rate for CO_2 partial pressure levels of 7.6 and 15 mm Hg. The required ventilation rates (based on metabolic work rate) can be converted to equivalent volume and weight penalties for various total suit pressure levels, as depicted in Figures 6-23 and 6-24. Note for a metabolic work rate of 2000 Btu/hr, approximately 4.3 CFM are required to maintain the CO_2 partial pressure level below 15 mm Hg. For a suit pressure level of 6.75 psia, this would result in an equivalent volume penalty of 600 in^3/hr of mission duration and an equivalent weight penalty of 24 lbs/hr of mission duration. These high penalties associated with higher suit pressure levels indicate that the simple purge flow concept, such as the oxygen purge system used on the Apollo Program, may be too bulky and heavy for the intended AEPS applications (especially the longer duration emergency systems such as Lunar Base and Mars).

This section discusses seven (7) potential emergency system configurations which might result if the technology recommendations emanating from the AEPS study are implemented. The schematics discussed are examples of combinations of recommended subsystems and components, and are not necessarily the only competitive combinations. Emergency system concepts applicable to Shuttle, Space Station, Lunar Base and Mars applications are included in this section.

6.4.1 Emergency System Concept 1 - Space Station/Shuttle (Figure 6-25)

This is a separate, independent emergency system concept which contains all required life support equipment for extravehicular operation during an emergency including an O_2 ventilation loop, a high pressure O_2 subsystem, a water heat transport loop and a thermal control subsystem.

The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. CO_2 and humidity control is accomplished by the addition of a fresh supply of oxygen at the ejector, which circulates the ventilation system at 6 CFM, and the purging of suit outlet ventilation flow at the dump valve. The dump valve maintains a back pressure of 6.75 ± 0.1 psia.

The high pressure O_2 subsystem contains 1.9 pounds of usable O_2 at 6,000 psia and 60°F and regulates the ejector upstream pressure to 200 ± 10 psia. In addition, this subsystem drives the gas-powered pump and regulates pump flow to 4.0 ± 0.2 lb/min and pump inlet water pressure to 6.9 ± 0.2 psia via a pressure accumulator. This

