7 ADVANCED EXTRAVEHICULAR PROTECTIVE SYSTEMS

James G. Sutton, Philip F. Heimlich, and Edward H. Tepper
Hamilton Standard Division, United Aircraft Corporation,
Windsor Locks, Conn.

INTRODUCTION

The U.S. manned space effort planned for the 1980s consists of long-duration missions with orbiting space stations, potential lunar bases, and possibly Mars landings. Extravehicular activity (EVA) is likely to take an increasingly important role in the completion of these future missions. With a potential need for two or three EVA missions per man per week, however, the use of expendables in the portable life support system may become prohibitively expensive and burdensome. For future EVAs to be effective in the total systems context, the portable life support system may need a regenerable capacity.

Hamilton Standard, with NASA funding, has been conducting an advanced extravehicular protective system (AEPS) study program. The objective of this AEPS study is to provide a meaningful appraisal of various regenerable and partially regenerable portable life support system concepts for EVA use in the 1980s and to identify the required new technology area.

STUDY METHOD

Study Evaluation Criteria

Selection of the most favorable EVA subsystem and system equipment has always posed a difficult problem. This is particularly true for the AEPS study, which deals with long-duration earth orbital, lunar surface, and martian surface missions in which the vehicle penalty for an AEPS configuration is more important than it was for the shorter term Gemini and Apollo programs. This factor reduces the validity of the traditional heavy emphasis on EVA equipment equivalent volume and weight within the evaluation criteria. Thus, to fulfill the objective of the AEPS study, 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.
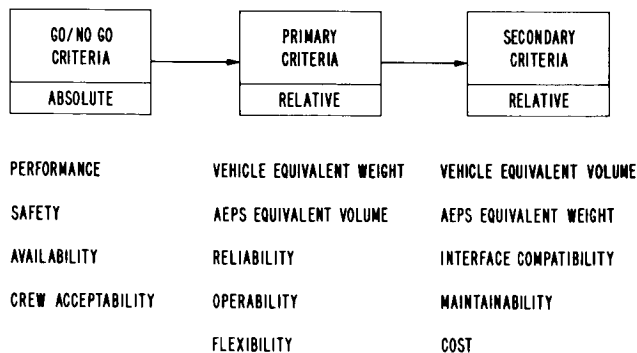
GO/NO GO CRITERIA	PRIMARY CRITERIA	SECONDARY CRITERIA
ABSOLUTE	RELATIVE	RELATIVE
PERFORMANCE	VEHICLE EQUIVALENT WEIGHT	VEHICLE EQUIVALENT VOLUME
SAFETY	AEPS EQUIVALENT VOLUME	AEPS EQUIVALENT WEIGHT
AVAILABILITY	RELIABILITY	INTERFACE COMPATIBILITY
CREW ACCEPTABILITY	OPERABILITY	MAINTAINABILITY
	FLEXIBILITY	COST

Figure 7.1 *Evaluation criteria.*

The determination of the AEPS study selection criteria is based on a recognition that some requirements are absolute, others are of primary importance, and still others represent second-order effects. The criteria used as a basis for the AEPS subsystem and system selection are shown in figure 7.1. 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 among surviving candidates.

The 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 the go/no go criteria, it receives no further consideration in the study and is listed as unacceptable and eliminated.

The primary criteria are the principal evaluation criteria for all concepts that pass the go/no go criteria requirements. The ratings applied to a candidate concept depend on its characteristics relative to the other candidates. Each candidate concept receives a rating of from 0 to 100 for each primary criterion. Each rating is then multiplied by the weighting factors defined in table 7.1 and these are added to obtain a total rating for each candidate concept. A candidate concept is selected if its overall rating is clearly the best of the competing concepts. If a clear-cut choice is not evident, the remaining competing concepts are reviewed against the secondary criteria.

Table 7.1 *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

The secondary criteria represent a step in depth of competitive evaluation that is 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 receives a rating from 0 to 100 for each criterion. Each rating is then multiplied by the weighting factors defined in table 7.2 and these are added to obtain a total rating for each candidate concept. A candidate concept is selected if its overall rating is clearly the best of all competing concepts.

In any event, the secondary criteria are applied against all recommended concepts to provide a systematic review of the overall acceptability of these selected concepts.

Study Flow

The AEPS study consisted of the following four basic tasks.

Study Plan and Specifications. The basic ingredients to a meaningful AEPS study are the study plan and the AEPS specifications. The diverse nature of earth orbital, lunar, and martian applications required that separate AEPS specifications be generated for each application.

The goal of these specifications are general guidelines representing the probable trends for earth orbital, lunar base, and martian landing missions in the 1980s. 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

Table 7.2 *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

operational procedures for donning/doffing, checkout, egress/ingress, recharge/regeneration, etc.; and to define applicable interface areas. In addition, vehicle environmental control/life support system models were established to serve as guides to determine the AEPS recharge/regeneration capabilities of the vehicle.

Subsystem Studies. The first step in the subsystem definition study was the preparation of subsystem requirements for each major functional area of each configuration. Based on these requirements candidate concepts were identified in each of the major subsystem areas (carbon dioxide control/oxygen supply, trace contaminant control, thermal control/humidity control, and power). In areas where in-house data were not complete, a literature survey was conducted and industry contacts made, as required. Once all data were assembled and candidate subsystem concepts identified, a preliminary evaluation was conducted to screen out and reject the obviously noncompetitive candidates. 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. If a concept was found unacceptable, sufficient auxiliary equipment was added to that subsystem, if possible, 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 were generated as required for comparison purposes among the candidate subsystems.

1. Vehicle launch weight (including expendables, spares, recharge 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.

The remaining candidate subsystems were then compared against the primary criteria. Further equipment was added or the arrangements modified, as required, to upgrade candidate subsystem concepts found 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. 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 penalities were reflected in the parametric analyses.

From the results of the subsystem evaluations, the best competing subsystems were selected for each AEPS configuration. Several subsystems that perform the same function were recommended for further study on the system levels.

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 martian base AEPS systems. The systems integration effort evaluated and defined the following elements, which 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 contaminant requirements.
8. Suit and vehicle interfaces.

The candidate baseline systems were then subjected to a competitive evaluation utilizing the established criteria and the parametric results of the subsystem studies. Results of the systems evaluation led to the selection of the candidate space station, lunar base and martian base AEPS baseline concepts.

Prior to a final review and interation of the AEPS baseline concepts, Hamilton Standard reviewed with NASA the general specifications and the evaluation criteria to assure that both are still consistent with the objectives of the study and the results to date. Upon satisfactory completion of this task, the AEPS baseline concepts were subjected to a detailed performance review and evaluation to optimize system performance. Components and subsystems were resized and system arrangements modified, as 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 regeneration procedures.
3. Maintenance procedures.

A safety/reliability evaluation of each baseline concept was conducted. Top level system FMEAs were conducted and single point and sequential failures were eliminated. This analysis also formed the basis for 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 control and displays, 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.

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

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, recommend approaches, and estimate resources to solve these problems.

SUBSYSTEM STUDIES

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 prejudgment of concept value prior to concept identification. Specific emphasis was placed in the areas of thermal control and CO_2 control/O_2 supply, as they represented the areas where the greatest benefits could be derived through reduction of vehicle penalties and AEPS volume and weight.

Initial effort results in the identification of 55 candidate thermal control concepts (table 7.3), 21 candidate CO_2 control concepts (table 7.4), 14 candidate O_2 supply concepts (table 7.5), and 3 candidate O_2 generation concepts (table 7.6). All 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 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 earlier.

Table 7.3 *Thermal control concepts.*

Expendables

    Water

        Water boiler

        Supercooled water boiler

        Supercooled water boiler with vapor regenerative cooling

        Water sublimator

        Supercooled water sublimator

        Supercooled water sublimator with vapor regenerative cooling

        Plate fin flash evaporator

        Nonesteady state pulse feed flash evaporator

        Static vortex flash evaporator

        Turbine-rotary vortex flash evaporator

Table 7.3 *Thermal control concepts. (Continued)*

Expendables (continued)

Water (continued)

Motor-rotary vortex flash evaporator

Multistage flash evaporator

Vapor diffusion through suit pressure valves

Vapor diffusion through water permeable membrane

Hydrogen Peroxide (H_2O_2)

H_2O_2 dissociation into H_2O and O_2

Ammonia (NH_3)

NH_3 boiler

NH_3 sublimator

Carbon Dioxide (CO_2)

CO_2 boiler

CO_2 sublimator

Methane (CH_4)

CH_4 sublimator

Cryogenics

Cryogenic O_2

Cryogenic H_2

Feces/urine sludge

Evaporation of H_2O from feces/urine sludge

Conduction

Conduction via the lunar or martian surface

Convection (Mars only)

Free convection

Forced convection

Hilsch tube

Table 7.3 *Thermal control concepts. (Concluded)*

Radiation

    Direct cooling

        LCG

        Heat pipe

        Water adsorption using:

            $LiCl \bullet 3H_2O$

            $CaCl \bullet 6H_2O$

            Molecular sieve

            Silica gel

            $LiBr \bullet 3H_2O$

            $Na_2Se \bullet 16H_2O$

    Indirect cooling

        Vapor compression refrigeration cycle using Freon

        Water adsorption cycle using NH_3

        Water adsorption cycle using LiBr

        Brayton cycle using Air

Thermal Storage

        Ice

        Subcooled ice

        Thermal wax—transit 86

        Eutectic salt—sodium sulphate ($Na_2SO_4 \cdot 10H_2O$)

        Phosphonium chloride (PH_4Cl)

        Hydrogen (H_2)

        Lunar or martian rock

Energy Conversion

        Thermoelectric

        Thermionic

        Thermodielectric

Hybrids

        Expendable/radiation—direct cooling

        Expendable/radiation—indirect cooling

        Expendable/thermal storage

        Radiation/thermal storage

        Thermal storage/water adsorption

Table 7.4 *Carbon dioxide control concepts.*

Expendables

    Solid sorbents

        Hydroxides

        Superoxides

        Peroxides

        Ozonides

    Liquid sorbent

        Hydroxide solutions

    Open loop

        Purge flow

Regenerables

    Solid sorbents

        Activated charcoal

        Molecular sieve

        Metallic oxides

        Solid amines

    Liquid sorbents

        Carbonate solutions

        Liquid amines

Electrochemical

        Hydrogen depolarized cell

        Two-stage carbonation cell

        One-stage carbonation cell

        Electrodialysis

        Fused salt

Mechanical

        Simple membrane diffusion

        Immobilized liquid membrane diffusion

        Mechanical freezeout

        Cryogenic freezeout

Table 7.5 *Oxygen supply concepts.*

O_2 Storage

        Gaseous

        Supercritical utilizing thermal pressurization

        Subcritical utilizing thermal pressurization

        Subcritical utilizing positive expulsion

        Solid

Solid Decomposition

        Superoxides

        Peroxides

        Ozonides

        Sodium chlorate candles ($NaClO_3$)

        Lithium perchlorate candles ($LiClO_4$)

Liquid Decomposition

        Hydrogen peroxide (H_2O_2)

        Reactant storage (N_2H_4/N_2O_4)

        Reactant storage (N_2H_4/H_2O_2)

Electrolysis

        Water electrolysis

Table 7.6 *Oxygen generation concepts.*

        Solid electrolyte

        Bosch reactor/water electrolysis

        Sabatier reactor/water electrolysis

Thermal Control

As a result of these evaluations, the following three general thermal control categories were selected for further study:

1. Expendable concepts utilizing water.
2. Radiation.
3. Thermal storage.

Five specific thermal control subsystem concepts were recommended to be carried into the systems integration phase of the AEPS study.

Water Boiler.   The water boiler (fig. 7.2) is an expendable thermal control concept that utilizes the heat of vaporization of water to provide direct cooling of the liquid cooling garment (LCG) loop and vent loop. The wick-fed water boiler also acts as the storage vessel for the expendable water.
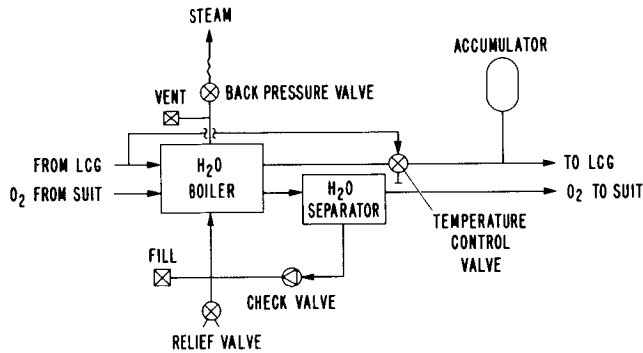
Figure 7.2 *Water boiler.*
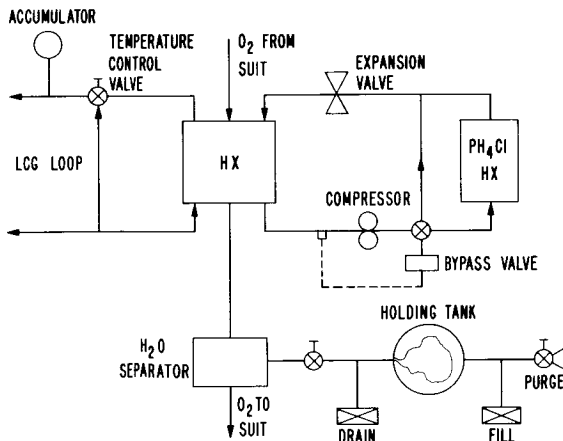
Figure 7.3 *Thermal storage using phosphonium chloride.*

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. Water removed by the water separator is fed into the water boiler, thus providing additional cooling capacity. A relief valve furnishes protection against overpressurization due to storage temperature fluctuations. Recharge is simply accomplished utilizing the fill valve. The water boiler is being recommended as a representative concept of all the expendable water concepts that utilize phase change to reject heat.

Thermal   Storage   with   Phosphonium Chloride (PH_4Cl).   Thermal storage (fig. 7.3) utilizing phosphonium chloride is a self-regenerable thermal control concept. The heat of fusion of PH_4Cl is 324 Btu/lb at 82° F and above 48 atm pressure. A vapor compression intermediate loop is utilized to raise the desired coolant temperature of 50° F at the vent loop/liquid heat transport loop heat exchanger to 82° F at the thermal storage unit. Humidity control is furnished by a water separator and holding tank that remove and store vent loop condensate. Vehicle penalties associated with this concept are relatively low since PH_4Cl will resolidify of its own accord at normal cabin temperatures.

