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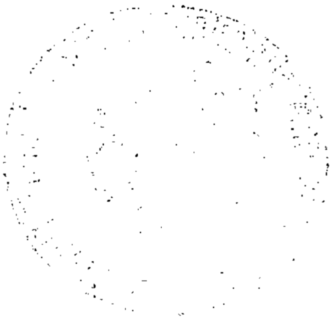
TRADE-OFF STUDY AND CONCEPTUAL DESIGNS OF REGENERATIVE ADVANCED INTEGRATED LIFE SUPPORT SYSTEMS (AILSS)



Prepared by
UNITED AIRCRAFT CORPORATION
Windsor Locks, Conn.
for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1970

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TRADE-OFF STUDY AND CONCEPTUAL DESIGNS OF REGENERATIVE ADVANCED INTEGRATED LIFE SUPPORT SYSTEMS (AILSS)

Prepared under Contract No. NAS 1-7905 by
Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION
Windsor Locks, Conn.

for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This report has been prepared by the Hamilton Standard Division of United Aircraft Corporation for the National Aeronautics and Space Administration's Langley Research Center in accordance with Contract NAS 1-7905. The report covers work accomplished between February 5, 1968 and the date of issue, and includes results obtained under Task 1,2 and 3 of the contract.

Appreciation is expressed to the technical monitors, Mr. W. D. Hypes and Mr. F. W. Booth of NASA-Langley Research Center, for their advice and guidance.

Particular thanks is due to the members of the life support industry for their voluntary aid and support in providing much-needed information on the various subsystem concepts. Within this report, acknowledgement is given to the organizations from which the information was received.

In addition, an expression of appreciation is made to the personnel at the NASA agencies - Langley Research Center, Manned Spacecraft Center, and Ames Research Center - and the Air Force agencies - Flight Dynamics Laboratories and Aerospace Medical Research Laboratories - for their significant contributions to this study.

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TRADE-OFF STUDY AND CONCEPTUAL DESIGNS OF REGENERATIVE ADVANCED INTEGRATED LIFE SUPPORT SYSTEMS (AILSS)

Hamilton Standard Division of United Aircraft Corporation

INTRODUCTION AND SUMMARY

For the early short-duration space flights, the development of environmental control and life support (EC/LS) equipment followed classic concepts based on open-loop, high performance, aircraft environmental control systems. In contemplation of longer duration flights, scientists and engineers have conceived and undertaken the development of equipment and techniques aimed at closing the loop of man's metabolic process. Regenerative concepts have been under study and development for some time for application to earth-orbital missions. A major example of this development is the research model regenerative Integrated Life Support System (ILSS) under continuing experimental evaluation at the Langley Research Center of the National Aeronautics and Space Administration.

Now it is necessary to examine the technology problem areas related to the non-resupplied longer duration mission wherein the absence of periodic resupply calls for an EC/LS system capable of establishing and maintaining a materials balance through the maximum practical regeneration of waste materials. The extended duration and no-abort implication of the mission increases the emphasis on reliability in the EC/LS system and makes maintainability of the system a necessity. Also, longer single-crew stay times require new emphasis on personnel provisions. Accordingly, the NASA Langley Research Center sponsored this study of regenerative Advanced Integrated Life Support Systems (AILSS) conducted by Hamilton Standard, a Division of United Aircraft Corporation.

The study effort was divided into three tasks, with Task 1 aimed primarily at producing the conceptual baseline designs. Task 2 was concerned with finalizing the concept and design as well as identifying pacing technological and developmental problems. Task 3 further amplified and refined the Task 1 and 2 information and investigated the impact on the AILSS selections of mission duration, crew size, power penalty, resupply, and flight date. As an additional subtask under Task 3, design concepts were also investigated for an integrated waste management system that would collect, transport, and store wet waste materials mixed with certain additives to produce a useful propellant fuel. This report describes the work accomplished for all three tasks, except the part of Task 3 concerning the waste management/propellant study, which is the subject of a separate report.

REPORT ORGANIZATION

This report is generally organized in accordance with the sequence of study activity. The study approach and selection philosophy, including a summary of the specification requirements and special system considerations such as design and maintainability guidelines, are presented in the Conduct of Study section. Subsequent sections describe the subsystems requirements for each function studied, together with an evaluation of the concepts investigated, and the selected subsystem concept to be used for the initial system synthesis.

The Selected EC/LS Systems section presents the system data -- schematic diagrams, weight, power, and volume summaries, and discussions -- for each selected EC/LS for the three power/heat source systems -- solar cells, solar cell/isotope, and Brayton cycle. In addition, a general system is described which is suitable for operation with any of the combinations of power systems and heat sources at minimum penalty.

The study of gases other than nitrogen as diluents in the cabin atmosphere is presented in the Diluent Study section. Diluents are considered from an analytical and a hardware, rather than a physiological, point of view. The Pacing Technology section identifies the pacing technological and developmental problems related to the three basic conceptual designs. The discussion includes a specific identification of each problem, a recommended approach to solving the problem, and an estimate of the time and effort required to solve the problem. In addition, there is a list of subsystem candidate concepts that were eliminated during the subsystem trades but have advantageous EC/LS applications if adequately developed.

The subtask covering the integrated waste management/propellant study is reported separately.

MAJOR CONCLUSIONS

As a result of this study, it is evident that a practical regenerative AILSS, suitable for the support of nine men for a 500-day non-resupply mission, is within the state-of-the-art achieveable for the 1976 to 1980 time period, provided the concepts selected for the AILSS undergo extensive and concentrated development effort starting early in 1970. This must be followed by comprehensive manned system testing. The principal subsystem concepts which are identified as best suited for the AILSS are summarized in figure 1.

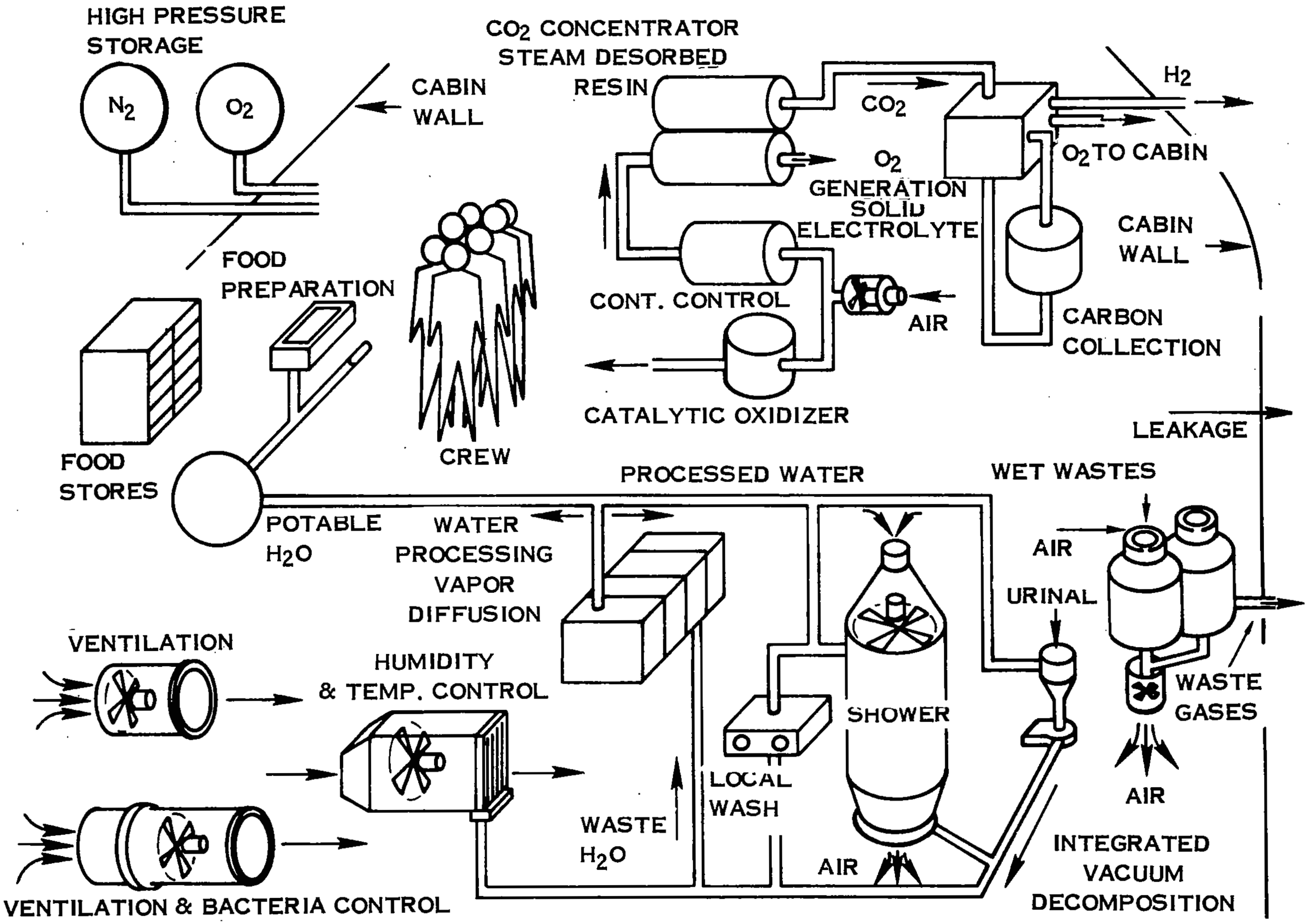

Figure 1. Advanced Integrated Life Support System

Although the subsystems designs selected for the general systems and each of the three specific systems have significantly different weight and power requirements, the basic concepts do not vary greatly. This is because of the AILSS selection criteria emphasis on maintenance and reliability and because of the assignment of similar weight penalties to the power sources. This leads to the selection of baseline concepts that, with minor modifications, are essentially independent of the power supply/heat source. The impact of this significant circumstance is assessed in the Selected EC/LS Systems section of this report.

The significant subsystem selections are reflected in figure 1. Included is the choice of vapor diffusion reclamation (VDR) in either the compression or the thermal distillation mode (depending on power source) and high temperature potable water storage for the water management subsystem. These choices clearly mirror the system concern for microbiological contamination because the inherent bacteria control of the VDR process is the final determining factor in its selection. Microbiological control is also a key factor in the waste removal determinations. When reclamation of fecal water proved to be unnecessary, the selection was reduced to a choice between storage or disposal of the waste material. The latent possibility of microbiological contamination in stored waste material leads directly to a decision to destroy the wastes and to the conception of the integrated vacuum decomposition technique selected for this purpose.

Carbon dioxide concentration is viewed as sufficiently established to allow for the selection of a simple and highly reliable scheme -- the steam desorbed resin concept. Selection of the solid electrolyte concept for generating oxygen directly from both carbon dioxide and water eliminates the need for conventional water electrolysis. High pressure gas storage is selected over the more conventional cryogenic storage due to its superior reliability, low maintenance requirements, and competitive weight for the relatively low-leakage AILSS mission.

Since food and food packaging requirements for the AILSS mission weigh practically the same as the balance of the EC/LS system, it is evident that the application of more aggressive research and engineering in the food management area might well produce significant overall gains for the entire system.

The system integration process underscores other considerations. The necessity for considering maintainability as the only practical means of assuring mission success is confirmed by the fact that the reliability analysis of the fully developed and qualified baseline system concepts indicates that the probability of completing the AILSS mission without a failure in the EC/LS system is about three in one million. This is in spite of the fact that, for a 500-day mission, only thirteen failures are estimated within the more than 500 on-line components in the system. Extensive development and resultant advances in subsystem reliability have been assumed in this reliability analysis.

The investigation of mission parameter impact on the AILSS system showed no significant changes to the basic AILSS will occur for a mission duration of approximately 200 to 900 days, crew size of 6 to 18 men, power penalty of 0 to 600 lb/kw, resupply, and flight dates well into the 1980's. The AILSS system will be affected to some extent for periods less than 200 days, high power penalty, or extremely power-limited missions, and pre-AILSS time periods. Detailed discussions concerning mission impact are included at the end of each subsystem section, as applicable, and in the Selected EC/LS System section of this report.

CONDUCT OF STUDY

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CONDUCT OF STUDY

This section presents the pertinent factors regarding the conduct of the AILSS study. Discussed are the study approach, selection philosophy, study flow, and study method. In addition, this section contains a specification requirements summary and general discussions of special system considerations including reliability, maintainability, modularity, commonality, fire safety, and microbiology.

STUDY APPROACH

In order to obtain a system overview as early as possible in the AILSS study, use was made of prior system studies, the contract statement of work, and discussions with the technical monitors to prepare and release a preliminary system specification early in the performance period. In addition, a set of evaluation criteria was established for the conduct of the subsystem and component trade studies. Using the specification as a guide to system requirements, tentative subsystem trades were completed on the basis of information obtained throughout the industry. These tentative subsystem selections were integrated into four baseline system concepts presented herein. Recycling of this sequence was accomplished as required to achieve the final integrated AILSS concepts.

Objectives

The objectives of this study are to:

1. Produce conceptual baseline regenerative EC/LS system designs that can serve as focal points for advanced research and development.

2. Single out pacing technological problems to enable an immediate concentration of research and development on these problems.

3. Provide the Government with EC/LS system concepts that can be used to gain insight into the requirements for a flexible research test bed and associated support equipment for researching the promising new concepts.

Assumptions and Guidelines

The aforementioned objectives are to be accomplished with certain guidelines and assumptions as agreed to with NASA Langley Research Center. These are identified for the AILSS study as follows:

1. Consideration of regeneration or "closing the loop" is given to all subsystem areas, with the exception of the food loop.

2. Consideration of integration of the EC/LS systems or subsystems with other vehicle systems, with the exception of power, is not required. Specifically, radiation shielding, meteoroid protection, etc., are not considered.

3. Overboard dump is limited to liquids and gases.

4. Thermal power interfaces are not defined in detail and radiators are treated as "black boxes" because the configuration, sizing, and details of radiator construction do not affect the selection of EC/LS subsystem concepts.

5. Cabin leakage is assumed to be zero for the purpose of designing the atmosphere contaminant control subsystem.

6. A whole body bath or shower shall be provided.

7. Manual handling of feces shall be precluded.

8. Suit loop definition and consideration of EVA operations are not required.

9. An onboard analysis instrumentation capability is required.

10. No specific vehicle configuration is considered.

Specification and Requirements Summary

The AILSS conceptual designs are based on the following models and requirements.

Mission model. -

Operational period	1976 to 1980
Mission duration	500 days
Resupply capability	none
Gravity mode	0 to 1 g (in any direction)
Vacuum exposure	operation after exposure to hard vacuum for one week

Crew safety	probability of 0.99 for 500-day mission
Equipment MTBF	1000 hours

Spacecraft model. - No specific vehicle configuration is defined for this study. The following assumptions, however, directly affect the EC/LS design.

Vehicle free volume	10 000 cu ft
Vehicle leakage	one lb/day maximum (for sizing O_2 and N_2 tanks only)
Wall heat leakage	zero
Vehicle heat load	
Communication	4000 watts
Instrumentation	800 watts
Control and guidance	1000 watts
Scientific equipment	1500 watts
Crew services	750 watts
Coolant temperature available from radiator	36 to 40° F
Heat rejection penalty	0.04 lb/Btu/hr at 50° F to 0.015 lb/Btu/hr at 250° F
Compartmentation	two, with possibility of entire crew in either compartment

Power heat sources and penalties

Design 1 - Power system: solar cell battery at 450 lb/kW
Process heat source: electrical at 450 lb/kW

Design 2 - Power system: solar cell battery at 450 lb/kW
Process heat source: radioisotope at 1600° F maximum temperature and 50 lb/kW

Design 3 - Power system: radioisotope powered Brayton cycle at 450 lb/kW
Process heat source: power system waste heat at 375° F maximum at no penalty

Design 4 - Suitable for operation with any of the above power systems and heat sources.

Crew model. -

Crew size	nine men

Metabolic rate (24 hr-zero g average)	10 320 Btu/man-day (150% basal metabolism rate)
Oxygen consumption	1.68 lb/man-day
Carbon dioxide production	2.06 lb/man-day
Metabolically formed water	0.78 lb/man-day
Respiratory, perspiratory, excreted, and consumed water	presented in Selected EC/LS Systems section of this report
Waste products	presented in Waste Control section of this report

Crew metabolic activity

Duty	8 hr	175% BMR
Sleep	8 hr	100%
Recreation	1 hr	500%
Eating and rest	6 hr	100%
Maintenance	1 hr	300%
24-hr average	----	150% BMR

Atmosphere model. -

Cabin pressure	7.0 to 14.7 ±0.25 psia, constant for mission
Gas composition	3.5 ± 0.1 psia oxygen, diluent nitrogen
Carbon dioxide partial pressure	
Normal	3.8 to 5.7 mm Hg
Normal maximum	7.6 mm Hg
Emergency maximum	15 mm Hg for 72 hr
Relative humidity	55 ± 5%
Cabin temperature	65 to 75° ± 2°F selectable
Number of repressurizations	two
Contaminant list	presented in Atmosphere Contamination Control section of this report

SELECTION PHILOSOPHY

Selection of the most favorable EC/LS process and equipment has always posed a difficult problem for the system engineer. This is particularly true for the AILSS study. When faced with making equipment and subsystem selections today of the best EC/LS system for a 1976 to 1980 non-resupply 500-day mission, it is clear that the problem has increased in complexity. In fact, the mission length and inability to abort require emphasis on maintainability and related system characteristics for assurance of mission success. This greatly reduces the validity of the traditional heavy weighting of equivalent weight within the selection criteria. Therefore, to fulfill the objectives of the AILSS study within the assumptions and guidelines listed previously, it has been necessary to establish criteria reflecting an emphasis on an optimum maintainable system rather than solely on an optimum equivalent weight system.

The selection or criteria is based on a recognition that some requirements are absolute, others are of primary importance, and still others are secondary in that they are largely desirable rather than necessary. The criteria used as a basis for selection in the AILSS study are shown in figure 2. These criteria encompass both the total system performance requirements and the projected flight hardware operational characteristics. Performance requirements are covered primarily in the absolute criteria. Hardware factors are heavily stressed in the primary criteria: reliability, crew time (maintainability), and equivalent weight. Some integration aspects are considered in the primary criteria evaluations, but they are covered principally in the secondary criteria.

The criteria are applied sequentially in the groups shown to eliminate concepts that fail on either an absolute or comparative basis and to provide the basis for selection between surviving candidates. If an eliminated candidate concept has a potential application if adequately developed, it will be identified as a possible research and development candidate in the Pacing Technology section of this report.

Absolute Criteria

Absolute 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 absolute criteria, no further consideration is given in the trade study and that particular concept is listed as unacceptable and is eliminated. If a concept does meet all of the absolute criteria, a relative ranking is assigned to aid in evaluating the concept should the primary characteristics fail to establish a clear-cut selection. This relative degree of acceptability is given as Very Good, Good, or Fair. The criteria against which this absolute assesement is made are listed as follows:

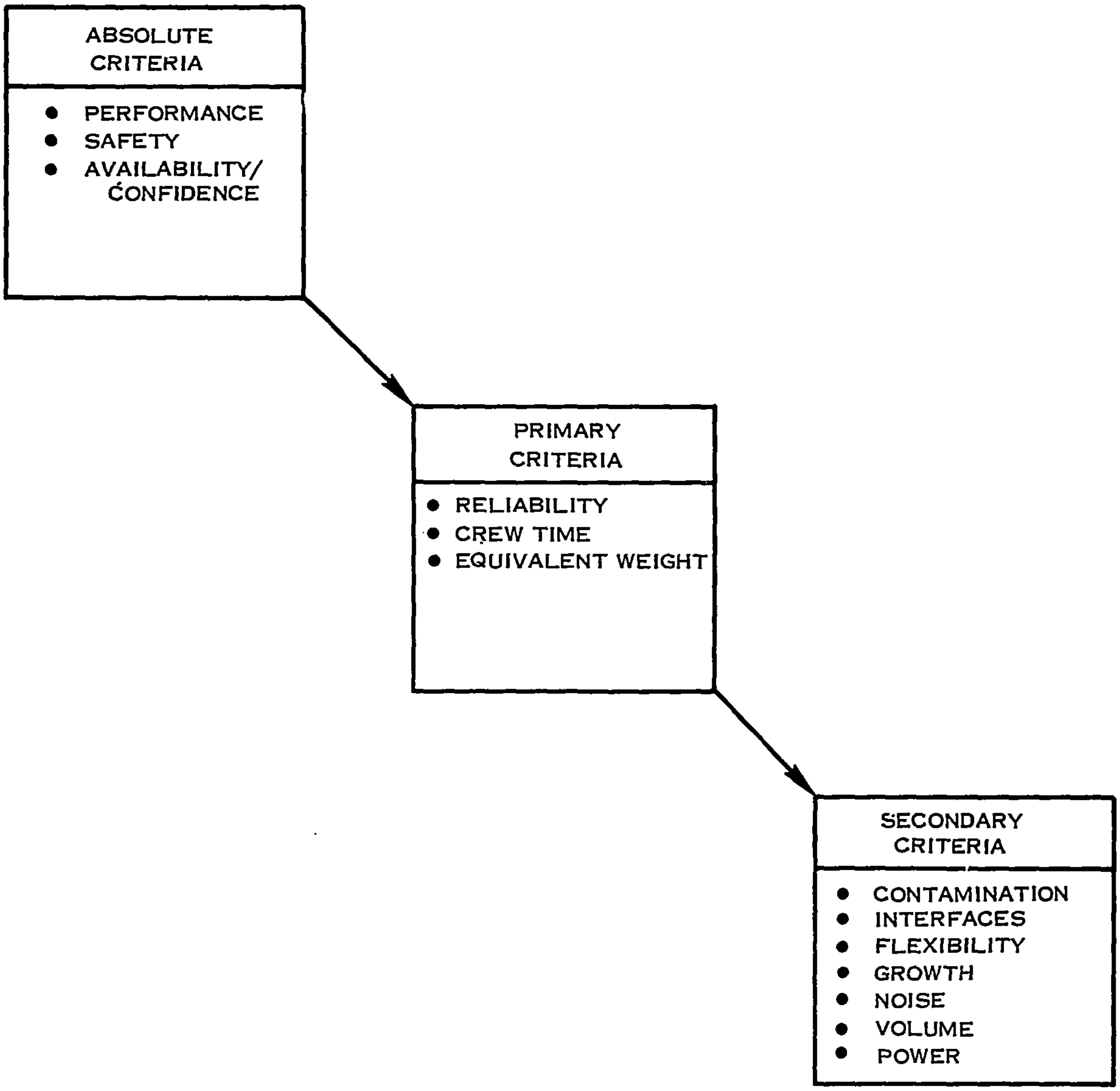


Figure 2. AILSS Selection Criteria

Performance. - To be considered as candidates, all concepts must be capable of meeting pertinent subsystem performance requirements at zero gravity. Acceptable mission performance dictates that the concept must have the potential for a 500-day in-space life and must be sufficiently maintainable to achieve this life. To provide a common basis, conceptual designs for each competing subsystem, system, or method are adjusted to meet the performance requirements.

Safety. - Each concept is considered with respect to fire, contamination, explosion hazards, hot spots, bacteriological problems, and crew hazards to determine if any of these are present. If a problem cannot be eliminated reasonably by careful design, by including additional control equipment, by using different materials, or by similar engineering solutions, the concept is eliminated. Hazards are investigated and considered during normal operation, off-design operation, and maintenance downtime.

Availability/confidence. - This is a measure both of the probability of the concept being fully operational within the time period of 1976 to 1980 (following reasonable development effort) and confidence in the existing information and approaches to problem solutions. As a result, it has the greatest impact on the selection of a concept for any particular time period. If the launch dates (1976 - 1980) were changed, the list of available candidate concepts would have to be revised accordingly. Availability/confidence is evaluated by an analysis of the candidate concept's present status, the concept approach, interfaces, and hardware requirements to resolve problems and eliminate design qualms.

Primary Criteria

These first order criteria are the principal criteria for all concepts that pass the absolute criteria requirements. The ratings applied to a candidate -- Very Good, Good, Fair, or Poor -- are dependent upon the characteristics of the candidate relative to the other candidates. A Poor rating rejects the concept from further consideration. A candidate concept is selected if its overall rating is clearly the best of the competing concepts. If two or more concepts are rated essentially equal, the absolute criteria ratings are reconsidered and a selection is made. If no clear choice is evident, the competing candidates are reviewed against the secondary criteria to confirm that no other considerations would preclude its use. Each of the primary characteristics is treated separately as follows:

Reliability. - Considered under this criterion is the basic unspared reliability and a number of other factors relating to limited-life items and the complexity of the maintenance requirement. Mean Time Between Failures (MTBF), applied to a particular concept, provides a quantitative measure of the reliability projection.

Assignment of a Good rating is made to those concepts whose MTBF approximates the mission duration of 12 000 hours, Very Good or Fair ratings are relative variances from this MTBF. Concepts that have unacceptable MTBF ratings in comparison to the other concepts for a particular subsystem/function are assigned Poor ratings.

Crew time. - This is an assessment of the stress laid upon the crew in terms of the time required for operation and both scheduled and unscheduled maintenance of EC/LS equipment items. This is the criterion where ease of maintenance, reflected in crew time, significantly influences the evaluation of a candidate.

Crew time is rated in a relative manner to reflect the comparative stress the candidate concepts impose on the crew due to the operation and maintenance of the subsystem or function under consideration.

Equivalent weight. - Most physical aspects of any concept can be converted to an equivalent weight penalty for purposes of comparison. This tool is used in this study to provide an objective basis for evaluating such considerations as fixed weight, expendables, power and heat rejection requirements, spares and redundancy to achieve reliability goals, suppression devices to maintain noise levels, and control devices to prevent contamination. These factors are converted to and included in the equivalent weight of the concept.

This characteristic is rated as the relative assessment of each of the candidate concepts to the others. As a rule-of-thumb, those concepts within 10 percent of the median of those considered are rated Good, with Very Good or Fair reflecting greater departures from the nominal weight. A Poor rating is assigned for weights 50 percent greater than the median weight, although some flexibility is allowed.

Secondary Criteria

The secondary criteria represent a step in the depth of the competitive evaluation of the leading concept contenders that is taken if no clear-cut selection is available. They also represent a systematic review of the overall acceptability of selected concepts. Ratings of the candidate concepts against secondary characteristics are relative assessments within each area of consideration, and the same rating identifications of Very Good, Good, Fair, and Poor are used. At this level of evaluation, however, a Poor rating does not necessarily disqualify a concept from further consideration.

Contamination. - A candidate subsystem's potential for contaminating the vehicle, equipment, atmosphere, or crew is assessed under this factor. Considered is the possibility of contaminant or bacteria generation. A candidate's tendency to contaminate can normally be overcome through adding equipment to process or destroy potential contaminants. The penalty of such equipment is considered in equivalent weight and maintainability factors.

Interfaces. - The number and type of interfaces are assessed as a measure of ease and ability of the concept to integrate with other equipment, the power supply, the vehicle, and the crew. Because of the broad physical and functional scope of a life support system, an interface check is necessary to assure that no unreasonable problems will be encountered in the eventual integration of the vehicle systems.

Flexibility. - This is a measure of the concept's ability to be used under more than one set of conditions (or interfaces or requirements) at minimum or no penalty. A concept, for example, that would integrate with all three power supplies at no penalty is given a more favorable consideration than one requiring a different design for each power supply. Included in this consideration is the degree of design point sensivity, that is, the capability for off-design performance.

Growth. - This factor encompasses the inherent characteristics of a concept that permit technological growth outside the AILSS mission. The degree to which a particular concept lends itself to future optimization is significant.

Noise. - Noise problems can usually be overcome by adding suppression devices that are translated into weight and maintainability criteria. If noise problems cannot be overcome, a high noise concept is eliminated under the performance criterion. As a second criterion, the relative noise is considered after suppression and/or the degree of difficulty or penalty in achieving suppression.

Volume. - The occupied volume, particularly within the crew area, is considered. The volume of the spares and maintenance items is included in this evaluation.

Power. - Power is a limiting-type factor of the second order. The first order criterion equivalent weight includes the concept's total demand from the power supply system. As secondary characteristics, the quantity and type of power required are evaluated. Insensitivity to type of power supply is considered, as well as the power duty cycle.

Impact of Mission Parameters

After the selection of each subsystem concept and system designs, consideration is given to the impact of mission parameter variation on the selected item. These parameters are:

Mission length. - The impact, if any, of a mission longer or shorter than the AILSS 500-day mission is discussed.

Crew size. - The impact, if any, of a crew size larger or smaller is discussed.

Power penalty. - The impact of a higher or a lower power penalty is evaluated. Also considered is the influence on selection of a power-limited vehicle application.

Resupply. - The impact of resupply capability is discussed.

Flight date. - The impact of a mission prior to or after the AILSS flight period is examined.

System Considerations

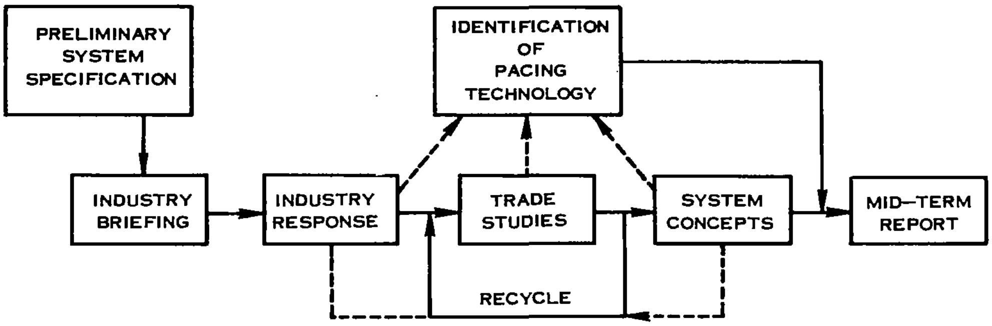
Upon completion of the subsystem trade-off evaluations, in which preliminary concept selections are made utilizing the selection criteria, the system integration is performed. Subsystems selected for integration are first chosen on a preliminary basis subject to reconsideration as a result of system integration requirements. In the event of a significant system-level impact of a selected concept-definition, the concept is recycled along with its original competitors for another evaluation considering the newly defined requirements. Descriptions of the manner and philosophy of the integration function are provided as the introduction and detail of the Selected EC/LS Systems section of this report.

STUDY FLOW

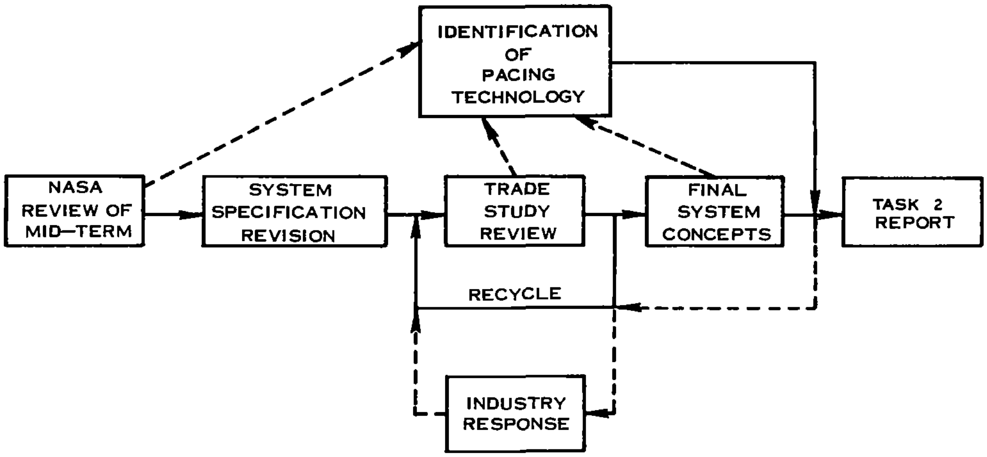
The planned flow of the study is pertinent as an aid in understanding the material accumulated in this report and the discussion of data in the subsequent sections. The AILSS study was scheduled as three tasks: Task 1 covering the initial six-month effort and Task 2 including the remainder of the AILSS definition. Task 3 investigated the impact of mission parameters on the AILSS designs. Figure 3 illustrates the major relationships between the Tasks 1, 2, and 3 study functions. A brief discussion of some of the tasks noted is given below.

EC/LS System Specification

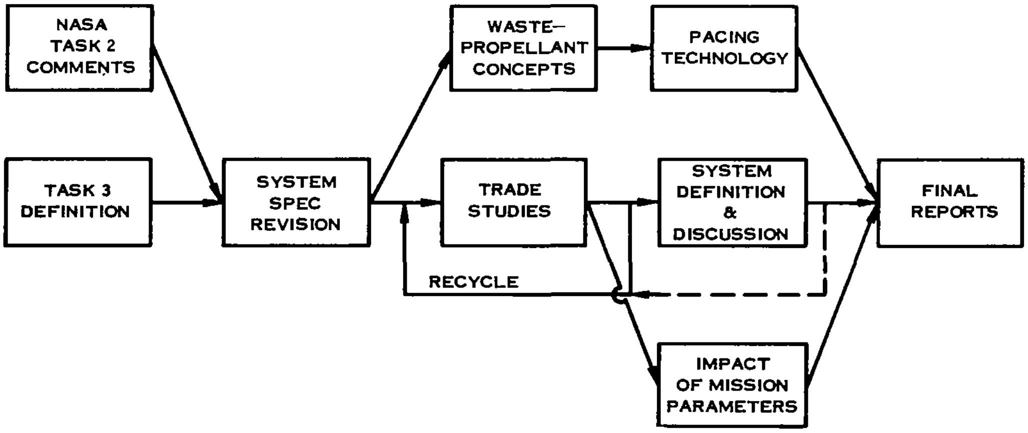
As the initial step of the study, definitions of performance requirements for the system were presented in a preliminary system specification approved by NASA Langley Research Center. A summary of this specification is presented under "Specification and Requirements Summary" in this section.



TASK 1



TASK 2



TASK 3

Figure 3. AILSS Study Flow

Industry Briefing

To inform industry immediately and uniformly of the AILSS program objectives, goals, and requirements, as well as to establish the basis on which subsystem information could be supplied by industry and utilized for this study, a briefing of the principal firms of the EC/LS community was conducted at an early point in the study. A list of companies actually attending this briefing, held on February 27, 1968, at Hamilton Standard, is included as table 1. Other firms contacted either by letter or by personal visit are also shown in this table.

Industry Response

Data requirements worksheets as shown in figure 4 were given to industry as the basis for organized response. This data together with information from other sources (study reports, technical papers, and various government agencies) were used in preparing the candidate concepts descriptions contained herein. Table 2 shows a listing by subsystem of the industry and government agencies whose data or information was used. Identical data requests were made to Hamilton Standard support groups for specific subsystem information relating to the Hamilton Standard fields of interest to assure that all data received would be organized for a uniform and objective review. The areas of specific Hamilton Standard inputs are noted on the industry list.

STUDY METHOD

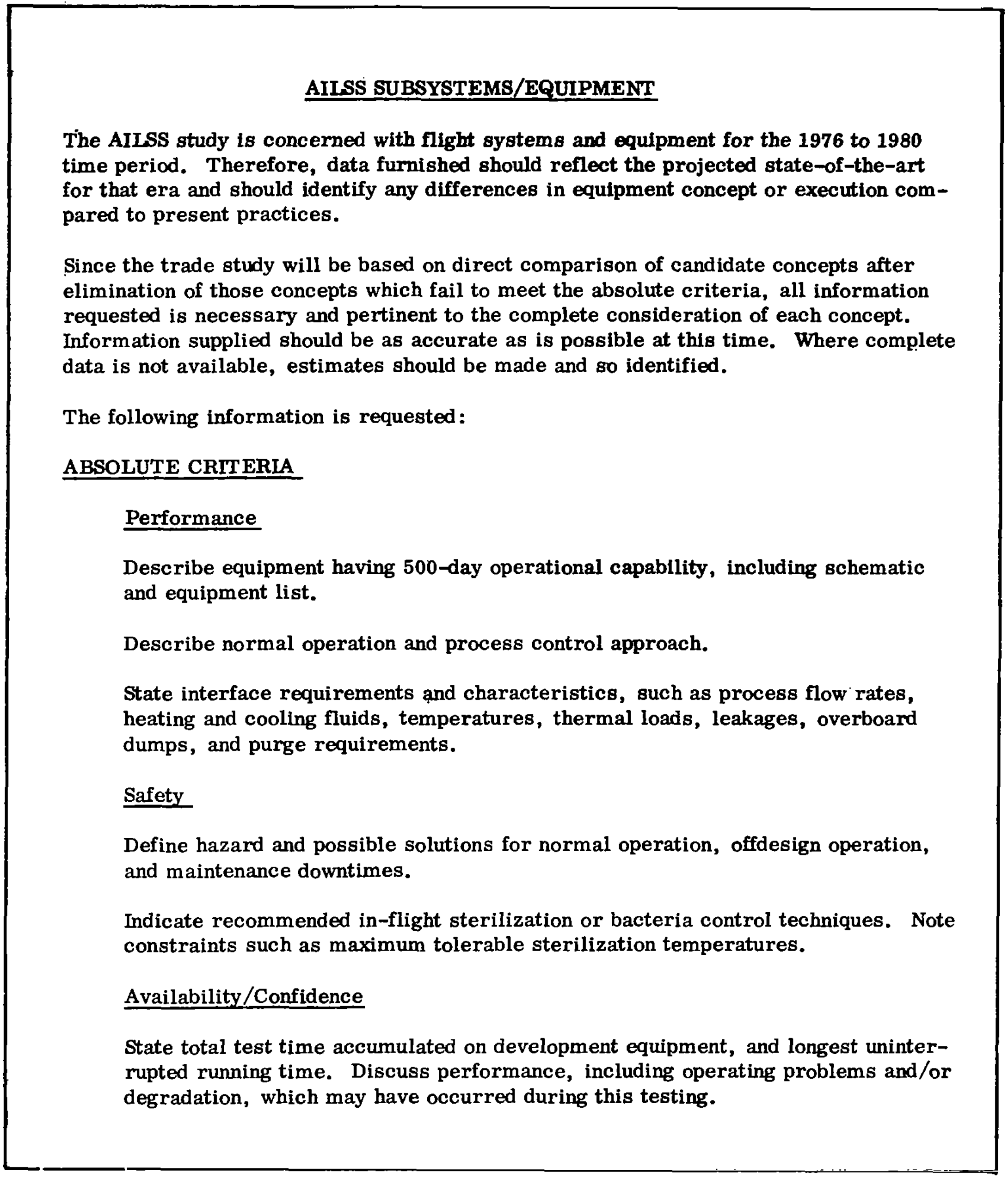
With the subsystem information received from Government agencies and industry, the trade studies were conducted utilizing the selection criteria mentioned previously. Where the data received were not complete enough to allow comparative evaluation, extrapolations were made, as required. In addition, any concept exhibiting less than the required spaceflight engineering practices or failing to meet the other AILSS requirements was redesigned to assure its being comparable and representative.

Since the absolute criteria function eliminates primarily the unsuitable candidates, subsystem selections are made mainly on the relative merits of inherent reliability, maintainability, and total equivalent weight. This approach is taken to arrive at clear-cut choices of equipment types required on a 500-day non-resupply (and non-abort) mission. The selected equipment must meet performance requirements as in traditional trades. However, greater emphasis is placed on inherent reliability and crew stress (crew time) than on total equivalent weight; hence, heavier subsystems may be selected over lighter ones. The full impact of this subsystem selection method is not realized

TABLE 1

AILSS INDUSTRY BRIEFING

AILSS INDUSTRY BRIEFING ATTENDEES	ADDITIONAL FIRMS CONTACTED FOR AILSS STUDY
Air Products & Chemicals, Inc.	Aerojet-General Corporation
Allis-Chalmers Manufacturing Company	Airite
Arde, Incorporated	Air Reduction Company, Incorporated
Atlantic Research Corporation	Amglo Corporation
Barnes Engineering Company	Arthur D. Little, Incorporated
Battelle Memorial Institute	Barneby-Cheney Company
Beckman Instruments, Incorporated	Beech Aircraft Corporation
Bendix Corporation	Block Engineering
Boeing Company	Chemtronics, Incorporated
Fairchild Hiller Corporation	Chrysler Corporation
The Garrett Corporation	Consolidated Electrodynamics Corporation
General American Transportation Corporation	The Emerson Electric Company
General Dynamics/Convair	FMC Corporation
General Dynamics/Electric Boat	Honeywell Incorporated
General Electric Company	Ionics, Incorporated
Grumman Aircraft Engineering Corporation	Isomet Corporation
IIT Research Institute	Life Support Systems
Marquardt Corporation	Linde
McDonnell Douglas Corporation	Ling-Temco-Vought, Incorporated
Melpar, Incorporated	Lion Research Corporation
M.S.A. Research Corporation	Litton Industries, Incorporated
Pall Corporation	Lockheed Missile and Space Company
Perkin-Elmer Corporation	Martin-Marietta Corporation
Pillsbury Company	Minnesota Mining and Manufacturing Company
TRW Incorporated	North American Rockwell Corporation
Westinghouse Research Laboratories	Panametrics, Incorporated
Whirlpool Corporation	Pratt & Whitney Aircraft
	RAI Research Corporation
	Science and Engineering Institute
	Space/Defense Corporation
	Stanford Research Institute
	Witco Chemical Company
	Worthington Corporation



AILSS SUBSYSTEMS/EQUIPMENT

The AILSS study is concerned with flight systems and equipment for the 1976 to 1980 time period. Therefore, data furnished should reflect the projected state-of-the-art for that era and should identify any differences in equipment concept or execution compared to present practices.

Since the trade study will be based on direct comparison of candidate concepts after elimination of those concepts which fail to meet the absolute criteria, all information requested is necessary and pertinent to the complete consideration of each concept. Information supplied should be as accurate as is possible at this time. Where complete data is not available, estimates should be made and so identified.

The following information is requested:

ABSOLUTE CRITERIA

Performance

Describe equipment having 500-day operational capability, including schematic and equipment list.

Describe normal operation and process control approach.

State interface requirements and characteristics, such as process flow rates, heating and cooling fluids, temperatures, thermal loads, leakages, overboard dumps, and purge requirements.

Safety

Define hazard and possible solutions for normal operation, offdesign operation, and maintenance downtimes.

Indicate recommended in-flight sterilization or bacteria control techniques. Note constraints such as maximum tolerable sterilization temperatures.

Availability/Confidence

State total test time accumulated on development equipment, and longest uninterrupted running time. Discuss performance, including operating problems and/or degradation, which may have occurred during this testing.

Figure 4. Data Requirements Worksheet (Page 1 of 2)

Compare present and projected (AILSS) flight hardware and define problem solutions and effort required to develop flight hardware.

PRIMARY CHARACTERISTICS

Reliability

Describe principal failures, symptoms, failure effects, and degraded modes.

Identify and predict the expected life of limited life items. Limited life as defined here is less than 30 000 hours (2.5 x mission). 2500 hours is desired target, but shorter life items may be used if they can be justified for the mission.

Crew Time

State scheduled and unscheduled maintenance requirements and time to service or repair. Describe startup and shutdown procedures.

List instrumentation, performance monitoring requirements, and fault isolation.

Equivalent Weight

State projected flight weight of unspared system, packaged expendables, and maintainable components. Give scaling factors and/or weight of 1/2 and 1/3 capacity units.

State average and peak power requirements, type and amount.

State flight hardware volume, volume of expendables, and maintainable weights.

Other Information

List any unique features including flexibility of offdesign performance. Discuss applicability of modular design and integration suggestions.

List and enclose available data or reports.

List personnel to be contacted regarding questions on this data.

Name

Title

Phone Number

Figure 4. Data Requirements Worksheet (Page 2 of 2)

TABLE 2
AILSS DATA SOURCES

SUBSYSTEM	CONCEPT	SOURCE OF DATA
Oxygen Storage	1. Chlorate candles for repressurization/leakage supply	Mine safety appliance corp.
	2. Catalytic decomposition of hydrogen peroxide for repressurization/leakage supply	Air products
	3. Hydrazine/nitrogen tetroxide reaction for repressurization/leakage supply	Applied physics laboratory/John Hopkins Univ.
	4. Cryogenic storage	The Garrett Corp., Bendix Corp.
	5. High pressure gaseous storage employing filament - wound tankage	Hamilton Standard
Water Electrolysis	1. Cabin air	National Aeronautics and Space Administration (NASA) - Ames Research Center, Battelle Memorial Institute, Lockheed Missile and Space Company Hamilton Standard
	2. Gas circulation	National Aeronautics and Space Administration (NASA) - Ames Research Center, Battelle Memorial Institute, Pratt & Whitney, Hamilton Standard
	3. Wick feed	National Aeronautics and Space Administration (NASA)-Langley Research Center, Allis-Chalmers Manufacturing Co., TRW Incorporated
	4. Ion Exchange Resin	Aerospace Medical Research Laboratories (AMRL), Ionics Inc.
Water Electrolysis (Continued)	5. Ion exchange membrane	National Aeronautics and Space Administration (NASA) - Langley Research Center, General Electric Company, Hamilton Standard
	6. Circulating electrolite	National Aeronautics and Space Administration (NASA) - Ames Research Center, Lockheed Missile and Space Company
	7. Rotating	Air Force Flight Dynamics Laboratory (AFFDL), Battelle Memorial Institute
CO_2 Removal and Concentration	1. Molecular sieve	Hamilton Standard
	2. Solid amine	General American Transportation Corp.
	3. Steam desorbed resin	Mine Safety Appliances Research Corporation, National Aeronautics and Space Administration (NASA) - Langley Research Center
	4. Electrodialysis	Ionics, Incorporated
	5. Carbonation cell	TRW, Incorporated
	6. Hydrogen depolarized cell	TRW, Incorporated
	7. Membrane diffusion	General Electric Company, Aerospace Medical Research Laboratories (AMRL)
	8. Liquid adsorption	General Dynamics, Hamilton Standard
	9. Mechanical freezeout	Hamilton Standard
O_2 Generation	1. Solid electrolyte	National Aeronautics and Space Administration (NASA) - Ames Research Center and Langley Research Center, Isomet Corp., Lockheed Missile and Space Co., Westinghouse Research Laboratories

TABLE 2 (Continued)

AILSS DATA SOURCES

SUBSYSTEM	CONCEPT	SOURCE OF DATA
O_2 Generation (Continued)	2. Bosch	National Aeronautics and Space Administration - Langley Research Center, Battelle Memorial Institute General American Transportation Corporation, TRW Incorporated
	3. Sabatier - methane cracking	Air Force Flight Dynamics Laboratory (AFFDL), National Aeronautics and Space Administration (NASA) - Langley Research Center, Boeing, Engelhard Minerals and Chemicals Corporation, Garrett Corp., Hamilton Standard, Isomet Corporation, Lockheed Missile and Space Co., McDonnell-Douglas Corp., TRW, Incorporated
	4. Sabatier - methane dump	Air Force Flight Dynamics Laboratory (AFFDL), National Aeronautics and Space Administration (NASA) - Langley Research Center, Boeing Co., Engelhard, Garrett Corporation Hamilton Standard, Isomet, Lockheed, McDonnell-Douglas Corporation, TRW Incorporated
Atmospheric Contamination Control - Trace Contaminants	Regenerable and nonregenerable charcoal, sorption, and catalytic oxidation	Barnebey - Cheney Company, Lockheed Missile and Space Company, Hamilton Standard
Cabin Temperature/ Humidity Control	All concepts	Hamilton Standard
Water Management - Reclamation	1. Vacuum distillation/ compression	General American Transportation Corp., Marquardt Corporation
	2. Vacuum distillation/ thermoelectric	Whirlpool Corporation, RCA
	3. Vacuum distillation/ Pyrolysis	General Electric Company, Aerospace Medical Research Laboratories (AMRL), Wright Patterson Air Force Base
	4. Flash evaporation/ Pyrolysis	Garrett Corporation
	5. Flash evaporation/ Pyrolysis	Garrett Corporation, Hamilton Standard
	6. Air evaporation - open	McDonnell-Douglas Corporation Hamilton Standard, Garrett Corporation
	7. Air evaporation - closed	Hamilton Standard
	8. Vapor diffusion	Hamilton Standard
	9. Vapor diffusion, compression	Hamilton Standard
	10. Reverse osmosis	Gulf General Atomics, DuPont
	11. Multifiltration	General Dynamics, Pall Corp.
Waste Control	1. Liquid germicide addition	Hamilton Standard
	2. Integrated vacuum drying	General Electric Company McDonnell-Douglas Corp.
	3. Flush flow oxygen incineration	General American Transportation/Hamilton Standard
	4. Pyrolysis/batch incineration	Lockheed/Hamilton Standard

TABLE 2 (Concluded)
AILSS DATA SOURCES

Waste Control (Continued)	5. Integrated vacuum decomposition	General American Transportation Corp.,/ Hamilton Standard
	6. Wet oxidation	Whirlpool Corporation/ Hamilton Standard
Crew Provisions	1. Food and feeding	Food and Nutrition Board of the National Academy of Science - National Research Council on Dietary Allowances 1963, U.S. Army Natick Laboratory, Food Laboratory, Whilrpool Corp.
	2. Personal hygiene	Republic Division of Fairchild Hiller, Hamilton Standard, Whirlpool, Clothing and Organic Materials Division of the U.S. Army Natick Laboratories , National Aeronautics and Space Administration (NASA) Manned Spacecraft Center, U.S. Air Force Materials Laboratory Wright-Patterson Air Force Base
Instrumentation and Control	1. Mass spectrometer	Perkin-Elmer Corporation, Beckman Instruments, Inc.
	2. Combustible gas measurement	General Monitors, Inc., Mine Safety Appliance Research Corporation, Instrument Division
	3. Trace contaminant measurement	Beckman Instruments, Inc.
	4. Dewpoint instrument	Cambridge Systems, Inc.
	5. Radioactivity instrumentation	Geiger-Muller

until total system integration is completed. A subsystem selection review is presented in the Selected EC/LS Systems description as part of the impact of system parameters to cover such factors.

In the candidate subsystem descriptions and in the selection sections, the effects of three possible electrical and thermal power supplies (see table below) are considered. Hardware weights and power penalties are included in the three total equivalent weight breakdowns. In general, the power source selections influence total equivalent weight (thermal power being the main factor) more than anything else. Heat power addition methods change, but operating concepts and most of the configurations do not. Subsystem selections for each power system design are synthesized into three total system designs.

Design	Name	Power System	Process heat source	Maximum heat source
1	Solar Cell	Solar cell/battery	Electrical energy from the power system	-
2	Solar Cell/ Isotope	Solar cell/battery	Heat energy from radioisotopes	1600°F
3	Brayton	Radioisotope (Brayton)	Heat energy from power system waste heat	375°F

The selection of subsystem concepts has been accomplished according to the procedure discussed below. It is significant to note that all steps are not necessarily applicable to all subsystems and that all subsystems do not necessarily enter the total system trade study at the same level.

The trade studies proceed generally according to the following steps using the previously defined criteria:

1. The several competing concepts for any function are first defined. Equipment is sized to meet specification performance requirements.

Concepts are roughly defined (at the component level) to determine such characteristics as flow rates, temperature levels, and pressure levels to permit determination of performance, reliability/safety, and maintainability.

In order to meet the 500-day mission requirement, most, if not all, of the subsystems have to be maintained. At the subsystem level, the approaches of redundancy, maintainability, and alternate/degraded modes of operation are examined. The desirability of having redundant modules as opposed to the replacement of components and/or parts is examined and the best approach and types of periodic maintenance (such as lubrication) are determined for each subsystem. Safety provision to eliminate unacceptable hazards are applied in like manner. Preliminary schematics and component lists are then generated, yielding basic subsystems concepts.

2. These subsystems are evaluated against the absolute evaluation criteria as previously described. Sufficient auxiliary equipment is added, where necessary and possible, to establish the concept's ability to meet performance requirements safely. If a candidate approach cannot be made acceptable, it is removed from further consideration at this point.

3. Further equipment is added or the arrangement modified, as required, to meet the subsystem specification interface requirements. All competing subsystems must accomplish the same task for valid comparison. Typical of such supplementary equipment are the following:

a. Noise attenuation devices

b. Additional water supply/tankage to make up for the low efficiency of a particular water reclamation concept

c. Electric heaters to provide high temperature heat sources where otherwise unavailable.

d. Supplementary contaminant control devices if one subsystem generates contaminants during some phases of operation.

4. The data listed on the data sheet shown in figure 5 together with information relative to the AILSS criteria are then generated as required for decision among the candidate subsystems.

5. All candidates that meet the absolute criteria are evaluated against the primary criteria and, if necessary, the secondary criteria as described previously in order to determine the best competing subsystem for each power source. The impact of mission parameters on the selected concept is also discussed.

6. When all subsystems have undergone the trade-off procedure, the selected candidates are combined into "baseline" systems (one for each power source). It is significant to note that several major elements cannot be fully evaluated until after this "baseline" is established. This includes such system dependent subsystems as cabin ventilation, cabin temperature control, cabin humidity control, heat rejection subsystems and instrumentation and controls.

7. The first in a series of iterations may now be required for such reasons as the following:

a. Equipment heat rejection to cabin atmosphere may require uncomfortable ventilation rates.

b. Coolant flows in the heat rejection subsystem may not be ideal for all subsystems.

c. Subsystem interfaces, material, or thermal balance optimization.

Trade Study Data Presentation

The format used for the presentation of most subsystem discussions follows the order of selection criteria (Performance, Safety, Availability, Reliability, etc.). Candidate descriptions are covered under the comments on performance. Emphasis is placed on operational considerations rather than on the theoretical aspects of design. Background information on the theoretical aspects may be found in other literature.

Data sheets (figure 5) and schematics are included to summarize the information presented for the concepts that were evaluated. Each concept is identified by its generic name and within its subsystem area.

Flight availability.- The availability noted is the date that the concept, considering its present status, could be qualified for flight assuming that a well defined program with adequate funding is initiated in early 1970. In determining this projection, the present hardware status, the known problem areas, the probable development areas, the long lead time items required, as well as the normal development and qualification time were considered.

Reliability.- The inherent reliability of the candidate concept assuming a flight qualified configuration is presented in terms of mean-time-between failures (MTBF). Under Spares/Redundant Units are listed the spares necessary to meet the subsystem reliability goal. The spares list was established through analysis of determining the probability of failure of each component and calculating the spares required to meet the subsystem goal. The resulting subsystem reliability estimate is also presented on the data sheet. Included in the spares list are replacements for limited life items. An item that is built into a concept, or is redundant, is identified by the letter R.

Crew time. - Crew time is divided into two categories; scheduled maintenance and unscheduled maintenance. The scheduled maintenance time estimations are the average times in hours expected to be expended on a particular concept for the entire mission, assuming the hardware is flight qualified. Estimates for unscheduled

SUBSYSTEM:

CONCEPT:

FLIGHT AVAILABILITY:
(1970 go-ahead)

RELIABILITY:	MTBF:

Spares/Redundant (R) Units:

CREW TIME (Hr/Mission):	Scheduled	Unscheduled

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit			
Expendables			
Spares/Redundant Units			
Electrical Power			
Thermal Power			
Radiator Load			
Total Equivalent Weight			

POWER (Watts):
Electrical
Thermal

VOLUME (ft^3):	Installed	Spares/Expendables	Total

Figure 5. Data Sheet

maintenance are based on the predicted probable failure rates and average times for repair of those parts most likely to fail. Each unscheduled maintenance time presented is the average repair time multiplied by the predicted average number of failures per mission. The times for both scheduled and unscheduled maintenance cover only the actual maintenance task. The times involved in fault detection, fault isolation, and post-check-out and return of the subsystem to an online status are not considered, because the first two times vary according to the instrumentation approach, and calculation of post-checkout time is necessarily gross at this stage of the study. However, these stress factors are considered qualitatively in the crew time evaluation.

Equivalent weight.- A weight table presenting the significant factors comprising the equivalent weight for each of three power systems is presented. The term basic unit refers to the parts of the candidate concept that are required to actually perform the function. Expendables and spares/redundant units refers to the weight of the expendables, spares, and/or redundant equipment required to attain the desired reliability for mission completion.

Power.- The power required in terms of electrical and thermal energy at any one time to perform an operation is noted for each of the three power systems.

Volume.- The estimated volumes of the concept, including volumes of spares and expendables are shown on the data sheet.

SPECIAL SYSTEM CONSIDERATIONS

As an introduction to the more specific discussions of the AILSS trade-offs and system integrations, certain areas lend themselves to a general discussion covering their application to the AILSS study. These areas are reliability, maintainability, modularity, commonality, fire safety, and microbiology. The approach or philosophy for each area has been implemented, when appropriate, and is discussed in the applicable subsystem or system sections.

Reliability

The criticality of the EC/LS systems for a 500-day non-resupplied long duration mission dictates that a major emphasis be placed on reliability. The minimum acceptable reliability established by the AILSS system specification as being a reasonable requirement for this mission is 0.99 with an MTBF (mean-time-between-failures) of 1000 hours, exclusive of scheduled maintenance. For reliability purposes the EC/LS system is subdivided into two separate groups: functional hardware and instrumentation. This allows the precise and total instrumentation requirements to be defined along with the final system. The functional equipment is apportioned with an overall reliability of 0.995 and an MTBF of 1500 hours; the instrumentation is apportioned with an overall reliability of 0.995 and an MTBF of 3000 hours. This apportionment is established on the basis that the reliability of the instrumentation is as important in a mission of this type as the life support equipment. The MTBF apportionment was obtained after considering the probable quantity, function, and probable location of the instrumentation in the EC/LS system.

In this study, it is necessary to establish a maintainability philosophy that allows fulfillment of the established reliability requirement and application of that philosophy to the system design. If complete redundancy on the subsystem level were incorporated to meet the reliability goal, four standby systems would be required, resulting in a 400 percent weight and volume penalty. Installed redundancy results in inefficient utilization of secondary equipment since equipment commonality cannot be used effectively and because each redundant component backs up only a single on-line unit. The backup equipment weight penalty can be significantly reduced through commonality, where many identical components can be practically backed up by a small number of spares. The spares for the AILSS amount to 50 percent of the installed hardware weight. Although a penalty is incurred through the expenditure of crew time in performing unscheduled maintenance, unless the total system unscheduled maintenance time is estimated to be greater than one percent of the mission, spares should be selected in preference to redundancy. A discussion of spare usage versus redundancy to achieve the desired reliability goals is presented under "Maintainability" in this section of the report.

The EC/LS equipment can be categorized in two classes: repairable and nonrepairable. Since it is theoretically possible to increase the reliability of the repairable equipment to any desired level by adding spares, the attainment of the system reliability goal is constrained only by the reliability of nonrepairable equipment such as liquid, gas and vacuum lines, fittings, tank shells, isolation valves, structures and extra-vehicular equipment. The probability of failure for this equipment can be minimized by replacing all fluid line fittings with welded connections, except where lines interface with replaceable components (these fittings should be designed to be replaceable or to have removable sealing surfaces), by designing all isolation valves such that no single failure will result in external leakage, and by increasing the structural hardware safety factors to minimize the possibility of failure.

Subsystem reliability.- The functional EC/LS equipment is composed of eight major subsystems. Since each subsystem is of equal importance in completing the mission, the reliability of these subsystems is apportioned equally resulting in a reliability of 0.9994 for each. To establish the reliability of the candidate concepts in the subsystem trades, the reliability of each component is determined in each of the concepts evaluated. The predicted equipment failure rates used assume that all hardware is fully developed and flight qualified. This is done for consistency and to identify those concepts with the highest potential reliability, regardless of the hardware's current development status. The failure rates are calculated on the basis of similarity to existing aerospace hardware and by synthesis of individual piece parts of a known failure rate. The probability of failure for each component is determined by combining the predicted failure rates, estimated operating times, and applicable "k" factors to reflect environmental severity.

Once the subsystem reliability is calculated and probable failures identified, each back-up component is considered for its addition to the system in one of three ways:

1. Active redundancy
2. Standby redundancy
3. Spares

Those spares or redundant components providing the greatest improvement in reliability are added until the subsystem reliability goal is met.

The reliability analyses and redundancy/spares optimization studies are usually based on the following assumptions:

a. Equipment failures are independent; i.e., failure of one item will not generate a failure in a downstream item.

b. Rapid fault detection/localization is available

c. Equipment replacement can be completed within the allowable downtime.

In order to make fullest utlization of the redundancy and spares, these features must be designed into the EC/LS.

The calculated MTBF's and reliability estimates for each concept under evaluation are provided on the concept data sheet as part of the subsystem concept evaluations. The MTBF is related to the unspared or inherent subsystem reliability by the equation:

$$R = e^{-12\ 000/\mathrm{MTBF}}$$

System reliability - The backup equipment requirements for each selected subsystem are reviewed and reevaluated on a system level in order to obtain the optimum combination of spares. The system reliability improvement provided by each spare is determined, and those spares or redundant components providing the most effective improvement in reliability are added until the system goal is met. The backup equipment penalty is also minimized by incorporating as much modularity and equipment commonality as possible. Separate discussions of modularity and commonality are presented in subsequent paragraphs of this section.

Detailed application and results of the reliability considerations are given in the Selected EC/LS Systems section of this report.

Maintainability

In order to achieve the reliability required for the 500-day mission, the EC/LS system requires both scheduled and unscheduled maintenance. This places great emphasis on man-machine interface considerations. System maintenance can be accomplished by repair, replacement or switching to standby or redundant units. To minimize the overall crew time, weight, and volume penalty, maintenance guidelines are necessary. The general maintenance guidelines and maintenance concepts used for this study are presented in the following paragraphs.

Maintenance guidelines -

1. Performance degradation or failure in one subsystem should not upset performance in any other subsystem.

2. Maintenance should be on a remove-and-replace basis.

3. Failure isolation techniques must isolate each failure symptom to the replacement level.

4. If detection techniques can be developed to anticipate wearout failures early enough to allow the crew to schedule the replacement at a convenient time, items previously considered for scheduled replacement can be maintained on an unscheduled basis.

5. Pre-installed redundant equipment is generally favored over spares when:

   a. Equipment is inaccessible
   b. Allowable downtime is short or zero
   c. The replacement of an item presents a potential crew hazard
   d. A component is backed up by only one spare

6. Pre-installed active redundant equipment is preferred when the instrumentation requirements for fault detection are excessive or otherwise impractical.

7. Spares should be selected when:

   a. Many identical components are used.
   b. Components experience wearout during the mission.

8. If the downtime requirements dictate redundancy, sparing should be considered if additional backup is required.

9. Degraded modes of operation should be provided for all critical functions to ensure a high probability of safe return.

10. All maintainable items should be designed to permit safe, easy and correct maintenance in a zero gravity environment.

11. Items should be designed or selected to utilize common fittings and components to the greatest extent practical.

12. Fittings should be selected and installed so as to be replaceable or to have removable sealing surfaces.

13. All isolation-type valves should be designed so no single failures will result in external leakage.

System maintenance.- The predominant maintenance method used for the AILSS is component replacement. In a few instances, where hazards such as high temperatures or a contamination potential exist during a maintenance function, preinstalled redundancy is provided. In no instance is actual component repair contemplated; that is, replacement of parts within a component (with the exception of seals). The two foremost arguments against equipment repair are as follows: substantially longer duration maintenance operations can result, and there would be a need for a workshop and test facility to ensure that the repaired component is repaired successfully prior to reinstallation in the system. Access to maintainable equipment will have to be incorporated in the basic vehicle layout and equipment arrangement. By itself, the clear access requirement could result in substantial system volume increases, especially if equipment is restricted to one-deep packaging. Figure 6 is a preliminary concept of how typical EC/LS components might be arranged along a cabin wall.

Liquid circuits.- Liquid circuits are expected to be particularly troublesome with regard to leakage detection and isolation, and vapor locking. Over the length of the mission being considered, gas is expected to accumulate in the liquid lines of the coolant circuit, water management system, water reclamation system, and portions of the crew provisions sections (e.g. shower), especially if water separators are less than perfect or if equipment failure requires opening of a liquid line for replacement. This vaporlock condition could adversely affect positive displacement pumps, tank storage capacities, and quantity level readouts. Certain techniques, such as vortex separation and the use of hydrophobic membranes and bladderless tanks, appear feasible in helping to overcome this serious problem. Although the number of sealing points will be significantly reduced and held to an absolute minimum through the use of welded/brazed joints at all manifold/equipment connections, it is not expected that leakage can ever be completely eliminated. Finding leaks could become a significant problem, especially with many insulated lines. In fact, unless some major breakthrough in instrumentation occurs, leakage isolation will be a manual process.

Toxic gases and liquids.- Toxic gases and liquids exist in portions of the system that require maintenance. Equipment must be provided, and time allowed, for purging these gases and liquids from the circuit, and for their isolation from the remainder of the circuit. The purging fluids must be compatible with the processes involved such that subsequent operation is not degraded. There are only a few such fluids available,

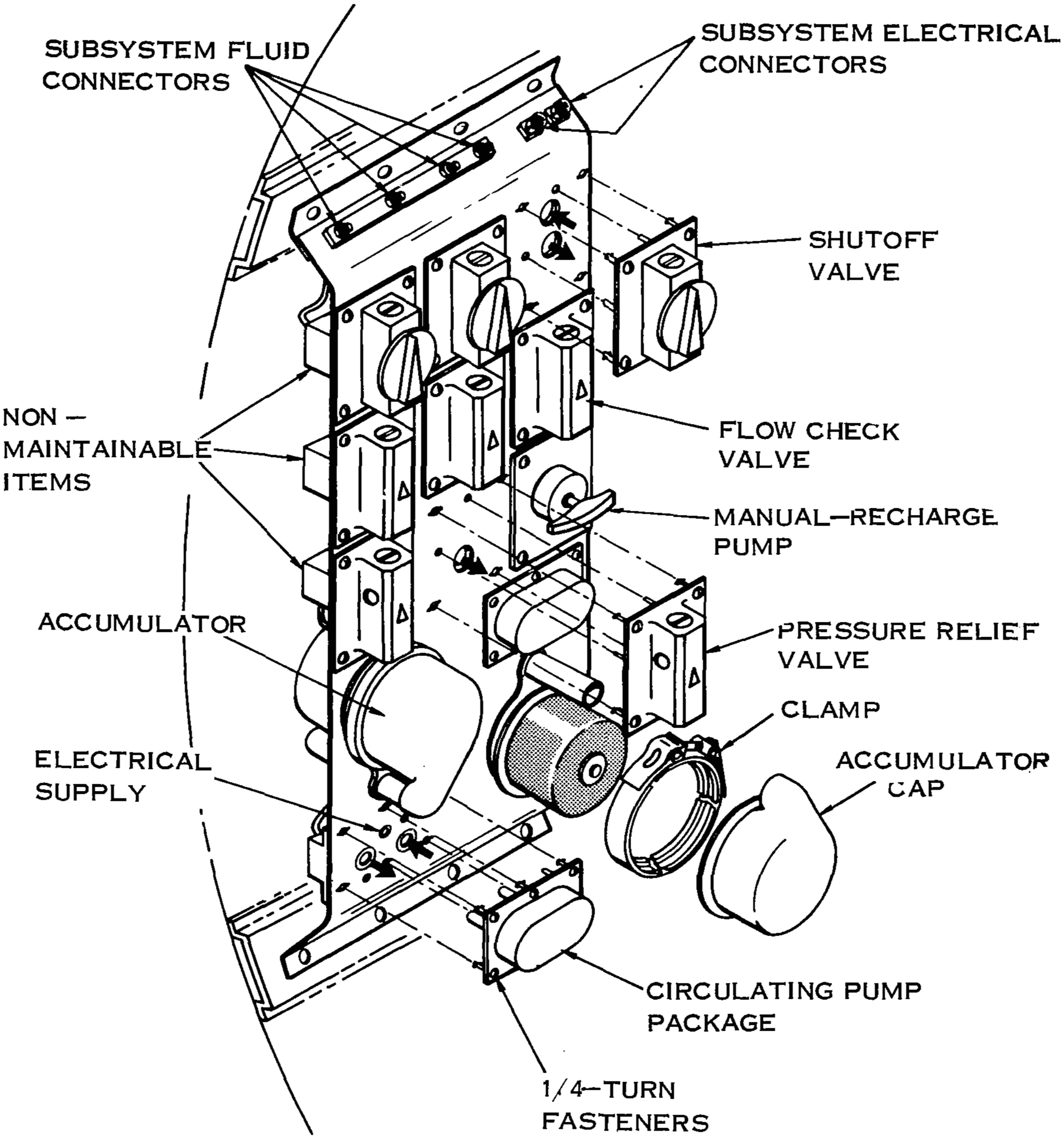


Figure 6. Preliminary EC/LS Component Installation

already stored on board. They are water, carbon dioxide, oxygen, and nitrogen. Water could be used as-is (e.g., flushing out the urinal) or heated to steam for sterilization. Carbon dioxide can be used to purge the carbon reactors prior to catalyst cartridge change, displacing a much more toxic gas, carbon monoxide. It appears that steam sterilization may be required in various portions of the water management system, waste management system, and urine reclamation system whenever a system upset or failure has let unsanitary water into the potable water areas. This steam, necessarily hot, will pose maintenance problems in terms of crew hazards during use and time and skill required to make/break all necessary connections and to properly actuate (manually) the correct valves at the correct time.

Tools.- The use of tools generally is neither desirable nor necessary. In a very few instances there are exceptions, for example, the use of a valve extension handle to isolate solid electrolyte stacks which operate at 1800°F. Tools usually require more skill on the part of the operator, are subject to misuse despite the best intentions, and have a tendency to lengthen maintenance times over those functions designed for replacement by the human hand.

Filters.- Filters, which are used in practically every subsystem, will require periodic changing. In liquid lines, the conservation of liquid ullage within the filter may be accomplished by adapting the filter to plug into the urinal and allowing fan suction pressure to empty the internal volume. Bacteria filters will require positive isolation and sealing with built-in valving that would operate during the removal process. New (dry) filters will have to be prefilled prior to installation to minimize the air entrainment in the circuit. To assure positive cleanout during the periodic flushing of contaminated water management system circuits, equipment will have to be designed with minimum feasible trapping spaces and pocketed areas. This problem of system cleanliness has far-reaching implications. Fine capillaries in water separators will provide a breeding ground for bacteria, expecially at the fairly warm temperatures used in the shower. In such an instance, the use of a bactericide or a steam purge offers a potential solution. Fortunately, most separators operate at approximately 40°F where bacteria growth is retarded. Large bacteria filters in the cabin ventilating system will be self packaged, probably in a structural plastic material. Closures will be folded out of the way when in use, but will provide for rapid sealing of the contaminated filter when changing is required. If a bacteria kill should prove desirable prior to storage (in sealed outer containers), some of the means discussed under Housekeeping in the Crew Provisions section of this report (i.e., UV lights, biocides, Beta radiation heating) will be effective.

Liquid tankage. - Liquid tankage, particularly water storage, represents a potential maintenance problem area. Bladder tanks, which have been used for space applications to date, are susceptible to bladder rupture. A method to detect such a failure in zero gravity is complex as are the problems of expelling the remaining liquid to any extra tank so that the bladder can be replaced. The choice of bladderless tanks for use on AILSS (see discussion in Water Management Section of this report) eliminates these problems. As bladderless tanks rely on surface tension forces to maintain positive expulsion, high reliability is obtained by the elimination of components susceptible to wearout failures. As a result of such a high reliability, no maintenance is anticipated except when the contents become contaminated. Even in this regard, these tanks have distinct advantages over bladder tanks for ease of flushing and gas purging.

Seals.- It is expected that with proper attention to system design comparatively few sizes of the familiar O-ring seals could replace every static seal expected to be broken. Spare seals do not consume much space or weight but can add substantially to the overall system reliability. It is anticipated that new seals would be installed whenever scheduled maintenance requires relatively frequent opening of a particular circuit. These seals would be included with the new replacement item.

Isotopes.- Radioisotopes, as used in Design 2, will require no maintenance themselves, due to their simple monolithic construction. The associated heat-transfer systems, however, could pose some difficult problems if not properly conceived. These potential problems arise out of the need for continuous cooling of the heat source to prevent overheating and possible self-destruction. With no allowable downtime for the individual isotope cooling mechanism, this equipment must be provided with standby redundancy with provisions to replace failed equipment during operation. Since operating temperatures are normally high (up to 1500°F) in these isotope circuits, the equipment on which some maintenance is anticipated must be kept cool to minimize hazards to the crew. Fortunately, this equipment is limited to simple valves and fans, with only low pressure gas and electrical connections. Heat transfer from the isotope to the heat load by direct conduction (without an intermediate cooling system) is practical only where the heat load is constant and failure-proof. A non-constant heat load or a failure thereof requires isotope cooling and/or removal, re-establishing the requirement for an independent gas cooling circuit.

Modularity

Modularity is a concept of equipment design based on a standardized function, capacity, or physical size which allows this equipment to adapt to changing requirements.

This concept approach can be applied to physical size requirements by the design of units and packages (modules) to predetermined dimensions to facilitate and allow preplanning of vehicle packaging arrangements. Various functions can be achieved by different arrangements of the packages in these modularized equipment bays. Increased capacity is achieved by the parallel operation of several units (modules), each of which independently performs an equal, fractional part of the total task.

It is the purpose of this study to investigate the factors that influence modularity as it pertains to the AILSS and to determine how these factors may be evaluated to permit optimization of the number of modules for a given required function.

In order to determine the optimal number of modules for any particular function, all the factors that influence this determination must first be defined and understood. For any given system, subsystem, or component, the relative impact of some influence factors will be greater than others. The following discussion considers the factors that might affect the modularity of any AILSS function. These factors may be classified into three broad categories: performance, maintainability,and configuration.

Performance.- Weight-reliability, power and sound suppression are the performance criteria used in modularity trade-offs.