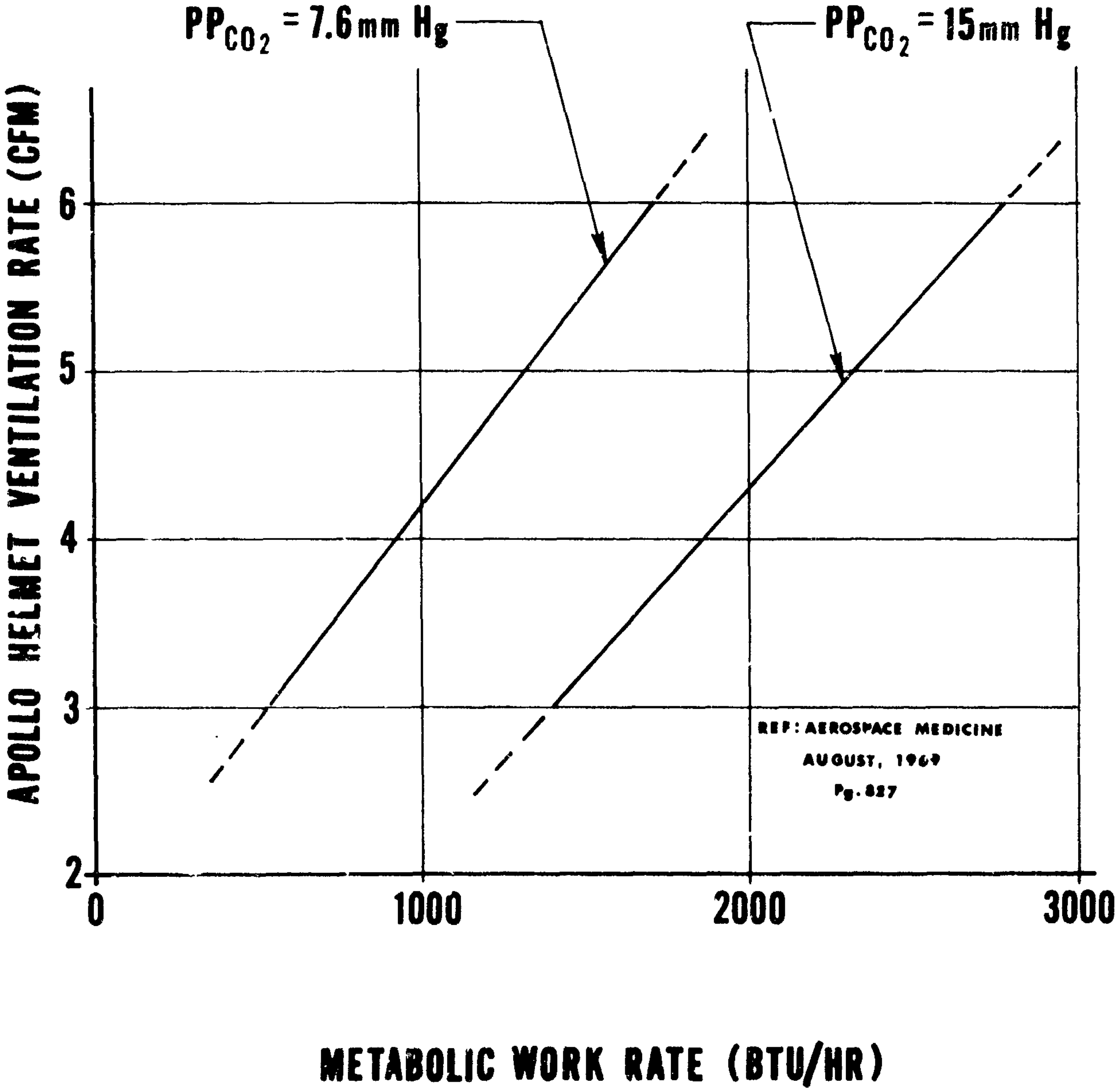


FIGURE 6—22. MEAN CARBON DIOXIDE INHALATION LEVEL VS WORK AND VENTILATION RATE

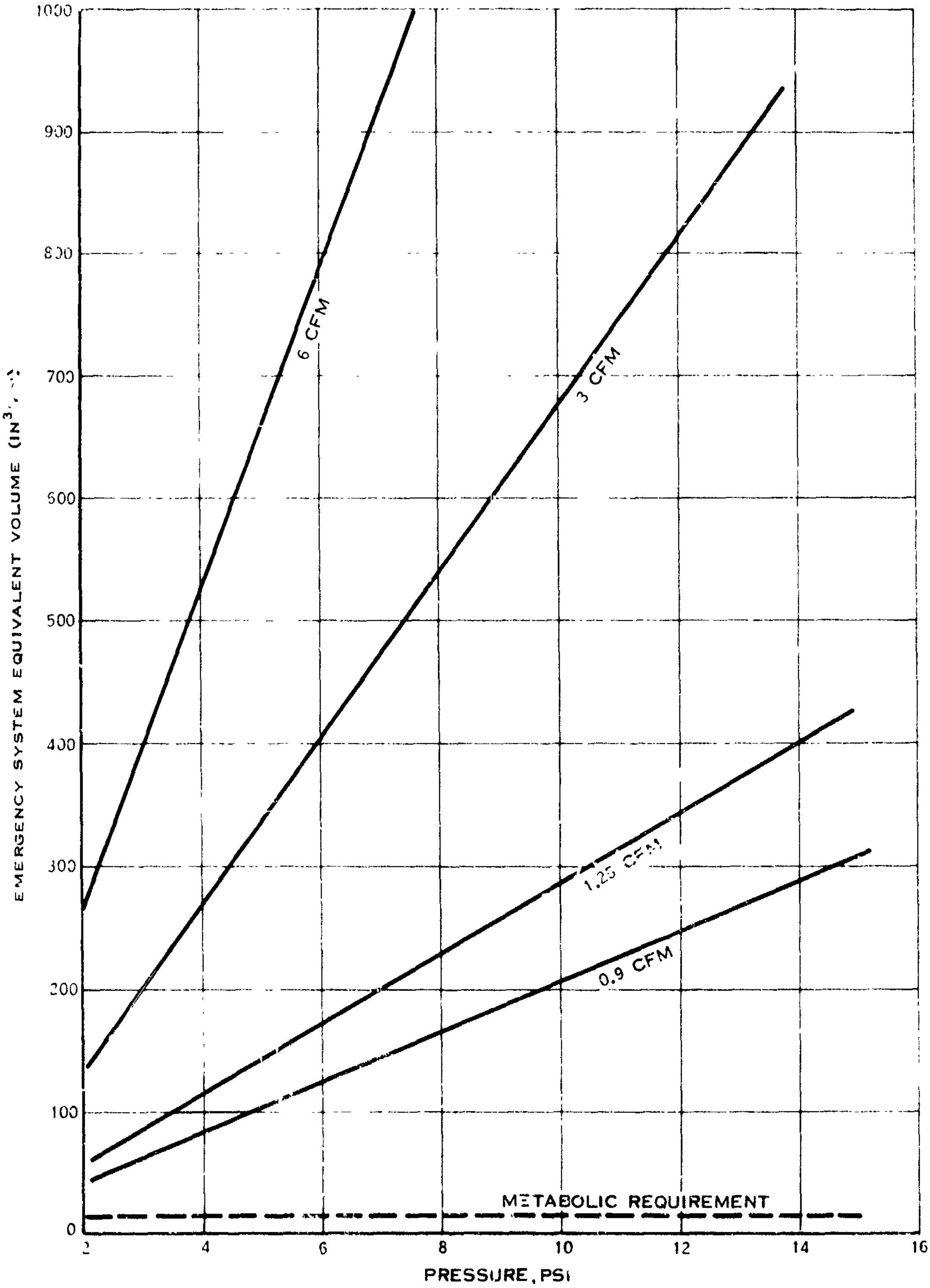


FIGURE 6–23. EMERGENCY PURGE FLOW SYSTEM VOLUME PENALTY VERSUS SUIT PRESSURE LEVEL

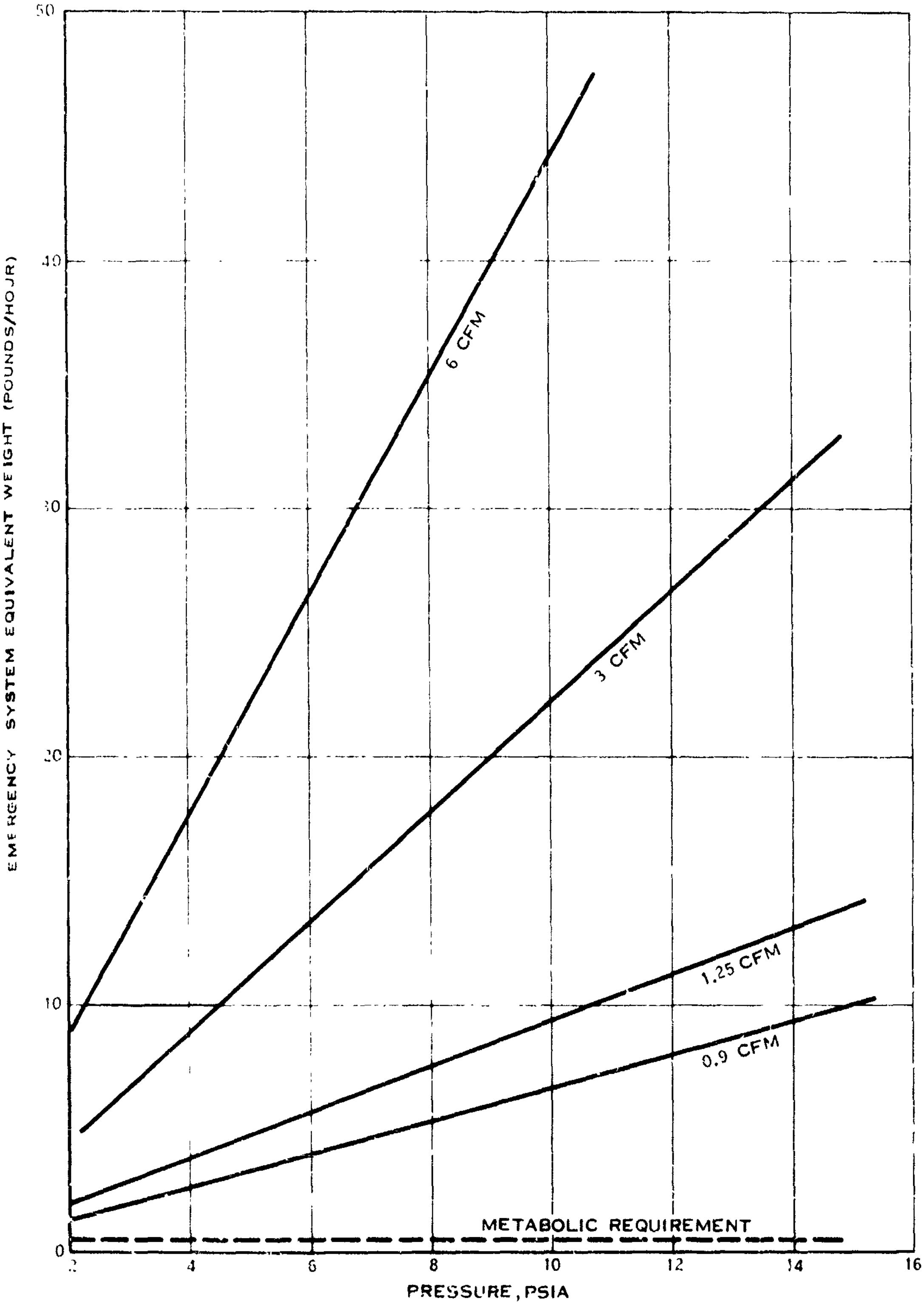
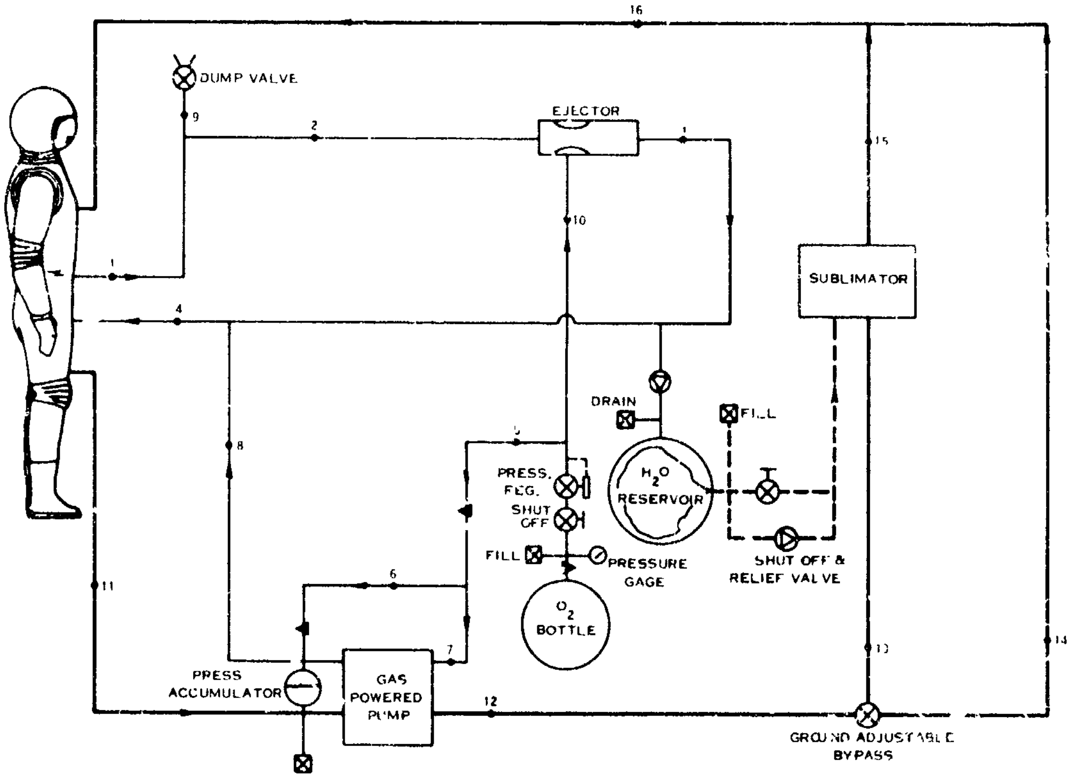


FIGURE 6—24. EMERGENCY PURGE FLOW SYSTEM WEIGHT PENALTY VERSUS SUIT PRESSURE LEVEL



VENT LOOP		STATION									
		1	2	3	4	5	6	[illegible]	8	9	10
TEMPERATURE	°F	75	75	70	70	60	60	60	66	75	[illegible]
VOLUME FLOW RATE	CFM	6.32	4.6[illegible]	5.94	6.06	.004	[illegible]15	.065	.123	1.70[illegible]	0454
TOTAL PRESSURE	PSIA	6.75	6.75	6.91	6.91	200	10.83	10.83	6.93	6.75	200
TOTAL WEIGHT FLOW	LB/HR	14,274	10.441	13.833	14.123	.29	.05	[illegible]	.29	3.833	3.396
O_2 WEIGHT FLOW	LB/HR	12.76	9.348	12.[illegible]4	13.03	.29	.05	.24	.29	3.43	3.396
CO_2 WEIGHT FLOW	LB/HR	1.093	.8	.8	.8					.293	
H_2O WEIGHT FLOW	LB/HR	.401	.293	.293	.293					.108	
O_2 PARTIAL PRESSURE	PSIA	6.035	6.035	6.36	.376	200	10.83	10.83	6.93	6.[illegible]35	200
CO_2 PARTIAL PRESSURE	PSIA	.376	.376	.29	.283					.376	
H_2O PARTIAL PRESSURE	PSIA	.339	339	.26	.249					.339	
DEW POINT	°F	68	68	60	59					[illegible]	

LIQUID LOOP		STATION					
		11	12	13	14	15	16
WEIGHT FLOW	LB/HR	240	240	67	[illegible]	67	240
TEMPERATURE	°F	65.8	65.8	65.8	65.8	45	60
PRESSURE	PSIA	6.93	10.83	10.73	9.33	9.33	9.33

FIGURE 6-25. EMERGENCY SYSTEM CONCEPT 1 – SPACE STATION/SHUTTLE

6.1.1 (Continued)

subsystem consists of an O_2 bottle, fill fitting, shut-off valve, pressure regulator and a low pressure quick disconnect for replacement (not shown).

The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is then cooled by direct conduction. Flow through the thermal control subsystem is regulated by a ground adjustable bypass valve (adjusted prior to flight).