Solid PH_4Cl sublimates at pressures below 500 psia at room temperature. As pressure is decreased further, gaseous PH_4Cl dissociates into two gases: hydrogen chloride and phosphene

(PH3); phosphene is highly toxic so the thermal storage unit has been concepted to minimize the probability of any failure resulting in external leakage.

Expendable/Direct Radiative Cooling. This concept (fig. 7.4) is a hybrid consisting of a water boiler and radiator connected in parallel throu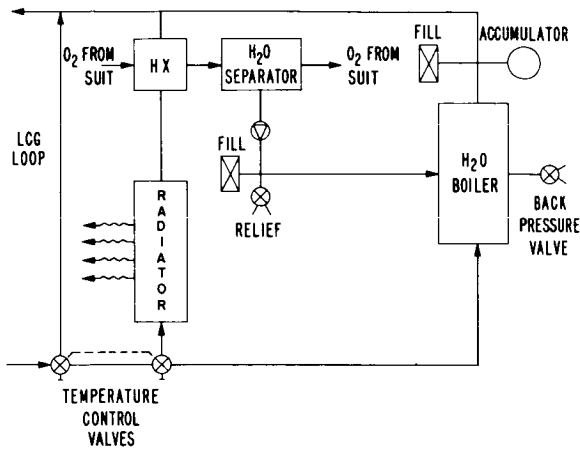gh the LCG temperature control valve. The temperature control valve selects the percentage of the heat load from the LCG that is shared by each subsystem. The radiator is sized to handle the average heat load while the water boiler handles peak loads; thus radiator size and water expended in the boiler are minimized. Humidity control is provided by a condensing heat exchanger and a water separator that feeds the separated water to the water boiler to provide additional cooling capacity. For low or no-load conditions, a variable conductance, area, or emissivity device must be used to prevent overcooling of the LCG.

Figure 7.4 *Expendable/direct radiative cooling.*

Expendable/Heat Pump. This hybrid concept (fig. 7.5) consists of a radiator/vapor compression cycle and a water boiler connected in parallel through an aut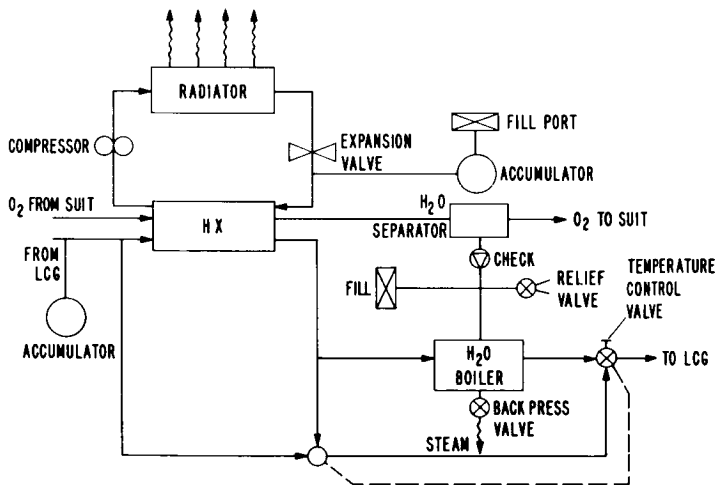omatic LCG temperature control valve. The temperature control valve selects the percentage of the heat load from the LCG that is shared by each subsystem. The radiator/vapor compression subsystem is sized to handle the average LCG heat load plus the heat load from the vent system while the water boiler handles peak heat loads. This minimizes radiator size, compressor size, and power consumption as well as water expended in the boiler. Humidity control is provided by the vapor compression cycle evaporator and the water separator that feeds the separated water to the water boiler to provide additional cooling capacity. For low or no-load conditions, a radiator bypass or compressor short circuit (not shown in schematic) or variable speed compressor is required to prevent overcooling at the evaporator.

Figure 7.5 *Expendable/heat pump.*

Expendable/Thermal Storage (PH4Cl). This hybrid concept (fig. 7.6) utilizes a water boiler in parallel with a PH4Cl thermal storage unit via an LCG temperature control valve. The temperature control valve selects the percentage of the heat load from the LCG that is shared by each subsystem, the intention being that the PH4Cl thermal storage unit will handle the average heat load and the
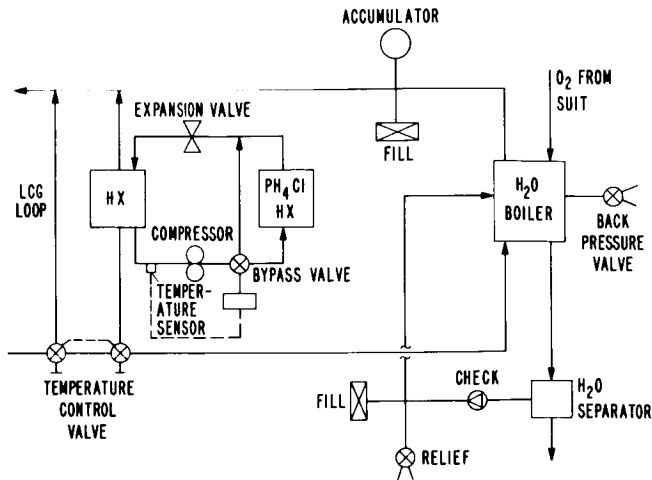
Figure 7.6 *Expendable/thermal storage using phosphonium chloride.*

water boiler will handle peak loads. Compressor power and expendable water thus are minimized. The water boiler provides humidity control by cooling the vent loop that feeds the separated water to the boiler via the water separator to provide additional cooling capacity. A bypass valve is utilized in the thermal storage subsystem to prevent overcooling under low or no-load conditions. This system is flexible in that it can be sized for a multitude of thermal load sharing combinations.

Carbon Dioxide Control/Oxygen Supply

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

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.

Metallic Oxides - Vehicle Regenerable. Metallic oxides (ZnO, MgO) react with CO_2 according to the reversible reaction

$$MO + CO_2 \rightleftharpoons MCO_3 + Q$$
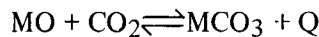
The carbonate readily decomposes with increasing temperature and, in some cases, may be solely vacuum regenerable. However, excessive volume change during the adsorb/desorb cycle affects the chemical's physical stability and is a prime consideration in any future development effort. For this study, the adsorbent was contained between screens with gas flow over rather than through the packaging. CO_2 diffusion into the thin oxide bed will be sufficient as long as the solid volume transition during adsorb/desorb does not result in an impregnable surface or if any extremely fine screen is not required. An alternate concept would consider a carrier to stabilize the solid adsorbent—possibly a thin layer of the oxide flame sprayed on a screen matrix.

In the vehicle regenerable configuration (fig. 7.7), the adsorbent is packaged in a cartridge that is replaced after each mission. An oven/vacuum chamber is provided within the vehicle for cartridge regeneration. Reclamation of the oxygen is possible with this system by directing gas to the vehicle CO_2 reduction system.

Metallic Oxides - AEPS Regenerable. A variation of the metallic oxide concept considers a cyclic or AEPS regenerable configuration (fig. 7.8). This concept provides for regeneration of the metallic oxide subsystem during the actual EVA mission. Two beds, similar in design to that described for the vehicle regenerable system, are provided, each containing electrical elements for regeneration and a cooling loop to cool the regenerated bed and maintain temperature control during operation.
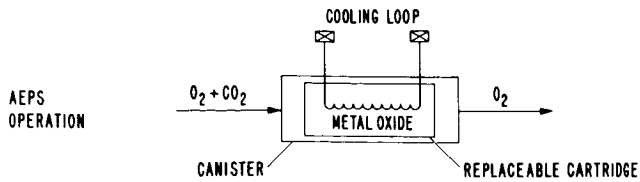
112

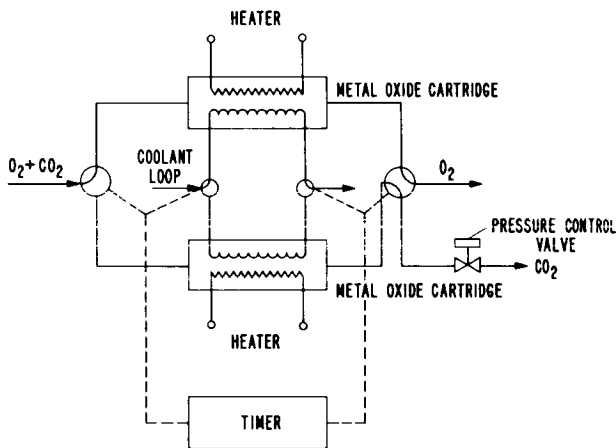Figure 7.7 *Metallic oxide–vehicle regenerable.*

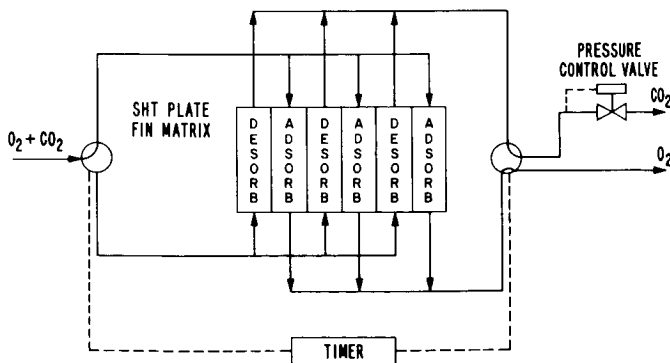
Figure 7.8 *Metallic oxide–AEPS regenerable.*

Figure 7.9 *Solid amine (SHT)–AEPS regenerable.*

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 onstream bed and to heat and expose to space vacuum the regenerating bed.

Solid Amine - AEPS Regenerable. An inert carrier is utilized to provide a stable amine adsorbent bed in this concept (fig. 7.9). The regenerable solid amine is packaged within the flow passages of a plate-fin matrix similar in design to an extended surface compact heat exchanger. Alternate flow passages contain adsorbing and desorbing material with the unique feature of an isothermal 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 nor requires energy for regeneration. A timer and valving is provided to cycle the packed beds from the online adsorb to the space vacuum desorb cycle.

The parametric analyses of the recommended subsystem concepts were then reviewed and updated to reflect the latest AEPS specification requirements for each of the three missions, space station, lunar base, and martian. Parametric data generated includes:

1. Vehicle equivalent weight versus total mission duration.
2. Vehicle equivalent volume versus total mission duration.
3. AEPS equivalent volume versus EVA mission duration.
4. AEPS equivalent weight versus EVA mission duration.
5. Accumulated resupply launch weight versus number of resupplies.

The results of these parametric analyses, which were utilized for selecting and sizing subsystems for the system studies, are presented in the following figures:
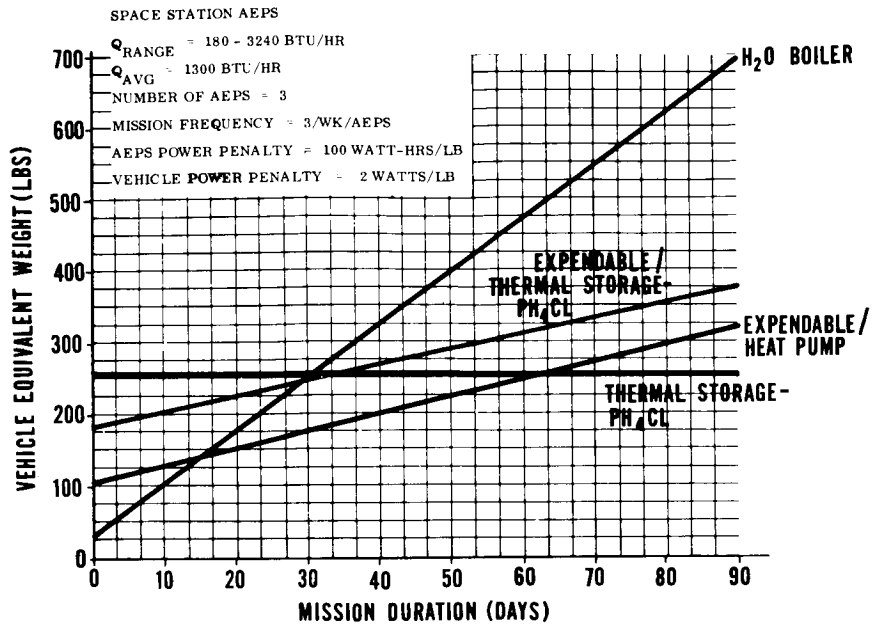
SPACE STATION AEPS

Q_{RANGE} = 180 - 3240 BTU/HR
Q_{AVG} = 1300 BTU/HR
NUMBER OF AEPS = 3
MISSION FREQUENCY = 3/WK/AEPS
AEPS POWER PENALTY = 100 WATT-HRS/LB
VEHICLE POWER PENALTY = 2 WATTS/LB

H_2O BOILER

EXPENDABLE / THERMAL STORAGE- PH_4CL

EXPENDABLE / HEAT PUMP

THERMAL STORAGE- PH_4CL

VEHICLE EQUIVALENT WEIGHT (LBS)

MISSION DURATION (DAYS)

Figure 7.10 (a) *Thermal control for space station AEPS.*

SPACE STATION AEPS

Q_{RANGE} 180 - 3240 BTU/HR
Q_{AVG} 1300 BTU/HR
NUMBER OF AEPS - 3
MISSION FREQUENCY 3/WK/AEPS
AEPS POWER PENALTY 8.3 WATT-HRS/IN^3

H_2O BOILER

EXPENDABLE / THERMAL STORAGE- PH_4CL

EXPENDABLE / HEAT PUMP

THERMAL STORAGE- PH_4CL

VEHICLE EQUIVALENT VOLUME (IN^3)