Weight reliability.- This factor is a measure of the total vehicle weight penalty including spares and redundant items, for a given function, consistent with the reliability requirements of the mission.

Lack of an abort capability, coupled with the long duration of the mission, necessitates implementing a maintainability philosophy heretofore not applied. To meet mission reliability requirements, it is necessary to carry spares. Hence, the weight penalty must include both primary equipment and spares. An outline of the technique used to optimize the module capacity for this influence factor follows.

A curve of total weight versus the number of modules is developed. The number of modules at the minimum weight point on the curve is used as the optimal number for this factor.

Most AILSS functions have one principal failure mode. A failure rate is assigned which is usually proportional to the number of primary modules, n, although the total function failure rate is sometimes independent of n. Expressed mathematically, usually

$$\lambda \text{ Total} = n\lambda_A$$

where λ_A = module failure rate (independent of n and capacity)

but sometimes λ Total = constant for any value of n.

Now consider a function being performed by a single module of known weight, W. If this function were performed by a modular system of n modules, the weight of each module may be expressed as

$$w = k \frac{W}{n}$$

The weight factor, k, accounts for the fact that the module weight is not a linear function of capacity and is generally larger than 1.0.

The total number of modules equals the sum of the number of primary modules, n, plus the spare modules, s, and is thus (n + s).

The total weight penalty is equal to the total number of modules times the module weight:

$$\text{Total weight penalty} = (n + s)\,w = kW \,\frac{n + s}{n}$$

The number of spares, s, can be found in figure 7 for a given reliability level and an estimated failure rate. A decision is required as to whether total failure rate is independent of or dependent upon the number of modules.

The k factor must be evaluated through design estimates. In fact, this is the only design weight estimate required. This weight factor may be plotted as a function of the number of primary modules, n. Typical k-versus-n curves are shown in figure 8. The equation for these curves generally will be of the form:

$$k(n) = \frac{nw + \text{constant}}{W + \text{constant}}$$

where W is the total weight of n modules, each weighing w.

The constant in the equation represents the weight of the module-associated equipment, such as the instrumentation that is necessary to support each module regardless of module size.

The weight versus the number of primary modules may now be plotted. Two examples, an expulsion tank and a pump, are shown in figure 9. The weight factor curves for these plots are shown in figure 8.

Multiple failure mode situations may require simultaneous consideration of the two failure rates. If these cannot be considered independently, modification of the basic approach, just illustrated, may be required. However, the basic techniques of separating design weight estimates, through a k curve, from reliability requirements and then generating a weight curve, should still be used.

Power.- This factor is a measure of vehicle power requirements for a particular function. Power drain of a given function usually increases with the number of modules performing the function, because one large component is usually more efficient than several smaller ones. From this standpoint, functions that draw power may be broken down into two classes, energy converters and energy dissipaters. Energy converters, such as pumps, fans, and heaters, are relatively insensitive to sizing from an efficiency standpoint over the AILSS size ranges. Hence, power

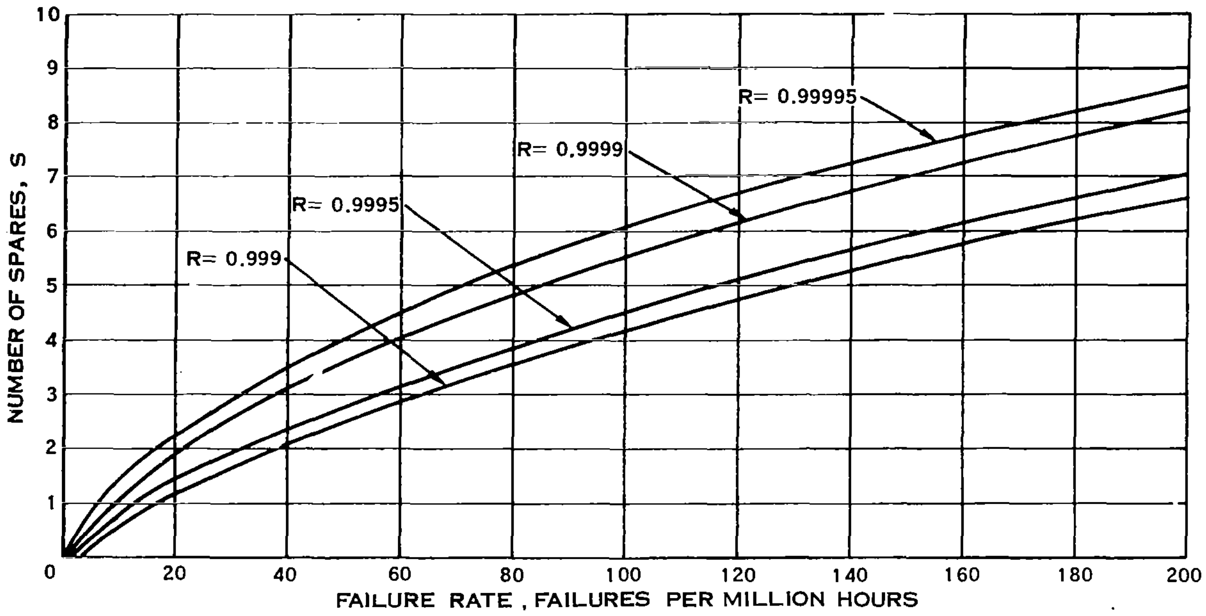


Figure 7. Number of Required Spares versus Failure Rate

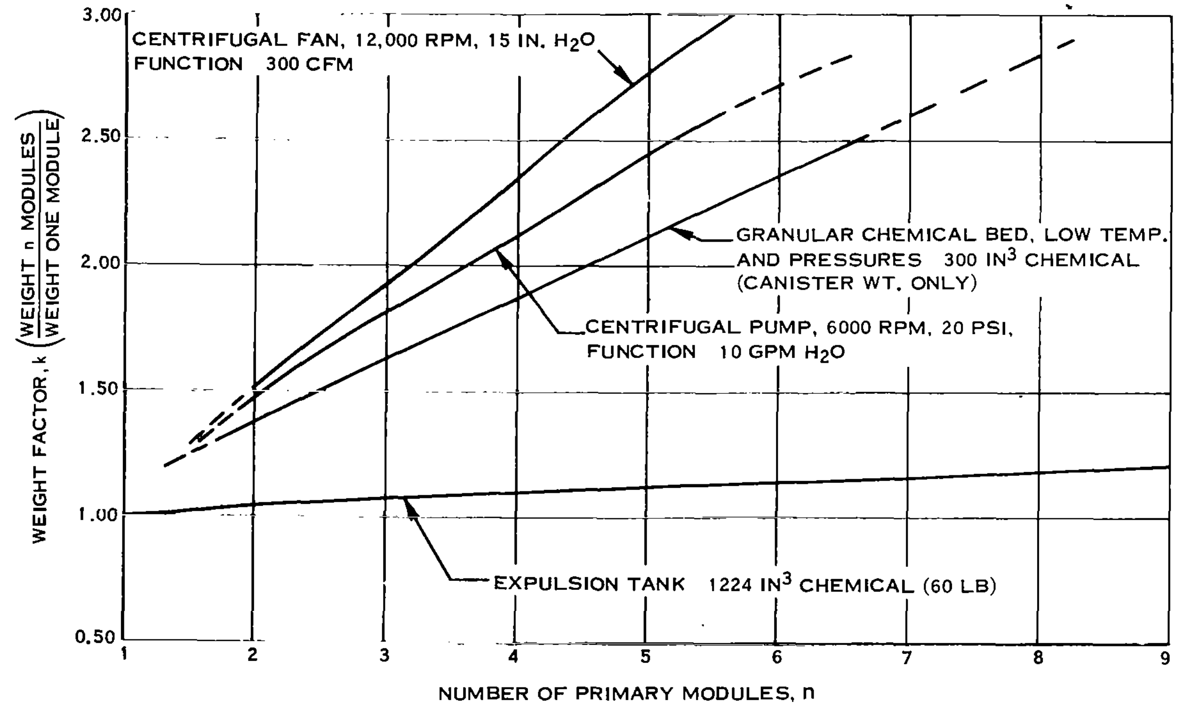


Figure 8. Weight Factor

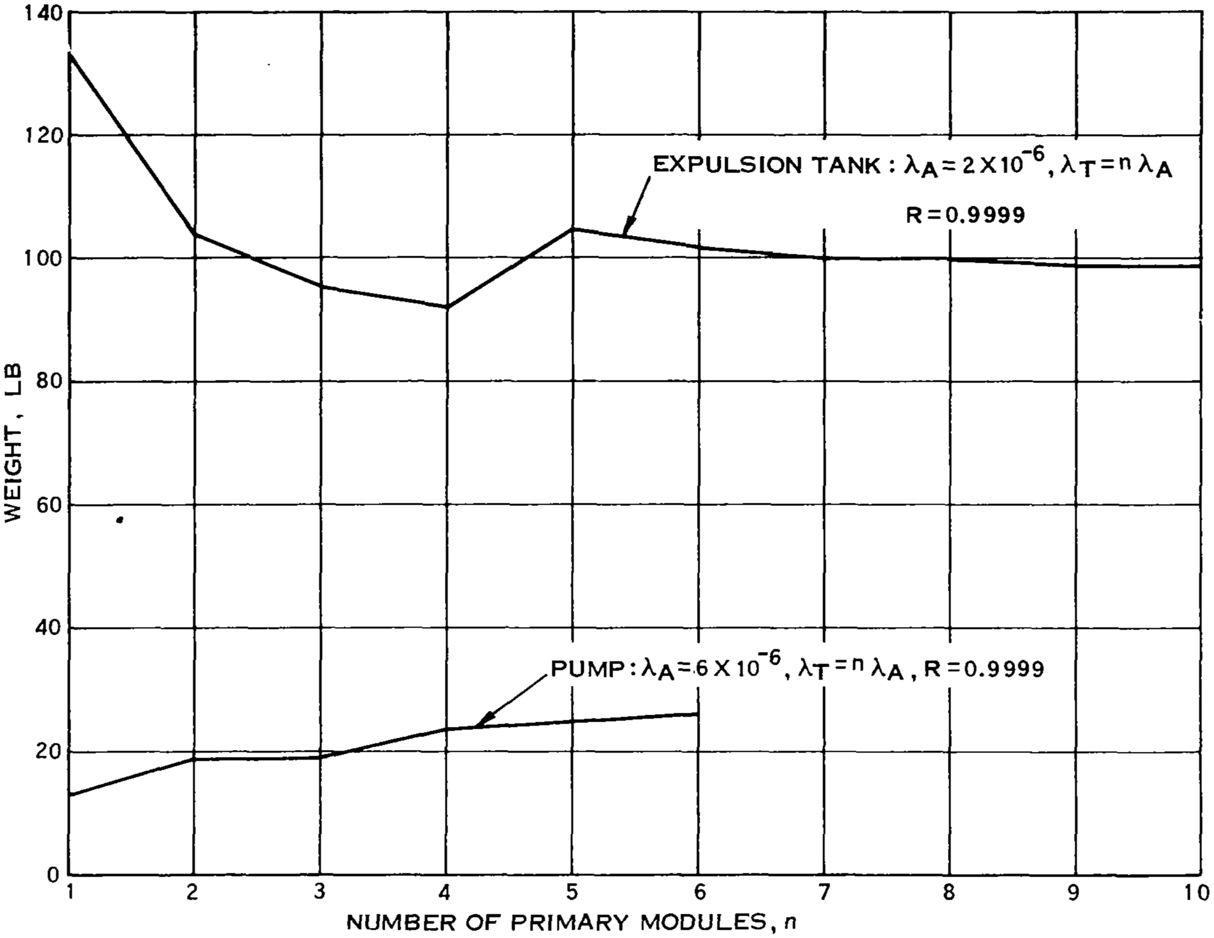


Figure 9. Influence of Modularity

considerations have little effect on the modularity of these functions. Energy dissipaters, such as servos, switches, and instruments, will draw power more in proportion to their number than to their function and, therefore, will be sensitive to modularity. As a result, power considerations dictate the use of the minimum number of modules for any power consuming function. This effect is usually minimal for energy converting functions and significant for energy dissipating functions.

The effect of power is also felt at the system level as all power not used for chemical conversion is dissipated to the cabin as heat. Both the power and heat requirements for a given modular subsystem can be converted to weight penalties depending on the power source and heat rejection method. The addition of these penalties to the total hardware penalty produces a total equivalent weight which serves as the basis for trade-offs between modular systems. A plot of the total equivalent weight versus the number of modules to perform a function should yield a curve from which the optimum number of modules can be determined from a minimum overall weight standpoint.

Sound suppression.- To maintain an acceptable level and quality of noise in the crew quarters, sound suppression techniques are needed. The complex nature of sound and its suppression and control, in combination with possible vehicle configuration constraints, prevents establishing any general criteria for modularization. Its application to modularity decisions will be more from a comparitive than an absolute standpoint. If the noise of a function is dependent on the number of modules, then minimum noise would be a valid parameter in choosing the number of modules.

Maintainability. - Maintenance time, complexity/crew stress during maintenance, fault isolation, and allowable downtime/failure effects are maintainability considerations.

Maintenance time: The time the crew spends maintaining a given function at nominal operating levels depends upon the number of modules performing the function and on the failure rate of each module. Failure rate and time to repair are generally independent of module capacity. Reliability considerations indicate that the number of failures usually increases with the number of modules. Because unit repair time is essentially constant, total maintenance time, therefore, increases directly with the number of modules.

Most AILSS equipment will have relatively low failure rates (when compared to mission duration). With a targeted mean time to repair of two hours, total unscheduled maintenance time for the entire system is expected to be one percent or less of the available mission man-hours. Therefore, total unscheduled maintenance time will not be great enough to warrant the usual consideration in a modularity decision. This factor, however, should be considered whenever the unit repair time is high or the use of a great number of modules is being considered.

Complexity/crew stress during maintenance: While equipment design must strive toward simple, hazard-free maintenance, it may prove impossible to avoid relatively difficult maintenance procedures for certain functions. In these instances, the number of failures and, hence, the total maintenance time, must be minimized. As explained above, this can be accomplished by minimizing the number of modules. This influence factor dictates that the more complex the maintenance procedures, the fewer the number of modules accomplishing the function.

Fault isolation: Once a functional failure has been detected, the source of the failure (some piece of equipment) must be determined. The more equipment associated with a given function, the more difficult it will be to isolate the faulty piece or part. This factor should be a measure of the penalties incurred, due to the additional monitoring equipment which is necessary for fault isolation required with a modularized function.

Allowable downtime/failure effects: A modular function being performed by n modules will lose 1/n of its capacity with a module failure. Its new capacity may be expressed as follows:

$$\text{Reduced capacity} = \left(1 - \frac{1}{n}\right) \text{(Original capacity)}$$

It can be seen that as n increases, reduced capacity approaches the original capacity. The impact of a single failure is reduced, therefore, as the number of modules is increased. This, in turn, means that more time is available to repair or replace the failed module before the effects of the failure become serious. This is always true where it is possible to maintain a failed module, while the other modules remain functional.

In summary, as the number of modules increases, allowable downtime increases and the effect of a failure is diminished. This factor will have particular impact when a significant reduction in functional capacity cannot be tolerated or when the time to repair is high.

Configuration. - Vehicle configuration, mission range, module size limitation, cost, equipment commonality, and minimum interfaces/system integration are configuration considerations.

Vehicle configuration: Detail requirements in the vehicle may have considerable impact on the modularity decision; however, two areas of interest will be of particular importance:

1. Number and arrangement of cabins/cabin interdependence
2. Geometry of available volume

Resolution of the first factor requires a general physical description of the vehicle.

For example, if the vehicle were to have four cabins, each requiring 200 cfm ventilating flow, it may prove easier to use four separate 200-cfm fans that to use a single 800-cfm fan with complex ducting and valving to connect the four cabins. On the other hand, a single cabin vehicle would minimize the impact of this factor on the modularity decision.

The second factor, vehicle geometry, places limits on the size and configuration of the equipment that can be located in any part of the vehicle.

Mission range: Generally, the most significant mission requirements that may vary are crew size, resupply interval, and mission duration. A modular system offers advantages in flexibility, in that a change in any of these requirements can be accepted without significant loss in optimal design by adding or eliminating modules. This flexibility to the requirements increases with decreasing module size.

Adding resupply periods to the AILSS would have significant impact on the module size of expendables only, effectively reducing required operating duration for this type of equipment.

Module size limitation: This factor must be considered as a check on the final modularity decision. Most functional equipment is feasible for manufacture over a certain size range. The module capacity decided upon must be within the state of the art of manufacture. For example, modularity considerations may indicate the use of ten 0.5-cfm fans to deliver a total of 5 cfm. The practical limitations of manufacture, however, may dictate a minimum fan size of 2.5 cfm. Hence, two 2.5 cfm fans would be used since the use of 0.5-cfm fans would be impractical.

This factor may limit the maximum as well as the minimum module size. For example, certain processes and materials cannot be made in very large sizes (e.g. a thin-walled ceramic part). This factor's influence will be felt principally at the component level.

Cost: Generally, an increase in modules will increase equipment costs. Other design factors may override this effect, however, and detail investigations for each function would be required to determine the lowest cost system. For example, for a multi-cabin vehicle it may be less expensive to use several life support systems (one in each cabin) than to use one life support system with complex plumbing and valving between cabins. Because cost is not otherwise considered in this study, it is mentioned here only to indicate that it ultimately will influence decisions.

Equipment commonality: Certain types of equipment will be used in all AILSS subsystems. Improvement in the maintaining and reduction in the total weight of the spares may be possible through the use of modules sized for the minimum required capacity throughout the AILSS. Several of these units could then be used in parallel where an additional capacity is needed. For example, if five separate pumps are required in a system with four pumping 10 gpm and one pumping 20 gpm, it would be advantageous to use two 10-gpm pumps in parallel instead of the one 20-gpm pump.

This factor can be applied only after the preliminary design of the overall system has been completed.

Minimum interfaces/system integration: To minimize interfaces and obtain a system of minimum complexity, modularizing of certain functions should be considered. A system where all functions but one are accomplished with two modules and the remaining function is accomplished with one module is an example of a case where modularizing the last function into two modules would yield two separate, half-sized systems, with fewer vehicle interfaces, and much improved flexibility.

Summary. - Each of the influence factors previously described usually is not optimal at the same number of primary modules for a given function. A compromise of some influence factors (if not all) is usually required. If a quantitative penalty is unavilable for assessing the overall effect of all the influence factors, a solution must be reached on the basis of judgement decisions. An approach to aid in making these decisions is to establish a matrix containing all the influence factors on a single form so that they can be compared and analyzed.

The major subsystem and system concepts presented in the subsequent sections of this report reflect this type of analysis. While in most cases this approach was not formalized, the basic factors were considered and are reflected in the systems concepts presented herein.

Commonality

Commonality is an approach to system design whereby the number of different components is minimized by using a particular component to perform as many functions as possible. This approach results in major advantages in the spares and maintenance areas. The number of components used to perform these same functions warrants a study to determine the feasibility, applicability, and weight penalties associated with using identical or common components for different subsystem applications within the AILSS.

The hardware projected for the AILSS flight period cannot be expected to operate continuously for 500 days without failures occurring. For continuous functional operation of all subsystems, the failed parts have to be repaired or the faulty components replaced. Due to the inherent complexity and the fine adjustments required in the detail assembly of AILSS hardware, replacement at the component level was selected as the primary means of maintenance, rather than actual component disassembly and repair.

Component replacement requires spares to be carried depending on the reliability of each different component and the number of each component used in the system. The total number of spares can be substantially reduced if similar components are made identical. With common equipment, each spare can back up a larger number of online fans in a system, and each fanhas a failure rate of 3.5 failures per million hours with each operating for a total of 12 000 hours, the following commonality combinations are possible:

No. of common fans	No. of spares/ each type	Total no. of spares
None common (1, 1, 1, 1)	2, 2, 2, 2	8
2 common, 1, 1	3, 2, 2	7
3 common, 1	3, 2	5
2 common, 2 common	3, 3	6
4 common	3	3

As illustrated by this example, it is advantageous to use as many identical components as possible to reduce the total number and types of spares required. The commonality approach to system design can only be applied to those items which are sufficiently adaptable to different functions. Each item must have a single configuration throughout its size range, and the configuration should be similar to that of items with similar but not identical functions, e.g., small two-way valves should have a configuration similar to that of small three-way valves. This family approach to component design has advantages in the design, manufacturing, and development areas, but primarily in the maintenance area. As all similar items have identical mounting schemes, crew stress is reduced by minimizing replacement procedures. This family approach combined with component need, provides the essential requirements of the commonality approach.

In order to obtain the ideal common item, material compatibility with all anticipated temperatures, pressures, and vehicle fluids is essential. Unfortunately, oxygen compatibility in high pressure systems requires special design techniques with respect to configuration and materials and, as a result, must be handled separately. The components considered as common for the purposes of this study are valves, fans, and pumps. Other components experience frequent use but do not lend themselves to the commonality approach and are therefore considered special equipment. These include: pressure regulators, temperature control and other modulating type valves, and equipment which requires definite design limits and operating bands. These components cannot be approached in the general manner of the common items and require specific investigation into each application.

The common items investigated here represent those items which are most frequantly needed, lend themselves to the commonality approach, and cover the size and performance requirements of the AILSS subsystems. Figures 10 and 11 illustrate typical curves that were generated to determine the weight and power for various common items.

Valves. - Valves can be divided into two major groups by size: small valves (1/4 to 3/4 inch line size) compatible with both liquids and gases at both low and high operating pressures (up to 1000 psi), and large valves (1 to 6 inch duct size) for gas usage at low operating pressures (up to 25 psi).

Small valves: Under the small valve group, both two-way and three-way valves are considered in conjunction with both manual and solenoid actuation. Check valves are also included. For small two-way and three-way manual and solenoid valves, a pressure balanced poppet concept was selected. This concept lends itself to bidirectional flow throughout the pressure and size range under consideration, whereas a pressure assisted poppet is feasible only at low pressure, and a servo valve has significantly lower inherent reliability and requires a given pressure band to guarantee uniform operation. Shear seal valves (ball, sleeve, etc.) do not appear to lend themselves to the module mounting approach and are also questionable from a reliability, contamination, and weight standpoint. The pressure balanced poppet operates independently of pressure forces and can be controlled over any pressure range with constant actuation force. This concept can be easily adapted to the family approach with the two-way and three-way valves having similar configurations.

Manifold mounting: Of primary importance, in any valve design, is the ability of the valves to be integrated into a fluid loop and to be maintained without undue crew stress and downtime for the subsystem and associated equipment. For small valves, such a configuration should be comprised of permanent valve housings interconnected by welded and/or brazed tubes. This manifold approach eliminates the need to break and make tube connections when replacing the valve components. The use of tube connections would require extra valve spares, but more important, it would require the need for tubing spares. Because fewer spares are required, the permanent manifold network with no connections offers the most maintainable and reliable system.

In the manifold mounting system design for the small valves, the valve mounts in the housing where it slides into the bore, with the proper porting and sealing surfaces, and is locked in place. The valve should be a cartridge type with replaceable external seals as illustrated in figure 12. The locking and mounting device should allow the valve to be removed and replaced entirely by hand. It should also allow the valve to be removed in two steps: the first, as a safety precaution, to relieve the pressure buildup behind the valve, and the second to allow the valve to be withdrawn safely in a manner similar to an automobile radiator cap. This configuration requires no tools, which would require greater access room, tool storage, and operator time and skill. By having all small valves maintained in this manner, crew stress is reduced through the use of identical replacement procedures.

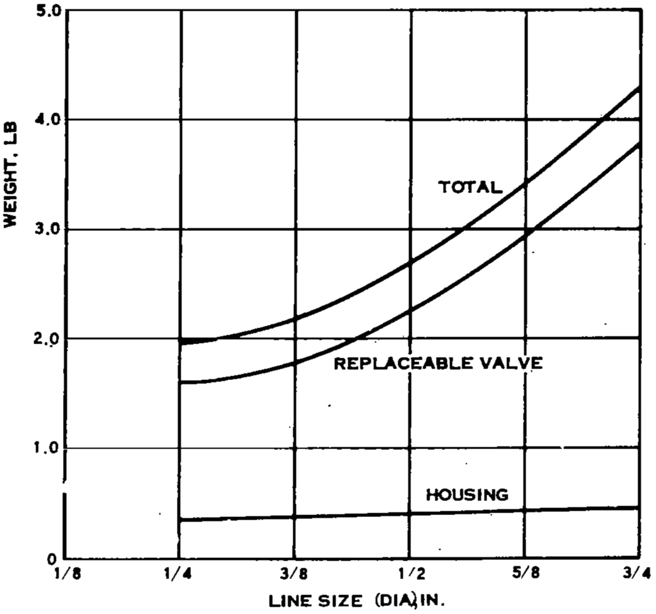


Figure 10. Two-and-three-way Solenoid Valves - Weight Versus Size

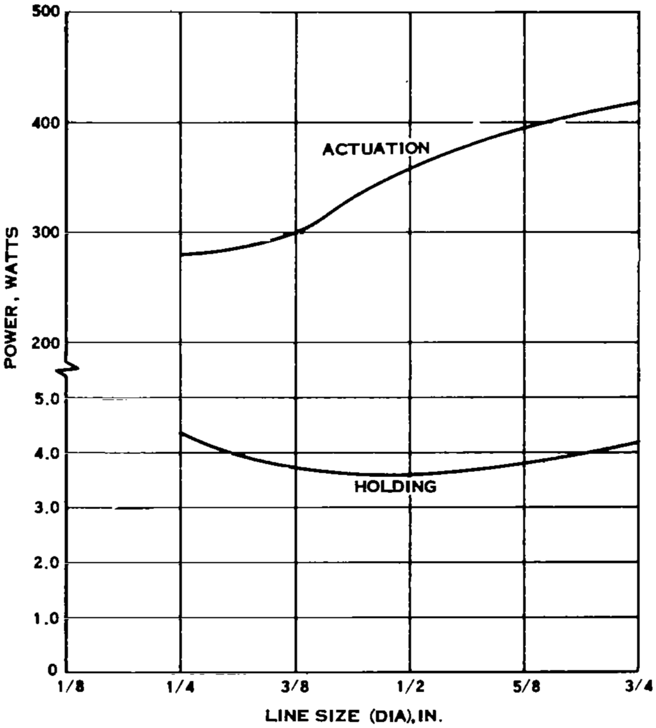


Figure 11. Solenoid Valve Power Requirement

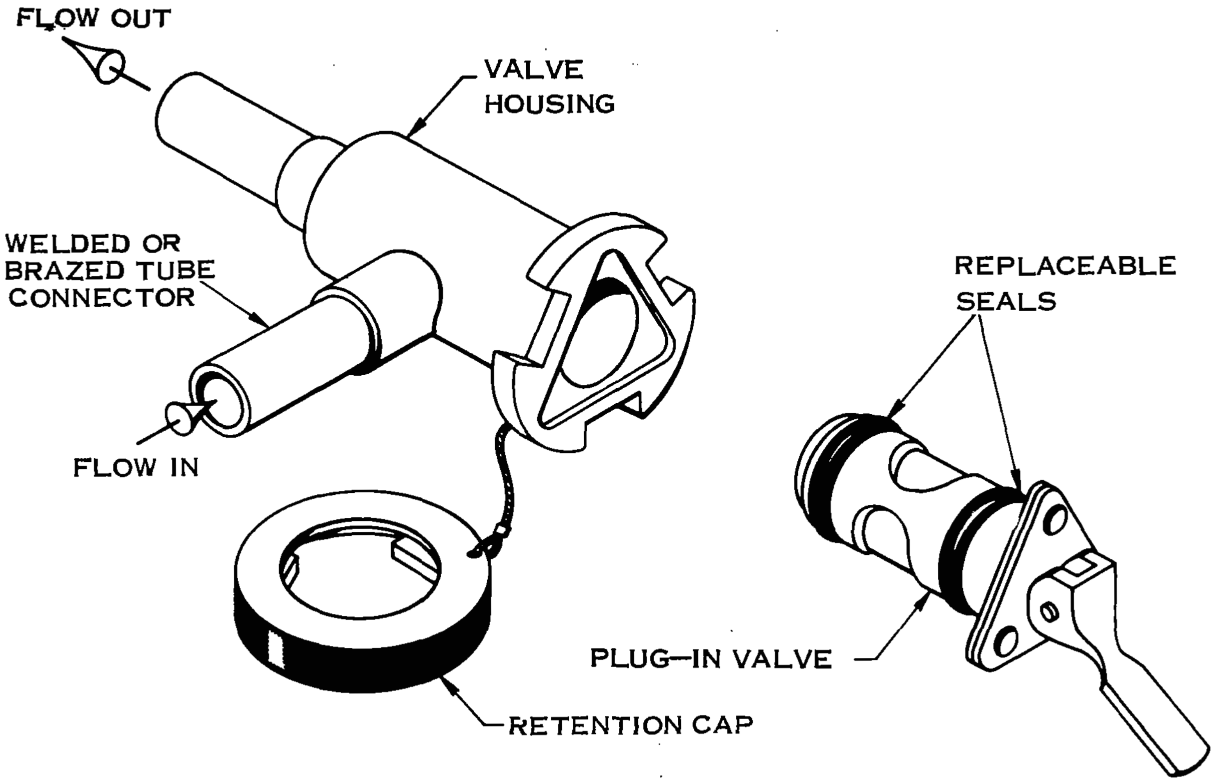


Figure 12. Common Valve Configuration

A problem present in this and all other types of mounting is spillage of local fluid when the valve is removed. This problem is amplified when dealing with toxic gas and liquid systems which could endanger crew health or contaminate surrounding equipment. Spillage (and subsequent air inclusion) remains a problem yet to be overcome before completely maintainable systems can be obtained.

The manifold mounting arrangement, combined with a three-way balanced poppet valve, can produce a valve with five different functions depending on manifold port selection. This concept allows any port to function as an inlet and, as the two poppets are opposed, no interflow is obtained between ports. By choosing different ports on the housing for inlets and outlets, and plugging any one port for two-way valves, five functions can be obtained as illustrated in figure 13.

Because of the universality of its functions, this three-way valve concept was used to size both the two-way and the three-way solenoid valves. This concept was chosen only for the solenoid valves because: two configurations are required for two-way solenoid valves, normally open and normally closed (as illustrated in figure 13), and the increased weight for the three-way valve over the two-way valve is not great when com-

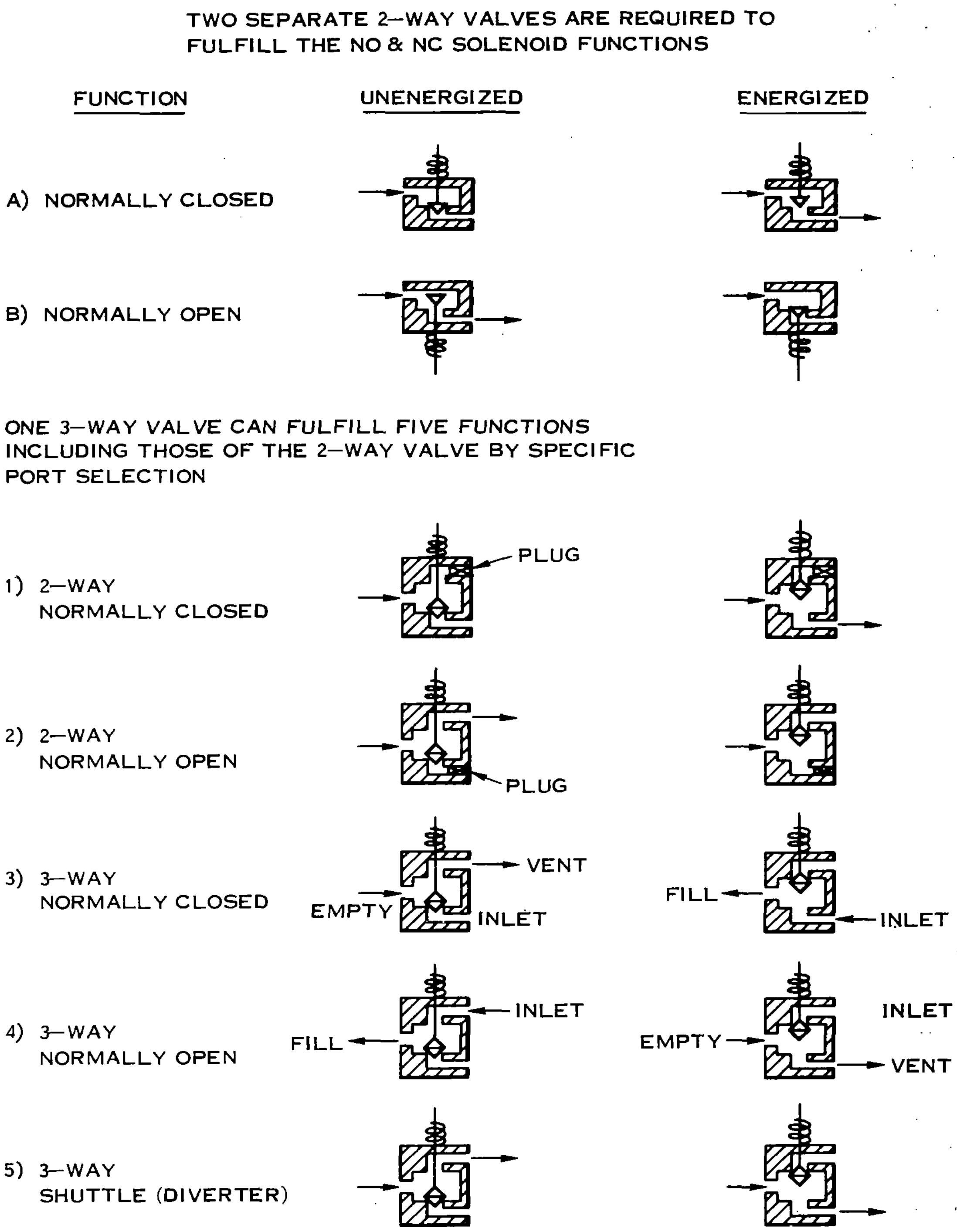


Figure 13. Two-Way/Three-Way Valve Functions

pared to the solenoid weight. As the actuation motion for this valve is linear, it can accept either manual or solenoid actuation. As a result, both the solenoid and three-way manual valve can be made to use the same housing, and the solenoid valve can be replaced by the manual three-way valve if necessary (i.e., as a last resort).

Solenoids: The weight and power data for solenoid valves reflect the use of double coil solenoids. This type of solenoid offers the minimum weight and power necessary to meet the force, gap, and duty requirements. The solenoid is composed of a high power coil which actuates the armature, a low power coil which continuously holds the solenoid in the actuated position, and a switch which shuts off the actuation coil and turns on the holding coil when the actuation is completed. The valve is returned to its original position when the power is shut off. The off position is selected for the major portion of the duty cycle to conserve power. The double coil solenoid appears preferable to the single coil and/or latching solenoids because of the following characteristics:

1. The force available from a solenoid increases as the gap decreases.

2. The force available at the gaps needed for this applications is only a fraction of the force produced at the no-gap fully actuated position.

3. A solenoid sized for continuous operation is much larger, for the same force and gap, than one rated for only intermittent operation.

To use a single coil solenoid would result in a much larger and heavier solenoid than needed and also in inefficient operation (from a power standpoint) because the work being done in the energized position is far greater than needed. A latching solenoid would also use an intermittent coil, but the holding mechanism would be larger than the holding coil being considered and would be more complex, resulting in a lower inherent reliability. The large power requirement for the actuation coil is due to the minimized weight of the coil. A larger coil could be used which could require less power, but the total weight of the system would be greater even though the external wiring, switches, and EMI suppression would be sized for the high power requirements.

Manual overrides: In space programs to date, manual overrides have been required on all automatic and power components to overcome most failure modes or irreplaceable hardware. On the AILSS, with replacement available, the need for manual overrides is not essential and is, therefore, not included in the solenoid valve weights. In certain applications, manual overrides may be desirable, as in the case of failure isolation (troubleshooting) and component isolation, in systems containing toxic fluids and redundant loops. These functions can also be served by adjacent shutoff valves.

The small, manually operated valves use a toggle and cam system as a means of actuation. This toggle type of operation appears desirable for on-off valving functions with no more than two discrete positions as in the two-way and three-way valves. It allows quick detection of valve position and saves on panel space, but most important, it allows quick differentiation of two-way and three-way valves from modulation or multiposition valves where it is more difficult to avoid rotary actuation.

Large valves: Under the large valve group, only manual two-way and three-way valves were considered, as other large valves have little demand except in special applications. Large automatic valves require either motor or servo actuation with the servo working either from line pressure or an external high pressure source. The final choice of actuation depends on the exact application of each item. This application dependency, combined with limited demand, restricts this type of equipment to the point where it is not applicable to the commonality approach and is, therefore, not included.

The primary requirement that influences the configuration of these valves is the need for a vacuum shutoff capability, which necessitates a leak-tight valve. A poppet type sealing arrangement is favored, as butterfly types cannot meet the leakage requirement and are also difficult to adapt to a three-way valve configuration. Disc-type shear seal valves can meet the leakage requirement but have weight limitations. As a result, poppet and poppet-type self-aligning flapper valves were considered. Due to the similarities in their weight, mounting, and actuation capabilities, the weight versus size curves for two-way and three-way valves (figure 10) reflect both configurations.

The low pressure requirement of these valves allows both rigid and flexible duct connections to be considered, but due to the mounting complexity (mounting the valve plus making duct connections), a captive face seal flange concept appears preferable. The flange approach allows the valve to be mounted and sealed on one surface and in one operation.

Rotating equipment. - In the area of fans and pumps, flow and pressure rise ranges for typical subsystems were used to size motor/rotor assemblies and, thus, to arrive at weight and power requirements. Flow and pressure rises outside the ranges studied are considered special applications and require specific investigation. As the state-of-the-art in this area is not likely to improve significantly in the next ten years, present day performance data and configurations were used to derive the weight and power data. The variable with the greatest influence on weight is the operational motor speed.

Motor speed is a compromise of the weight, noise, efficiency, bearing life, and specific speed range of each rotor type. These are all interdependent, so no clear speed choice is obvious. The ideal speed range is narrowed down by the specific speed range for efficient operation of each rotor type. Within this range, operating noise and longevity are the prime factors influencing the final speed choice. A fan speed of 12 000 rpm and pump speeds of 6000 rpm appear to most efficiently cover the flow and pressure ranges considered, but lower speeds could offer longer, quieter operation.

Bearing life is of greatest importance to the reliability of rotating equipment. Gas bearings offer the longest life and lowest friction operation, but they are very sensitive to contaminants and vibrations (especially nonoperating) and they depend on some auxiliary equipment. Sleeve bearings are limited by their susceptibility to contamination, which greatly affects their performance, and by lubricants, which may generate atmospheric contaminants. As a result, ball bearings, while far from perfect, appear to offer a reasonable compromise choice for air-moving equipment. They can be made redundant at a very low cost in weight.

For the purposes of this study, ac motors were used to size fans and pumps in order to obtain consistency throughout the study and because of the availability of background data. Motor cooling is essential for continuous operation of this equipment and is obtained from the pumped fluid where enough mass flow is available. Otherwise, an external coolant source is used as in the case of centrifugal fans and vacuum compressors.

Fan mounting was not considered in specific detail as present subsystems normally employ these components as either the first or last item in a subsystem. This allows greater accessibility and avoids the need for inline connections. The component is mounted with only one duct connection required, thereby reducing the complexity of replacement. Therefore, detailed mounting configurations were not derived because of the feasibility of the present approach.

Conclusions. - The major advantage of commonality is the minimization of spare components and replacement procedures. In contrast, the only disadvantage of the commonality approach is that the extra effort required to achieve acceptable maintenance features results in a slight increase in component weight penalty. However, reduced crew stress, obtained through a minimum of replacement procedures, more than offsets any weight penalties incurred.

Fire Safety

The extended mission duration of the AILSS will introduce more severe fire safety design problems than have been encountered in manned space programs to date. These problems, which will require consideration throughout the complete AILSS program, must be considered on a systems basis to be effective. Fire safety is closely related to other safety aspects such as structural integrity, maintenance requirements, and equipment performance, but because of the complexity of the problem, it will require as much attention as all other safety aspects combined.

The systems approach to fire safety recognizes the interdependence of many aspects of the problem, and allows the incorporation of the broad but meaningful objective of minimizing risk to the mission. Without this approach, one safety problem may be solved at the expense of introducing others. For example, there is little advantage in requiring nonflammable fabrics for some applications if the only materials that meet this requirement have poor abrasion properties. The use of such material could seriously jeopardize the performance of equipment and crew comfort, and these two factors directly affect mission risk and safety. A more appropriate alternative may be to prevent ignition sources from being located near flammable fabrics, and to provide extinguishing equipment and techniques capable of dealing with the improbable fire. The increased demands for crew comfort reliability, and maintainability for the duration of the extended AILSS mission necessitate treating the entire subject of fire safety on a systems basis.

In the systems approach, fire safety is divided into two interdependent categories:

1. Design for the prevention of ignition
2. Design for a defensive capability

This approach, with priorities given to the two broad categories in the order shown, has several advantages. First, it allows flexibility for optimum solution of many safety problems and it minimizes the risk to mission objectives. Second, it will make fire a very improbable event, even with the flexibility of solution. Third, it recognizes that fire hazards cannot be completely eliminated from a life supporting atmosphere and gives complete protection by providing an adequate means to combat any possible fires.

Design for the prevention of ignition. - The probability of ignition can be greatly reduced by the selection of nonflammable or fire retardant materials and by the elimination of ignition sources. Potential ignition sources with AILSS oxygen enriched atmosphere which should receive particular attention are electrical connectors and switches, hot surfaces, and hot gases. Careful selection and/or design of the AILSS hardware and system, together with an Apollo-type material control program, will minimize ignition sources.

Design for a defensive capability. - Design for defensive capability considers four items: minimizing propagation, detection, extinguishment, and recovery plan.

Minimizing propagation: Fire propagation can be minimized by several factors or combinations of factors. The first factor is the inherent flammability of the materials used in the hardware design. Flame spread rates, in general, will be higher at the 7.0 psia (50% O_2) atmosphere than in normal air, but slow burning materials in any atmosphere will provide the most time for extinguishment. Compromises arise when slow burning materials exhibit low ignition temperatures or produce noxious fumes, etc.

Depending on the location of ignition, the cabin circulating fans may provide convection currents that will propagate a fire. Whether such air flow currents can be effectively eliminated within the required few seconds by shutting down the fans remains to be determined. Stopping the fans raises the hazard of crew suffocation. To avoid this possibility, oxygen masks must be provided in convenient locations in the cabin for protection from the toxic products of combustion.

Another factor to be considered in minimizing the propagation of a fire is isolation. It can be accomplished by compartmentation of equipment, by appropriate system valving, and by flooding with an extinguishing agent to block all propagation paths. This latter method may be feasible in fan duct-work and around other components which combine ignition sources with potential fuels such as lubricants. Compartmentation can be quite effective in reducing propagation rates on large and small scales. The cabin may be divided into compartments by a fire wall so that damage will be confined to a predetermined area. More important is the advantage that the entire cabin will not require venting to space to remove contamination.

Detection: Several types of detection devices are available for industrial and aircraft application. They operate on:

- Temperature
- Ultraviolet emission
- Rate of temperature rise
- Infrared emission
- Photoelectric smoke detection
- Vapor detection
- Pressure
- Rate of pressure rise
- Electrical power monitoring

It is apparent that more than one type of detector must be used in the AILSS. Detection requirements within the life support subsystems will vary from those in the cabin. The actual selection of detectors will depend on the detailed design of the hardware; consequently, the actual selection must be deferred until the development phase of the program.

Extinguishment: Controlling fires is a primary step in complete extinguishment. It is seldom possible, when dealing with fire in flammable materials such as fabrics, seals, paper, etc., to completely extinguish the fire with the first application of an agent. Even if this is possible in some cases, the penalty associated with hardware for this purpose would be prohibitive for a little gain in safety. It is generally more practical to reduce or "knockdown" the fire in the initial attack to stop the extension of damage, and then undertake the task of completing extinguishment. Table 3 lists a number of extinguishing methods considered for the AILSS and rates their significant features.

The following list of extinguishing agents (from table 3) is recommended for consideration and evaluation during the development phase of the AILSS. It is anticipated that some combination of these agents will provide adequate protection, but the choice will depend largely on the systems design and materials and the vehicle configuration.

TABLE 3

COMPARISON OF EXTINGUISHING METHODS

Method	Class of fire (a)	Mode of action	Personnel hazards	Knockdown	Cleanup
Water (Straight stream)	A, B	Cooling Smothering	Good	Fair	Fair
Waterfog (Fine droplet pattern)	A, B	Cooling Smothering Radiation shielding	Good	Good	Fair
Water (Protein foam)	A, B	Cooling Smothering Radiation shielding Chemical inhibiting	Fair	Good	Poor
Water (High expansion foam)	A, B	Cooling Smothering Radiation shielding	Fair	Good	Poor
Water (Methyl cellulose foam)	A, B	Cooling Smothering Radiation shielding	Fair	Unknown	Fair
Carbon dioxide	B, C	Cooling Smothering	Poor	Poor	Good
Nitrogen	B, C	Cooling Smothering	Poor	Poor	Good
Liquid nitrogen	B, C	Cooling Smothering	Poor	Unknown	Good
Dry chemicals	A, B, C	Smothering Chemical inerting Radiation shielding	Fair	Good	Poor
Freon 1301	B, C	Cooling Smothering Chemical inerting	Fair	Unknown	Good
Starvation	A, B, C	Cut off oxygen supply	Poor	Poor	Good
Decompression	A, B, C	Remove oxygen	Poor	Poor	Good

[a] A = Solid combustibles
B = Liquid combustibles
C = Electrical

Selected extinguishing methods	Reason/use
Water	Nontoxic
Straight stream, variable pattern nozzle	"Knockdown" and penetration of solids
Waterfog	
High expansion foam	Total cabin flooding
Methyl cellulose foam	Within equipment and equipment bays
Freon 1301	Explosion suppression

It is recommended that a water supply, hoses, and variable pattern nozzles be provided as part of the primary fire protection equipment for the AILSS. A variable pattern nozzle is one that can be adjusted from a straight stream to some predetermined fog-cone angle. This will allow the fog to be used for quick "knockdown" and control, and the straight stream can be effective for completing extinguishment in the cabin or within the various subsystems.

Recovery plan: While fire in the AILSS can be made highly improbable, the possibility cannot be eliminated. Therefore, provisions must be made for extinguishing and recovering from such an occurrence. Each component, subsystem, and the system as a whole must be designed to allow for this. As a minimum, provision for safe return of the spacecraft and its crew must be provided. Beyond this, it may be desirable to design the system so that a minor fire will not cause mission degradation.

These goals may be achieved by examining each component, subsystem, and the system as a whole with respect to fire hazards, establishing preventive methods, providing accessibility for extinguishment, formulating decontamination procedures, and protecting spares. The potential size of the fire, the speed, and the hazards should be considered throughout the design and development phases so that the desired recovery level will be achieved as an integral part of the system and not as an afterthought.

Microbiology

Comments regarding the overall microbiological problems of a 500-day space mission are included in the following paragraphs. A statement of the problem, a discussion of the approach, and specific recommendations for the selected subsystem are included within the particular subsystem discussions and, as applicable, within the system discussions.

Microbe/man interaction. - Man and the microorganism interact in a manner dependent upon the nature of the microoganism and the conditions prevailing in man at the time of contact. The microorganism can be antagonistic, symbiotic, or inactive in its relationship with man. Conversely, man's defensive mechanisms, a hostile environment, or chemotherapy can neutralize or destroy the microorganism or be ineffectual. A delicate balance of nature exists between man and microorganisms.

In space vehicles, this balance tips toward microorganism supermacy. Isolation in a weightless, closed environment causes physiological changes in man. The skin loses its elasticity and bacteriostatic properties. The derma and mucosa are more sensitive and irritable. In addition, the "normal" residual microbial flora changes spontaneously or through dietary influence and other factors. These conditions seriously affect man's resistance and ability to avoid, diagnose, and treat microbially induced diseases.

Therefore, under these circumstances, all microorganisms must be considered pathogenic unless proven otherwise. It follows that strong emphasis must be placed on prevention and/or control of microbial contamination during extended, manned space missions.

Microorganisms. - The microorganisms encountered in the space vehicle are mainly those indigenous to man, and cover a broad taxonomic range: viruses, bacteria, yeast, and fungal varieties. They are separable into two groups: host dependent or free living.

The viruses and pleuropneumonia-like organisms(PPLO bacteria) are host-dependent, requiring living tissue for their propagation. Conditions in the space vehicle do not favor their growth but certain viruses remain viable for significant periods of time outside of the host tissue.

Bacteria, yeast and fungi are free-living organisms. They exist and grow in the space vehicle and its systems where an aqueous medium of nutritive value is available. Desiccation does not kill many. Their growth produces disease, fouls equipment, pollutes water, degrades materials, and produces poisonous byproducts, including gases, aldehydes, acids, exotoxins, and endotoxins.

Byproducts. - Bacteria and fungi produce numerous metabolic byproducts. Some byproducts are released freely into the surrounding medium or atmosphere while others are contained within the organism. Exotoxins and endotoxins are notable examples.

The exotoxins of botulinus, diphtheria, and tetanus bacilli are destroyed by heat, and only botulinum toxin (one of the most potent poisons known) is effective when ingested. The fact that spores of Clostridum Botulinum are occasionally found in the human intestinal tract requires that measures be taken to ensure that this microorganism is not present somewhere in the water system. This is best accomplished by keeping fecal wastes isolated from the water system. The exotoxin of Staphylococci is particularly debilitating to man. Since it is heat stable, the organism must be controlled or eliminated from the food supply by proper food processing before and during the flight.

Endotoxins are associated with many types of bacteria and are commonly cell-wall components. They are characteristically far less toxic than the exotoxins, are heat stable, and are retained by microbial filters if still associated with the cell-wall complex. When ingested, endotoxins and other microbial byproducts can be a minor nuisance under ordinary circumstances. Space travel will cause stresses on the crew that render these materials more toxic.

Additional microbial byproducts are the gases, acids, aldehydes, etc. which many organisms produce. Control of microbial growth is necessary to prevent the formation of these byproducts.

Spores. - The Bacilli, Clostridium, Actinomycetales, fungi, and yeasts form encapsulated entities during their life cycles called spores. This resting or rejuvenating stage resists heat, chemicals, irradiation, desiccation, lack of food, and other adverse environmental conditions. The spore germinates when conditions are favorable. The resistant spore is one reason for the failure of sterilization procedures.

Microbiological Control. - Microbiological control is defined as the destruction, elimination, or reduction of microorganisms to levels which maintain the continuous good health and well being of flight personnel. To achieve these levels, the following steps or ideas require emphasis:

1. All microorganisms are considered hazardous regardless of nonpathogenicity on Earth.
2. Detection or monitoring procedures are required to determine the presence, concentration, and viability of microorganisms.

3. Effective control methods are instituted routinely and as required to sterilize or decontaminate infected areas.

Specific microbiological control methods are discussed in each subsystem analysis. Some known and experimental control procedures are listed in table 4 to indicate the range of available methods. The application of a particular method or a combination of methods depends on several factors, including the degree of control required, the microbial species involved, and the sensitivity of recipient material to the treatment procedure.

The following is a summary of microbiological control procedures used in the AILSS to reduce the problems discussed in the preceding paragraphs. Most of these procedures attack the problems by suppressing bacteria growth.

Atmosphere Control

a. Atmosphere

"Absolute" filters and prefilters
Catalytic oxidation (adjunct)

b. Carbon Dioxide Concentration and Reduction

Heat, wet and dry
Biological filters
pH control (inherent to system)
Scrubbing (inherent to system)

Crew Provisions (Equipment and Crew)

Equipment

Presterilization
Nonbiodegradable materials
Vacuum and filtration cleaning
Ultraviolet radiation
Biocides
Clothes washer

Water Management

Biocides
Heat, wet and dry
Biological filters
Membrane filtration (inherent to selected system)
Continuous (or frequent) monitoring

Waste Management

"Absolute" filters
Heat and dry
Biocides
Pyrolysis

Crew

Personal Hygiene
Immunization
Medicines and Drugs
Biocidal soaps and lotions
Treated clothing
Shower

TABLE 4

MICROBIAL CONTROL METHODS

Temperature	Other Physical
Heat, dry	Ultrasonic
Heat, wet	Osmotic pressure
Refrigeration	pH
Freezing	Microflotation
Freeze-thaw cycles	Centrifugation
Pyrolysis	Filtration
Oxidation	Scrubbing
Distillation	Maceration
	Rapid Decompression
Radiation	**Chemical**
Beta Particles	Biocidal agents
Gamma rays	Gas sterilants
X-rays	Photodynamic agents
Ultraviolet rays	Antibiotics
Microwaves (heat)	Sonochemical
Infrared (heat)	Metallic ions
	Aerosols
Electrical	**Biological**
Electrohydraulics	Bacteriophage
Electrolytic shock	Colicins
Electrophoresis	Enzymes
Electrostatic precipitation	Immunization
	Isolation
	Personal hygiene

OXYGEN AND NITROGEN STORAGE

CONTENTS

OXYGEN AND NITROGEN STORAGE

Metabolic oxygen requirements are provided by the reduction of crew-produced carbon dioxide and water in the oxygen generation subsystem. The existence of vehicle gas leakage and cabin repressurization requirements necessitates onboard storage of the primary cabin atmospheric constituents, oxygen and nitrogen. Estimated storage requirements are shown in table 5. The demand for quantities of makeup gas is determined by a cabin total pressure controller whose configuration is dependent on the particular storage candidate selected. Rapid cabin repressurization (measured in minutes rather than hours) is not considered necessary since a one-half inch micrometeroroid penetration requires approximately one hour to depressurize a 5000 ft^3 compartment to 4.0 psia. Thus, ample time is available for the crew to transfer to another compartment while repairs are being made.

Oxygen and nitrogen storage systems fall into three general classifications: high pressure gaseous, chemical, and cryogenic storage. Each of these general categories is further subdivided into specific candidate concepts. Since the requirements for cabin repressurization and cabin leakage vary substantially with respect to flow rate and stability of demand, some supply concepts are considered for repressurization or cabin leakage alone. The object of this approach is to determine whether some combination of concepts can achieve a higher overall rating than one specific concept supplying the needs of both repressurization and cabin leakage. Oxygen and nitrogen storage are described together, under both high pressure gaseous and cryogenic storage. Regardless of the particular gas stored, the storage systems are virtually identical. Chemical storage concepts are discussed separately, except for those candidates which chemically deliver both oxygen and nitrogen.

High pressure (3000 psia) gaseous storage employing filament-wound tankage is selected for use on the AILSS to provide oxygen and nitrogen for cabin repressurization and cabin leakage.

Use of a single oxygen tank is considered undesirable because a tank failure would be catastrophic. Thus, a ground rule is established that oxygen supply system redundancy is required. Nitrogen supply system redundancy is not considered necessary, because the loss of a single nitrogen tank would result in eventual depletion of nitrogen from the cabin until a 100 percent oxygen composition is reached. Although this constitutes a degraded mission mode, a nitrogen tank failure can be tolerated without the catastrophic consequences accompanying a single oxygen tank failure. It is assumed that adequate meteoroid protection (a vehicle consideration) is afforded equally to all of the candidates considered, and no further consideration of this problem area is given.

TABLE 5
GAS STORAGE REQUIREMENTS

Cabin repressurization

Five hours maximum to repressurize a 5000 ft^3 cabin to 7.0 psia (50/50 oxygen-nitrogen mixture)

Total gas for repressurization equivalent to that required to provide two complete repressurizations of a 10 000 ft^3 cabin to 7.0 psia

Total quantity for repressurization of both compartments: 394 lb O_2, 346 lb N_2

Cabin leakage*

Maximum of 1.0 lb/day

Total quantity for cabin leakage: 267 lb O_2, 246 lb N_2

Total storage requirements

661 lb Oxygen
592 lb Nitrogen

Maximum usage rate = 0.534 lb/day oxygen, 0.492 lb/day nitrogen

*Cabin leakage can be characterized by two extremes: capillary-free molecular flow typical of elastomer-metal seal leaks and bulk flow typical of larger openings. Maximum nitrogen leakage occurs with the former condition and maximum oxygen leakage occurs with the latter. Because the type of leakage is not specified and, in fact, is unpredictable, the quantities of oxygen and nitrogen shown here are the maximums for either type of leakage extremes.

The method used in this study to determine the number of oxygen tanks required is to first trade-off all candidates assuming that one full-size oxygen supply system is necessary. The equivalent weights for the oxygen storage candidates summarized in the data sheets reflect one full-size tank (no redundancy). Once the concept selection is made, a further trade-off is performed to determine the optimum number of tanks required (two full-size, three half-size, etc.). This is accomplished by comparing total system reliability and equivalent weight for a varying number of tanks. After the optimum number of tanks is determined, the evaluation candidates are reviewed again to determine whether the original candidate selection is still valid.

OXYGEN AND NITROGEN STORAGE CONCEPTS

The candidates evaluated for the storage of oxygen and nitrogen are as follows:

1. High Pressure Gaseous Storage
   a. Oxygen storage in:
      1) Steel tankage
      2) Filament-wound tankage
   b. Nitrogen storage in:
      1) Titanium tankage
      2) Filament-wound tankage
2. Combination Oxygen Storage
   a. High pressure gaseous storage for repressurization
      1) Steel tankage
      2) Filament-wound tankage
   b. Water electrolysis for oxygen leakage supply, utilizing an oversized oxygen generation subsystem.
3. Chemical Storage
   a. Oxygen storage
      1) Alkali and alkaline earth peroxides and superoxides
      2) Chlorate candles
      3) Hydrogen peroxide

- b. Combined oxygen/nitrogen storage
  - 1) Catalytic decomposition of nitric oxide
  - 2) Hydrazine/nitrogen tetraoxide reaction

4. Cryogenic Storage of Oxygen and Nitrogen

- a. Supercritical with thermal pressurization
- b. Subcritical with positive expulsion
- c. Subcritical with thermal pressurization
- d. Solid cryogenic storage (oxygen only)

The first four of the candidates summarized below are eliminated due to their inability to meet the AILSS absolute criteria. The remaining candidates receive acceptable absolute criteria ratings and are then evaluated further.

Alkali and Alkaline Earth Peroxides and Superoxides

Use of nonregenerable alkali and alkaline earth peroxides and superoxides for oxygen generation is rejected on the basis of an unacceptable performance rating. This concept has received widespread attention for extravehicular life support equipment. The solid chemicals absorb water and carbon dioxide and produce carbonates, bicarbonates, and oxygen. The reaction can be triggered with either carbon dioxide or water vapor, either of which is consumed in the reaction. While advantageous on short-term missions where a closed water and oxygen loop are not required, this process is not practical for longer missions because it uses an expendable with a high inherent weight.

Subcritical Cryogenic Storage with Positive Expulsion

Subcritical cryogenic storage employing positive expulsion is rejected on the basis of an unacceptable rating for availability/confidence. This candidate utilizes a bladdered storage vessel to provide liquid delivery. Bladders which will withstand flexing at cryogenic temperatures for extended periods are not sufficiently developed to provide acceptable gas storage system flight hardware by 1980. Thus, this candidate is eliminated from further consideration.

Catalytic Decomposition of Nitric Oxide

This concept, using catalytic decomposition of nitric oxide to produce oxygen and nitrogen, is rejected for its inability to pass the absolute criteria. While the reaction appears to be theoretically possible, no evidence has been found of its commercial use. Thus, because the feasibility of the reaction has not been demonstrated and because no development effort is being performed, this candidate receives an unacceptable rating for availability/confidence.

Solid Oxygen Storage

Oxygen stored as a cryogenic solid at -400°F has recently received limited attention as a reserve system for a breathing gas supply on space missions. However, the mechanics of transporting the solid oxygen and utilizing it as a primary storage system for on-demand supply is currently considered impractical. Thus, solid oxygen storage does not meet the AILSS mission performance requirements and is eliminated. Solid oxygen storage, however, may possess significant advantages as an emergency or reserve source for other missions.

High Pressure Gaseous Storage

The high pressure gaseous storage of oxygen and nitrogen at ambient temperature is an inherently simple storage and delivery system. A storage pressure of 3000 psi is selected for all gaseous storage systems considered. This pressure results in a minimum tankage weight for oxygen (at a somewhat greater than minimum volume) and a low weight for nitrogen tankage (although not a minimum) which is consistent with achieving a reasonable storage volume.

Several advanced tank materials are available and are therefore included in this study. Nitrogen tankage may use titanium or filament-wound material, and oxygen tankage may use stainless or maraging (a) steels and filament-wound material. Titanium is not oxygen-compatible on impact and is therefore not considered for oxygen storage.

Stored oxygen can be used to supply both cabin leakage make-up and repressurization quantities, or the required repressurization quantities alone, with oxygen leakage make-up provided by supplementary stored water electrolized in the oxygen generation system by using a larger electrolysis unit as a larger solid electrolysis system. This latter combination operating concept is considered along with the other high pressure storage candidates, because the water electrolysis function is assumed to be already present in the oxygen generation subsystem.

A separate electrolysis unit (in addition to the electrolysis function performed in the primary oxygen generation system) could be used for oxygen leakage supply. A

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[a] Iron alloy, 18 to 25% nickel, age hardened on basic martensitic structure (hence, maraging). Treatment process results in high strength and toughness.

repressurization supply using a separate electrolysis unit would be impractical from an equivalent weight standpoint due to the high flow rate requirements. A separate unit, however, would show no advantages over an integrated electrolysis approach and is therefore not considered as a candidate.

A variation of high-pressure gas storage is possible whereby the oxygen and nitrogen are thoroughly mixed and stored in one vessel. Such a system is similar to the present separate gas storage concept in weight, volume and configuration , but lacks the mixture ratio flexibility of separate storage. The gas can be withdrawn only at the mixture ratio within the tank. Separate storage systems would be required for leakage and repressurization make-up because the leakage from a mixed gas cabin, possibly characterized by capillary-free molecular flow, does not consist of gas in the same ratio as the cabin mixture. It is this lack of flexibility when compared to separate gas storage that prevents the mixed gas concept from being considered as a valid independent candidate system.

A general data sheet and schematic (figure 14) are presented to summarize the high pressure storage candidates. Since the power supply types do not influence the weights or powers for these candidates, the data is applicable to Designs 1, 2, and 3.

Absolute criteria . -

Performance: The advantages of high pressure gaseous storage systems are numerous. Storage pressure is not sensitive to environmental heat, so indefinite standby with essentially zero use rate is possible. These systems do not require special pressure control concepts to prevent tank overpressurization. Moreover, since the delivery is not directly dependent on fluid heat addition, high repressurization flows can be achieved. Gaseous storage systems which combine high pressure with high discharge flows generally require application of thermal energy to achieve fluid delivery at cabin temperatures. During repressurization, the tank metal heat capacity can be utilized (with an internal heat exchanger or by wrapping the outlet line around tank circumference) to maintain the delivery fluid temperature high enough to prevent regulator freezeup (above -60°F) and liquification during regulator throttling. An additional heat exchanger is required during repressurization downstream of the pressure regulator to warm the fluid for cabin delivery. In spite of its heat requirements, the high pressure gaseous storage and delivery system is inherently simple in concept and operation.

Safety: As with existing high pressure gaseous stage systems, the presence of quantities of stored gas at high pressures constitutes a potential safety hazard. No other areas of concern regarding safety are apparent in this method of storage. No additional safety hazard is introduced when an oversized electrolysis or solid electrolyte system is used to supply cabin leakage make-up.

Availability/confidence: Systems which deliver gases for consumption from an initial high pressure gaseous state have been used extensively in both commercial and aerospace applications. High pressure gaseous storage (7500 psi) has been used during the Mercury program for metabolic and leakage supply requirements, and for portable extravehicular space life support equipment.

The development work currently being pursued on high pressure storage systems is primarily in the area of materials. Development of titanium bottles reduces the tank weight penalty below that of stainless steel. Titanium bottles, however, are not recommended for storage of oxygen because they fail impact tests. Stainless and maraging steel bottles are currently being used for the storage of oxygen (inconel bottles are also currently being used for oxygen storage at a substantial weight penalty).

Various concerns are currently developing boron filament-wound pressure vessels and other composite material vessels with a metallic liner. Filament-wound pressure vessels offer a significant weight reduction below conventional materials on a strength-to-weight basis. Composite materials, however, require substantially more development effort than stainless steel, maraging steels, or titanium.

Primary criteria. -

Reliability: The MTBF for the high pressure storage concept is estimated to be 328 000 hours. No tank redundancy is required from a reliability standpoint. Two spare pressure regulators are required to achieve a subsystem reliability of 0.999871 (for either O_2 or N_2 storage for total supply requirements). Using water electrolysis to supply cabin leakage oxygen make-up reduces concept MTBF, but it is still far greater than mission duration and additional spares required are few if any. For example, use of the solid electrolyte system for electrolysis to supply cabin leakage oxygen makeup requirements reduces the MTBF to 96 500 hours. No additional spares are required to achieve a system reliability of 0.999811.

Crew time: The high pressure gas tank is nonmaintainable and is located outside of the vehicle pressure shell. All other portions of this system are located within the vehicle pressure shell, and (once the shutoff valve is closed) the lines may be opened and maintained by simple plug-in replacements as required. No scheduled maintenance exists for this system. Use of water electrolysis for cabin leakage supply does not add significantly to the total crew time required for the mission.

Equivalent weight: The ultimate strengths for the pressure vessel materials that are considered are projected from today's state-of-the-art to the 1977 to 1980 time period to allow for expected normal development. Burst pressure factors are reduced for currently developed materials (stainless steel, titanium, maraging steels, etc.) to 1.5 (from a present value of 2.0) to allow for improvements in quality control. The burst pressure factor for advanced composite materials is retained at 2.0. Candidates are not penalized for the power required for heating during repressurization supply

HIGH PRESSURE GASEOUS STORAGE

Flight Availability : 1974 (Data corresponds to 1978 technology)

	Nitrogen Storage for Repress. and leakage		Oxygen Storage for Repress. and leakage		Oxygen Storage for Repress. and water electrolysis for leakage (numerical values base on electrolysis in a solid electrolyte O_2 generator)	
MTBF (hr)	328 000		328 000		96 500	
Crew time (hr/mission) sched/un sched	0/0.05		0/0.05		0/0.06	
Eq. weight (lb)	Titanium	Fil. wound	St. steel	Fil. wound	St. steel	Fil. wound
Basic unit	418	294	439	259	337	225
Expendables	636	636	712	712	750	750
Spares/red.	9	9	9	9	20	20
Elect. pwr	0	0	0	0	24	24
Radiator load	0	0	0	0	4	4
Total eq. wgt.	1063	939	1160	980	1135	1023
Volume (ft^3)	48.5		41.8		33.2	
Spares	2 pressure regulators		2 pressure regulators		2 pressure regulators	

Figure 14. (Page 1 of 2)

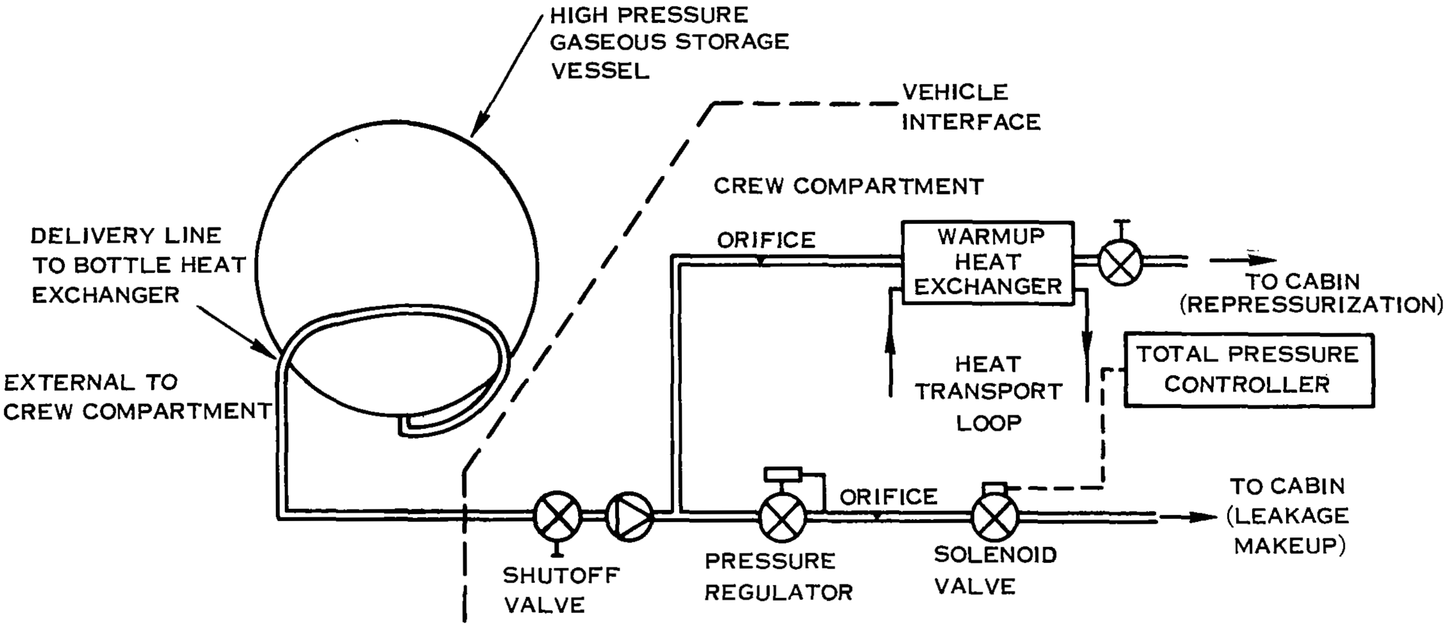


Figure 14. High Pressure Gaseous Storage Concept (Page 2 of 2).

because this system utilizes waste heat from the thermal transport loop. The weights for filament wound tankage utilizes projected data for boron filament-wound material with a resin matrix. The total equivalent weight for these systems is summarized in figure 14.

If water electrolysis is used for leakage make-up, 405 lb is required for water storage and electrolysis stack weight and power penalty, whereas the leakage make-up portion of the filament-wound tankage totals is only 362 lb. As a result, there is no weight advantage for using electrolysis of water for oxygen leakage make-up.

Secondary criteria. - High pressure gaseous storage presents no potential areas of contamination. Integration with the oxygen generation subsystem for leakage make-up by water electrolysis adds no additional contamination problems because it is already present in the system. A high pressure gaseous storage system for the total supply requirements possesses excellent interface characteristics (only interface required is thermal transport loop connection to the space radiator). The use of electrolysis for oxygen leakage supply, however, results in significantly poorer interface characteristics. The high pressure gaseous candidates (for total supply requirements) possess good flexibility. This is due to the rapid repressurization times which can be achieved, the ability to use mixed gas storage, and the ability to utilize multiple tanks without any performance or weight penalty. The use of electrolysis for oxygen leakage reduces flexibility because the maximum supply rate is relatively fixed. Moreover, electrolysis for leakage supply utilizing an oversized unit possesses a relatively poor overall flexibility due to its dependence on the availability and functioning of this item. No significant growth differences are apparent between any of the candidates. Increases in material ultimate strengths and reductions in burst pressure factors with time give the high pressure gaseous storage concepts good growth characteristics. No noise is apparent in the high pressure gaseous concepts or when combined with the O_2 generation subsystem because the unit is already present in the AILSS. The volume of high pressure tankage, when used in conjunction with electrolysis, produces one of the lowest total system volumes. The use of high pressure gaseous storage for oxygen or nitrogen requirements results in a total volume which is average among the candidates evaluated. The repressurization power quality is excellent for all high pressure concepts because waste heat can be utilized. The electrolysis method has a slightly lower overall power rating because electrical power is required to supply oxygen leakage makeup.

Chlorate Candles

Chlorate candles produce oxygen through an exothermic sodium chlorate reaction. Chlorine production is controlled by chemical additives. Present chemical oxygen development in the alkali and alkaline earth chlorate and perchlorate grouping is confined to sodium chlorate. Although the oxygen yield per pound of chemical is lower than with lithium perchlorate (not evaluated because of reaction control difficulties and other problems), the equivalent oxygen density is comparable to cryogenic systems (sodium chlorate density of 158 lb/ft^3 with a 36 percent oxygen yield). Chemicals in this classification, generally formed in long cylindrical candles are one-shot generators. The candles for cabin repressurization are electrically ignited as required and are contained in a common storage vessel outside the vehicle. The sodium chlorate oxygen generation system for cabin leakage supply is located within the vehicle pressure shell. The candle element is replaced after use and cooldown by simple insertion of a new candle into the container where it is retained with a screw-on cap/outlet filter. Systems employing chlorate candles for repressurization and cabin leakage are different as shown in figure 15.

<u>Absolute criteria</u>. -

Performance: The chlorate candle system for cabin leakage makeup is substantially less effective than that for repressurization, due to the difficulty in achieving adequate control of the reaction at the low usage rates required. The minimum linear burn rate (in./hr) of chlorate candles is limited. Thus, the minimum candle diameter and achievable length fixes the minimum oxygen quantities delivered. Once ignited, the reaction cannot be stopped until a candle burns to completion. Exact gas quantities are not as available on demand, and cabin pressure/mixture control is therefore more difficult to achieve.

Safety: No insoluble safety problems are apparent in the utilization of chlorate candles for the low flow rates required to make up cabin leakage. The moderate pressure levels during cabin repressurization represent a slight safety problem. The inability to control or to extinguish an ignited candle could impose a potential safety hazard.

Availability/confidence: Chlorate candle systems presently are being developed to supply oxygen for metabolic consumption and leakage in extravehicular life support equipment as well as for current use in the mining industry. Overall effort is currently in the later prototype development stage and normal development is expectd to produce flight hardware by 1974.