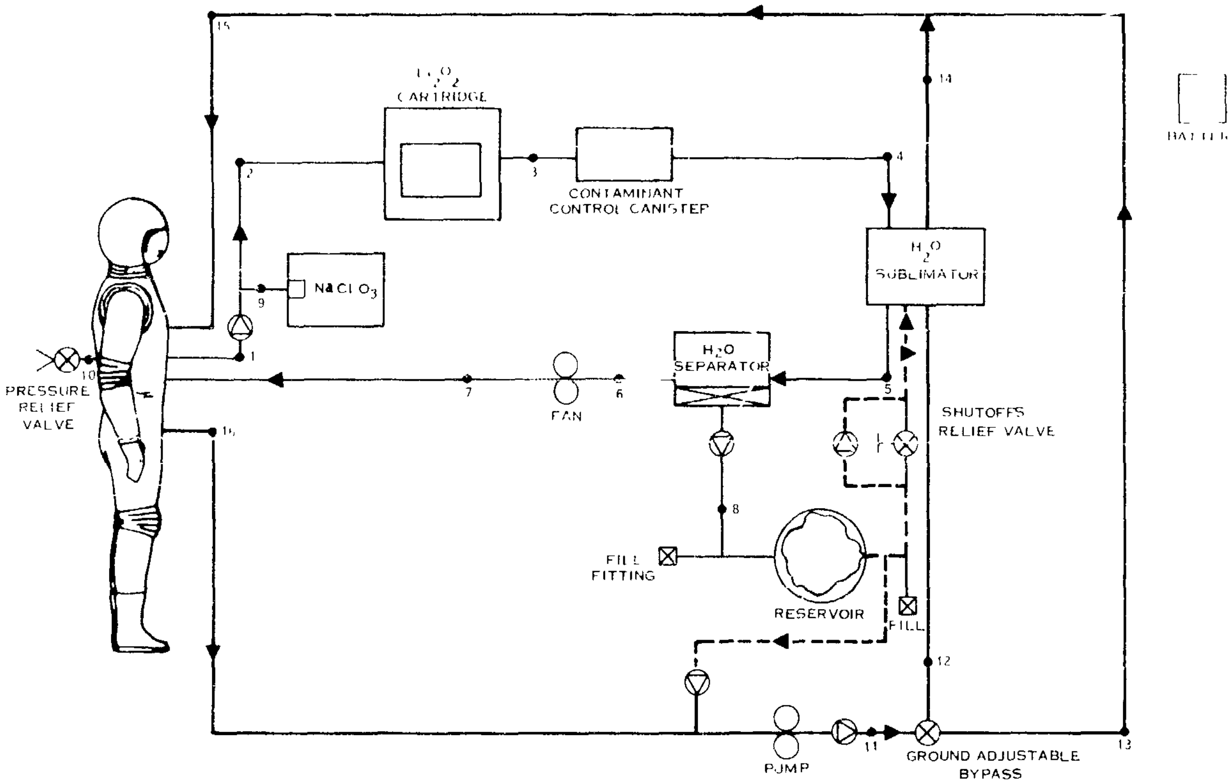
The water heat transport loop is temperature conditioned by a water sublimator. The bladder within the water reservoir is pressurized by the O_2 ventilation loop and supplies the sublimator with feedwater. The thermal control subsystem consists of a water sublimator, a water reservoir, fill and drain fittings, and a shut-off and relief valve.

The estimated total volume and weight for this AEPS Emergency system are 512 in^3 and 14.5 pounds, based on an average metabolic rate of 1500 BTU/hr for an emergency EVA duration of 30 minutes.

6.1.2 Emergency System Concept 2 - Space Station/Shuttle (Figure 6-26)

This is a separate, independent concept which contains all the required life support equipment for extravechicular operation during an emergency including an O_2 ventilation loop, a water heat transport loop, a power supply and operating controls. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. Oxygen from the suit enters the lithium peroxide (Li_2O_2) cartridge which removes CO_2 from the ventilation loop and generates oxygen. Odors and trace contaminants are then removed through physical adsorption by activated charcoal in the contaminant control canister. The O_2 then passes to a water sublimator which cools the circulated O_2 and condenses the entrained moisture. The cooled O_2 continues to the water separator where the condensed water vapor is removed and transferred to the sublimator feedwater reservoir. The cool, dry O_2 then passes to the fan which circulates a ventilation flow of 6 acfm to the suit. The metabolic oxygen make-up requirement is provided by the Li_2O_2 chemical release of O_2 plus the output of a sodium chlorate candle. The Li_2O_2 oxygen release is metabolically controlled at approximately one-half the instantaneous total requirement while the fixed output of the candle is sized for one-half the metabolic peak of 2500 Btu/hr. The excess oxygen generated by the candle, while the crewman is working at less than 2500 Btu/hr, is vented overboard by the suit pressure control valve.

The water heat transport loop cools the suited crewman by supplying cool water through the liquid cooling garment utilized for the primary AEPS system operation. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. The thermal control subsystem is an expendable concept utilizing



VENT LOOP	UNITS	STATION									
		1	2	3	4	5	6	7	8	9	10
TEMPERATURE	F	79	86	176	179	50	50	72	50	150	79
VOLUME FLOW RATE	CFM	6.27	6.43	7.44	7.54	5.99	6.0	6.00			0.073
TOTAL PRESSURE	PSIA	6.622	6.622	6.583	6.533	6.472	6.452	6.75		6.622	6.622
TOTAL WEIGHT FLOW	LBS/HR	13.736	13.973	13.76	13.76	13.6	13.6	13.6		0.314	0.1347
O_2 WEIGHT FLOW	LBS/HR	12.284	12.521	12.598	12.598	12.598	12.598	12.598		0.314	0.161
CO_2 WEIGHT FLOW	LBS/HR	1.087	1.087	0.797	0.797	0.797	0.797	0.797			0.0102
H_2O WEIGHT FLOW	LBS/HR	0.365	0.365	0.365	0.365	0.205	0.205	0.205	0.16		0.0035
O_2 PARTIAL PRESSURE	PSIA	5.929	5.957	5.991	5.979	6.022	6.002	6.281		8.341	5.929
CO_2 PARTIAL PRESSURE	PSIA	0.381	0.377	0.280	0.2[illegible]6	0.277	0.277	0.29			0.381
H_2O PARTIAL PRESSURE	PSIA	0.312	0.308	0.312	0.308	0.173	0.173	0.179			0.312
DEW POINT	F	65	64	65	64.65	50	50	50			65

LIQUID LOOP	UNITS	STATION					
		11	12	13	14	15	16
WEIGHT FLOW	LBS/HR	240	67	173	67	240	240
TEMPERATURE	F	65.8	65.8	65.8	45	60	65.8
PRESSURE	PSIA	10.36	10.26	8.86	8.86	8.[illegible]	[illegible]

FIGURE 6–26. EMERGENCY SYSTEM CONCEPT 2 – SPACE STATION–SHUTTLE

6.4.2 (Continued)

a water sublimator and a bladder reservoir. The ground adjustable bypass valve is set prior to flight for the anticipated cooling requirements of the individual crewman.

The estimated total volume and weight for this emergency system concept are 512 in^3 and 14.1 pounds based on an average metabolic rate of 1500 Btu/hr for an emergency duration of 30 minutes.

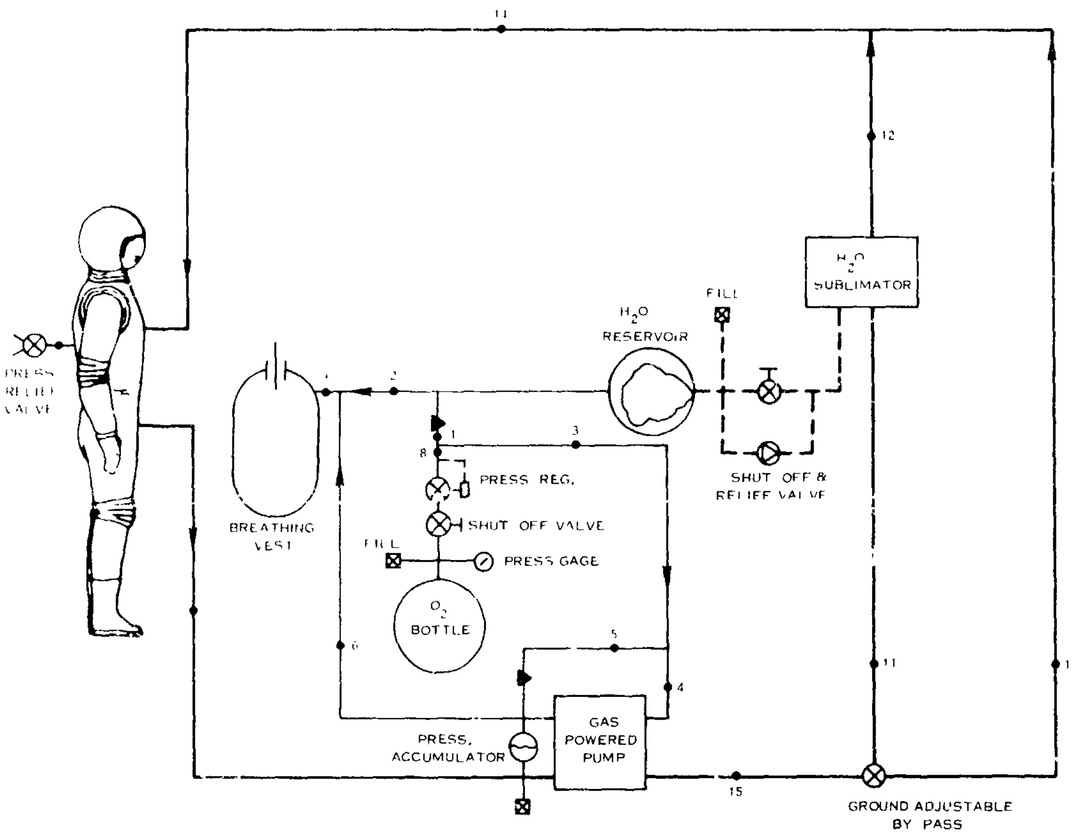
6.4.3 Emergency System Concept 3 - Space Station/Shuttle (Figure 6-27)

This is a separate, independent concept which contains all required life support equipment for extravehicular operation during an emergency including an oxygen breathing vest/mouth piece assembly, a high pressure O_2 subsystem, a water heat transport loop and a thermal control subsystem.

The oxygen breathing vest/mouth piece assembly provides fresh oxygen at the oral nasal face area as a direct function of crewman inhalation/exhalation rate. The breathing vest consists of a double-walled garment covering the upper torso and worn over the liquid cooling garment. Because the vest is restrained on the outside by the inner suit wall, any torso volumetric change causes an equal volumetric change in the vest. During an inhalation, the reduction in volumetric size of the vest forces the displaced oxygen to the oral nasal area through the mouth piece. During exhalation, flow through the mouth piece ceases and the vest is refilled with fresh oxygen from the high pressure oxygen subsystem. Exhaled breath is purged out of the suit at the dump valve which maintains suit pressure at 6.75 ± 0.1 psia.