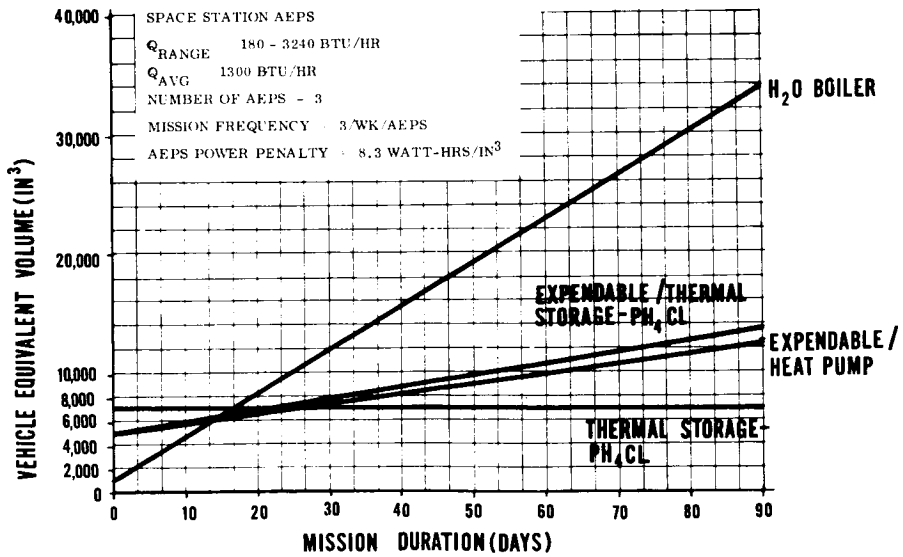MISSION DURATION (DAYS)

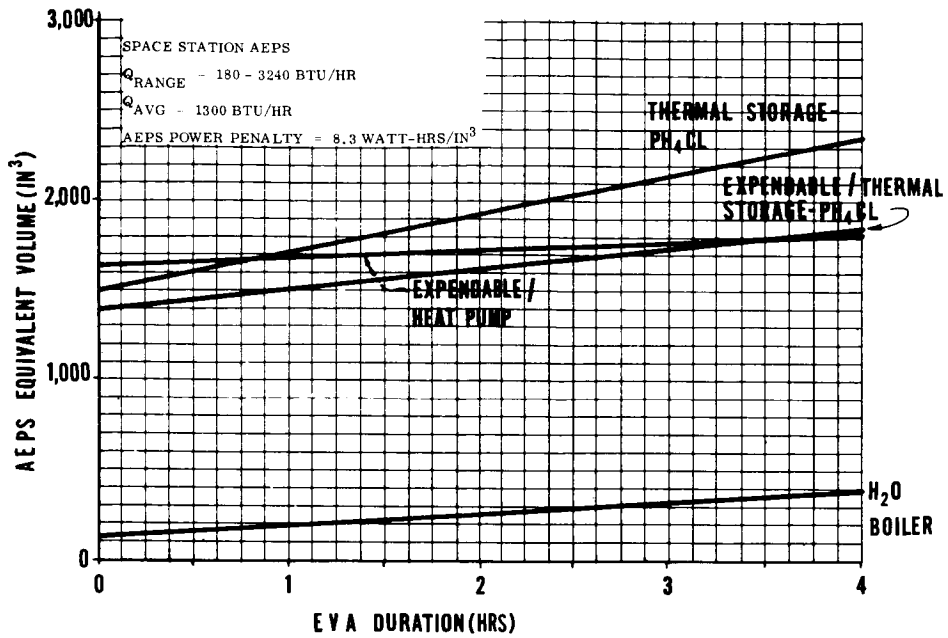**Figure 7.10 (b)** *Thermal control for space station AEPS.*

114

Figure 7.10 (c) *Thermal control for space station AEPS.*

Figure 7.10 (d) *Thermal control for space station AEPS.*
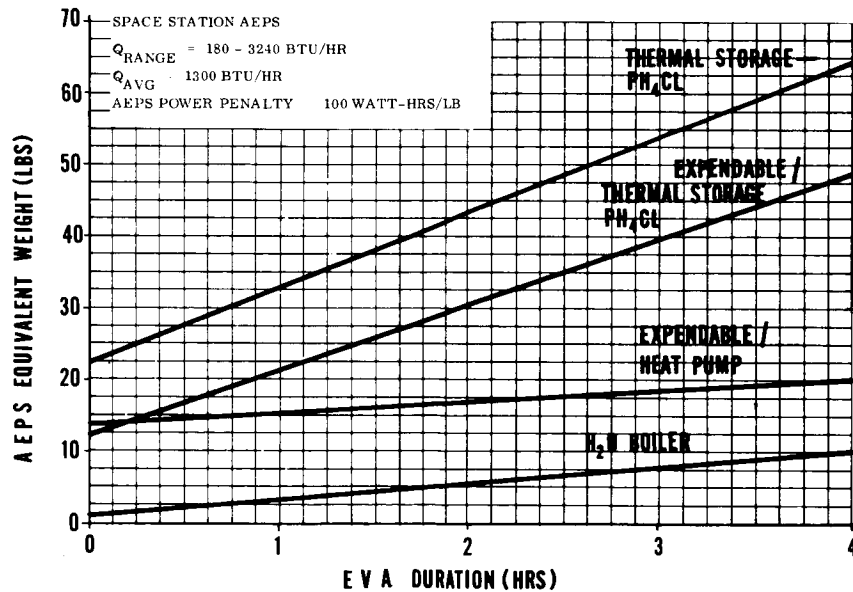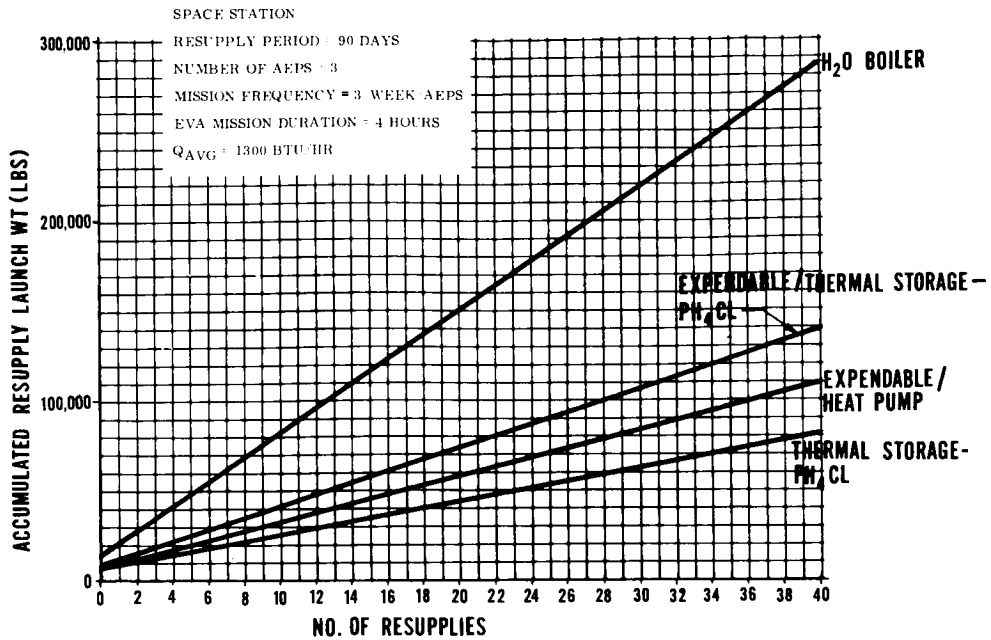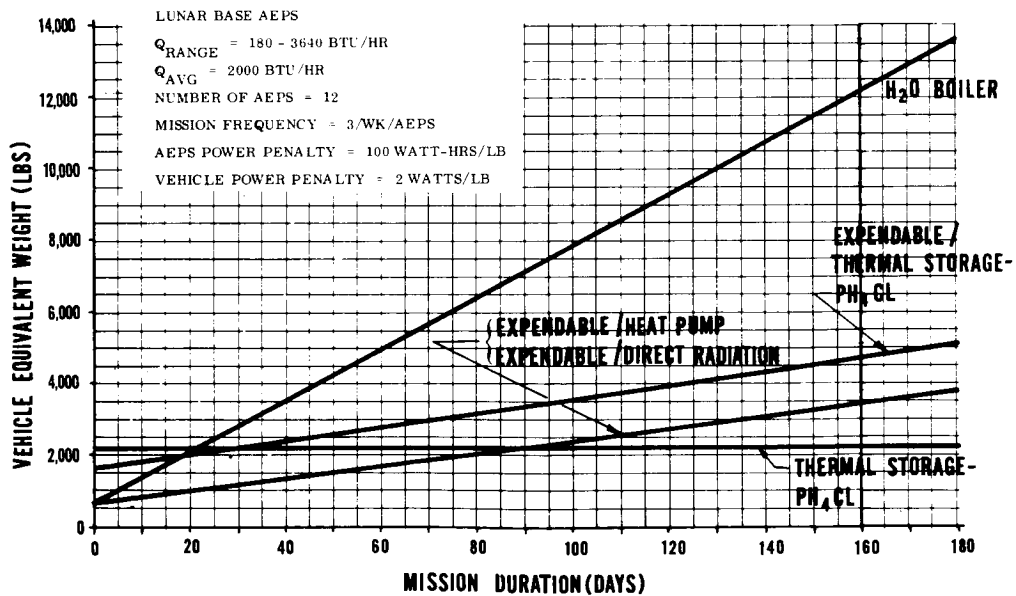
Figure 7.10 (e) *Thermal control for space station AEPS.*

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

H$_2$O BOILER
EXPENDABLE/THERMAL STORAGE-PH$_4$CL
EXPENDABLE/HEAT PUMP
THERMAL STORAGE-PH$_4$CL

ACCUMULATED RESUPPLY LAUNCH WT (LBS)

NO. OF RESUPPLIES

Figure 7.11 (a) *Thermal control for lunar base AEPS.*

LUNAR BASE AEPS
Q_{RANGE} = 180 - 3640 BTU/HR
Q_{AVG} = 2000 BTU/HR
NUMBER OF AEPS = 12
MISSION FREQUENCY = 3/WK/AEPS
AEPS POWER PENALTY = 100 WATT-HRS/LB
VEHICLE POWER PENALTY = 2 WATTS/LB

H$_2$O BOILER
EXPENDABLE/THERMAL STORAGE-PH$_4$CL
EXPENDABLE/HEAT PUMP
EXPENDABLE/DIRECT RADIATION
THERMAL STORAGE-PH$_4$CL

VEHICLE EQUIVALENT WEIGHT (LBS)
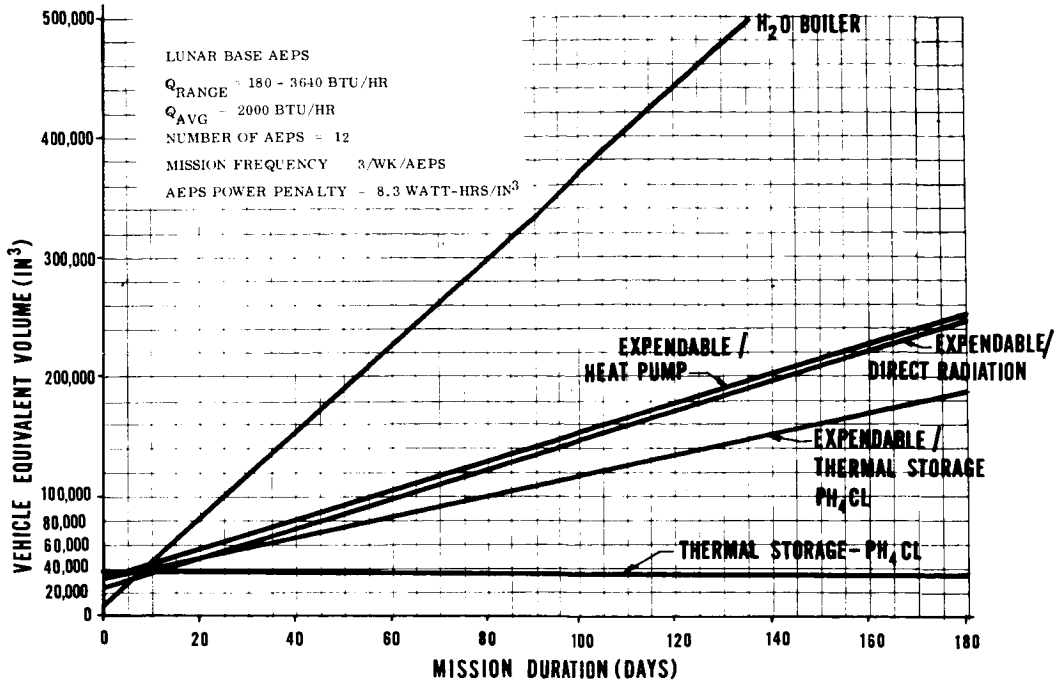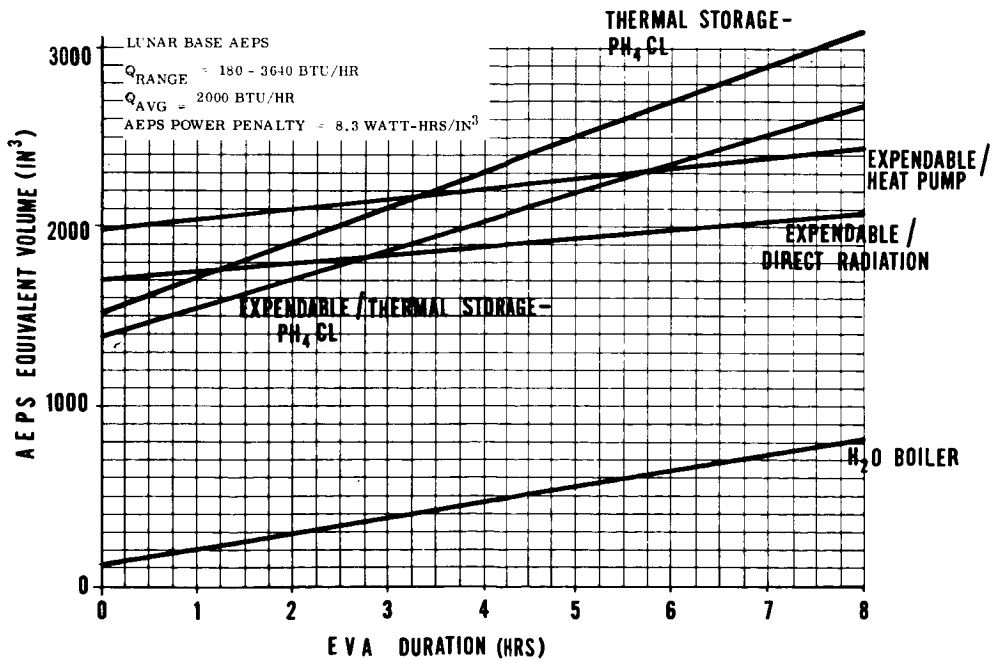
MISSION DURATION (DAYS)