<u>Primary criteria</u>. -

Reliability: Estimates of reliability for chlorate candles are not presently available. Good system reliability is expected, however, because adequate redundancy can be provided to compensate for failures of the chlorate ignition system.

Crew time: As previously discussed, chlorate candle oxygen generation systems vary conceptually for repressurization and cabin leakage requirements. The chlorate combustion chamber, relief valves, heat exchangers, and heat exchanger redundancy valving are located outside of the vehicle pressure shell due to the high temperatures of the fluid in this stage of the system. The regulator portion of the system is located

SUBSYSTEM: Oxygen Storage

CONCEPT: Chlorate Candles for Repressurization and Leakage Supply

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: Not available MTBF: Not available

Spares/Redundant (R) Units:

Repressurization Supply
2 - Pressure Regulator
1 - Heat Exchanger (R)

Leakage Supply
2 - Chlorate Candles
50 - Chlorate Candles - Exp.

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
Repressurization	0	0.05
Leakage	12.5	0.05

EQUIVALENT WEIGHT (lb):	Designs 1, 2 and 3 Repressurization	Leakage
Basic Unit	392	5
Expendables	1090	735
Spares/Redundant Units	4	29
Electrical Power	0	0
Thermal Power	0	0
Radiator Load	443	0
Total Equivalent Weight	1929	769

POWER (Watts): None
Electrical
Thermal

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Repressurization	14.6	0.3	14.9
Leakage	1.2	4.3	5.5

Figure 15. (Page 1 of 2)

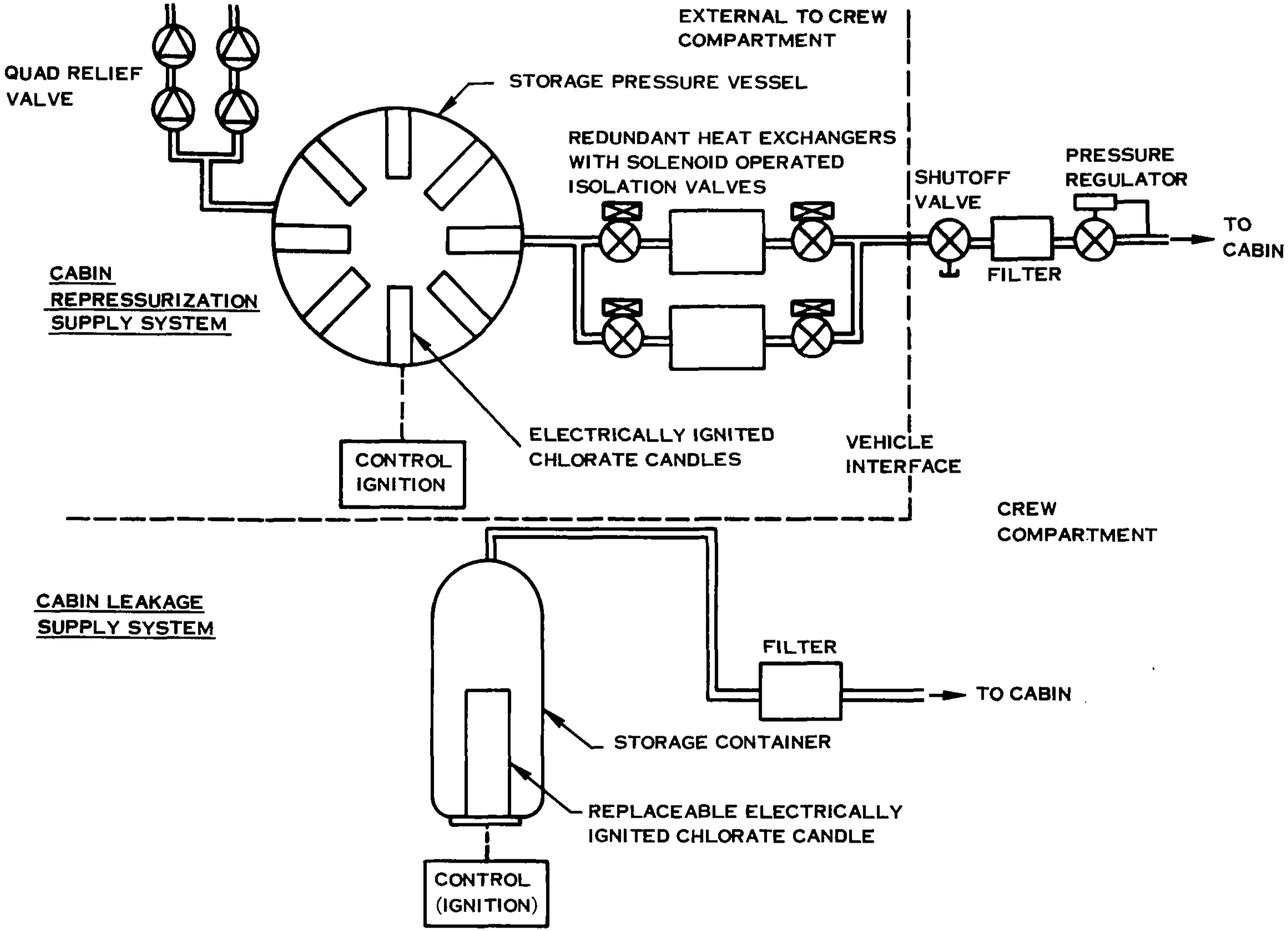


Figure 15. Chlorate Candle Oxygen Supply Concept (Page 2 of 2).

within the vehicle pressure shell and is maintained by plug-in replacement. No scheduled maintenance exists for this system.

Due to the required scheduled replacement of chlorate candles and the difficulty in achieving reaction control for low cabin oxygen leakage rates, a substantially high crew stress is anticipated for this supply system.

Equivalent weight: The utilization of individual sodium chlorate oxygen supply systems for repressurization and cabin leakage results in the equivalent weights summarized in figure 15. Since this electrical power required is negligible, the electrical power penalties are the same for all designs.

Secondary criteria. - The only potential contamination problem with the chlorate candle concepts would be the inability of chemical additives to inhibit the production of chlorine gas. Interface characteristics are very good; the leakage system requires a manual replacement of candles while the repressurization use requires an interface with the space radiator for heat rejection. Flexibility is limited because, once a candle is ignited, the reaction cannot be controlled. Growth characteristics are good because gas quantity requirements can be handled by simply igniting the stored candles as required. The total system volumes for the chlorate candle concepts are very low due to the high density of sodium chlorate. Power required is negilible because the only power required is that necessary to ignite the candles.

Hydrogen Peroxide

Hydrogen peroxide, stored as a liquid in bladdered tanks at low pressures, reacts with a catalyst (silver wire screen) to produce oxygen and water ($2H_2O_2 \rightarrow 2H_2O + O_2$). The actual mass ratio of H_2O/O_2 is 1.36. The oxygen and water produced have a residual hydrogen peroxide content of one and ten ppm, respectively. An absorbent bed is required to remove hydrogen peroxide vapor from the oxygen stream. The reaction is exothermic and the heat of reaction is equal to 2630 Btu/lb O_2. During cabin repressurization, the minimum quantity of heat which must be rejected is 53 600 Btu/hr. Since the adiabatic temperature of decomposition is approximately 1370° F, the repressurization supply system is provided with its own space radiator. Due to the substantial heat rejection requirements for high oxygen generation rates, a hydrogen peroxide system is inherently better suited to conditions of low utilization rate. An optimized hydrogen peroxide system is shown schematically in figure 16.

Absolute criteria. -

Performance: Hydrogen peroxide oxygen generation systems are highly advantageous in situations where a water deficit exists. About 0.6 to 0.7 pounds per day of water can be made available. A water separator is required to separate and deliver water and oxygen to the individual storage reservoirs prior to delivery.

Safety: The presence of hydrogen peroxide in the cabin constitutes a safety problem because of its high toxicity. Concentrated H_2O_2 blisters the skin on contact, and vapors and aerosols entrained with the oxygen are harmful to the human respiratory system. Most structural materials act as a catalyst with H_2O_2 on contact.

Availability/confidence: A hydrogen peroxide system designed to produce up to 0.2 lb/hr of oxygen for 24 hours has been fabricated. Problems with the combined phase separator/storage vessel were encountered during development. The contaminants caused the porous nonwettable filter to pass liquid into the vapor storage area. Additional development, however, can be expected to remedy this problem. It appears that bladder materials are available which result in a low hydrogen peroxide decomposition rate for periods greater than one year. Hydrogen peroxide systems have also been used by the Navy for aircraft carrier catapult propulsion systems and other uses. Although zero-gravity operation must be demonstrated, it is expected that workable flight hardware could be produced by 1976.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 131 500 hours. Storage tank redundancy is required. The optimum number of tanks for reliability/weight effectiveness is five tanks, each of which stores 25 percent of the mission requirement. A quad-relief valve (four check valves arranged to provide fail-safe operation), a redundant heat exchanger, and five additional miscellaneous spares are required to achieve a reliability of 0.999558.

Crew time: The bladder-type supply tanks, catalytic reactors, heat exchangers, and associated automatic valving are located outside of the vehicle pressure shell due to the nature and temperature of the fluid in this stage of the system. Hence, a redundant tank and a redundant heat exchanger are required, because flight replacement of these items is prohibitively time consuming and hazardous. All other portions of this system are located within the vehicle pressure shell and, since the fluid within the lines is safe once the H_2O_2 supply is shut off, the lines may be opened.

Equivalent weight: The total equivalent weight of the hydrogen peroxide oxygen supply system for repressurization and cabin leakage requirements is summarized in figure 16. Differences do not exist between the concepts for the three power supply designs because electrical power is not required.

Secondary criteria. - The escape of hydrogen peroxide vapor to the cabin constitutes a potential area of contamination. The hydrogen peroxide concepts for cabin leakage and repressurization supply contain two common interfaces: pressure supply and water supply (to the potable water tanks). The repressurization concept contains a third interface with a space radiator for heat rejection. Considerable flexibility is achieved, since potable water is produced along with the oxygen. Although the generation rate can be controlled, the overall growth potential is limited by the amount of

SUBSYSTEM: Oxygen Storage

CONCEPT: Catalytic Decomposition of Hydrogen Peroxide for Repressurization and Leakage Supply

FLIGHT AVAILABILITY: 1976
(1970 go-ahead)

RELIABILITY: 0.999558

MTBF: 131 500

Spares/Redundant (R) Units:

- 1 - Hydrogen Peroxide Storage Tank
- 2 - Pressure Regulator
- 1 - Peroxide Vapor Absorber
- 2 - Phase Separator (R)
- 1 - Heat Exchanger (R) - For Repressurization Supply Only
- 1 - 2-Way Solenoid Valve (R) - For Repressurization Supply Only
- 1 - Relief Valve (R)
- 1 - Pressure Gage (R)
- 1 - Fill Valve (R)

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	0	0.1

EQUIVALENT WEIGHT (lb):	Designs 1, 2, and 3	
	Repressurization	Leakage
Basic Unit	246	172
Expendables	870	567
Spares/Redundant Units	314	191
Electrical Power	0	0
Thermal Power	0	0
Radiator Load	2160	3
Total Equivalent Weight	3590	933

POWER (Watts): None
Electrical
Thermal

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Repressurization	17.0	3.6	20.6
Leakage	12.0	2.6	14.6

Figure 16. (Page 1 of 2).

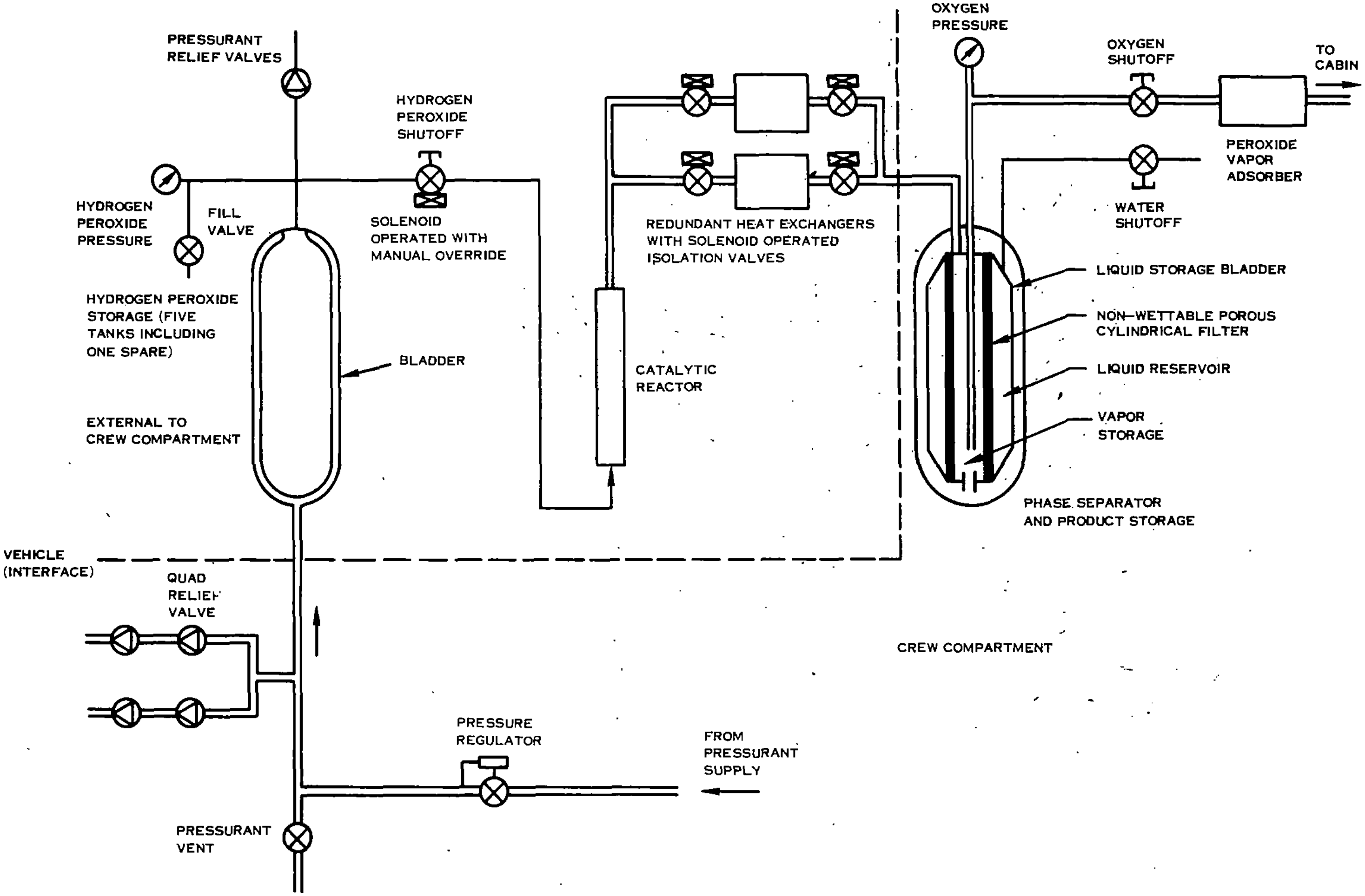


Figure 16. Hydrogen Peroxide Oxygen Supply Concept (Page 2 of 2).

H_2O_2 available and the long term decomposition of the hydrogen peroxide. No noise-producing components are required for system operation. The volume requirements of either the leakage or the repressurization supply system are average among the candidates evaluated. Power quality is excellent because no power-consuming components are required.

Hydrazine/Nitrogen Tetroxide Reaction

A concept which extends the use of storable rocket bipropellants of hydrazine and nitrogen tetraoxide into the life support area has been proposed. The system reacts hydrazine (N_2H_4) with hydrogen peroxide (H_2O_2) or nitrogen tetroxide (N_2O_4) as an oxidizer to produce an oxygen/nitrogen mixture and water. The use of nitrogen tetroxide results in a lower water production rate than with hydrogen peroxide. The heat rejection requirements utilizing nitrogen tetroxide are substantially lower than with hydrogen peroxide. Moreover, employing nitrogen tetroxide as an oxidizer results in a significantly lower total weight of reactants required (over hydrogen peroxide). Thus, nitrogen tetroxide is selected over hydrogen peroxide as an oxidizer in the concept considered here to react with hydrazine (the fuel). This system is shown schematically in figure 17.

Absolute criteria. -

Performance: The reactants of hydrazine and nitrogen tetroxide burn hypergolic ally over a wide range of mixture ratios and pressures to produce the desired oxygen and nitrogen inflow rates required for leakage makeup and repressurization. Neither oxidizer can deliver 100 percent pure oxygen, but both can provide 100 percent nitrogen. Adequate composition control, therefore, is provided.

Safety: The presence of stored quantities of nitrogen tetroxide and hydrazine represents a significant area of concern in the event of supply line rupture due to the nature of these fluids. Adequate provisions must be made to prevent crew exposure to the unreacted quantities of fuel and oxidizer.

Availability/confidence: No development work has been performed on the nitrogen tetroxide/hydrazine gas supply system described. Similar systems have been utilized, however, for rocket propulsion, but the requirements of supplying breathable gas for human consumption dictate that extensive development effort is required to produce flight hardware.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 112 000 hours. Both the hydrazine and the nitrogen tetroxide tanks require redundancy. The optimum number of tanks for reliability/weight effectiveness is five tanks of each type, each of which stores

25 percent of the mission requirement. Relief valves, a redundant heat exchanger, a redundant metering device, and three additional miscellaneous spares are required to achieve a reliability of 0.999464.

Crew time: The bladder-type supply tanks, gas generator, catalyst bed, heat exchangers, and associated automatic valving are located outside of the vehicle pressure shell due to the nature and temperature of the fluid in this stage of the system. Hence, redundant tanks, a fuel and oxidizer metering device, and a heat exchanger are required, because flight replacement of these items would be prohibitively time consuming and hazardous. All other portions of this system are located within the vehicle pressure shell, and, since the product fluids are safe, the lines may be opened and maintained in the event of a failure. No scheduled maintenance exists for this system.

Equivalent weight: The items comprising the total equivalent weight of the hydrazine/nitrogen tetroxide gas supply system are summarized in figure 17. No power is required, and all designs are identical.

Secondary criteria. - The storage and reaction of hypergolic propellants represents a significant potential area of contamination. The hydrazine/nitrogen tetroxide concept for cabin leakage and repressurization supply contain two common interfaces: pressurant supply and potable water delivery. The repressurization supply system contains a third interface with a space radiator for heat rejection. Considerable flexibility is achieved since potable water is produced with the oxygen and the oxygen/nitrogen mixture ratio which can be varied. The overall growth characteristics are limited to the supply of fuel and oxidizer available, although the rate of oxygen/nitrogen supply can be controlled. No noise-producing components are employed. The exhaust noise of the product gas is common to all candidates evaluated and, therefore, is not considered in a relative comparison. The volume of both the leakage and repressurization supply systems are among the highest of the candidates considered. No power consuming components are required for system operation.

Supercritical Cryogenic Storage with Thermal Pressurization

Cryogenic systems may be used for oxygen or nitrogen, and they are classified by the storage state, method of pressurization, and delivery state. Cryogens may be stored either as a single phase homogeneous fluid or as a two-phase liquid/vapor mixture which requires separation. Oxygen and nitrogen cryogenic storage systems are discussed jointly since no differences exist in the implementation.

Figure 18 illustrates a generalized pressure-enthalpy diagram for either oxygen or nitrogen. This diagram separates the fluid properties into two distinct regions: the single-phase region and the two-phase (liquid and vapor) region. The portion of the single-phase region to the left of the saturated liquid line (and below the critical pressure) is compressed (or subcooled) liquid. The portion to the right of the saturated

SUBSYSTEM: Oxygen and Nitrogen Storage

CONCEPT: Hydrazine/Nitrogen Tetroxide Reaction for Repressurization and Leakage Supply

FLIGHT AVAILABILITY: 1980
(1970 go-ahead)

RELIABILITY: 0.999464 MTBF: 112 000

Spares/Redundant (R) Units:

1 - Nitrogen Tetroxide Storage Tank (R)
1 - Hydrazine Storage Tank (R)
1 - Heat Exchanger (R)
2 - Pressure Regulator
1 - Reactant Metering Device (R)
1 - Phase Separator and Storage Tank

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	0	0.1

EQUIVALENT WEIGHT (lb):

	Design 1, 2 and 3 Repressurization	Leakage
Basic Unit	474	316
Expendables	1508	1021
Spares/Redundant Units	530	341
Electrical Power	0	0
Thermal Power	0	0
Radiator Load	3640	4
Total Equivalent Weight	6152	1682

POWER (Watts): None
Electrical
Thermal

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Repressurization	26.0	5.2	33.2
Leakage	18.5	3.3	21.8

Figure 17. (Page 1 of 2).

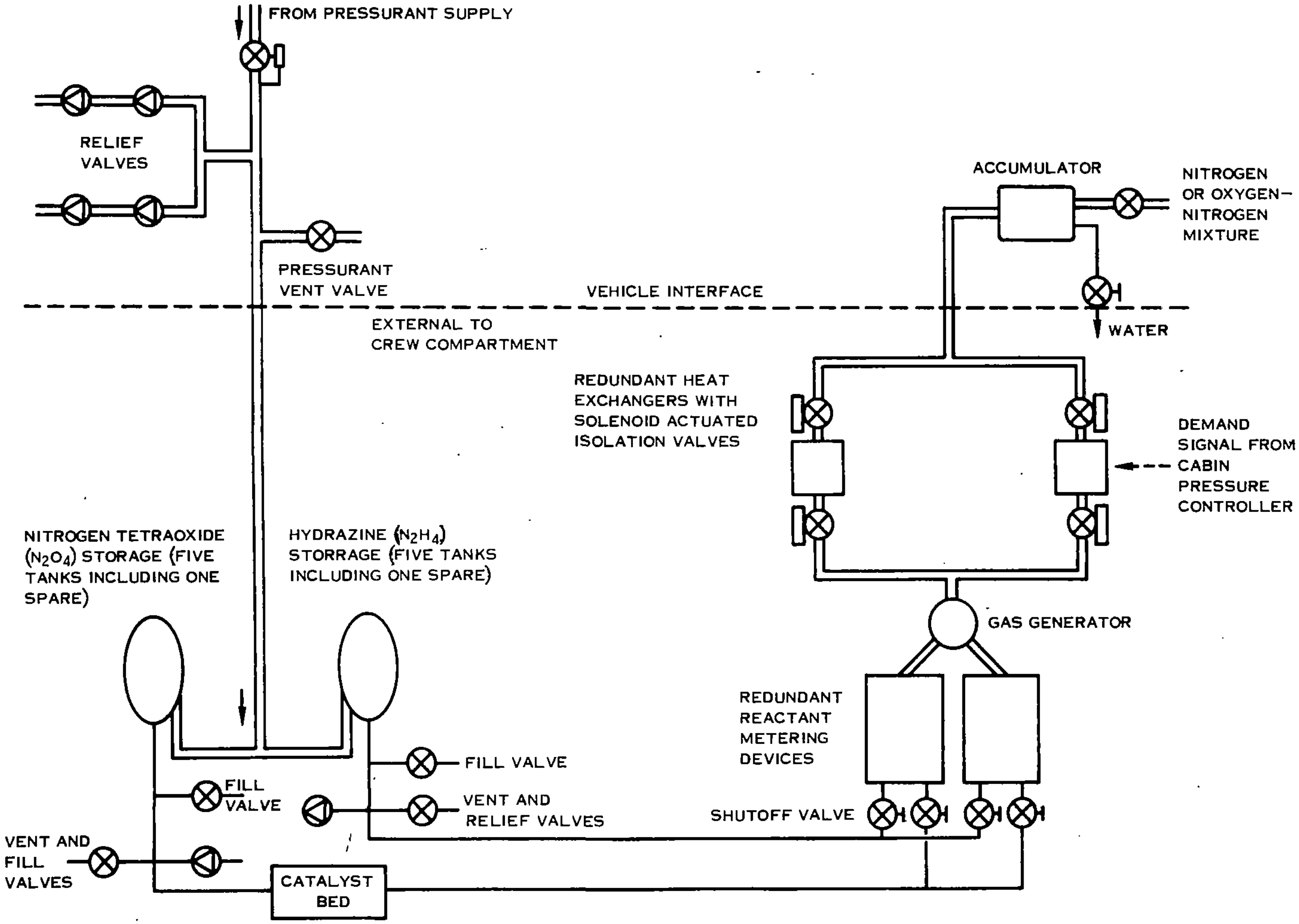


Figure 17. Hydrazine/Nitrogen Tetroxide Chemical Storage Concept (Page 2 of 2)

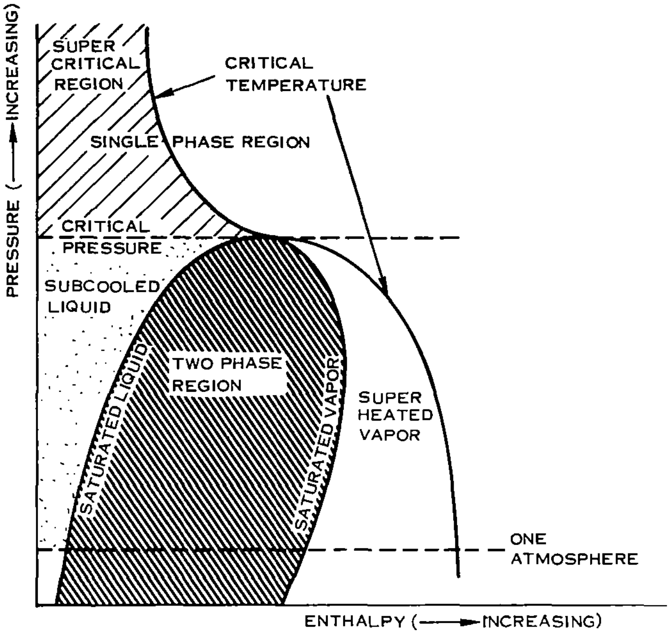


Figure 18. Generalized Pressure/Enthalpy Diagram

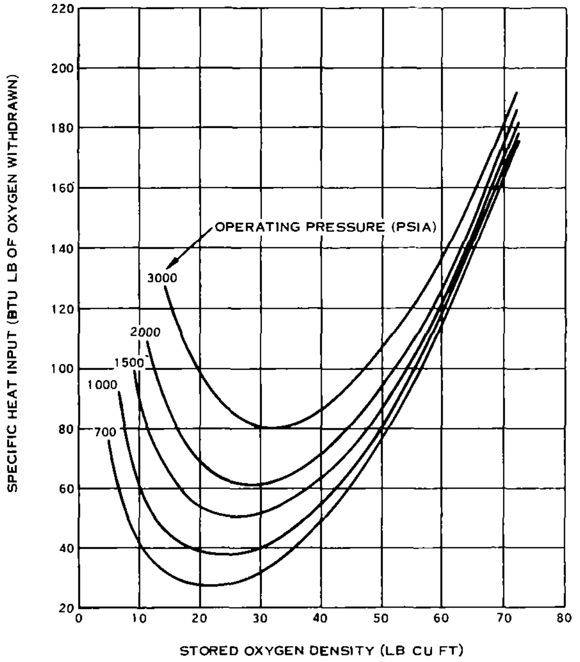


Figure 19. Specific Heat Input for Isobaric Operation - Supercritical Oxygen

vapor line (and below the critical pressure) is superheated vapor. The portion of the single-phase region lying above critical pressure (and connecting the compressed liquid and superheated vapor regions) is the supercritical region. The fluid in this region is characterized as being a homogeneous single-phase mixture of liquid and vapor.

Supercritical storage simplifies the problems of zero-gravity delivery and fluid quantity measurement. The primary consideration in the design of supercritical storage vessels is in balancing the heat transfer properties of the insulation system with the thermodynamic properties of the stored cryogen within the specified mission requirements. Early supercritical oxygen storage systems utilized power supplied to an extended surface electrical heater located within the inner storage sphere to provide the energy required to deliver fluid. The specific heat required per unit mass of fluid withdrawn from a storage vessel at constant pressure is a function solely of the thermodynamic properties of the stored fluid and, for oxygen, this is shown in figure 19. It can be observed from the shape of the curves that: 1) the specific energy requirements for withdrawal are increased with increasing constant pressures, and 2) during a typical delivery, the specific energy requirements for withdrawal at a constant pressure decreases to a minimum and then increases at lower densities.

The cryogenic storage selected for the Biosatellite program, with a basic mission of one month (twice that of the Gemini mission), required the development of second generation hardware to fulfill the mission requirements. For the AILSS study evaluation, a technique is selected that supplies added insulation performance by utilizing the refrigeration capacity of the existing cryogen. This is accomplished by providing a concentric vapor-cooled shield within the evacuated annulus attached to the delivery line. Exiting fluid cools the shield, reducing heat transfer to the cryogen and increasing the fluid temperature. This barrier consists of a metallic foil with highly reflective surface facing outward.

Absolute criteria. -

Performance: The storage of low boiling point fluids such as oxygen and nitrogen, at cryogenic conditions has, in the past, provided a definite weight advantage over high pressure gaseous storage for large fluid quantities. The higher fluid storage density at low to moderate pressures for cyrogenic systems gives rise to reduced storage vessel weight per unit of stored mass. This advantage is offset by limited rate of expulsion, sensitivity to environmental heat leak, increased complexity of delivery (especially in zero gravity), and limited periods of nonvented standby.

Pressurization and expulsion is accomplished by providing the fluid with thermal energy. This method of isobaric energy addition for the evaluated supercritical concept is shown in figure 20. The delivery fluid is withdrawn and heated by the thermal transport loop to ambient temperature. The warm high pressure fluid passes into a tank pressure sensing flow control valve. A varying portion of the gas is directed to

SUBSYSTEM: Oxygen and Nitrogen Storage

CONCEPT: Supercritical Cryogenic with Thermal Pressurization

FLIGHT AVAILABILITY: 1973 (The data below correspond to 1979 technology)
(1970 go-ahead)

RELIABILITY: 0.999394 MTBF: 80 600

Spares/Redundant (R) Units:

1 - Pressure Control Heat Exchanger
1 - Warmup Heat Exchanger
2 - Pressure Regulator
2 - Delivery Selector Valve
3 - Pressure Transducer

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
Oxygen or nitrogen	0	0.2

EQUIVALENT WEIGHT (lb):	Design 1, 2 and 3	
	Oxygen	Nitrogen
Basic Unit	300	326
Expendables	727	644
Spares/Redundant Units	12	12
Electrical Power	0	0
Thermal Power	0	0
Radiator Load	0	0
Total Equivalent Weight	1039	982

POWER (Watts): None
Electrical
Thermal

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Oxygen	32.6	0.6	33.2
Nitrogen	45.2	0.6	45.8

Figure 20. (Page 1 of 2).

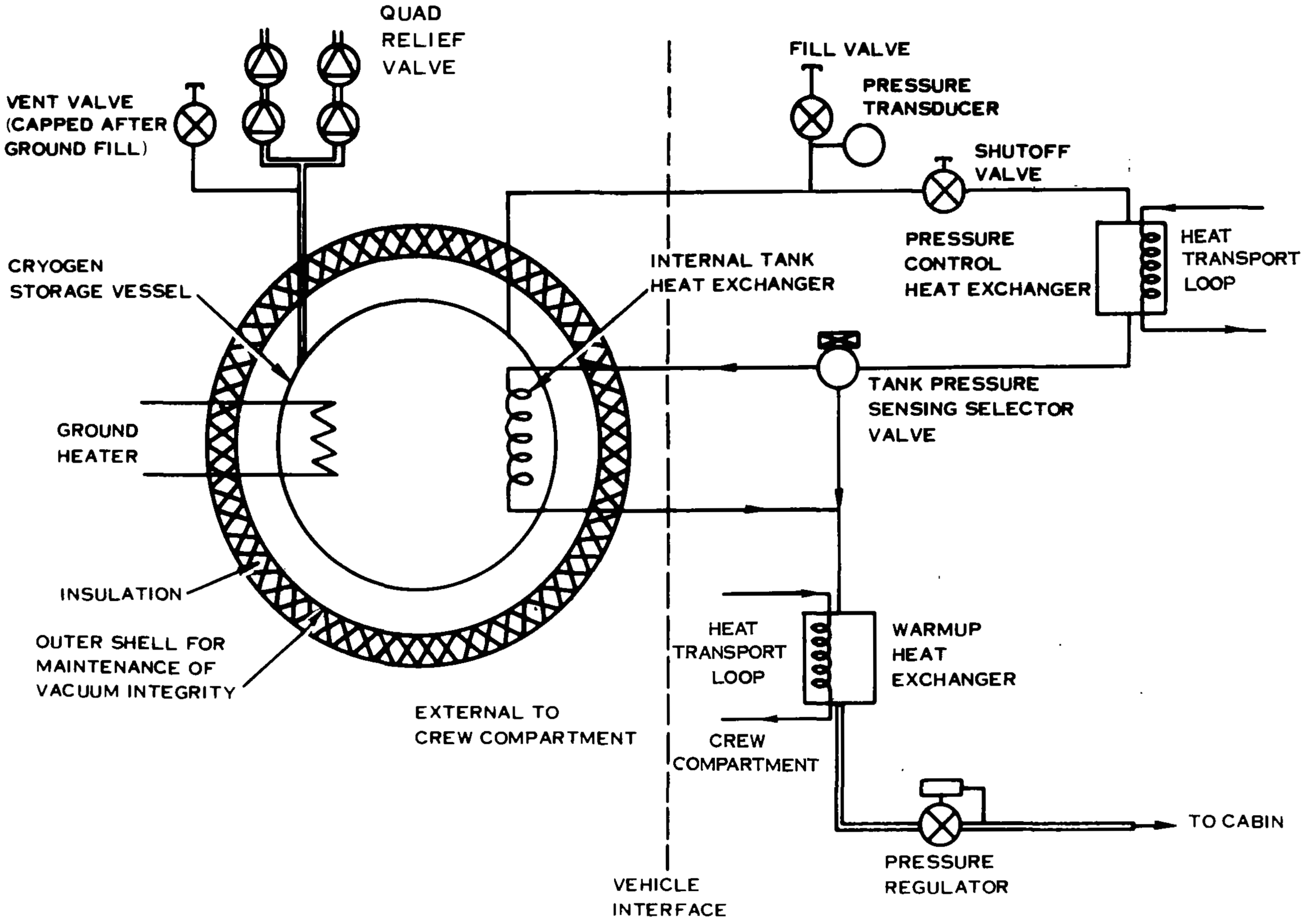


Figure 20. Supercritical Storage System (Page 2 of 2).

a heat exchanger within the storage vessel providing energy for repressurization and maintaining isobaric operation. The gas is directed into a second heat exchanger for reheating prior to delivery to the cabin. The electrical heater shown is used only for ground operation.

Fluid quantity measurement in a supercritical storage system is simplified, because the mass of the homogeneous fluid remaining in the vessel is directly proportional to the fluid density which may be determined by a capacitance matrix that measures the fluid dielectric constant. An alternate method, which has been used, is to measure the power required to drive a small fan immersed in the tank. This also eliminates temperature stratification within the fluid and provides higher heat transfer coefficients for internal energy exchange.

Cryogenic storage systems require somewhat different pressure control methods than high pressure storage systems. The allowable cabin pressure regulation band is such that oxygen and nitrogen for cabin leakage are demanded only every 10 days. Since this dwell would overpressurize the storage tanks, the oxygen boiloff must be dumped directly to the cabin. Cabin oxygen partial pressure is controlled by regulating the water flow rate to the oxygen generation subsystem. If excessive boiloff occurs, it is dumped overboard. Nitrogen boiloff is valved so that it can be dumped overboard in the event that cabin leakage is lower than the target rate.

Safety: The presence of moderate storage pressures (600 to 1000 psi) and cryogenic fluids constitutes a potential safety problem. No other areas of concern are apparent in the supercritical storage concept.

Availability/confidence: Supercritcal storage systems have been utilized on all manned space flights to date, with the exception of Mercury, and are being or have been developed for the MOL and AAP flights with mission durations of up to 56 days. Confidence in achieving mission durations of 500 days with a supercritical system is good.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 80 600 hours. No tank redundancy is required from a reliability standpoint. The major portion of the reliability penalty is incurred in the pressure control section. The pressure control equipment is installed within the vehicle and should be readily accessible and maintainable. A quad-relief valve, pressure transducer voting circuit, and nine additional miscellaneous spares are required to achieve a reliability of 0.999394.

Crew time: The bladderless cryogenic storage vessel with its internal components is nonmaintainable and is located outside of the vehicle pressure shell. All other portions of this system are located within the vehicle pressure shell and, since the delivered fluid is safe, the lines may be opened and items maintained by replacement as required. No schedule maintenance exists for this system.

Equivalent weight: The supercritical storage systems are sized to supply both repressurization and cabin leakage requirements, since the inherent boiloff can supply leakage demands. A supercritical system sized for repressurization only has essentially the same equivalent weight as one sized for both requirements, since the boiloff has to be vented to prevent tank overpressurization. The supercritical concept is not penalized for the heating required during repressurization, since this can be provided at a zero penalty by waste heat.

Secondary criteria. - No potential areas of contamination are evident in the supercritical cryogenic storage system. The interfaces are limited to a heating fluid between the cryogenic heat exchangers and the space radiator. Flexibility is somewhat limited, because a lower leakage rate (less than 1 lb/day) would require insulation system improvements that are beyond the state-of-the-art (or an equivalent weight penalty with projected 1979 insulation system performance). Moreover, the use of smaller tanks would impose the same penalties. Increased cabin leakage rates, however, could be provided quite easily, since insulation performance would become less critical. The peculiar withdrawal characteristics of fluid in the supercritical state somewhat limits the growth gains to be achieved through development. No noise producing components are inherent in the supercritical storage system. The total system volume is relatively good in relation to the candidates evaluated. The power quality is excellent, since waste heat is supplied for thermal energy.

Subcritical Cryogenic Storage with Thermal Pressurization

The extension of missions beyond 90 days, coupled with the withdrawal characteristics of supercritical fluid and the insulation requirements of supercritical systems, has led to the development of subcritical storage systems. For ground service, these systems have been well established. However, the zero-gravity storage and delivery of a two-phase mixture requires significant development effort.

Figure 21 illustrates the specific energy requirements for fluid withdrawal for various subcritical delivery modes (as well as supercritical). The higher minimum and more constant specific energy requirements for subcritical storage allows for reduced insulation requirements and eliminates venting losses during periods of minimum usage rate. Figure 22 shows such a system. The method of fluid delivery utilizes selective phase withdrawal to achieve maximum thermodynamic performance. The system is sized so that the minimum vent rate equals the minimum use rate requirements (i.e., the vent rate for the oxygen tanks equals the oxygen portion of cabin leakage). Thus, no fluid dumping is required to maintain isobaric operation, as would be required in a supercritical system.

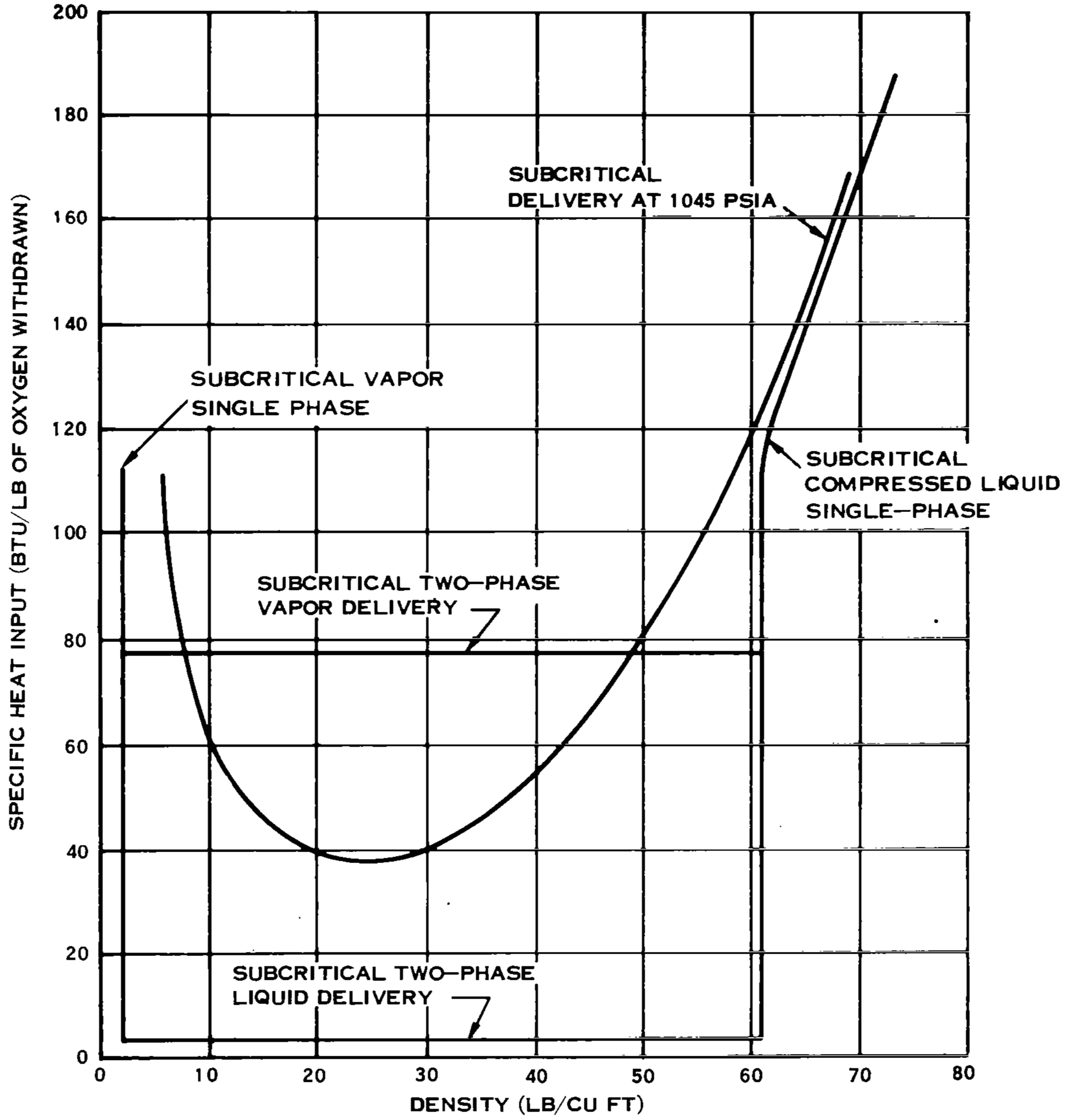


Figure 21. Specific Energy Input for Isobaric Operation - Oxygen

After tank pressure has built up to operating pressure, and the shutoff valve is opened, fluid delivery can begin. Fluid selection (either liquid or vapor) is dependent on tank pressure. As flow rate increases, tank pressure decays and the selector valve permits low energy fluid (liquid) to be withdrawn from the tank. The fluid passes through the annular space without making contact with the vapor-cooled shields, causing some degradation in insulation performance. The fluid is warmed to ambient temperature in the external pressure control heat exchanger and then flows back through the evacuated annular space, where it passes through the internal tank heat exchangers. Heat is transferred to the stored cryogen to provide energy for pressurization so as to maintain isobaric operation. The fluid is then directed to an external warmup heat exchanger where it is heated to ambient temperature for delivery.

During periods of low demand, when tank pressure is high, the selector valve allows vapor (high energy fluid) to be drawn. The exiting vapor absorbs heat from the annular shields, the outer shell, and from the external shields, thus reducing heat transfer to the stored cryogen. No warmup heat exchanger is required because the vapor leaving the outermost shield is warm enough to be used directly.

This method of maintaining isobaric operation by phase withdrawal selection during zero-gravity operation requires that the liquid and vapor phases of the stored cryogen be properly oriented. Several concepts are available for achieving phase orientation of the stored cryogen phases. Vapor delivery can be ensured at one end of the storage vessel by utilizing nonwetting surfaces, while liquid withdrawal is provided by passive surface tension devices. A second method employed uses a concept of throttling the liquid to a lower temperature and vaporizing it with heat supplied by the stored cryogen. A different approach employs a capillary wick device to ensure liquid delivery. Advanced methods of phase separation such as dielectrophoresis are currently being investigated.

Absolute criteria. -

Performance: Short-term performance data indicates that the AILSS specification can be met by both oxygen and nitrogen subcritical tankage. Some projection in the state of the art of insulation is required to meet the minimum flow requirements without additional boiloff. Positive phase control and lower operating pressures are the significant differences between the subcritical and supercritical concepts.

Safety: Since the storage pressures are low (50 psia), only the presence of cryogenic fluids would constitute a potential safety problem.

Availability/confidence: In the proposed subcritical storage system, most items have been developed and qualified on the Gemini and Biosatellite programs. The proposed method of fluid quantity measurement uses an integrating flowmeter currently under development. Thus, extensive development is not anticipated on external system components. Significant effort, however, is required to ensure phase orientation under

SUBSYSTEM: Oxygen and Nitrogen Storage

CONCEPT: Subcritical Cryogenic Storage with Thermal Pressurization

FLIGHT AVAILABILITY: 1977 (The data below corresponds to 1979 technology)
(1970 go-ahead)

RELIABILITY: 0.999595 MTBF: 81 400

Spares/Redundant (R) Units:

- 2 - Pressure Regulator
- 2 - Delivery Selector Valve
- 1 - Warmup Heat Exchanger
- 3 - Pressure Transducer

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
Oxygen or Nitrogen	0	0.2

EQUIVALENT WEIGHT (lb):	Design 1, 2 and 3	
	Oxygen	Nitrogen
Basic Unit	236	278
Expendables	668	598
Spares/Redundant Units	12	12
Electrical Power	0	0
Thermal Power	0	0
Radiator Load	0	0
Total Equivalent Weight	916	888

POWER (Watts): None
Electrical
Thermal

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Oxygen	31.6	0.6	32.2
Nitrogen	44.2	0.6	44.8

Figure 22. (Page 1 of 2).

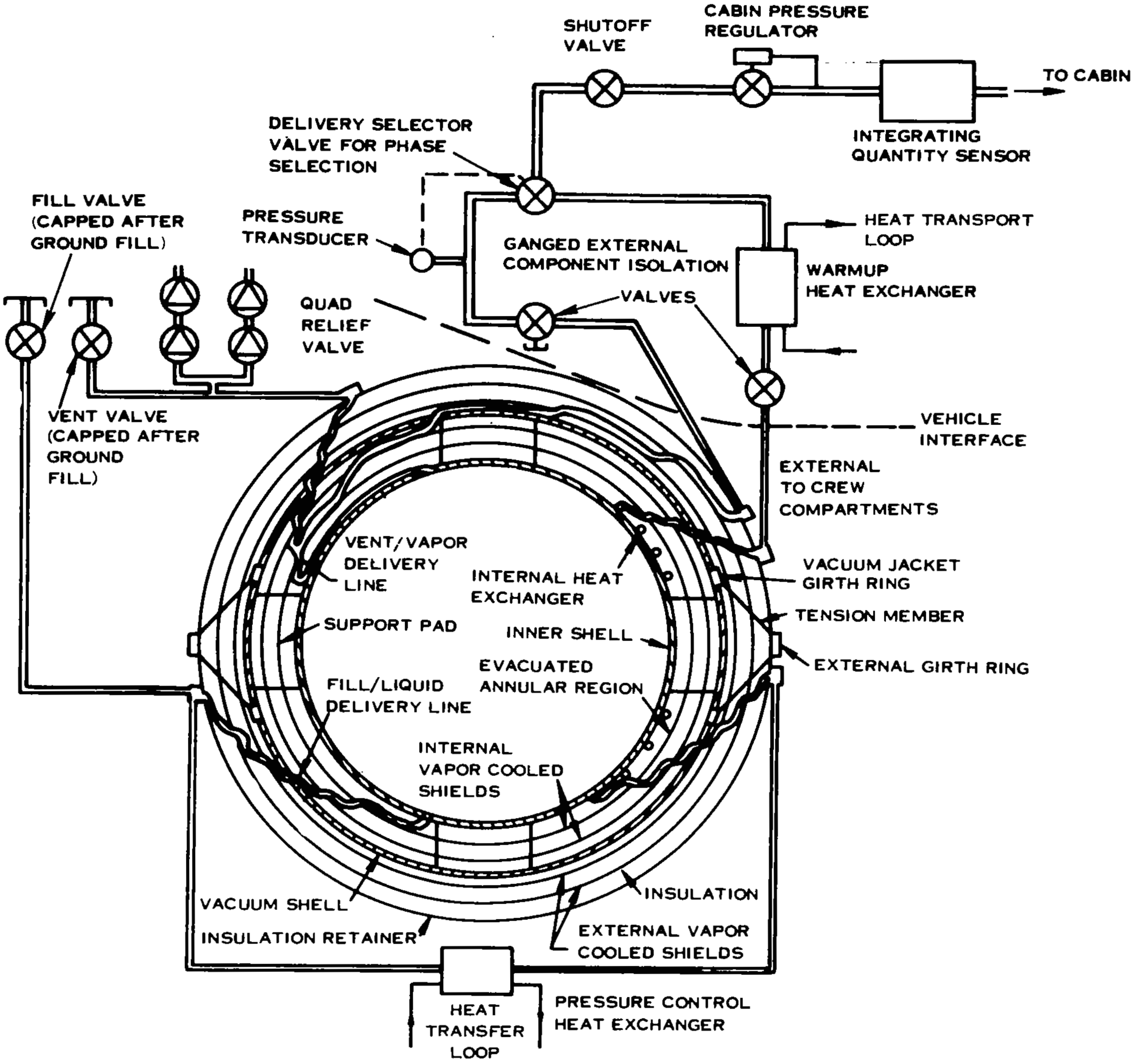


Figure 22. Subcritical Cryogenic Storage System (Page 2 of 2)

zero-gravity operation and to demonstrate the feasibility of the insulation techniques on missions with durations exceeding one year.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 81 400 hours. No tank redundancy is required from a reliability standpoint. The major portion of the reliability penalty is incurred in the pressure control section. This equipment is installed within the vehicle and should be readily accessible and maintainable. Such measures as the use of a quad-relief valve, a pressure transducer voting circuit, capping the fill and vent valves after filling the system, and improving the external heat exchangers have been used to achieve a reliability of 0.999595 for 500 days. A completely redundant external fluid circuit can be provided at the expense of increased weight to achieve a reliability greater than 0.999595.

Crew time: The cryogen storage vessels with internal components are located outside of the vehicle pressure shell. All other portions (warmup heat exchangers, delivery selector valve, integrating fluid quantity sensor, etc.) are located within the vehicle pressure shell. These items can be isolated and replaced as required by failure. Since the system provides fully automatic delivery once the vented standby mode is reached, scheduled maintenance is not anticipated.

Equivalent weight: The subcritical storage systems are sized to supply both repressurization and cabin leakage requirements, since the inherent boiloff can supply leakage demands. A subcritical system sized for repressurization only would have essentially the same equivalent weight as one sized for both requirements, since the boiloff would have be vented to avoid tank overpressurization (at a considerable sacrifice in reliability). The total equivalent weight is noted in figure 22.

Secondary criteria. - Potential areas of contamination are not apparent in the subcritical storage concept. The only interface required is between the cryogenic heat exchangers and the thermal transport loop. Considerable flexibility can be achieved in that an increase in cabin leakage above the target of one lb/day will reduce the required insulation system performance (i.e., more heat leak can be allowed to the stored cryogen). However, the performance penalty for a lower-than-target leakage rate or an increase in the number of tanks (smaller tanks for redundancy) more than offsets this flexibility. Growth is limited to expected development gains. The flat specific energy of a fluid withdrawal curve for a subcritical system allows significant insulation system optimization (which cannot be achieved for a supercritical system due to its peculiar withdrawal energy requirements). As with all the gas storage candidates evaluated, no noise producing components are present. The total volume for the thermally-pressurized subcritical system for oxygen and nitrogen is one of the lowest total system volumes of the candidates evaluated. Power quality is excellent because heating for repressurization is supplied by waste heat.

EVALUATION AND SELECTION - OXYGEN STORAGE

Designs 1, 2, and 3

High pressure filament wound tankage is selected for oxygen storage for all three power systems. A summary chart of the eleven candidates and their relative ratings with respect to the evaluation is shown in table 6. The use of water electrolysis for cabin oxygen leakage make-up offers no weight advantage and penalizes reliability. As a result, combination oxygen supply system was not selected.

Absolute criteria. - Of the eleven specific concepts evaluated, three are given unacceptable absolute criteria ratings and are rejected. These are solid cryogenic storage, alkali and alkaline earth peroxides and superoxides, and subcritical cryogenic storage with positive expulsion. Concepts which deliver both oxygen and nitrogen (as a mixed gas) are evaluated under the nitrogen storage equipment selection discussion. All other candidates have acceptable absolute ratings.

Primary criteria. - Of the eight remaining oxygen storage concepts, two are eliminated due to excessively high total equivalent weights. These are the chlorate candle and catalytic decomposition of hydrogen peroxide concepts for oxygen storage. A summary of the primary criteria is shown in table 7.

Secondary criteria. - The six remaining concepts are carried through the secondary criteria level, where an oxygen storage concept is selected. Of these candidates, four receive similar overall primary and secondary criteria ratings which have much lower reliability and less flexibility than the other two. These four concepts are the supercritical cryogenic, the subcritical cryogenic, and the combination concepts utilizing high pressure gaseous storage in conjunction with an oversized electrolysis unit for leakage supply. Thus, on the basis of poorer overall primary and secondary characteristics, these concepts are eliminated. The two remaining concepts utilize high pressure gaseous storage for both repressurization and leakage supply and differ only in the tankage material utilized. The ratings of these two concepts are very similar with respect to both primary and secondary criteria. However, the lower equivalent weight and increased growth potential of the filament-wound tankage is considered sufficient to offset the increased development required and result in its selection for the AILSS.

Selection: - The high pressure gaseous storage utilizing filament-wound tankage is selected to fulfill the oxygen storage requirements for the AILSS mission for both repressurization and leakage make-up purposes.

TABLE 6
EVALUATION SUMMARY - OXYGEN STORAGE

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		High pressure gaseous storage		High pressure gaseous storage & an oversized electrolysis unit.		Cryogenic Storage
		Steel tankage	Filament-wound tankage	Steel tankage	Filament wound tankage	Solid Cryogenic Storage
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Good	Good	Good	Good	Unacceptable
	Safety	Good	Good	Good	Good	Fair
	Avail./Conf.	Very good	Good	Very good	Good	Fair
						Eliminated
Primary	Reliability	Very good	Very good	Good	Good	
	Crew Time	Very good	Very good	Very good	Very good	
	Equivalent Weight	Good	Very good	Good	Very good	
Secondary	Contamination	Very good	Very good	Very good	Very good	
	Interfaces	Very good	Very good	Fair	Fair	
	Flexibility	Very good	Very good	Good	Good	
	Growth	Good	Very good	Very good	Very good	
	Noise	Very good	Very good	Very good	Very good	
	Volume	Good	Good	Very good	Very good	
	Power	Very good	Very good	Good	Good	
		Eliminated	Selected	Eliminated	Eliminated	

TABLE 6
EVALUATION SUMMARY - OXYGEN STORAGE - Concluded

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Chemical storage			Cryogenic storage		
		Alkali & alkaline earth peroxides & superoxides	Chlorate candles Repress./leakage	Cataltyic decomposition of H_2O_2 Repress./leakage	Subcritical with positive expulsion	Subcritical thermal press.	Supercritical with thermal press.
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Unacceptable	Fair/Good	Good	Good	Good	Good
	Safety	Very good	Good	Fair	Good	Good	Good
	Avail./Conf.	Very good	Very good	Good	Unacceptable	Fair	Good
		Eliminated			Eliminated		
Primary	Reliability		Good	Good		Good	Good
	Crew Time		Fair	Fair		Good	Good
	Equivalent Weight		Poor	Poor		Very good	Very good
			Eliminated	Eliminated			
Secondary	Contamination					Very good	Very good
	Interfaces					Very good	Very good
	Flexibility					Fair	Fair
	Growth					Good	Fair
	Noise					Very good	Very good
	Volume					Good	Good
	Power					Very good	Very good
						Eliminated	Eliminated

TABLE 7
OXYGEN AND NITROGEN STORAGE DATA SUMMARY

Candidates	Total equivalent weight (lb)				Reliability MFBF (hr)	Crew time (hr/mission)
	Oxygen			Nitrogen		
Concepts	Repress.	Leakage	Repress. and Leakage combined	Repress. and Leakage Combined		
High pressure storage[c]						
Stainless steel	N. C.	N. C.	1189	N. C.	328 000	0.05
Filament wound	643	395	1005	981	328 000	0.05
Titanium	N. A.	N. A.	N. A.	1110	328 000	0.05
High pressure storage plus Electrolysis[c]						
Stainless steel	N. C.	N. C.	1165	N. A.	96 500	0.06
Filament wound	643	405	1048	N. A.	96 500	0.06
Chlorate candles	1994	769	2763	N. A.	Not available	12.6
Hydrogen peroxide	3739	933	4617	N. A.	131 500	0.1
Hydrazine/nitrogen tetroxide[a]	6434	1659	8093[a]	—	112 000	0.1
Cryogenic storage[c]						
Supercritical	1059	—[b]	1059	1018	80 600	0.2
Subcritical	938	—[b]	938	926	81 400	0.2

Notes:

N. A. Not appliciable

N. C. Not considered

[a] Used for oxygen and nitrogen supply

[b] Bleed off used for leakage makeup

[c] Based on a single storage tank, one each for oxygen and nitrogen

Oxygen Tankage Optimization

A trade-off study was performed to determine the optimum number of oxygen tanks because of the study ground rule established to require redundancy in the oxygen supply subsystem. Reliability estimates for a varying number of redundant tanks (two full-size, three half-size, etc.) show that the effect of reliability improvement is insignificant for high-pressure gaseous storage. Thus, the optimum number of tanks is selected primarily on the basis of equivalent weight. Figure 23 illustrates the weight variation as a function of the number of tanks for filament-wound tankage, for the AILSS mission. An examination of figure 23 reveals that the weight differential resulting from going from two full-size (high pressure) to three half-size, and from three half-size to four third-size tanks, is approximately 520 and 200 pounds respectively. Increasing the number of tanks to five (quarter-size) results in a weight savings of only 100 pounds and thus, is not considered worthwhile. Therefore, four tanks, each holding one-third the required oxygen, are selected as optimum. The equivalent weight for the selected oxygen storage system (employing tank redundancy) is 1337 pounds. A reexamination of the primary selection contenders reveals that the selection of high-pressure gaseous storage using filament-wound tankage is still valid. Moreover, the filament-wound tankage benefits from the requirement for tank redundancy because the equivalent weight difference between steel and filament-wound tankage obviously increases when the change is made from a single full-sized tank (no redundancy) to redundant tankage. Moreover, the cryogenic candidates are penalized weight-wise even more than the high pressure concepts by tank redundancy (not including two full-sized cyrogenic tanks which are prohibitive from an equivalent weight standpoint). This is due to the fact that the percentage of boiloff per tank increases significantly as the tank size is reduced. Thus, the optimized oxygen storage system selection employs high pressure gaseous storage in filament-wound tankage utilizing four third-size tanks.

EVALUATION AND SELECTION - NITROGEN STORAGE

Design 1, 2, and 3

High pressure tankage for nitrogen storage is selected for all three power supplies. A summary of the candidates and their relative ratings with respect to the evaluation criteria is shown in table 8 and supporting data were shown in figure 7. A discussion of the candidate evaluation follows.

Absolute criteria. - Two of the seven nitrogen storage candidates are eliminated due to an inability to meet the availability/confidence absolute criterion. These are the catalytic decomposition of nitric oxide and subcritical cryogenic storage employing positive expulsion.

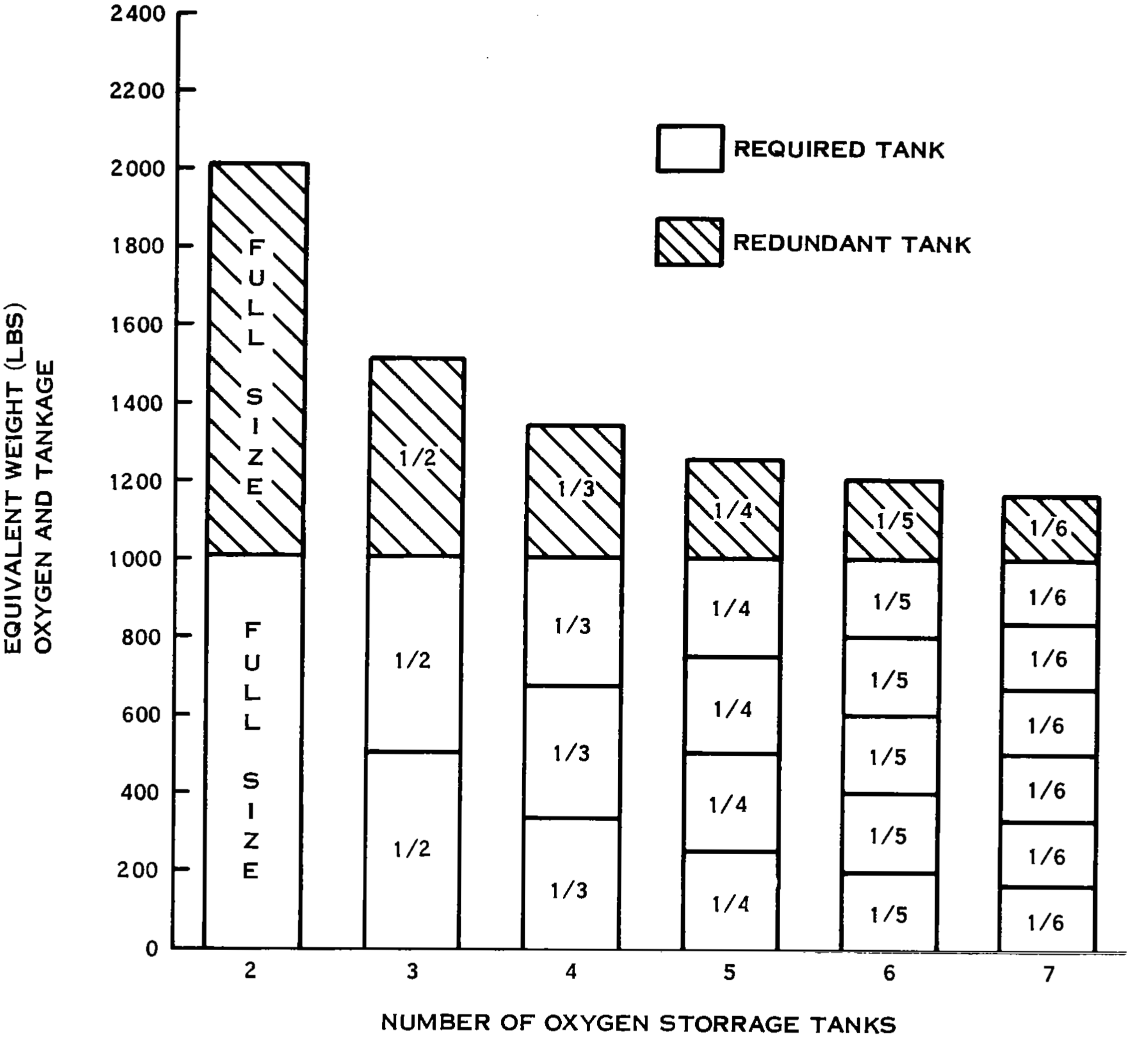


Figure 23. Filament - Wound Tank Modularity Optimization

TABLE 8
EVALUATION SUMMARY - NITROGEN STORAGE

		High pressure gaseous storage		Chemical storage		Cryogenic storage		
		Titanium tankage	Filament wound tankage	Catalytic decomposition of nitric oxide	Hydrazine/nitrogen tetroxide reaction	Subcritical with positive expulsion	Subcritical with thermal pressurization	Supercritical with thermal pressurization
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Good	Good	Good	Good	Good	Good	Good
	Safety	Good	Good	Fair	Fair	Good	Good	Good
	Avail./Conf.	Very good	Good	Unacceptable	Fair	Unacceptable	Fair	Good
				Eliminated		Eliminated		
Primary	Reliability	Very good	Very good		Good		Good	Good
	Crew Time	Very good	Very good		Fair		Good	Good
	Equivalent Weight	Good	Very good		Poor		Very good	Good
					Eliminated			
Secondary	Contamination	Very good	Very good				Very good	Very good
	Interfaces	Very good	Very good				Very good	Very good
	Flexibility	Very good	Very good				Fair	Fair
	Growth	Good	Very good				Good	Fair
	Noise	Very good	Very good				Very good	Very good
	Volume	Good	Good				Good	Good
	Power	Very good	Very good				Very good	Very good
		Eliminated	Selected				Eliminated	Eliminated

Primary criteria. - The hydrazine/nitrogen tetroxide reaction concept, even though it supplies both oxygen and nitrogen, has an equivalent weight substantially higher than comparable concepts. Thus, the hydrazine/nitrogen tetroxide reaction is rejected because of its high equivalent weight. All of the remaining concepts have reasonably competitive primary characteristics.

Secondary criteria. - After completion of the primary criteria evaluation, two cryogenic and two high-pressure gaseous storage concepts remain. Since the cryogenic storage concepts possess relatively poorer primary characteristics (relative to the high-pressure gaseous storage concepts), it is desirable to examine their secondary characteristics to determine whether offsetting factors exist. The significantly poorer flexibility and growth characteristics of the cryogenic concepts in combination with their poorer primary ratings on reliability and crew time are considered sufficient justification for rejection. The slight edge of the subcritical over the supercritical storage system (for equivalent weight and the secondary characteristic of growth) is insufficient to allow its retention. This is especially evident when the Fair relative availability/confidence rating of the subcritical cryogenic storage system is considered. The two remaining candidates are both high-pressure gaseous storage concepts and differ only in the tankage material employed (titanium versus filament-wound). The lower equivelent weight and increased growth potential, however, of the filament-wound tankage are considered sufficient to offset the increased development required and result in its selection.

Selection: - The high-pressure gaseous storage utilizing filament-wound tankage is selected to fulfill the nitrogen storage requirements for the AILSS mission.

SUMMARY

High pressure (3000 psi) gaseous storage utilizing tanks manufactured of filament wound material was selected for use with all three power supplies. A single tank is used for nitrogen storage and four one-third-size tanks for oxygen storage. This form of storage was selected for AILSS because of low crew time demands, high reliability, low weight, and good flexibility. The selection was further supported by the decision to provide oxygen tank redundancy and the relatively low (1 lb/day) vehicle leakage projected for the 500 day AILSS.

IMPACT OF MISSION PARAMETERS

Mission Length

Based on the AILSS selection criteria, high pressure gaseous storage would be selected for both shorter and longer mission lengths.

As the mission duration is progressively decreased from 500 days, the selection of high pressure filament wound tankage becomes more obvious. For a 9 man, 500 day AILSS mission on a single tank basis subcritical cryogenic storage offers a slight weight advantage over high pressure gaseous storage (regardless of the tank material considered). As mission duration decreases the stored quantities required also decrease. The smaller storage tankage has a detrimental effect upon cryogenic systems since the increasing surface area to volume ratio (as mission length decreases) increases the boiloff rate. The magnitude of the cryogenic weight penalty is highly dependent upon vehicle gas leakage and cryogenic insulation system effectiveness. Thus, these statements apply to the specific missions considered and cannot be applied on a general basis. For the specific case cited, the weight advantage of subcritical cryogenic storage over high pressure gaseous storage in filament wound tankage disappears for a mission duration of approximately 300-350 days. For mission durations less than this, filament wound tankage enjoys an increasing weight advantage.

Crew Size

Smaller crew sizes and therefore smaller cabins tend to penalize cryogenic storage systems since the smaller tank sizes significantly increase the boiloff rate. Conversely, larger crew sizes (with resultantly larger storage tanks) reduce the surface area to volume ratio, which has a sizeable impact upon boiloff. However, it must be pointed out again that the expected boiloff rate must be compared to vehicle gas leakage (on an individual case basis) to determine if a weight penalty is associated with excess boiloff.

Power Penalty

Changes in the power penalty have no effect upon any of the candidates evaluated since fluid heating is supplied without penalty via the space radiator (for repressurization supply only) and no power consuming components are required.

Resupply

Resupply is not expected to alter the choice of high pressure gaseous storage. It does tend to favor the high pressure storage tankage because of the single phase nature of the gas, and the relatively easier method of transfering and connecting charged tanks.

The candidate which would benefit the most from resupply is the chlorate candle oxygen supply system since it is the heaviest candidate, with sodium chlorate comprising the bulk of the concept weight. However, the weight is sufficiently high to make the chlorate candle concept uncompetitive with other contenders (regardless of the resupply time). The hydrogen peroxide and hydrazine/nitrogen tetroxide concepts are also grossly noncompetitive from a weight standpoint and would not materially benefit from resupply.

Flight Date

All leading gas storage candidates are currently available but with increased weight and size than projected for the 1980 AILSS mission. If the flight date were advanced, no change in the relative ranking of the candidates would occur. However, if the cabin leakage were to increase significantly because of the early flight date, the subcritical cryogenic concept would become more competitive. If the flight date is extended beyond 1980, it appears that the need for long term storage, the use of air-locks, and presumably a reduction in vehicle leakage make-up requirements will all favor selection of improved high pressure gaseous storage tankage.

PRESSURE AND COMPOSITION CONTROL

CONTENTS

PRESSURE AND COMPOSITION CONTROL

The pressure and composition control subsystem must provide a regulated cabin pressure with an oxygen and nitrogen mixture at any pressure between 7.0 psia and 14.7 psia (± 0.25 psia) and a nominal oxygen partial pressure of 3.5 psia. All selected subsystems are compatible with this range of pressures. For the design point, however, a 7.0 psia mixture (nominally 3.5 O_2 and 3.5 psia N_2) was selected and used throughout the study. Cabin repressurization and leakage makeup must be provided as required. Cabin pressure and composition control cannot be approached as an independent entity since it is highly dependent on the source and nature of the supply system, and on the leakage and oxygen consumption rates. The solid electrolyte oxygen generation system selected for the AILSS produces from carbon dioxide and water all the metabolic oxygen required. Cabin leakage and repressurization are supplied by a high pressure storage system. The AILSS gas supply subsystems are discussed below and are shown in figure 24.

COMPOSITION CONTROL

Due to the large missmatch (30:1) of metabolically consumed oxygen and leakage oxygen and since transient partial pressure upsets due to metabolic usage variations are three times larger than the leak rate, it is necessary to control oxygen partial pressure by modulation of the oxygen generation system output. Since the leak rate which includes both oxygen and nitrogen is essentially constant, it is simpler to have it controlled independently of the varying metabolic rate. Therefore, composition control, the ratio of oxygen to nitrogen in the cabin, is obtained by controlling the partial pressure of oxygen by the O_2 generation system and the cabin total pressure of 7.0 psia by the leakage makeup system. Cabin pressure and composition are established initially by the repressurization system discussed below.

In the AILSS, the solid electrolyte process generates the oxygen required for metabolic consumption by combined electrolysis of collected carbon dioxide and water. Carbon dioxide is processed as collected because of the difficulty involved in storing large quantities of the gas. Water, however, may easily be accumulated, stored, and used as required. Feed water to the solid electrolyte reactor is automatically modulated to control the cabin oxygen partial pressure to 3.5 psia.

LEAKAGE MAKEUP

Total pressure control is effected by admitting both oxygen and nitrogen to the cabin on a demand signal of the total pressure control. With a controlled gas composition, the ratio of leak rates is therefore defined. A drop in total cabin pressure is then a leakage indication, and is used to actuate both oxygen and nitrogen inflow.

High pressure gaseous storage of oxygen and nitrogen imposes requirements which dictate the method of composition control for leakage supply. Since tank pressure can differ between the oxygen and nitrogen supplies, total pressure regulators alone are not adequate for directly supplying the proper oxygen/nitrogen mixture to the cabin for leakage requirements. This is due to the fact that, although the regulator flow is choked, the differing upstream pressures (with regulation to the same downstream pressure in the cabin) result in oxygen/nitrogen composition variations. This occurs even if individual regulators are perfectly matched, because one regulator will open ahead of the other when cabin pressure falls to the point where makeup supply is required. This results in a further variation in oxygen/nitrogen composition and possible premature depletion of one of the sources. Thus, it is necessary to use individual regulators to regulate the tank supply pressure to some intermediate pressure (50 to 100 psia) for each gas, and to provide an orifice in each individual gas supply line. The regulators fix the upstream pressure, and orifice sizing presets the proper oxygen/nitrogen mixture ratio, which is maintained regardless of individual tank pressures.

Since system requirements dictate that total pressure control be utilized, a total pressure signal activates the solenoid valves located downstream of the fixed orifices in the oxygen and nitrogen supply lines, and flow is discharged directly to the cabin air distribution ducting. The solenoid valves are actuated simultaneously when cabin pressure falls below the low limit of its regulation band. Each valve is supplied with a manual override so that oxygen or nitrogen flow can be separately varied to allow manual adjustments in cabin composition. Thus, the gas storage concept selection and oxygen generation system operation permit pressure and composition control to be achieved with simple and reliable hardware.