The high pressure O_2 subsystem contains 1.6 pounds of usable O_2 psia at 60°F and regulates the gas powered water pump inlet pressure by a pressure regulator and supplies the breathing vest with oxygen through a flow control orifice. Controlling the pump gas inlet pressure to 10.8 ± 0.2 psia and the pump liquid cooling loop inlet pressure to 6.9 ± 0.2 psia via a pressure accumulator provides a pump flow of 4.0 ± 0.2 lb/min. This subsystem consists of an O_2 bottle, fill fitting, shut-off valve, pressure regulator and a low pressure quick disconnect for replacement (not shown). The water heat transport loop cools the suited crewman by supplying and circulating cool water through a network of tubes built into the crewman's undergarment. The skin is cooled by direct conduction and the mean skin temperature is lowered to where little, if any, perspiration occurs. Flow through the thermal control subsystem is regulated by a ground adjustable by-pass valve.

The water heat transport loop is temperature conditioned by a water sublimator. A bladder water reservoir pressurized by the oxygen low pressure line supplies the sublimator with feedwater. The thermal control subsystem consists of a water sublimator, a water reservoir, fill and drain fittings, and a shut-off and relief valve.



VENT LOOP		STATION								
		1	2	3		5	6	7	8	9
TEMPERATURE	°F	60	60	60	60	60	65	75	60	60.5
VOLUME FLOW RATE	CFM	0.651	1.022	0.080	0.065	0.015	0.123	1.38	0.794	1.25
TOTAL PRESSURE	PSIA	10.85	6.91	10.85	10.83	10.83	6.93	6.75	10.85	6.91
TOTAL WEIGHT FLOW	LBS/HR	2.68	2.66	0.29	0.24	0.05	0.29	3.110	2.97	2.97
O_2 WEIGHT FLOW	LBS/HR	2.68	2.68	0.29	0.24	0.05	0.29	2.73	2.97	2.97
CO_2 WEIGHT FLOW	LBS/HR							0.293		
H_2O WEIGHT FLOW	LBS/HR							0.087		
O_2 PARTIAL PRESSURE	PSIA	10.85	6.91	10.85	10.83	10.83	6.93	5.95	10.85	6.91
CO_2 PARTIAL PRESSURE	PSIA							0.462		
H_2O PARTIAL PRESSURE	PSIA							0.339		
DEW POINT	°F							68		

LIQUID LOOP		STATION					
		10	11	12	13	14	15
WEIGHT FLOW	LBS/HR	240	67	67	173	240	240
TEMPERATURE	°F	65.8	65.8	45	65.8	60	65.6
PRESSURE	PSIA	6.93	10.73	9.33	9.33	9.33	10.83

FIGURE 6–27. EMERGENCY SYSTEM CONCEPT 3 – SPACE STATION–SHUTTLE

6.4.3 (Continued)

The estimated total volume and weight for this AEPS Emergency System are 468 in^3 and 14.2 pounds, based in an average metabolic rate of 1500 Btu/hr for an emergency duration of 30 minutes.

6.4.4 Emergency System Concept 4 - Space Station (Figure 6-28)

This emergency system concept, when considered in conjunction with the AEPS primary system, contains all required life support equipment for extravehicular operation during an emergency. System reliability is predicated on the assumption that no single failure can occur that will create a massive decompression of the oxygen circuit, either within the suit or life support system; that is, the system is designed to be rugged enough to preclude this possibility. Therefore, the same duct work may be utilized for both the emergency and primary life support system with the following prime functions being made redundant:

1. The emergency battery is utilized in the event that the primary battery fails to function or that it is becoming evident that failure of the battery is about to take place. A failed primary battery is easily detected by the simultaneous drop-off in voltage and current drain of the fan, pump, compressor, and battery.

2. The emergency fan is required in the event of a primary fan failure. Check valves are required downstream of both the primary and emergency fans to prevent flow short circuitry. A speed sensor easily measures a fan failure or drop in performance.

3. The emergency pump is required in the event of a primary pump failure. Check valves to prevent short circuitry (shown schematically in the Figure) are an inherent part of the pumps because they are positive displacement devices. Measuring pressure head and/or current and voltage drain easily measures a pump failure.

4. The emergency CO_2 and contaminant control system and the oxygen supply system consists of an Li_2O_2 cartridge/canister assembly, a contaminant control canister and a chlorate candle. In the event of a high pressure oxygen system failure, clogging of the debris trap and/or failure of the metallic oxide and contaminant control canisters, this entire emergency subsystem is utilized.

5. An emergency thermal control capability is an inherent part of the primary subsystem. The water boiler is sized for an entire normal mission capability although it is utilized under normal conditions for handling thermal peak loads. The PH_4Cl thermal storage subsystem has the capability of

6.4.4 (Continued)

performing an entire normal mission at average heat loads in addition to an emergency capability at emergency heat loads. For this reason, the compressor is sized for the emergency condition. The automatic temperature control valve is provided with a manual over-ride to preclude loss of operation of the valve. In the event the PH_4Cl thermal storage loop fails, the boiler provides thermal control by directly conditioning the liquid cooling loop and indirectly cooling the vent loop with the LCG in the thermal storage evaporator. In the event the boiler fails, the PH_4Cl thermal storage loop provides direct cooling of the LCG and the vent loop in the evaporator.

In addition to the above, a dump valve is provided for purging of any over production of oxygen from the chlorate candle and the Li_2O_2 canisters.

The estimated total volume and weight for this AEPS emergency configuration (the delta increase over the primary system) is 222 in^3 and 8.0 pounds, based in an average metabolic rate of 1500 Btu/hr for an emergency EVA duration of 30 minutes.

6.4.5 Emergency System Concept 5 -- Lunar Base (Figure 6-29)

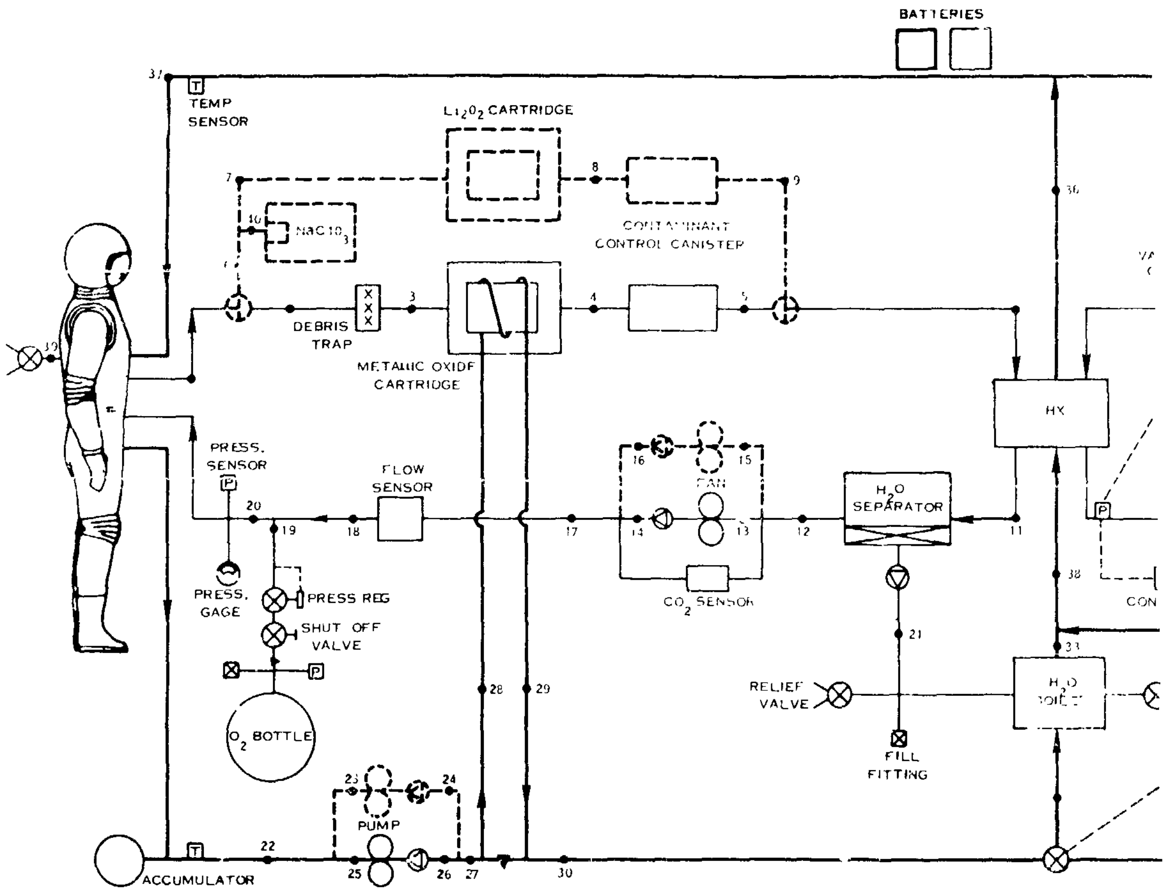
This concept contains all the required life support equipment for emergency atmosphere revitalization and thermal control during extravehicular operation. This system, in combination with the AEPS Concept 4 primary system, provides redundant subsystems and components (denoted by dashed lines) to ensure continued function of the O_2 ventilation loop, oxygen supply subsystem, the water heat transport loop, the power supply and operating controls. Integration of these components into the primary system provides a maximum emergency capability for maximum weight and volume impact.

Emergency CO_2 and trace contaminant control is provided by a cooled LiOH cartridge and activated charcoal in a loop bypassing the primary metallic oxide system. Valves at the inlet and outlet provide positive bypass and sealing of the system when not in use. The LiOH loop would be placed in operation when the primary system has indicated a failure such as debris trap plugging, high CO_2 level or high odor level.

Both prime movers, the cooling loop pump and the vent loop fan, have backups with check valves preventing recycle through the idle component.

The redundant high pressure O_2 subsystem contains 0.52 pounds of usable O_2 at 6000 psia and 65°F, and regulates the pressure in the ventilation loop to 5.5 ± 0.1 psia (considering a Lunar Base total pressure of 10.0 psia). This subsystem consists of an O_2 bottle, fill fitting, pressure gages, shutoff valve and pressure regulator. The system would only be activated in emergency conditions noted by low vent loop pressure or low primary O_2 supply pressure. Other than the pump, redundancy in the water heat transport loop is not required.