116

Figure 7.11 (b) *Thermal control for lunar base AEPS.*

Figure 7.11 (c) *Thermal control for lunar base AEPS.*
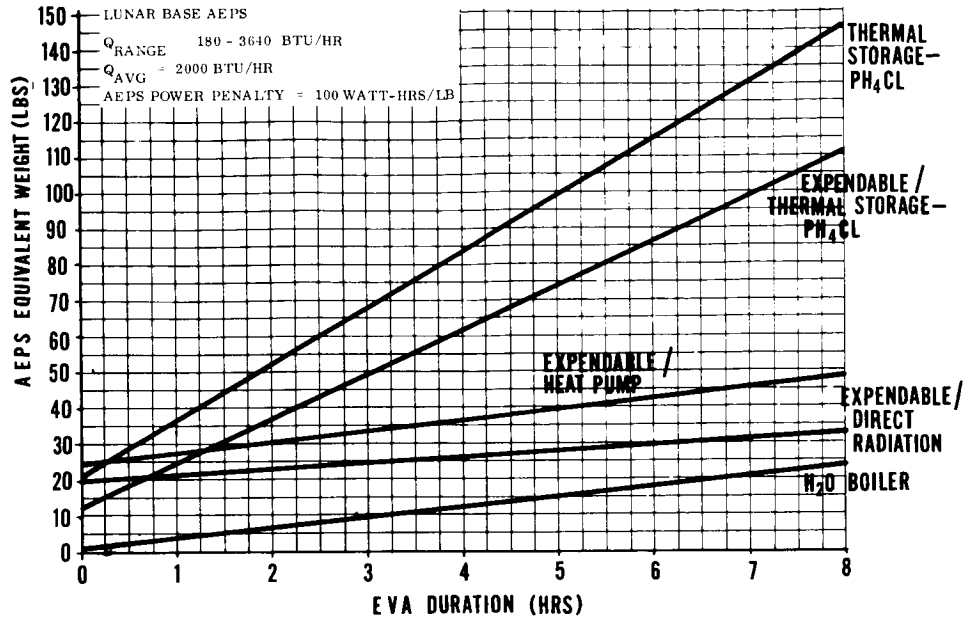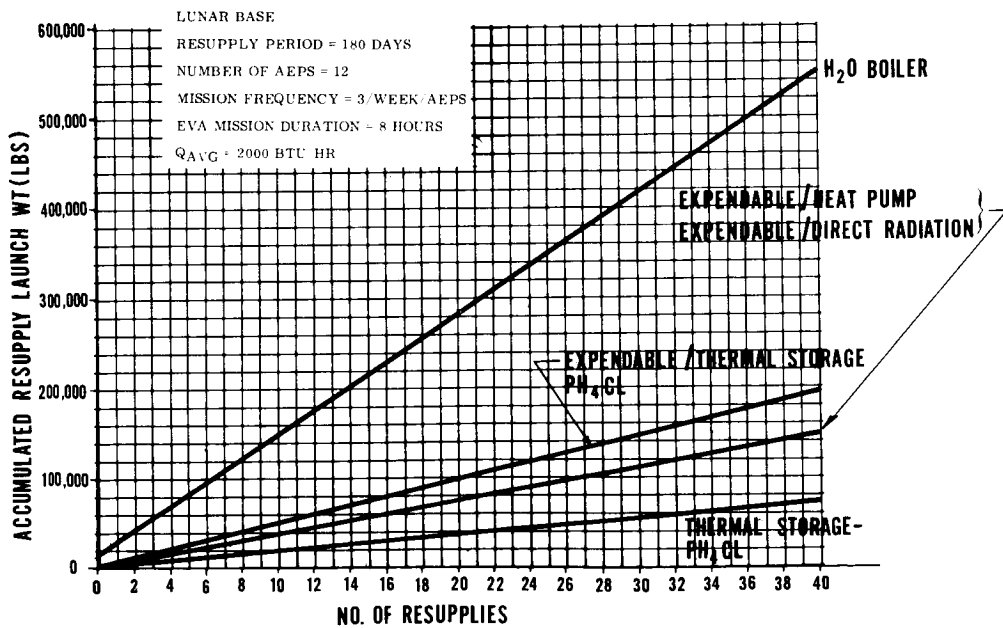
117

Figure 7.11 (d) *Thermal control for lunar base AEPS.*

Graph content:
- Y-axis: AEPS EQUIVALENT WEIGHT (LBS), 0 to 150
- X-axis: EVA DURATION (HRS), 0 to 8
- LUNAR BASE AEPS
- Q_{RANGE} = 180 – 3640 BTU/HR
- Q_{AVG} = 2000 BTU/HR
- AEPS POWER PENALTY = 100 WATT-HRS/LB
- Curves labeled: THERMAL STORAGE-PH_4CL; EXPENDABLE/THERMAL STORAGE-PH_4CL; EXPENDABLE/HEAT PUMP; EXPENDABLE/DIRECT RADIATION; H_2O BOILER

Figure 7.11 (e) *Thermal control for lunar base AEPS.*

Graph content:
- Y-axis: ACCUMULATED RESUPPLY LAUNCH WT (LBS), 0 to 600,000
- X-axis: NO. OF RESUPPLIES, 0 to 40
- 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
- Curves labeled: H_2O BOILER; EXPENDABLE/HEAT PUMP; EXPENDABLE/DIRECT RADIATION; EXPENDABLE/THERMAL STORAGE PH_4CL; THERMAL STORAGE-PH_4CL

MARS AEPS

Q_{RANGE} = 0 - 3600 BTU/HR
Q_{AVG} = 1400 BTU/HR
NUMBER OF AEPS = 3
MISSION FREQUENCY = 5/WK/AEPS
AEPS POWER PENALTY = 100 WATT-HRS/LB
VEHICLE POWER PENALTY = 2 WATTS/LB

H_2O BOILER
EXPENDABLE / THERMAL STORAGE - PH_4CL
THERMAL STORAGE - PH_4CL
EXPENDABLE / HEAT PUMP
EXPENDABLE / DIRECT RADIATION

VEHICLE EQUIVALENT WEIGHT (LBS)

MISSION DURATION (DAYS)

Figure 7.12 (a) *Thermal control for martian AEPS.*

MARS AEPS

Q_{RANGE} 0-3600 BTU/HR
Q_{AVG} 1400 BTU/HR
NUMBER OF AEPS = 3
MISSION FREQUENCY = 5/WK/AEPS
AEPS POWER PENALTY = 8.3 WATT-HRS/IN^3

H_2O BOILER
EXPENDABLE / HEAT PUMP
EXPENDABLE / DIRECT RADIATION
EXPANDABLE / THERMAL STORAGE - PH_4CL
THERMAL STORAGE - PH_4CL

VEHICLE EQUIVALENT VOLUME (IN^3)
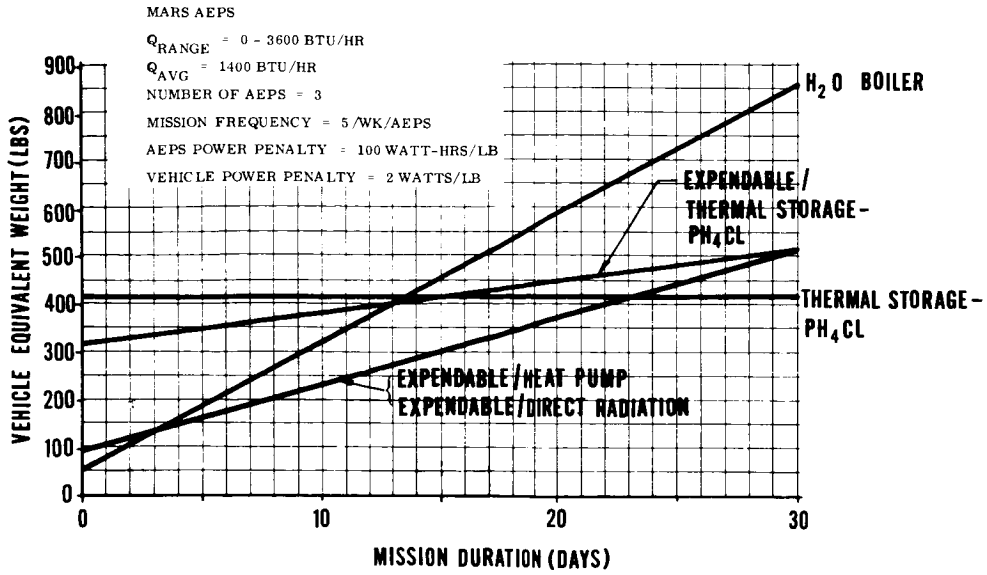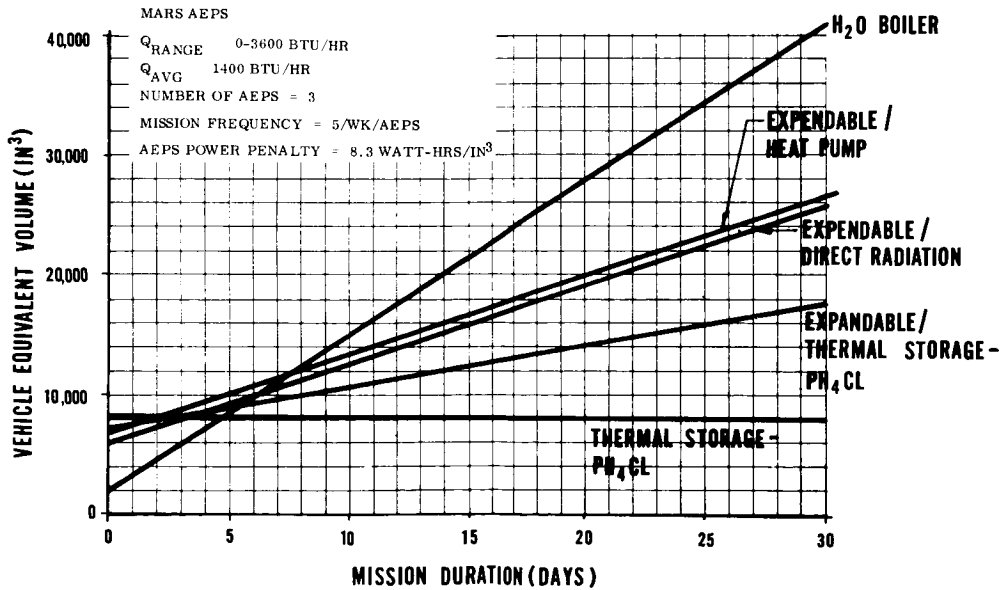
MISSION DURATION (DAYS)

Figure 7.12 (b) *Thermal control for martian AEPS.*

Figure 7.12 (c) *Thermal control for martian AEPS.*
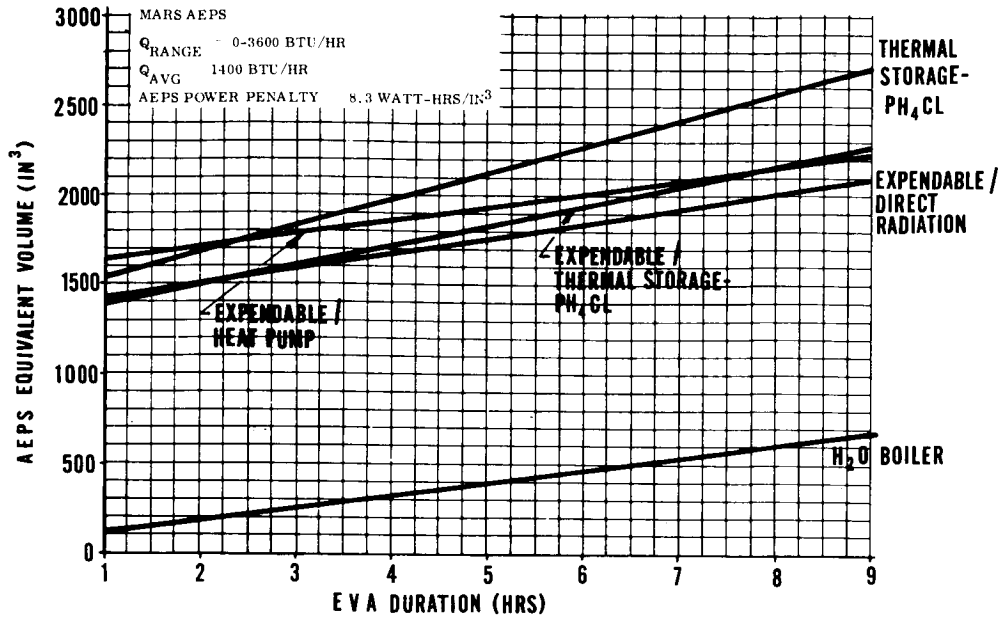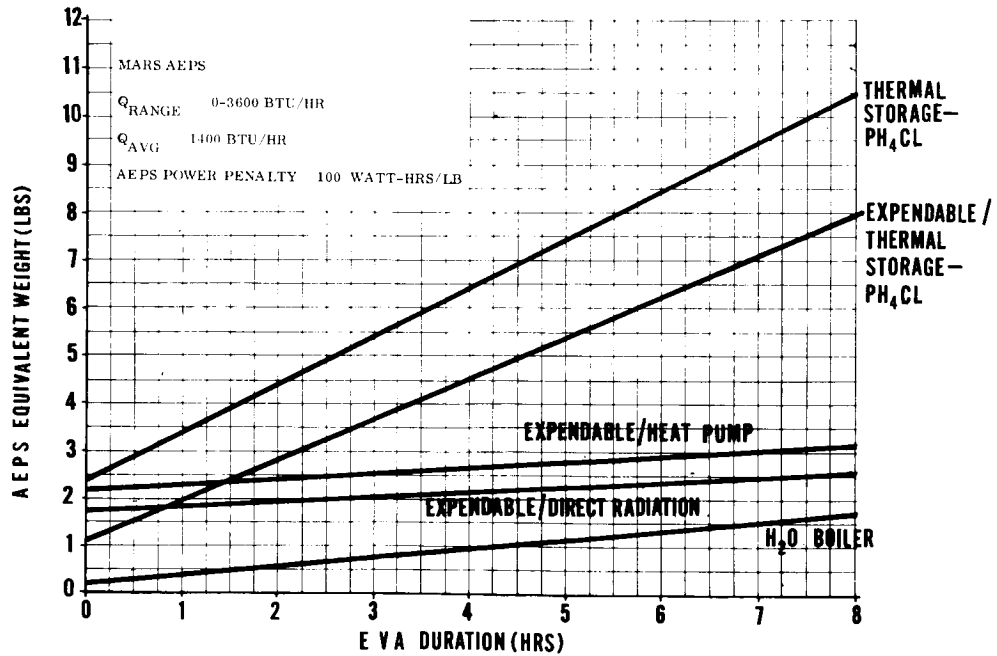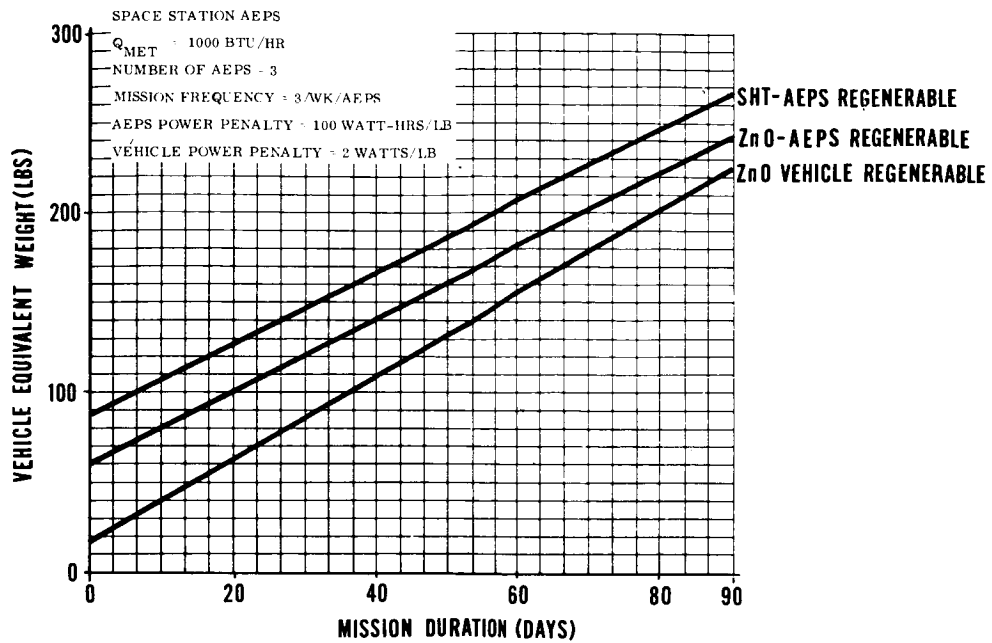