REPRESSURIZATION

An additional function of the pressure and composition control subsystem is to provide a means of cabin repressurization. The control method utilized can be either manual or automatic (solenoid valves activated by low total pressure). There are a number of reasons why manual repressurization control is more desirable. Current space missions utilize automatic pressure and composition control, because the spacecraft volumes are small and a cabin wall penetration results in rapid depressurization. Thus to protect the crew from sudden exposure to hypoxia, it has been necessary to use automatic repressurization control. However, use of large cabin volumes and compartmentation of the vehicle reduce the need for instantaneous action in the event of cabin depressurization. A 5000 ft^3 compartment (AILSS configuration assumed to be two 5000 ft^3 compartments) takes approximately one hour to depressurize to 4 psia

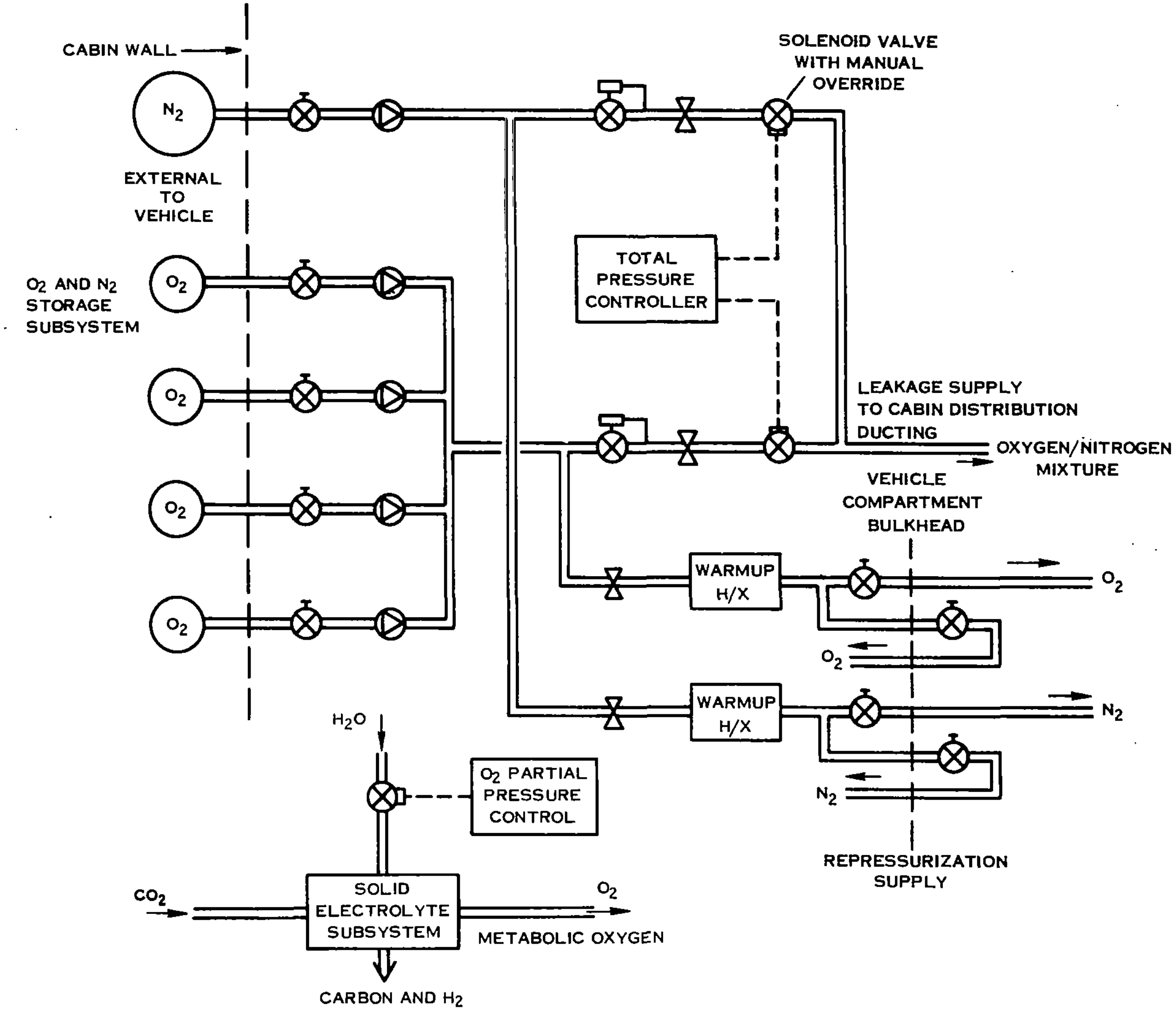


Figure 24. Pressure/Composition Control Schematic

in the event of a one-half inch diameter micrometeoroid penetration. Thus, ample time is available to monitor and actuate manual control equipment, or detect and locate the failure, or transfer to another compartment. During this one-hour period (for a one-half inch penetration), approximately 80 pounds of cabin air is lost. Larger penetrations increase the rate of cabin air loss and decrease the depressurization time, although other likely penetrations still provide ample time for corrective action. Also, since cabin wall penetrations would most likely be repaired by pressure-suited crewmen in a completely depressurized cabin, automatically maintaining cabin pressure in the area of 7 psia regardless of the penetration size is wasteful. Hence, automatic repressurization control in the event of cabin depressurization is neither necessary nor desirable. A total pressure-actuated audible warning signal with a 6.5 psia setpoint is sufficient to alert the crew to take corrective action.

Several other factors favor manual over automatic repressurization control. Since cabin depressurizations might be either scheduled or unscheduled, the infrequency of the event (two complete cabin repressurizations available if required) favors design simplicity. Furthermore, reliability and leakage considerations dictate that the cabin dump valves be capped after cabin bleeddown (following launch). The presence of the 3000 psia storage tanks favors manual control valves rather than a pressure regulator or solenoid valves, which could fail open (although the rate of pressure increase would be relatively low due to the large cabin volume).

The allowance of long repressurization times (5 hours maximum) provides more than adequate time to manually control repressurization gas quantities without possibility of overshoot. Manual repressurization is accomplished (from the adjacent compartment) by first bringing the oxygen partial pressure to 3.5 psia (by monitoring total cabin pressure). When this is accomplished, the oxygen flow is shut down, the nitrogen inflow valve is opened, and the nitrogen inflow is continued until a total pressure of 7.0 psia is reached. Thus, for the reasons cited, and since manual control is the most reliable approach, manual repressurization control is selected without a formal trade-off.

During repressurization, rapid expansion of the gas during throttling results in a delivery temperature of approximately zero degrees F. Thus, heat exchangers are required for gas delivery at cabin temperatures. The selected gas storage/pressure and composition control system is shown in figure 24. Since the repressurization lines for each gas must be plumbed to both cabins, the optimum location for the heat exchangers is upstream of the shutoff valves. An orifice upstream of the heat exchanger provides for gas expansion (with resultant cooldown). If this orifice were not provided, expansion would occur in the shutoff valve, and four heat exchangers would be required (one downstream of each shutoff valve). Repressurization valving is provided so that control is accomplished from the adjacent cabin.

SUMMARY

The selected pressure and composition control system shown in figure 24 is highly reliable, possesses inherent simplicity, and allows great flexibility. Equivalent weight is not a factor in its selection since the tankage valving, pressure regulators, and heat exchanger weights are included in the gas storage system evaluation (as well as the reliability, crew stress, etc.) of these items.

WATER ELECTROLYSIS

CONTENTS

WATER ELECTROLYSIS

Water electrolysis, CO_2 concentration, and CO_2 reduction processes combine to perform the O_2 generation /CO_2 control function. However, there are too many possible combinations of candidate concepts to give each one individual consideration. Thus, the best water electrolysis and CO_2 concentration processes are first chosen independently and are then combined, as applicable, with each CO2 reduction process to form integrated O_2 generation/CO_2 control candidates. These integrated candidates are then compared and the best one is selected. Comparison of integrated concepts is necessary because some reduction concepts generate oxygen directly while others generate water, making direct comparison impossible. Consequently, water electrolysis, CO_2 removal and concentration, and integrated O_2 generation/CO_2 control are considered in successive sections of this study.

Although the CO_2 reduction concept selected later in this study does not require a separate water electrolysis unit, use of any of the alternative reduction processes considered would make one necessary. Consequently, as a result of the AILSS tradeoff results, a gas circulation electrolysis concept is recommended where required. A simplified representation of this concept is shown in figure 25. Oxygen rather than hydrogen is recirculated to pick up feed water for the cells. This concept has a low equivalent weight, no inherent water feed or gas collection problems, and positive thermal process control. Simplified representations of other candidate concepts are shown in figure 26.

Water electrolysis may be used in one of the following two ways, depending on the selected CO_2 reduction concept:

1. To generate all metabolic oxygen and to recover hydrogen for recycle to a carbon dioxide reduction process.

2. To generate makeup oxygen (that part of the metabolic oxygen requirement not supplied by recovery from carbon dioxide), discharging byproduct hydrogen overboard.

Electrolysis unit sizing is based on the AILSS metabolic oxygen consumption rate of 15.1 pounds per day, with 13.5 pounds per day recovered from carbon dioxide and 1.6 pounds per day makeup oxygen produced by electrolysis of purified waste water.

All water electrolysis concepts produce oxygen by the electrochemical process:

$$2H_2O \rightarrow 2H_2 + O_2$$

and differences are therefore relatively minor. This makes identification of an outstanding concept very difficult. These concepts may be classified in several ways that include:

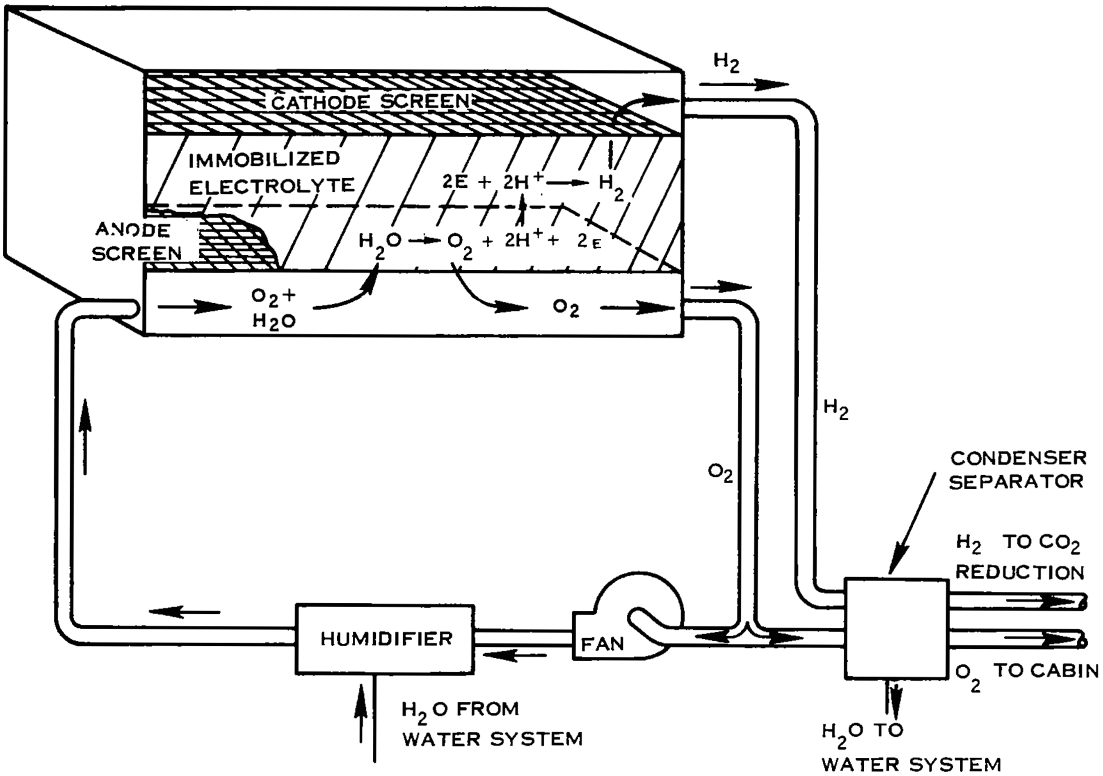


Figure 25. Gas Circulation Electrolysis

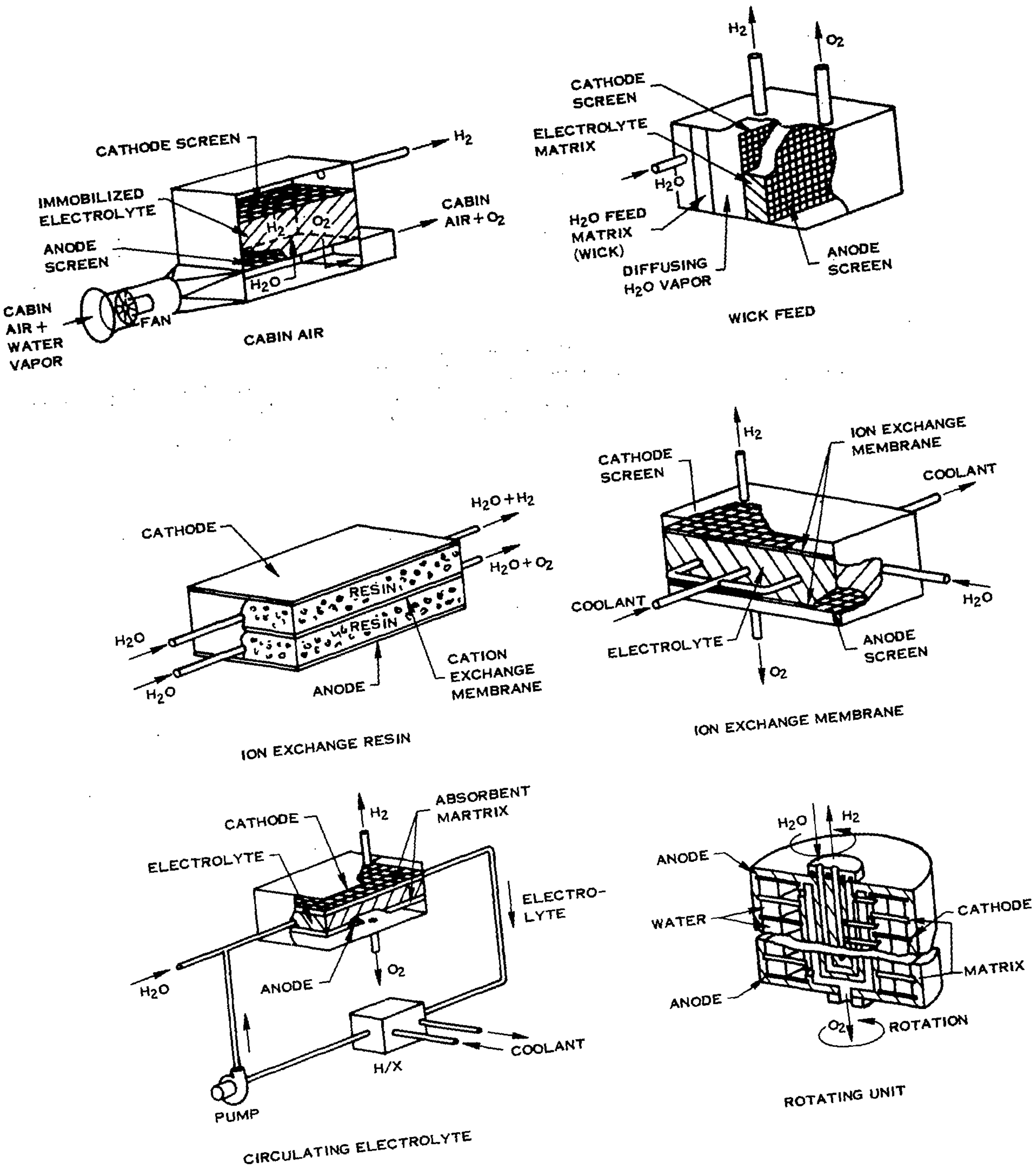


Figure 26. Other Electrolysis Concepts

1. Feedwater source
2. State of water in cell
3. Chemical nature of electrolyte
4. Physical nature of electrolyte
5. System configuration

Because a given concept may be described in so many ways, giving it a consistent label is difficult. The concept labels chosen for this study are shown in table 9, which lists each of the concepts according to the classification listed above.

Equivalent weights for all three power/heat source designs (all electric, electric/isotope, and Brayton cycle) are identical for any one electrolysis concept. This is true because the power penalty is the same for both electrical power sources and because there is no heating requirement (excepting startup) for any of the electrolysis concepts that were considered.

An approach not included as a candidate is the hydrogen diffusion concept. This concept is not included because a zero-gravity version is not adequately defined for evaluation and the concept does not appear to offer any advantages for the AILSS. The concept involves the use of palladium-silver alloy as an electrolysis cathode. It is unique in that it produces pure, dry hydrogen at a pressure significantly higher than cell ambient pressure. This general concept is used extensively in the electrochemical Sabatier system discussed briefly in the O_2 Generation/CO_2 Control section, but neither concept is an AILSS candidate.

WATER ELECTROLYSIS CONCEPTS

Cabin Air Unit

The cabin air concept is described schematically in figure 27 and quantitatively on the corresponding data sheet. In normal operation, fans pump cabin air through the water vapor electrolysis cell modules and back into the cabin atmosphere. As air passes through the modules, water vapor is removed and oxygen is added to it. Within each cell, the hygroscopic electrolyte absorbs water vapor from the air and carries it to the electrodes, where it is electrolyzed to oxygen and hydrogen. This oxygen enters the air stream passing through the cell and is thereby added to the cabin atmosphere. The hydrogen is pumped to the CO_2 reduction subsystem, which tends to complete the materials balance by hydrogenating CO_2 to form water.

TABLE 9

CLASSIFICATION OF WATER ELECTROLYSIS CONCEPTS

Concept	Feed water source	State of water in cell	Chemical nature of electrolyte	Physical nature of electrolyte	System configuration
Cabin air	Water vapor in cabin air	Vapor	Acid	Liquid immobilized in matrix	Cabin air processed in single pass
Gas circulation	Water management system	Vapor	Acid or base	Liquid immobilized in matrix	Oxygen or hydrogen recirculated through humidifier and cell modules
Wick feed	Water management system	Vapor	Base	Liquid immobilized in matrix	Liquid water wicked into cell where it evaporates
Ion exchange resin	Water management system	Liquid	Base	Solid	Liquid water supplied directly to cell
Ion exchange membrane	Water management system	Liquid	Acid	Free liquid	Feed water mixes with free liquid electrolyte
Circulating electrolyte	Water management system	Liquid	Base	Free liquid	Feed water added to circulating electrolyte
Rotating	Water management system	Liquid	Base	Free liquid	Feed water added to maintain electrolyte level in rotating cell module

SUBSYSTEM: Water Electrolysis

CONCEPT: Cabin Air Unit

FLIGHT AVAILABILITY: 1976
(1970 go-ahead)

RELIABILITY: 0.999386 MTBF: 2500 hr

Spares/Redundant (R) Units:

- 3 - Module, Electrolysis
- 1 - Controller
- 4 - Fan
- 2 - H_2 Regulator
- 2 - H_2 Compressor
- 1 - Isolation valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	0	3.6

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	229	229	229
Expendables	0	0	0
Spares/Redundant Units	82	82	82
Electrical Power	1237	1237	1237
Thermal Power	0	0	0
Radiator Load	211	211	211
Humidity Control Credit	-95	-95	-95
Total Equivalent Weight	1664	1664	1664
POWER (Watts):			
Electrical	2745	2745	2745
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	10.1	5.7	15.8

Figure 27. (Page 1 of 2)

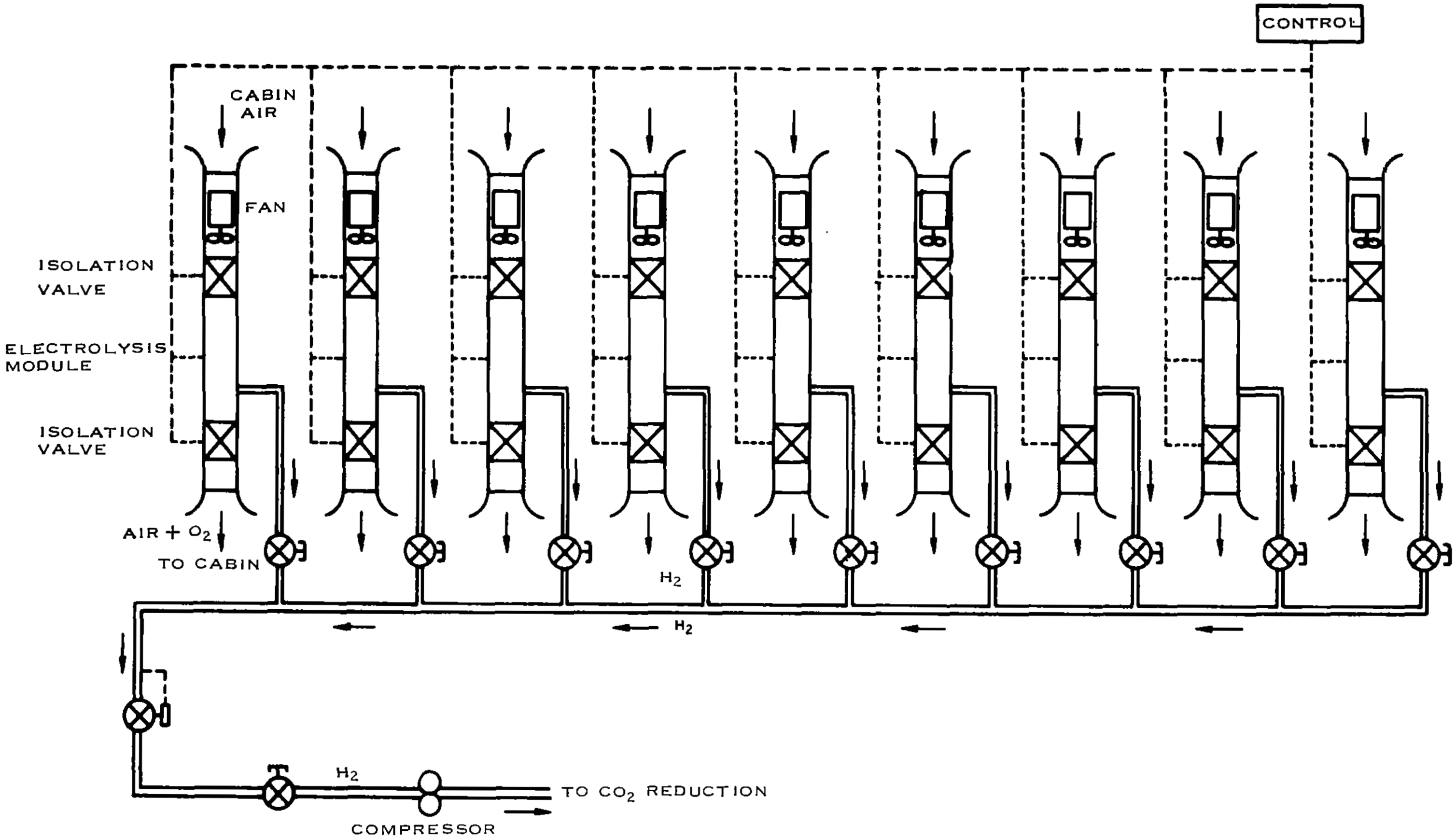


Figure 27. Cabin Air Concept (Page 2 of 2).

The cabin air concept is unique in that it is a strictly vapor phase process, electrolyzing water directly from cabin air rather than from the water management system. The concept has considerable impact on the life support system in that it performs a part of the atmosphere humidity control function. The electrolyte is immobilized in a matrix and must be acidic to prevent neutralization by carbon dioxide in the atmosphere. In addition to the cell modules, the equipment includes fans, a hydrogen compressor, cell module isolation valves, and control devices. Alternatives to hydrogen transfer by compressor, assumed here, are high pressure rise fans (a high power penalty) and use of a hydrogen stripper cell, an electrochemical device now being developed. Process thermal control, inherent in this concept, occurs by transfer of waste heat to the cabin air stream, resulting in a high air flow requirement of about 400 cfm. This high air flow results in relatively large cell assemblies.

The large number of modules (nine) is the result of technical compromise. If there were fewer modules, each one would have to be larger in flow length or face dimensions. Increased flow length requires higher air velocity, and pressure drop is a limiting factor. Increased face width results in air distribution and structural support problems. Face height, the number of cells in a stack, is limited by the relationship of cell voltage drop to power supply voltage. In addition, module size is limited by difficulty in handling large cell pairs during maintenance. The number of modules may have a significant impact on attractiveness of the cabin air concept. If a single large module could be used, for example, spare equipment would weigh three times as much as operating equipment, but system failure rate and corresponding crew time would be much reduced.

The cabin air concept has possible problems at abnormal operating conditions. Low cabin humidity (below 30 or 40 percent) dries out the electrolyte matrix, doing irreversible damage. High cabin humidity (above about 75 percent) may flood the matrix, washing electrolyte out of cells optimized for normal humidity. Automatic fan shutdown would give considerable protection against abnormal humidity, but the cells may have sufficient inherent protection because increasing humidity results in dilution of the electrolyte, which results in higher current density and, therefore, a high electrolysis rate that inhibits excessive electrolyte dilution. Such protection, however, is obtained at the expense of current or voltage control. Cabin depressurization could boil electrolyte out of the matrix, and adequate protection against cabin depressurization requires appropriate ducting and solenoid isolation valves triggered by low cabin pressure. Use of these valves add 33 pounds to the total equivalent weight.

Absolute criteria. -

Performance: Experimental data for two versions of this concept leave little doubt that it can meet requirements under AILSS atmospheric conditions. These 1000 and 2000 hour experimental runs also indicate that these requirements can probably be met for the entire mission.

Safety: The simplicity of the cabin air concept results in questionable safety. It is an open system rather than a closed cycle, increasing its potential for contaminating cabin air, especially under upset conditions. Normal carryover of the acid electrolyte, however, has been shown to be very low. As its major safety advantage, this concept is the only one that does not deliver pure or concentrated oxygen. A correctable weakness is potential leakage of air into the hydrogen stream at the compressor suction.

Availability/confidence: The cabin air concept can be developed for a flight as early as 1976. Development is now in the early prototype phase. Batteries of cells have been packaged into units with less than one man capacity. A prototype of the phosphoric acid concept has already been operated for 2000 hours without performance degradation. A single sulfuric acid cell has run successfully for 1000 hours. Despite this proven endurance, much further investigation is required on the effects of fluctuating cabin humidity and temperature. In addition, further work is needed on sealing, manifolding, and control.

Primary criteria. -

Reliability: Although low cell current density and operating temperature result in a lower cell failure rate than other concepts, the large number of individual cells required results in a lower MTBF value than any other concept, less than one-fourth the AILSS mission length. The necessity of the large number of cell modules was explained earlier, in the concept description. As in all other electrolysis concepts, the cell modules themselves have the highest failure rate. Repair of fourteen failures must be provided for to achieve a reliability of 0.9998. Failures are being repaired on the lowest practicable level by replacement of cell pairs. Two spare electrolysis modules with interchangeable cell pairs are required to accommodate cell failures. One additional spare module is required to accommodate isolation valve failure during depressurization. There are no limited life components. The only critical potential failure mode identified is oxygen leakage into the hydrogen compressor. Such leakage canbe eliminated by good design.

Crew time: Estimated crew time is very low, with no scheduled maintenance and close to average unscheduled maintenance. Repair of the unit requires breaking a hydrogen line, a stress condition common to all electrolysis concepts. Unlike all other concepts, however, there is no oxygen line to be disconnected. The expected number of repairs is 4.8 during an average mission.

Equivalent weight: With high power consumption, total equivalent weight is slightly higher than that of any other concept, except for one that has an extremely high equivalent weight. High power is a result of high cell voltage and the high air process rate. The cabin air concept removes considerable atmospheric water vapor. This results in a significant humidity control credit, which is included in the total equivalent weight estimate.

Secondary criteria. - Secondary criteria are contamination potential, interface complexity, flexibility, growth potential, noise, volume, and power characteristics. As discussed previously under Safety, the potential for contaminating the cabin atmosphere with electrolyte is considerable. The electrolyte itself is even more prone to contamination by trace gases in the cabin atmosphere. The cabin air concept has only one subsystem interface, the carbon dioxide reduction section. The flexibility of both system and cell concepts is very good. Small units can be distributed around the cabin, and the cell can be integrated into any subsystem with a water vapor stream, obviating the need for condensation and separation. Growth characteristics are favorable for longer missions because crew time and spares weight are low. For larger crews, however, equivalent weight becomes increasingly less competitive. The noise level of the fans is moderately high. Volume and power are higher than for most other concepts.

Gas Circulation

The gas circulation electrolysis concept is described schematically and quantitatively in figure 28. In normal operation, water from the water management subsystem is fed to an evaporator by a metering pump. Oxygen from the cell modules circulates over the evaporator, picking up water, and returns to the cell module inlet (alternative versions use hydrogen circulation and/or capillary evaporators). Within the cells, water vapor is absorbed from the circulating oxygen stream into an electrolyte matrix, where it is electrolyzed for form oxygen and hydrogen. Most of the oxygen generated is recirculated through the water evaporator and back to the cell modules. The rest of the oxygen and the hydrogen pass through a condenser-separator, from which the oxygen goes to the cabin to satisfy metabolic requirements and the hydrogen goes to the CO_2 reduction subsystem. Condensate is pumped to the water management system. Heat is removed by coolant tubes passing through the cell modules, thereby providing positive temperature control of the process. The oxygen generation rate is controlled by the simultaneous variation of electrolysis current and feed pump speed.

Oxygen-side feed is chosen for the proposed version of this concept since it minimizes the maintenance of hydrogen line components. In addition to the cell modules, the equipment includes a water metering pump, an evaporator, a circulation fan, a condenser-separator, a condensate pump, and control devices.

Absolute criteria. -

Performance: The circulation version of this vapor feed concept has been tested and can meet performance requirements. Although there has been no life testing of the recommended configuration, performance of the vapor feed cell is proven. Good performance is expected since the design eliminates nitrogen or oxygen in the hydrogen line due to feedwater degassing. It is not susceptible to cabin conditions (e.g., depressurization) as is the cabin air concept.

Safety: The gas circulation concept is comparatively safe. The electrolyte is immobilized in a matrix, so the potential for electrolyte contamination of the cabin therefore is low. The operating temperature is high enough to prevent bacteria growth in the wet evaporator wick. The circulating oxygen must be handled with the usual safety procedures.

Availability/confidence: The gas circulation concept can, with a strong effort, be developed for a flight as early as 1977. Development is now well into the research phase. Although system testing has been limited to several short runs, components are relatively well developed. The electrolysis unit components used in the testing just mentioned have had over 300 000 hours of testing in the fuel cell mode. Although this unit circulates hydrogen rather than oxygen, units that add water vapor on the oxygen side of the cells have also been developed. Much experience with evaporation from wicks has been gained as a result of aerospace programs on air evaporation water recovery units.

Primary criteria. -

Reliability: System MTBF is about half the mission duration. Failures on the cell level are assumed. To obtain a reliability of 0.9998, seven cell failures and one manifold or structure failure must be accommodated. Each module contains 16 cells that form eight cell pairs, which must be both replaceable and interchangeable. Detection and isolation of hydrogen leaks is a problem, as it is on all other electrolysis concepts. The condenser-separator is a limited life item.

Crew time: Scheduled time is close to average, while unscheduled time exceeds that of most other concepts. Cell module repair is somewhat difficult, with 1.7 such repairs expected on the average mission. The electrolysis cell module is conceived for replacement at the cell level. This requires breaking seven interfaces (including two electrical) in a typical compressed flat stack arrangement. Even with sophisticated manifolding and isolation, some difficulty is likely to be experienced in closing off the coolant circuit, although cold plate mounting is a possibility. Including cooldown and startup, this procedure is likely to take two to three hours. Carbon dioxide entrapment during maintenance may be a problem if an alkaline electrolyte is used. Replacement of any equipment in the coolant circuit (i.e., temperature control valve, startup heater, evaporator, condenser-separator) will require shutdown of the entire unit for periods of up to two hours for each maintenance function. The condenser-separator is a scheduled maintenance item consuming two hours every 100 days. Active cooling allows equilibrium conditions to be attained and maintained with minimum crew attention.

Equivalent weight: The total equivalent weight of the gas circulation concept is lower than that of any other concept, a result of low power consumption and very low hardware weight. Low power results from the use of catalytic electrodes operating at a high temperature, about 180° F.

SUBSYSTEM: Water Electrolysis

CONCEPT: Gas Circulation

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999539 MTBF: 5700 hr

Spares/Redundant (R) Units:

2 - Electrolysis Module	2 - H_2 Regulator
3 - Water Metering Pump	2 - O_2 Regulator
1 - Check Valve	3 - Water Pump
1 - Evaporator	2 - Control
6 - Condenser/Separator	1 - Heater
2 - Modulating Valve	2 - Fan
2 - Temperature Control	

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	8.0	4.2

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	123	123	123
Expendables	0	0	0
Spares/Redundant Units	141	141	141
Electrical Power	832	832	832
Thermal Power	0	0	0
Radiator Load	88	88	88
Total Equivalent Weight	1184	1184	1184
POWER (Watts):			
Electrical	1844	1844	1844
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	4.1	5.4	9.5

Figure 28. (Page 1 of 2)

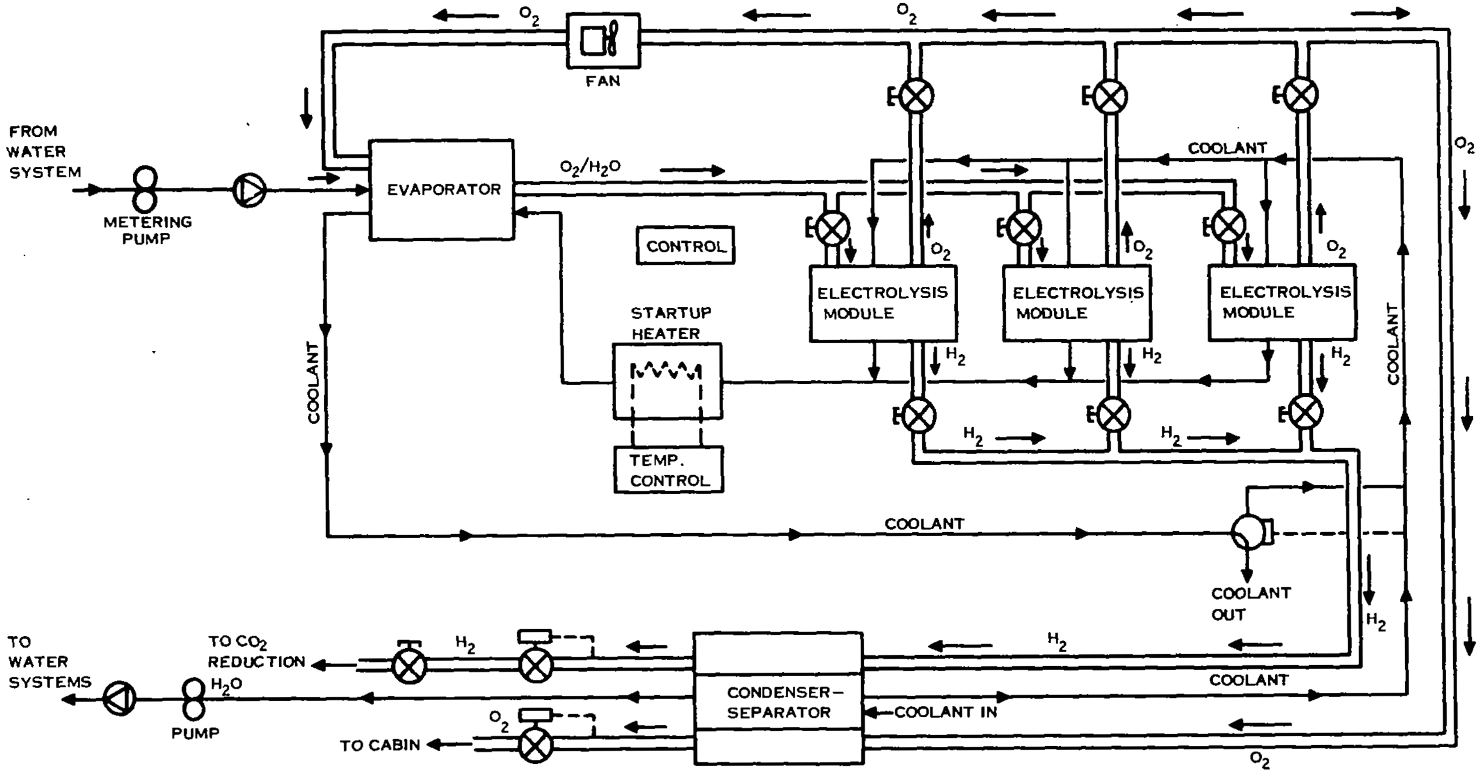


Figure 28. Gas Circulation Concept (Page 2 of 2)

Secondary criteria. - Contamination of the cabin atmosphere by electrolyte carry-over or leakage is unlikely, because the electrolyte is immobilized within a semiclosed system. Danger of contamination of the electrolyte is reduced by the inherent distillation (evaporation from the wick) process. Interface complexity is typical for water management and thermal control connections, and also for cabin air and carbon dioxide reduction section interfaces. Flexibility in oxygen generation rate is only fair, but the concept can be implemented in several ways (air or nitrogen could be circulated instead of pure oxygen) and the cell modules themselves can be integrated into the system in even more ways. The potential for growth in terms of mission length and increased crew size is average. Noise is low, with a low oxygen circulation rate. Volume is lower than that of any other concept. Gas circulation and one other concept have lower power consumption than all other concepts considered.

Wick Feed

The wick feed concept is described schematically in figure 29 and quantitatively on the corresponding data sheet. In normal operation, water from the water management subsystem is fed to the module by a metering pump. This inlet water travels through a wick into the cells. Within the cells, water evaporates into the product hydrogen stream and diffuses across that stream to the electrolyte matrix, where it is absorbed. The absorbed water is electrolyzed, and the product gases leave through a condenser-separator, which lowers their dewpoint. Condensate water is pumped to the water management system. Periodically, accumulated gas must be vented through a gas-liquid-solids separator, to prevent vapor locking of the cells with gas dissolved in the feed water.

This concept is not as flexible as some other liquid feed concepts, because the electrolysis rate is limited by the water vapor diffusion rate within the cells. Lack of positive temperature control further limits operational flexibility. The oxygen generation rate can be controlled by varying voltage, but a voltage-limiting device is essential to maintain acceptable performance. In addition to the cell modules, equipment includes a feed pump, a circulating pump, a condenser-separator, a condensate pump, a gas-liquid-solids separator, and control devices.

Absolute criteria. -

Performance: Reasonable performance of a large scale unit has been proven in the NASA Langley Integrated Life Support System. Endurance capability appears satisfactory, provided the evolved gas is vented, but tests have been less than 1000 hours.

Safety: The wick feed concept is relatively safe. There are no special problems. The electrolyte is immobilized in a matrix, and the potential for cabin contamination is relatively low.

Availability/confidence: The wick feed concept can, with an unusually strong effort, be developed for a flight as early as 1974. Development is now well into the prototype phase. A four-man unit has completed a 360-hour test as part of the NASA Langley Research Center Integrated Life Support System. Cell parts have survived 5000 hours of continuous testing. Work on a zero gravity gas separator may be pacing but has been started. Without it, gas dissolved in the feedwater will cause electrolysis unit shutdown.

Primary criteria. -

Reliability: System MTBF is about half the mission duration. Failures on the cell level are assumed. To obtain a reliability of 0.9998, seven cell failures and one manifold or structure failure must be accommodated. Each module contains 16 cells that form eight cell pairs, which must be both replaceable and interchangeable. There are two salient reliability problems in the wick feed system for which correction is assumed. The first is detection and isolation of hydrogen leaks. The second is dissolved gas in the feed water that gets trapped in the cell modules. The condenser-separator has a limited life of about 100 days.

Crew time: Compared with other concepts, scheduled time is above average, while unscheduled time is below average. The condenser-separator must be replaced every 100 days. Automatic gas purging is possible. All components are designed for the replacement approach to maintenance. Electrolysis stacks are replaceable as modules rather than as individual cells. The system does not have to be shut down, because each of the three-on-line modules is isolatable from the process. Replacement of any other components requires system shutdown. During the average mission, 1.7 electrolysis module repairs are expected. Gas purging will probably take additional time.

Equivalent weight: Very low power consumption results in nearly the lowest equivalent weight of all concepts.

Secondary criteria. - Contamination potential of the wick feed concept is relatively low because the electrolyte is immobilized in a matrix. Vapor phase transfer of water to the matrix reduces the likelihood of electrolyte contamination by feedwater impurities. Interface complexity is typical with water management and thermal control connections in addition to cabin air and carbon dioxide reduction section interfaces. Flexibility is average. Growth potential is average for larger crews or longer missions. Noise level is very low. Volume is very low compared with other concepts. Wick feed and one other concept have a lower power consumption than all other concepts.

SUBSYSTEM: Water Electrolysis

CONCEPT: Wick Feed

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999695

MTBF: 5700 hr

Spares/Redundant (R) Units:

- 2 - Electrolysis Module
- 3 - Metering Feed Pump
- 2 - Check Valve
- 6 - Condenser/Separator
- 2 - H_2 Regulator
- 2 - O_2 Regulator
- 3 - Water Pump
- 3 - Circulating Pump
- 2 - Gas, Liquid, Solid Separator
- 2 - Control

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	10.0	3.1

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	139	139	139
Expendables	0	0	0
Spares/Redundant Units	146	146	146
Electrical Power	832	832	832
Thermal Power	0	0	0
Radiator Load	88	88	88
Total Equivalent Weight	1205	1205	1205
POWER (Watts):			
Electrical	1845	1845	1845
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	5.1	6.3	11.4

Figure 29. (Page 1 of 2)

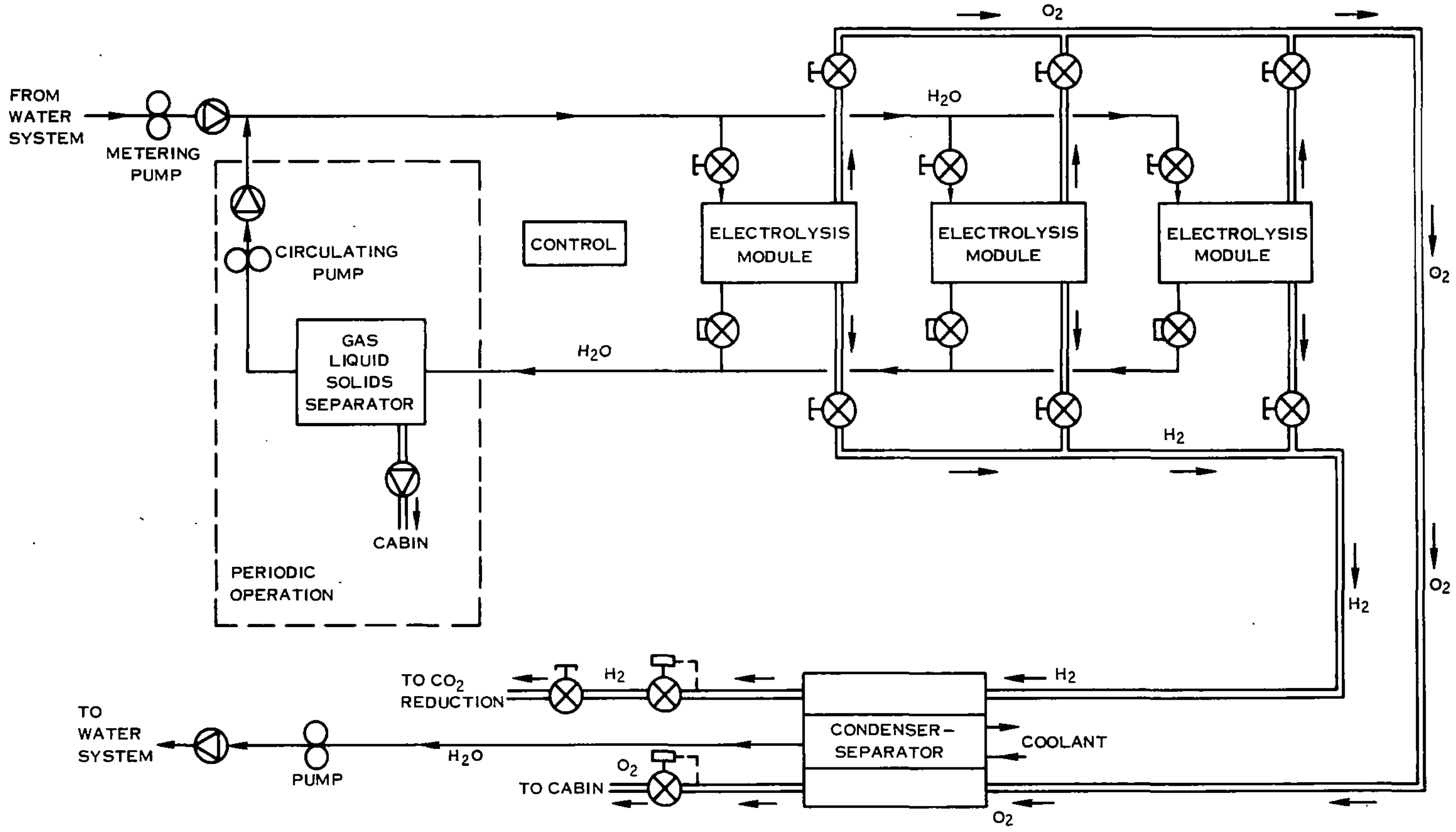


Figure 29. Wick Feed Concept (Page 2 of 2).

Ion Exchange Resin

Figure 30 presents the schematic diagram for this concept. Quantitative data are presented on the corresponding data sheet, The distinguishing feature of the ion exchange resin unit is that the electrolyte is a solid. Toxic hazard, leakage, or entrainment is therefore relatively unlikely. This feature is obtained at the expense of power. Each cell consists of a single cation exchange membrane separated from the electrodes by passages containing solid electrolyte granules, a macroporous, cation-conducting packing. In addition to the cell modules, the equipment includes a condenser-separator, a cooler, a surge tank, and a water return pump.

In normal operation, water is pumped to the cell modules, where it enters the passages on either side of the membrane separator in each cell. Electrolysis of this water generates hydrogen and oxygen which leave the unit through a condenser-separator. Condensate water is cooled in a heat exchanger and pumped through a surge tank and back to the cell module inlet. Feed water is added to the surge tank on demand to replace electrolyzed water. Provision for venting gases dissolved in the feedwater is probably necessary to avoid oxygen-hydrogen mixtures, but this problem has not been previously identified.

Because liquid water can rapidly be supplied to cell electrodes, the oxygen generation rate is highly flexible. Thus, cabin oxygen partial pressure is easily maintained by adjusting the electrolysis current as required. As discussed previously, feed water is added on demand when electrolyte volume is low. Unit pressure is controlled by product gas pressure regulators connected to a hydrogen-oxygen-water differential pressure controller. Cell module temperature is held close to ambient by a coolant control valve on the heat exchanger.

Absolute criteria. -

Performance: Available information indicates that performance of the ion exchange resin concept should be adequate, but there appears to be no proof of endurance capability.

Safety: The unit is extremely safe. There is little chance of hydrogen and oxygen mixing. The electrolyte is a solid and cannot leak unless a serious structural failure occurs. If it does leak, it will not be a safety hazard.

Availability/confidence: The ion exchange resin concept can be developed for a flight as early as 1975. Development is now arrested in the prototype phase. No recent work has been done on any aerospace version, but a prototype version has been built for the United States Navy. This experience should hasten development of an aerospace version, once initiated.

Primary criteria. -

Reliability: System MTBF is about half the mission duration. Failures on the cell level are assumed. Seven cell failures and one manifold or structure failure must be accommodated. Each module contains 16 cells that form eight cell pairs, which must be both replaceable and interchangeable. There are two salient reliability problems in this system for which correction is assumed. The first is detection and isolation of hydrogen leaks. The second is dissolved oxygen in the feed water that evolves into the generated hydrogen. The condenser-separators have a limited life of about 100 days.

Crew time: The ion exchange resin concept and one other have the highest scheduled crew time, and unscheduled time is also above average. The condenser-separators must be replaced periodically. Automatic gas purging is assumed. All support components of electrolysis modules are maintainable by replacement. This operation requires complete system shutdown and about one-half hour of labor. Each of three electrolysis modules is replaceable as a unit without requiring system shutdown, because the modules can be isolated from the balance of the system. Module change will require about two hours of maintenance time. Each module weighs 67 pounds, which imposes an accessibility and transfer problem requiring some type of restraint hardware. An average of 1.7 of such repairs during the mission is expected.

Equivalent weight: Equivalent weight is much higher than that of any other concept. This results from high power consumption caused by the high inherent resistance of the electrolyte material.

Secondary criteria. - As discussed under Safety, the ion exchange resin does not pose a potential contamination problem, and hydrogen leakage is the only direct hazard. There is, however, significant danger of electrolyte poisoning by impurities in the feed water, resulting in performance degradation. Interface complexity is typical with water management and thermal control connections in addition to cabin air and carbon dioxide reduction section interfaces. With direct water feed, flexibility in the oxygen generation rate is considerable. One growth feature is that this unit is easily combined with an electrochemical carbon dioxide concentrator to handle any crew size and respiratory quotient. However, high crew time is a growth liability. Noise level is very low and continuous. The ion exchange electrolyte volume is close to average. With high internal resistance, electrical power far exceeds that of any other candidate concept.

Ion Exchange Membrane

Figure 31 presents the schematic diagram for this concept. Quantitative data are presented on the corresponding data sheet. In normal operation, a pressure regulator on the water feed line admits water as required to replace that consumed by the electrolysis process. This inlet water then enters the cell modules by mixing with the electrolyte. Within each cell, electrolyte is contained between ion exchange membranes which act as an ion-conducting bridge between the electrodes and the liquid electrolyte, permitting oxygen

SUBSYSTEM: Water Electrolysis

CONCEPT: Ion Exchange Resin

FLIGHT AVAILABILITY: 1975
(1970 go-ahead)

RELIABILITY: 0.999624

MTBF: 5650 hr

Spares/Redundant (R) Units:

2 - Electrolysis Module
3 - Feed Pump
1 - Check Valve
2 - Accumulator
2 - Circulating Pump
10 - Heat Exchanger/Separator
2 - H_2 Regulator
2 - O_2 Regulator
2 - Current Controller

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	16.0	4.2

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	318	318	318
Expendables	0	0	0
Spares/Redundant Units	265	265	265
Electrical Power	2080	2080	2080
Thermal Power	0	0	0
Radiator Load	470	470	470
Total Equivalent Weight	3133	3133	3133
POWER (Watts):			
Electrical	4633	4633	4633
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	9.8	6.0	15.8

Figure 30. (Page 1 of 2)

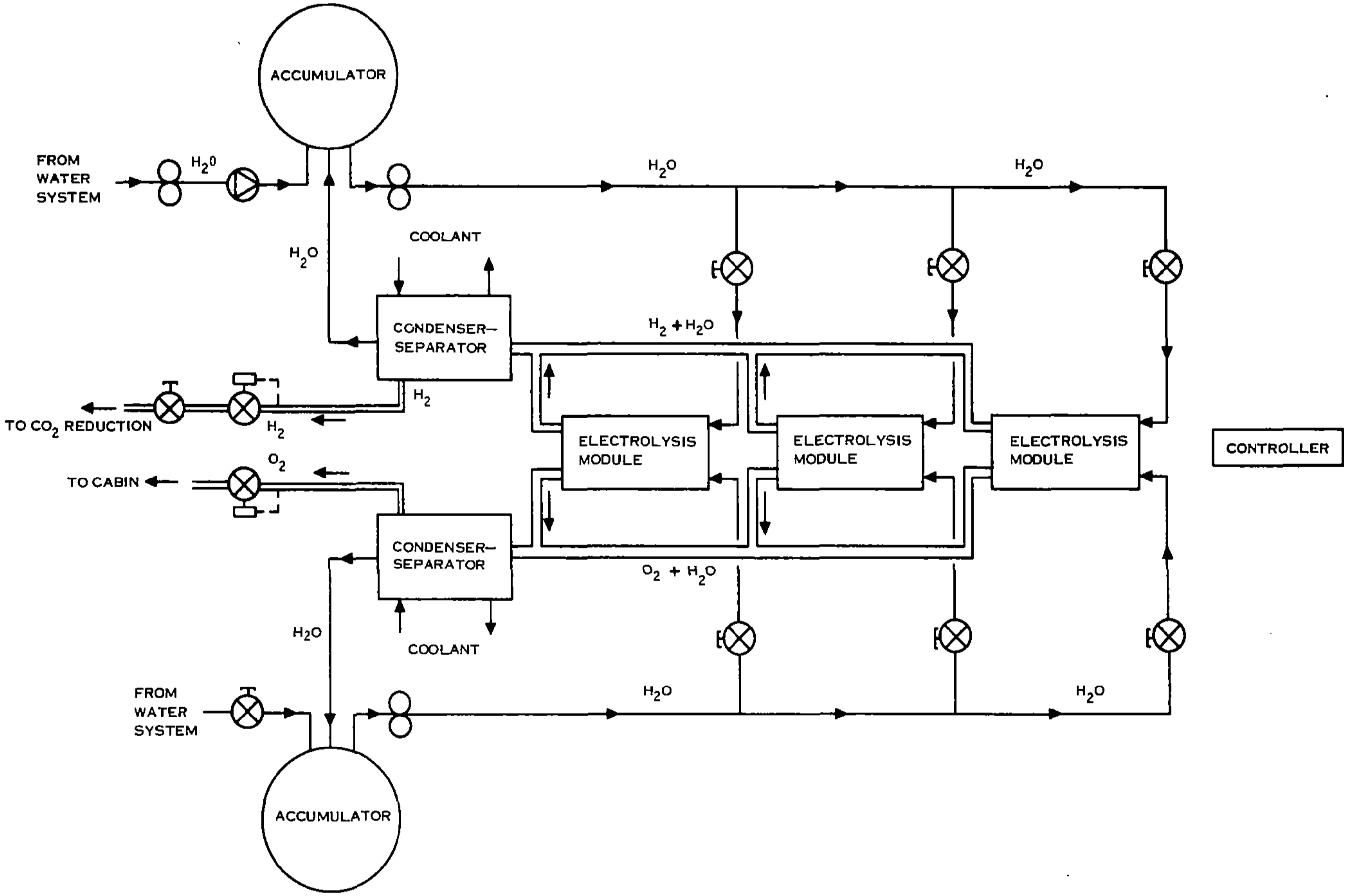


Figure 30. Ion Exchange Resin Concept (Page 2 of 2).

SUBSYSTEM: Water Electrolysis

CONCEPT: Ion Exchange Membrane

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999709 MTBF: 6300 hr

Spares/Redundant (R) Units:

2 - Electrolysis Module
4 - Solenoid Shutoff Valve
2 - Accumulator/Controller
10 - Condenser/Separator
2 - O_2 Regulator
2 - H_2 Regulator
2 - Controller
1 - Check Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	16.0	3.8

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	183	183	183
Expendables	0	0	0
Spares/Redundant Units	162	162	162
Electrical Power	997	997	997
Thermal Power	0	0	0
Radiator Load	138	138	138
Total Equivalent Weight	1480	1480	1480
POWER (Watts):			
Electrical	2210	2210	2210
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	9.3	5.7	15.0

Figure 31. (Page 1 of 2).

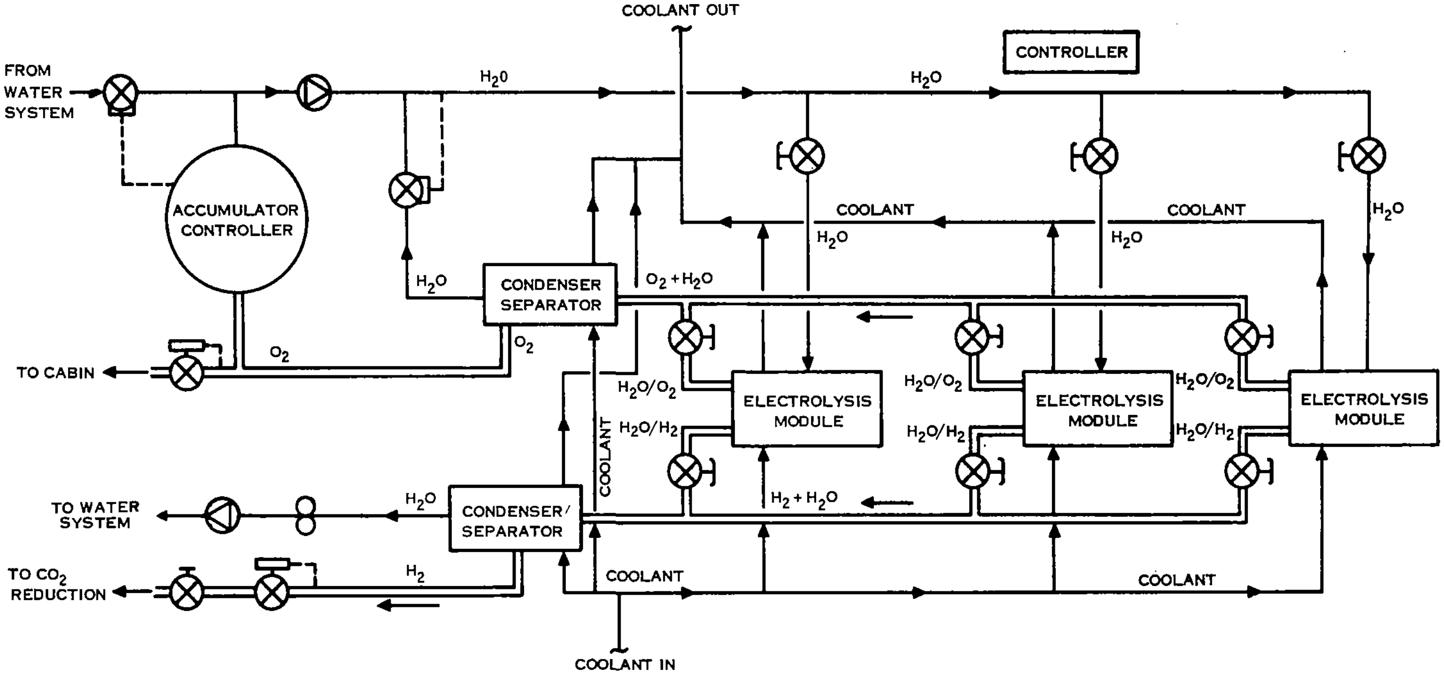


Figure 31. Ion Exchange Membrane Concept (Page 2 of 2).

and hydrogen formation on the dry sides of the membranes. Product oxygen and hydrogen flow out through a condenser-separator which removes water vapor and entrained electrolyte. Need for a gas separation device to remove gas dissolved in the feed water has not been defined.

Because liquid water can be rapidly supplied to the cell electrodes, the oxygen generation rate is highly flexible. Thus, cabin oxygen partial pressure is easily maintained by adjusting the electrolysis current as required. As discussed previously, feed water is added on demand when the electrolyte volume is low. Unit pressure is controlled by pressure regulators connected to the hydrogen-oxygen-electrolyte differential pressure controller. Cell module temperature is controlled by coolant tubes running through the modules.

Absolute criteria. -

Performance: Ability to meet performance requirements has been proven, but prototype problems with corrosion and stable operation have prevented a successful demonstration of endurance.

Safety: The ion exchange membrane concept is unsafe if its safety devices malfunction. Electrolyte is entrained in the cell module outlet gases, but the condenser-separators prevent the electrolyte from entering the cabin atmosphere. The greater danger is leakage of the corrosive liquid electrolyte into the cabin or into the thermal control system. However, the cabin can be protected by enclosing the cell modules in acidproof containers.

Availability/confidence: The ion exchange membrane concept can be developed for a flight as early as 1977. Development is now in the prototype phase. A small prototype was built for the Air Force Flight Dynamics Laboratory Atmosphere Regeneration System and run for about 40 hours, and a four-man unit was installed in the NASA Langley Research Center Integrated Life Support System. However, these units were plagued with problems of materials compatibility, current distribution, and coolant distribution. Although no breakthroughs are required, solutions to these problems are likely to delay considerably the fabrication of a flightworthy unit.

Primary criteria. -

Reliability: System MTBF is slightly over half the mission length. Failures on the cell level are assumed. Six cell failures and one manifold or structure failure must be accommodated. The modules will be repaired on the cell pair level. All cell pairs must be interchangeable and replaceable. There are two salient reliability problems in the ion exchange membrane system, for which correction is assumed. The first is detection and isolation of hydrogen leaks. The second is dissolved gas in the feed water that gets trapped in the cell modules. The condenser-separators are limited life items.

Crew time: This concept and one other have the highest scheduled crew time, while unscheduled time is somewhat above average. Scheduled maintenance consists of replacing each of the two condenser-separators every 100 days. This requires about two hours for each, and complete system shutdown. The unscheduled maintenance consists of removal and replacement of other components in the event of their malfunction. Excluding the electrolysis module, replacement of other components will also require system shutdown for about one-half hour. Each of three electrolysis modules is replaceable as a unit. Replacement of one module does not require system shutdown and will take about two hours. The expected number of such repairs per mission averages about 1.3. Failure of other components will require system shutdown and about one-half hour of repair time. Purging of gas dissolved in the feed water will probably take additional time.

Equivalent weight: This concept has low hardware weight and power consumption, giving it an equivalent weight substantially below the average of all candidate concepts.

Secondary criteria. - Danger of contamination is considerable, as described under Safety. Also, with direct liquid water feed, contamination of the electrolyte by impurities in the feed water is a potential problem. Interface complexity is typical with water management and thermal control connections in addition to cabin air and carbon dioxide reduction section interfaces. Flexibility in oxygen generation rate is considerable, as previously discussed. The growth potential is average for larger crews or longer missions. Noise level is very low. Volume and power are slightly below average.

Circulating Electrolyte

Figure 32 presents the schematic diagram for this concept. Quantitative data are shown on the corresponding data sheet. In normal operation, a pressure regulator on the feed water line admits water as required to replace water consumed by the electrolysis process. This inlet water then joins the circulating electrolyte, which enters the cell modules. Within each cell, electrolyte flows between absorbent matrices on either side. The electrolyte saturates these matrices, and contained water is converted to hydrogen and oxygen gas upon contact with electrodes on the outside of each matrix. Electrolyte emerging from the cell modules is cooled in a heat exchanger and is pumped back through the accumulator-controller to return to the cell modules. Also included in this circuit is a gas separator which vents gas in the feed water as it comes out of solution.

The circulating electrolyte concept retains the efficiency advantages of a free liquid electrolyte while physically separating the electrolysis and cooling functions. Because liquid water can be rapidly supplied to cell electrodes, the oxygen generation rate is highly flexible. Thus, cabin oxygen partial pressure is easily maintained by adjusting the electrolysis current as required. As discussed previously, feed water is added on demand when electrolyte volume is low. Unit pressure is controlled by pressure regulators connected to a hydrogen-oxygen-electrolyte differential pressure controller.

SUBSYSTEM: Water Electrolysis

CONCEPT: Circulating Electrolyte

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999680 MTBF: 5300 hr

Spares/Redundant (R) Units:

- 8 - Electrolysis Module
- 2 - Shutoff Valve
- 14 - Solenoid Shutoff Valve
- 2 - H_2 Regulator
- 2 - O_2 Regulator
- 2 - Heat Exchanger
- 4 - Circulating Pump
- 4 - Surge Tank
- 3 - Controller
- 20 - Check Valve
- 2 - Assembly Container
- 2 - Temperature Control

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	0	2.2

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	192	192	192
Expendables	0	0	0
Spares/Redundant Units	393	393	393
Electrical Power	860	860	860
Thermal Power	0	0	0
Radiator Load	106	106	106
Total Equivalent Weight	1551	1551	1551
POWER (Watts):			
Electrical	1980	1980	1980
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	10.3	19.0	29.3

Figure 32. (Page 1 of 2)

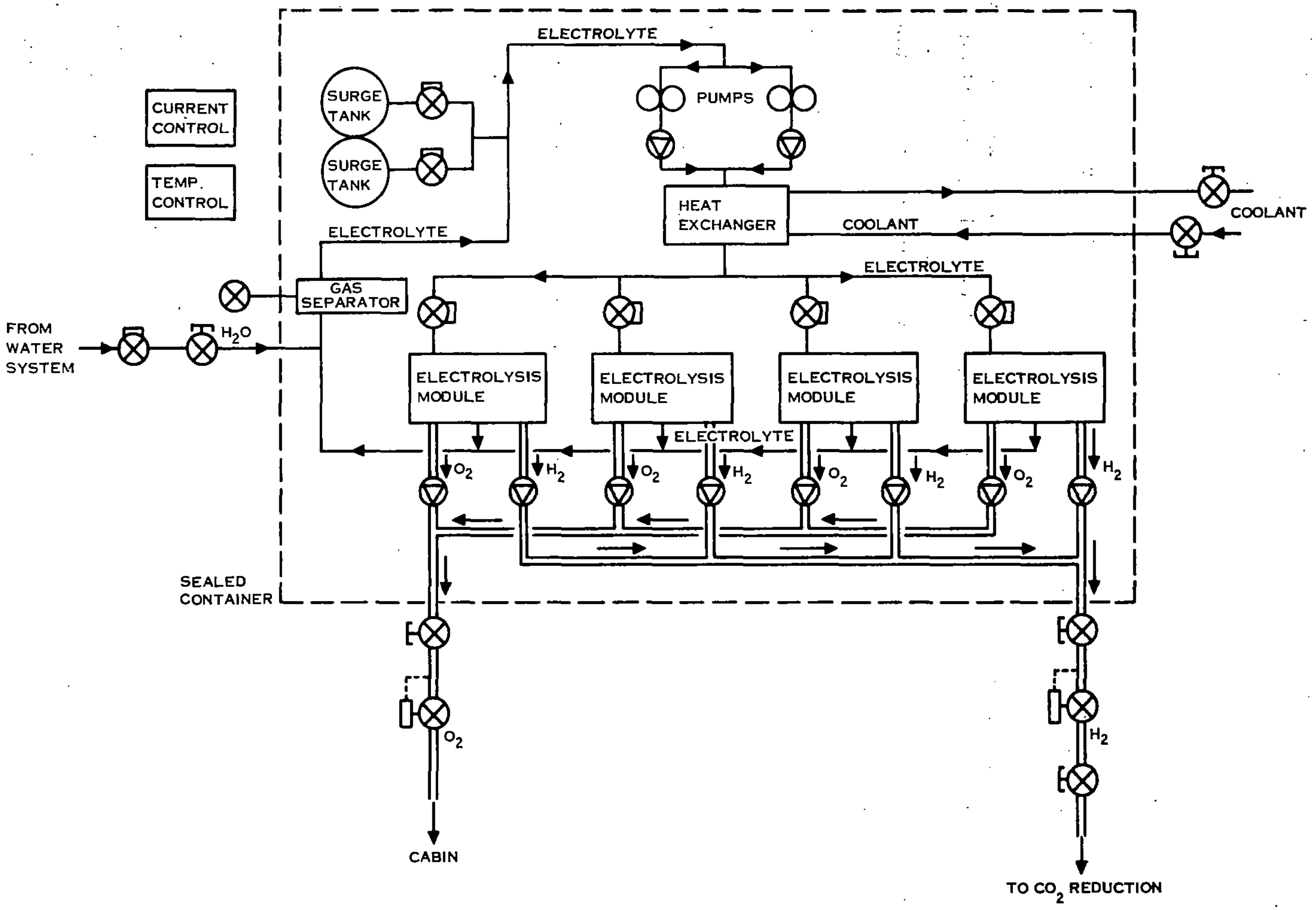


Figure 32. Circulating Electrolyte Concept (Page 2 of 2).

Cell module temperature is held close to ambient by a coolant control valve on the heat exchanger. In addition to the electrolysis modules, the equipment includes an electrolyte cooler, a circulation pump, an accumulator-controller, a gas separator, and instrumentation and controls.

Absolute criteria. -

Performance: Performance capability over an extended period has been demonstrated experimentally with a laboratory model.

Safety: The circulating electrolyte concept is inherently hazardous. Leakage of the free corrosive electrolyte would be very dangerous. This problem can be controlled by sealing the unit in a protective outer casing, but the inherent danger still exists. Because hydrogen and oxygen passages are separated by two matrices and a liquid electrolyte stream, the relative danger of explosion is very low.

Availability/confidence: The circulating electrolyte concept can be developed for a flight by 1977. Development is now in the prototype phase. Total development test time is at least 20 000 hours, and a four-man unit has run 72 hours in a manned system test and 720 continuous hours unmanned. The need for a zero-gravity gas separator is recognized, but none has been developed. This may retard development.

Primary criteria. -

Reliability: System MTBF is slightly less than half the mission duration. Since this concept utilizes a circulating electrolyte, any external leakage of this caustic fluid into the cabin would be detrimental to surrounding equipment. Thus, the concept considered here incorporates four cell stack modules and redundant electrolyte circulation pumps in a sealed container, with two of the modules running and two redundant. Two standby sealed units, each containing four spare modules, are required. No maintenance will be considered within these containers other than electrically switching out failed components. This system may also experience a cell vapor lock resulting from gases dissolved in the feed water. This will require a separator of unknown design and periodic purging of the system. There are no limited life items.

Crew time: Estimated crew time for circulating electrolyte is lower than that of any other concept, with no scheduled maintenance and unscheduled time well below average. This results from the sealed unit concept. Maintenance on this system is limited to replacement of control valves external to a sealed system. In view of the corrosive and toxic circulating electrolyte, all the components containing the electrolyte are sealed within a protective container. Electrolyte leakage, therefore, is isolated within the container. No maintenance is required for these components. Leakage or a component malfunction is handled by valving off the failed system and valving on a redundant system. This operation is expected to occur about 1.3 times during the average mission. Gas purging will probably take additional time.

Equivalent weight: The circulating electrolyte concept has close to the lowest power penalty, but it has the highest hardware weight, resulting in a moderate total equivalent weight, slightly below average. High hardware weight results from high redundancy, caused by the sealed unit concept, which is necessary for safety.

Secondary criteria. - Electrolyte leakage into the cabin or coolant system is possible. With direct liquid water feed, contamination of the electrolyte by impurities in the feedwater is also a potential problem. Interface complexity is typical, with water management and thermal control connections in addition to cabin air and carbon dioxide reduction section interfaces. Flexibility in the oxygen generation rate is considerable, as previously discussed. The growth potential is moderate. Noise level is low and continuous. Volume is considerably higher than that of any other concept. Power consumption is nearly the lowest of all concepts.

Rotating Unit

Figure 33 presents a simplified schematic diagram for this concept. Quantitative data are presented on the corresponding data sheet. The distinguishing feature of a rotating electrolysis unit is that it rotates to provide a free gas-liquid interface, avoiding the use of unusual gas separation devices and permitting the use of ordinary industrial control techniques. A typical unit contains three segmental cell modules which are individually replaceable. Within each cell, the oxygen and hydrogen compartments are separated by an asbestos diaphragm in the liquid phase and a rubber diaphragm in the gas phase. Feed water is added on demand when low electrolyte volume is sensed by a conventional liquid level detector.

Major design problems are mechanical. The two basic problems are presented by the stationary-rotational interface and what happens inside the unit when it stops rotating. The first problem is one of rotating connections and seals. It has been reduced by design features such as a photoelectric pickup for the low electrolyte level signal. Electrolyte containment when the unit stops rotating has been provided by centrifugal valves, although electronic valves connected to a speed sensor may work better. Cooling occurs internally by evaporation and externally by convection to cabin air.

Absolute criteria. -

Performance: The rotating concept has demonstrated an ability to meet the performance requirements, but it has not established an endurance capability, partly because of mechanical troubles.

SUBSYSTEM: Water Electrolysis

CONCEPT: Rotating Unit

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999566 MTBF: 6800 hr

Spares/Redundant (R) Units:

- 3 - Rotating Electrolysis Module
- 2 - Solenoid Shutoff Valve
- 2 - Cooling Fan
- 2 - Check Valve
- 6 - Condenser/Separator
- 2 - H_2 Regulator
- 2 - O_2 Regulator
- 4 - Controller
- 3 - Pump

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	8.0	4.8

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	125	125	125
Expendables	0	0	0
Spares/Redundant Units	322	322	322
Electrical Power	1030	1030	1030
Thermal Power	0	0	0
Radiator Load	148	148	148
Total Equivalent Weight	1625	1625	1625
POWER (Watts):			
Electrical	2280	2280	2280
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	5.5	7.5	13.0

Figure 33. (Page 1 of 2)

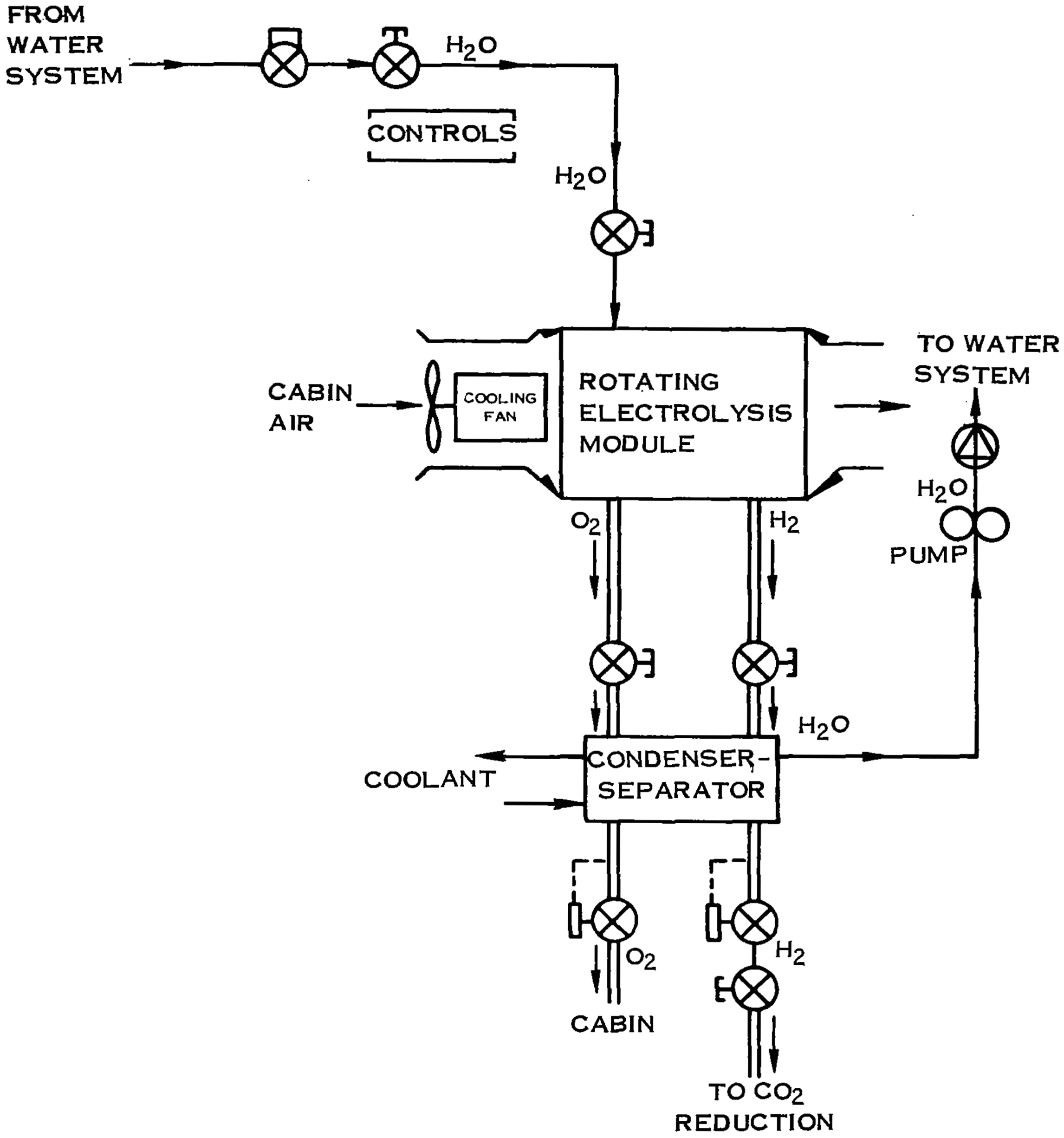


Figure 33. Rotating Electrolyte Concept (Page 2 of 2).