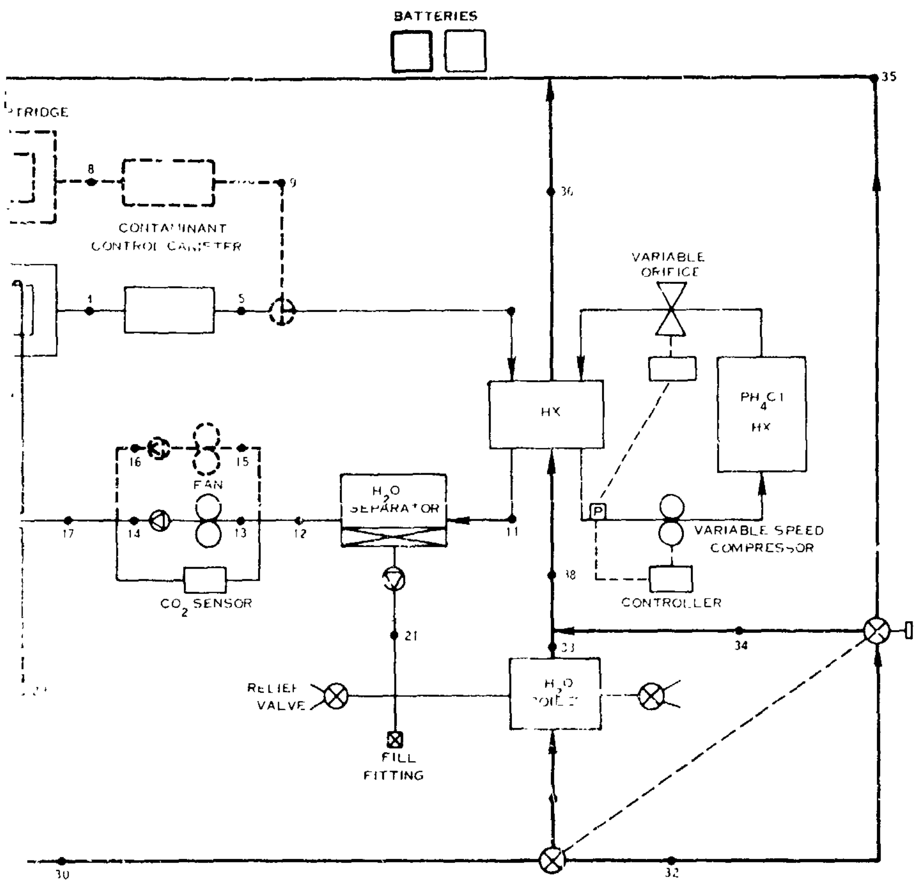
FOLDOUT FRAME 1



VENT LOOP	UNITS	STATION 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TEMPERATURE	°F	79					79	86	179	179	179	50	50	50	72	50	72
VOLUME FLOW RATE	CFM	6.31					6.33	6.49	7.49	7.58	7.58	6.03	6.05			6.05	6.0
TOTAL PRESSURE	PSIA	6.621					6.611	6.611	6.572	6.522	6.512	6.462	6.442	6.442	6.75	6.442	6.7
TOTAL WEIGHT FLOW	LB/HR	13.736					13.736	13.973	13.76	13.76	13.76	13.6	13.6			13.6	13
O_2 WEIGHT FLOW	LB/HR	12.284					12.284	12.521	12.598	12.598	12.598	12.598	12.598			12.59	
CO_2 WEIGHT FLOW	LB/HR	1.087					1.087	1.087	0.797	0.797	0.797	0.797	0.797			0.797	0.7
H_2O WEIGHT FLOW	LB/HR	0.365					0.365	0.365	0.363	0.365	0.365	0.205	0.205			0.205	0.20
O_2 PARTIAL PRESSURE	PSIA	5.93					5.922	5.936	5.987	5.937	5	6.013	5.996			5.996	[illegible]
CO_2 PARTIAL PRESSURE	PSIA	0.380					0.379	0.373	0.277	0.277	0.277	0.276	0.274			0.274	0.2
H_2O PARTIAL PRESSURE	PSIA	0.311					0.310	0.302	0.308	0.308	0.308	0.173	0.172			0.172	0.17
DEW POINT	°F	65					65	63	64	64	64	49	49			49	50

LIQUID LOOP	UNITS	STATION 22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
WEIGHT FLOW	LB/HR	240	210	240			240			240	102.5	137.1	102.5	197.5		210	240
TEMPERATURE	°F	65.8	65.8	65.8			65.9			65.9	65.9	65.9	45	65.9		60	60
PRESSURE	PSIA	[illegible]	18	23.2	18	23.2	[illegible]			23	22.9	22.3	21.7	21.7	20.4	20.4	20.4

FIGURE 6–28. EMERGENCY SYSTEM CONCEPT 4 – SPACE STATIO

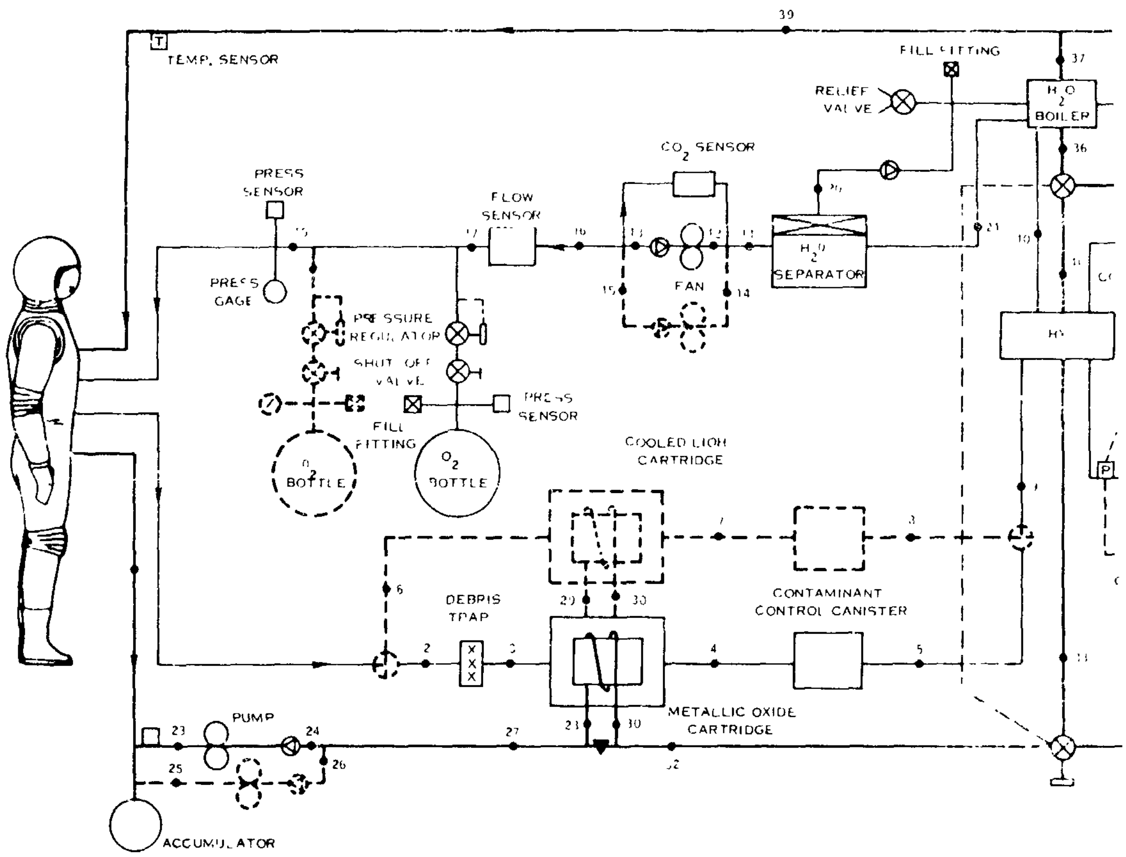


STATION																
7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	39	40
56	.76	179	179	50	50	50	72	50	72	72	72	72	72	50	79	150
6.49	7.49	7.58	7.58	6.03	6.05			6.05	6.00	6.00	6.00		6.00			
6.611	6.572	6.522	6.512	6.462	6.442	6.442	6.75	6.442	6.758	6.758	6.75	6.75	6.75		6.526	6.516
13.373	13.76	13.76	13.76	13.6	13.6			13.6	13.6	13.6	13.6		13.6		0.1847	0.314
12.521	12.598	12.598	12.598	12.598	12.598			12.598		12.598	12.598		12.598		0.161	0.314
1.087	0.797	0.797	0.797	0.797	0.797			0.797	0.797	0.797	0.797		0.797		0.0102	
0.365	0.365	0.365	0.365	0.205	0.205			0.205	0.205	0.205	0.205		0.205	0.16	0.0035	
5.936	5.987	5.937	5.927	6.013	5.996			5.996	6.289	6.281	6.281	75	6.281		5.835	6.516
0.313	0.277	0.277	0.277	0.276	0.274			0.274	0.29	0.29	0.29		0.29		0.380	
0.307	0.306	0.308	0.308	0.173	0.172			0.172	0.179	0.179	0.179		0.179		0.311	
63	64	64	64	49	49			49	50	50	50		50		65	

STATION										
28	29	30	31	32	33	34	35	36	37	38
		240	102.[illegible]	137.[illegible]	102.[illegible]	197.5		240	240	240
		65.9	65.9	65.9	45	65.9		60	60	57.1
		23	22.9	22.3	21.7	21.7	20.4	20.4	20.4	21.7