Figure 7.12 (d) *Thermal control for martian AEPS.*

SPACE STATION AEPS

Q_{MET} · 1000 BTU/HR
NUMBER OF AEPS - 3
MISSION FREQUENCY - 3/WK/AEPS
AEPS POWER PENALTY · 100 WATT-HRS/LB
VEHICLE POWER PENALTY - 2 WATTS/LB

SHT-AEPS REGENERABLE
ZnO-AEPS REGENERABLE
ZnO VEHICLE REGENERABLE

VEHICLE EQUIVALENT WEIGHT (LBS)

MISSION DURATION (DAYS)

Figure 7.13 (a) *Carbon dioxide control/oxygen supply for space station AEPS.*

SPACE STATION AEPS

Q_{MET} · 1000 BTU/HR
NUMBER OF AEPS = 3
MISSION FREQUENCY = 3/WK/AEPS
AEPS POWER PENALTY · 8.3 WATT-HRS/IN^3

ZnO-VEHICLE REGENERABLE

SHT-AEPS REGENERABLE
ZnO-AEPS REGENERABLE

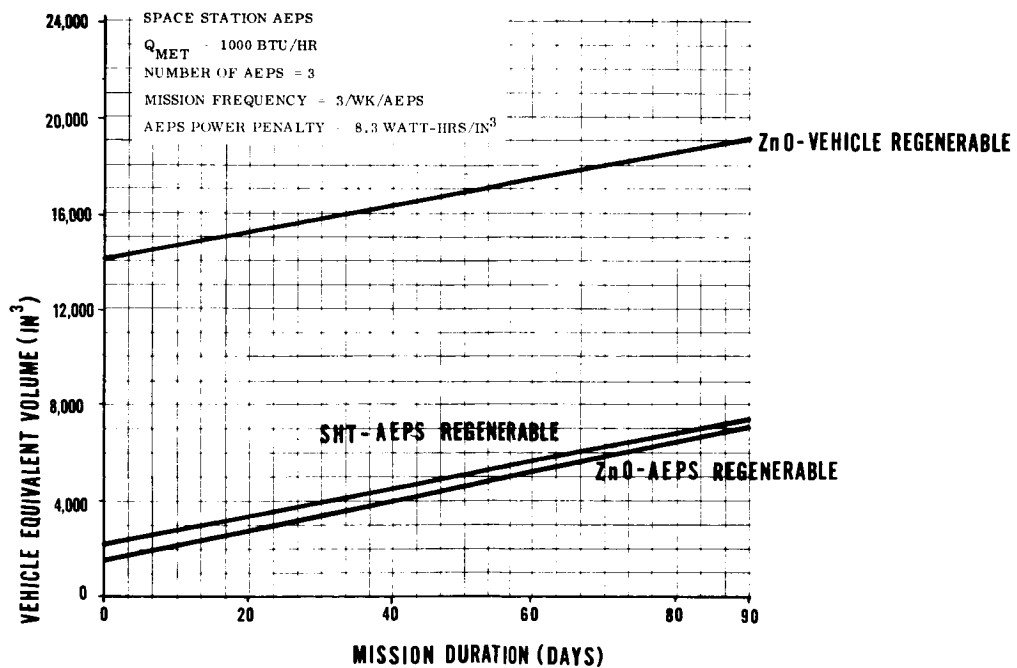VEHICLE EQUIVALENT VOLUME (IN^3)

MISSION DURATION (DAYS)

Figure 7.13 (b) *Carbon dioxide control/oxygen supply for space station AEPS.*
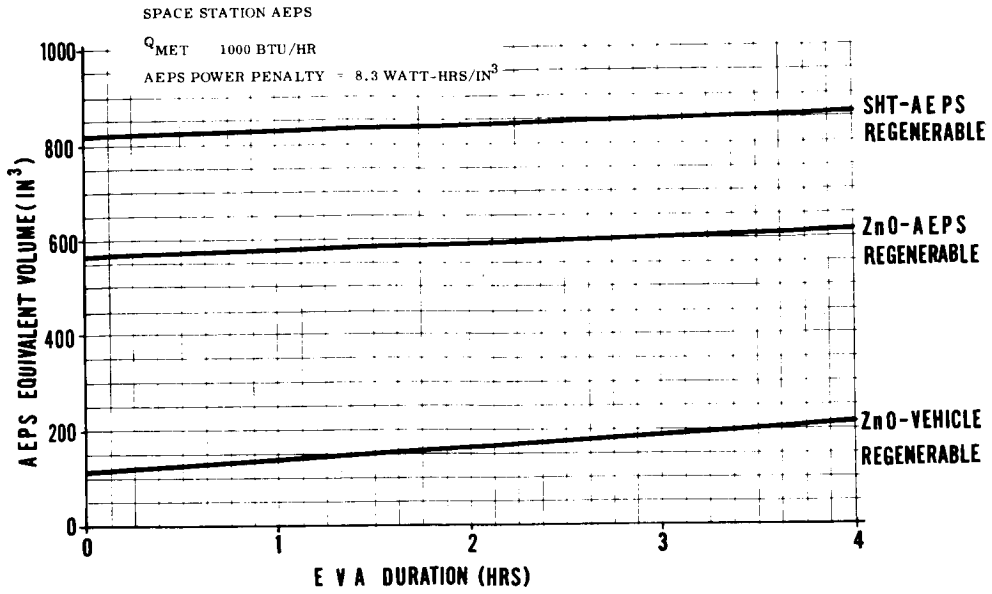
Figure 7.13 (c) *Carbon dioxide control/oxygen supply for space station AEPS.*

Figure 7.13 (d) *Carbon dioxide control/oxygen supply for space station AEPS.*

122

Figure 7.13 (e) *Carbon dioxide control/oxygen supply for space station AEPS.*
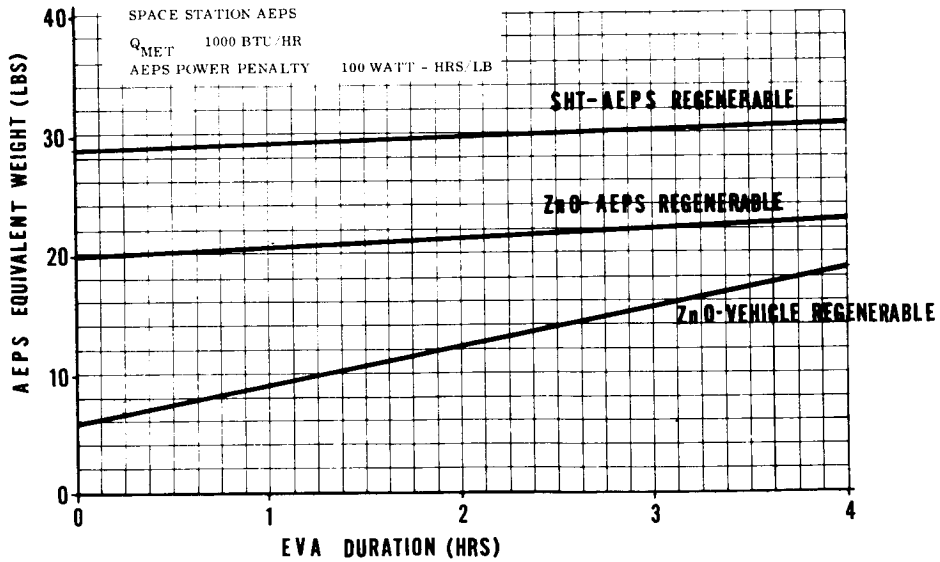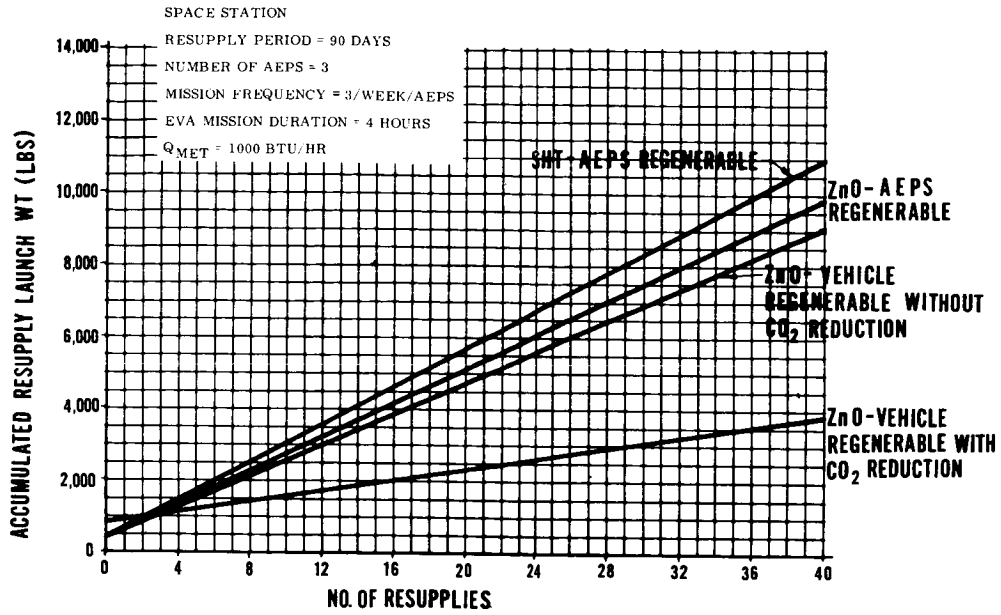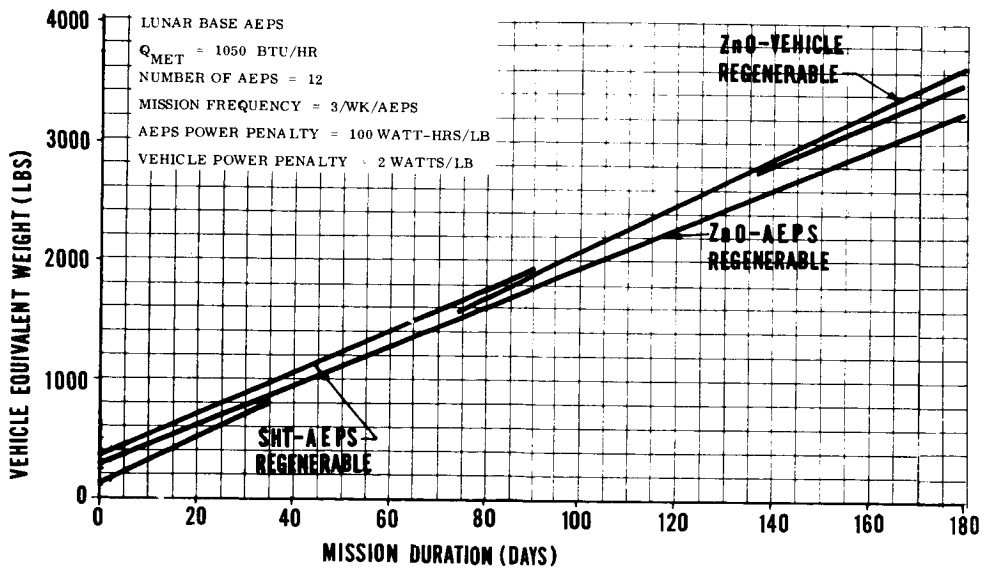