Safety: Inherent safety problems are carryover and leakage of the free corrosive electrolyte. Electrolyte carryover may be excessive and probably requires an external condenser-separator to remove it. Such a condenser would also prevent condensation in product gas lines. Electrolyte leakage is possible during rotation and, if caused by internal valve failure, is particularly dangerous during maintenance.

Availability/confidence: The rotating concept could be developed for a flight by 1977. Development is now arrested in the prototype phase. A prototype model exists, but endurance is totally unproven.

Primary criteria. -

Reliability: System MTBF is slightly greater than that of any other concept but still about half the mission duration. Although the unreliability of the rotating components and associated sealing problems is inherent in this concept, its more conventional gravity sensitive cell has a higher estimated MTBF than the zero-gravity matrix concepts. This results in a total unit reliability that is similar to the other zero-gravity concepts. Each unit has been subdivided into three separate cell sections, only one of which is required to operate. Three standby units are required to achieve the desired reliability. The condenser-separator is a limited life item.

Crew time: Scheduled time is close to average, while unscheduled time is higher than that of any other concept. The condenser-separator must be replaced every 100 days, a two-hour job. The major maintenance problem appears to be connected with failure of the cell rotation mechanism. While replacement of the motor/drive system is not expected to be a difficult task, the absence of rotation may cause an upset of the electrolyte level, allowing potassium hydroxide solution into the oxygen or hydrogen delivery lines. Repair of the dynamic seal requires pumpout of the cell prior to repairs but it is doubtful that the electrolyte could ever be completely drained, thereby creating a hazardous maintenance procedure. Cell module failure of some type is expected to occur about 1.5 times on the average mission.

Equivalent weight: Moderately high spares weight and power consumption combine to give the rotating unit the second highest equivalent weight of all concepts.

Secondary criteria. - Contamination of the cabin atmosphere by electrolyte carryover or leakage is a possibility that must be avoided by careful design. With direct liquid feed, contamination of the electrolyte by impurities in the feed water is a potential problem. Interface complexity is typical, with water management and thermal control connections in addition to cabin air and carbon dioxide reduction section interfaces. Flexibility in the oxygen generation rate is considerable because of the direct liquid feed. The growth potential is moderate, Noise level, with proper design of the rotating unit, is potentially low and continuous. Compared with other concepts, volume and power are slightly below average.

EVALUATION AND SELECTION: WATER ELECTROLYSIS

Designs 1, 2, and 3

The oxygen-side gas circulation concept is selected as the water electrolysis configuration which best meets the AILSS criteria. Since no heat power is needed, except for startup, the configuration and performance of all units are identical for Designs 1, 2, and 3.

Table 10 summarizes the concept selection evaluation, and table 11 presents a data summary for all concepts. The following discussion shows that the selected concept has a low equivalent weight and is relatively free from potential problems.

Absolute criteria. -

Performance: All concepts are judged capable of supplying oxygen and hydrogen at the required rates with no significant differences in performance. Consequently, all concepts are rated Good.

Safety: The cabin air concept is judged Fair because of potential electrolyte contamination of the cabin atmosphere and potential oxygen leakage into the hydrogen transfer system, although filtration and pressure regulation should provide adequate protection. The gas circulation, wick feed, and ion exchange resin concepts have no special safety problems and therefore receive a relative rating of Very Good. The ion exchange membrane, circulating electrolyte, and rotating concepts have inherent problems of corrosion electrolyte carryover, leakage, and spillage and therefore are rated Fair.

Availability/confidence: The cabin air concept is limited to a Good rating, although much testing has been accomplished, because no large-scale units have been developed. The gas circulation concept availability/confidence is considered Good, because the concept reflects proven vapor-feed cell technology without having the hardware problems of the other concepts. Despite gas entrapment problems, a large-scale wick feed unit has operated in the NASA Langley Research Center Integrated Life Support System, so its availability is judged Very Good. Two other concepts that also may require a means of gas separation are ion exchange resin and ion exchange membrane. In addition, the ion exchange resin concept lacks aerospace development, and ion exchange membrane has repeatedly failed endurance tests although it has been integrated with two aerospace oxygen generation/CO_2 control systems. As a result, ion exchange resin is rated Fair and ion exchange membrane is rated Good. The circulating electrolyte concept also needs a gas separation device, and has materials problems which require attention. Therefore, its availability is judged Fair. The rotating concept has an electrolyte containment problem and lacks endurance testing; its availability evaluation is Fair.

TABLE 10
EVALUATION SUMMARY - WATER ELECTROLYSIS

Power Supplies **Design 1 - Solar Cell** **Design 2 - Solar Cell/ Isotopes** **Design 3 - Brayton**		Candidate Concepts						
		Cabin air	**Gas circulation**	**Wick feed**	**Ion exchange resin**	**Ion exchange membrane**	**Circulating electrolyte**	**Rotating**
CRITERIA	**DESIGN**	**1 2 3**	**1 2 3**	**1 2 3**	**1 2 3**	**1 2 3**	**1 2 3**	**1 2 3**
Absolute	**Performance**	Good	Good	Good	Good	Good	Good	Good
	Safety	Fair	Very Good	Very good	Very good	Fair	Fair	Fair
	Avail./Conf.	Good	Good	Very good	Fair	Good	Fair	Fair
Primary	**Reliability**	Poor	Fair	Fair	Fair	Fair	Fair	Fair
	Crew Time	Very good	Good	Fair	Fair	Fair	Good	Fair
	Equivalent Weight	Good	Very good	Very good	Poor	Good	Good	Good
		Eliminated			Eliminated	Eliminated		Eliminated
Secondary	**Contamination**		Very good	Very good			Fair	
	Interfaces		Fair	Fair			Fair	
	Flexibility		Good	Fair			Very good	
	Growth		Good	Good			Good	
	Noise		Good	Very good			Very good	
	Volume		Very good	Very good			Poor	
	Power		Very good	Very good			Very good	
			Selected	Eliminated			Eliminated	

TABLE 11
DATA SUMMARY

Concept	MTBF Hours	Crew Time Hours per Mission		Total Equivalent Weight Pounds	Electrical Power Watts
		Scheduled	Unscheduled		
Cabin Air	2500	0	3.6	1610	2745
Gas Circulation	5700	8.0	4.2	1184	1844
Wick Feed	5700	10.0	3.1	1205	1844
Ion Exchange Resin	5650	16.0	4.2	3133	4633
Ion Exchange Membrane	6300	16.0	3.8	1480	2210
Circulating Electrolyte	5300	0	2.2	1551	1980
Rotating Unit	6800	8.0	4.8	1625	2280

Summary: All candidates have satisfactory absolute criteria ratings. The gas circulation and wick feed concepts have consistently high ratings.

Primary criteria. -

Reliability: The MTBF of the cabin air concept is significantly lower than that of any other, so it is rated Poor. All other concepts have MTBF values equal to approximately half of the mission duration. These concepts rate Fair.

Crew time: Repair time for the cabin air concept is nearly the lowest and there is no scheduled maintenance time, so the concept rates Very Good. The gas circulation concept takes somewhat more time, in the 10 to 20 hour range, and is rated Good. The wick feed time estimate is also in this range, but purging of gas (which entered dissolved in the feed water) will probably require considerable time for monitoring and adjustments, so the concept is downrated to Fair. The ion exchange resin and ion exchange membrane concepts require still more time and have stress problems with free liquid and free electrolyte, respectively; these concepts rate Fair. Although the circulating electrolyte concept has the lowest crew time because of its built-in redundancy, a gas purging problem similar to that previously described limits its rating to Good. The rotating concept has about average estimated time, but crew stress due to the possibility of corrosive electrolyte leakage during maintenance downrates it to Fair.

Equivalent weight: The gas circulation and wick feed concepts have the lowest equivalent weights of the candidates considered and are rated Very Good. The cabin air, ion exchange membrane, circulating electrolyte, and rotating concepts are relatively heavier and rate Good; the cabin air concept weight includes a credit for its humidity control contribution. The ion exchange resin concept has a significantly higher weight, because of high power consumption, and rates Poor.

Summary: The gas circulation concept has the best primary criteria ratings. However, ratings of the wick feed and circulating electrolyte concepts are sufficiently favorable to warrant further consideration. Other concepts are eliminated from further consideration; cabin air for poor reliability, ion exchange resin for high equivalent weight, and ion exchange membrane and rotating concepts for lack of any outstanding qualities.

Secondary criteria. - Atmospheric contamination by the gas circulation and wick feed concepts is potentially low, and their rating is therefore Very Good. Potential for leaking corrosive electrolyte into the cabin or coolant system results in a Fair contamination rating for the circulating electrolyte concept. All three concepts require coolant for either module cooling or water vapor condensation, and interfaces are comparable, with a Fair rating for each concept. Positive cooling control gives the gas circulation concept high flexibility, resulting in a Good rating for this criterion. The wick feed concept does not have this feature and is rated Fair. Direct liquid feed and positive cooling control give the circulating electrolyte concept substantial flexibility, meriting a Very Good rating. Growth potential of the three concepts is comparable, and they are rated

Good in this respect. Circulation rate in the gas circulation concept is low and it is rated Good for noise. Liquid pumping in the wick feed and circulating electrolyte concepts produces very little noise, and these concepts rate Very Good. Of all water electrolysis candidates, gas circulation and wick feed concepts have the lowest volumes, rating Very Good, and circulating electrolyte has the highest volume, rating Poor. All three concepts consume relatively little power and are rated Very Good in that respect. In summary, secondary criteria ratings of the gas circulation and wick feed concepts are comparable. Ratings of the circulating electrolyte concept are somewhat less satisfactory. Concept selection therefore requires reconsideration of primary criteria.

Selection. - Compared with the wick feed concept, the gas circulation concept has superior primary criteria ratings, with lower crew stress and slightly lower equivalent weight. Gas circulation secondary criteria ratings are as good as those of the wick feed concept, with better flexibility. The gas circulation concept is selected for AILSS Designs 1, 2, and 3. Gas circulation and water addition are on the oxygen side of the cells. This concept has a low equivalent weight, no inherent water feed or gas collection problems, and good thermal process control. The wick feed concept, if the problem of gas entrapment is resolved, becomes a good backup since it is much more developed at this time. The cabin air concept, which has no oxygen or water interfaces, has inherent advantages if its problems can be solved during development.

IMPACT OF MISSION PARAMETERS

Mission Length

Because electrolysis concepts require no expendables, mission duration has little effect on relative equivalent weight. Ratings are therefore unchanged by mission duration, and gas circulation remains the selected concept.

Crew Size

Changing crew size has no significant influence on relative attractiveness of the candidate concepts. All ratings therefore remain the same, and the gas circulation concept is selected for all crew sizes.

Power Penalty

Changing power penalty has no significant influence on equivalent weight relationships among the candidate concepts. As power penalty is decreased, the relative position of the ion exchange resin concept improves but not so much that its "poor" equivalent weight rating changes, even at 50 percent of the AILSS power penalty. For increasing power penalty, total equivalent weight of the ion exchange electrolyte concept increases rapidly. Equivalent weight of the rotating concept also increases more rapidly than that of the gas circulation concept so that its equivalent weight rating changes from "good" to "fair", Ion exchange electrolyte is affected more by power penalty than other concepts because it requires over 60 percent more power than any other concept. Thus, gas circulation remains the selected concept for all power penalties.

Because of its low power requirement, the gas circulation concept is also recommended for a situation where power availability is critical.

Resupply

The AILSS mission lasts 500 days without resupply. With increasing resupply frequency, the relative weight of the cabin air concept increases significantly because it has low spares weight, while the relative weight of the circulating electrolyte concept decreases enough to improve its equivalent weight rating. Nevertheless, the gas circulation concept would still be selected because of better absolute criteria, better secondary criteria, and freedom from resupply penalty.

Flight Date

The gas circulation concept is selected as the best concept for the AILSS mission and would therefore be the choice for any mission occurring in 1977, its earliest availability date, or later. The wick feed concept would be selected for similar missions in the 1974-1977 period, because its primary and absolute criteria ratings are superior to those of any other conept available in that period.

CO_2 REMOVAL AND CONCENTRATION

CONTENTS

CO_2 REMOVAL AND CONCENTRATION SUBSYSTEM

A steam desorbed resin concept is selected for all AILSS designs because it is the only one with consistently high ratings in all important areas, with particularly high reliability, low equivalent weight, and high flexibility. This process, which uses alternate cycles of fixed-bed absorption and steam regeneration, has the lowest volume of all concepts and, where isotope or waste heat is available, has the lowest electrical power.

CO_2 removal and concentration, as well as water electrolysis, is a potential part of the O_2 generation/CO_2 control subsystem, which is discussed in the next section of this study. The need for this separate section to determine the best CO_2 removal and concentration technique is to allow subsequent, straightforward comparison of integrated O_2 generation/CO_2 control concepts. This approach was discussed in the beginning of the previous section.

The CO_2 control requirements directly reflect the two objectives, removal and concentration. First, CO_2 concentration in the cabin atmosphere must be controlled to an acceptable level. This requirement is stated in the system specification as follows: In the unusual situation, where all nine men are in the same compartment, CO_2 partial pressure (normal maximum) must not exceed 7.6 mm Hg; when the crew is fairly evenly distributed between the two compartments, CO_2 partial pressure (normal) must be maintained between 3.8 and 5.7 mm Hg; during emergencies, CO_2 partial pressure (emergency maximum) must not exceed 15 mm Hg for a maximum period of 72 hours. To meet these requirements, a single concentrator serving both compartments is adequate, although use of multiple concentrators is discussed in the Selected EC/LS Systems section of this report.

The crew consumes oxygen from the spacecraft atmosphere and exhales carbon dioxide into the atmosphere at a rate of 18.54 pounds per day. This CO_2 must be removed from the atmosphere for two reasons; first, the CO_2 concentration, with no removal, would build up to a toxic level in less than 30 hours; second, the AILSS is regenerative, and CO_2 must be collected (concentrated) for processing by the CO_2 reduction unit, which recovers oxygen (for crew consumption) from the concentrated CO_2. This CO_2 concentration is an integral part of the fused salt CO_2 reduction process, but all other reduction concepts require a separate concentrator. Integration of CO_2 concentration units with CO_2 reduction and water electrolysis units is discussed in the O_2 Generation/CO_2 Control section of this report.

The second requirement is that the purity of the concentrated CO_2 must exceed 98 percent. The CO_2 should be pure enough to limit pressure buildup in the O_2 generator. The influence of CO_2 purity on subsystem selection is discussed later in this section under Evaluation and Selection, and its influence on system design is discussed in the O_2 Generation/CO_2 Control section of this report.

Nine candidate concepts and their characteristics are listed in table 12. These concepts are classified under regenerable solid sorption, electrochemical concentration, or miscellaneous, with three candidates in each category. Alternative versions of many of these concepts were investigated, although only the most competitive versions participated in the final selection process. The solid sorption processes use beds of solid, granular chemicals contained in canisters. As air containing CO_2 passes through these beds, the granules remove the CO_2 by physical adsorption (molecular sieves) or by forming a weak chemical bond (immobilized amines or ion exchange resins). The CO_2 is desorbed for concentration by application of heat, vacuum, or both. The electrochemical processes remove CO_2 from air by absorbing it in an alkaline electrolyte or water. The resulting ions are electrochemically transferred across a membrane and converted back to pure, gaseous CO_2. The membrane diffusion process removes CO_2 because it diffuses through the membrane far faster than air does. The liquid absorption process is similar to the solid sorption processes. CO_2 forms a weak bond with the liquid and is subsequently released by the application of heat. In the mechanical freezeout process, the temperature is lowered until the CO_2 solidifies, while the air remains gaseous.

The steam desorbed resin concept is selected for each of the AILSS designs. Figure 34 is a simplified representation of its operating principle, which is described in the following concept evaluation subsection.

CO_2 REMOVAL AND CONCENTRATION CONCEPTS

The most competitive versions of the candidate CO_2 removal and concentration concepts are discussed here in terms of the AILSS criteria. Alternative versions are briefly reviewed.

Molecular Sieve

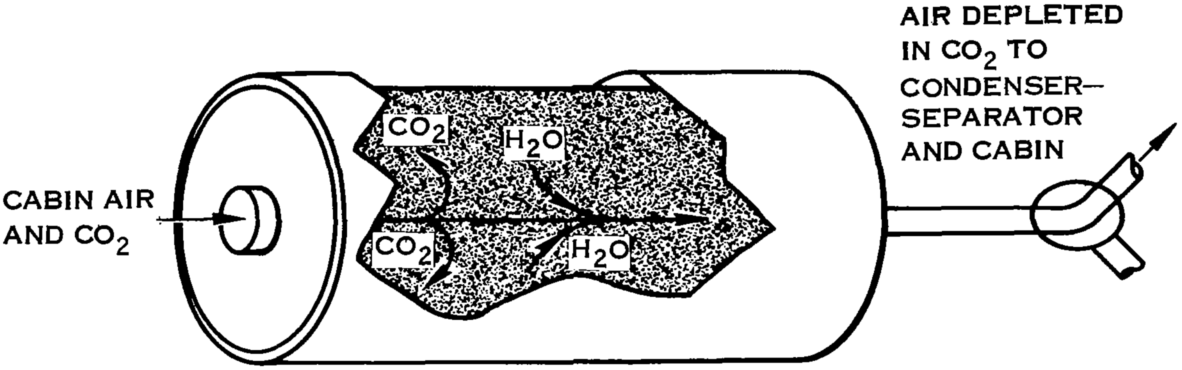
The molecular sieve concept is described quantitatively and schematically in figure 35. Basic to the operation of this four-bed sorption system is a sorbent material that has a high affinity for CO_2; an artificial zeolite (molecular sieves) is used. Two canisters function alternately in adsorbing and desorbing modes. Since the sorbent has a preferential affinity for water vapor, an additional pair of desiccant canisters, usually containing silica gel, is used to adsorb the moisture from the process stream before it enters the CO_2 removal beds.

Air drawn from the humidity control system by the process flow fan passes

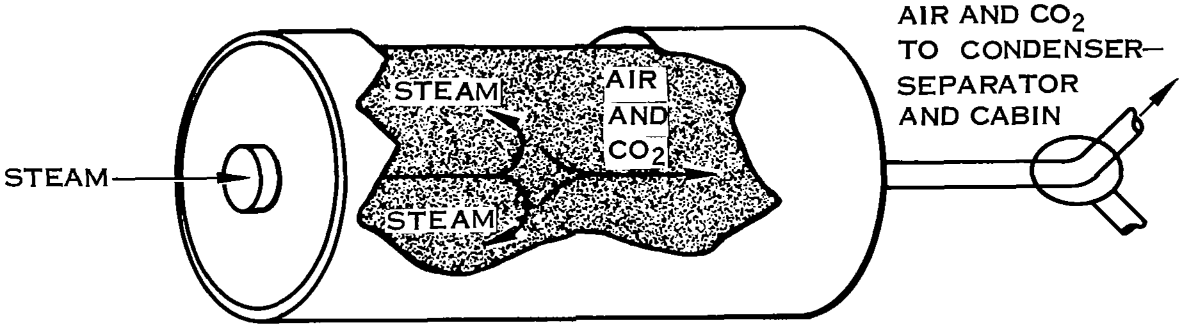
TABLE 12

CLASSIFICATION OF CO_2 CONCENTRATION CONCEPTS

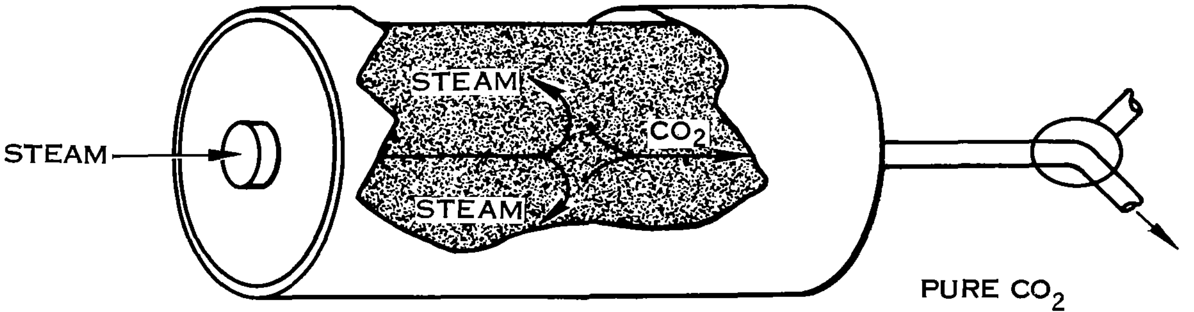
Concept	Category & mechanism	Nature of operation	Characteristics
Molecular sieve	Regenerable solid absorption	Cyclic - uses 2 desiccant & 2 CO_2 removal beds	Delivers dry CO_2 with some N_2 - needs thermal power
Solid amine	Regenerable solid absorption	Cyclic - uses 2 beds	Delivers wet CO_2 with some N_2 - needs thermal power
Steam desorbed resin	Regenerable solid absorption	Cyclic - uses 2 steam regenerated beds	Delivers wet CO_2 with some N_2 - needs thermal power
Electrodialysis	Electrochemical - resin electrolyte	Continuous - also electrolyzes H_2O in process	Delivers wet, pure CO_2 - all electrical
Carbonation cell	Electrochemical - immobilized electrolyte	Continuous - no H_2 involved in process	Delivers wet, pure CO_2 - all electrical
H_2 depolarized cell	Electrochemical - immobilized electrolyte	Continuous - generates power & water but requires H_2 & O_2	Delivers wet CO_2 - H_2 mixture - all electrical
Membrane diffusion	Miscellaneous - gaseous diffusion	Continuous - staged membranes also dehumidify cabin air	Delivers wet, pure CO_2 - all electrical
Liquid absorption	Miscellaneous - regenerable liquid absorption	Continuous - recycled, regenerated liquid used	Delivers wet CO_2 - uses thermal power
Mechanical freezeout	Miscellaneous - refrigeration cycle	Cyclic - uses 2 desiccant beds & cycled freezing heat exchangers	Delivers dry CO_2 with some N_2 - all electrical



ABSORPTION
(CO_2 REMOVAL)



DESORPTION — 1ST PHASE
(AIR PURGE)



DESORPTION — 2ND PHASE
(CO_2 CONCENTRATION)

Figure 34. Steam Desorbed Resin Concept

through a heat exchanger, which rejects the fan heat, and then through the adsorbing desiccant bed, where the stream is dried to a dewpoint of -85°F. The air continues through a second heat exchanger, which rejects the heat of water adsorption, to the adsorbing molecular sieve canister, where CO_2 is removed by adsorption on the zeolite. Effluent air returns to the cabin through the desorbing desiccant canister, where desorption of the contained water rehumidifies the air and regenerates the desiccant bed.

The remaining components of this subsystem are simultaneously engaged in recovering previously adsorbed carbon dioxide. The canister that had been adsorbing carbon dioxide from cabin air is isolated from the other canisters and is ready for desorption, which is a sequenced operation. In the first phase, atmospheric gas filling the void volume in the isolated, desorbing, zeolite canister is first returned to the concentrator inlet by the compressor. The accompanying reduction in canister pressure to 0.1 psia causes partial desorption of air and carbon dioxide, which return with the void volume gas. This ullage and adsorbed air recycling is necessary for delivery of high purity CO_2.

In the second phase of this recovery operation, the compressor discharge is diverted into the accumulator by a solenoid operated valve. The compressor maintains reduced pressure in the desorbing zeolite canister and transfers the carbon dioxide to the accumulator as it is desorbed. This desorption process is accelerated by the transfer of heat at 200°F to the zeolite bed from the heating fluid which circulates through coils in the bed. Near the end of the cycle, cold fluid replaces the hot fluid to precool the bed prior to adsorption. System operation is controlled by a timer that cycles the valves in a predetermined manner. The only alternate mode is vacuum desorption, which is used to remove CO_2 from the atmosphere in case of CO_2 pump failure or a thermal loop failure. This mode would be used only in an emergency, because both CO_2 and air are lost in the process.

Other versions of the molecular sieve concept differ in the method of desorption or in the manner in which heat is applied to achieve thermal desorption. The version just described uses hot and cold water in a coil heat exchanger for heating and cooling of CO_2 removal (molecular sieve) beds, and it uses heatless (ambient temperature) desorption of desiccant (silica gel) beds. The CO_2 removal beds desorb at 200°F and 0.1 psia, and the desiccant beds desorb by a rapid pressure swing cycle. Alternative versions of the molecular sieve process, rejected after thorough study because of higher equivalent weight, lower reliability, or poor availability, are:

1. Heatless desiccant desorption, and molecular sieve desorption at 375°F and 1.0 psia.

2. Thermal desorption of all sorbent beds (375°F at 1.0 psia for the CO_2 removal bed and 200°F for the desiccant bed) by internal heating.

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Molecular Sieve

FLIGHT AVAILABILITY: 1975
(1970 go-ahead)

RELIABILITY: 0.999578 **MTBF:** 10 500 hr

Spares/Redundant (R) Units:

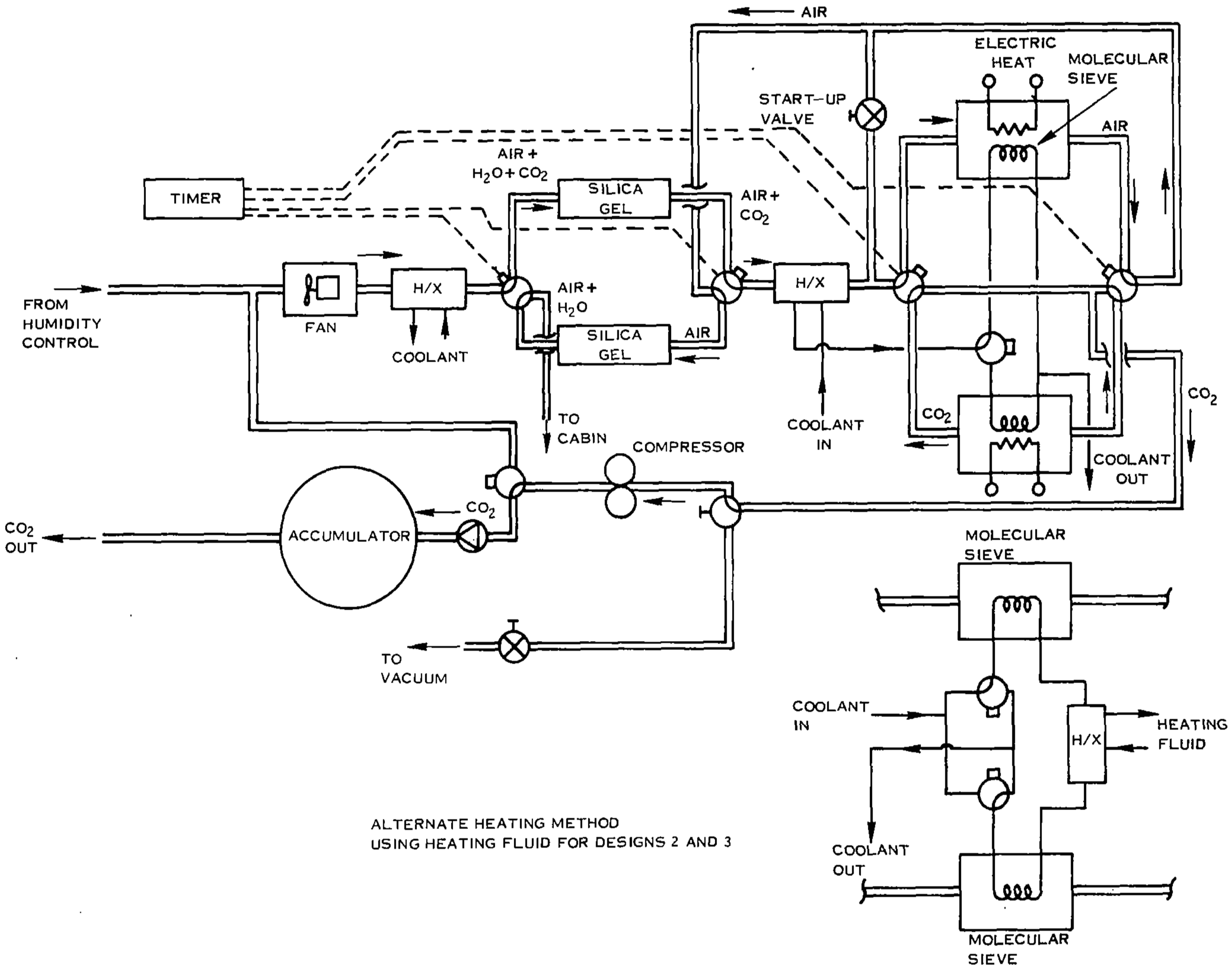
- 2 - Molecular Sieve Canister
- 2 - Silica Gel Canister
- 2 - Fan
- 1 - Heat Exchanger
- 3 - Timer
- 5 - Canister Diverter Valve
- 3 - Actuator
- 1 - Check Valve
- 2 - Compressor
- 2 - Solenoid Valve, 3-way, Coolant
- 1 - Heater (Designs 2 and 3)
- 2 - Heater Controller
- 2 - Solenoid Valve, 3-way
- 1 - Manual Diverter Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	0	2.3

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	379	393	385
Expendables	0	0	0
Spares/Redundant Units	324	331	331
Electrical Power	376	237	237
Thermal Power	0	15	0
Radiator Load	114	114	114
Total Equivalent Weight	1193	1090	1067
POWER (Watts):			
Electrical	837	528	528
Thermal	0	309	309

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	28	9	37

Figure 35. (Page 1 of 2)



ALTERNATE HEATING METHOD
USING HEATING FLUID FOR DESIGNS 2 AND 3

Figure 35. Molecular Sieve Concept (Page 2 of 2).

3. Hot gas desiccant bed desorption at 200° F and molecular sieve desorption at 375° F and 1.0 psia.

4. Heatless desorption of all beds -- rapid pressure swing cycling of desiccant beds and adiabatic molecular sieve desorption at 0.01 psia.

5. Thermoelectric temperature cycling of all beds, with heat of adsorption pumped up to supply heat of desorption.

Absolute criteria. -

Performance: The molecular sieve concept has demonstrated an ability to concentrate high purity CO_2 at the specified partial pressure levels. Nevertheless, purity is limited by coadsorption and codesorption of a small but significant quantity of oxygen and nitrogen.

Safety: This concept has no special safety hazards. Materials are not flammable and gas leakage cannot result in a toxic or explosive condition. Desiccant action should prevent bacterial growth in the silica gel beds.

Availability/confidence: A high temperature, high power version can be developed for a flight as early as 1973, while the low temperature version just described can be ready for a 1975 flight. Development experience with the high power version will drastically hasten development of this lower power version, which is now in the early prototype phase. More development efforts have been expended on this concept (high power version) than on any other for space application. Consequently, confidence in flightworthy hardware is high. One prototype, for example, is currently operating satisfactorily in the NASA Langley Integrated Life Support System chamber. The vacuum pump-compressor, which evacuates the CO_2 removal bed to 0.1 psia and delivers desorbed CO_2 to a 40 psia accumulator, needs considerable development.

Primary criteria. -

Reliability: System MTBF is slightly less than mission length. The four-way gas valves and the associated actuators and timers have the highest failure rates. There are no limited life items.

Crew time: Total repair time is lower than for any other concept. Repair of items most likely to fail is straightforward, and corresponding startup, monitoring, and cleanup time is minimal. There is no scheduled maintenance.

Equivalent weight: Low hardware weight and power give this concept an equivalent weight well below average. A moderate thermal power requirement results in an equivalent weight reduction of 116 pounds for Design 2 and 139 pounds for Design 3.

Secondary criteria. - The absence of any toxic materials or gases precludes cabin contamination. Major interfaces include: the thermal control loop, CO_2 reduction, humidity control, and electrical subsystems. No water management interface is required because CO_2 is delivered to the accumulator essentially free of water. This feature is considered a significant advantage of the molecular sieve concept because the limited life condenser-separator required for many of the other concentrator candidates requires scheduled maintenance. It is also desirable to avoid breaking the integrity of the water management loop for maintenance of another subsystem. With regard to flexibility, any physical adsorption concept automatically adjusts to changing inlet concentrations by removing more or less CO_2. This feature and the ability of the concentrator to mate with any reduction system are considered to be significant advantages. Growth prospects are good, with a relatively flat equivalent weight curve (as mission duration and/or crew size vary). Noise suppression will be somewhat more difficult than with most other concentrators because the vacuum pump-compressor pressure ratio is high and the compressor load is cyclic. Concentrator volume is close to average. The relatively large accumulator is used so that a two-hour concentrator downtime would not affect operation of the CO_2 reduction system. A reduction system failure can be handled simply by allowing the CO_2 accumulator to dump back into the cabin when the accumulator reaches its maximum allowable pressure. CO_2 partial pressure buildup in the cabin is slow, and degraded operation in this mode could continue for 20 hours before the 15 mm emergency limit would be exceeded. Power is well below average.

Solid Amine

Some solid materials used for CO_2 sorption do not require a dry process stream. As a result, fewer sorption beds are required. Currently, the most competitive materials are the immobilized amines and ion exchange resins. Treated charcoal and metallic oxides were considered but later rejected. Other materials to improve this approach may be developed before the AILSS mission. The evaluation of this system, however, has been made using available data based on an immobilized amine such as a silica gel carrier impregnated with a mixture of ethylene glycol, sodium sarcosinate, and binding agents.

Figure 36 describes this concept quantitatively and schematically. Air drawn from the cabin by the fan enters the sorbent bed, where both water and CO_2 are removed. The air then returns to the cabin through a valve. A timer operates motor driven valves, which select the absorbing and desorbing canisters. Cold thermal control fluid is directed to the absorbing canister by a solenoid operated valve. This fluid is heated by a heat exchanger before entering the desorbing canister. Carbon dioxide delivery is difficult because the gas contains considerable water vapor, and a pressure of 40 mm Hg is needed for desorption. A condenser-separator and a water-cooled two-stage vacuum pump-compressor are required to deliver CO_2 from 40 mm Hg to 40 psi. Condensing will occur in the delivery pump. A bypass line to the absorb-

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Solid Amine

FLIGHT AVAILABILITY: 1976
(1970 go-ahead)

RELIABILITY: 0.999426

MTBF: 14 100 hr

Spares/Redundant (R) Units:

- 2 - Canister
- 3 - Disc Valve
- 2 - Fan
- 2 - Motor/Gear Box
- 1 - Heater (Designs 2 and 3)
- 2 - Three-way Valve, Coolant
- 6 - Condenser/Separator
- 1 - Heat Exchanger
- 1 - Heater Controller
- 2 - Vacuum Pump
- 3 - Timer
- 2 - Water Regulator
- 1 - Diverter Valve
- 2 - Solenoid Valve, 3-way
- 2 - Check Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	8.0	1.7

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	330	377	337
Expendables	0	0	0
Spares/Redundant Units	293	303	303
Electrical Power	865	142	142
Thermal Power	0	80	0
Radiator Load	263	263	263
Total Equivalent Weight	1751	1165	1045
POWER (Watts):			
Electrical	1923	316	316
Thermal	0	1607	1607

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	25	8	33

Figure 36. (Page 1 of 2)

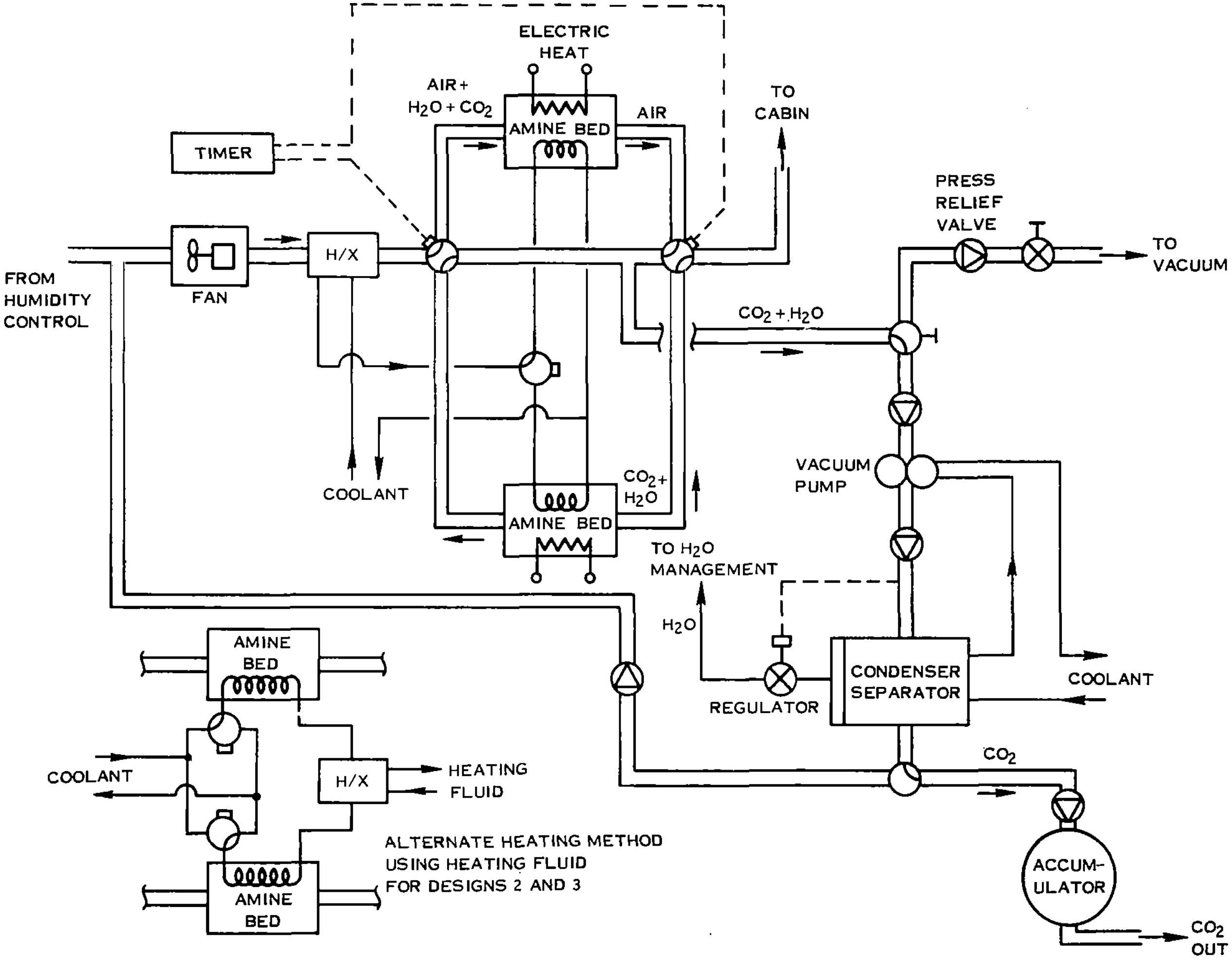


Figure 36. Solid Amine Concept (Page 2 of 2)

ing bed inlet is used during initial desorption to recycle adsorbed and void-volume air, preventing collection of impure CO_2. The only alternate mode for CO_2 removal is vacuum desorption, where CO_2 is dumped overboard rather than delivered to the accumulator. This is an emergency mode because CO_2, water, and air are lost in the process.

Absolute criteria. -

Performance: Acceptable delivery purity is expected. Amine carryover could be a problem, but test results indicate that the outlook is favorable.

Safety: The only potential safety hazard is amine carryover resulting from a breakdown of the active impregnant material. Amine vapor is somewhat toxic, and prolonged exposure could cause respiratory illness. Materials are not flammable, and gas leakage cannot result in a toxic or explosive condition. Bacteria growth may occur in the condenser-separator. Maintenance should be safe.

Availability/confidence: The solid amine concept can be developed for a flight as early as 1976. Development is now in the early prototype phase. A large scale prototype has been built and tested, but degradation characteristics are not fully established.

Primary criteria. -

Reliability: System MTBF is slightly greater than mission length. The solenoid gas valves and timer have the highest failure rates. The condenser-separator requires periodic, scheduled replacement.

Crew time: Crew time is very low, with unscheduled time well below average. Repair of items most likely to fail is straightforward, and corresponding startup, monitoring, and cleanup time is minimal.

Equivalent weight: Hardware weight is moderate, but a high power requirement results in above-average equivalent weight for Design 1. Most of the power is for thermal application, and equivalent weight is, therefore, lower by 621 pounds for Design 2 and by 741 pounds for Design 3, which is somewhat below average.

Secondary criteria. - Amine carryover contamination of the cabin is of concern, although present data shows the quantity to be small. Moreover, development of sorbents from which no carryover occurs is likely. This concentrator interfaces with the following subsystems: humidity control, electrical, thermal control, water management, and CO_2 reduction. Thermal control and water management interfaces are the most troublesome during maintenance. Small changes in CO_2 generation will automatically result in an increase in cabin partial pressure and, thereby, an increase of CO_2 removal. This feature and the ability of the concentrator to interface with any

CO_2 reduction concept are good flexibility characteristics. For Design 1, growth characteristics are good for mission length and fair for crew size. For Designs 2 and 3, growth characteristics are generally good. Noise level from cyclic compressor operation is somewhat objectionable. Volume is close to average. Electrical power consumption is somewhat above average for Design 1 and well below average for Designs 2 and 3.

Steam Desorbed Resin

A data sheet and schematic for a steam regenerable, ion exchange resin CO_2 removal system are shown in figure 37. A simplified representation of this concept was shown in figure 34. Use of two sorbent beds operating cyclically is also a characteristic of the preceding concept. Steam desorption, however, is used to displace CO_2 from the sorbent bed, rather than thermal heat alone. This permits rapid collection of previously absorbed CO_2 so that the desorption phase of the cycle is much shorter than the absorption phase. The long absorption phase permits a lower cabin air process rate than other sorption concepts, which use strictly thermal desorption. This feature also permits use of a single sorbent bed, alternately absorbing and desorbing. This single bed version, however, has a high power consumption for steam generation during desorption and a high heat rejection rate during absorption. The use of two cyclic beds, operating out of phase, cuts these penalties in half. Use of more than two beds results in great complexity. Even with two beds, energy storage (a battery) is included in Design 1 to eliminate power peaks and reduce maximum power. The sorbent material currently used is a commercially available chlormethylated polystyrene divinylbenzene copolymer, aminated with diethylenetriamine.

In normal operation, both beds may be absorbing, or one may be absorbing and the other desorbing, at any given time. Each bed desorbs only 25 percent of the time. When both beds are absorbing CO_2, cabin air is directed through both beds, in parallel, by a single fan. The ion exchange resin in each bed absorbs CO_2 on a preset timed cycle until effluent CO_2 concentration is 40 to 50 percent of influent concentration. The cycle is timed so that when one bed reaches this condition, it begins the desorption phase (while the other bed continues absorption), with influent air bypassing this bed. During desorption, steam at ambient pressure is generated and directed into the desorbing resin bed. For the first part of this phase, steam condensing on the sorbent displaces absorbed CO_2 farther and farther along the bed. At the same time, void volume air is displaced through a valve to the cabin. In the second part of the desorption phase, this valve diverts to the concentration position, and nearly pure saturated CO_2 is delivered to the accumulator by a compressor. At the end of the desorption phase, bed temperature is 180° to 200° F and a significant quantity of condensed steam is dispersed throughout the solid resin. When the absorption phase starts, this condensed steam evaporates into the influent cabin air, cooling the bed and making room for more CO_2. A condenser-separator removes this water vapor from the effluent air. Another condenser-separator removes excess water vapor from the CO_2 before it enters the accumulator.

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Steam Desorbed Resin

FLIGHT AVAILABILITY: 1976
(1970 go-ahead)

RELIABILITY: 0.999433 MTBF: 17 000 hr

Spares/Redundant (R) Units:

1 - Ion Exchange Resin Bed
2 - Fan
4 - Diverter Valve, Solenoid
1 - Steam Generator
10 - Condenser/Separator

3 - Timer
2 - Solenoid Valve, Shutoff
2 - Compressor
2 - Water Regulator
1 - Check Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	16.0	1.5

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	269	231	200
Expendables	0	0	0
Spares/Redundant Units	231	231	231
Electrical Power	453	81	81
Thermal Power	0	62	0
Radiator Load	195	195	195
Total Equivalent Weight	1148	800	707
POWER (Watts):			
Electrical	1008	180	180
Thermal	0	828	828

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	18	6	24

Figure 37. (Page 1 of 2)

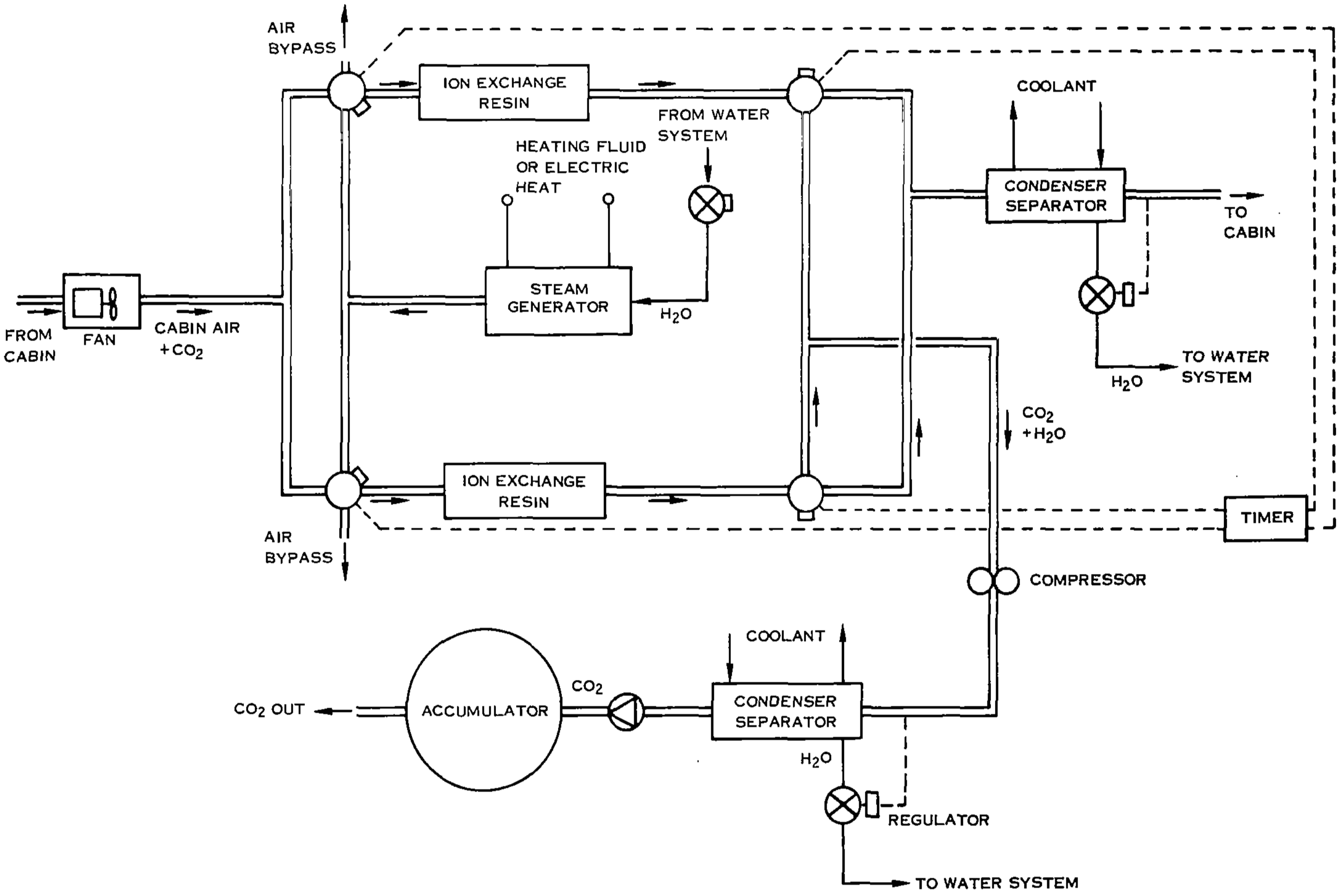


Figure 37. Steam Desorbed Resin Concept (Page 2 of 2)

Absolute criteria. -

Performance: Acceptable delivery purity is expected. Elimination of amine carryover from this sorbent is expected during development.

Safety: There are no special problems, except possible amine carryover which is unlikely. Materials are not flammable, and gas leakage cannot result in a toxic or explosive condition. Periodic processing of steam should help prevent bacteria growth in the condenser-separators. The steam at ambient pressure is safe. Maintenance should be safe.

Availability/confidence: The steam desorbed resin concept can be developed for a flight as early as 1976. Development is now in the early prototype phase. A large scale prototype has been built, and sorbent degradation appears unlikely. The pacing item may be the zero gravity steam generator or a compressor that handles wet CO_2 efficiently.

Primary criteria. -

Reliability: System MTBF is considerably greater than mission length, because the system is a simple one. The timer, solenoid gas valves, and compressor have the highest failure rates. The condenser-separators require periodic, scheduled replacement.

Crew time: The steam desorbed resin concept and two others have the highest scheduled maintenance, while unscheduled maintenance is well below average. Scheduled maintenance time is for periodic replacement of the two water separators. All maintenance is straightforward, and startup, monitoring, and cleanup time is low.

Equivalent weight: Very low hardware weight and low power give this concept an equivalent weight well below the average for Design 1, especially with a battery for electrical energy storage. Most of the power is for thermal application, and equivalent weight is, therefore, lower by nearly 350 pounds for Design 2 and by about 450 pounds for Design 3, close to the lowest equivalent weight of all candidate concepts.

Secondary criteria. - Some minor amine carryover has been noticed during testing but the possibility of serious cabin contamination is remote. Amine vapor is somewhat toxic, and prolonged exposure could cause respiratory illness. Concentrator interfaces include: electrical, thermal control, water management, and CO_2 reduction subsystems. Thermal control and water management interfaces involve the most roublesome maintenance. This concentrator is very flexible: it has no restrictions with respect to reduction subsystem interfaces, and it adjusts automatically to small changes in the CO_2 generation rate by removing more CO_2 when the CO_2 concentration in the cabin increases. Furthermore, effluent air can be dumped to the humidity control subsystem, eliminating a condenser-separator. For all designs, growth is fairly good in terms of mission length and very good in terms of crew size. Intermittent compressor operation (20 to 30 minutes per hour) may be bothersome from a noise standpoint. The resulting high compressor mass flow rate is offset by the fact that the compressor inlet pressure is at ambient. This concept and one other have the lowest system volume. Electrical power is well below average for Design 1 and lower than that of any other concept for Designs 2 and 3.

Electrodialysis

Figure 38 is a data sheet and schematic of an electrodialysis concentrator. In normal operation, the fan pumps cabin air through a humidifier, through the absorber compartments of the four-compartment cells, and back to the cabin. In the humidifier, recycled liquid water migrates through the membrane into the air stream. This humid air enters an absorber compartment, where contained carbon dioxide is scrubbed out by reaction with hydroxyl ions migrating through an anion transfer membrane. The hydroxyl ions are formed by water electrolysis in an adjacent anode compartment. Carbonate ions formed by reaction of CO_2 and hydroxyl ions migrate through another anion transfer membrane into a concentrator compartment. Here, they reform gaseous CO_2 by reaction with hydrogen ions migrating across a cation transfer membrane. These hydrogen ions are formed by water electrolysis in the cathode compartment. Reformed CO_2 is pumped through a condenser-separator to the CO_2 accumulator. Hydrogen and oxygen are formed by water electrolysis at the cathode and anode, respectively. Oxygen is returned to the cabin atmosphere, and hydrogen is fed through a condenser-separator to the Sabatier or Bosch CO_2 reduction process (coupling with the solid electrolyte CO_2 reduction process is impractical, because the combination would produce excess oxygen, upsetting the system materials balance). Water is supplied to the anode and cathode compartments to balance byproduct oxygen and hydrogen generation.

Absolute criteria. -

Performance: Although delivery purity has not been established, electrochemical processes such as this should produce extremely pure CO_2.

Safety: Proximity of hydrogen and oxygen represents a potential explosion or fire hazard. The electrolyte is not corrosive, and there are no other special hazards.

Availability/confidence: The electrodialysis concept can be developed for a flight by 1977. Development is now in the prototype phase. Four- and ten-man prototypes have been delivered to government agencies, and new membranes of considerable strength have been developed.

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Electrodialysis

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999756 MTBF: 4400 hr

Spares/Redundant (R) Units:

2 - Electrodialysis Module
2 - Fan
1 - Humidifier
2 - Compressor
10 - Condenser-Separator
1 - Check Valve
2 - Flow Control Valve
4 - Water Regulator (2 each type)
2 - Power Supply
3 - Pump

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	16.0	8.2

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	322	322	322
Expendables	0	0	0
Spares/Redundant Units	511	511	511
Electrical Power	1110	1110	1110
Thermal Power	0	0	0
Radiator Load	336	336	336
Electrolysis Credit	- 592	- 592	- 592
Total Equivalent Weight	1687	1687	1687

POWER (Watts):			
Electrical	2463	2463	2463
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	21	6	27

Figure 38. (Page 1 of 2)

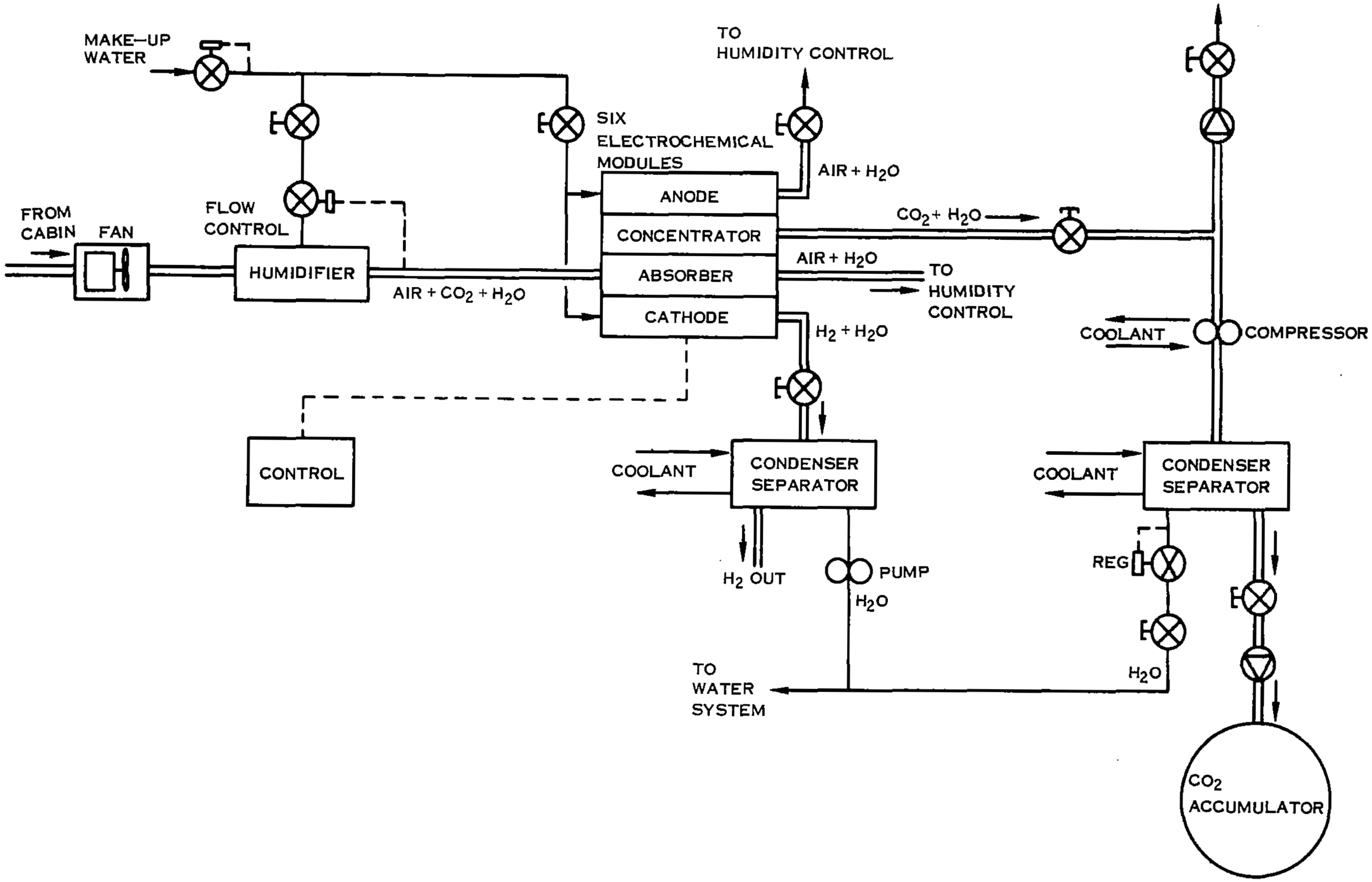


Figure 38. Electrodialysis Concept (Page 2 of 2)

Primary criteria. -

Reliability: System MTBF is less than half the mission length. The electrochemical unit itself has the highest failure rate. This unit is divided into six modules, each containing five cell stacks. By making each module removable and interchangeable, only two standby units are needed. The condenser-separator needs periodic scheduled replacement.

Crew time: Total crew time is higher than for any other concept and includes the highest expected unscheduled repair time. Repair of the item most likely to fail requires breaking liquid lines and a hydrogen line. Fault isolation and monitoring are relatively complex. These factors are likely to augment crew time considerably.

Equivalent weight: Weights are identical for all designs. Hardware weight is comparable to that of other concepts, but high electrolysis power results in above-average equivalent weight for all designs. The high power is partially compensated by a 592 pound reduction in the main electrolysis unit because of the byproduct oxygen and hydrogen generated by this concentrator.

Secondary criteria. - Cabin contamination by hydrogen is possible. The electrolyte, potassium carbonate, might also contaminate the cabin if a cell were destroyed, but this would be more an annoyance than a hazard. Concentrator interfaces include: humidity control, electrical, thermal control, water management, and reduction subsystems. In addition, the stack output lines include both oxygen and hydrogen lines. The thermal control, water management, and hydrogen interfaces are undesirable. Electrical adjustments can give this unit capacity flexibility over a narrow range. However, inability to interface with a solid electrolyte CO_2 reduction subsystem (excess oxygen generated would upset the system materials balance) limits flexibility. The unit could be designed to perform much of the electrolysis function. Growth characteristics are fair for all designs, with increasing complexity, crew time, and equivalent weight for longer missions or larger crews. Delivery pump requirements are less severe than for most concentrator concepts because CO_2 is delivered from ambient pressure on a noncyclic basis. As a result, noise suppression would be easy to accomplish. Volume is well below average. A large portion of the volume is required for the accumulator. Power consumption is well above average.

Carbonation Cell

Figure 39 shows a data sheet and schematic of this electrochemical CO_2 concentrator. In normal operation, cabin air passes through a humidifier and then enters the first of three electrochemical stages that recover CO_2 in successively purer form. In the humidifier, water vapor is transferred from the humid outlet air to the inlet air, through a semipermeable membrane which separates the two air streams. This humidified air is then ready to enter the electrochemical unit, which consists of a first stage scrubber cell module, a second stage basic cell module, and a third stage acidic cell module. Liquid water is fed to the electrolyte compartments of each module to compensate for water evaporated into the outlet gas streams. The first stage removes about half of the CO_2 (and some oxygen) from the inlet air stream, which exits through the humidifier to the inlet of the cabin humidity control subsystem. The CO_2 concentrate stream goes to the second stage, which further concentrates the CO_2 in a manner similar to that of the first stage. The third stage further concentrates the CO_2 to at least 99 percent, by electrochemical removal of oxygen. The concentrated CO_2 is pumped through a condenser-separator to an accumulator.

The second stage could be omitted by increasing the size of the third stage. For evaluation purposes, the three-stage concept was chosen because more information is available and the differences between evaluations of the two concepts are not significant.

Abnormal operation is quite practical for this concentrator. The CO_2 transfer rate is roughly proportional to current over a fairly wide range. Thus (assuming parallel electrical connection of modules within any stage), if one of the eight electrochemical modules fails electrically, the current and CO_2 transfer rate will show a compensating increase in the remaining units. Current limiters, however, are required to prevent water electrolysis (occurring at current densities above 30 amp/ft^2), for which there is no provision in the cell design.

Absolute criteria. -

Performance: Although delivery purity has not been fully established, electrochemical processes such as this should produce extremely pure CO_2.

Safety: This concept differs from other electrochemical concepts in that hydrogen is neither consumed nor evolved. The corrosive electrolyte represents some hazard, although it is immobilized within the cells.

Availability/confidence: The carbonation cell concept can be developed for a flight by 1979. Development is now arrested in the prototype phase. One stage has had some endurance testing, but work on others has been limited to parametric testing. No system tests have been run, and materials problems are serious.

Primary criteria. -

Reliability: System MTBF is less than half the mission length. The electrochemical unit itself has the highest failure rate. Each of its three sections is subdivided into eight modules so that only one spare is required for each section. All modules in the standy section must be removable and interchangeable with corresponding modules in the on-line section to accommodate eight failures in each section.

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Carbonation Cell

FLIGHT AVAILABILITY: 1979
(1970 go-ahead)

RELIABILITY: 0.999621

MTBF: 3900 hr

Spares/Redundant (R) Units:

1 - Basic
1 - Acidic Cell
1 - Electrochemical Scrubber

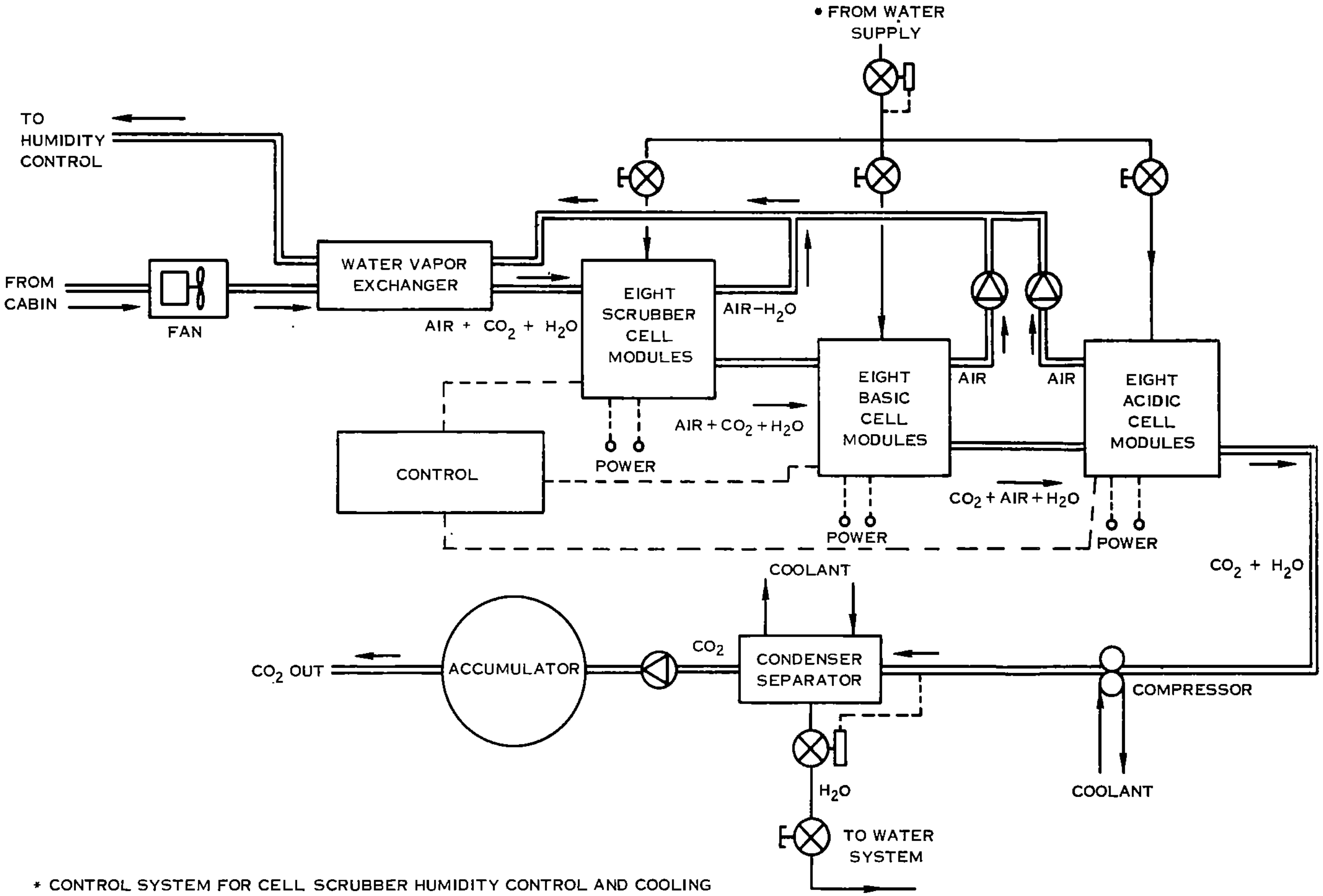
2- Fan
1-Water Vapor Exchanger
2-Check Valve
4-Regulator (2 each type)
2-Power Supply
6-Condenser-Separator
2-Compressor

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	8.0	7.7

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	341	341	341
Expendables	0	0	0
Spares/Redundant Units	312	312	312
Electrical Power	825	825	825
Thermal Power	0	0	0
Radiator Load	250	250	250
Total Equivalent Weight	1728	1728	1728
POWER (Watts):			
Electrical	1832	1832	1832
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	19	7	26

Figure 39. (Page 1 of 2)



* CONTROL SYSTEM FOR CELL SCRUBBER HUMIDITY CONTROL AND COOLING

Figure 39. Carbonation Cell Concept (Page 2 of 2)

The condenser-separator requires periodic, scheduled replacement.

Crew time: Scheduled time is close to average, while unscheduled time is well above average. Repair of items most likely to fail requires breaking liquid lines, but the immobilized electrolyte should not leak. Fault isolation and monitoring are relatively complex. These factors tend to augment crew time somewhat.

Equivalent weight: High electrolysis power results in above-average equivalent weight, which is the same for Designs 1, 2, and 3.

Secondary criteria. - The absence of hydrogen from this particular electrochemical concept makes cabin contamination unlikely. Traces of electrolyte might enter the cabin but the possibility is small. Thermal loop and water management interfaces are undesirable because of increased maintenance problems associated with liquid loops. Small load capacity adjustments can be effected by varying the current density of the cell. This feature and the ability to interface with any reduction subsystem are good flexibility characteristics. Growth characteristics are fair for all designs, with increasing complexity, crew time, and equivalent weight for longer missions or larger crews. Delivery pump noise suppression will be easier to accomplish for the electrochemical concentrators than for most other concepts, because the CO_2 is delivered from ambient pressure on a noncyclic basis. Also, the pump is water jacketed and will tend to suppress the noise automatically. Volume is well below average. Power consumption is above average for all designs.

Hydrogen Depolarized Concentrator

A data sheet and schematic of this concentrator are presented in figure 40. Input power for the electrochemical concentration unit is not required, because the concentration process is superimposed on a fuel cell type reaction between oxygen and hydrogen, which generates electricity. Inlet air is passed through a humidifer before entering the cell. Within the cell, carbon dioxide is transferred from the process air to a hydrogen atmosphere through an electrolyte maintained in a porous matrix. Outlet process gas returns to the cabin through the other side of the humidifer where water is transferred to the inlet stream through a membrane. Hydrogen and oxygen are continuously supplied to the concentration cell by the electrolysis cell, and a pump delivers the CO_2 and the excess hydrogen to an accumulator through a condenser-separator. Electrical power generated continuously by this system can be conditioned for use or dissipated.

Absolute criteria. -

Performance: Although delivery purity has not been established, electrochemical processes generally produce extremely pure CO_2. Delivered CO_2 should contain no air, but it does contain considerable hydrogen in this concept. This requires either reaction or separation of hydrogen in the CO_2 reduction process.

Safety: Proximity of hydrogen and oxygen represents a potential explosion or fire hazard. The corrosive electrolyte is an additional hazard, although it is immobilized within the cells.

Availability/confidence: The hydrogen depolarized cell concept can be developed for a flight by 1978. Development is now well into the research phase. Single cell endurance and parametric testing have been extensive.

Primary criteria. -

Reliability: System MTBF is less than half the mission length. The electrochemical unit itself has the highest failure rate. This unit is divided into eight replaceable modules, and one complete eight-module standby unit is needed to accommodate eight failures. The condenser-separator needs periodic, scheduled replacement.

Crew time: Scheduled time is close to average, while expected unscheduled repair time is well above average. Repair of items most likely to fail requires much time for purging and monitoring. Moreover, repair is somewhat hazardous because hydrogen flows throughout the system; this will tend to increase maintenance time.

Equivalent weight: Low net hardware weight and low net power give this concept the lowest equivalent weight for Design 1 and an identical, well-below-average equivalent weight for Designs 2 and 3. These values include a credit of 140 pounds for the power generated.

Secondary criteria. - Cabin contamination by hydrogen leakage is quite possible. More remote is the possibility of electrolyte (K_2CO_3) contamination. This concentrator interfaces with the humidity control, electrical, thermal control, water management, water electrolysis, and CO_2 reduction subsystems. Except for the Bosch and Sabatier concepts, it does not satisfactorily interface with any CO_2 reduction subsystem. Problems previously discussed are associated with the water management and thermal control interfaces. The interface with the water electrolysis subsystem also creates some limitations. When the electrolysis subsystem requires maintenance, the concentrator has to be shut down. Growth characteristics are fairly good (limited by high failure rate) for mission length and good (limited by increasing complexity) for crew size. Like other electrochemical concentrators, noise characteristics are very good. The chief source of noise is the CO_2 delivery pump which, for this unit, delivers CO_2 from ambient pressure on a noncyclic basis. The water-jacketed compressor is a natural noise suppressor. Excluding accumulator requirements, the volume is significantly greater than that of other concepts because hydrogen, a low molecular weight gas, is stored with the carbon dioxide, and a longer downtime is required during maintenance. Net electrical power consumption is well below average for all designs, but the need for an output power converter is undesirable.