ICY SYSTEM CONCEPT 4 — SPACE STATION

FOLDOUT FRAME 1

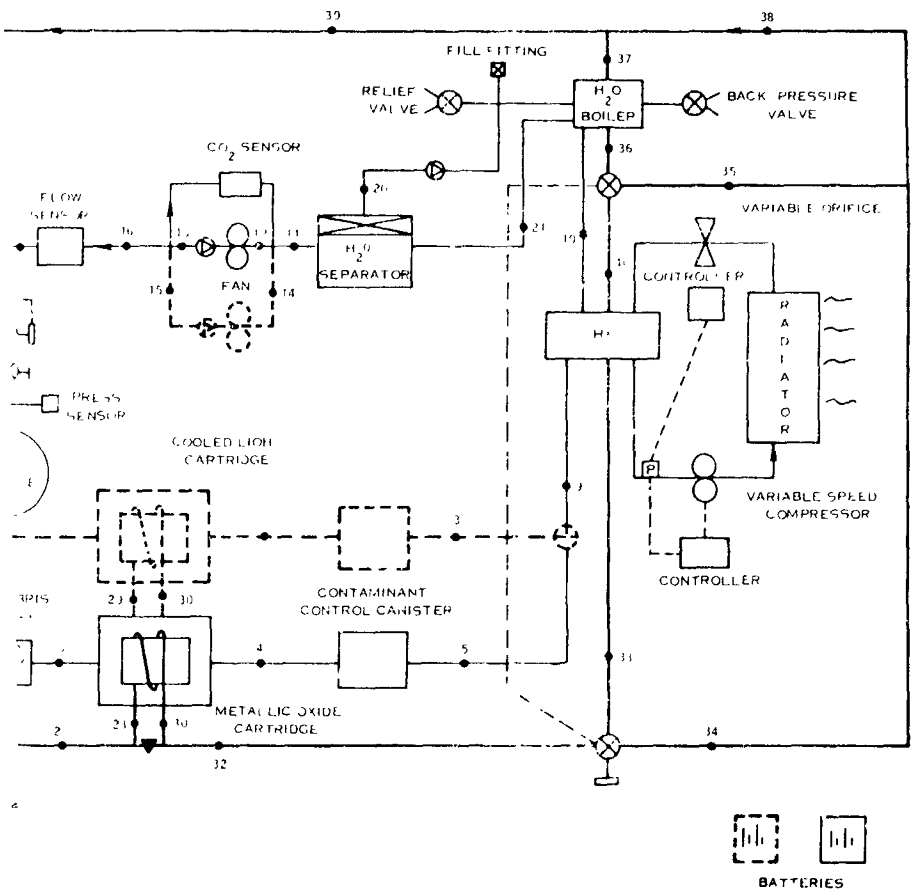


VENT LOOP	UNITS	STATION 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TEMPERATURE	°F	79					79	90	94	94	55	50			50	72
VOLUME FLOW RATE	CFM	6.51					6.52	6.52	6.63	6.64	6.13	6.17			6.17	5.[illegible]
TOTAL PRESSURE	PSIA	5.282					5.272	5.23[illegible]	5.183	5.173	5.123	5.053			5.053	5.5[illegible]
TOTAL WEIGHT FLOW	LB/HR	11.322					11.32[illegible]	11.012	11.012	11.012	10.887	10.842			10.842	10.[illegible]
O_2 WEIGHT FLOW	LB/HR	9.84					9.84	9.84	9.84	9.84	9.84	9.84			9.84	9.8[illegible]
CO_2 WEIGHT FLOW	LB/HR	1.107					1.107	0.797	0.797	0.797	0.797	0.797			0.797	0.7[illegible]
H_2O WEIGHT FLOW	LB/HR	0.375					[illegible]	0.375	0.375	0.375	0.250	0.205			0.205	0.2[illegible]
O_2 PARTIAL PRESSURE	PSIA	4.539					4.589	4.645	4.599	4.591	4.633	4.616			4.616	5.0[illegible]
CO_2 PARTIAL PRESSURE	PSIA	0.374					0.374	0.274	0.272	0.271	0.273	0.269			0.26[illegible]	0.2[illegible]
H_2O PARTIAL PRESSURE	PSIA	0.309					0.309	0.314	0.312	0.311	0.217	0.168			0.168	0.1[illegible]
DEW POINT	°F	65					65	66	65	65	55	49			49	51

LIQUID LOOP	UNITS	STATION 22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
WEIGHT FLOW	LB/HR	240			24[illegible]	240	2[illegible]	[illegible]	40	40	[illegible]	[illegible]	240		141.5	141
TEMPERATURE	°F	[illegible]			68.[illegible]	68.[illegible]	[illegible]	[illegible]	68.6	68.6	[illegible]	[illegible]	69		70.4	70
PRESSURE	PSIA	[illegible]			[illegible]	[illegible]	23.2	23.2	23.2	23.0	[illegible]	23.0	22.9		20.4	21

FIGURE 6-29. EMERGENCY SYSTEM CONCEPT 5 — LUNAR BASE

FOLDOUT FRAME 2



STATION															
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
79	90	94	94	5 5	50			50	72	7 2	72	72	72	50	50
6 52	6 52	6 63	6 64	6 13	6 17			6.17	5.91	5.91	5 92		6 0		6 13
5 272	5 233	5 183	5 173	5 123	5 053			5,053	5 51	5 51	5 5	5 5	5 5	5,073	5,073
10 321	11 012	11,012	11 012	10 887	10 842			10,842	10,842	10,842	10,842	0 258	11 1	0 17	10 942
9 84	9 84	9 84	9 84	9 84	9.84			9 84	9 84	9 84	9.84	0 258	10,098		9 84
1 10[illegible]	0 797	0,797	0,797	0 797	0 797			0 797	0 797	0 797	0 797		0 797		0,797
[illegible]	0 375	0 375	0 375	0 250	0 205			0 205	0 205	0,205	0 205		0,205	0 17	0 205
1 569	4 645	4,599	4 591	4 633	4 616			4 616	5 033	5,033	5 023	5 5	5,023		4,632
[illegible]	0 274	0 272	0,271	0 273	0 269			0 269	0 233	0,292	0,292		0 29		0 271
[illegible]	0 314	0 312	311	0 217	0 168			0 168	0 184	0 184	0,184		0 179		0 170
[illegible]	[illegible]	65	65	55	49			49	51	51	51		50		49

STATION													
[illegible]	28	29	30	31	32	33	34	35	36	37	38	39	40
[illegible]	3	40	40		[illegible]	[illegible]		141 5	141,5	98 5	141 5	240	240
[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	59		70 4	70 1	45	70 4	60	70 4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22 9		20 4	21 6	20 4	20.4	20 4	21,7

NCY SYSTEM CONCEPT 5 — LUNAR BASE

6.4.6 Emergency System Concept 6 - Mars (Figure 6-30)

This is a separate, independent concept which contains all the required life support equipment for emergency atmosphere revitalization and thermal control during extravehicular operation including an O_2 ventilation loop, a water heat transport loop, a power supply and operating controls. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. Oxygen from the suit enters the lithium peroxide (Li_2O_2) cartridge which removes CO_2 from the ventilation loop. Odors and trace contaminants are then removed through physical adsorption by activated charcoal in the contaminant control canister. The O_2 then passes to a water boiler which cools the circulated O_2 and condenses the entrained moisture. The cooled O_2 continues to the water separator where the condensed water vapor is removed and transferred to the water boiler to provide additional cooling capacity. The cool, dry O_2 then passes to the fan which circulates a ventilation flow of 6 acfm to the suit.

The metabolic oxygen make-up requirement is provided by the Li_2O_2 chemical release of O_2 plus the output of a sodium chlorate $NaClO_3$ candle. The Li_2O_2 oxygen release is metabolically controlled at approximately one-half the instantaneous total requirement while the fixed output of the candle is also sized for one-half the metabolic peak of 2500 Btu/hr. The excess oxygen generated by the candles while the crewman is working at less than 2500 Btu/hr is vented overboard by the suit pressure control valve.

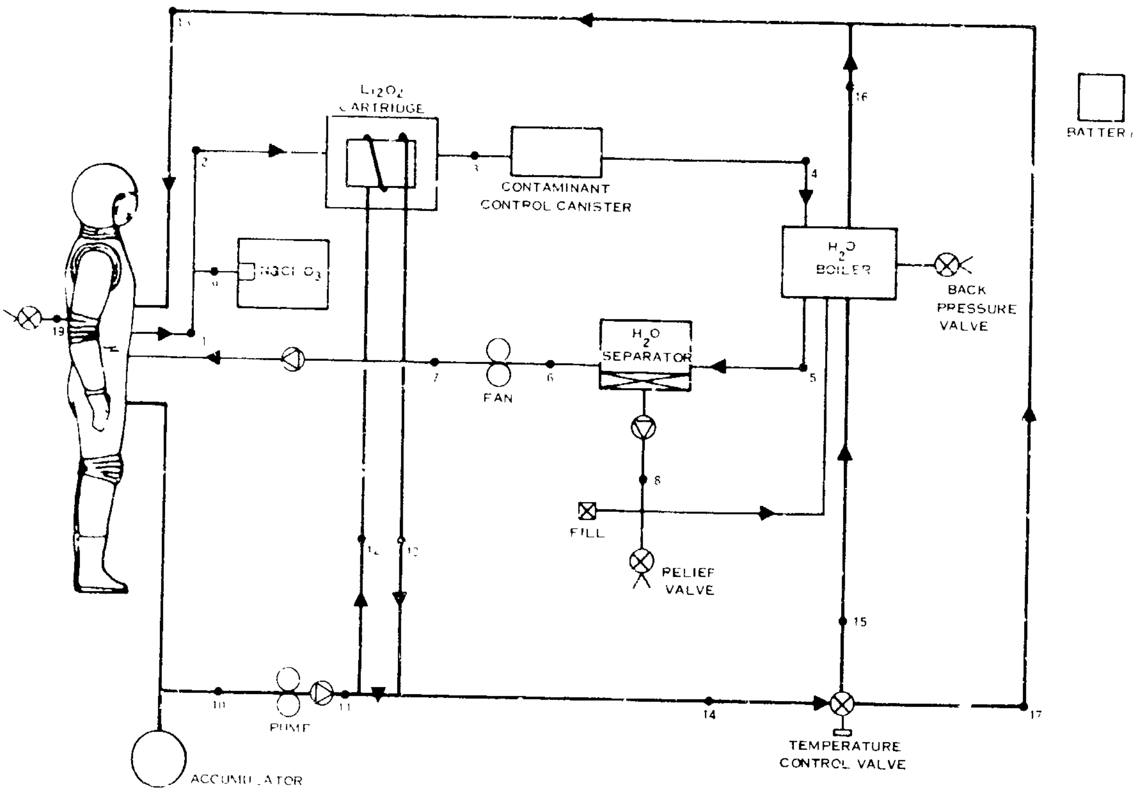
The water heat transport loop cools the suited crewman by supplying and circulating cool water through the liquid cooling garment utilized for the primary system operation. A pump circulates the cooled water through the water heat transport loop at a flow rate of 4 lb/min. A portion of this flow is directed to the Li_2O_2 canister for temperature control and to remove the heat of reaction released during CO_2 absorption and oxygen generation. Flow through the thermal control subsystem is set prior to EVA for the anticipated cooling requirements of the individual crewman.