Figure 7.14 (a) *Carbon dioxide control/oxygen supply for lunar base AEPS.*

123

Figure 7.14 (b) *Carbon dioxide control/oxygen supply for lunar base AEPS.*

Figure 7.14 (c) *Carbon dioxide control/oxygen supply for lunar base AEPS.*
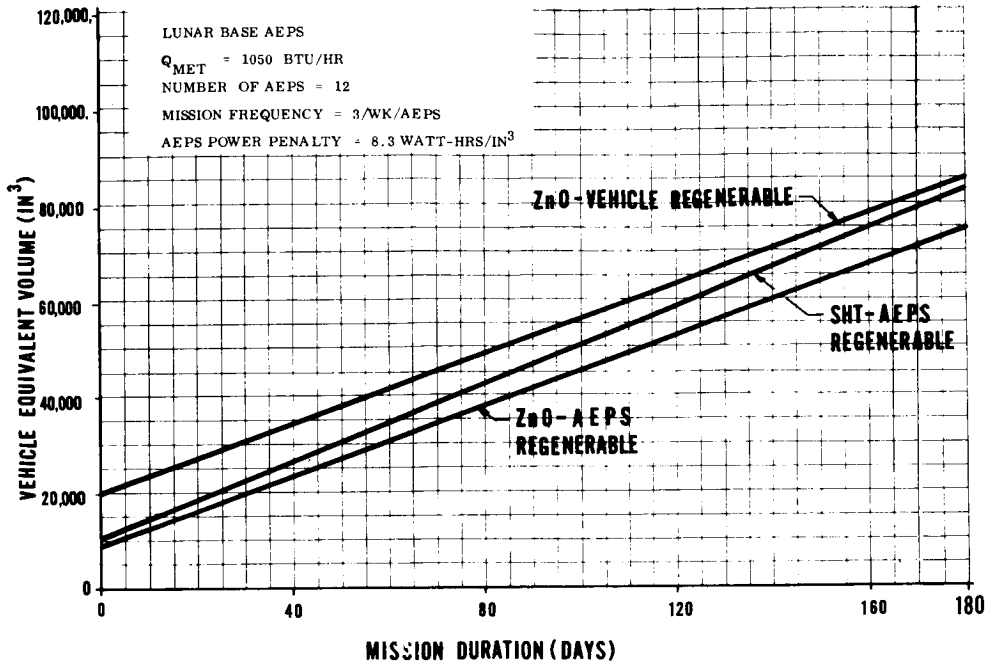
124

Figure 7.14 (d) *Carbon dioxide control/oxygen supply for lunar base AEPS.*

Figure 7.14 (e) *Carbon dioxide control/oxygen supply for lunar base AEPS.*

125

Figure 7.15 (a) *Carbon dioxide control/oxygen supply for martian AEPS.*

Figure 7.15 (b) *Carbon dioxide control/oxygen supply for martian AEPS.*
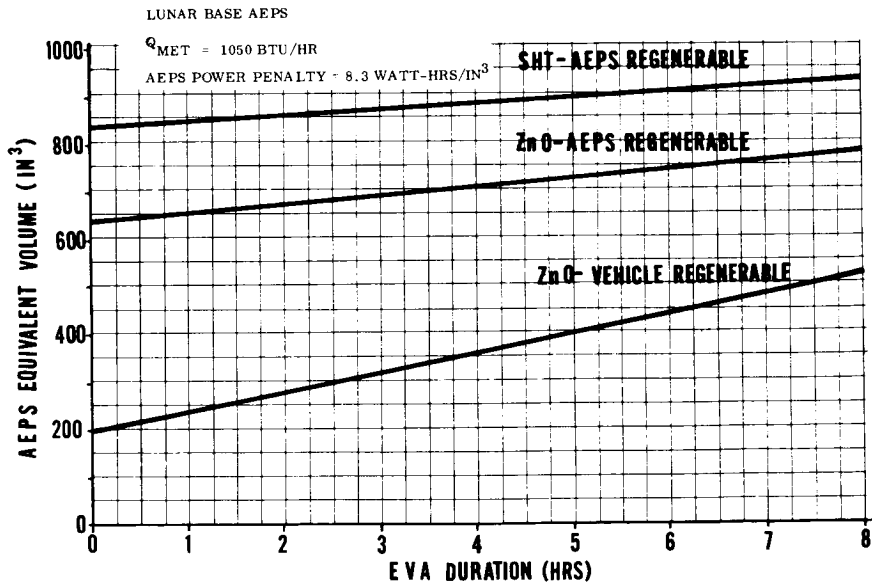
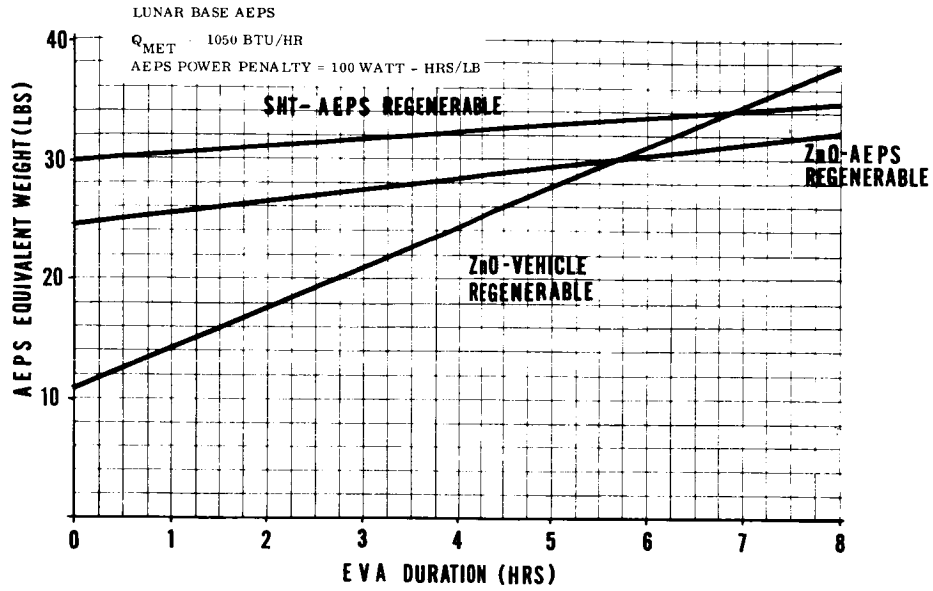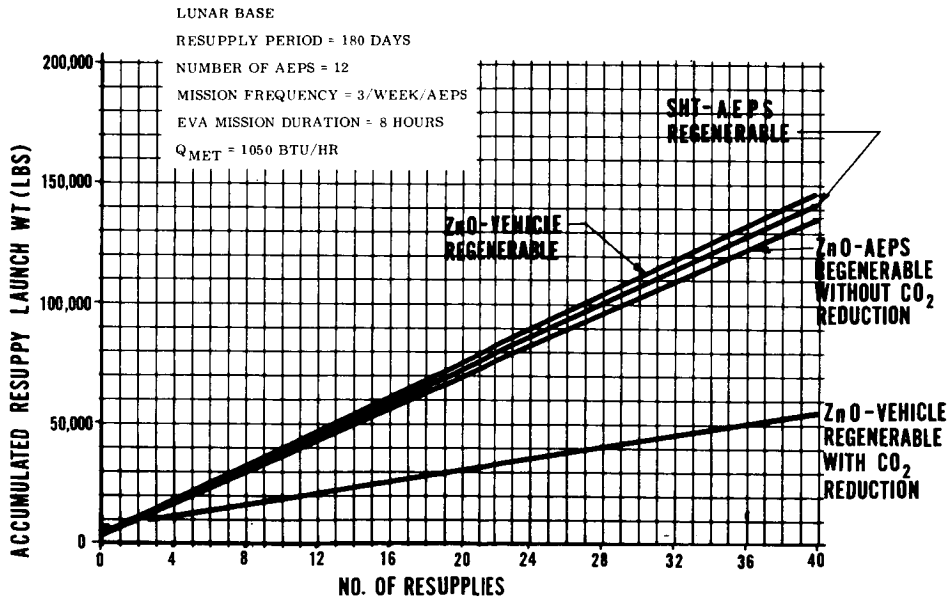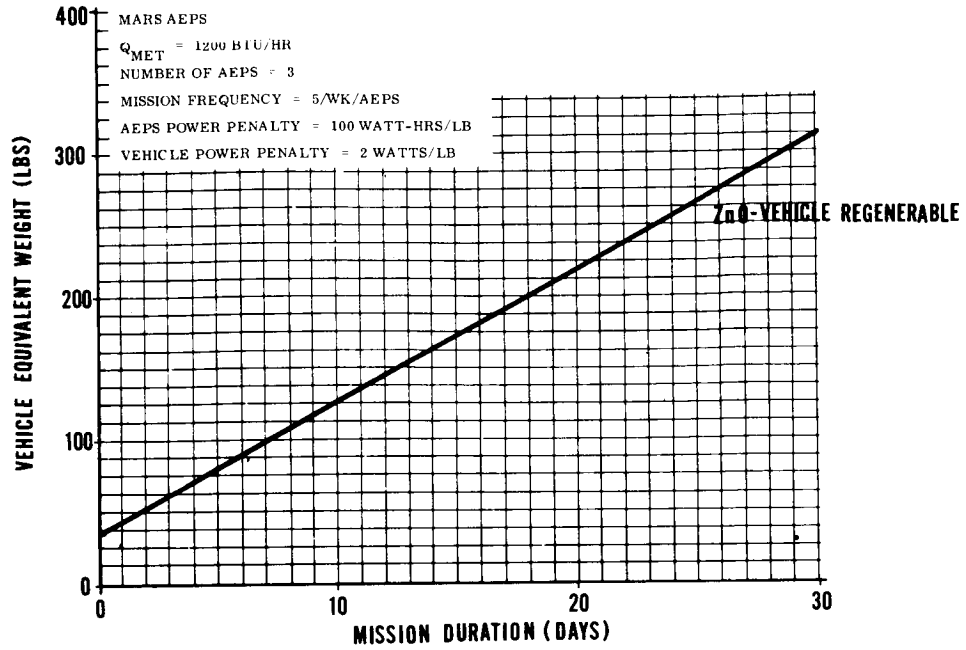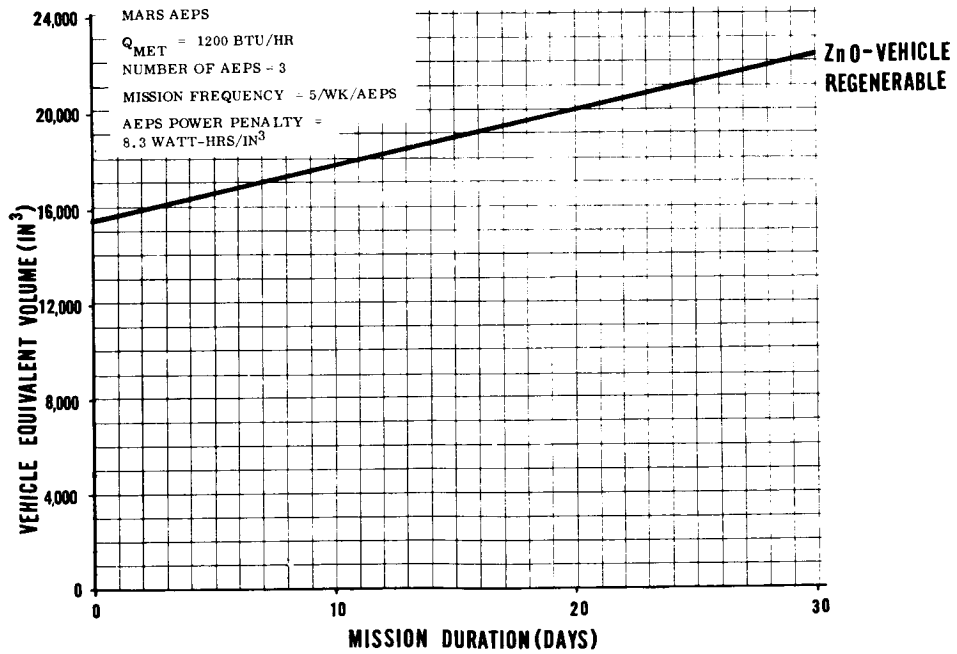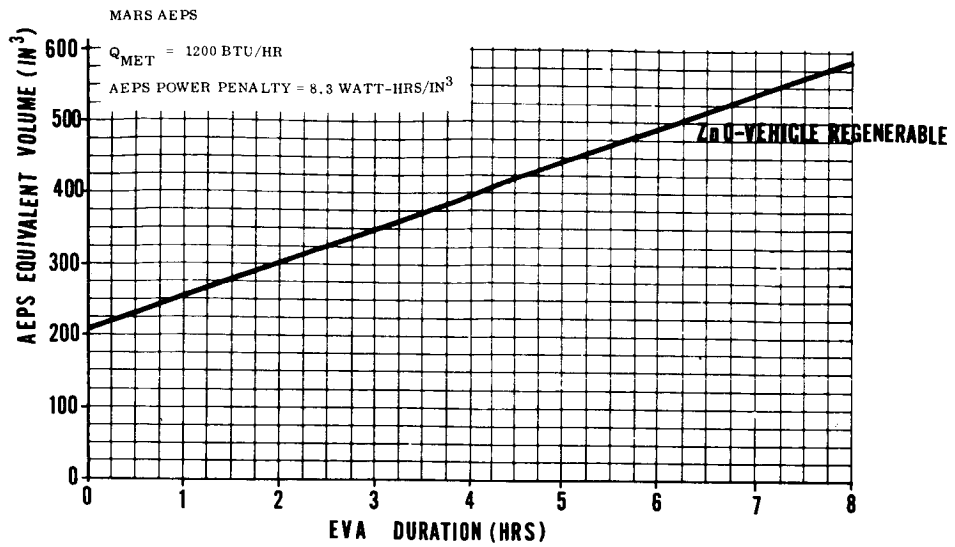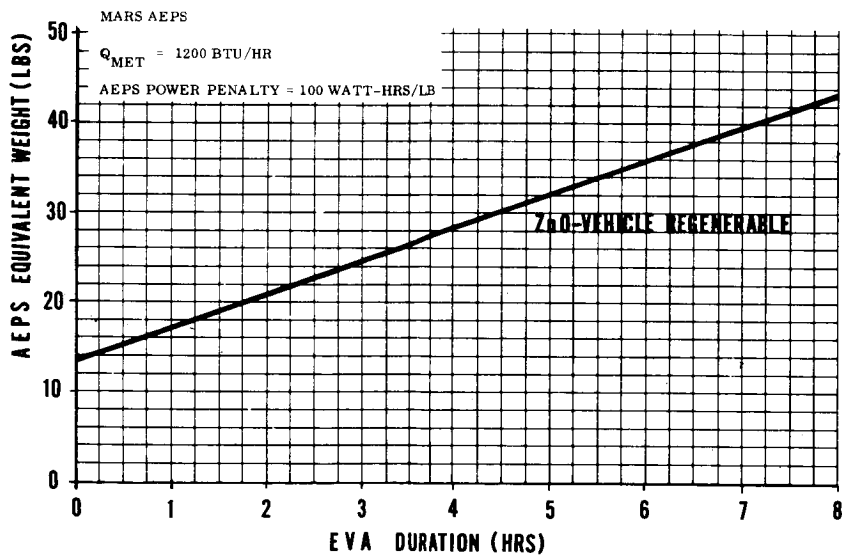**Figure 7.15 (c)** *Carbon dioxide control/oxygen supply for martian AEPS.*

Figure 7.15 (d) *Carbon dioxide control/oxygen supply for martian AEPS.*

127

SYSTEM STUDIES

The system studies combined the selected candidate subsystem concepts into candidate baseline space station, lunar base, and martian AEPS schematics. The following schematics and flow charts are representative of potential AEPS configurations that might result if the technology recommendations emanating from the AEPS study are implemented.