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Hydrogen Depolarized Cell

FLIGHT AVAILABILITY: 1978
(1970 go-ahead)

RELIABILITY: 0.999623 MTBF: 4600 hr

Spares/Redundant (R) Units:

1 - CO_2 Concentrator
3 - Fan
2 - Power Converter
2 - Compressor
9 - Condenser/Separator
2 - Water Regulator
1 - Check Valve
1 - Diverter Valve
1 - Temp Conditioner
1 - H_2 Regulator
1 - O_2 Regulator
1 - Water Pump
1 - Control

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	8.0	7.8

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	255	255	255
Expendables	0	0	0
Spares/Redundant Units	193	193	193
Electrical Power	357	357	357
Thermal Power	0	0	0
Radiator Load	68	68	68
Total Equivalent Weight	873	873	873
POWER (Watts):			
Electrical	619	619	619
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	51	6	57

Figure 40. (Page 1 of 2)

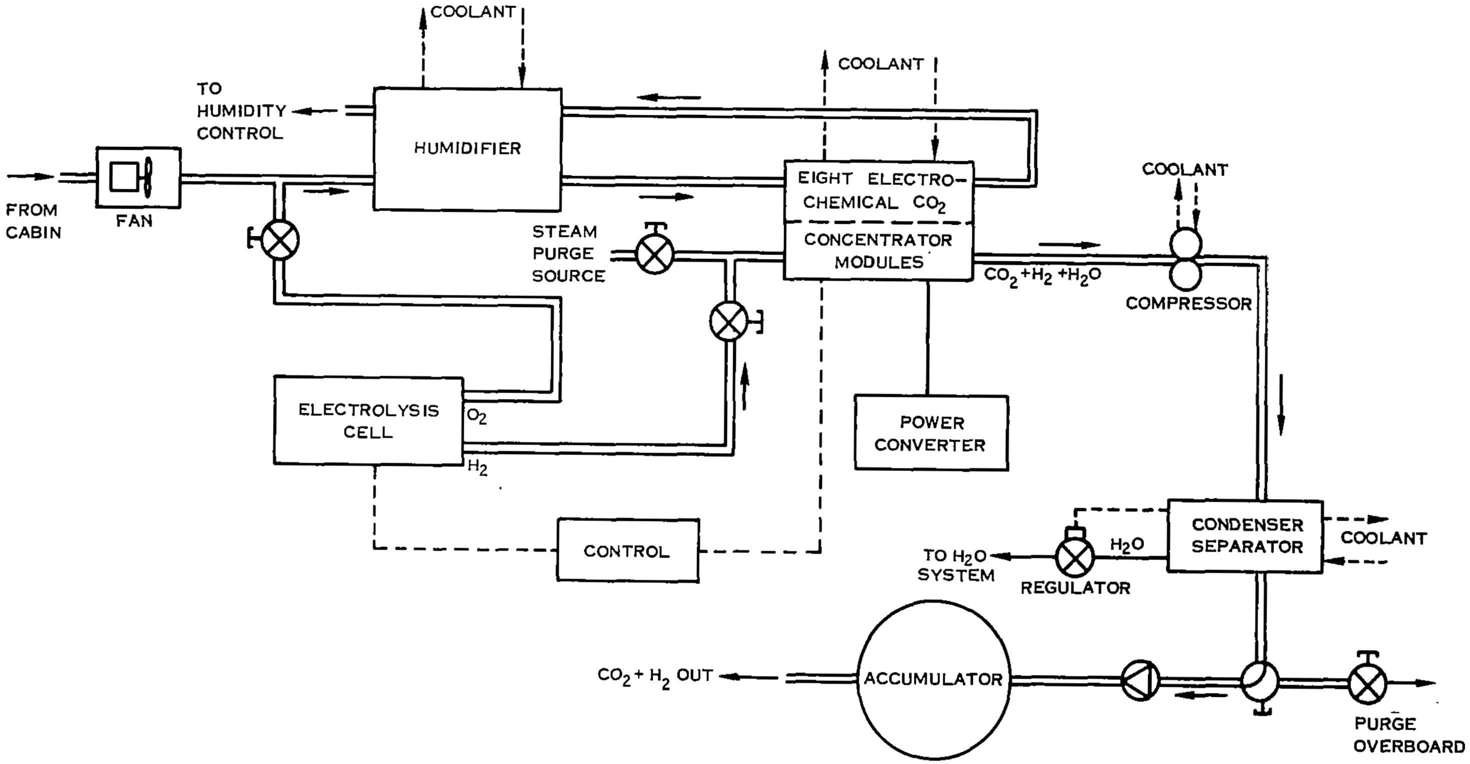


Figure 40. Hydrogen Depolarized Cell Concept (Page 2 of 2).

Membrane Diffusion

Concentration by membrane permeation is a mass transfer process accomplished by a total pressure difference and selective diffusion. The degree of separation is dependent on the difference in transfer rates of the component gases across the membrane. Membranes have been developed that are highly permeable to CO_2. These membranes contain a CO_2 hydrolysis catalyst to increase permeability. As a result, just two membrane stages are required to deliver 99 percent pure CO_2.

Figure 41 is a data sheet and schematic of the two-stage membrane diffusion concentrator. Inlet air drawn from the humidity control subsystem is forced through the concentrator by a low pressure ratio fan. The air then passes through a heat exchanger, which rejects the fan heat, and through the first stage, which consists of 36 modules. Each module is one cubic foot in volume and includes a stack of 85 membrane sheets. As the air passes through the stack, a portion of the flow permeates the walls. Because the membrane is more permeable to CO_2 than oxygen and nitrogen, the permeated gas has a higher CO_2 concentration. Air that does not permeate the walls is returned to the cabin. Two stages are required to achieve the desired CO_2 purity; thus, the CO_2 enriched air leaving the first stage is recompressed, recooled, and delivered to the second stage. Gas that does not permeate the second stage membranes is returned to the inlet of the first stage. The gas permeated through the membranes is pumped through a condenser-separator to the accumulator. A large quantity of water is delivered because of the water's high membrane permeability. In fact, water permeability is 15 times greater than CO_2 permeability through the membranes. Calculations indicate that approximately 20 pounds of water vapor per day will be transferred through the membrane, condensed, and delivered to the water management system.

Absolute criteria. -

Performance: The two-stage membrane unit evaluated here will deliver 99 percent pure CO_2. Higher purity can be obtained with additional stages at little cost in equivalent weight.

Safety: The concept has no normal safety hazards, but there are two potential problems. If the membranes should dry out, they would be a potential fire hazard. The cesium bicarbonate/sodium arsenate catalyst could poison the water condensate if extracted by the water vapor passing through the membrane. While these problems must be considered, they should be controllable.

Availability/confidence: The membrane diffusion concept can be developed for a flight as early as 1978. Development is now in the research phase. Spectacular advances in membrane performance have occurred during the past few years and a two-man concentration unit has been integrated into a system designed for the F4C aircraft. Use as a second stage in the concentration process does not involve many of the problems associated with use as a first stage separator and should be considered for increasing purity when used in conjunction with solid sorption concentration concepts. Consequently, prototype development can be started now and a membrane final filter can be developed for a flight as early as 1976.

Primary criteria . -

Reliability: System MTBF is far greater than mission length because of long membrane life. However, the effect of membrane filler chemical deterioration could not be evaluated, reducing confidence in this value. The compressors and pump have the highest failure rates. The condenser-separators require periodic scheduled replacement.

Crew time: The membrane diffusion concept and two others have the highest scheduled crew time, but unscheduled repair time is lower than that of any other concept. High scheduled time results from periodic replacement of the two water separators. The need to break the liquid line during pump repair will tend to increase repair time.

Equivalent weight: The membrane diffusion concept has the lowest Design 1 power of all candidate concepts, but its very high hardware weight (despite minimum spares weight) increases total equivalent weight to just below average for all designs. Most of this weight is in the package structure. Equivalent weight is identical for all designs. This concept removes considerable atmospheric water vapor and, therfore, receives a significant humidity control credit.

Secondary criteria. - Membrance rupture and exposure to the atmosphere could allow traces of the immobilized liquid to contaminate the atmosphere, but the quantity and the toxicity of these contaminants -- cesium bicarbonate and sodium arsenate -- is limited. However, they must be kept out of the potable water supply. The concentrator interfaces, listed in order of difficulty, are as follows: water management, thermal control, CO_2 reduction, humidity control, and electrical subsystems. The first two interfaces are undesirable. Increases in CO_2 production will result in increased cabin concentration, which automatically increases the removal capacity of the concentrator. It is flexible enough to interface with any reduction subsystem. Confidence is high that any desired purity may be attained. With low failure rate and crew time, growth is extremely good for longer missions. Growth characteristics are fair in terms of increasing crew size, somewhat better for Design 1. Two compressors and one fan are constantly running during operation of this unit. The first stage compressor is required to deliver the CO_2 (and water) from 0.1 psia. Noise suppression, while helped by the water-cooled compressor jackets, is more difficult than for many of the other concepts. As previously mentioned, membrane surface area requirements are currently very large and volume is nearly the highest of all concepts. Power consumption is lower than that of any other concept for Design 1 and well below average for Designs 2 and 3.

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Membrane Diffusion

FLIGHT AVAILABILITY: 1978
(1970 go-ahead)

RELIABILITY: 0.999749

MTBF: 31 100 hr

Spares/Redundant (R) Units:

- 2 - Membrane Module
- 2 - Fan
- 1 - Heat Exchanger
- 10 - Condenser/Separator
- 4 - Compressor (2 each type)
- 2 - Check Valve
- 3 - Water Pump
- 1 - Diverter Valve
- 2 - Water Regulator

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	16.0	0.8

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	1000	1000	1000
Expendables	0	0	0
Spares/Redundant Units	172	172	172
Electrical Power	196	196	196
Thermal Power	0	0	0
Radiator Load	60	60	60
Humidity Control Credit	-110	-110	-110
Total Equivalent Weight	1318	1318	1318
POWER (Watts):			
Electrical	436	436	436
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	52	3	55

Figure 41. (Page 1 of 2)

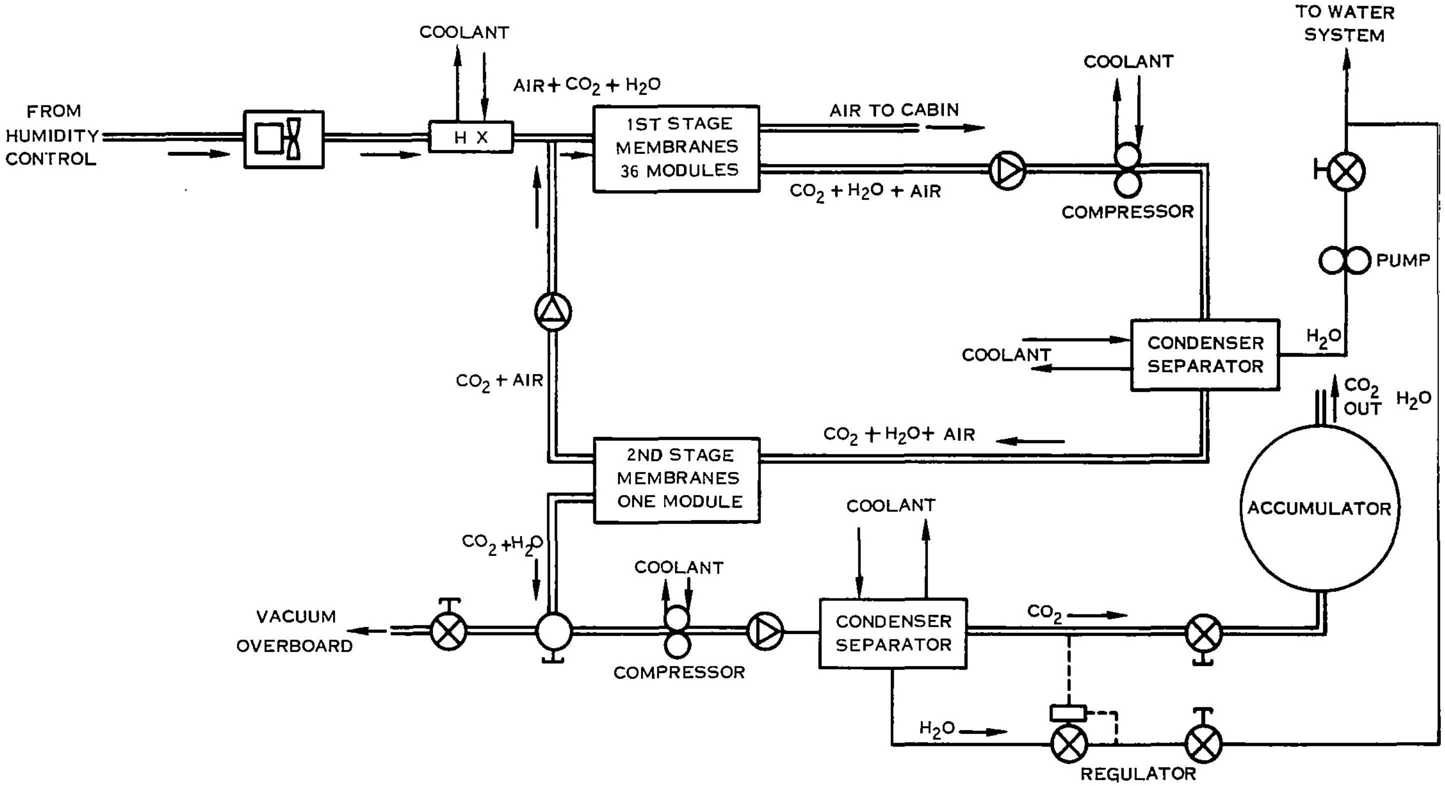


Figure 41. Membrane Diffusion Concept (Page 2 of 2)

Liquid Absorption

Continuous removal of CO_2 can be accomplished by mixing the cabin atmosphere with a liquid absorbent, separating the product liquid (formed by a reaction of CO_2 and the absorbent) from the process stream , and regenerating the absorbent and releasing the CO_2 by the addition of heat. Several of the liquid absorbents that can be used are as follows: monoethanolamine (MEA), diethanolamine (DEA), diethylene glycolamine, methyl diethanolamine, alkayid-M, and potassium carbonate. Of these , MEA is the most efficient. Liquid LIMEA (low iron content monoethanolamine) systems are currently employed on nuclear submarines for CO_2 removal.

Figure 42 illustrates a zero-gravity version of the liquid absorption concentrator. To reduce the problem of cabin contamination, potassium carbonate was used as the liquid absorbent for this study. Inlet air from the humdity control subsystem enters the contactor and mixes with the potassium carbonate. The gas-liquid mixture is carried through the contractor, where mass transfer of CO_2 from the process air to the sorbent takes place. To facilitate this transfer, the contactor is filled with a ceramic saddle packing. Carbon dioxide, water, and potassium carbonate react to form potassium bicarbonate according to the following equation: $CO_2 + H_2O + K_2CO_3 \rightleftarrows 2KHCO_3$. Air and liquid absorbent leave the contactor and enter a phase separator, where the air is returned to the cabin through an activated charcoal bed and the liquid is pumped through the rest of the loop. A regenerative heat exchanger and a heater are used to heat the potassium bicarbonate to a temperature sufficient to reverse the above reaction (180°F) and release the CO_2. Another separator is used to separate the released CO_2 and water vapor from the liquid sorbent. The liquid returns through the regenerative heat exchanger and a cooler to the contactor inlet. CO_2 is delivered by a two-stage compressor, which forces the gas through a condenser-separator to the accumulator.

Absolute criteria. -

Performance: The liquid absorption concept should have good performance characteristics. However, evolution of dissolved air with delivered CO_2 is a potential purity problem.

Safety: A free corrosive liquid is always a serious safety hazard. Liquid could escape from the unit by entrainment in processed air or by leakage. Nevertheless, good design can make this concept reasonably safe.

Availability/confidence: The liquid absorption concept can be developed for a flight by 1980. Although no insurmountable design problems should occur, this concept is entirely undeveloped as a zero gravity system. Confidence for application to the AILSS is therefore limited.

Primary criteria . -

Reliability: System MTBF is considerably higher than mission length. However, potential corrosion problems limit confidence in this evaluation. The liquid-air separator, the separator pump, and the compressor have the highest failure rates. The condenser-separator needs periodic scheduled replacement.

Crew time: Crew time is low, with unscheduled repair time well below average because of the low failure rate. However, repair of the liquid-air separator and its pump requires breaking corrosive liquid lines. This stress condition may augment repair time substantially.

Equivalent weight: Hardware weight is lower than that of any other concept. For Design 1, power is low and equivalent weight is well below average. Most of the power is thermal power and, therefore, equivalent weight is lower by 371 pounds for Design 2 and by 445 pounds for Design 3, making it lower than all other concepts.

Secondary criteria. - The possibility of atmospheric contamination by the sorbent because of a leak or due to maintenance is high. Subsystem interfaces are: water management, thermal control, CO_2 reduction, humidity control, and electrical. The liquid interfaces are undesirable. This concentrator has good flexibility. It will adjust automatically to increasing CO_2 production and will interface with any CO_2 reduction subsystem. Growth characteristics are very good in every respect. CO_2 delivery requirements are similar to those of the electrochemical concepts. CO_2 is delivered to a 40 psi accumulator from ambient pressure. The delivery pump is water jacketed, and low speed fans are employed to suppress noise. The liquid absorption concept has one of the lowest volumes of all concepts considered. Electrical power consumption is below average for Design 1 and nearly the lowest for Designs 2 and 3.

Mechanical Freezeout

A data sheet and schematic of this concentrator are presented in figure 43. This concept uses a regenerative air cycle to refrigerate cabin air and freeze out contained CO_2, which is then concentrated by direct sublimation to the gas phase. Dehumidified cabin air is compressed and cooled in a series of regenerative heat exchangers. At a temperature of -180° F, air cooling is provided by sublimating CO_2 in the freezing heat exchangers. As the air temperature drops further to -200° F, the contained CO_2 begins to freeze out. Sublimated CO_2 is pumped out of the system into an accumulator.

Air at the resulting reduced air temperature (about -220° F) is passed through the cold side of the CO_2 freezing heat exchanger, thus providing the heat sink. Air-motor power output is applied to the compressor to reduce the required motor input power. Reheated process air is then returned to the cycling silica gel desiccant beds to pick up desorbing water before re-entering the cabin atmosphere.

SUBSYSTEM: CO_2 Removal and Concentration

CONCEPT: Liquid Absorption

FLIGHT AVAILABILITY: 1980
(1970 go-ahead)

RELIABILITY: 0.999650 MTBF: 20 600 hr

Spares/Redundant (R) Units:

- 1 - Contactor
- 3 - K_2CO_3 Absorbent Charges
- 3 - Motorized Separator
- 2 - Fan
- 1 - Heat Exchanger
- 1 - Heater
- 2 - Temperature Control
- 2 - Compressor
- 1 - Check Valve
- 6 - Condenser/Separator
- 2 - Water Regulator

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	8.0	1.2

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	157	182	157
Expendables	0	0	0
Spares/Redundant Units	229	229	229
Electrical Power	552	107	107
Thermal Power	0	49	0
Radiator Load	167	167	167
Total Equivalent Weight	1105	734	660
POWER (Watts):			
Electrical	1226	238	238
Thermal	0	988	988

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	18	6	24

Figure 42. (Page 1 of 2)

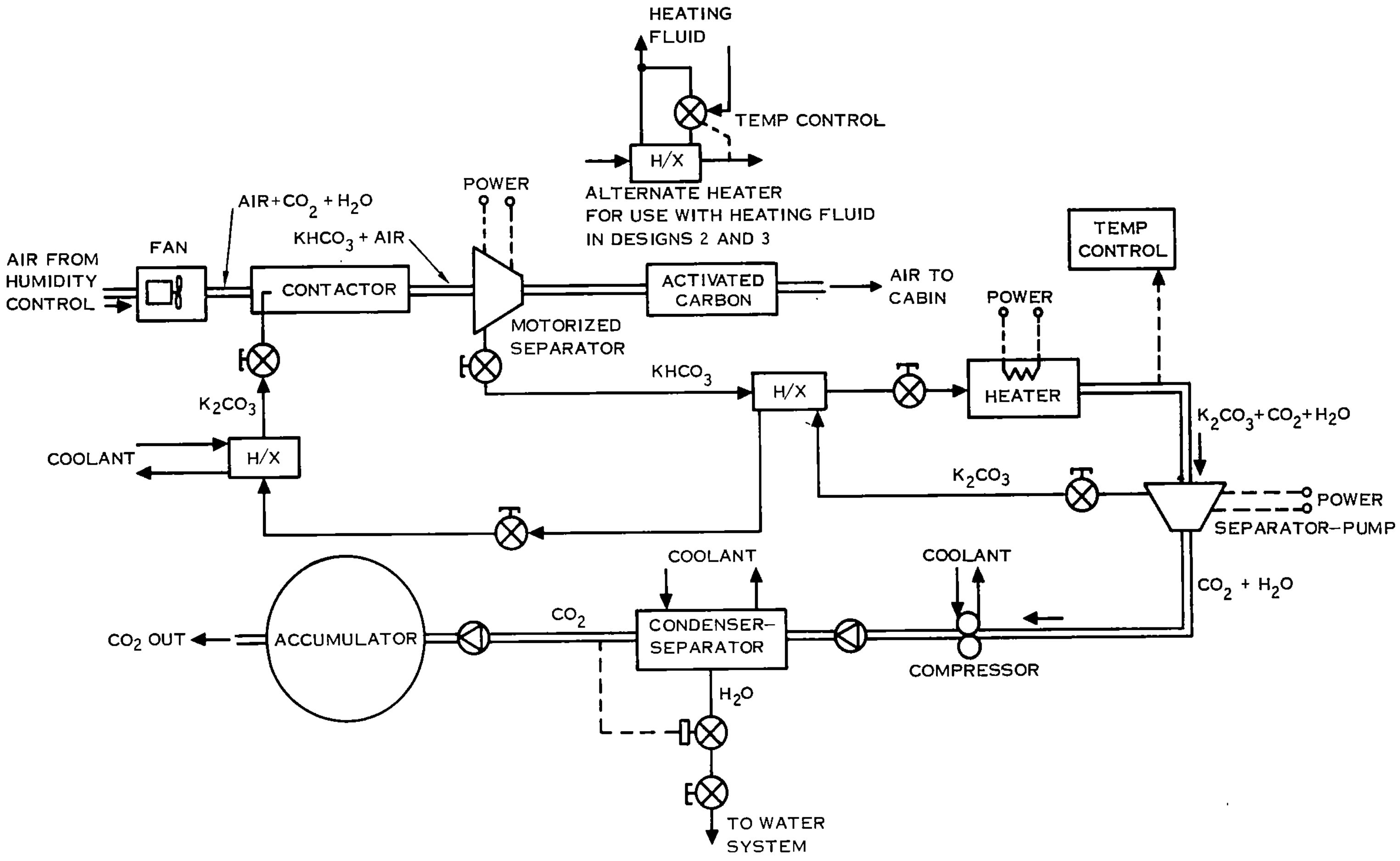


Figure 42. Liquid Absorption Concept (Page 2 of 2)

SUBSYSTEM:	CO_2 Removal and Concentration
CONCEPT:	Mechanical Freezeout

FLIGHT AVAILABILITY: 1978
(1970 go-ahead)

RELIABILITY: MTBF:

Spares/Redundant (R) Units:

2 - CO_2 Collector
2 - Silica Gel Canister
4 - Diverter Valve, 4-way, Hot
6 - Diverter Valve, 4-way, Cold
3 - Motor, Turbine, Compressor Assy
3 - Heat Exchanger (1 each type)
1 - Check Valve
1 - Diverter Valve, 3-way
3 - Timer
2 - Compressor
3 - Solenoid Valve, 3-way

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	0	4.2

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	540	540	540
Expendables	0	0	0
Spares/Redundant Units	520	520	520
Electrical Power	1590	1590	1590
Thermal Power	0	0	0
Radiator Load	484	484	484
Total Equivalent Weight	3134	3134	3134
POWER (Watts):			
Electrical	3540	3540	3540
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	28	9	37

Figure 43. (Page 1 of 2).

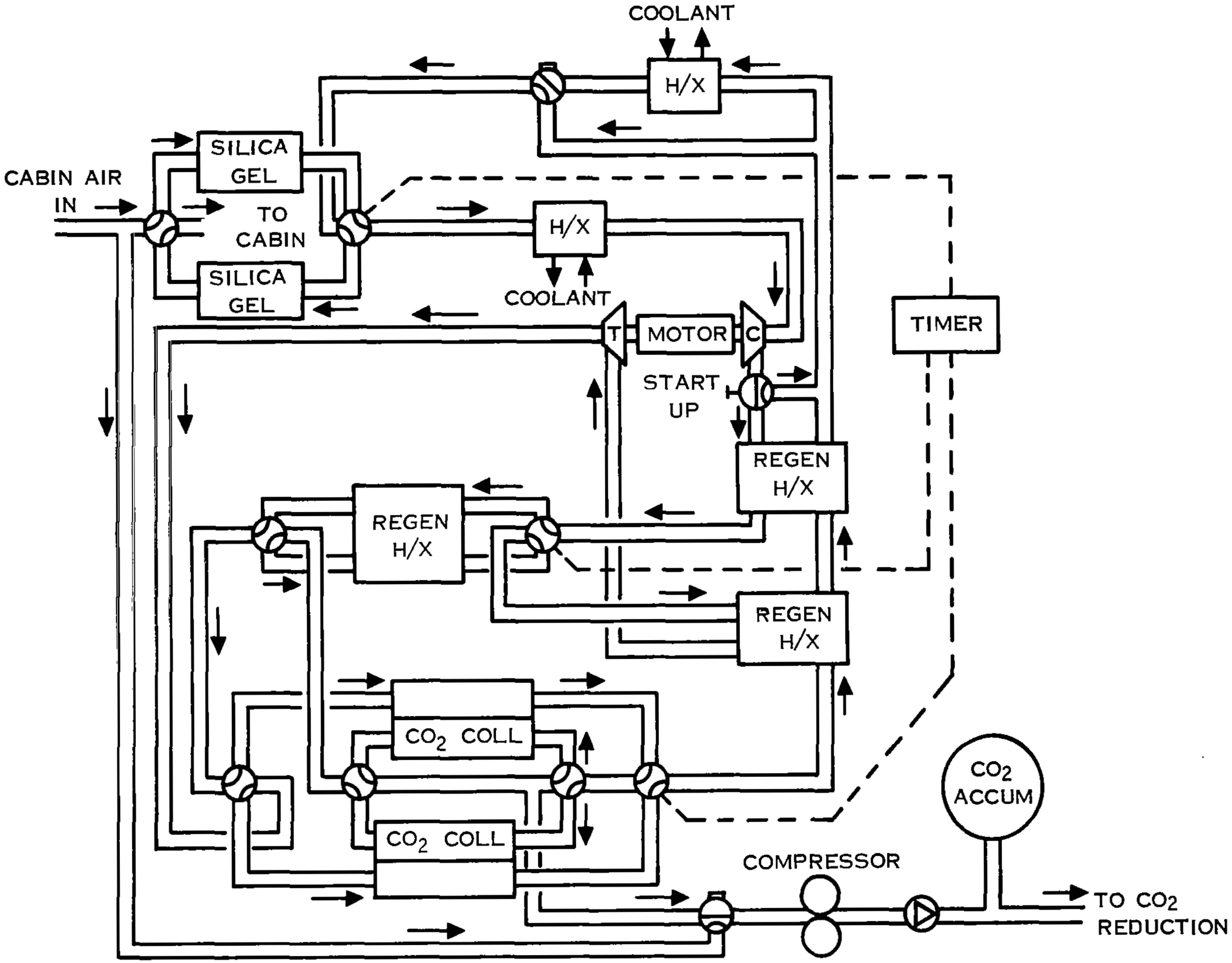


Figure 43. Mechanical Freezeout Concept (Page 2 of 2).

As shown in the schematic, eight timed valves are used to cycle the silica gel beds, a regenerative heat exchanger, and the two CO_2 collection heat exchangers. The regenerative heat exchanger is cycled to prevent excessive buildup of water condensed out at dewpoints lower than that obtained in the desiccant beds. The sublimation and collection process is similar to that of the molecular sieve system. Instead of a packed zeolite bed, a finned heat exchanger is used. Sublimated CO_2 is dry and will contain some ullage air, but high purity is expected.

Absolute criteria. -

Performance: Performance predictions of the freezeout system, using practical rotating machinery and heat exchanger performance values, indicate that AILSS requirements can be met. Purity data is not available, but performance should be comparable to that of a four-bed molecular sieve unit.

Safety: The concept has no special hazards. Materials are not flammable, and gas leakage cannot result in a toxic or explosive condition. There are no conditions that encourage bacterial growth, and maintenance presents no danger.

Availability/confidence: The mechanical freezeout concept can be developed for a flight by 1978. The process must be highly efficient to be at all competitive, and the required components are no more advanced than the research phase. Problem items are the compressor, the expander, and the freezing heat exchanger. There is no present development effort on this approach.

Primary criteria. -

Reliability: System MTBF is just under half the mission length. The four-way gas valves and their actuators have the highest failure rates. There are no limited life items.

Crew time: The mechanical freezeout concept requires no scheduled maintenance, and unscheduled repair time is close to average. Replacement of items most likely to fail is straightforward. A motor-driven compressor-turbine represents the most unique maintenance item in this system. Five gas duct connections and an electrical connection must be broken to replace this item.

Equivalent weight: High hardware weight and very high power consumption result in an equivalent weight identical for all designs and far higher than that of any other concept.

Secondary criteria. - No toxicity hazard is possible with this concentrator because toxic materials or gases are not used or generated. Interfaces are required with the thermal control loop, CO_2 reduction, temperature and humidity control, and the electrical subsystem. One of the significant advantages of this concept, shared only with the molecular sieve concept, is the lack of a water management interface. Regardless of the means of concentration, humidity handling is required. For those concepts not employing a desiccant or some other means of water removal prior to CO_2 removal, the humidity must be removed in the CO_2 delivery line by a condenser-separator and must be delivered to the water management subsystem. This concept avoids the problem with the use of a desiccant. Any CO_2 reduction system can be mated to this concentrator. Adding to the flexibility of the concentrator is its characteristic of removing CO_2 at an increased rate when the cabin concentration is high. For all designs, growth is fairly good for longer missions and poor for larger crews. Noise suppression will present a significant problem, as both compressors are inherently noisy. This is the noisiest concept considered for the AILSS, so it will require more noise suppression than usual. Volume is nearly average. Power consumption far exceeds that of any other concept.

EVALUATION AND SELECTION: CO_2 REMOVAL AND CONCENTRATION

The steam desorbed resin concept is selected for all AILSS designs because of its all-around superiority. Table 13 summarizes the evaluation and a data summary is shown in table 14. The nine candidate concepts are rated for the three power/heat source designs. Differences in the three designs influence only equivalent weight sufficiently to change the ratings from one design to another. Such changes result where significant thermal power can be supplied both electrically and in other ways. These weight ratings are then used with the identical ratings for other criteria to make a selection for each design.

Design 1

Absolute criteria. -

Performance: CO_2 concentration rate and purity are important performance factors. All concepts can remove and concentrate CO_2 at an adequate rate, and different performance ratings must therefore be based on differences in product purity. Concepts with acceptable but limited (by coadsorbed or dissolved air) purity are molecular sieve, solid amine, steam desorbed resin, liquid absorption, and mechanical freeze-out. These concepts are rated Good. Purity of the membrane and three electrochemical concepts is potentially unlimited, and their performance is judged Very Good.

Safety: With no inherent problems, safety of the molecular sieve concept is Very Good. With some possibility of amine carryover, safety of the solid amine and steam desorbed resin concepts is judged Good. A safety evaluation of Good also applies to the electrodialysis and hydrogen-depolarized electrochemical concepts, where presence of hydrogen and oxygen is a potential fire or explosion hazard. Safety of the carbonation cell concept, which does not have this potential hazard, is Very Good. Possible fire

TABLE 13
EVALUATION SUMMARY - CO_2 REMOVAL AND CONCENTRATION

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Solid sorption			Electrochemical			Miscellaneous		
		Molecular sieve	Solid amine	Steam desorbed resin	Electrodialysis cell	Carbonation cell	H_2 depolarized Cell	Membrane diffusion	Liquid absorption	Mechanical freezeout
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Good	Good	Good	Very good	Very good	Very good	Very good	Good	Good
	Safety	Very good	Good	Good	Good	Very good	Good	Good	Fair	Very good
	Avail./Conf.	Very good	Fair	Good	Good	Fair	Fair	Good	Fair	Fair
Primary	Reliability	Fair	Good	Good	Fair	Fair	Fair	Good	Good	Fair
	Crew Time	Very good	Good	Good	Poor	Fair	Fair	Good	Fair	Very good
	Equivalent Weight	Good Good Good	Fair Good Good	Good Very good Very good	Fair Fair Fair	Fair Fair Fair	Very good Very good Good	Good Good Fair	Good Very good Very good	Poor Poor Poor
		Elim.	Eliminated		Eliminated	Eliminated	Eliminated	Elim.	Eliminated	Eliminated
Secondary	Contamination	Very good		Good				Good		
	Interfaces	Good		Good				Fair		
	Flexibility	Good		Very good				Good		
	Growth	Fair		Good				Very good		
	Noise	Fair		Fair				Fair		
	Volume	Good		Very good				Poor		
	Power	Good		Good				Very good		
		Elim		Selected				Elim.		

TABLE 14
DATA SUMMARY: CO2 REMOVAL AND CONCENTRATION

CONCEPT	DESIGN	MTBF HOURS	CREW TIME HOURS		TOTAL EQUIVALENT WEIGHT POUNDS	POWER WATTS	
			SCHEDULED	UNSCHEDULED		ELECTRICAL	THERMAL
Molecular Sieve	1	10 500	0	2.3	1193	837	0
	2				1090	528	309
	3				1067	528	309
Solid Amine	1	14 100	8.0	1.7	1751	1923	0
	2				1165	316	1607
	3				1045	316	1607
Steam Desorbed Resin	1	17 100	16.0	1.5	1148	1008	0
	2				800	180	828
	3				707	180	828
Electrodialysis Cell	1	4 400	16.0	8.2	1687	2463	0
	2						0
	3						0
Carbonation Cell	1	3 900	8.0	7.7	1728	1832	0
	2						0
	3						0
H_2 Depolarized Cell	1	4 600	8.0	7.8	873	619	0
	2						0
	3						0
Membrane Diffusion	1	31 100	16.0	0.8	1318	436	0
	2						0
	3						0
Liquid Absorption	1	20 600	8.0	1.2	1105	1226	0
	2				734	238	988
	3				660	238	988
Mechanical Freezeout	1	5 780	0	4.2	3134	3540	0
	2						
	3						

hazard and toxicity problems limit the membrane diffusion concept to a rating of Good. Liquid absorpition has more definite problems with potential for carryover or leakage of corrosive liquid. In addition, this free liquid makes maintenance dangerous, and the safety rating of this concept is only Fair. With no inherent problems, safety or mechanical freezeout is Very Good.

Availability/confidence: The molecular sieve concept has the most successful operating history and therefore has the highest rating, Very Good. The solid amine concept requires more development, and also because the nature of the sorbent (a mixture of chemicals deposited on a solid carrier) raises doubt about bed life, confidence in availability is only Fair. The steam desorbed resin concept also needs considerable development, but bed life problems are less likely and availability is Good. Availability of electrodialysis is also Good, based on development of a large concentration unit for the United States Navy. Other electrochemical concepts need still more development, and their availability for the AILSS is judged Fair. Based on recent advances, availability of membrane diffusion is considered Good. Liquid absorption and mechanical freezeout, however, require substantial development, and confidence in their availability is Fair.

Summary: All candidate concepts have satisfactory absolute criteria ratings. Molecular sieve ratings are highest, with membrane diffusion and electrodialysis also very attractive.

Primary criteria. -

Reliability: With MTBF falling short of the AILSS mission duration, inherent reliability of the molecular sieve concept is only Fair. Mechanical MTBF of the solid amine and steam desorbed resin concepts exceeds mission duration, and reliability of these concepts is judged Good. The three electrochemical concepts have MTBF values considerably shorter than mission duration, resulting in Fair reliability. Despite a mechanical MTBF far exceeding that of any other concept, membrane diffusion is limited to a Good rating because of questionable stability of membrane filler chemicals. With solution of potential corrosion problems, MTBF of liquid absorption is nearly twice the mission duration, resulting in Good reliability. Reliability of mechanical freezeout, which has a relatively low MTBF, is only Fair.

Crew time: The molecular sieve concept has the lowest total crew time with no scheduled maintenance and therefore has the highest rating, Very Good. Solid amine requires scheduled maintenance for water separator replacement, but its unscheduled repair time is slightly lower and its overall crew time is Good. The steam desorbed resin concept requires more scheduled but less unscheduled maintenance, and its rating is also Good. Electrodialysis requires more unscheduled maintenance than any other concept, mostly for breaking liquid and hydrogen lines, and its crew time is therefore Poor. The carbonation and H_2 depolarized cell concepts are somewhat lower in both scheduled and unscheduled maintenance, with Fair overall crew time. Maintenance on all electrochemical concepts is somewhat hazardous because of the presence of corrosive liquids and/or hydrogen and oxygen. Despite considerable scheduled time for water separator replacement, membrane diffusion has less unscheduled maintenance than any other concept and is therefore rated Good. Repair of the liquid absorption concept may be hazardous because of the corrosive liquid, and its crew time, although relatively low, is therefore judged Fair. Mechanical freezeout has Very Good crew time, because it has no scheduled maintenance and the expected emergency repairs are straightforward and safe.

Equivalent weight: Equivalent weight make-up for all candidate concepts is shown in table 15. With the lowest total equivalent weight of all, the hydrogen depolarized cell concept is rated Very Good. Compared with this concept, weight of the molecular sieve concept is more than 300 pounds higher and is considered Good. The solid amine concept is about 900 pounds heavier and is judged Fair. Weight of the steam desorbed resin concept, 266 pounds higher, is Good. The electrodialysis and carbonation electrochemical concepts are both much heavier and are rated Fair. Equivalent weight of the membrane diffusion concept, especially with credit for humidity control, is Good, as is the weight of the liquid absorption concept. Mechanical freezeout is extremely heavy; its 2200 pound disadvantage makes it unacceptable, and it is eliminated from further consideration.

Summary: For Design 1, the molecular sieve, steam desorbed resin, and membrane diffusion concepts have roughly equivalent overall primary criteria ratings. They are therefore to be compared at the secondary level. The electrodialysis and mechanical freezeout concepts are judged unacceptable, while the other candidates are generally less acceptable than the first three mentioned and are therefore eliminated from further consideration.

Secondary criteria. - The molecular sieve concept has no contamination problems and is rated Very Good. The steam desorbed resin concept has some potential for amine carryover, and the membrane diffusion concept could contaminate the water supply with membrane filler chemicals; however, both concepts are judged Good.

In addition to CO_2 reduction and thermal control interfaces, the molecular sieve concept has a humidity control interface and the steam desorbed resin concept has a water management interface. Although cycling valves at the molecular sieve coolant interface and water condensation at the steam desorbed resin interface are potential trouble areas, interface complexity is considered Good for both concepts. The membrane diffusion concept, with both humidity control and water management interfaces, is considered Fair.

All three concepts can easily mate with any CO_2 reduction concept, but later in this section it is shown that the steam desorbed resin concept is relatively attractive for all power supply/heat source combinations, while the molecular sieve and membrane diffusion concepts have relatively higher equivalent weight and are less attractive

TABLE 15
EQUIVALENT WEIGHT SUMMARY

Concept	Design	Equivalent weight (lb)						
		Basic unit	Spares/ redundancy	Electrical power	Thermal power	Radiator load	Credit	Total equivalent weight
Molecular sieve	1	379	324	376	0	114	——	1193
	2	393	331	237	15	114	——	1090
	3	385	331	237	0	114	——	1067
Solid amine	1	330	293	865	0	263	——	1751
	2	377	303	142	80	263	——	1165
	3	337	303	142	0	263	——	1045
Steam desorbed resin	1	269	231	453	0	195	——	1148
	2	231	231	81	62	195	——	800
	3	200	231	81	0	195	——	707
Electrodialysis	1	332	511	1110	0	336	-592	1687
	2	332	511	1110	0	336	-592	1687
	3	332	511	1110	0	336	-592	1687
Carbonation cell	1	341	312	825	0	250	——	1728
	2	341	312	825	0	250	——	1728
	3	341	312	825	0	250	——	1728
H_2 depolarized cell	1	255	193	357	0	68	——	873
	2	255	193	357	0	68	——	873
	3	255	193	357	0	68	——	873
Membrane diffusion	1	1000	172	196	0	60	-110	1318
	2	1000	172	196	0	60	-110	1318
	3	1000	172	196	0	60	-110	1318
Liquid absorption	1	157	229	552	0	167	——	1105
	2	182	229	107	49	167	——	734
	3	157	229	107	0	167	——	660
Mechanical freezeout	1	540	520	1590	0	484	——	3134
	2	540	520	1590	0	484	——	3134
	3	540	520	1590	0	484	——	3134

for Designs 2 and 3. This is reflected in flexibility, which is considered Very Good for the steam desorbed resin concept and Good for the other two.

The molecular sieve concept is relatively well developed, and its potential for further technological growth is only Fair. Experimental studies of different configurations and modified sorbent materials may result in an improved version of the steam desorbed resin concept, and its growth potential is considered Good. With basic membrane improvements and improved packaging and configuration, growth potential of the membrane diffusion concept is Very Good.

Compressor problems give all three concepts Fair noise ratings. Steam desorbed resin has Very Good volume, molecular sieve has Good but significantly higher volume, and the much higher volume of membrane diffusion is considered Poor. Membrane diffusion has the lowest Design 1 power of all concepts and is rated Very Good. Power requirements of molecular sieve and steam desorbed resin, considerably higher, are Good.

In summary, the steam desorbed resin concept has the best overall ratings on secondary criteria.

Selection. - Considering all criteria levels, the steam desorbed resin concept is selected for Design 1 because all absolute and primary characteristics are entirely satisfactory and overall secondary characteristics are superior, with outstanding flexibility and volume.

Design 2

Ratings for Design 2 differ only in the area of equivalent weight. Some equivalent weight values are the same as those for Design 1 because they require electrical power only, while others use the isotope heat source and are reduced because of the lower heating penalty. The three electrochemical concepts and the membrane diffusion and mechanical freezeout concepts remain unchanged, while the three solid sorption concepts and the liquid absorption concept have lower weights. Thus, for Design 2, the liquid absorption concept has Very Good equivalent weight, the lowest of all concepts. The steam desorbed resin and hydrogen depolarized cell concepts are not much heavier, and their equivalent weight is also Very Good. Weight of the molecular sieve and solid amine concepts is Good, with solid amine considerably reduced from its Design 1 weight. Relative equivalent weight positions for electrodialysis, carbonation cell, membrane diffusion, and mechanical freezeout concepts are the same as for Design 1.

Thus, the equivalent weight rating of steam desorbed resin is improved, while those of molecular sieve and membrane diffusion remain unchanged. Its low equivalent weight then makes steam desorbed resin clearly superior at the primary criteria level. The steam desorbed resin concept is therefore selected for Design 2.

Design 3

Again, ratings differ only in the area of equivalent weight. Qualitative changes in equivalent weight are the same for Design 3 as for Design 2, but reductions are slightly greater. This change is sufficient to downrate two of the concepts that don't benefit from the decrease in power penalty. Thus, all ratings are the same as for Design 2, except that the hydrogen depolarized cell is reduced to Good and membrane diffusion to Fair. The steam desorbed resin concept is therefore selected for Design 3 for the same reasons it was selected for Design 2.

SUMMARY

The steam desorbed resin concept is selected for all three AILSS designs. It is the only one with consistently high ratings in all important areas, with high reliability and especially good total equivalent weight, flexibility, and volume.

IMPACT OF MISSION PARAMETERS

Mission Length

The influence of mission duration on reliability is important mainly for longer missions, where reliability of the moelecular sieve concept tends to become unsatisfactory, giving additional support to the steam desorbed resin selection. Crew time is proportional to mission length for all concepts, and there are no relative changes. Because expendables are not required by any concept, mission length has only a small influence on equivalent weight. The spare equipment requirements are such that as missions become longer the equivalent weight positions of the solid amine, hydrogen-depolarized cell, and membrane diffusion concepts improve. Thus, for Design 1 the hydrogen depolarized concept has a 400 pound weight advantage for an 800 day mission; nevertheless, its inherent reliability is unsatisfactory for such a long mission, and it would not be selected. For Design 1 missions exceeding five years, membrane diffusion may have a significant weight advantage. These effects do not occur for Designs 2 and 3. The steam desorbed resin concept remains the choice for missions shorter than 500 days. In summary, mission length changes would not change the AILSS selection of steam desorbed resin except for missions exceeding five years, where membrane diffusion might be more attractive.

Crew Size

Changes in crew size affect equivalent weight in the same relative way for all concepts and there are no significant relative changes.

Power Penalty

Because of its relatively high power requirement, the selected steam desorbed resin concept is favored by lower power penalties and is less attractive for higher penalities. The effect, however, is not sufficient to change the selection even if electrical power penalty is doubled.

If electrical power supply were critical for a Design 1 application, the membrane concept would offer the lowest power requirement. A 572 watt power reduction is possible at the expense, however, of 170 pounds equivalent weight and a considerably larger volume.

Resupply

The AILSS mission lasts 500 days without resupply. Periodic resupply would reduce initial launch weight no more than 30 percent, the reduction depending on spares weight. Thus as resupply frequency increases, the selected steam desorbed resin concept and the molecular sieve concept become relatively more attractive, because they have relatively high spares weight, and their equivalent weight ratings tend to change from Good to Very Good. Because both concepts show an equivalent improvement, steam desorption continues to be selected.

Flight Date

The steam desorption concept is selected as best for the AILSS mission and would therefore be the choice for any mission occuring in 1976 or later. For earlier flights, only the molecular sieve concept is available. This concept has low equivalent weight and outstanding crew time and safety.

O_2 GENERATION/CO_2 CONTROL

CONTENTS

O_2 GENERATION/CO_2 CONTROL

Detailed requirements for oxygen generation and carbon dioxide removal and reduction are given in the system specification. In general, the requirements are to generate 15.1 pounds of oxygen per day and to remove and process 18.5 pounds of carbon dioxide per day for the nine man crew. Overboard discharge of oxygen itself or oxygen in the form of carbon dioxide or carbon monoxide is to be avoided if possible. The problem is to select the system that best meets these requirements with regard to the AILSS evaluation criteria.

The solid electrolyte concept is selected for all AILSS designs, primarily on the basis of its low equivalent weight, its superior secondary criteria ratings, and because a separate water electrolysis unit is not needed. A simplified representation of this concept is shown in figure 44.

SUBSYSTEM INTEGRATION

A comparison of the concepts whose functions do not exactly correspond to one another presents both the systems analyst and reader with a difficult problem. Each candidate concept must have transfer penalties included until all systems - with their transfer penalties perform the same function. One trouble is that derivation of the transfer penalty is usually vague and must be accepted on faith. This difficulty is especially confusing in a study such as this where equivalent weight is not the salient criterion. Another trouble with the transfer penalty approach is that an oxygen generation/carbon dioxide control system tends to be judged by its reduction section alone. This is a mistake, because, for example, two reduction concepts can have very different MTBF values, but the corresponding system values may be nearly identical if the same water electrolysis concept (which has significantly lower MTBF) is used with both.

This study avoids these problems by eliminating a separate discussion of carbon dioxide reduction. Some reduction concepts generate water, others generate oxygen; some need a concentrator, others do not; some need a large water electrolysis unit, others a small one, and still others none at all. Comparison is meaningless and diversionary. Consequently, reduction concepts are discussed and compared on the system level only. These systems generate all the oxygen required by the crew and control all the carbon dioxide produced by the crew. This system level approach has been preceded by subsystem reviews of water electrolysis and carbon dioxide concentration.

Figure 45 depicts potential candidate systems. Alternative process combinations may be defined by moving across the figure without any horizontal skips. Examples are:

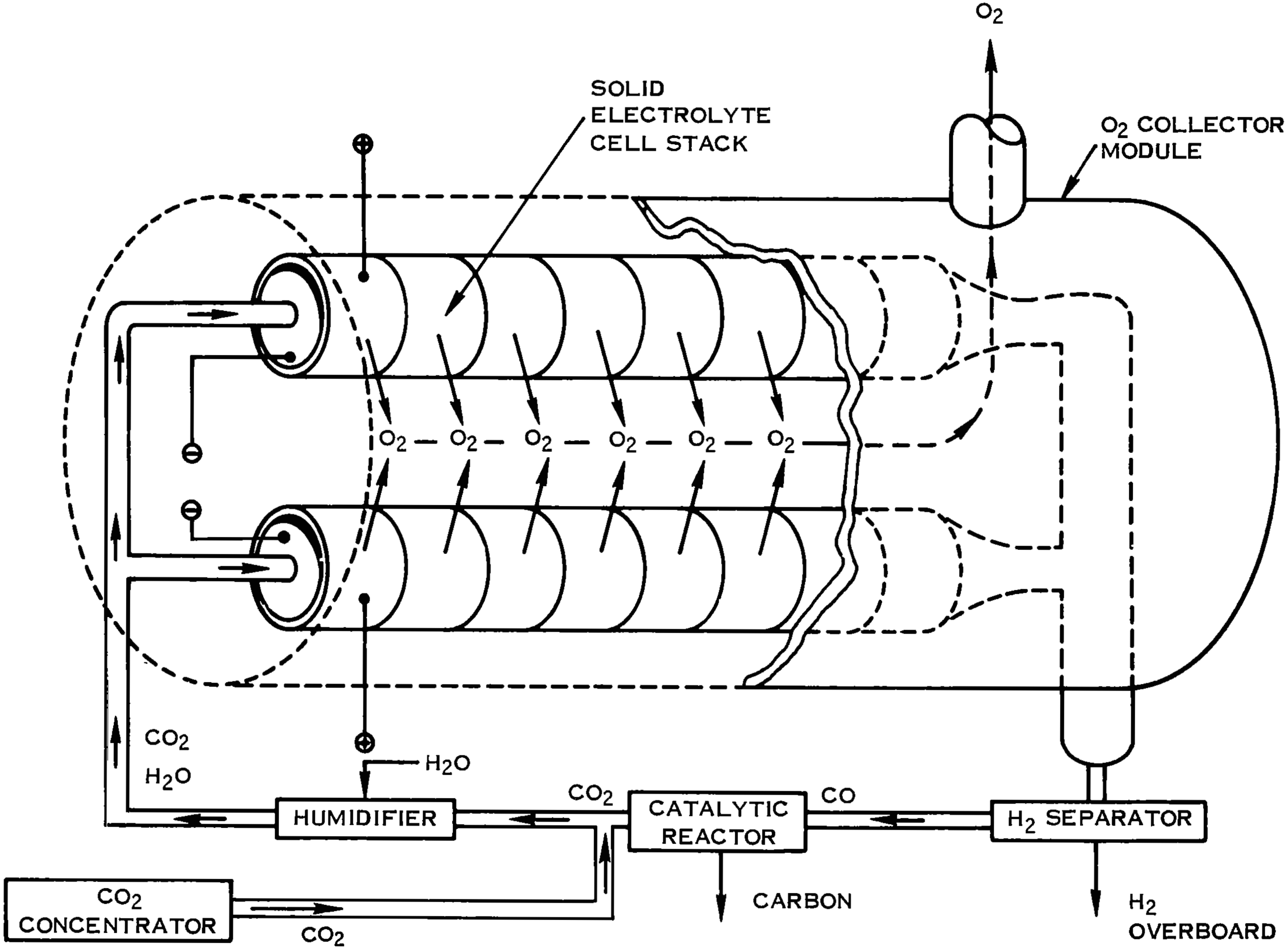


Figure 44. Solid Electrolyte Oxygen Generator Concept

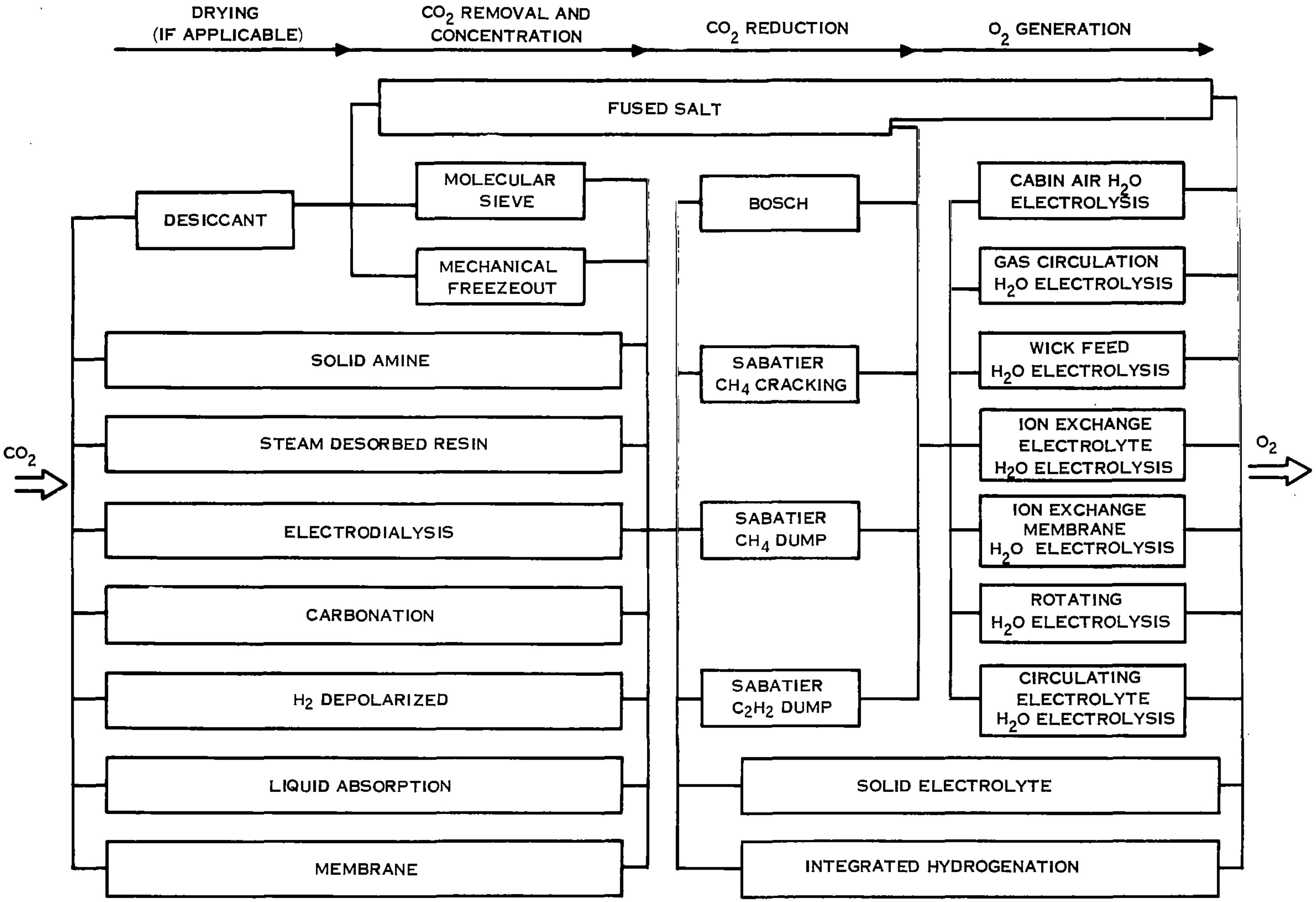


Figure 45. O_2 Generation/CO_2 Control Alternatives

1) Desiccant/molecular sieve CO_2 concentration/Bosch CO_2 reduction/ water electrolysis

2) Desiccant/fused salt CO_2 reduction/water electrolysis

There are many such combinations for the processes shown, and not all are shown on the chart.

As noted before, meaningful comparison of the oxygen and water generation units must be made by placing the candidates on an equivalent basis. The basis is generation of 15.1 pounds of oxygen per day and collection and reduction of 18.5 pounds of carbon dioxide per day. To achieve these objectives, the basic carbon dioxide reduction units must be combined with previously selected carbon dioxide concentrators and/or water electrolysis units. The basic reduction concepts selected for evaluation are fused salt, solid electrolyte, Bosch, Sabatier with methane cracking, and Sabatier with methane or acetylene dump. The recovery of oxygen from water is necessary for all concepts, because part of the inspired oxygen is used for metabolic water generation, and the oxygen recovered from expired carbon dioxide must therefore be supplemented. Figure 46 is a useful aid for process comparison, although it is oversimplified because its objective is to stress the similarities and differences among candidate concepts.

The fused salt process collects carbon dioxide directly from dried cabin air and electrolyzes it directly to oxygen. However, the quantity of oxygen recovered from the carbon dioxide is not quite sufficient for crew consumption, and a small water electrolysis unit must be added to meet the requirement. Thus, the fused salt system consists of the basic reduction unit and a water electrolysis unit. A separate CO_2 concentrator is not required.

The solid electrolyte process requires concentrated carbon dioxide, which is humidified so that electrolysis of the water-carbon dioxide mixture produces the full oxygen requirement, and so the solid electrolyte system consists of a carbon dioxide concentrator and the basic reduction unit. A separate water electrolysis unit is not required.

The Bosch and Sabatier-methane cracking processes generate water from concentrated carbon dioxide, and large electrolysis units are therefore required to generate oxygen, in addition to the carbon dioxide concentrator and the basic reduction unit.

The Sabatier-methane dump process, which reduces carbon dioxide to water and dumps hydrogen as methane to space, consists of a carbon dioxide concentrator, the basic reduction unit, a water electrolysis unit, and stored expendable hydrogen.

The Sabatier-acetylene dump process reduces carbon dioxide to water and dumps hydrogen and carbon as acetylene to space. Thus, the Sabatier-acetylene dump system consists of a carbon dioxide concentrator, the basic reduction unit, a water electrolysis unit, and stored expendable hydrogen.

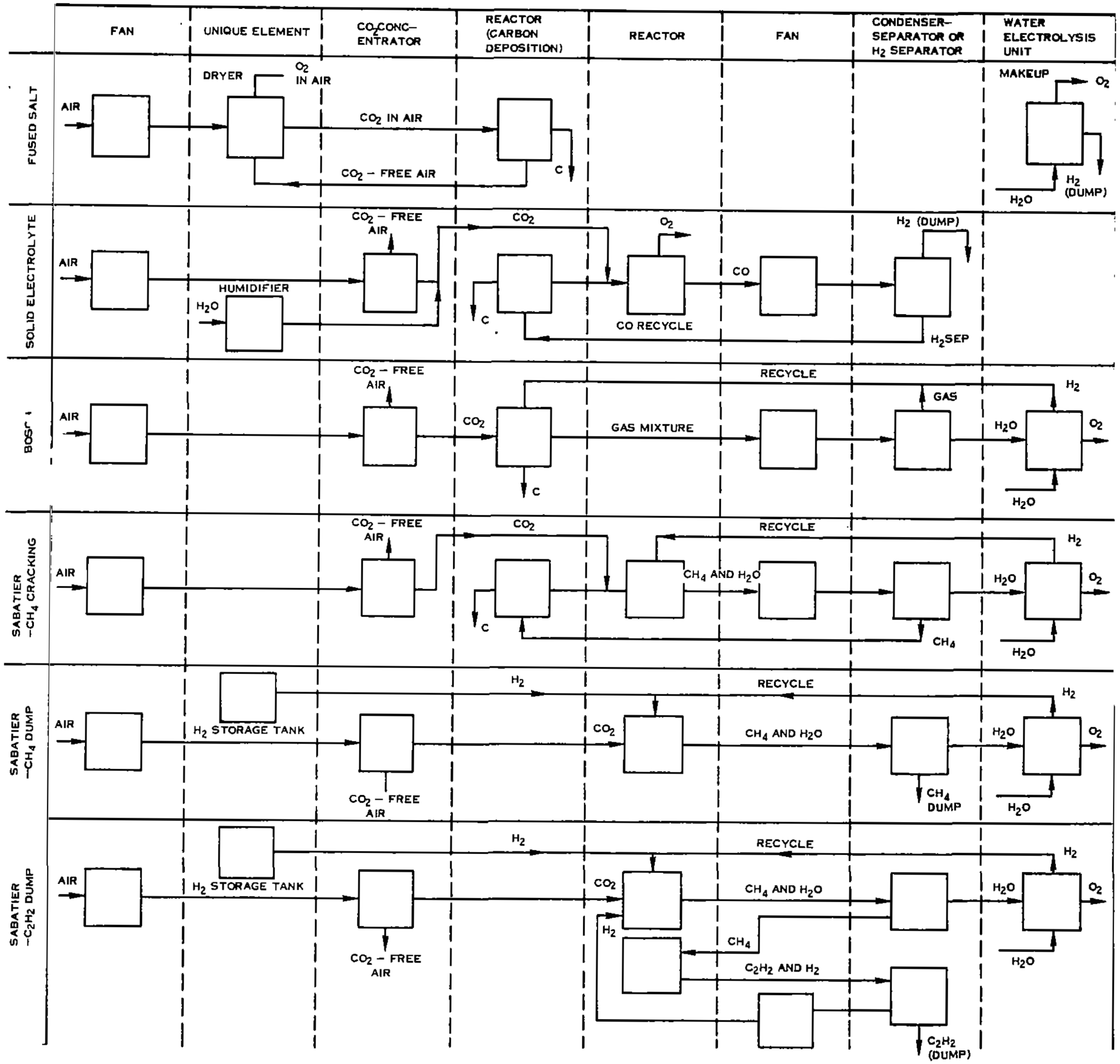


Figure 46. Concept Comparison

GENERAL ASPECTS

Prior to concept evaluation, the following section discusses the general topics of carbon dioxide purity, power/heat source design, and reduction unit maintenance.

Carbon Dioxide Purity

Carbon dioxide impurities, when delivered to the reduction unit, can present a major problem; that is, the presence of nitrogen can cause a fairly rapid pressure buildup in the closed circuit. Consequently, high purity of delivered CO_2 is important. Impurities are defined as gases other than carbon dioxide and water vapor. Oxygen carryover, in general, is consumed in the reduction reactor, resulting in a subsystem penalty. Assuming that one percent of the impurity is delivered as oxygen, a 0.2 lb/day increase (about one percent) in the oxygen process rate is the result. This is not excessive and can be tolerated. A 0.2 lb/day nitrogen carryover into the reactor represents the remaining one percent impurity, and this requires a purge rate of about 2.0 lb/day of gas to eliminate the nitrogen. An overboard dump at this rate results in a 600-pound system penalty for the oxygen loss, with no penalty for the loss of the 400 pounds of accompanying carbon. The alternative to overboard dump, selected for the AILSS, is to oxidize the purge stream components (to prevent cabin atmosphere contamination) and reprocess the resulting oxidized stream (mostly CO_2) through the CO_2 concentrator.

Alternative solutions to the impurity problem are to add a second stage of concentration or to select a concentrator capable of delivering 99.99 percent purity. This would obviate the need for a continuous high purge rate. The electrochemical concentration concepts deliver potentially pure CO_2, but high reliability must be developed and proven. For other concepts, a membrane second stage is desirable only if the selected approach proves impractical, because a single stage process is preferred. Although these alternatives were not selected for the AILSS, the further implications of these alternative solutions are discussed in the Selected EC/LS Systems section.

Power/Heat Source Design

An oxygen generation/carbon dioxide reduction system must be selected for each of the three power/heat source designs. Concept selection is the same for all three designs, although heat source inputs vary.

Electrolysis units do not require supplementary heat because adequate heat is generated by electrolysis process inefficiency. Many CO_2 concentration concepts, including the selected one, can utilize isotope or waste heat. Thus, where such heat is available, O_2 generation/CO_2 control total equivalent weight can be reduced by decreasing power penalty of the CO_2 concentrator. The Bosch Process is the only reduction concept that can effectively utilize isotope heat (none can use low temperature waste heat). Overvoltage within the fused salt and solid electrolyte processes generates sufficient heat for maintaining those processes at desired temperature levels, while the Sabatier reaction and the disproportionation reaction (associated with the solid electrolyte process) are sufficiently exothermic to obviate the need for supplementary heating.

Another possible application of high temperature process heat for CO_2 reduction (exclusive of CO_2 concentration) is the Sabatier-methane cracking unit. The reaction is endothermic, requiring heat. The reaction, however, occurs at 1800°F; too high to be supplied with heat from a 1600°F radioisotope heat source, and partial isotope heating is not attractive, so that electrical heating is therefore assumed.

Reduction Unit Maintenance

The outstanding single characteristic of the CO_2 reduction concepts under consideration is the very high operating temperatures encountered (500° to 1800° F). From a maintenance viewpoint, the adverse effect of these high temperatures influences the following areas, all of which must be considered in the design of each concept.

Access. - Access to the equipment is severely limited by the large amounts of insulation required to maintain a safe touch temperature on the exterior surfaces. The removal of insulation, alone, is likely to be a time-consuming operation. As a result, even the simplest maintenance task becomes extremely hazardous when the system is hot, leading to the need for as much automation as possible. The simple turning of a valve at 1800° F requires a cooled insulated handle or the use of tools.

Instrumentation. - High temperatures limit the types of instrumentation that can be used. This could leave an information gap in the otherwise automatic fault-detection equipment (i.e., readout of secondary effects) and it could significantly lengthen the fault isolation time.

Seals. - The use of unconventional seals on devices that require maintenance is likely to increase maintenance time and the large temperature differentials experienced when a system is restarted after maintenance can be expected to induce leakage, even in a previously sealed joint.

Carbon removal. - An outstanding problem associated with most CO_2 reduction concepts is carbon handling. These concepts produce solid carbon with characteristics ranging from a fine (wet) dust to solid chunks. Because of the large quantity of carbon expected (approximately 2520 pounds), some method of removing the carbon from the point of formation to a storage area must be incorporated. One of the more important considerations in this respect is that the formed carbon cannot come into contact with the cabin atmosphere while hot because it would generate CO, CO_2, and possible other contaminants. It must first be cooled in a nonoxidizing atmosphere, a time consuming but necessary step, both from a contaminant-generation and manual handling viewpoint.

Carbon handling is achieved through scheduled maintenance with the periodic replacement of carbon collecting cartridges. Each cartridge contains sufficient catalyst, volume, and filters to assure proper carbon formation and containment during the operating cycle, and clean handling during the replacement mode. An alternative carbon collection scheme of continuous mechanical removal was considered. This process involves continuous removal of carbon from the catalyst surface (where it is formed) by a mechanical scraping or cutting device. The carbon is transported by the process gas flow to a downstream collector which filters the carbon out of the gas stream. The collector is replaced (or cleaned out) when full.

The cartridge, with an integral catalyst, is considered to be a more practical approach for the removal of carbon for the following reasons:

1. The catalysts used to date actually react with the incoming gas streams, and have a definite and significant concumption rate. Even with a continuous removal scheme, catalyst replacement would require periodic shutdown of the device.

2. The filter itself, in a continuous removal device, would have to serve as a storage container, unless further system integration would allow the transfer of carbon to, say, empty food containers. This procedure, in turn, would likely require an automated transfer procedure and added hardware complexity.

3. The mechanical stripper would be less reliable than a passive catalyst-filter cartridge.

The continuous carbon removal process might be competitive if a good use could be found for the carbon (perhaps for odor control) or if the process could be operated to continuously flush the carbon overboard, thus eliminating transfer to storage. For this study, however, the dumping of solids has been disallowed. For all systems, carbon cartridge replacement is scheduled every 10 days. The actual cartridge replacement should take no longer than 2 hours. Cool-down is accomplished during operation of the alternate canister.

Another maintenance problem results from the high temperatures in these systems, which produce a variety of carbon compounds and other contaminants. These contaminants include CO, CO_2, CH_4, and H_2. As a result, all maintenance internal to the system requires system evacuation to space and inert gas refill prior to opening the system to the cabin atmosphere for repairs. CO_2 appears well suited for the refill gas and is selected for the AILSS, for two reasons: (1) it is the normal hot gas of the system and will not degrade component performance, and (2) it does not require another purge cycle before system restart, as another gas would. Suitable purge arrangements provided for carrying out these operations are shown in the subsystem schematic diagrams.

O_2 GENERATION/CO_2 CONTROL CONCEPTS

For the following evaluation, the candidate CO_2 reduction concepts are combined, where applicable, with the gas circulation water electrolysis concept and with the steam desorbed resin CO_2 concentration concept.

Fused Salt

The fused salt system is described schematically in Figure 47. It operates at 1200° F and is an integrated electrochemical carbon dioxide reduction concept that does not require a CO_2 concentrator but does need a small water electrolysis section to meet the AILSS performance requirements. The water electrolysis section is about one-tenth the size of those used with hydrogenation concepts (1.7 lb O_2/day instead of 15.1 lb O_2/day). In addition to the reactor, the reduction section includes a regenerative heat exchanger, a cycling regenerable desiccant unit, a fan, and control devices.

During normal operation of the reduction section, cabin air is processed directly through the unit and is then returned to the cabin atmosphere. As it passes through the unit, carbon dioxide is removed and oxygen is added to the air in a single step. A desiccant unit dries the air before it enters the reduction unit and rehumidifies the air when it exits. This prevents water vapor electrolysis, which causes hydrogen generation at the same electrode where carbon is formed, resulting in electrolyte occlusion within the byproduct carbon.

The reduction unit contains nine one-man modules. Each module bears some physical similarity to a steel plate rolling mill. The reciprocating cathode plate, consisting of a nickel foil surface and a supporting plate, is supported by several floating driver rollers. Separated from the foil surface is a row of anode scrubbing rollers. Between these anode rollers and the foil surface is an intermediate row of electrolyte reservoir rollers. These porous ceramic reservoir rollers are filled with fused electrolyte. This electrolyte is transferred from the reservoir rollers to both the anode rollers and to the foil-covered cathode plate. This provides a continuous electrolyte film from anode rollers to cathode plate, held by surface tension.

In operation, predried cabin air enters each module, passes over the anode scrubber rollers, and exits. As this air passes through the modules, CO_2 is removed from it by rapid absorption into the thin electrolyte film, and oxygen generated by the overall chemical reaction,

$$CO_2 \longrightarrow C + O_2$$

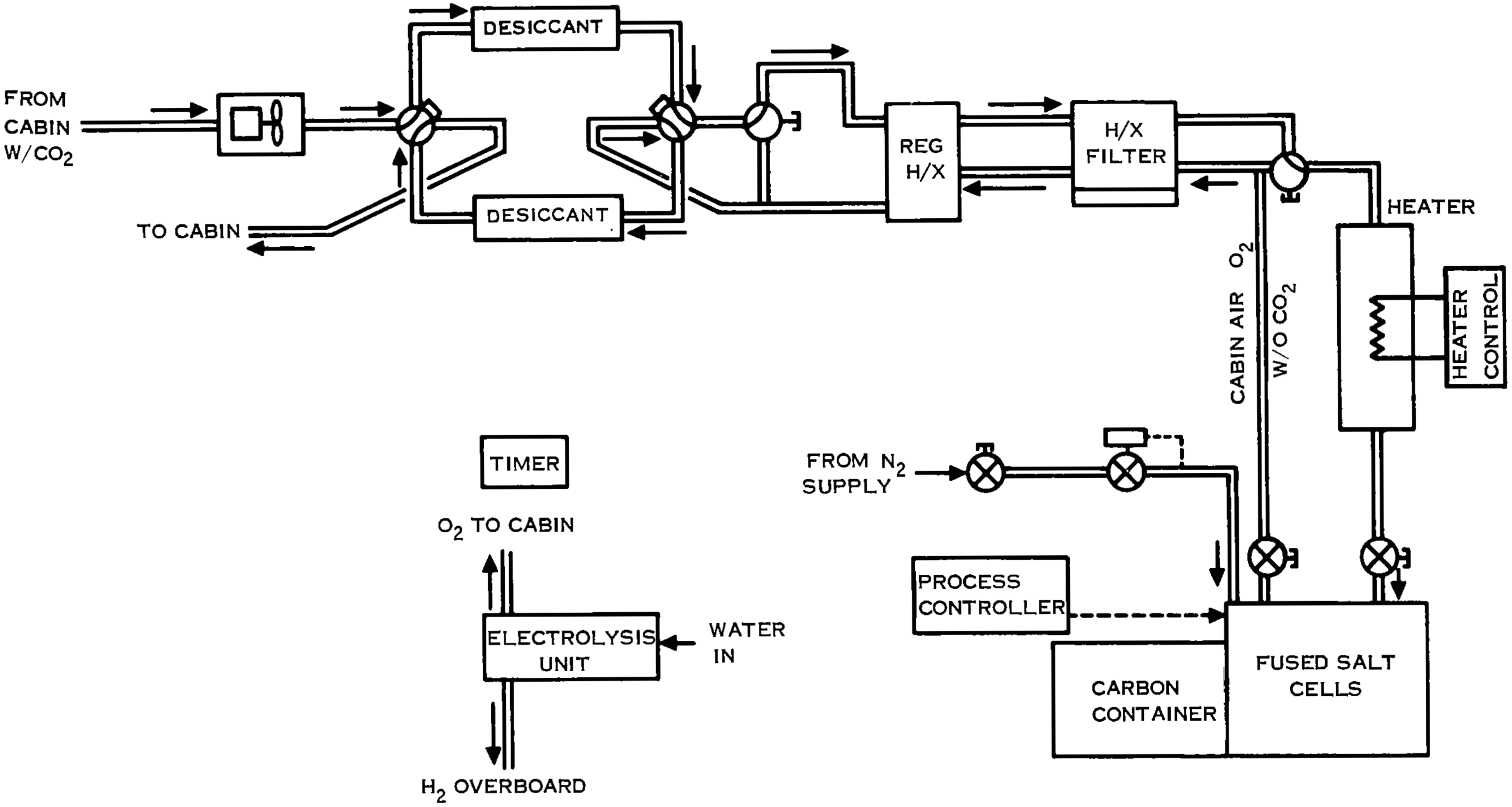


Figure 47. Fused Salt Concept

enriches the air stream. Carbon formed in the electrochemical reaction deposits on the foil surface of the cathode plate. This deposit does not interrupt the process, because it acts electrochemically like the foil. The carbon deposit contains five percent electrolyte, which is continuously replaced by electrolyte stored within the porous reservoir rollers. Periodically, the foil is mechanically advanced, withdrawing carbon from the module and providing a fresh cathode surface for further carbon deposition. Useful life of the modules, about 300 days, is limited by anode degradation and by electrolyte capacity of the reservoir rollers.

Absolute criteria. -

Performance: The fused salt concept is not dependent on gravity, and good performance is anticipated.

Safety: A unique safety feature of the fused salt concept is that it normally contains no toxic or flammable gases, except in the small electrolysis unit. However, the direct interface of the reduction unit with the cabin atmosphere presents some danger. An upset might result in generation of carbon monoxide or other toxic contaminants, which would be added directly to the cabin atmosphere. Electrolyte carryover to the atmosphere is unlikely because it would freeze in the regenerative heat exchanger. Although the molten electrolyte is extremely corrosive, leakage would probably be self-controlling in a zero-gravity environment, with the electrolyte freezing upon contact with cabin air.