The thermal control subsystem is an expendable concept utilizing a water boiler.

The estimated total volume and weight for this emergency system concept are 518 in^3 and 15.8 pounds, based on an average metabolic rate of 2000 Btu/hr for an emergency duration of one(1) hour.

6.4.7 Emergency System Concept 7 - Mars (Figure 6-31)

This emergency system concept, when considered in conjunction with the AEPS primary system contains all required life support equipment for extravehicular operation during an emergency. System reliability is predicated on the assumption that no single failure can occur that will create a massive decompression of the oxygen circuit, either within the suit or life support system; that is, the system is designed

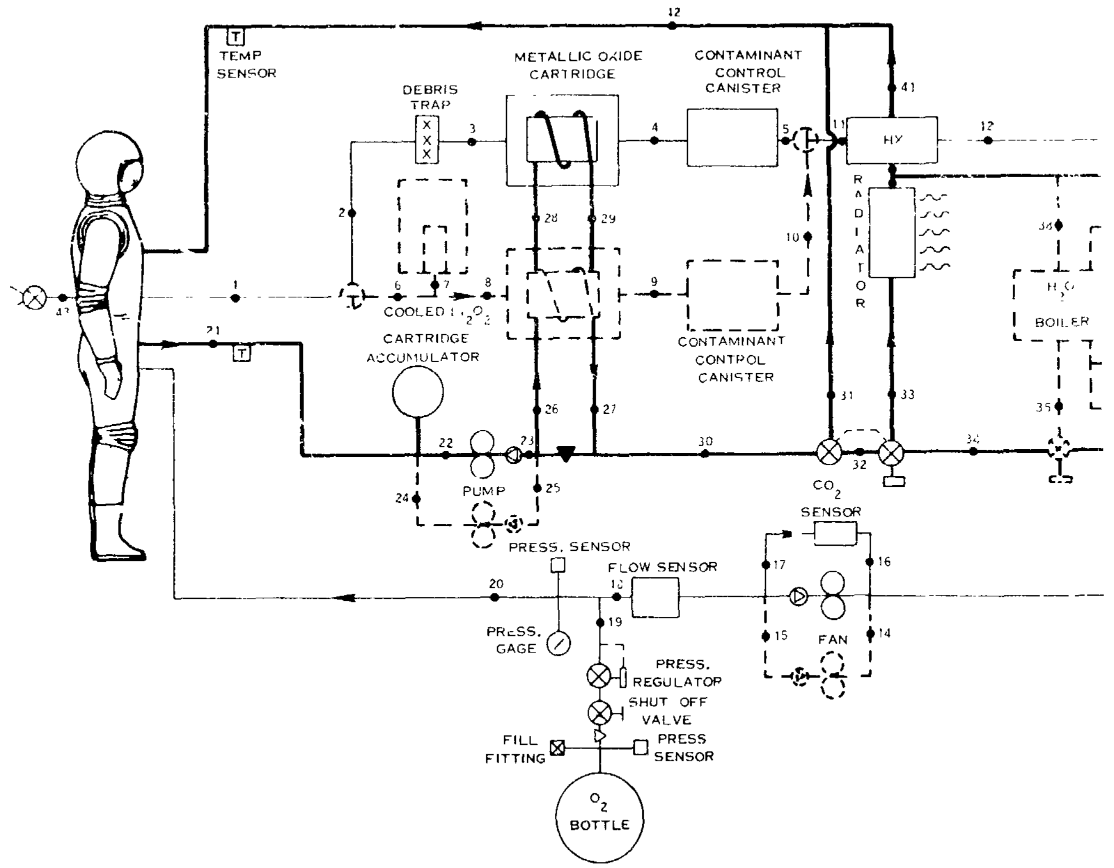


VENT LOOP	UNITS	STATION									
		1	2	3	4	5	6	7	8	9	19
TEMPERATURE	F	79	81	101	104	50	50	72		150	79
VOLUME FLOW RATE	CFM	6 37	6 52	6 74	6 79	6 08	6 10	60		153	05
TOTAL PRESSURE	PSIA	5 382	5 382	5 343	5 293	5 243	5.243	5.223		5 382	5.382
TOTAL WEIGHT FLOW	LB/HR	[illegible]	11,543	11 314	11 314	11 1	11 1	11 1	.214	.241	0931
O_2 WEIGHT FLOW	LB/HR	9 696	9 937	10 098	10 098	10 098	10 098	10 098		241	.0805
CO_2 WEIGHT FLOW	LB/HR	[illegible]	[illegible]	[illegible]	797	797	797	797			0093
H_2O WEIGHT FLOW	LB/HR	419	419	419	419	205	205	.205	.214		0033
O_2 PARTIAL PRESSURE	PSIA	[illegible]	4 635	4.724	4 675	4 799	4 781	5 031		5 382	4 618
CO_2 PARTIAL PRESSURE	PSIA	410	401	272	271	273	272	29			410
H_2O PARTIAL PRESSURE	PSIA	354	346	347	347	170	170	179			354
DEW POINT	F	68	67	67	67	49	49	50			68

LIQUID LOOP	UNITS	STATION								
		10	11	12	13	14	15	16	17	18
WEIGHT FLOW	LB/HR	240	240	40	40	240	98	98	142	240
TEMPERATURE	F	67 3	67 3	67 3	85 .3	70.4	70.4	45	70 4	60
PRESSURE	PSIA	18	22.1	22 1	21 9	21.9	21.8	20 4	20 4	20 4

FIGURE 6–30. EMERGENCY SYSTEM CONCEPT 6 – MARS

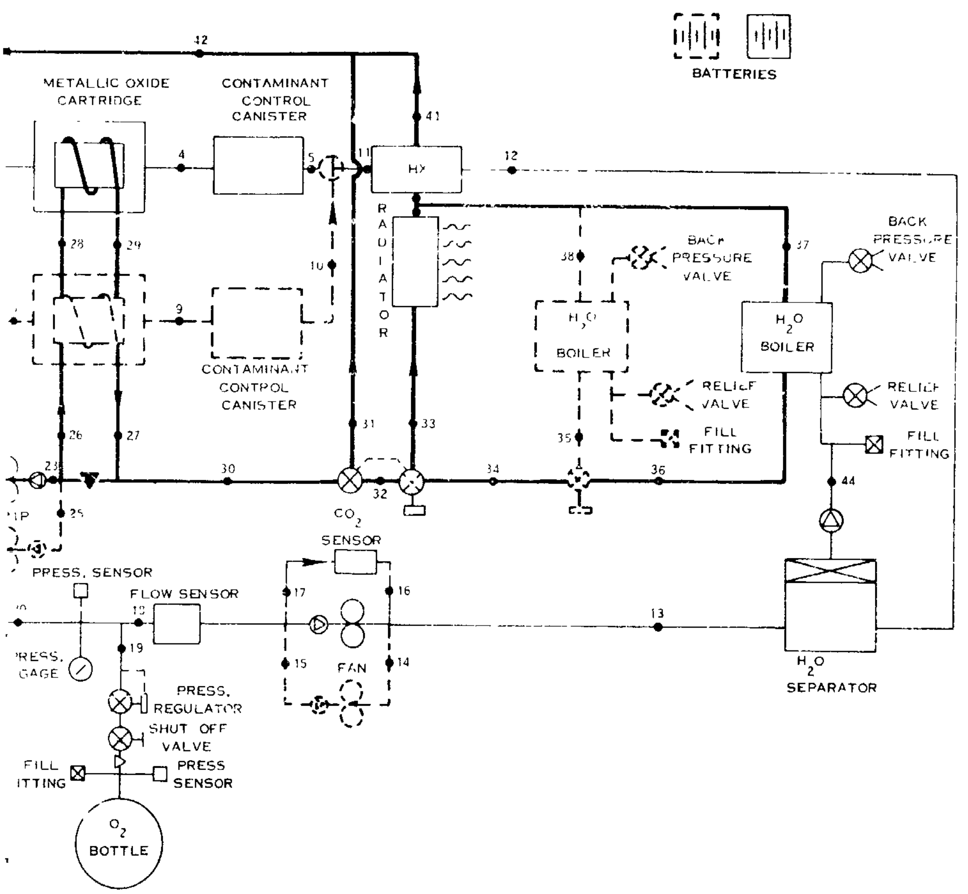
FOLDOUT FRAME



VENT LOOP	UNITS	STATION 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TEMPERATURE	°F	79					79	150	81	101	104	104	50	50	50	72	
VOLUME FLOW RATE	CFM	6.37					6.29	0 132	6 30	6.55	6.64	6.65	5.98	5.99	5.99	6.0	
TOTAL PRESSURE	PSIA	5.382					5.372	5.372	5.372	5.333	5.283	5.273	5.233	5.202	5.203	5.51	
TOTAL WEIGHT FLOW	LB/HR	11,302					11,302	0 241	11,543	11,414	11,414	11 414	11.1	11 1	11.1	11.1	
O_2 WEIGHT FLOW	LB/HR	9 696					9 696	0 241	10,037	10,098	10,098	10,098	10,098	10,098	10,098	10,098	
CO_2 WEIGHT FLOW	LB/HR	1 187					1 187		1,187	0.797	0,797	0.797	0.797	0 797	0.797	0.797	
H_2O WEIGHT FLOW	LB/HR	0 419					0.419		0 419	0.419	0 419	0.419	0.205	0.205	0 205	0.205	
O_2 PARTIAL PRESSURE	PSIA	4.618					4.599		4 599	4.696	4.661	4.651	4.771	4.751	4.751	5 041	
CO_2 PARTIAL PRESSURE	PSIA	0 410					0.415		0.415	0 279	0.272	0.272	0.278	0 278	0 278	0.29	
H_2O PARTIAL PRESSURE	PSIA	0 354					0 358		0 358	0 358	0.350	0.350	0.174	0.174	0.174	0 179	
DEW POINT	°F	68					69		69	69	68	68	49	49	49	50	