AEPS Concepts

Space Station 1 (fig. 7.16).   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 12 heat transport loop, a power supply, instrumentation, and operating controls and displays. The O_2 ventilation loop circulates a reconditioned and replenished O_2 supply through the suit. The O_2 from the suit enters the atmosphere regeneration subsystem and first passes through the debris trap where solid particles and 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 that 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 that circulates a ventilation flow of 6 acfm to the suit.

The high-pressure O_2 subsystem contains 0.75 lb 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 his 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 that consists of a water boiler and phosphonium chloride thermal storage unit. A Freon 12 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.

The estimated total volume and weight for this AEPS configuration are 2500 in.^{3} and 77 lb based on average metabolic rate of 1000 Btu/hr for an EVA duration of 4 hr.

Space Station 2 (fig. 7.17).   This AEPS concept is similar to concept 1 except:

1.   The vehicle regenerable metallic oxide CO_2 control subsystem is replaced by an AEPS regenerable solid amine plate-fin matrix that removes both CO_2 and water vapor from the O_2 ventilation loop thus providing both CO_2 and humidity control. This is a cyclic concept using a 30-min full cycle. Energy released during the adsorb cycle is conducted to the regeneration portion of the subsystem thus supplying the endothermic heat of desorption.

Figure 7.16 *AEPS concept 1, space station.*
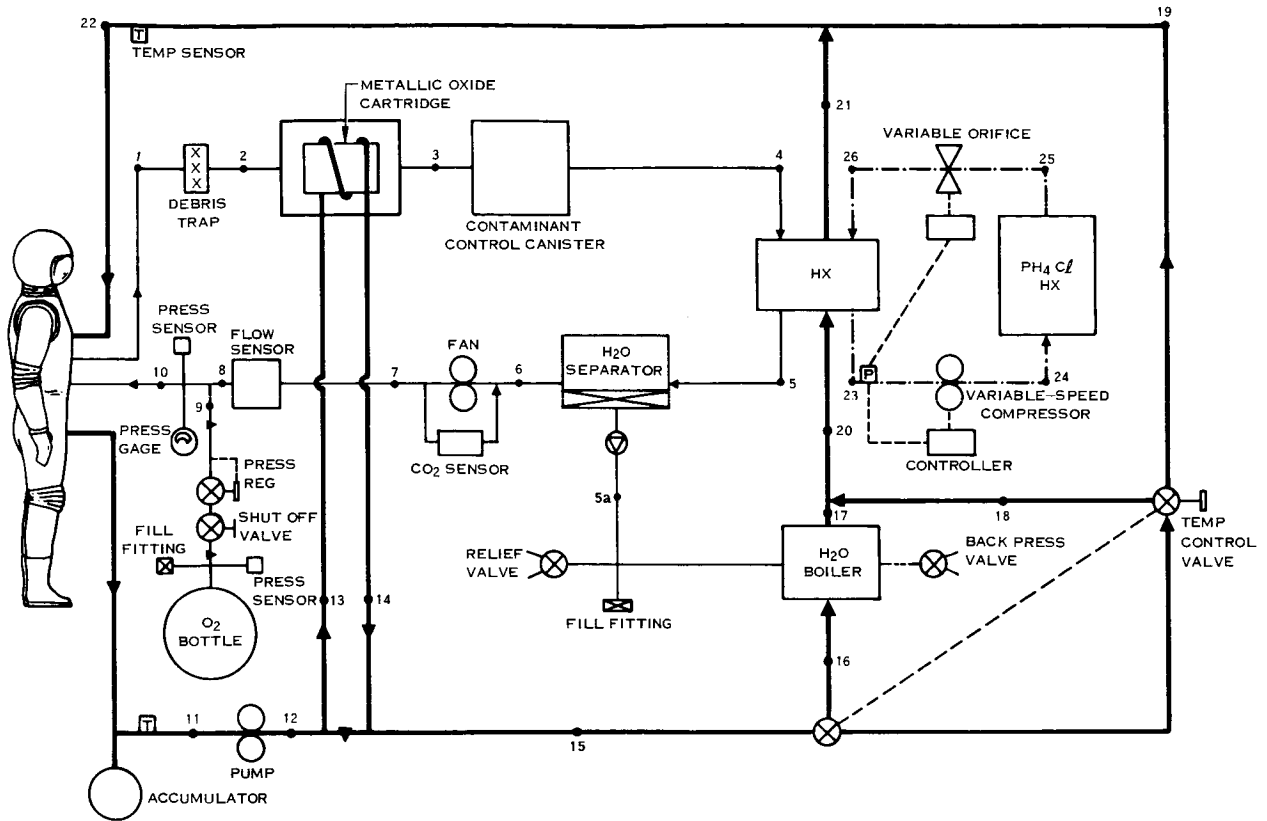
Vent Loop	Station										
	1	2	3	4	5	5a	6	7	8	9	10
Temperature, °F	79	79	79	79	50	---	50	72	72	72	72
Volume flow rate, FT^3/min	6.315	6.32	6.20	6.24	5.90	---	5.93	5.96	5.965	.072	6.037
Total pressure, psia	6.9	6.89	6.86	6.82	6.78	---	6.76	6.99	6.987	6.987	6.987
Total weight flow, lb/hr	14.225	13.225	14.030	14.030	13.898	---	13.898	13.898	13.898	.169	13.067
O_2 weight flow, lb/hr	13.531	13.531	13.531	13.531	13.531	---	13.531	13.531	13.531	.169	13.7
CO_2 weight flow, lb/hr	.357	.357	.162	.162	.162	---	.162	.162	.162	---	.162
H_2O weight flow, lb/hr	.337	.337	.337	.337	.205	.132	.205	.205	.205	---	.205
O_2 partial pressure, psia	6.49	6.48	6.51	6.48	6.55	---	6.52	6.75	6.75	6.987	6.75
CO_2 partial pressure, psia	.13	.13	.056	.056	.058	---	.059	.06	.06	---	.059
H_2O partial pressure, psia	.28	.28	.294	.285	.176	---	.175	.181	.181	---	.179
Dewpoint, °F	63	63	64	63	50	---	50	50	50	---	50

Station

Liquid Loop	11	12	13	14	15	16	17	18	19	20	21	22
Weight flow lb/hr	240	240	40	40	240	18.2	18.2	221.8	0	240	240	240
Temperature, °F	64.7	64.8	64.8	68.2	65.5	65.5	45	65.5	--	63.7	60	60
Pressure, psia	18	22.3	22.3	22.3	22.1	22.0	21.7	21.7	20.4	21.7	20.4	20.4

Station

Freon Loop	23	24	25	26
Weight flow, lb/hr	18	18	18	18
Temperature, °F	50	150	82	45
Pressure, psia	61.4	103	102	61.8

Figure 7.16 *AEPS concept 1, space station. (Concluded)*

Figure 7.17 *AEPS concept 2, space station.*

130
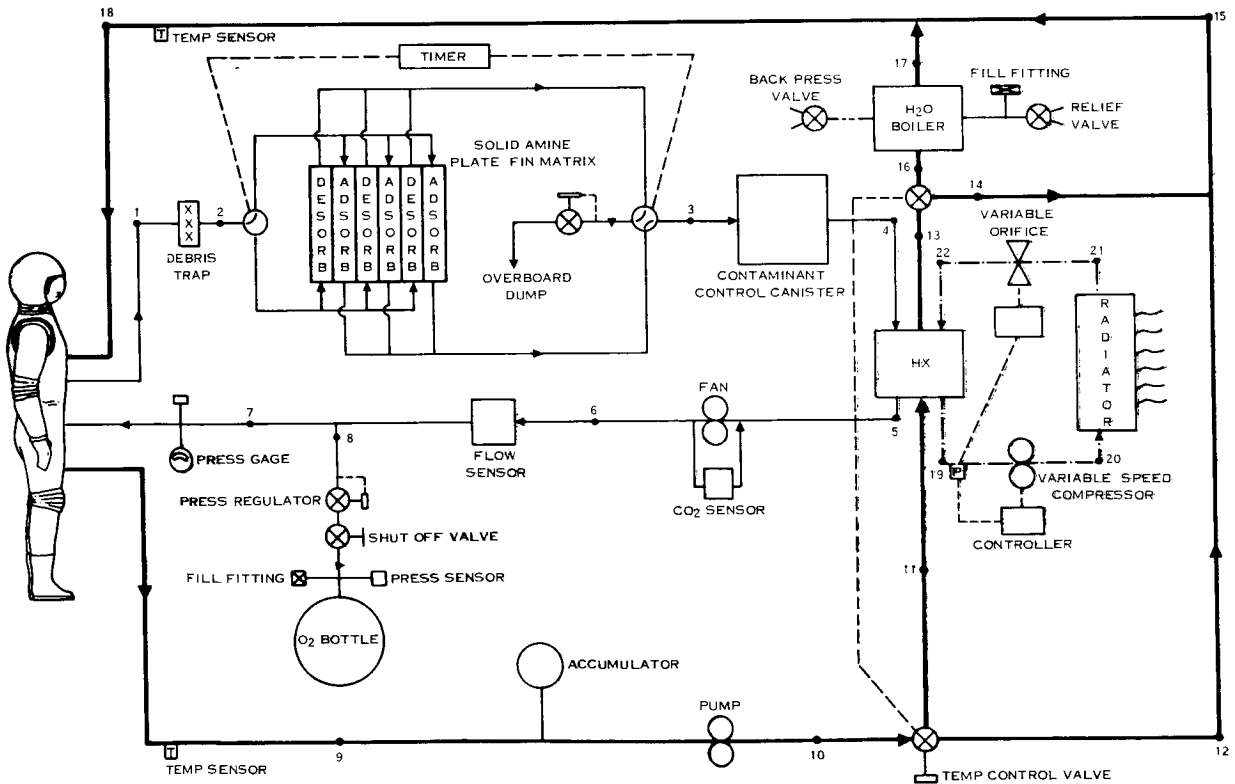
Station								
Vent Loop	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Temperature, °F	79	79	79	79	50	72	72	72
Volume flow rate, FT³/min	6.315	6.32	6.18	6.22	5.92	5.97	6.037	.072
Total pressure, psia	6.9	6.89	6.84	6.80	6.76	6.99	6.987	6.987
Total weight flow, lb/hr	14.225	14.225	13.898	13.898	13.898	13.898	14.067	.169
O_2 weight flow, lb/hr	13.531	13.531	13.531	13.531	13.531	13.531	13.7	.169
CO_2 weight flow, lb/hr	.357	.357	.162	.162	.162	.162	.162	---
H_2O weight flow, lb/hr	.337	.337	.205	.205	.205	.205	.205	---
O_2 partial pressure, psia	6.49	6.48	6.61	6.57	6.53	6.75	6.75	6.987
CO_2 partial pressure, psia	.13	.13	.055	.057	.057	.059	.059	---
H_2O partial pressure, psia	.28	.28	.178	.177	.175	.182	.179	---
Dew point, °F	63	63	50	50	50	51	50	---

Station										
Liquid Loop	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Weight flow, lb/hr	240	240	240	0	240	202	202	38	38	240
Temperature, °F	64.7	64.8	64.8	---	62.3	62.3	62.3	62.3	45	60
Pressure, psia	18	22.3	22.2	20.4	21.7	20.4	20.4	21.3	20.4	20.4

Station			
Freon Loop	**19**	**20**	**21**	**22**
Weight flow, lb/hr	11	11	11	11
Temperature, °F	50	340	180	45
Pressure, psia	61.4	350	349	61.8

Figure 7.17 *AEPS concept 2, space station. (Concluded)*

2. The thermal control subsystem is a hybrid expendable/radiation heat pump subsystem and consists of a water boiler and a Freon 12 refrigeration system. The Freon 12 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 nighttime 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 liquid transport loop. The estimated total volume and weight for this AEPS configuration are 3100 cu in. and 65 lb based on an average metabolic rate of 1000 Btu/hr for an EVA duration of 4 hr.