Availability/confidence: Development is well into the research stage. However, integrated flight hardware based on present data would be far heavier than competing concepts. An optimized, lightweight unit will probably not be available by 1980. Consequently, availability must be regarded unacceptable.

Solid Electrolyte

This system contains a CO_2 concentrator (the selected steam desorbed resin unit discussed in the CO_2 concentrator section), the solid electrolyte unit, a CO disproportionation reactor, regenerative heat exchangers, a humidifier, a hydrogen separator, a recycle compressor, and control devices. No separate water electrolysis system is necessary. Figure 48 presents a schematic and quantitative data on this concept.

The solid electrolyte system recovers oxygen from carbon dioxide and water vapor in a single reaction step at 1800° F, but it requires a second reaction step at 1000° F for carbon deposition. During normal operation of the reduction section, inlet carbon dioxide joins the circulating reaction gas stream and then passes through the humidifier, where it picks up water from the water management system. The humidifier is assumed to be a wick package, but a capillary device is also possible. Humidification is necessary because the concentrated CO_2 is dehumidified to prevent a condensate phase from

SUBSYSTEM: O_2 Generation/CO_2 Control

CONCEPT: Solid Electrolyte/Steam Desorbed Resin Concentrator

FLIGHT AVAILABILITY: 1979
(1970 go-ahead)

RELIABILITY: 0.999106
(includes CO_2 concentrator)

MTBF: 3480 hr

Spares/Redundant (R) Units:

5-R-Standby Solid Electrolyte

Expendables:
50 catalyst cartridges

- 2 - Master Control
- 2 - CO_2 Inlet Regulator
- 2 - Check Valve
- 1 - Humidifier
- 2 - Solenoid Valve
- 2 - Heater Control

- 1 - Hydrogen Separator
- 1 - Heat Exchanger
- 3 - 4-way Valve
- 1 - Catalyst Cartridge
- 1 - Catalyst Reactor
- 2 - Compressor

NOTE: Spares list does not include CO_2 Concentrator. See individual data sheets.

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	126.8	8.4

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	525	487	456
Expendables	640	640	640
Spares/Redundant Units	373	373	373
Electrical Power	1351	979	979
Thermal Power	0	62	0
Radiator Load	331	331	331
Total Equivalent Weight	3220	2872	2779
POWER (Watts):			
Electrical	3004	2872	2779
Thermal	0	828	828

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	99	150	249

Figure 48. (Page 1 of 2).

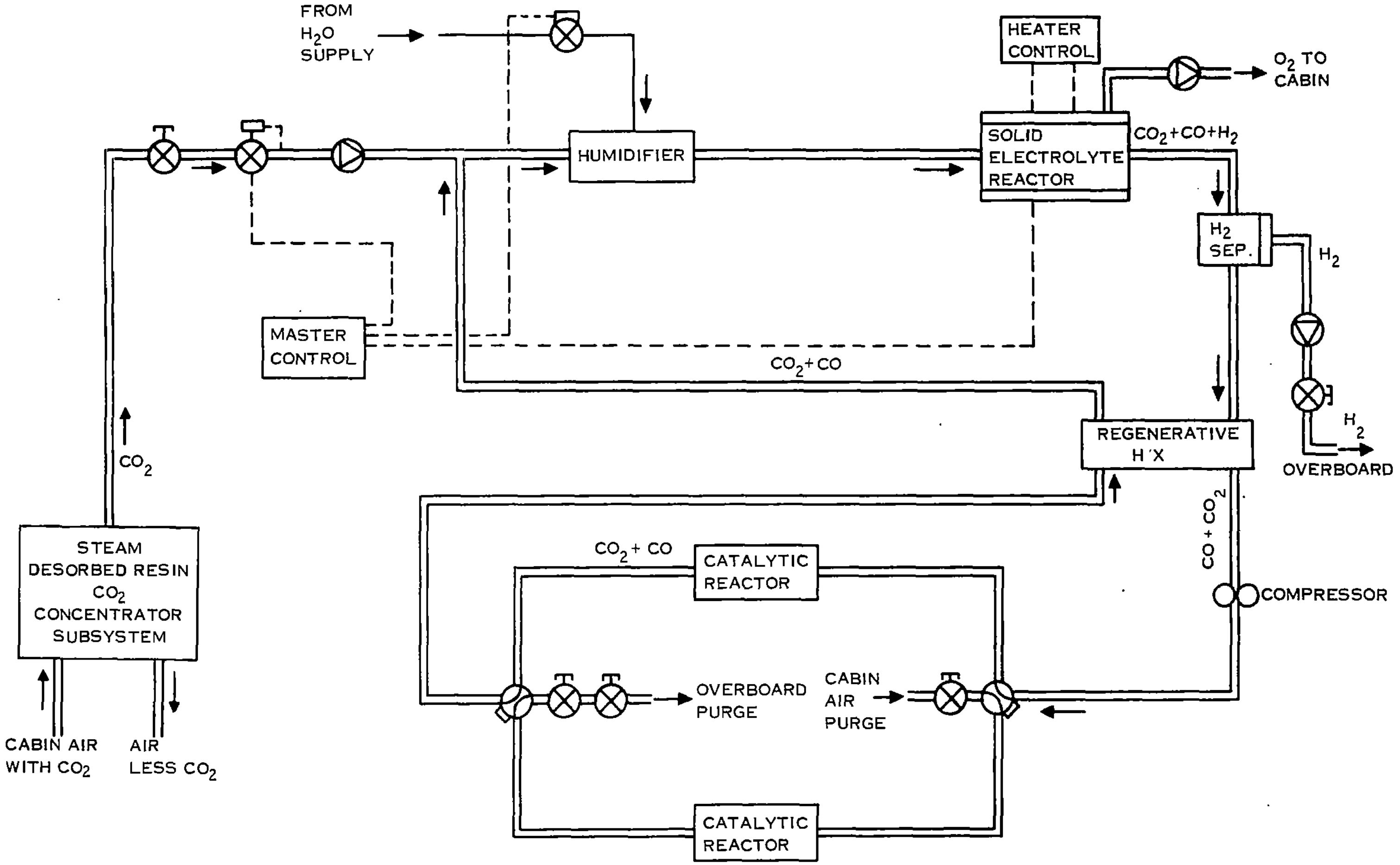


Figure 48. Solid Electrolyte Concept (Page 2 of 2)

forming in the CO_2 accumulator. This rehumidification approach also permits close control of oxygen generation rate. The humidified gas stream then enters the solid electrolyte reactor.

Within the reactor, which consists of stacks of ceramic cylinders or disks surrounded by an insulated outer casing, oxygen is formed at 1800°F by the following overall simultaneous reactions:

$$2\ CO_2 \longrightarrow 2\ CO + O_2$$

$$2H_2O \longrightarrow 2\ H_2 + O_2$$

These reactions are actually assisted by the electrochemical transfer of oxygen ions from the cathode (on one side of the ceramic electrolyte) through the electrolyte to the anode (on the other side) where oxygen gas is formed. Oxygen, which is the only gas that penetrates the electrolyte, is discharged to the cabin atmosphere. The reactor effluent, containing carbon monoxide and some hydrogen, must also contain a small percentage of carbon dioxide, because the solid electrolyte material would decompose if all the carbon dioxide were reacted. This effluent is cooled to 1000°F and passes through a hydrogen separator. Here pure hydrogen is removed through palladium alloy tubes and is dumped directly overboard. The gas stream then goes to the disproportionation reactor. Within the disproportionation reactor, carbon is deposited by the following reaction:

$$2CO \longrightarrow C + CO_2$$

Carbon is deposited on the catalyst and carbon dioxide is recycled at aboult 1/3 scfm through a compressor and back to the solid electrolyte reactor. Normal operation of the concentration section has already been described.

The question of unwanted side reactions is especially pertinent to the solid electrolyte process. A thorough equilibrium study shows the following (results of recent experiments are in very good agreement): (1) carbon will not form in the solid electrolyte reactor; (2) carbon will form on the hydrogen separator only if the temperature is below 1260°F and the palladium acts as a catalyst; (3) carbon will form in the heat exchanger unless it is made of a noncatalytic material; (4) methane concentration will not exceed 0.1 percent, and it is unstable in the hotter part of the system; (5) side reactions forming organic materials other than carbon monoxide, carbon dioxide, methane, and carbon will not occur. Experimental data indicate that carbon formation on the palladium hydrogen separator can be avoided. These data also show a need for development of a noncatalytic heat exchanger, compressor, and reactor housing (this, in fact, pertains to any carbon-forming reduction process) and for a hydrogen separator experimental study to find the influence of operating temperature on life and on carbon formation. These characteristics form the basis for a prediction of considerable development effort but no insurmountable problems.

The oxygen generation rate can be controlled in several ways including modulation of the water addition rate, recycle rate, and current. Experiments have indicated that on-off current control is satisfactory. Passive or forced air convection cooling of the reactors is anticipated. Use of a liquid coolant would add interface and maintenance complexity.

Absolute criteria. -

Performance: Both chemical reactors have performed well for at least 100 days of continuous operation, but they have not been coupled to form a functional system.

Safety: The solid electrolyte process is reasonably safe. The circulating gas contains considerable carbon monoxide, but this contaminant would probably be oxidized to carbon dioxide if it leaked into the cabin atmosphere. The hydrogen hazard is minimized by mixing hydrogen with other gases and by discharging it overboard just after formation. The system does contain pure, high temperature oxygen.

Availability/confidence: Development is now well into the research phase. The solid electrolyte concept needs much further development, but no major breakthroughs appear necessary and it appears that a system can be fully qualified for a 1979 flight. Extensive research on the solid electrolyte reaction itself has been done by three companies, and work on the disproportionation reaction and hydrogen separation has been done by other members of the aerospace industry. The solid electrolyte concept described herein has not been run as an integrated system, although such a run is scheduled. Completed testing includes a three-week water-free system test, a successful pre-flight vibration test, a successful 2016-hour solid electrolyte single cell test, a successful solid electrolyte cell stack test exceeding 100 days, and a 100-day disproportionation reactor test.

Primary criteria. -

Reliability: System MTBF is less than one-third of the mission duration. This is also true for all other integrated oxygen generation concepts. The reduction unit has a much higher failure rate than the concentration unit. The four-way solenoid valves are the specific components most likely to fail. The solid electrolyte cell stack is assumed to be a limited-life item. Each stack has a life of 300 days with a 3-sigma of 100 days, and a leakage failure rate of 1. 7 failures per million hours. The analysis is also based on a modularized hardware concept, which is considered to be the best approach for accommodating both electrical and leakage failures. Eleven modules contain five cell stacks each. Three modules are for initial operation, three for replacement, and the remaining five for standby redundancy. If electrical failure occurs in a cell stack, the four remaining stacks in the module continue to operate. If a leakage failure occurs, the entire module must be taken out of service. Standby redundancy is used to eliminate stack/module maintanance other than electrical switching.

Crew time: The estimated crew time is high compared with the Sabatier-methane dump concept, but scheduled and unscheduled maintenance are somewhat lower than for all other carbon-depositing reduction concepts. Scheduled maintenance is mostly for catalyst cartridge replacement, but cell stack monitoring and switching is also a factor. Cell stack startup time is estimated to be two hours. Unscheduled maintenance time is most likely associated with cell stack failure. The humidifier and water components have inherent spillage problems during replacement. Spare solid electrolyte stacks are contained in the reactor where they are valved into or out of the system flow. No replacement is required in this arrangement. A special insulated tool, however, is required to manipulate the hot isolation valves in the event of failure. The resultant downtime is virtually zero. Carbon is inactive, and containment during system operation and replacement should be controlled by the cartridge concept previoulsy described.

Equivalent weight: This concept has a particularly low spare/redundant equipment weight, and low electrical power consumption, giving it an equivalent weight lower than any other candidate concept.

Secondary criteria. - The solid electrolyte concept reduction section contains the flammable gas hydrogen and the toxic gas carbon monoxide, which would probable oxidize to carbon dioxide on leakage to the cabin atmosphere. These gases must be purged before maintenance. The system also contains pure, high temperature oxygen. Use of nickel in the section should be avoided to prevent the formation nickel carbonyl, which is extremely toxic. The system interfaces with the thermal control system and with the water management system in only one section. This concept has considerable flexibility in that the water/carbon dioxide feed ratio can be varied with little effect on cell stack performance, and the carbon dioxide reduction/oxygen generation rate can be easily varied by modulating current.

Any one of several potential technological improvements could reduce total equivalent weight significantly. Three of these potential improvements are in the areas of carbon handling, integration, and power consumption. First, with proper design and operation, the system produces hard, granular carbon (although much of the carbon produced experimentally has been soft, powdery, and sticky). This permits development of an automatic carbon handling system (an experimental semiautomatic system has been successful). Second, close coupling with an electrochemical carbon dioxide concentrator which generates humidified carbon dioxide continuously would have operational advantages. Third, power reduction by use of thinner cells may prove feasible.

With a relatively low recycle rate and no separate water electrolysis unit, noise is quite low. The volume is high but typical of carbon deposition reduction concepts. Power is comparable to most other concepts.

Bosch

The Bosch concept discussed here includes the selected carbon dioxide concentrator, the Bosch reactor, and the selected gas circulation water electrolysis concept. This system is described quantitatively and schematically in figure 49. The Bosch system uses a single carbon dioxide reduction reactor operating at 1200° F. It is a hydrogenation process.

During normal operation of the reduction section, a reaction gas stream circulates at about 5 cfm through the catalytic reactor, the regenerative heat exchanger, the condenser-separator, the compressor, and back to the reactor. As the gas circulates, carbon dioxide (from the concentrator) and hydrogen (from electrolysis) are added, and water generated by the reaction is removed (after condensation) to the water management system. Within the reactor, water vapor and carbon are formed on a steel wool catalyst by the following reaction:

$$CO_2 + 2H_2 \rightleftharpoons C + 2H_2O$$

Carbon is removed from the system by periodic replacement of the carbon-loaded catalyst cartridge. Normal operation of the concentration and electrolysis sections has already been described in preceding sections of this report.

Experience has shown that the Bosch process is easily controlled. An infrared instrument measures carbon dioxide partial pressure in the loop and, at a low concentration limit, signals a solenoid valve to let in more carbon dioxide. Hydrogen is added to maintain the selected total pressure. Although the reaction is exothermic, additional heating is needed to compensate for unavoidable losses.

Absolute criteria. -

Performance: Although carbon generation and electrolysis contol problems have prevented long endurance runs, reaction control has proven especially easy in the NASA Langley unit. Confidence that carbon problems can be solved is good.

Safety: The Bosch system has no unique safety problems or features, compared with the other closed cycle processes. The circulating gas contains considerable carbon monoxide, but this contaminant would probably be oxidized to carbon dioxide if it leaked into the cabin atmosphere. Hydrogen is present throughout the reduction section.

Availability/confidence: The Bosch concept can be developed for a flight as early as 1977 with a steam desorbed resin CO_2 concentrator and a gas circulation water electrolysis unit. Development is now in the prototype phase. Confidence in the availability of Bosch system hardware is good, despite excessive mechanical difficulties with prototype equipment. The most serious reduction problems are carbon carryover from the reactor cartridge and carbon formation outside of the cartridge. Recent

SUBSYSTEM: O_2 Generation/CO_2 Control

CONCEPT: Bosch/Gas Circulation Electrolysis/Steam Desorbed Resin Concentrator

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY:		MTBF:	
Designs 1 and 3:	0.998485	Designs 1 and 3:	3270 hr
Design 2:	0.998615	Design 2:	3360 hr

(including electrolysis and concentrator)

Spares/Redundant (R) Units:

Designs 1 and 3

2 - Reactor
51 - Catalyst Cartridges-Exp.
2 - Fan
2 - Check Valve
2 - Heater Control
2 - Master Control
1 - Heat Exchanger
6 - Water Separator
3 - Pump
2 - CO_2 Inlet Regulator
2 - H_2 Inlet Regulator
3-4 way Valve

Design 2

One less heater control, one additional fan control and one additional heat exchanger are required. Note: List does not include CO_2 concentrator or electrolysis unit. See appropriate data sheets.

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	142.8	13.0

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	544	539	475
Expendables	640	640	640
Spares/Redundant Units	500	499	500
Electrical Power	1494	980	1122
Thermal Power	0	78	0
Radiator Load	400	400	400
Total Equivalent Weight	3578	3132	3137
POWER (Watts):			
Electrical	3317	2174	2489
Thermal	0	1143	828

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	77	166	243

Figure 49. (Page 1 of 3).

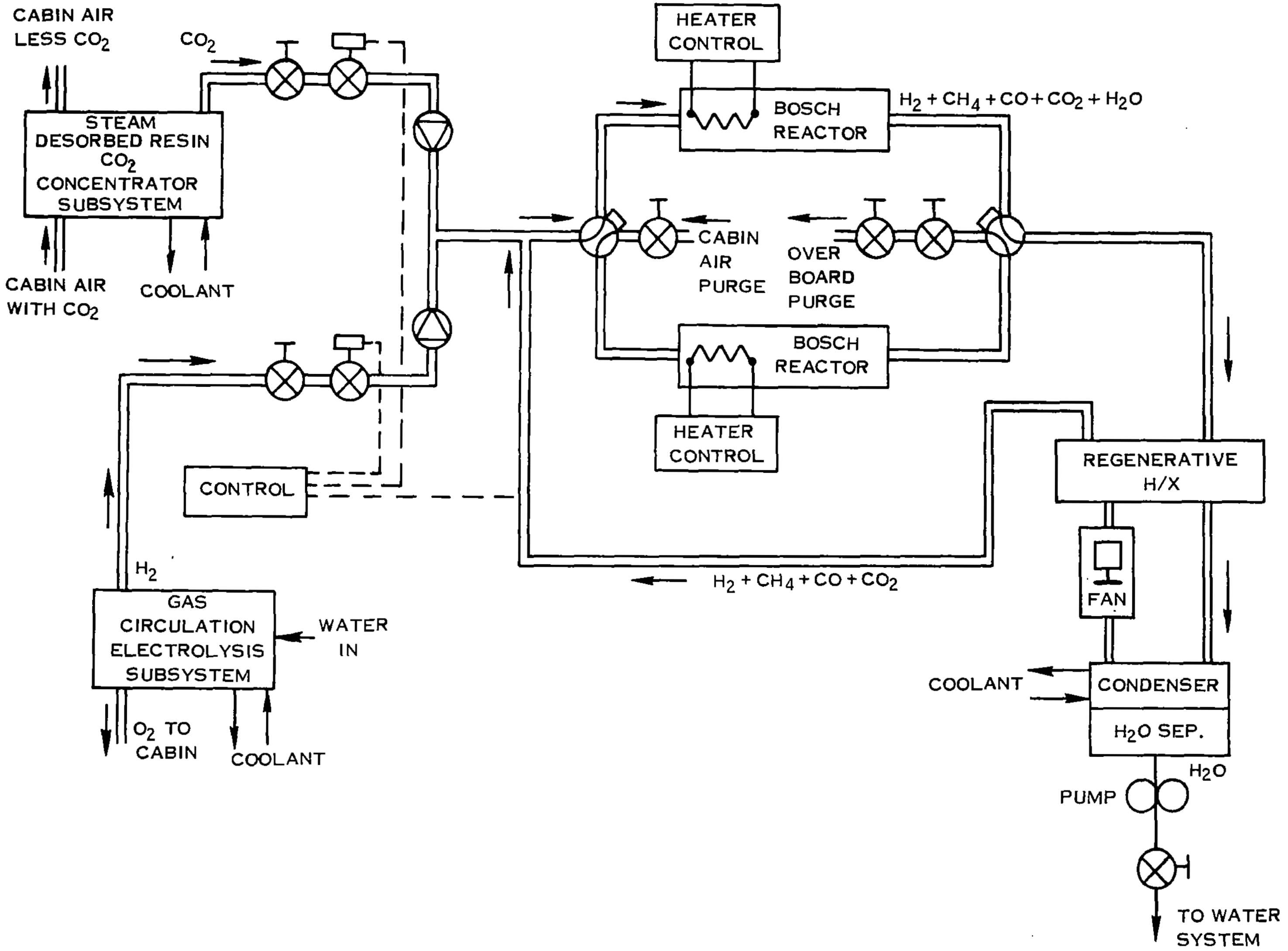


Figure 49. Bosch CO_2 Reduction Concept, Designs 1 and 3 (Page 2 of 3)

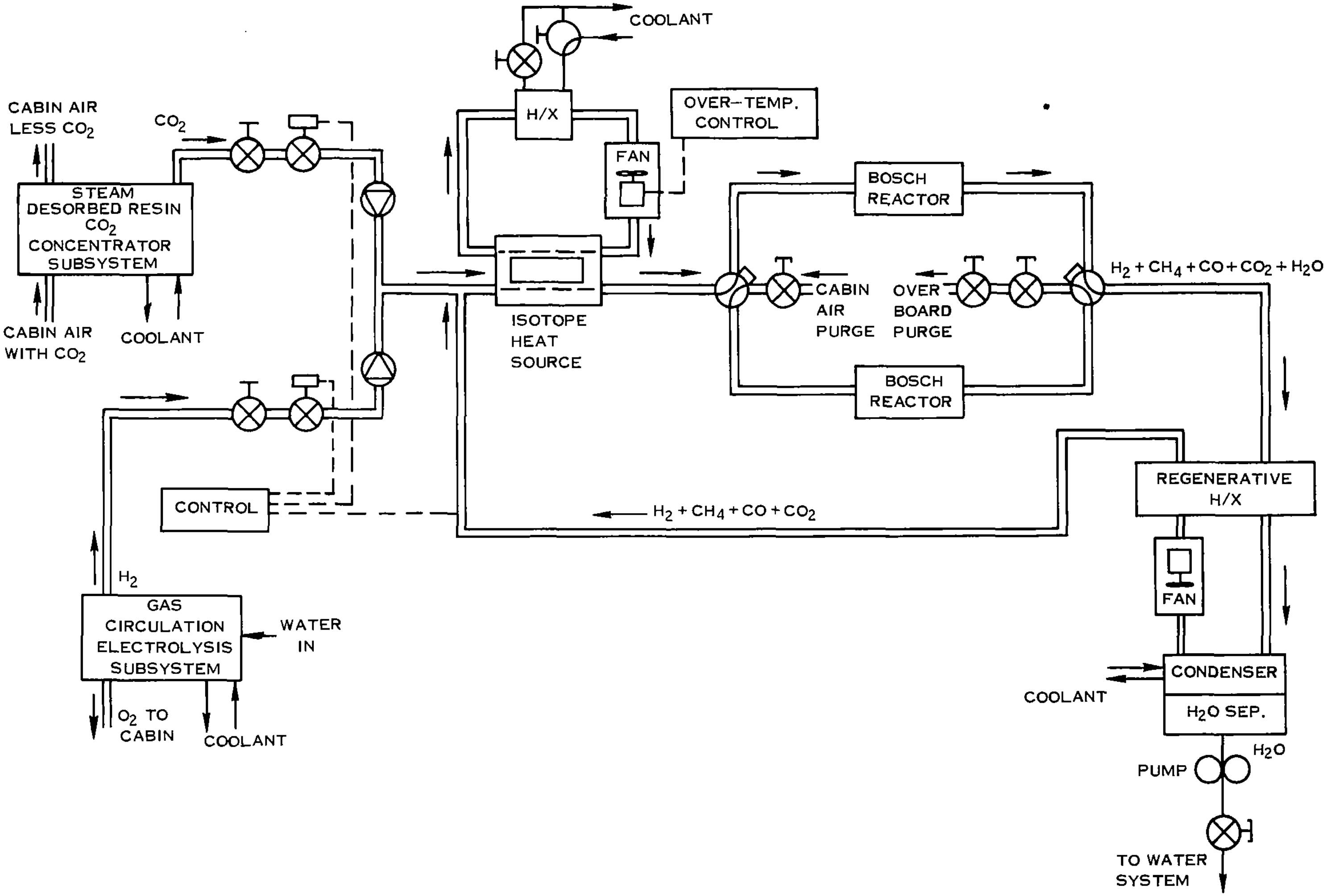


Figure 49. Bosch CO_2 Reduction Concept, Design 2 (Page 3 of 3)

experiments indicate realistic solutions to these problems. Complete carbon retention has been attained, and copper has proven to be noncatalytic. Prototype carbon dioxide concentration equipment is well-proven, but the availability of the Bosch system is limited by water electrolysis equipment development.

Primary criteria. -

Reliability: The system MTBF is less than one-third of the mission duration. The water electrolysis unit has a much higher failure rate than either the CO_2 concentration or the reduction unit. The electrolysis modules are the specific components most likely to fail. Problems associated with the reduction unit are replacement of high temperature components, contaminant leakage, and carbon handling and containment. The high operating temperature may compromise seal and instrument reliability.

Crew time: Estimated crew time is in the 130 to 160 hour range, with about 10 percent for unscheduled maintenance. The scheduled maintenance is mostly for catalyst replacement, but also for water separator replacement. Unscheduled maintenance is most likely for replacement of electrolysis cells. To date, the Bosch system has been plagued by difficulties in the control of carbon activity and containment. Carbon removal is effected by changing the catalyst-filter canisters as previously described. Due to the presence of iron and iron carbides observed in the generated carbon, there is a possibility that with some advances in magnetic materials with higher Curie temperatures the carbon will eventually be controllable through magnetic fields. A better approach may be materials improvement, where recent developments have been very promising. The presence of carbon monoxide in the separator gas ducting requires purging prior to removal. Purge and removal/reinstallation time should not exceed two hours. This is a scheduled maintenance procedure occuring every 100 days. The fan, pump, and assorted valving and controls should offer no unique maintenance problems other than the possibility of carbon contamination of components near the reactor, as previously mentioned.

Equivalent weight: The Bosch system has the second lowest equivalent weight of the candidate concepts. The Design 2 weight is particularly competitive, because only the Bosch concept can make effective use of isotope heat, reducing power penalty.

Secondary criteria. - The Bosch concept has some potential contamination problems in addition to those in the concentration and electrolysis sections, which were discussed earlier. The reduction section contains the flammable gases hydrogen and methane and the toxic gas carbon monoxide, which would probably oxidize to carbon dioxide on leakage to the cabin atmosphere. These gases must be purged before maintenance.

This system interfaces with the thermal control system in all three sections and with the water management system in two sections. Its flexibility is average. Growth potential is good for larger crews and only fair for longer missions because of high crew time. The noise level is moderate, with the relatively high gas recycle rate. Volume is high but typical of carbon deposition concepts. The electrical power consumption is average for Designs 1 and 3 and 1143 watts lower for Design 2, with an isotope heat source for both concentration and reduction sections.

Alternative design. - An alternative design concept for the Bosch process is the integrated hydrogenation approach. This approach is equally applicable to the Sabatier process with methane dump or with methane cracking, but the experimental work was done on the Bosch process.

The outstanding feature of this approach is the elimination of the need to condense and separate water out of the hydrogenation reactor effluent. A double loop system is used to achieve this. One loop is the standard hydrogenation loop, except that the condenser-separator is replaced with a water-adsorbing desiccant canister. The other loop includes a desorbing desiccant canister (which had been adsorbing in the hydrogenation loop on the previous half-cycle), a fan, a water vapor electrolysis unit, and a cooler. In addition, there is another desiccant canister (located between the desorbing desiccant and the electrolysis unit) for water vapor surge prevention. A wick evaporator, with liquid feed from water management, and a catalytic burner are also included but may not be necessary in a fully developed system.

During normal operation, the water vapor generated by the hydrogenation reaction is adsorbed by the desiccant and is subsequently desorbed through the surge control desiccant to the electrolysis unit. This unit adsorbs water vapor from the circulating stream and electrolyzes it to produce oxygen for crew consumption and hydrogen for recycle to the hydrogenation reacter.

A preliminary evaluation of the integrated hydrogenation concept indicated that it had no overall advantage over the regular hydrogenation concepts with regard to the AILSS criteria. In addition, it introduced new problems such as contaminant carryover within the system, and its availability/confidence was somewhat lower. Consequently, this concept is not included in the comparison summary.

Sabatier-Methane Cracking

This system is described quantitatively and schematically in figure 50. The Sabatier-methane cracking concept uses two chemical reactors in the reduction section, operating at 600° and 1800°F. It is a hydrogenation process. In addition to the reduction section, the system includes CO_2 concentration and water electrolysis sections, which were described previously. In addition to the reactors, the reduction system includes regenerative heat exchangers, a recycle compressor, a condenser-separator, a condensate pump (which could be eliminated during system integration), and control devices.

During normal operation of the reduction section, carbon dioxide (from the concentrator) and hydrogen (from electrolysis) are combined with the recycle stream from the methane cracking reactor, and this mixture enters the hydrogenation reactor. Here the carbon dioxide is hydrogenated to form water vapor and methane by the following reaction:

$$CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O$$

This reaction may be nearly isothermal at about 500°F or it may have any temperature profile from 100°F up to about 800°F, depending on the reactor design approach. Water vapor in the reactor effluent is condensed, separated from the methane, and transferred to the water management system. The methane continues into the methane cracking reactor where it is partially (60 to 85 percent) decomposed to carbon and hydrogen at about 1800°F, by the following reaction:

$$CH_4 \rightleftharpoons C + 2H_2$$

Carbon is removed from the system by periodic replacement of the carbon-loaded catalyst cartridge. Hydrogen and methane in the reactor effluent can be separated and recycled (to the hydrogenation and methane cracking reactors, respectively), or recycling of the unseparated mixture to the hydrogenation reactor may prove practical. Normal operation of the concentration and electrolysis functions has already been described in previous sections of this report.

Experience with the methane dump version of the Sabatier process indicates the importance of close feed control. Tight control of the methane cracking version, however, is undoubtedly less important because the process is cyclic. A control scheme similar to that suggested for the Bosch process would probably be satisfactory. That is, an infrared instrument measures carbon dioxide partial pressure in the loop and, at a low concentration limit, signals a solenoid valve to let in more carbon dioxide. Hydrogen is added to maintain the selected total pressure. The hydrogenation reactor may be cooled by passive heat rejection to the surroundings, by rejection to air blown over the reactor, or by rejection to a liquid coolant (not recommended for AILSS because of high temperature coolant heating and maintenance problems). The cracking reaction is endothermic, requiring electrical heating.

Absolute criteria. -

Performance: Several full-scale Sabatier reactors have operated satisfactorily in spacecraft simulators for periods approaching 1000 hours. Although long-term poisoning of the Sabatier catalyst is still a question, there is no evidence of it. Performance tests of methane cracking reactors are very promising, and long endurance is not required because the catalyst cartridge must be replaced frequently to dispose of the collected carbon.

SUBSYSTEM: O_2 Generation/CO_2 Control

CONCEPT: Sabatier-Methane Cracking/Gas Circulation Electrolysis/Steam Desorbed Resin Concentrator

FLIGHT AVAILABILITY: 1980
(1970 go-ahead)

RELIABILITY: 0.998400 MTBF: 3200 hr
(including electrolysis & concentrator)

Spares/Redundant (R) Units:

1 - Sabatier Reactor
1 - Catalyst Cartridge
2 - Methane Cracker
2 - CO_2 Regulator
6 - Condenser/Separator
3 - Condensate Pump
2 - Compressor
3 - 4-way Diverter Valve
1 - Hydrogen Separator
2 - Check Valve
3 - Heater Control
2 - Hydrogen Regulator
3 - Controller

Expendables: 50-catalyst cartridges
NOTE: List does not include CO_2 Concentrator or Electrolysis. See individual data sheets.

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	142.8	13.2

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	601	563	532
Expendables	640	640	640
Spares/Redundant Units	515	515	515
Electrical Power	1762	1390	1390
Thermal Power	0	62	0
Radiator Load	482	482	482
Total Equivalent Weight	4000	3652	3559
POWER (Watts):			
Electrical	3916	3088	3088
Thermal	0	828	828

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	94	183	277

Figure 50. (Page 1 of 2)

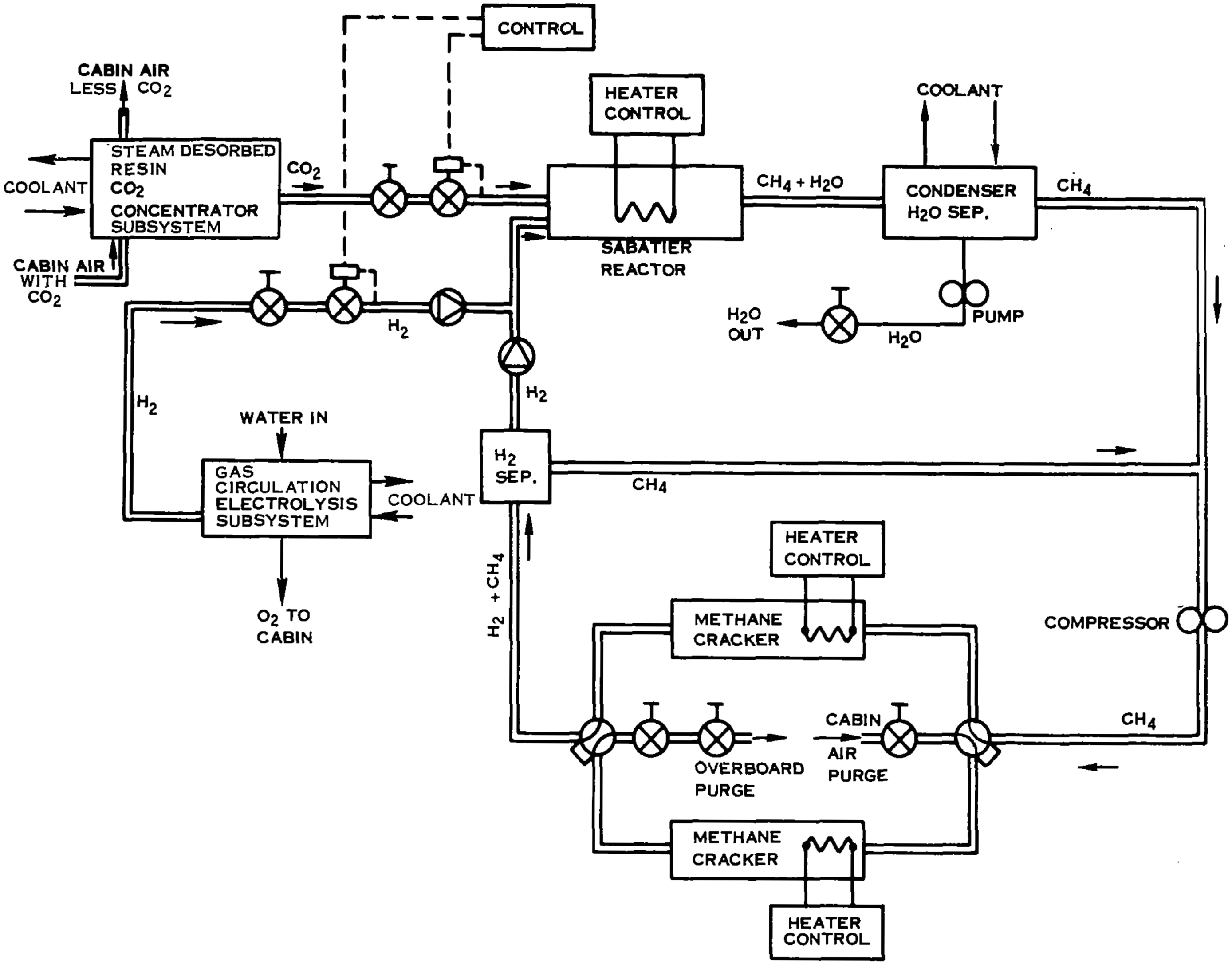


Figure 50. Sabatier CO_2 Reduction with Methane Cracking Concept (Page 2 of 2)

Safety: The Sabatier-methane cracking system has some safety problems. Although dangerous carbon monoxide concentrations are avoided, the thermal mass of the reduction section is considerable, with the carbon deposition (cracking) reactor at 1800°F. Hydrogen is present throughout the reduction section.

Availability/confidence: The Sabatier-methane cracking concept can be developed for a flight as early as 1980. Overall concept development is now in the research phase, although some portions are much more advanced. Thus, the development status of this Sabatier process is mixed. The hydrogenation reacter portion of the system is well developed, with several government and industry installations.

A prototype unit successfully completed a 60-day test as an integrated element of a life support system, and another unit completed a similar 28-day test. In addition, laboratory models have received extensive testing. The development of methane cracking, however, has remained in the laboratory research stage. Adequate catalysts have been found, but additional work on catalyst selection is needed. Methane conversions of 85 percent appear to be feasible. The longest experimental run was 194 hours. However, no serious methane cracking development problems are anticipated. Coupling the hydrogenation and cracking reactions may be more difficult. Because this has not been done experimentally, the quantitative effect of uncracked methane on the hydrogenation reaction isn't known, and the stability of the integrated system has not been verified. The separation of hydrogen and methane at the recycle compressor outlet would eliminate these potential problems at the expense of added complexity. This separation would require a palladium tube hydrogen separator or a hydrogen stripper cell (an electrochemical device under development at Battelle).

Primary criteria. -

Reliability: The system MTBF is less than one-third of the mission duration. The water electrolysis unit has a much higher failure rate than either the CO_2 concentration or the reduction unit. The electrolysis modules are the specific components most likely to fail. Problems associated with this concept are replacement of high temperature components, contaminant leakage, and carbon handling. The high operating temperature may compromise seal and instrument reliability.

Crew time: The estimated crew time is in the 130 to 160 hour range, with about 10 percent for unscheduled maintenance. Scheduled maintenance is mostly for catalyst cartridge replacement, but also for water separator replacement. Unscheduled maintenance is most likely for replacement of the electrolysis cells. The major maintenance area in the Sabatier system is expected to be the methane cracker. This system produces carbon at 1800° F, which is significantly higher than the other carbon deposition reactors. This necessitates longer cooling periods prior to carbon handling and more insulation, which will interfere with access and cooling rates. Carbon properties are largely unknown. The condenser-water separator has problems pertaining to spillage during disassembly and the special start-up procedures required to obtain proper operation of the phase separator after assembly. The controllers, valving, and compressor should offer no unique maintenance requirements.

Equivalent weight: Relatively high power consumption results in a total equivalent weight somewhat higher than that of the concepts previously described. Comparison with the Bosch concept shows that the cause of this situation is heat loss from the endothermic, high temperature, methane cracking reactor. The solid electrolyte concept also uses an endothermic high temperature reactor, but its heat loss is limited by its small size.

Secondary criteria. - The Sabatier concept has some potential contamination problems in addition to those of the concentration and electrolysis sections, previously discussed. The reduction section contains the flammable gases hydrogen and methane. Purging of these gases before maintenance, however, is not essential. The Sabatier catalyst may be poisoned by some contaminats in the cabin air, especially the sulfides. This system interfaces with the thermal control system in all three sections and with the water management system in two. Flexibility is average. The ability to operate in a degraded methane dump mode is of little value for the AILSS mission, and the hydrogenation reaction feed ratio is probably quite limited. Growth potential is only fair with moderately high equivalent weight and crew time. The noise level is low with the relatively low gas recycle rate. Volume and power are higher than any other candidate concept.

Alternative Sabatier concepts. - Another integrated carbon dioxide concentration-reduction concept deserves mention. This approach uses a treated zeolite that also serves as a hydrogenation catalyst (a mixture of zeolite and regular hydrogenation catalyst might be just as good). Carbon dioxide is adsorbed from cabin air in the usual manner. During the desorption or reaction half-cycle, the bed is heated to about 700° F and hydrogen is admitted, hydrogenating adsorbed carbon dioxide to form water and methane. This process thus appears to eliminate the need for a carbon dioxide compressor and accumulator. However, a compressor is still needed to exhaust air from the bed before heating, and an accumulator is still needed for the methane-water mixture, or at least for the methane. In addition, the zeolite is heated to a considerably higher temperature than in a normal concentrator, requiring more insulation and coolant, and resulting in an increased heat rejection penalty. Also, water formed in the reaction must be completely removed from the bed before cooling. For these reasons, this modified Sabatier process is less attractive than the previously described Sabatier process.

Another alternative version of the Sabatier concept, which is distinguished by its unique components, is the electrochemical Sabatier process. This process is not included in the concept comparison because it does not seem to offer any significant advantage over the regular Sabatier process and because its early state of development makes definition uncertain. During normal operation, concentrated carbon dioxide is reduced in two different electrochemical units, and oxygen is generated in two electrochemical units. The system consists of five major units: a water vapor electrolysis module, a carbon dioxide concentrator, a water electrolysis-carbon dioxide reduction reactor, a hydrogen separator-carbon dioxide reduction reactor, and a methane cracking reactor. Water vapor in the cabin air is electrolyzed to form oxygen and hydrogen as air flows through the electrolysis module. The oxygen mixes with the cabin air, and the hydrogen is transferred to the hydrogen separator-carbon dioxide reduction reactor. At the same time, carbon dioxide from the concentrator is fed, at nearly equal rates, to both the water elecrolysis-carbon dioxide reduction reactor and the hydrogen separator-carbon dioxide reduction reactor. In the water electrolysis-carbon dioxide reduction reactor, water from the two carbon dioxide reduction reactions is electrolyzed to from oxygen and hydrogen, which immediately reacts with carbon dioxide at the cathode (a silver-palladium tube filled with Sabatier catalyst) to produce methane and water. The water is immediately electrolyzed, and the methane goes to the methane cracking reactor, after first passing through the hydrogen separator-carbon dioxide reduction reactor for removal of unreacted hydrogen. The methane cracking reactor cracks the methane formed in the carbon dioxide reduction reactions to form carbon and hydrogen. The carbon remains in the reactor (until removed periodically), and the effluent gas stream, containing hydrogen and unreacted methane, returns to the methane cracking reactor inlet after passing through the hydrogen separator-carbon dioxide reduction reactor for removal of contained hydrogen. In the hydrogen separator-carbon dioxide reduction reactor, hydrogen is electrochemically stripped from the entering gas streams at the anode. This hydrogen then reacts with concentrated carbon dioxide fed to the catalyst-filled cathode to produce methane and water, as in the water electrolysis-carbon dioxide reduction unit. Excess methane generated within the system is vented to space. The quantity vented is dependent on the crew oxygen consumption and carbon dioxide generation rates.

Sabatier-Methane Dump

This system is described quantitatively and schematically in figure 51. The Sabatier-methane dump system uses a single reduction reactor operating at about 600°F. It is a hydrogenation process. In addition to the reduction section, the system includes CO_2 concentration and water electrolysis sections, which were described previously. In addition to the reactors, the reduction section includes a regenerative heat exchanger, a condenser-separator, a condensate pump (which can be eliminated during subsystem integration), a hydrogen supply tank, and control devices. This system does not generate carbon, but dumps it overboard as methane (CH_4).

During normal operation of the reduction section, carbon dioxide (from concentration) and hydrogen (from electrolysis and/or storage) are combined and fed to the hydrogenation (Sabatier) reactor. Here the carbon dioxide is hydrogenated to form water vapor and methane by the following reaction:

$$CO_2 + 4H_2 \rightleftharpoons CH_4 + 2\,H_2O$$

This reaction may be nearly isothermal at about 500°F, or it may have any temperature profile from 100°F up to about 800°F, depending on reactor design approach. Water vapor in the reactor effluent is condensed, separated from the methane, and transferred to the water management system. The methane is then dumped to space together with the excess hydrogen. Normal operation of the CO_2 concentration and water electrolysis sections has already been described in the preceding sections of this report.

Experience with the methane dump version of the Sabatier process indicates the importance of close feed control and a 10 volume-percent hydrogen excess in the feed for maximum CO_2 conversion. A constant feed rate control is probably best, with feed ratio/total pressure control an alternative. The reactor may be cooled by passive heat rejection to the surroundings, by rejection to air blown over the reactor, or by rejection to a liquid coolant (not recommended for the AILSS because of resulting interface complexity and maintenance problems).

Absolute criteria. -

Performance: Satisfactory performance of large scale units has been proven for durations approaching 1000 hours. Although long-term resistance to catalyst poisoning has not been proven, there is no evidence of degradation.

Safety: This concept uses stored hydrogen which is a safety hazard. Although the operating temperature is relatively low and the high thermal mass of a carbon deposition reactor is not present, the stored hydrogen represents considerable fuel for a potential fire. Hydrogen is also present throughout the reduction section.

Availability/confidence: The Sabatier-methane dump concept can be developed for a flight as early as 1973, although a water electrolysis unit will not be ready until 1974. Prototype development is advanced enough to allow immediate start of the flight hardware phase. Thus, confidence in the availability of this process is very high. The hydrogenation reactor is well developed, with several government and industry installations. A prototype unit successfully completed a 60-day test as an integrated element of a life support system, and another unit completed a similar 28-day test. In addition, laboratory models have received extensive testing. No great difficulty with hydrogen storage is anticipated. The availability of this concept is limited only by the availability of a water electrolysis unit.

Primary criteria. -

Reliability: The system MTBF is less than one-third of the mission duration. The water electrolysis unit has a much higher failure rate than either the CO_2 concentration or the reduction unit. The electrolysis modules are the specific components most likely to fail. Problems associated with this concept are minimal. Catalyst poisoning has never been detected but, to some degree, it is an unknown. A prolonged upset in

SUBSYSTEM: O_2 Generation/CO_2 Control

CONCEPT: Sabatier-Methane Dump/Gas Circulation Electrolysis/Steam Desorbed Resin Concentrator

FLIGHT AVAILABILITY: 1973 (reduction section only)
(1970 go-ahead)

RELIABILITY: 0.998153 MTBF: 3440 hr
(incl. concentrator & electrolysis)

Spares/Redundant (R) Units:

- 1 - Sabatier Reactor
- 2 - CO_2 Regulator
- 6 - Condenser/Separator
- 3 - Condensate Pump
- 2 - CH_4 Regulator
- 2 - Selector Valve
- 4 - H_2 Regulator
- 2 - Check Valve
- 2 - Controller
- 3 - Transducers

NOTE: List does not include CO_2 Concentrator or Electrolysis. See individual data sheets.

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	42.8	12.7

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	437	399	368
Expendables	2093	2093	2093
Spares/Redundant Units	447	447	447
Electrical Power	1314	942	942
Thermal Power	0	62	0
Radiator Load	368	368	368
Total Equivalent Weight	4659	4311	4218
POWER (Watts):			
Electrical	2917	2089	2089
Thermal	0	828	828

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	25	14	39

NOTE: Hydrogen tankage is additional 200 ft^3 external to cabin

Figure 51. (Page 1 of 2).

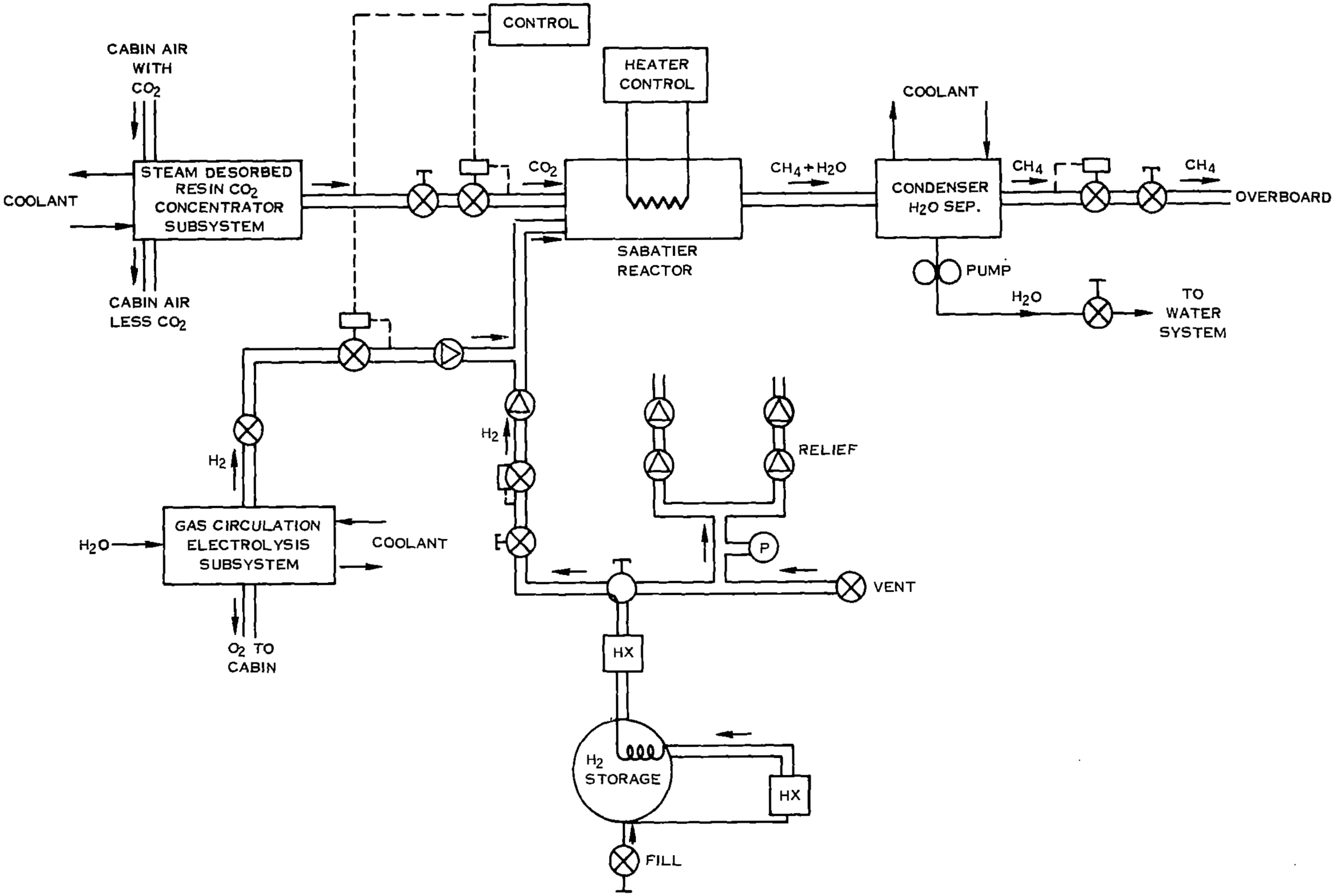


Figure 51. Sabatier CO_2 Reduction with Methane Dump Concept (Page 2 of 2)

reaction feed conditions could cause mission failure because unreacted CO_2, with its contained oxygen, could be lost overboard.

Crew time: The estimated crew time is under 60 hours, much lower than any other concept. This reduction occurs because no carbon is formed in the process, eliminating the time-consuming carbon handling. Scheduled maintenance is mostly for water separator replacement. Unscheduled maintenance is most likely for replacement of electrolysis cells.

Equivalent weight: This concept has a far higher equivalent weight than any other concept. This high weight occurs because the expendable weight (hydrogen and associated tankage) is heavier than the expendable weight (catalyst cartridges) of the other concepts.

Secondary criteria. - The Sabatier methane dump concept has some potential contamination problems in addition to those of the concentration and electrolysis sections discussed earlier. The reduction section contains the flammable gases hydrogen and methane but they are discharged overboard. The Sabatier catalyst may be poisoned by some contaminants in the cabin air, especially the sulfides. The system interfaces with the thermal control system in all three sections and with the water management system in two sections. Flexibility is poor, because if reactor inlet conditions (feed ratio, temperature, flow rate) vary, a considerable penalty in hydrogen or carbon dioxide loss can result. The growth potential is poor, because of the high expendable rate. Noise level is extremely low. Volume, with hydrogen stored outside the cabin, is extremely low. If storage volume is included, the total volume is still slightly lower than that of any other concept. Power consumption is comparable to most other concepts.

Methane utilization. - Using the methane instead of dumping it could have a significant impact on net effective equivalent weight and on the overall attractiveness of the concept. Further study is necessary to determine whether such a net weight reduction credit is realistic. The most obvious use is for attitude control of the vehicle. Less likely is its use as a fuel. Use of the methane would require the addition of transfer and possibly, storage equipment. Attitude control would probably be obtained by the controlled release of high pressure, ambient temperature methane. Resistojet attitude control is an alternative. The quantitative impact of this implementation is noted later in the section titled Summary.

Sabatier-Acetylene Dump

This concept has similarities to both of the Sabatier systems previously described. That is, it involves both methane cracking (to acetylene and hydrogen rather than to carbon and hydrogen) and dumping of hydrogen (in the form of acetylene rather than methane) to space. The concept avoids certain drawbacks of the methane cracking and methane dump approaches. Stating the two most important of these points as advantages, (1) methane cracking results in a gas (acetylene) rather than solid carbon, which presents a handling problem; and (2) far less stored hydrogen is needed, because much less hydrogen is lost to space.

During normal operation of the reduction section, carbon dioxide (from concentration) and hydrogen (from electrolysis, storage, and/or recycle) are combined and fed to the hydrogenation (Sabatier) reactor. Here the carbon dioxide is hydrogenated to form water vapor and methane by the following reaction:

$$CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O$$

This reaction may be nearly isothermal at about 500°F, or it may have any temperature profile from 100°F up to about 800°F, depending on reactor design approach. Water vapor in the reactor effluent is condensed, separated from the methane, and transferred to the water management system. The methane enters a methane cracking reactor, where it is decomposed at high temperature by the reaction:

$$2CH_4 \rightleftharpoons C_2H_2 + 3H_2$$

The acetylene is dumped to space. The hydrogen is separated from the effluent acetylene in a silver-palladium membrane separator and is recycled to the hydrogenation reactor. Normal operation of the CO_2 concentration and water electrolysis sections has already been described.

Several types of methane cracking reactor have been studied in recent research efforts. There include electric arc discharge reactors, microwave plasma reactors, and noncatalytic thermal reactors operating at about 3000°F. To make the Sabatier-acetylene dump concept practical, a high-conversion reactor must be developed to minimize side reactions, which form solid carbon or unwanted hydrocarbons.

If the ratio of vehicle leakage to metabolic oxygen consumption is sufficiently high, the Sabatier-acetylene dump concept suggests a well-integrated system, with oxygen leakage makeup by electrolysis of stored water and elimination of all stored hydrogen. This approach could be applied to the AILSS if the total vehicle leakage rate were 3.3 pounds per day, or higher.

Absolute criteria. -

Performance: Experiments indicate that conversion to acetylene of at least 90 percent can be attained. Thus, satisfactory performance is indicated.

Safety: Like other CO_2 reduction processes, Sabatier-acetylene dump involves flammable gases and high temperature reactors. The danger may be higher for this concept, however, because acetylene is extremely reactive and the methane cracking reactor operates at an extremely high temperature.

Availability/confidence: This process is represented by a number of development efforts, all in the early research phase. Although results are promising, development of a flight-qualified system before the mid-1980's is unlikely. Thus, the Sabatier-acetylene dump concept cannot be applied to the AILSS and is not discussed further.

EVALUATION AND SELECTION

The solid electrolyte system was selected for the AILSS, based primarily on its very low total equivalent weight and also on its consistently superior secondary criteria ratings. The comparison of the oxygen generation concepts was based on integrated combinations of the CO_2 concentration, CO_2 reduction, and water electrolysis subsystems. Concept selection ratings are presented in table 16, and a data summary, including a total equivalent weight break down, is shown in table 17.

Design 1

Absolute criteria. -

Performance: All concepts are judged capable of generating oxygen at an adequate rate and controlling carbon dioxide to a satisfactory level. Therefore, the performance rating of all concepts is Good. Loss of CO_2, which could occur from the Sabatier-methane or acetylene dump systems, is a break in the closed system concept and could easily result in an excessive weight penalty. On the other hand, most other systems (solid electrolyte, Bosch, and Sabatier-methane cracking) must reprocess sufficient CO_2 to remove the nitrogen impurities from the system. The fused salt system has neither of these problems.

Safety: All concepts have different but approximately equivalent safety problems and are rated Fair. All systems have hot reactors that cannot be manually maintained without prior cooling, and all carbon-forming systems can generate carbon monoxide if air contacts the hot carbon. In addition, the fused salt system may generate toxic gases from contaminants in the atmosphere that pass through it, and the hot corrosive melt is a potential hazard. Solid electrolyte can leak toxic carbon monoxide and has some explosive potential, although the hydrogen is diluted with carbon monoxide and carbon dioxide. The Bosch concept can leak toxic carbon monoxide or potentially explosive hydrogen and methane and has a very high thermal mass. Sabatier with methane dump can also leak hydrogen or methane and has the added disadvantage of a large supply of stored flammable hydrogen. Sabatier with acetylene dump requires little or no stored hydrogen, but the cracking reaction occurs at extremely high temperature.

TABLE 16
EVALUATION SUMMARY - O_2 GENERATION/CO_2 CONTROL

Power Supplies
Design 1 - Solar Cell
Design 2 - Solar Cell/Isotopes
Design 3 - Brayton

		Candidate Concepts																	
		Fused salt			Solid electrolyte			Bosch			Sabatier-methane cracking			Sabatier-methane dump			Sabatier-acetylene dump		
CRITERIA	DESIGN	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Absolute	Performance	Good			Good			Good			Good			Good			Good		
	Safety	Fair			Fair			Fair			Fair			Fair			Fair		
	Avail./Conf.	Unacceptable			Fair			Good			Fair			Very good			Unacceptable		
		Eliminated															Eliminated		
Primary	Reliability				Fair			Fair			Fair			Fair					
	Crew Time				Good			Fair			Fair			Very good					
	Equivalent Weight				Very good	Very good	Very good	Good	Very good	Good	Fair	Fair	Fair	Poor	Poor	Poor			
								Elim		Elim	Eliminated			Eliminated					
Secondary	Contamination				Fair			Fair											
	Interfaces				Good			Poor											
	Flexibility				Good			Fair											
	Growth				Good			Fair											
	Noise				Good			Fair											
	Volume				Good			Good											
	Power				Good			Good											
					Selected				Elim										

TABLE 17 (Page 1 of 2)

DATA SUMMARY
O_2 GENERATION/CO_2 CONTROL

	Design	MTBF Hours	Crew Time Hours		Total Equivalent Weight Pounds	Power, Watts	
			Scheduled	Unscheduled		Electrical	Thermal
Solid electrolyte	1	3480	126.8	8.4	3220	3004	0
	2				2872	2176	828
	3				2779	2176	828
Bosch	1	3270	142.8	13.0	3578	3317	0
	2	3360			3132	2174	1143
	3	3270			3137	2489	828
Sabatier-methane cracking	1	3200	142.8	13.2	4000	3916	0
	2				3652	3088	828
	3				3559	3088	828
Sabatier-methane dump	1	3440	42.8	12.7	4659	2917	0
	2				4311	2089	828
	3				4218	2089	828

TABLE 17 (Page 2 of 2)

DATA SUMMARY
O_2 GENERATION/CO_2 CONTROL

Concept	Design	Equivalent weight (lb)						
		Basic Unit	Expendables	Spares-Redundancy	Electric power	Heat power	Radiator penalty	Total
Solid electrolyte	1	525	640	373	1351	0	331	3220
	2	487	640	373	979	62	331	2872
	3	456	640	373	979	0	331	2779
Bosch	1	544	640	500	1494	0	400	3578
	2	539	640	499	980	62	400	3132
	3	475	640	500	1122	0	400	3137
Sabatier-methane cracking	1	501	640	515	1762	0	482	4000
	2	563	640	515	1390	62	482	3652
	3	532	640	515	1390	0	482	3559
Sabatier-methane dump	1	437	2093	447	1314	0	368	4659
	2	399	2093	447	942	62	368	4311
	3	368	2093	447	942	0	368	4218

NOTE: Equivalent weights of a gas circulation water electrolysis unit and a steam desorbed resin CO_2 concentrator are included where applicable.

Availability/confidence: Confidence in availability of the fused salt and Sabatier-acetylene dump systems is Unacceptable, because AILSS flight concepts are not sufficiently developed at this time. Confidence in the solid electrolyte is acceptable, but a Fair rating has been given to it because full scale components have not been tested as an integrated system. Availability of the Bosch concept is considered Good, because a full-scale unit has been run as an integrated system, although solution of the carbon handling problem has not been proven. Sabatier-methane cracking availability is Fair, because full-scale components have not been tested as an integrated system. Confidence in Sabatier-methane dump availability is Very Good because full-scale systems have run successfully in several installations.

Summary: The fused salt and Sabatier-acetylene dump concepts are eliminated from further consideration because they are not likely to be available for the AILSS. All other concepts have acceptable, identical performance and safety ratings. Based on availability/confidence, Sabatier-methane dump rates highest, with Bosch next best. The solid electrolyte and Sabatier-methane cracking concepts are acceptable.

Primary criteria. -

Reliability: All concepts have an MTBF of less than one-third of the mission length and therefore have Fair inherent reliability. This occurs because these ratings represent the additive effects of integrating two or three subsystems, each with its own MTBF.

Crew time: Crew time is fairly high for all concepts requiring replacement of carbon-filled catalyst cartridges. However, the solid electrolyte concept not only requires less crew time than other carbon-depositing concepts, which are rated Fair, but it also has the lowest unscheduled repair time of oxygen generation concepts and therefore merits a Good rating. The Sabatier-methane dump concept generates methane instead of carbon and requires far less crew attention, and it therefore has Very Good crew time characteristics.

Equivalent weight: The total equivalent weight estimates are presented in table 17. Solid electrolyte has Very Good total equivalent weight, the lowest of all concepts. The Bosch concept is 350 pounds heavier, with higher spares weight and power, and it is judged Good. Sabatier-methane cracking has a still higher weight due to a high heat loss, and it is considered Fair. Sabatier-methane dump has a Poor equivalent weight because of its high expendables consumption rate. Methane utilization might make this concept more competitive.

Summary: The solid electrolyte concept has the best primary criteria ratings. Other concepts do not rate as well and are eliminated at this point.

Selection. - With good total equivalent weight and crew time, the solid electrolyte concept has the best primary criteria ratings and its absolute and secondary criteria ratings, shown on table 16, are satisfactory. This concept is therefore selected for the Design 1 AILSS.

Design 2

Absolute criteria. - Absolute criteria ratings are unchanged from Design 1.

Primary criteria. - The reliability and equivalent weight situations for Design 2 are different from Design 1. In Design 2, the Bosch reactor uses isotope instead of electrical heat, resulting in a slight increase in MTBF. This change, however, is not sufficient to affect the reliability ratings, which are the same as for Design 1. Equivalent weight is lower for all concepts because the CO_2 concentrator (common to all concepts) uses isotope heat at a lower penalty. Relative equivalent weights and corresponding ratings are the same as for Design 1, except for the Bosch concept. This concept uses isotope heating in the reduction section, so that its weight is only 260 pounds higher than solid electrolyte for Design 2. Both of these concepts are therefore rated Very Good. As a result, Design 2 primary criteria ratings of solid electrolyte and Bosch concepts are more nearly equal than in Design 1, and secondary criteria should be considered.

Secondary criteria. - Both the solid electrolyte and the Bosch concepts have potential contamination problems. The solid electrolyte can leak toxic carbon monoxide or explosive hydrogen, and its palladium hydrogen separator is easily poisoned by sulfur compounds. The Bosch can also leak toxic carbon monoxide and explosive hydrogen and methane. Both concepts can contaminate the cabin atmosphere during carbon removal, although the high carbon monoxide concentration in solid electrolyte is potentially more dangerous. Thus, contamination characteristics of both concepts are considered Fair, because the relative differences are not sufficient for differentiation.

The solid electrolyte system has significantly fewer interfaces than the Bosch. The difference is that the solid electrolyte system interfaces with the thermal control system in the concentrator section only and with the water management section in the reduction section only, while the Bosch system interfaces with the thermal control system in the reduction, concentration, and electrolysis sections, and with the water management system in the reduction and electrolysis sections. Consequently, the solid electrolyte concept has Good interface characteristics, while the Bosch concept has relatively Poor ones.

The solid electrolyte has Good flexibility because it can tolerate unlimited water vapor in the CO_2 feed stream and because it permits simple cabin oxygen concentration control. Flexibility of the Bosch concept is considered Fair, because its water vapor tolerance is more limited, and its total equivalent weight is competitive for only one of the three AILSS designs.

Technological growth potential for the solid electrolyte concept is Good, while that of the Bosch is Fair. Noise characteristics of the solid electrolyte concept are Good, while those of the Bosch with its higher gas recirculation rate are only Fair. There is little distinction between the concepts with respect to volume and power, and both are considered Good.

Selection. - The solid electrolyte concept is selected for Design 2, because of its better crew time, interface, flexibility, growth, and noise characteristics.

Design 3

Absolute and primary criteria ratings are the same as those of Design 1. Use of Brayton cycle waste heat by the CO_2 concentrator, which is common to concepts evaluated at the primary level, results in the same weight reduction for each concept. Thus, the relative equivalent weight situation is the same as for Design 1, and corresponding equivalent weight ratings are the same.

Accordingly, the solid electrolyte concept is selected for Design 3 for the same reasons it was the Design 1 choice.

SUMMARY

The solid electrolyte concept is selected for all three AILSS oxygen generation system designs. This system comprises a solid electrolyte CO_2 reduction section and a steam desorbed resin CO_2 concentrator. A concept of the AILSS compact solid electrolyte unit is represented in figure 52.

Several alternatives are less satisfactory for the AILSS. Availability of competitive versions of the fused salt and Sabatier-acetylene dump processes is doubtful. The Bosch concept is a close competitor to solid electrolyte, but its equivalent weight is higher and some of its secondary characteristics are marginal. The Sabatier-methane cracking concept is heavier and less developed than the Bosch, and has no potential advantages. Further development of this conept is therefore not recommended. The Sabatier-methane dump concept is unsatisfactory for the AILSS because of high equivalent weight, but it is potentially attractive for certain other missions, to be discussed later in this section. Utilization of the methane byproduct for propellant or fuel would result in a very competitive AILSS concept if a net equivalent weight credit of about 1300 pounds resulted.

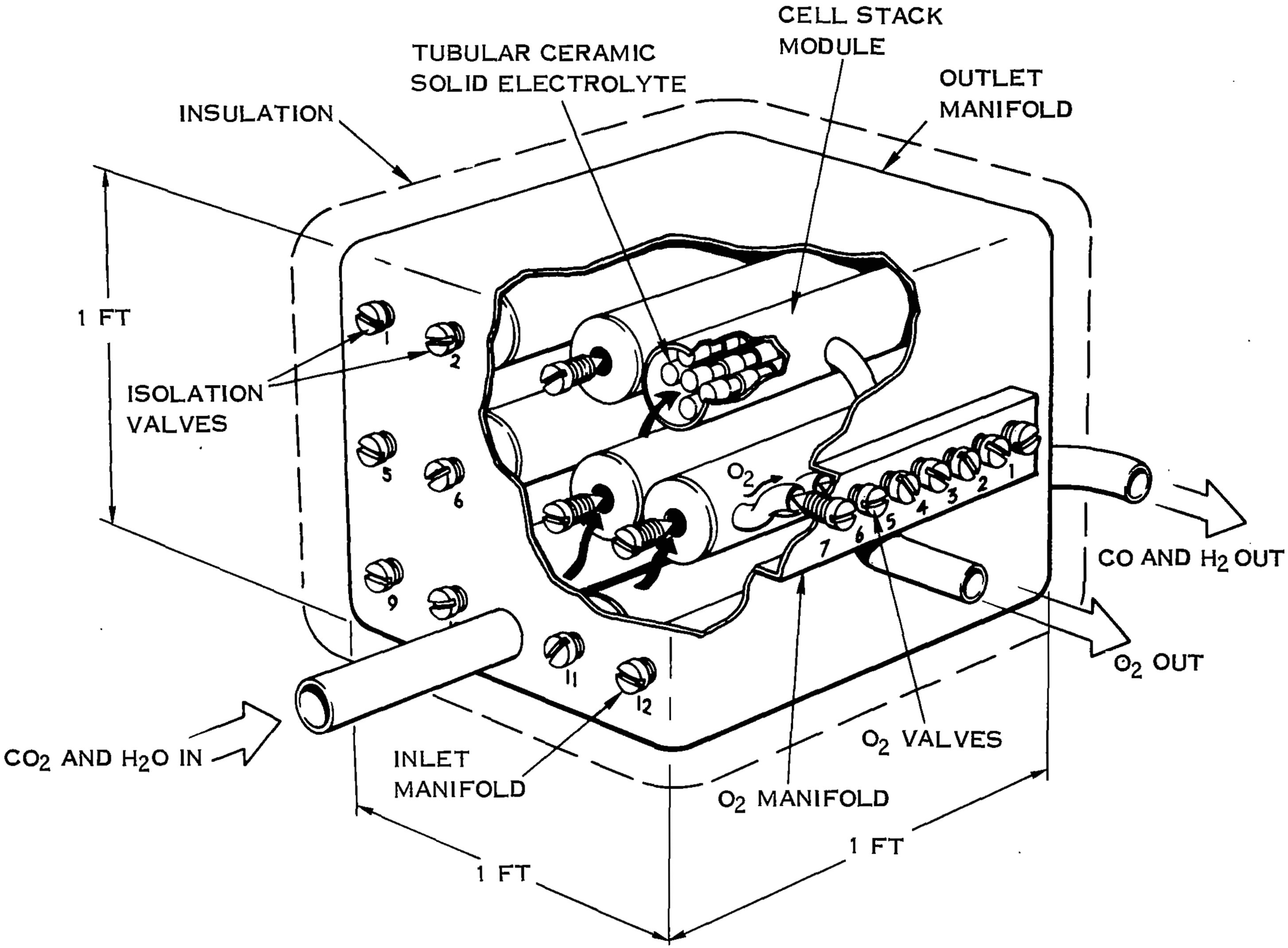


Figure 52. Solid Electrolyte Concept

IMPACT OF MISSION PARAMETERS

Mission Length

The effect of mission duration on equivalent weight is significant because all concepts use considerable expendables. Solid electrolyte continues to be selected for longer missions, although a membrane diffusion rather than steam desorbed resin CO_2 concentrator section may be best for missions exceeding five years. When mission length is reduced to about 200 days, however, equivalent weight of the Sabatier-methane dump concept becomes competitive. This concept would then be selected because of better absolute and secondary characteristics. Thus, for shorter missions the Sabatier-methane dump concept with gas circulation water electrolysis and steam desorbed resin CO_2 concentration is selected.

Crew Size

The effect on equivalent weight of varying crew size is much the same as that of varying mission duration. Thus, for small crews the high expendables rate of Sabatier-methane dump is a relatively small handicap, and its equivalent weight is competitive. For crews of up to three members, Sabatier-methane dump with gas circulation electrolysis and steam desorbed resin concentration is recommended. For larger crews, solid electrolyte with steam desorbed resin concentration should be chosen.

Power Penalty

Changing power penalty has little effect on equivalent weight relationships among the candidate concepts. The relative position of the Sabatier-methane cracking concept improves as power penalty is decreased, but not so much that its equivalent weight rating changes, even at 50 percent of the AILSS power penalty.

Thus, in accordance with previous discussions of the influence of power penalty on water electrolysis and CO_2 concentration selections, solid electrolyte reduction with steam desorbed resin concentration is recommended for power penalties approaching 50 percent of the AILSS value. There is no change for higher power penalties.

If power consumption were critical, the solid electrolyte concept would still be the probable choice. Sabatier with methane dump has less than 100 watts lower power consumption, whereas its total equivalent weight is more than 1400 pounds higher than that of the solid electrolyte concept.

Resupply

The AILSS mission lasts 500 days, without resupply. Periodic resupply would decrease initial launch weight of all carbon-forming concepts considerably, with approximately equal reductions in catalyst cartridges and spare equipment. For the Sabatier-methane dump concept, initial launch weight could be reduced still more with nearly double the impact. Thus, comparing Sabatier-methane dump with resupply with the carbon deposition concepts without resupply, the methane dump concept might be selected for a resupply period less than 400 days. If equal resupply period for all concepts is assumed, the Sabatier-methane dump concept might be selected for resupply periods less than 300 days. If selected, the Sabatier-methane dump concept would include a gas circulation water electrolysis section and a steam desorbed resin CO_2 concentration section.

Flight Date

System selection is very sensitive to flight date. The AILSS solid electrolyte concept will not be available for flights before 1979. For flights between 1977 and 1979, the Bosch concept with gas circulation water electrolysis and steam desorbed resin CO_2 concentration would be selected. For still earlier flights, the Sabatier-methane dump concept with wick feed electrolysis and molecular sieve concentration would be the choice.

For post-1980 missions, either the fused salt or the Sabatier-acetylene dump concept may be competitive with solid electrolyte.

ATMOSPHERIC CONTAMINATION CONTROL

CONTENTS

Page

ATMOSPHERIC CONTAMINATION CONTROL

The function of the atmospheric contamination control subsystem is to maintain the concentration of trace gases, biological micro-organisms, and wet and dry particulate matter in the cabin atmosphere at acceptable levels so that the health and comfort of the crew is safeguarded.

The atmospheric contamination control system consists of a trace gas control subsystem composed of a large sorbent bed, a catalytic oxidizer, and several small sorbent beds; a bacterial contamination control subsystem consisting of three high flow rate, $0.3\,\mu$ filters; and a particulate contamination control subsystem composed of several debris traps and roughing filters.

In this design there is an innovation in concept not readily apparent. The catalytic oxidizer rather than charcoal is the main trace gas contaminant control device. In this way the large expendable weight penalty associated with charcoal is avoided. Because the oxidizer catalyst does not take part in the reactions, it is not used up, and because the physical size of the unit is small, even the high temperature does not cause a high power drain. The large sorbent bed, located in parallel with the oxidizer, is for ammonia control.

A small sorbent bed placed before the oxidizer prevents ammonia oxidation to toxic products, but, except for ammonia, no other contaminants are kept out of the oxidizer. Contaminants that may poison the bed, such as H_2S and the halogenated hydrocarbons, are allowed to do so; for this reason, the beds are provided with an excess amount of catalyst. Complete oxidation of all contaminants is assured, because the oxidizer is maintained at 700°F, which is high enough to oxidize 100 percent of any contaminant including methane. Another small sorbent bed is placed downstream of the oxidizer. It contains lithium carbonate and is used to remove acid gases formed in the oxidizer.