LIQUID LOOP	UNITS	STATION 21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
WEIGHT FLOW	LB/HR	240			240	240	80	80	40	40	240		240	157.7	114	114	
TEMPERATURE	°F	67 3			67.3	67.3	67 3	76.3	77 3	67 3	70.4		70.4	70 4	70.4	70.4	
PRESSURE	PSIA	18	18	22 9	18	22 9	229	227	22 9	22.	22 7		22.6	22.5	22 5	22 4	

FIGURE 6-31 EMERGENCY SYSTEM CONCEPT 7 — MARS



STATION														
8	9	10	11	12	13	14	15	16	17	18	19	20	43	44
81	101	104	104	50	50	50	72			72		72	79	
6 30	6.55	6 64	6.65	5.98	5.99	5.99	6.0			6.00		6.00	.05	
5 372	5.333	5.283	5.273	5 233	5.202	5.203	5.51			5.5		5.5	5.382	
11.543	11 414	11.414	11 414	11.1	11.1	11.1	11.1			11.1		11.1	0.0931	0.214
10.037	10.098	10.098	10.098	10.098	10.098	10.098	10.098			10.098		10.098	0.0805	
1 187	0 797	0.797	0 797	0.797	0.797	0.797	0 797			0 797		0 797	0 0093	
0 419	0.419	0.419	0 419	0.205	0 205	0.205	0.205			0.205		0.205	0.0033	0.214
4 599	4 696	4.661	4.651	4.771	4.751	4 751	5.041			5.031		5.031	4 618	
0 415	0.279	0.272	0 272	0.278	0 278	0.278	0.29			0.290		0.290	0 416	
0 358	0 358	0 350	0.350	0.174	0.174	0.174	0 179			0.179		0.179	0.354	
69	69	68	68	49	49	49	50			50		50	68	

STATION														
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
40	40	240		240	157 7	114	114			114	157 7	240	240	240
3	67.3	70.4		70.4	70 4	70.4	70 4			45	70.4	58.3	60	60
22 9	22	22 7		22.6	22.5	22.5	22 4			21 4	21 4	21.4	20.4	20.4

RGENCY SYSTEM CONCEPT 7 — MARS

6.1.7 (Continued)

to be rugged enough to preclude this possibility. Therefore, the same ductwork may be utilized for both the emergency and primary life support system with the following prime functions being made redundant:

1. The emergency battery is utilized in the event that:

   a. the primary battery fails to function

   b. that it is becoming evident that failure of the battery is about to take place.

   A failed primary battery is easily detected by the simultaneous drop-off in voltage and current drain of the fan, pump, compressor and battery.

2. The emergency fan is required in the event of a primary fan failure. Check valves are required downstream of both the primary and emergency fans to prevent flow short circuiting. A speed sensor easily measures a fan failure or drop in performance.

3. The emergency pump is required in the event of a primary pump failure. Check valves to prevent short circuiting (shown schematically in the figure) are an inherent part of the pumps because they are positive displacement devices. Measuring pressure head and/or current and voltage drain easily measures a pump failure.

4. The emergency CO_2/contaminant control subsystem and O_2 supply subsystem consists of a liquid cooled Li_2O_2 cartridge/canister assembly, a contaminant control canister and a chlorate candle. In the event of a high pressure oxygen system failure, clogging of the debris trap. and/or failure of the metallic oxide and contaminant control canisters, the entire emergency subsystem is utilized.

5. An emergency thermal control capability is almost an inherent part of the primary subsystem. The primary expendable/direct radiation system radiator is sized for average normal heat loads and is therefore, not capable of handling the higher emergency heat loads. A small emergency water boiler is added for topping off of the radiator in the event the primary water boiler fails. The automatic temperature control valve is provided with a manual override to preclude loss of operation of the valve. In addition, a shut-off valve is included for the emergency water boiler. In the event the radiator fails, the primary water boiler provides thermal control.

6.4.7 (Continued)

In addition to the above, a dump valve is provided for purging over production of oxygen from the chlorate candle and the Li_2O_2 canister.

The estimated total volume and weight for this emergency configuration (the delta increase over the primary system) are 518 in^3 and 15.8 pounds, based on an average metabolic rate of 2000 Btu/hr for an emergency EVA duration of one hour.

7.0 NEW TECHNOLOGY

7.0 NEW TECHNOLOGY

After establishment of the AEPS baseline concepts, a portion of the study effort was directed toward generation of a priority listing of required technology development activity to permit the AEPS recommendations to be implemented. This section presents the new technology requirements and recommendations listed in order of priority.

7.1 Thermal Control

Requirement - Thermal control subsystem that requires a minimum of expendables.

Recommendations

a. Identify, evaluate and operationally develop candidate thermal storage materials possessing a heat of fusion greater than 300 BTU/lb and melting between 50 to 150°F. One such candidate material--phosphonium chloride (PH_4Cl)--has been identified and analytically evaluated during conduct of the AEPS study, and is hereby recommended for further research and development. In addition, an investigation to determine the correlation between heat of fusion and crystal composition and structural properties is recommended to identify and, if required, synthesize promising materials with a high heat of fusion.

b. Design and develop a light-weight, deployable radiator with improved thermal performance characteristics. Research and development is recommended to develop improved radiator surface coatings and treatments to optimize the performance and minimize potential surface degradation due to dust, meteorites and/or normal operational wear.

7.2 CO_2 Control

Requirement - Regenerable CO_2 control subsystem that provides the performance, regeneration and life characteristics for an AEPS-type application.

Recommendation - Operationally develop a solid regenerable CO_2 sorbent and associated hardware. Two candidate families of solid regenerable sorbents--metallic oxides and solid amines--have been identified and analytically evaluated during conduct of the AEPS study, and are hereby recommended for further research and development.

7.3 O_2 Supply

Requirement - High cyclic life (1000 cycles minimum)/high pressure (6000 psi nominal) O_2 supply subsystem that minimizes EVA equipment volume and meets life requirements for AEPS-type applications.

(continued)

7.3 Recommendations

a. Develop high cyclic life/high static strength (ultimate strength equals 280,000 psi minimum) pressure vessel material. Materials research and development in the areas of stainless steels, filament wound materials, etc., is recommended.

b. Design and develop a nominal 6000 psi quick disconnect oxygen fill fitting.

c. Develop a method, and the associated hardware, to step up the Vehicle/Base oxygen supply pressure of 3000 psi to 6000 psi for AEPS oxygen recharge.

7.4 Power Supply

Requirement - High energy density (100 watt-hours per pound minimum)/multiple recharge capability (100) power supply that minimizes EVA equipment volume and meets life requirements for AEPS-type applications.

Recommendation - Operationally develop a high energy density, rechargeable electric storage battery. One candidate--a lithium-nickel halide battery--was identified during conduct of the AEPS study, and it (together with any other battery demonstrating a similar or greater energy capacity) is recommended for further research and development.

7.5 Contaminatnt Control

Requirement - Contaminant control subsystem that maintains the concentration of particulate matter, biological micro-organisms, and trace gases at acceptable levels so that the health and comfort of the crewman is safeguarded.

Recommendation - Confirm or modify the AEPS contaminant model selected and determine the effect of long term intermittent exposure upon the suited crewman; then design, develop and test the contaminant control subsystem to confirm performance characteristics.

7.6 Humidity Control

Requirement - Humidity control subsystem that meets life requirements for AEPS-type applications.

Recommendation - Results of the AEPS study indicate that a condensing heat exchanger in series with either an elbow wick separator or a hydrophobic/hydrophyllic screen separator are the optimum choices for an AEPS-type application. Research and development to determine the effect of contamination and bacterial/fungus growth upon the performance of both of these concepts is recommended to permit design and development of a long life humidity control subsystem.

7.7 Prime Movers

Requirements - Prime movers that have a minimum power consumption and meet the long life requirements of an AEPS-type application.

Recommendation - Design and develop longer life prime movers (i.e., fan, pump, and variable-speed compressor) that have higher compressor efficiency and lower electronics and bearing losses than those presently being utilized in aerospace programs.

7.8 Automatic Temperature Control

Requirement - Attain improved crewman comfort, decrease the number of required crewman manual operations and obtain more efficient use of expendable water.

Recommendation - Design and develop an automatic temperature controller. Further research and development is recommended to determine the signal parameters that provide accurate automatic temperature control, and to develop the required hardware.

7.9 Miscellaneous

The following miscellaneous areas of required new technology are identified and recommended for further effort (not in any order of priority):

a. Develop automated equipment to permit simple, rapid checkout of the AEPS. The present Apollo EMU PLSS requires approximately thirty (30) minutes for checkout prior to egress of the vehicle.

b. Investigate and evaluate potential integration (both functional and physical) of the crewman's personal maneuvering equipment with the AEPS for EVA missions in a zero gravity environment.

c. Improve the thermal isolation characteristics of the Thermal Meteoroid Garment (TMG), thus decreasing the peak thermal load on the AEPS thermal control subsystem.

d. Improve the Liquid Cooling Garment (LCG) heat transfer characteristics. This permits the liquid heat transport loop to operate at a higher temperature and thus decreases the power penalty associated with the thermal control subsystems which utilize a vapor compression (heat pump) cycle.

e. Conduct manned testing to evaluate the short-term and long-term physiological effects of various candidate pressure suit levels (3.5 to 14.7 psia) upon the crewman. Specific factors to be determined are:

7.9 (Continued)

- Required versus tolerable O_2 prebreathing time
- O_2 partial pressure exposure limitations including frequency and duration
- Safe decompression/recompression levels, rates and frequency

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