Lunar Base 3 (fig. 7.18). This AEPS concept is similar to concept 2 except the thermal control subsystem is composed of a PH_4Cl thermal storage unit and a Freon 12 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. The estimated total volume and weight for this AEPS configuration is 4500 cu in. and 193 lb based on an average metabolic rate of 1050 Btu/hr for an EVA duration of 8 hr.
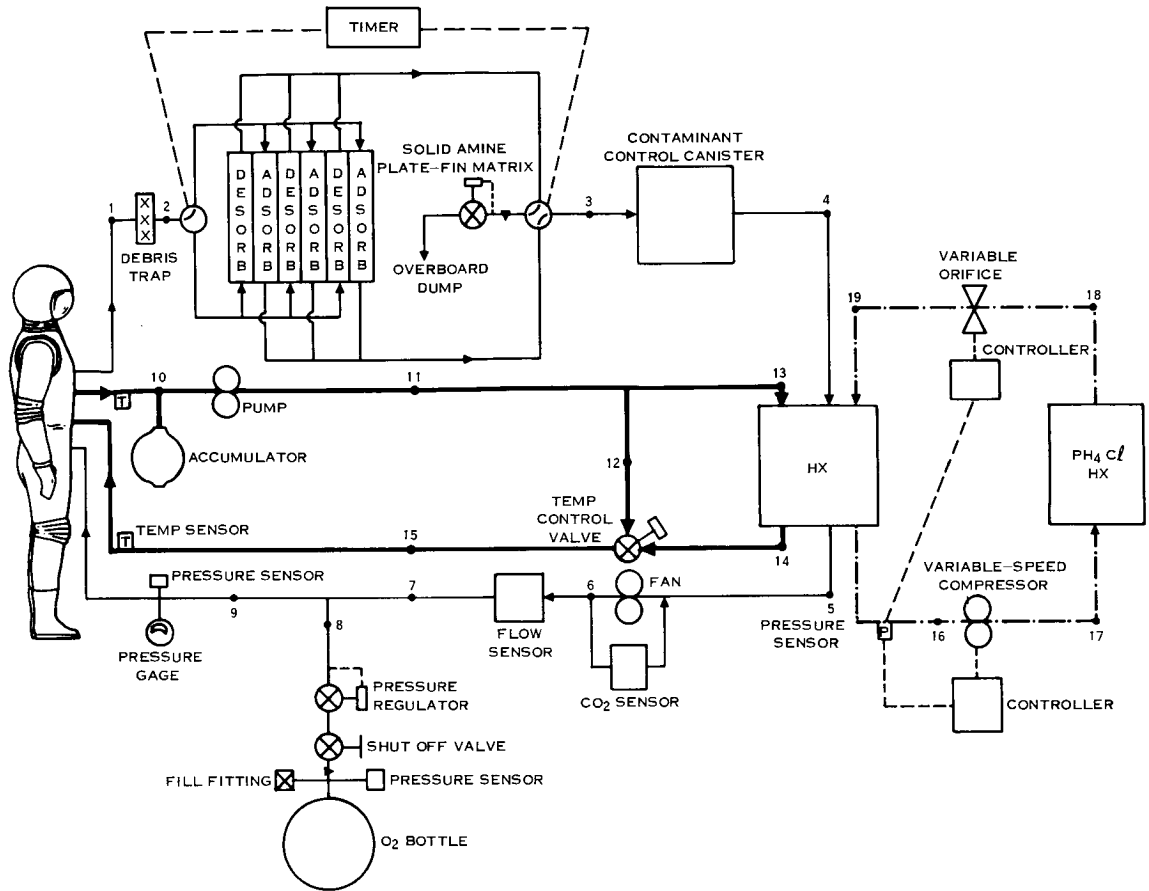
Vent Loop	Station								
	1	2	3	4	5	6	7	8	9
Temperature, °F	79	79	79	79	50	72	72	72	72
Volume flow rate, FT^3/min	6.31	6.31	6.21	6.25	5.94	6.00	6.00	.066	6.08
Total pressure, psia	6.9	6.89	6.84	6.80	6.76	6.99	6.987	6.987	6.987
Total weight flow, lb/hr	14.224	14.224	13.887	13.887	13.887	13.887	13.887	.178	14.067
O_2 weight flow, lb/hr	13.52	13.52	13.52	13.52	13.52	13.52	13.52	.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	6.56	6.52	6.75	6.75	6.987	6.75
CO_2 partial pressure, psia	.13	.13	.057	.057	.057	.058	.058	---	.058
H_2O partial pressure, psia	.29	.29	.18	.18	.18	.18	.18	---	.18
Dew point, °F	64	64	50	50	50	50	50	---	50

Figure 7.18 *AEPS concept 3, lunar base.*

Liquid Loop	Station					
	10	11	12	13	14	15
Weight flow, lb/hr	240	240	167	73	73	240
Temperature, °F	66.7	66.8	66.8	66.8	45	60
Pressure, psia	18	21.3	21.3	21.3	20.5	20.4

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	103	102	61.8

Figure 7.18 *AEPS concept 3, lunar base. (Concluded)*

Lunar Base 4 (fig. 7.19).   This AEPS concept is similar to concept 1 except the thermal control subsystem utilized is similar to that described in concept 2. The estimated total volume and weight for this AEPS configuration is 3500 cu in. and 100 lb based on an average metabolic rate of 1050 Btu/hr for an EVA duration of 8 hr.
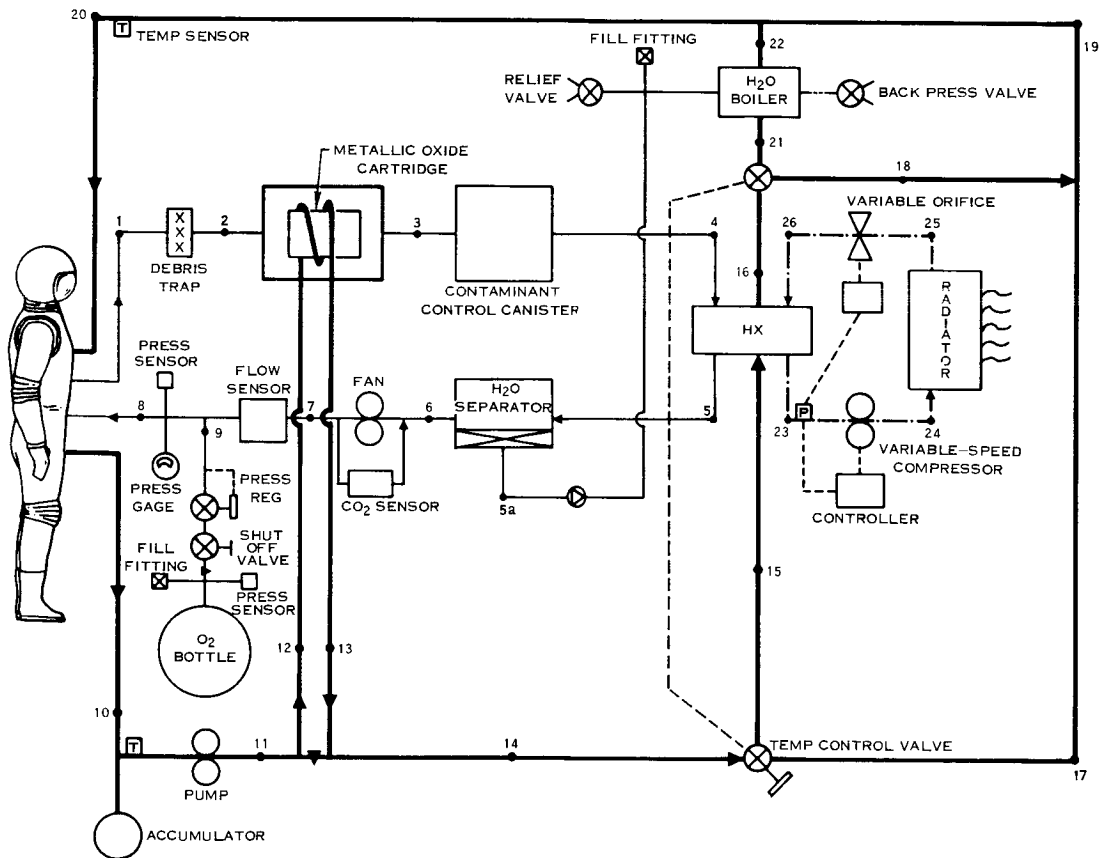

Figure 7.19 *AEPS concept 4, lunar base.*

133

Vent Loop	Station									
	1	2	3	4	5	5a	6	7	8	9
Temperature, °F	79	79	79	79	50	---	50	72	72	72
Volume flow rate, FT^3/min	6.3	6.3	6.25	6.29	5.91	---	5.93	5.99	6.09	.066
Total pressure, psia	6.9	6.89	6.86	6.82	6.78	---	6.76	6.99	6.987	6.987
Total weight flow, lb/hr	14.224	14.224	14.019	14.019	13.887	---	13.887	13.887	14.067	6.987
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 wieght flow, lb/hr	.367	.367	.162	.162	.162	---	.162	.162	.162	---
H_2O weight flow, lb/hr	.337	.337	.337	.337	.205	.132	.205	.205	.205	---
O_2 partial pressure, psia	6.49	6.48	6.52	6.48	6.55	---	6.53	6.75	6.75	6.987
CO_2 partial pressure, psia	.13	.13	.056	.056	.056	---	.056	.059	.059	---
H_2O partial pressure, psia	.28	.28	.29	.29	.176	---	.175	.181	.179	---
Dew point, °F	63	63	64	64	50	---	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	66.7	66.8	66.8	70.4	67.5	67.5	64.7	---	64.7	64.7	60	64.7	45
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	14.6	14.6	14.6	14.6
Temperature, °F	50	340	180	45
Pressure, psia	61.4	350	349	61.8

Figure 7.19 *AEPS concept 4, lunar base. (Concluded)*

Martian Base 5 (fig. 7.20). This AEPS concept is similar to concept 1 except the thermal control subsystem is a hybrid expendable/direct radiative cooling subsystem and consists of a water boiler and a direct radiator. Water in the heat transport loop exiting the radiator is the coolant in the humidity control 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. The estimated total volume and weight for this AEPS configuration is 3100 cu in. and 84 lb based on an average metabolic rate of 1200 Btu/hr for an EVA duration of 8 hr.
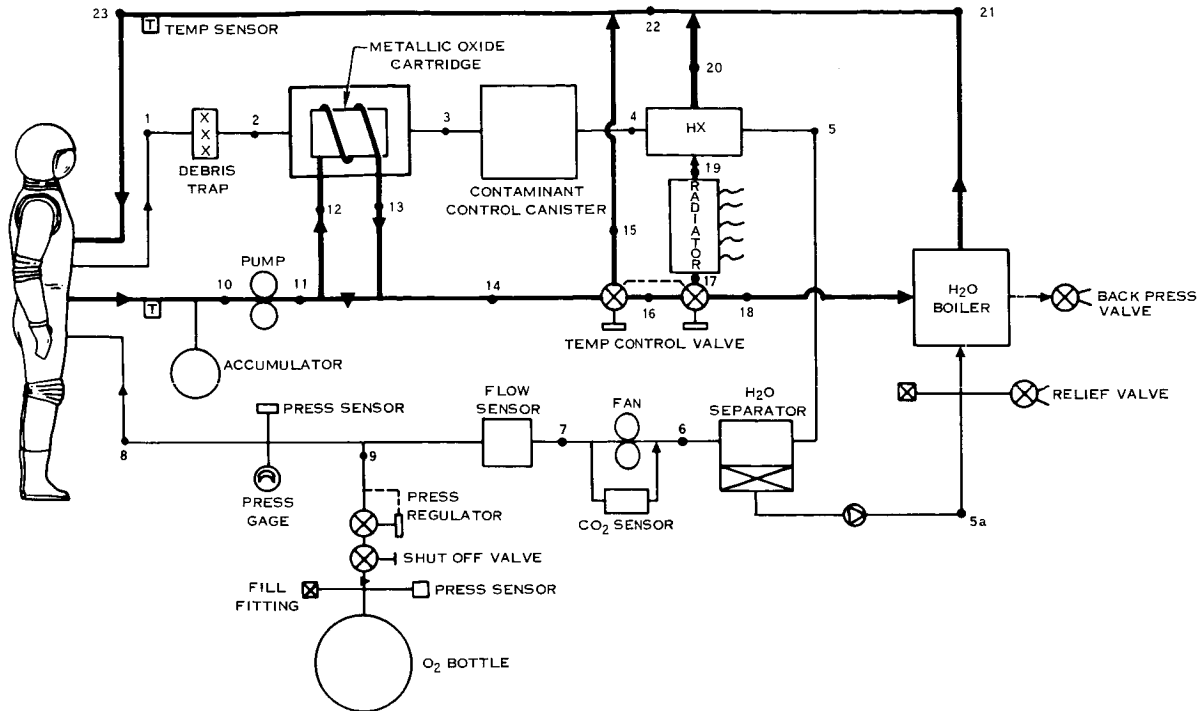
Station

Vent Loop	1	2	3	4	5	5a	6	7	8	9
Temperature, °F	79	79	79	79	50	---	50	72	72	72
Volume flow rate, FT^3/min	6.28	6.29	6.23	6.26	5.90	---	5.92	5.96	6.04	.086
Total pressure, psia	6.93	6.92	6.87	6.83	6.79	---	6.77	7.02	7.02	7.02
Total weight flow, lb/hr	14.24	14.24	14.01	13.01	13.87	---	13.87	13.87	14.07	.203
O_2 weight flow, lb/hr	13.5	13.5	13.5	13.5	13.5	---	13.5	13.5	13.7	.203
CO_2 weight flow, lb/hr	.396	.396	.162	.162	.162	---	.162	.162	.162	---
H_2O weight flow, lb/hr	.345	.345	.345	.345	.205	.141	.205	.205	.205	---
O_2 partial pressure, psia	6.50	6.49	6.52	6.48	6.55	---	6.53	6.76	6.75	7.02
CO_2 partial pressure, psia	.14	.14	.057	.057	.057	---	.057	.059	.058	---
H_2O partial pressure, psia	.29	.29	.29	.29	.18	---	.18	.17	.17	---
Dew point, °F	64	64	64	64	50	---	50	50	50	---

Station

Liquid Loop	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Weight flow, lb/hr	240	230	40	40	240	167	240	45	28	45	45	28	240	240
Temperature, °F	64.3	64.4	64.4	68.5	65	65	65	65	65	45	49	45	60	60
Pressure, psia	18	21.5	21.5	21.4	21.4	20.4	21.3	21.2	20.8	20.8	20.4	20.4	20.4	20.4

Figure 7.20 *AEPS concept 5, martian base.*

NEW TECHNOLOGY RECOMMENDATIONS

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

Thermal Control

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 the AEPS study.

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.

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 the AEPS study.

O_2 Supply

Develop a high cyclic life/high static strength material for a 6000 psi oxygen bottle.

Power Supply

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.

Contaminant Control

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.

Humidity Control

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.

Prime Movers

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

Automatic Temperature Control

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.

Miscellaneous

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:

  • Required versus tolerable O_2 prebreathing time

  • O_2 partial pressure exposure limitations including frequency and duration

  • Safe decompression/recompression levels, rates and frequency