TRACE GAS CONTROL SUBSYSTEM

In order to adequately design a trace gas contaminant control subsystem for the AILSS, it is necessary to define a model of the contaminant atmosphere. In this case, the model consists of three parts: a list of representative gaseous contaminants, generation rates, and tentative space maximum allowable concentrations. The model is shown in table 18.

The choice of contaminants in the model was made from those known to be biologically generated in significant amounts and from those that have been reported as present in four or more of the following test facilities:

1. NASA Langley Integrated Life Support System Chamber
2. Boeing MESA Chamber

TABLE 18

TRACE GAS CONTAMINATION MODEL

Contaminant	Production rate		Allowable Concentration		Principal toxic effect	Process rate	Equilibrium concentration
	Biological	Equipment	TLV	SMAC			
	lb/hr	lb/hr	ppm	ppm		lb/hr	ppm
Acetaldehyde, CH_3 CHO	8.24×10^{-8}		200	40	Irritant	3.4	0.0002
Acetone, CH_3 $COCH_3$	1.82×10^{-7}		1 000	200	Narcotic	3.4	0.0295
Ammonia, NH_3	2.36×10^{-4}		50	10	Irritant	53.5	7.75
Benzene, C_6H_6		1.44×10^{-5}	25	5	Narcotic - blood poison	3.4	1.63
n-Butanol, $C_4H_{10}O$	1.08×10^{-6}		100	20	Narcotic - irritant	3.4	0.0128
Butyric Acid, $C_4H_8O_2$	6.22×10^{-4}		39	8	Irritant	9000	0.298
Carbon Monoxide, CO	9.20×10^{-6}	1.08×10^{-5}	50	10	Blood poison	3.4	6.26
Cyclohexane, C_6H_{12}		1.30×10^{-6}	300	60	Narcotic	3.4	0.0136
Dichlorodifluoromethane, CCl_2F_2		3.60×10^{-5}*	1 000	200	Narcotic	3.4	2.62
Ethanol, C_2H_6O	3.31×10^{-6}		1 000	200	Narcotic - irritant	3.4	0.676
Hydrogen, H_2	7.27×10^{-6}	2.91×10^{-5}	30 000	30 000	Asphixiants	3.4	152.0000
Hydrogen sulfide, H_2S	4.15×10^{-9}		10	2	Irritant	3.4	0.0001
Methane, CH_4	1.17×10^{-4}	2.52×10^{-5}	53 000	53 000	Asphixiants	3.4	79.0000
Methanol, CH_3OH	1.25×10^{-6}	1.78×10^{-5}	200	40	Narcotic - irritant	3.4	5.42
Methylene chloride, CH_2Cl_2		3.60×10^{-5}	500	100	Narcotic	3.4	3.76
Pyruvic acid, $C_3H_4O_3$	1.73×10^{-4}		2.5	0.5	Irritant	9000	0.0331
Toluene, C_7H_8		1.20×10^{-5}	200	40	Narcotic - blood poison	3.4	1.159
Vinyl chloride, C_2H_3Cl		9.90×10^{-5}	500	100	Narcotic	3.4	13.800

* ASSUMED THE SAME AS FOR METHYLENE CHLORIDE.

3. Aerospace Medical Research Laboratory Evaluator
4. School of Aerospace Medicine Chamber
5. Sealab II

The list, as constructed, includes significant contaminants associated with specific AILSS equipment selections.

Although generation rates are considered constant in the model, such an assumption does not pretend to represent the physical situation. Problems of startup, peak loads, leaks, opening maintainable systems, equipment failure, and accidents may cause upsets in the rates at which some contaminants are generated. Where possible, these upsets have been estimated as closely as possible and used in the equipment sizing process, but it must be pointed out that the model is not intended to represent the actual atmosphere. It is, rather, a tool to permit the adequate sizing of equipment. In the actual system, there is no way to tell, short of actual manned testing, whether the subsystem will perform satisfactorily.

The tentative space maximum allowable concentrations were adjusted from threshold limit values published by the American Conference of Governmental Industrial Hygienists, except for butyric acid and pyruvic acid which were obtained from a Lockheed report (NASA CR-66346). The method of adjustment, from Stokinger, essentially reduces all but the combustible limits by a factor of five for a seven-psia operation. Despite this ability to calculate a space maximum allowable concentration, nothing is implied about the validity of the limits, particularly with mixtures of toxic gases. Too much is unknown in this field for such an interpretation, and the whole toxicological area remains a matter for conjecture.

It should be noted that the use of the model involves a certain method that deserves comment. With this method, contaminants of similar toxicological effect (e.g., irritants, narcotics, etc.) are grouped together and their toxicological effect is considered additive. Coupling this with a selection of the principal removal mechanisms (sorption, and oxidation) permits a determination of the required processing rates, assuming 100 percent removal. A safety factor of two was used to account for inefficient removal and for upsets.

The useful removal mechanisms for trace gas control include sorption and catalytic oxidation. In many applications, generation rates are often low enough so that spacecraft leakage plays a significant role as a control device. However, the AILSS specification does not permit this means to be used. Thus, attention is devoted to the consideration of sorption or catalytic oxidation. Within this framework, however, there are numerous possibilities involving specific materials and arrangements of equipment. Three have been selected for this tradeoff study: nonregenerative charcoal/catalytic oxidation, regenerative charcoal/catalytic oxidation, and catalytic oxidation/sorption. Schematically, there is little difference between these methods, but there are significant differences in weight and power requirements.

The basic differences are found in the intended functions of the equipment. In the first two methods, charcoal is the main contaminant removal element, with catalytic oxidation used for such relatively nonsorbable gases as hydrogen, methane, and carbon monoxide. In the third, catalytic oxidation is the main contaminant removal element, with various sorbents used for the removal of gases that prove troublesome, one way or another, in the oxidation process.

Regardless of the concepts employed, there are two contaminants that are flow-limited, i.e., require processing rates too high for practical consideration in the equipment suggested. These are butyric acid and pyruvic acid. They are both biologically produced and cannot be controlled at the source. For the purposes of this study, it is assumed that these will be removed from the atmosphere as a result of their infinite solubilities in water in the condensing heat exchanger where the gas processing rate is high enough to control them.

The candidate control methods are described below for the three power plant designs. Designs 1 and 3 are identical since high temperature heating requirements (600 to 700° F) must be provided by electrical heating. The Design 2 applications use isotope heat as required.

Nonregenerable Charcoal/Catalytic Oxidation

Absolute criteria. -

Performance: This concept employs a charcoal bed with replaceable cartridges and two installed redundant catalytic oxidizers. The charcoal bed is intended to remove most of the general contaminants and it is nonregenerable. The process rate through this unit is 50 cfm. For purposes of sizing, an activated coconut shell charcoal such as Barnebey-Cheney BD or GI is used. The catalytic oxidizer is intended to remove carbon monoxide, hydrogen, and methane. The process rate through this unit is 2 cfm. A catalyst such as 0.5 percent paladium on alumina operating at 700° F is recommended. The oxidizer is protected from catalyst poisons and from discharging toxic acid gases by a presorber and a post sorber. The post sorbent bed is designed to remove acid gases that form in the oxidizer and contains lithium carbonate. The pre-sorbent bed is designed to remove ammonia and, at least partially, gases that might poison the catalyst. It contains copper sulfated Sorbeads for ammonia control and unspecified materials for the other gases. It remains for future development work to assess the catalyst poisoning potential of the incoming gases and the materials needed to remove them.

In Designs 1 and 3 (see figure 53) where electrical power is used to heat the oxidizer, the heating element is installed in each oxidizer and it heats both the process flow and the catalyst bed directly. A regenerative heat exchanger is also included in the oxidizer. Normal temperature control is achieved by an on-off heater controller that responds to catalyst bed temperature. In the event a catalyst bed fails, the heater is simply shut off and the flow is diverted to the good oxidizer.

In Design 2, a single installed radioisotope heat source is used, but because it cannot be turned off at will, it is installed as a separate unit rather than in the catalyst bed. The regenerative heat exchanger is also a separate unit. The catalyst beds, then, are heated by the hot process gases flowing through them. Normal temperature control is achieved by bypassing part of the process flow around the regenerative heat exchanger and mixing the hot and cold streams before they enter the isotope heater. The bypass control valve responds to a bed temperature sensor-controller. In the event a catalyst bed fails, flow is simply diverted to the good bed.

During normal operation, a single oxidizer is used. But during upset conditions, both oxidizers may be used in parallel with the effect of nearly doubling the process flow. Because the normal design condition includes a safety factor of two on both process rate and catalyst bed size, it was not felt necessary to include a variable flow fan.

Safety: There are two safety hazards associated with this concept that deserve mention. The first and probably least critical is the combustibility of the charcoal. There is, in this concept, about 1600 pounds on board and, although its ignition temperature is relatively high, if it should ignite, the amount of heat and noxious gases produced would present a hazard to the crew.

A more important hazard posed by the charcoal is its ability to support bacterial growth, especially when loaded with adsorbed organic materials. In addition to posing a possible bacteria carryover problem, such contamination greatly increases the danger in handling the bed when it is removed from service. Neither of these problems is believed to be serious enough, however, to eliminate this system from consideration.

Availability/confidence: The Non-Regenerable Charcoal/Catalytic Oxidation concept can, with a strong effort, be developed for a flight as early as 1973 (1974 for Design 2). Charcoal adsorption is well established for some, but not all, important contaminants. Catalytic oxidizer development is in the prototype development stage.

A wide variety of charcoals is available that singly or in combination should prove suitable. More data is needed, however, to accurately size such materials for specific purposes. The suggested catalyst has undergone considerable testing to establish its suitability for removing CO_2, H_2 and CH_4, but little reliable data is available on the effects of poisoning. Although it was possible to recommend lithium carbonate as an effective oxidizer post sorbent, a considerable effort may be required to develop pre-sorbers that will effectively reduce catalyst poisoning. It is believed to be a tractable problem, however, within the time span indicated because of the limited number of contaminants involved.

SUBSYSTEM: Atmospheric Contamination Control - Trace Contaminants

CONCEPT: Nonregenerable Charcoal/Catalytic Oxidation

FLIGHT AVAILABILITY: 1973 for Designs 1 and 3, 1974 for Design 2
(1970 go-ahead)

RELIABILITY: 0.999930

MTBF: 78 100 hr (Designs 1 & 3)
169 000 hr (Design 2)

Spares/Redundant (R) Units:

2-Fan
1-Charcoal Canister
1-Presorb Canister
1-Catalytic Oxidizer
1-Heater Control
1-Post-sorb Canister

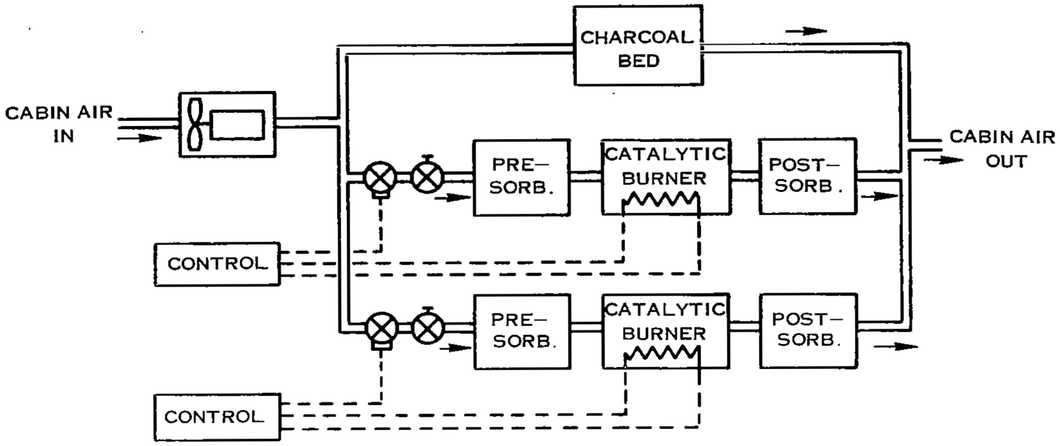
CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	17.5	0.3

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	81	93	81
Expendables	1875	1875	1875
Spares/Redundant Units	96	96	96
Electrical Power	74	42	74
Thermal Power	0	3	0
Radiator Load	23	23	23
Total Equivalent Weight	2149	2132	2149
POWER (Watts):			
Electrical	165	92	165
Thermal	0	73	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	66	4	70

Figure 53. (Page 1 of 2)

Designs 1 and 3



Design 2

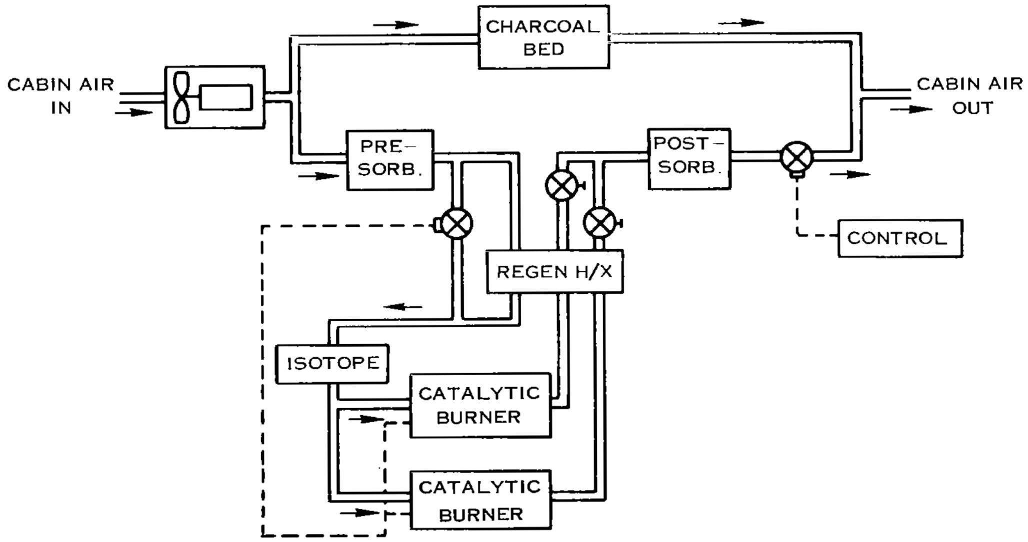


Figure 53. Nonregenerable Charcoal/Catalytic Oxidation (Page 2 of 2).

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 78 100 hours for Designs 1 and 3, and 169 000 hours for Design 2. The lower MTBF for the electrical heater results from the required temperature controller. The calculated reliability is 0.999930.

Crew time: The only scheduled maintenance in this subsystem is the replacement of the charcoal filter. This operation must be performed 25 times during the mission, and it is estimated to require 0.7 hours per replacement for a total scheduled maintenance time of 17.5 hours.

Unscheduled maintenance might involve replacement of the fan, catalyst bed, pre- or post sorbent beds, or controller. No special stress is associated with any of these operations. It is estimated that unscheduled maintenance will require 0.3 hours per mission.

Equivalent Weight: The equivalent weights for the three power supplies are shown on the concept data sheet, figure 53. The high weight of this system is caused by the large quantity of expendable charcoal involved, 1580 pounds.

Secondary criteria. - As explained earlier, there is a potential bacterial contamination problem associated with this equipment. Interfaces with other systems are minimal. The flexibility of this system is rather poor because of the close relationship between contaminant generation rate, process rate, and sorbent or catalyst quantities. Severe contamination upsets can be met only by altering the operating parameters. The overall growth is not good because of the high weight of the expendables used in the main sorbent beds. However, the oxidizer does have good growth characteristics from the standpoint of mission length, but not from crew size. Noise levels are low. Volume is greater than for the other systems considered because of the expendable storage required. Finally, power is low and essentially without peaks.

Regenerable Charcoal/Catalytic Oxidation

Absolute criteria. -

Performance: This concept is quite similar to the preceding concept, except for the regeneration feature of the charcoal. Here, two charcoal beds are used: one on-line adsorbing while the other is being desorbed to space at a temperature of 580°F. The process rate for this unit is 50 cfm. For purposes of sizing, an activated coconut shell charcoal such as Barnebey-Cheney BD or GI is used. The catalytic oxidizer is intended to remove only methane, carbon monoxide, and hydrogen. The process rate for this unit is 2 cfm. A catalyst such as 0.5 percent paladium on alumina operating at 700°F is recommended. The oxidizer is protected from catalyst poisons and from discharging toxic gases by a presorber and a post sorber. The post sorbent is lithium carbonate. The pre-sorbent bed contains copper sulfated Sorbeads to remove ammonia and an unspecified material to remove gases that might poison the catalyst. It remains for future development work to assess the catalyst poisoning potential of the incoming gases and the materials needed to remove them.

In Designs 1 and 3 (see figure 54) , electrical power is used to heat both the charcoal beds and the oxidizer. The charcoal beds operate on a 10 day adsorb-10 day desorb cycle, and the heating elements are installed directly in the beds. The heating elements for the oxidizers are also installed directly in the beds and are used to heat both the process flow and the beds directly. A regenerative heat exchanger is also included in the oxidizers. In both the charcoal beds and the oxidizers, normal temperature control is achieved by an on-off heater controller that responds to bed temperature. In the event a catalyst bed fails, the heater in that unit is simply shut off and the flow is diverted to the good oxidizer.

In Design 2, a single separately installed radioisotope heat source is used to heat both the charcoal beds and the oxidizer. In this case, two separate parallel gas streams flow through the isotope heater: one goes to the charcoal bed and passes through tubes embedded in it to supply heat during the desorb cycle, the other is the process flow that goes to the oxidizer. Temperature control in the charcoal bed is achieved by regulating the hot gas flow in response to a temperature sensor in the bed. A bed bypass loop is provided to permit this regulation. In the oxidizer bed, normal temperature control is achieved by bypassing part of the process flow around the separately installed regenerative heat exchanger and mixing the resulting hot and cold streams before they enter the isotope heater. The bypass control valve responds to a bed temperature sensor-controller. In the event of a catalyst bed failure, the flow is simply diverted to the good bed.

During normal operation a single oxidizer is used, but during upset conditions both oxidizers may be used in parallel with the effect of nearly doubling the flow. Because the normal design condition includes a safety factor of two for both the process rate and the sorbent and catalyst bed sizes, it is not deemed necessary to include a variable flow fan.

Safety: There are two slight safety hazards associated with this concept. The first is the combustibility of the charcoal and the second is the ability of the charcoal to support bacterial growth. Neither of these is viewed as particularly serious for this design; the quantity of charcoal is small and it does not require handling under normal operation. Periodic desorption to space at 580°F should destroy most of the bacteria.

Availability/confidence: The Regenerable Charcoal/Catalytic Oxidation concept can, with a strong effort, be developed for a flight as early as 1979 (1980 for Design 2). Catalytic oxidizer development is in the prototype development phase and regenerable charcoal is in the early research phase.

Charcoal regeneration by heated vacuum desorption requires considerably more development work to bring the process to a satisfactory level for a reliable design. The suggested catalyst has undergone considerable testing to establish its suitability for removing CO, H_2 and CH_4, but little reliable data is available on the effect of poisoning. Although it was possible to recommend lithium carbonate as an effective oxidizer post sorbent, a considerable effort may be required to develop pre-sorbers that will effectively reduce catalyst poisoning, but it is believed to be a tractable problem within the time space indicated because of the limited number of contaminants involved.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 47 600 hours for Designs 1 and 3, and 96 500 hours for Design 2. The lower MTBF for Designs 1 and 3 results from the several electrical heater controllers. The calculated reliability is 0.999890.

Crew time: Scheduled maintenance for this concept involves manually changing the charcoal beds from the adsorb to the desorb mode. This operation must be performed 50 times during the mission, and it is estimated to require 0.25 hours for a total of 12.5 hours.

Unscheduled maintenance might involve replacement of the fan, catalyst bed, pre- or post sorbent beds, or controller. No special stress is associated with any of the operations. It is estimated that unscheduled maintenance will require 0.3 hours per mission.

Equivalent weight: The equivalent weights for the three power supplies are shown on the concept data sheet, figure 54. The relatively low weight of this system results from the low quantity of charcoal required, 128 pounds.

Secondary criteria. - There is no serious contamination problem associated with this equipment and interfaces with other systems are minimal. A limited amount of flexibility is achieved by the parallel mode of catalytic oxidizer operation, but the close relationship between contaminant generation rate, processing rate, and sorbent or catalyst quantities does not permit a wide latitude in this area. Overall growth is considered quite good from the standpoint of mission length but not from crew size. Noise levels are low, and volume is quite low. Power is high except for Design 2 where it is equivalent to the other concepts.

Catalytic Oxidation/Sorption

Absolute criteria. -

Performance: Schematically (see figure 55), this concept appears to be similar to nonregenerable charcoal/catalytic oxidation, but there are significant differences.

Here, the catalytic oxidizer is the main contaminant removal device, with various sorbents employed to remove specific contaminants that cannot be satisfactorily removed in the oxidizer. The catalyst recommended is 20 percent paladium on alumina operating at 700°F. The process rate through the catalyst bed is 3 cfm. The catalyst beds, which may be operated singly or in parallel, are oversized to allow for catalyst poisoning. No particular effort is made to prevent catalyst poisoning.

The main sorbent bed, which processes 50 cfm of cabin air, and the catalytic oxidizer presorber are included to remove ammonia only. For this purpose, copper sulfated Sorbeads are recommended because of their relatively good ammonia sorption capabilities, because bed exhaustion is indicated by a color change, and because they do not support microbiological growth.

The catalytic oxidizer post sorbent is intended for the removal of acid gases that result from the partial oxidation of halogenated hydrocarbons. For this purpose, a bed of lithium carbonate is recommended because of the relatively good sorption characteristics of this material with the acid gases anticipated.

In Designs 1 and 3, electrical power is used to heat the oxidizer. A heating element is installed in each oxidizer and heats both the process flow and the catalyst bed directly. A regenerable heat exchanger is also included in the oxidizer. Normal temperature control is achieved by an on-off heater controller that responds to catalyst bed temperature. In the event a catalyst bed fails, the heater is simply shut off and the flow is diverted to the redundant oxidizer.

In Design 2, a single installed isotope heat source is used, but because it cannot be turned off at will, it is installed as a separate unit rather than in the catalyst bed. The beds, then, are heated by the hot process gases flowing through them. Normal temperature control is achieved by bypassing part of the process flow around the separately installed regenerative heat exchanger and mixing the hot and cold streams before they enter the isotope heater. The bypass control valve responds to a bed temperature sensor-controller. In the event a catalyst bed fails, the flow is simply diverted to the good bed.

During normal operation, a single oxidizer is used, but during upset conditions, both oxidizers may be used in parallel with the effect of nearly doubling the process flow. Because the initial design includes a safety factor of two for both process rate and catalyst bed size, it is not necessary to include a variable flow fan.

Safety: This system has no significant safety hazards. Unlike charcoal, copper-sulfated Sorbeads are not combustible nor do they support bacterial growth.

Availability/confidence: The Catalytic Oxidation/Sorption concept can, with a strong effort, be developed for a flight as early as 1973 (1975 for Design 2). Catalytic oxidizer development is in the prototype development phase while sorbent development ranges from the late prototype stage for some contaminants to the early research stage for others.

SUBSYSTEM: Atmospheric Contamination Control - Trace Contaminants

CONCEPT: Regenerable Charcoal/Catalytic Oxidation

FLIGHT AVAILABILITY: 1979 for Design 1 & 3, 1980 for Design 2
(1970 go-ahead)

RELIABILITY: 0.999890

MTBF: 47 600 hr (Designs 1 & 3)
96 500 hr (Design 1)

Spares/Redundant (R) Units:

- 2 - Fan
- 1 - Charcoal Cartridge
- 1 - Catalytic Oxidizer
- 1 - Heater Control
- 2 - Valve, Manual, 4-way
- 2 - Heater Control
- 1 - Presorb Canister
- 1 - Post-sorb Canister

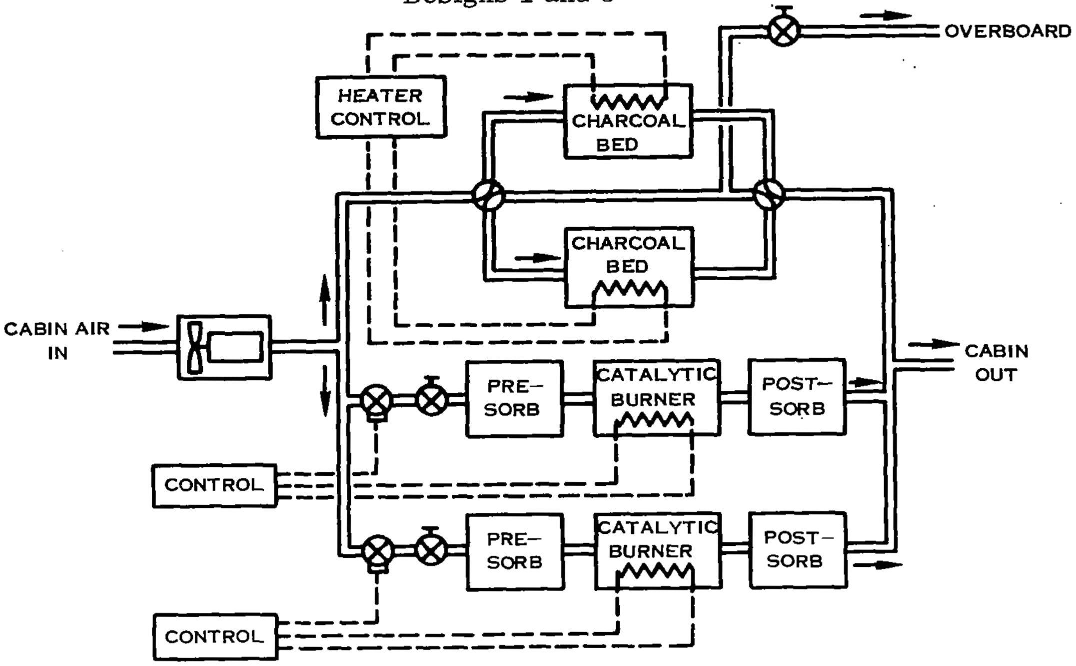
CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	13	0.5

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	179	219	179
Expendables	21	21	21
Spares/Redundant Units	76	72	76
Electrical Power	242	43	242
Thermal Power	0	22	0
Radiator Load	73	73	73
Total Equivalent Weight	591	450	591
POWER (Watts):			
Electrical	538	95	538
Thermal	0	443	0

VOLUME (ft^3):	Installed	Spares	Total
	8.0	4.0	12.0

Figure 54 (Page 1 of 2)

Designs 1 and 3



Design 2

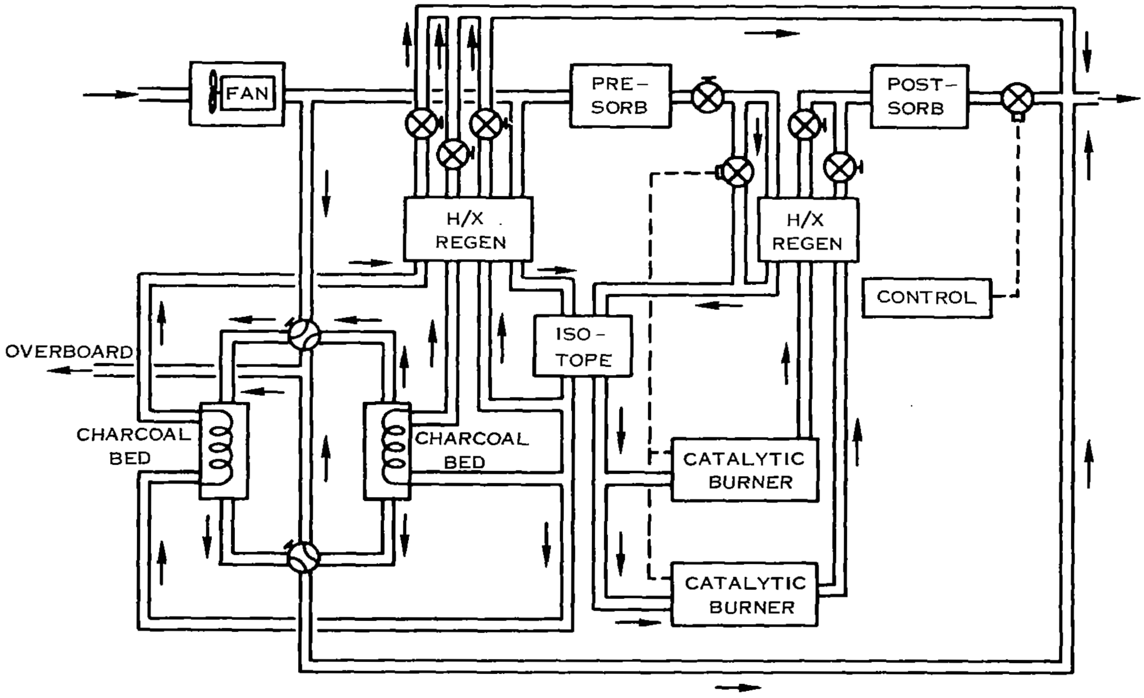


Figure 54. Regenerable Charcoal/Catalytic Oxidation (Page 2 of 2).

SUBSYSTEM: Atmospheric Contamination Control - Trace Contaminants

CONCEPT: Catalytic Oxidation/Sorption

FLIGHT AVAILABILITY: 1973 for Designs 1 & 3, 1975 for Design 2.
(1970 go-ahead)

RELIABILITY: 0.999930

MTBF: 78 000 hr (Designs 1 & 3)
169 000 hr (Design 2)

Spares/Redundant (R) Units:
- 2-Fan
- 1-Sorbent Canister
- 1-Catalytic Oxidizer
- 1-Presorb Canister
- 1-Post-sorb Canister
- 1-Heater Control

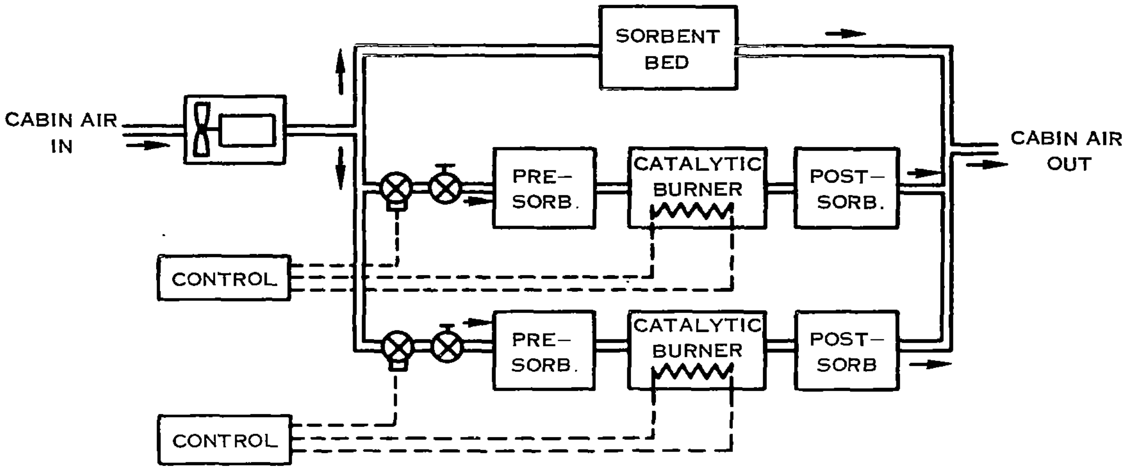
CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	0.7	0.3

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	125	142	125
Expendables	150	150	150
Spares/Redundant Units	109	109	109
Electrical Power	95	41	95
Thermal Power	0	6	0
Radiator Load	30	30	30
Total Equivalent Weight	509	478	509
POWER (Watts):			
Electrical	211	91	211
Thermal	0	120	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	9	4	13

Figure 55. (Page 1 of 2)

Designs 1 and 3



Design 2

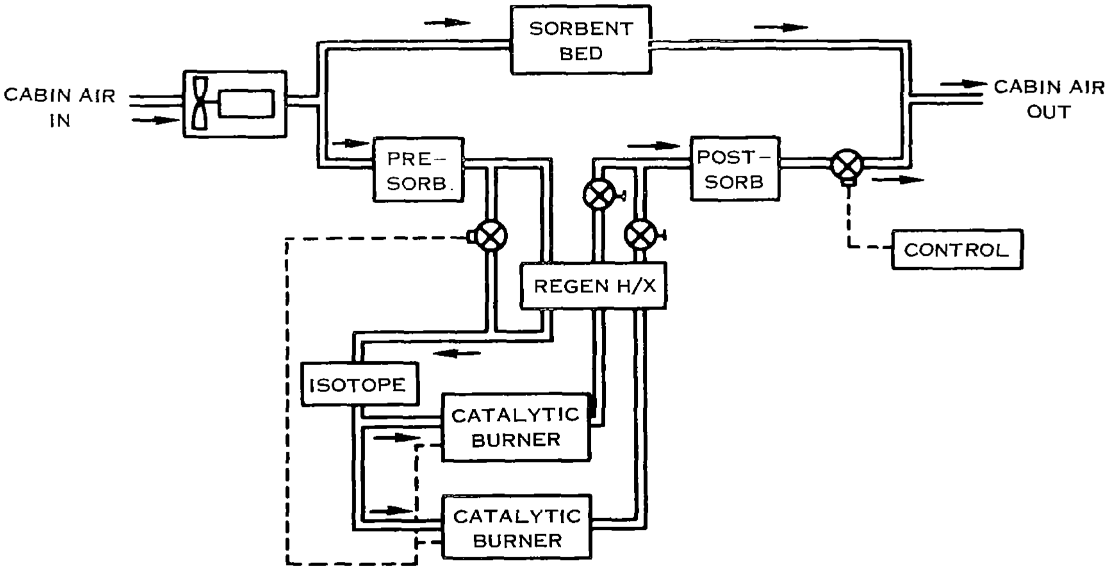


Figure 55. Catalytic Oxidation/Sorption (Page 2 of 2).

The recommended catalyst has undergone considerable testing to establish its suitability for removing CO, H_2 and CH_4, and for resisting poisoning, but more operating data is required. Sorbent performance is well established for some contaminants, but is lacking for others. More development is therefore required, and the level of effort appears reasonable considering the time involved.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 78 000 hours for Designs 1 and 3, and 169 000 hours for Design 2. The lower MTBF for Designs 1 and 3 results from the electrical heater controller. The calculated reliability is 0.999930.

Crew time: The only scheduled maintenance in this subsystem is the replacement of the main sorbent filter. This operation is performed once during the mission and involves replacement of the entire unit. This procedure is estimated to require a total of 0.7 hours.

Unscheduled maintenance might involve replacement of the fan, catalyst bed, pre- or post sorbent, or controller. No special stress is associated with any of these operations. It is estimated that unscheduled maintenance will require 0.3 hours per mission.

Equivalent weight: The equivalent weights for the three power supplies are shown on the data sheet, figure 55.

Secondary criteria. - There is no serious contamination problem associated with this concept and interfaces with other systems are minimal. A limited amount of flexibility is achieved by the parallel mode of catalytic oxidizer operation, but the close relationship between contaminant generation rate, processing rate, and sorbent or catalyst quantities does not permit a wide latitude in this area. Growth is limited, too, because the main sorbent is not regenerable, but the catalytic oxidizer does have good growth characteristics from the standpoint of mission length but not from crew size. Noise levels are low. Volume and power also are low.

Evaluation and Selection: Design 1

Evaluation ratings for Design 1, as well as the other designs, are shown in table 19, and pertinent data are summarized in table 20.

Absolute criteria. - Each trace gas control candidate concept is believed capable of performing the control function adequately; therefore, all are rated Good (see table 19).

Because of the fire hazard and the bacterial growth possibility in the large quantity of charcoal required in the nonregenerable charcoal/catalytic oxidation concept, and because of the need to change the beds, the safety rating is only Fair. Both of these

TABLE 19
EVALUATION SUMMARY - TRACE GAS CONTROL

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts								
		Nonregenerable charcoal/catalytic oxidation			Regenerable charcoal/catalytic oxidation			Catalytic oxidation/sorption		
CRITERIA	DESIGN	1	2	3	1	2	3	1	2	3
Absolute	Performance	Good			Good			Good		
	Safety	Fair			Good			Very good		
	Avail./Conf.	Good			Good			Good		
Primary	Reliability	Very good			Very good			Very good		
	Crew Time	Fair			Good			Very good		
	Equivalent Weight	Poor	Poor	Poor	Good	Very good	Good	Very good	Very good	Very good
		Eliminated								
Secondary	Contamination				Good			Good		
	Interfaces				Fair			Good		
	Flexibility				Good			Fair		
	Growth				Good			Fair		
	Noise				Good			Good		
	Volume				Good			Good		
	Power				Fair			Good		
					Eliminated			Selected		

TABLE 20

DATA SUMMARY-TRACE GAS CONTROL

Concept	Design	MTBF, hrs	Crew Time, hrs		Total Equivalent Weight, lb	Power, watts		Volume, ft^3
			Scheduled	Unscheduled		Electrical	Thermal	
Non Regenerable Charcoal/ Catalytic Oxidation	1	78 100	17.5	0.3	2149	165	0	70
	2	169 000			2132	92	73	
	3	78 100			2149	165	0	
Regenerable Charcoal/ Catalytic Oxidation	1	47 600	13	0.5	591	538	0	12
	2	96 500			450	95	443	
	3	47 600			591	538	0	
Catalytic Oxidation/ Sorption	1	78 000	0.7	0.3	509	211	0	13
	2	169 000			478	91	120	
	3	78 000			509	211	0	

problems exist to a lesser degree in the regenerable charcoal/catalytic oxidation concept, so it is rated Good. The remaining concept has neither of these difficulties, so it is rated Very Good.

All concepts are rated Good under availability. All need considerable development work to insure adequate performance, but the effort for each appears about equal and well within the capability of present technology.

On the basis of the absolute criteria, then, all concepts are acceptable and nearly equivalent. Safety considerations give the top rating to the catalytic oxidation/sorbent concept and the bottom rating to the nonregenerable charcoal/catalytic oxidation concept.

Primary criteria. - All MTBF's are greatly in excess of the mission length, and so all concepts are rated Very Good under reliability.

The unscheduled maintenance for all systems is equal, and the biggest difference lies in scheduled maintanance. On this basis, nonregenerable charcoal/catalytic oxidation is rated Fair at 17.5 hours, regenerable charcoal/catalytic oxidation is rated Good at 12.5 hours, and catalytic oxidation/sorption is rated Very Good at 0.7 hours.

The equivalent weight of the nonregenerable charcoal/catalytic oxidation concept is higher by a factor of 4 or 5 than the other systems; it is rated Poor. The regenerable charcoal/catalytic oxidation concept is rated Good while the catalytic oxidation/sorption concept is rated Very Good.

Selection. - After undergoing primary criteria ratings, nonregenerable charcoal/catalytic oxidation appears distinctly poorer than the other two systems. It is rejected from further considerations.

The other two concepts are rather close in the ratings but catalytic oxidation/sorption holds a significant advantage in crew time. This, coupled with a slight but definite weight advantage, led to its selection for Design 1.

The secondary criteria ratings for the two top concepts reveal no factors that might upset this selection.

Evaluation and Selection: Design 2

Absolute criteria: - The evaluation of all the absolute criteria and the ratings of each concept for this design are the same as for Design 1.

Primary criteria: - The evaluation of reliability and crew time and their ratings for each concept for this design are the same as for Design 1.

The equivalent weight of the nonregenerable charcoal/catalytic oxidation concept is again higher than the other concepts by a factor of five and again receives a rating of Poor. Both the regenerable charcoal/catalytic oxidation concept and the catalytic oxidation/sorption concept are quite close in total equivalent weight and are both rated Very Good.

Selection. - As before, nonregenerable charcoal/catalytic oxidation can be rejected on the basis of its poor equivalent weight. The two remaining concepts, however, are quite close, but based on better ratings under safety and crew time, catalytic oxidation/sorption is selected over regenerable charcoal/catalytic oxidation.

The secondary criteria ratings for the two top concepts reveal no factors that might upset this selection.

Evaluation and Selection: Design 3

The evaluation of all criteria, the ratings of each concept, and the selection are the same as for Design 1.

Summary

In summary, the trace gas control subsystem concept selected is catalytic oxidation/sorption for all three designs.

This selection must be tempered, however, with the realization that the regenerable charcoal/catalytic oxidation concept was a close contender and that significant improvements in that method could tip the scale in its favor. It is therefore, recommended that work on that concept be continued.

It should also be apparent from the foregoing discussion that the entire area of trace contaminant control suffers from a lack of sufficient experimental data. For that reason, it cannot be overemphasized that this, or any other, design cannot be accepted as satisfactory without manned tests. In addition, it is recommended that extensive test work be undertaken or continued to further define the following areas:

1. Spacecraft materials and equipment off-gassing characteristics.
2. Space maximum allowable concentrations of contaminants
3. Synergistic effects of contaminants
4. Interaction of control mechanisms
5. Base performance of control mechanisms
    a. charcoal sorption and desorption characteristics
    b. catalyst performance and poisoning characteristics
    c. other sorbents for control of problem contaminants such as hydrogen sulfide, ammonia, nitrogen dioxide, sulfur dioxide and, possibly, pyruvic and butyric acid.

BACTERIAL CONTAMINATION CONTROL SUBSYSTEM

Airborne bacterial control is a major consideration for the EC/LS system. Although the initial atmospheric contamination by microbes will be relatively low because of all the precautions against contamination taken in the pre-flight routine, natural microbiological flora (bacteria, fungi, etc.) is found on the skin, in the oral and nasal cavities and in the intestinal tract of all men, and the crew will be no exception. Unless some means of active control is employed, contamination of the spacecraft is inevitable.

The microbial shedding rate from an individual lies in a range from 1800 to 62 000 organisms per minute. In a closed environment the skin loses its bacteriostatic function, and cleansing procedures are reductive only. Therefore, shed bacteria will increase in number, and a change in bacterial types will be noted. Most of these bacteria will be trapped by the clothing; nevertheless, appreciable numbers will be released to the cabin atmosphere. It is estimated that an astronaut shedding in the order of 3000 bacteria/minute to the atmosphere will produce 4.3 million/day, and a crew of nine 38.7 million/day.

The microbiological problem is not simply numbers, but disease production, cross infection, contamination of systems (water reclamation) and stored materials, and deterioration of equipment functionality. It is obvious that the atmosphere control subsystem must effectively control, reduce, or eliminate microorganisms to provide a safe habitable atmosphere. An atmospheric control subsystem should effect a 95 percent reduction, or better, assuming a microbiological population in the thousands per cubic foot. Recommendations of 20 to 100 microbes/cubic foot have been advanced as a maximum level.

Methods to reduce bacterial numbers include filtration, electrostatic precipitation, impingement, air centrifuge, and electrophoresis. At this time, filtration is judged to be the only acceptable approach, because it provides for safe and absolute control and permits a flexible and easily maintained installation.

Based on the above considerations, the production rate was taken as 3000 bacteria per man per minute and the maximum allowable concentration as 20 bacteria per cubic foot. A minimum process rate of 1420 cfm at 95 percent removal efficiency is necessary to meet this requirement.

The AILSS design requires replaceable (estimated life of 50 days) 95-percent efficient filters rated at 0.3μ. The filters are installed on the inlet of three bacteria control fans; two in the crew compartment and one in the equipment compartment. Each fan is designed to pass 750 cfm for a total of 2250 cfm passing through the bacterial filter. For convenience in handling, four small filter elements are used with each fan. The bacterial filters are protected by a 50 μ particulate filter and a hydrophobic-hydrophilic debris trap. This arrangement is depicted in figure 56.

The problem of the disposition of the exhausted filters cannot be overlooked. The filters will contain live bacteria and an abundance of organic matter. Handling the filters during removal and storage should not pose any particular problems because the time in contact with them would be short. Some bacteria would undoubtedly be dislodged during this handling but the number should not be significant and should pose no undue hazard to the crew.

The real problem is during the long term storage of the filters because the entrapped bacteria grow and become a potential health hazard. Three possible methods of storing the filters appear to be feasible:

1. Direct storage in sealed plastic bags

2. Heat sterilization followed by storing in sealed plastic bags

3. Continuous exposure to β -radiation during use and storage - no plastic bags required.

Each of these methods is discussed below. A fourth method, that of disposing of the spent filters in the waste collectors, was rejected because the filters are generally made of fiberglass which will not readily decompose in the vacuum decomposition process selected for waste management.

Direct Bagged Storage

In this method, the loaded filters are removed from the duct, placed directly in plastic bags, and stored in a locker. Each bag is fitted with a bacterial filter and is allowed to breathe through the filter. Thus, the pressure inside and outside the bag is always equal without the danger of the bacteria within the bag getting out. Storing the bagged filters in a locker would prevent accidental tearing of the bags. However, since the bacteria within the bags would still be alive, odor might be produced, growth could continue, and a potential hazard would exist if the bags were inadvertently ruptured.

No power is associated with this method of storage, and the bags provided the only weight penalty. For 120 filters, this penalty is estimated to be 24 pounds. It is assumed that a storage locker would be included in any case.

Heat Sterilized/Bagged Storage

This method is much like the preceding one except that the filters are enclosed in the bags and sterilized by heating to 350°F and holding at that temperature for one hour.

After cooling, the bagged filters are stored. Since all living matter is killed during sterilization, no growth occurs during storage.

The additional penalty for this concept is provided by the sterilization oven. The total equivalent weight breakdown is shown below.

Item	Weight penalty (lb) for designs 1, 2, and 3
Basic unit (oven and bags)	64
Spare heaters and controller	10
Electrical power	15
Thermal power	0
Radiator penalty	5
Total	94

Continuous β -radiation

This method provides continuous bacteriological control prior to and during use, as well as in storage. It employs a radioactive material such as strontium-90 which emits only β -radiation. This material is adsorbed in a thin layer on thin sheets, rods, or pellets and imbedded in the filter. With proper design, the effective bacteria kills could be 100 percent.

The advantage of this technique is that it maintains the filter in a state of continuous sterility at an insignificant weight penalty. The disadvantage, of course, is that each filter presents a source of radiation that, without proper design and handling techniques, could be hazardous to the crew. It is believed that additional shielding would be required over that provided by the filter supporting structure, especially over the face of the filter during handling (β -particles with 0.54 mev energy could travel about one foot in the AILSS cabin gas). It is estimated that the shielding and storage weight is about 120 pounds.

Filter Storage Method Selection

In view of the preceding discussion, it is recommended that the AILSS employ the heat sterilized bagged method of filter storage. It is effective in preventing bacteria contamination without posing a potential radiation hazard.

The total equivalent weight for bacterial contamination control using heat sterilized/ bagged storage is shown in the following table:

Item	Weight (lb) for designs 1, 2, and 3
Filters (120 filters @ 5 lb each)	600
Storage bags and processing	94
Electrical power penalty (Fans)	253
Radiator penalty	75
Total equivalent weight	1022

PARTICULATE CONTAMINATION CONTROL SUBSYSTEM

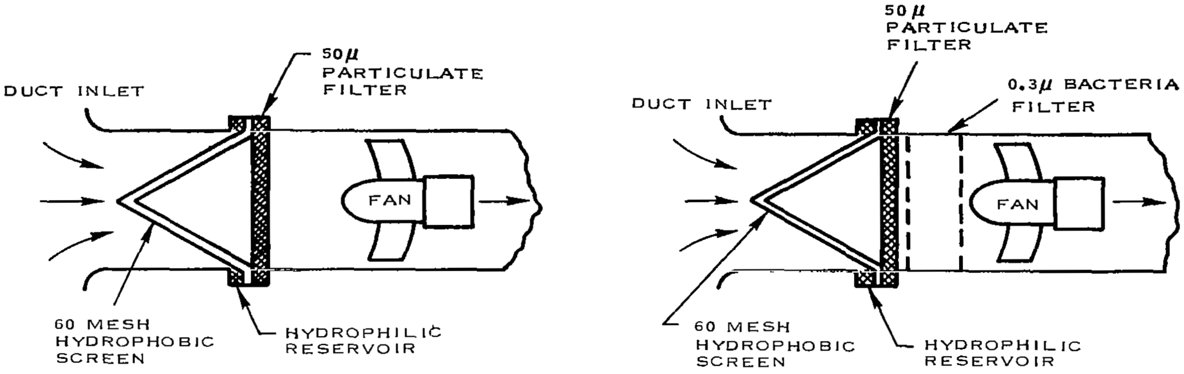
The particulate contaminants include aerosols and wet and dry debris. These must be controlled in the cabin and prevented from entering any of the fans that process cabin air. All such fans carry at least a debris trap to stop wet and dry particulate matter. The fans of interest (because of high flow rates) together with the type of particulate filters provided are described below and in figure 56.

Item	Number	Particulate control
Bacterial fans	3	Roughing filter and debris trap
Temp-humidity control fans	3	Roughing filter and debris trap
Ventilating fans	2	Debris trap

The debris trap consists of a Teflon coated 60-mesh, conical screen across the duct inlet with its perimeter imbeded in a reservoir filled with a removable hydrophilic material such as Refrasil. Vomitus or other wet debris cannot pass through the screen because of its hydrophobic surface. This material slides along the upstream side of the screen and eventually reaches the reservoir where it is retained. This same screen also prevents large solid debris from passing through. The particulate filter is a common medium-high efficiency 50 μ roughing filter.

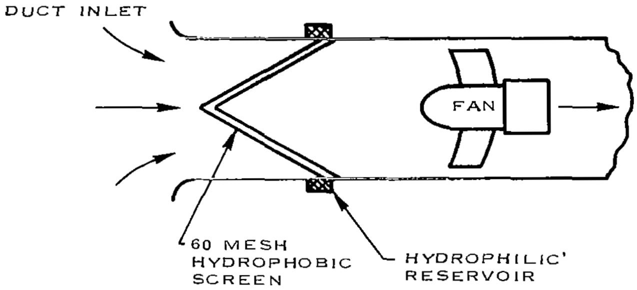
The equivalent weight summary for particulate contamination control is shown in the following table:

Item	Weight penalty (lb) for designs 1, 2, and 3
Basic units	70
Electrical power	198
Thermal power	0
Radiator penalty	60
Total	328



TYPICAL INSTALLATION FOR TEMP-HUMIDITY CONTROL FAN

TYPICAL INSTALLATION FOR BACTERIAL CONTROL FAN



TYPICAL INSTALLATION FOR VENTILATING FAN

Figure 56. Typical Fan Installation

SELECTED SYSTEM

The atmospheric contaminants are controlled in the AILSS in a number of different ways. Trace gas control is achieved by a combination of catalytic oxidation and sorption. Bacteria and particulates are both controlled by mechanical filtration. Used filters are to be bagged, sterilized, and stored.

The total equivalent weight summary of the various components of the atmospheric contamination control subsystem is shown below:

	Weight penalty (lb)		
Item	Design 1	Design 2	Design 3
Trace gas control	509	478	509
Bacterial contamination	1022	1022	1022
Particulate contamination	328	328	328
Total	1859	1828	1859

INSTRUMENTATION

Instrumentation of the atmospheric control subsystem is provided to accomplish two functions: to monitor the peformance of the equipment and to monitor the general toxicological condition of the cabin. The following functions are provided to monitor equipment performance:

1. Monitor flow through all components individually
2. Monitor pressure drop across each component
3. Monitor and control catalytic oxidizer bed temperature
4. Monitor catalytic oxidizer heater current and voltage
5. Monitor chemical performance of oxidizer and sorbents

In the event of an upset in cabin conditions, sufficient to introduce enough combustibles to cause exothermic overheating of the catalyst bed, the system is designed to shut down the process flow to the unit. This would represent a most serious condition on board the spacecraft should it occur. The likelihood, however, is virtually nonexistant. It would require about a 50-fold increase in the generation of methane, or a 100-fold increase in the generation of hydrogen, or a nearly 2000-fold increase in the carbon monoxide generation rate. On this basis, it is believed that no additional provisions need to be made for this unlikely situation.

The monitoring of equipment performance is arranged to isolate equipment failures as a function separate from the monitoring of general toxicological levels. The sorption beds are instrumented with a gas chromatograph having sensing taps located at the inlets and outlets of the beds. Performance is assessed by comparing the inlet (cabin) and outlet ammonia concentration. Normally, the cabin ammonia concentration is about 7 ppm. If the bed is operating satisfactorily, the outlet concentration should read zero. With the selected chromatograph, discussed in the Instrumentation and Control section of this report, no reading for ammonia is obtained until the concentration reaches about 0.1 ppm. The bed should be changed at the first sign of breakthrough.

Performance of the catalytic burner is measured by injecting a test contaminant into the bed and monitoring the outlet for signs of breakthrough. In this case, methane is the selected contaminant, because it is the most difficult hydrocarbon to remove and it is basically nontoxic. The procedure is to inject a pressure-regulated fixed volume of methane into the bed from a high pressure bottle. Because the flow rate through the bed is known, an upstream concentration measurement is unnecessary. The bed outlet concentration is measured before and after injection with a simple combustible gas meter. An increase in reading indicates a failure of the oxidizer. The reason for selecting this type of performance measurement technique is that it gives a positive measure of the catalyst performance that is within the accuracy of available instrumentation.

Monitoring the general toxicological level in the cabin is accomplished at the sorbent bed inlet with gas chromatograph capable of detecting and identifying a wide variety of gaseous contaminants. In addition to enhancing the system's ability to provide for the health and well-being of the crew, such a measuring capability assists in the recognition of unusual or unanticipated equipment failures. It should be pointed out, however, that this instrumentation is not intended primarily for fault isolation.

IMPACT OF MISSION PARAMETERS

Because the bacterial contamination and particulate contamination control subsystems were not selected from a group of contending concepts, changes in mission parameters do not affect these subsystems. The discussion below, therefore, is limited to the trace gas control subsystem.

Mission Length

In general, variations in mission duration do affect the atmospheric contamination control system selections. Below 500 days, the three concepts keep the same relative ratings down to about 100 days. At that point, the non-regenerable charcoal/catalytic oxidation concept becomes equivalent to the regenerable charcoal/catalytic oxidation concept in total equivalent weight because the saving in direct expendables of the former exceed the reduction in power of the latter. At this point, too, these two concepts become essentially equivalent in the other criteria ratings. In the 25-30-day region, non-regenerable charcoal/catalytic oxidation becomes even more attractive and would be selected over either regenerable charcoal/catalytic oxidation or catalytic oxidation/sorption.

Above 500 days, regenerable charcoal/catalytic oxidation becomes more attractive because its power increases more slowly than the expendables of either of the other two concepts. It would be selected in this region.

Crew Size

Changes in crew size affect system selection primarily in terms of maintenance and equivalent weight. For the former evaluation, total mission time is so much in excess of total maintenance time that any changes in maintenance hours per crew member will have a negligible effect on system selection.

The general effect of changes in crew size on total equivalent weight is the same as changes in mission duration because both directly alter the total quantity of contaminants to be removed and, hence, the weight and power of the system. In addition, changes in crew size also effect the rate of contaminant removal and, as a result, tend to have a slightly larger effect on power than changes in mission duration. Nevertheless, this latter effect is relatively small, and for all practical purposes can be ignored.

The relative total equivalent weight ratings, then, are the same for all crew sizes up to nine men. For crew sizes of more than nine men, the added contaminant load would favor the selection of the regenerable charcoal/catalytic oxidation concept whose power remains nearly constant (it actually rises slightly as noted above) and which has no significant expendables.

Power Penalty

The only criterion that is affected by changes in power penalty is total equivalent weight. Because power penalty is only a fraction of total equivalent weight, the concept selection is not expected to change except in the face of gross changes in penalty.

Changes in power penalty over a moderate range have a negligible effect on the non-regenerable charcoal/catalytic oxidation concept's total equivalent weight because of its very high expendable weight. And, although this concept has the lowest power requirement, it would not be chosen for a power critical mission because of the very high weight increase associated with the small reduction in power possible.

The regenerable charcoal/catalytic oxidation and catalytic oxidation/sorption systems are close in equivalent weight ranking, but the former requires more electrical power in Designs 1 and 3 than the latter and so will tend to improve in ranking as power penalty shrinks and becomes poorer as power penalty increases. The crossover point occurs at about 200 lb/kw, but, even below that, catalytic oxidation/sorption would still have a slight edge in overall ratings so that no change in selection would occur.

In Design 2, the total amount of thermal (isotope) power required is so small for either competing concept that changes in isotope power penalty have no effect on ratings or selection. For a power critical mission, then, catalytic oxidation/sorption would be the best choice.

Resupply

Resupply capability does not change the contaminant control subsystem selection. Both the selected catalytic oxidizer sorbent concept and the second best regenerable charcoal/catalytic oxidizer concept are not very adaptable to a resupply mode of operation. The expendables for these concepts are only a fraction of the required launch weights, and quite small in absolute value. Non-regenerable charcoal may be resupplied, but it could reduce launch weights below that of the selected concept only if resupply periods less than 90 days were used. From an overall systems standpoint, however, a resupply cycle of less than about 180 days does not appear feasible for an AILSS type mission.

Flight Date

The effect of launch date on trace contaminant control subsystem concept selection presents a particularly difficult problem. This is because a major part of the development task regardless of the subsystem concept considered is to define adequately the nature of the contamination problem. For example, the projected 1973 availability date for the non-regenerable charcoal/catalytic oxidation concept or the selected catalytic oxidation/sorption concept assumes that both hardware development and contamination control requirement definition can go on concurrently and that both can be achieved adequately for a 500 day mission by 1973. The other concept, regenerable charcoal/catalytic oxidation, because of its added complexity, will require from five to six years more for final hardware development for the weights and powers discussed.

It is of interest to note that the regenerable charcoal/catalytic oxidation concept might be used prior to the projected availability date of 1979.with an over design factor of up to four before the weight exceeds that of nonregenerable charcoal/catalytic oxidation. Thus, if for some unanticipated reason, it is not possible to develop the selected catalytic oxidation/sorption concept, it might make considerably more sense to use a regenerable charcoal/catalytic oxidation system prior to 1979 and simply make up for the lack of confidence in its performance by gross over-design.

Based on the projected availability dates, there is no reason to change the selection of the catalytic oxidation/sorption concept because of changes in launch date.

THERMAL CONTROL

CONTENTS

THERMAL CONTROL

The Thermal Control section contains a discussion of water separation, cabin temperature and humidity control, ventilation, and the heat transport liquid circuit. Temperature and humidity control is considered jointly because both functions can be performed in a single unit. Water separator selection is also included as part of the temperature control selection since it greatly influences the design and power requirements and in many concepts becomes an integral part of the heat exchanger.

A detailed discussion of water separation concepts precedes the temperature and humidity control section. This discussion includes descriptions of the water separators used with the cabin heat exchangers, and other separation concepts considered for use as part of the other AILSS subsystems. Specific water separator selections for use in the different subsystems are also presented.

Air flow for temperature and humidity control provides a significant portion of the ventilation or, more specifically, the cabin air circulation requirements. Additional ventilation fan flow requirements are derived and defined in this section.

The design of the liquid heat transport circuit is based largely on the integration of EC/LS subsystems and internal cabin heat loads (such as the communication and scientific experimentation equipment). Several assumptions must be made concerning the total energy load to be dissipated, (air or liquid cooling, latent or sensible), and its location in the vehicle. A load range must be specified to ensure adequate performance over all anticipated operating conditions. Lastly, because a hard definition of the vehicle or its exact loads does not exist, the selected system concept must exhibit some degree of flexibility and be capable of adapting to other than defined conditions. The choice of a power plant has a significant influence upon the liquid heat transport system design, not only from the standpoint of equipment selection but also from the standpoint of process heat availability and characteristics.

WATER SEPARATION

Liquid/gas separation techniques are required not only in the temperature and humidity control subsystem but within several other areas of the EC/LSS. The other areas to be considered are in the 1) water reclamation system, 2) waste water collection system, 3) carbon dioxide concentrator section, and 4) crew provisions washing devices. It would appear desirable to select a common method of phase separation for all applications to minimize overall system design complexity and maintenance requirements. This is not a realistic goal, however, because some areas require the separation of a small amount of liquid from a high flow gas stream, whereas other applications necessitate the removal of small quantities of gas from liquid lines.

Moreover, the fluid streams vary considerably as to flow rate, operational time, temperature, pressure drop, corrosive properties, and contamination.

The requirement for zero-gravity operation complicates the achievement of adequate phase separation and eliminates most commercial methods presently available. Separation concepts for space flight must not only meet performance objectives but must possess minimum equivalent weight, high reliability, and low crew maintenance time. The development of flight hardware to meet these objectives has proved to be a difficult task. Of the hardware presently available, none has demonstrated completely satisfactory performance.

Water separators used in the humidity control system and in the water reclamation system are treated as part of the candidate concepts. In many instances, the separators are integral parts of a hardware concept being evaluated (e.g. the integral wick heat exchanger) and cannot be considered separately. Applications in the waste management, CO_2 concentration, and crew provisions subsystems, however, may be considered separately.

General water separator requirements and applications are given on table 21.

TABLE 21

WATER SEPARATION

REQUIREMENT	APPLICATION	MECHANISM
Free Moisture a) Large Air/ Water Ratio b) Low Air/ Water Ratio	Humidity Control Process Dehumidification Wet Waste Collection	Inertial and Combined Dynamic/Capillary
Condenser/Separator a) Dehumidification b) Steam Condensation	Humidity Control Process Dehumidification Water Reclamation	Capillary, Inertial, and Combined Dynamic/ Capillary
Deaerators	Liquid Line Maintenance	Capillary (Hydrophobic/ Hydrophilic)
Aerosol Removal	Cabin Air Filtering	Dynamic (Filtration) Electrostatic

Separation Concepts

The water handling concepts considered for zero-gravity operation fall into two general categories: those utilizing predominantly inertial forces (dynamic devices) and those relying primarily on capillary forces to achieve liquid/gas separation (static devices). In some applications, a combination of these two methods is used. These concepts may be classified as follows:

1. Inertial
   - a. Motor driven centrifugal
   - b. Air turbine centrifugal
   - c. Vortex centrifugal
2. Capillary
   - a. Integral wick (in heat exchanger)
   - b. Face wick (on heat exchanger)
   - c. Membrane devices
3. Combined
   - a. Porous plate labyrinth
   - b. Elbow/wick
   - c. Hydrophobic/hydrophilic screen

Figure 57 presents sketches of some of the available water separation devices.

Inertial concepts. - Liquid/gas separation in zero gravity requires the substitution of capillary and/or inertial forces for gravitational forces. The creation of strong inertial forces is accomplished by generating a centrifugal field, several methods of which are available. These are basically free moisture separators.

Rotary separators: The air turbine and motor driven centrifugal phase separators are similar except for the means of achieving rotation. Both concepts employ a rotating vaned drum (or other rotating device) which imparts a centrifugal force to the water in the entering gas stream. The centrifugal force tending to force the liquid drops to the wall is opposed by the shear forces in the gas stream tending to maintain the flow of the drops back along the axis of rotation. The ratio of centrifugal to shear forces must be sufficient to effectively collect the liquid drops. A rotating gutter is employed to collect the drops as they are spun off the rotating vanes (or collector plates). A stationary Pitot tube collects the water from the rotating gutter. The velocity head at the Pitot tube is converted to a static head, and the water readily flows out of the separator to the collection system. As long as the Pitot tube remains submerged in liquid and a minimum back pressure is maintained on the Pitot tube outlet, there will be no air inclusion in the delivery flow; however, startup problems are possible.

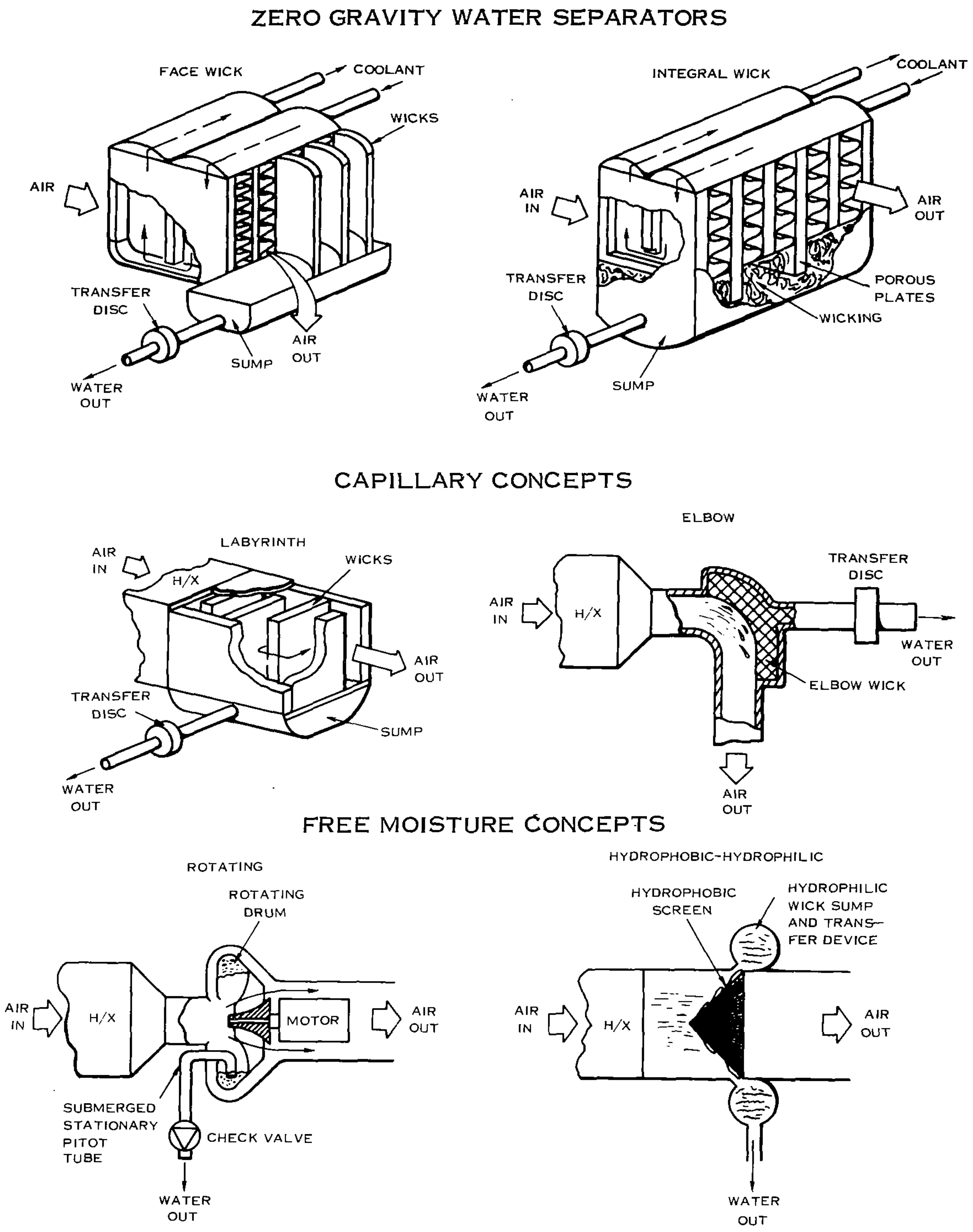


Figure 57. Zero Gravity Water Separation.

Vortex separator: The vortex separator obtains its centrifugal effects by directing the gas tangentially into a vortex chamber. This device contains no moving parts but is less efficient than the air turbine and motor driven centrifugal separators, because the stationary walls of the vortex unit produce significantly higher shear forces.

The use of inertial forces to achieve phase separation implies greater power requirements than with capillary devices, because of irreversabilities accompanying inertial forces applications.

Capillary concepts. - The capillary devices utilized for liquid/gas separation rely mainly on material properties rather than mechanical means.

Integral wick: The integral wick heat exchanger combines the condensing and separation functions in a single unit. This unit contains a gas side layer consisting of a metal wick (either metal felt or porous plates may be used) sandwiched between fin sheets. Alternate gas and coolant passages are employed in a stack configuration. The wicks are fed into a side-mounted sump which accumulates water and acts as a wick manifold. A hydrophilic transfer disc, with an applied pressure differential in contact with the wick sump, transfers water to the collection system.

Face wick: The addition of face wicking to a conventional heat exchanger (at the air outlet face) is a compromise between the elbow and the integral wick concepts. Using a hydrophilic coating on the air side fins of a conventional heat exchanger minimizes gas pressure drop. Water droplets transported to the heat exchanger outlet face contact the strips of wicking, enter the wick, and are transported to a hydrophilic transfer disc similar to that previously discussed. The wicking may be installed as sheets forming a vaned elbow, minimizing free moisture carry-over. In the event of excessive wick degradation, the wick may be replaced, whereas in an integral wick unit the whole heat exchanger requires replacement. Due to the large integral wick heat exchanger sizes (approximately 85 pounds each for the cabin heat exchangers), this penalty would be excessive.

Membrane devices: Membrane separation devices utilize a semipermeable material that allows water vapor diffusion at a rate several thousand times greater than the carrier gas. The membrane is exposed on one side to cabin pressure with the opposite side maintained at a low pressure (less than 0.1 psia). Due to the relatively high diffusion rate of water vapor through the membrane, water vapor permeates without the necessity of condensing. A folded construction is required to maintain a compact unit due to the large membrane surface areas required to separate the water quantities encountered in spacecraft life support applications. The membrane must be maintained at a relative humidity on the order of 50 percent to prevent dryout. This design could be made integral with the membrane CO_2 concentrator concept.

Combined concepts. -

Porous plate labyrinth: When liquid droplets come in contact with a surface where the potential energy may be reduced, the droplet will wet the surface (hydrophilic). This principle is the basis of the porous plate separation technique. Due to the tendency of the droplets to concentrate toward the center of the ducting under laminar flow and zero-gravity conditions, it is necessary that transverse convolutions be used to intercept the drops and direct them to the porous plate surface where capillary forces prevent air from entering the pores. By maintaining a differential pressure below the bubble point of the porous plate, gas-free liquid may be transferred through the plate.

Elbow/wick: The elbow separator also employs both inertial and capillary forces to separate and transfer liquid. As the gas stream enters the 90-degree elbow lined with wicking, inertial forces force the heavier water particles to the wicking where capillary forces drain the water to a hydrophilic transfer disc. Capillary forces, in conjunction with a pressure differential across the disc, transfer liquid to the collection system.

Hydrophobic/hydrophilic screen: This concept utilizes both surface types to achieve zero-gravity phase separation. The entering gas stream contacts a conical-shaped screen (with the apex of the cone facing the gas stream) coated with a hydrophobic material. The free water droplets are deflected to the base of the cone while the gas flows through the screen. Hydrophilic transfer discs are provided at the base of the cone around its circumference. A pressure differential maintained across the discs by a pressure-controlled pumping system transfers the water to storage tanks.

Electrophoresis: A different category of phase separation considered includes an electrostatic technique referred to as electrophoresis or dielectrophoresis. An artificial gravity field may be established in a dipolar dielectric medium by superimposing a non-uniform electrical field. The force field generated within a liquid will exert buoyant forces on gas bubbles, moving them to a collection area. This technique would appear desirable for contaminated fluid not compatible with capillary separation techniques. However, contaminated fluids normally have high electrical conductivities due to high ionic concentrations. With the relatively high conductivities of urine, too great a voltage potential would be required to establish the necessary force field resulting in an inefficient process. Thus, this technique may not prove practical under the same conditions which make capillary applications also impractical. Although it is recommended that additional investigations be made in this area, insufficient information is available to seriously consider electrophoresis at this time.

Equipment selection. - The liquid/gas separation techniques selected for specific AILSS applications are summarized as follows:

Waste collection subsystem (urine/air separator): A motor-driven centrifugal concept is selected to separate urine from the cabin air during the collection process and to transfer the urine to the water management subsystem (with most of the pressure head provided by a pump. The corrosive nature of urine and its solid content dictate the selection of a separator device that is not affected by clogging. ILSS experience has indicated that a motor-driven unit is perferable to an air turbine in reducing stalling conditions during startup and in improving overall torque characteristics. The inherently high shear stress of the vortex separator results in a high equivalent weight, eliminating it from consideration. Problems anticipated with the selected concept include bearing drag and corrosion and the transfer of air to the liquid storage tanks (due to uneven load).

Atmosphere control system (CO_2 concentrator, H_2O/CO_2 separator): A porous plate condenser/separator is selected to fulfill the requirements of the carbon dioxide concentrator.

Other possible applications considered include use of the water electrolysis system, electrochemical CO_2 concentrator, CO_2 reduction systems, etc.

The choice of porous plates as the major water separating device used in the AILSS subsystems is contingent on positive phase separation with no moving parts plus the requirement of maintenance and parts replacement. Bacteria and other microscopic clogging limit the life of the porous plates and necessitate scheduled replacement every 100 days. As a result of the total number of separators needed and the frequency of replacement required, a common configuration and replacement approach is essential.

The concept shown in figure 58 allows replacement of the porous plate by breaking and making the quick disconnect fasteners mating the cold plate and porous plate. Removal of the porous plate via disconnects subsequently unseals the interface connections for the gas inlet, gas outlet, and condensate outlet. Sealing of the connections is again obtained by replaceable face seals mounted on the cold plate. The use of the cold plate allows replacement at the failed level without breaking into the interfacing coolant circuit. This approach displays the features necessary for zero-g maintenance: complete isolation from the fluid transport system, replacement at the failed level, replacement of the sealing elements, and one-step mounting and sealing which minimizes replacement time and complexity.

Crew provisions subsystem (shower water/cabin air separator): The hydrophobic/hydrophilic concept is selected to separate water from the shower cabin air stream. The operation of this concept has been previously described. Inertial concepts are eliminated from consideration due to their excessive power requirements and the flow

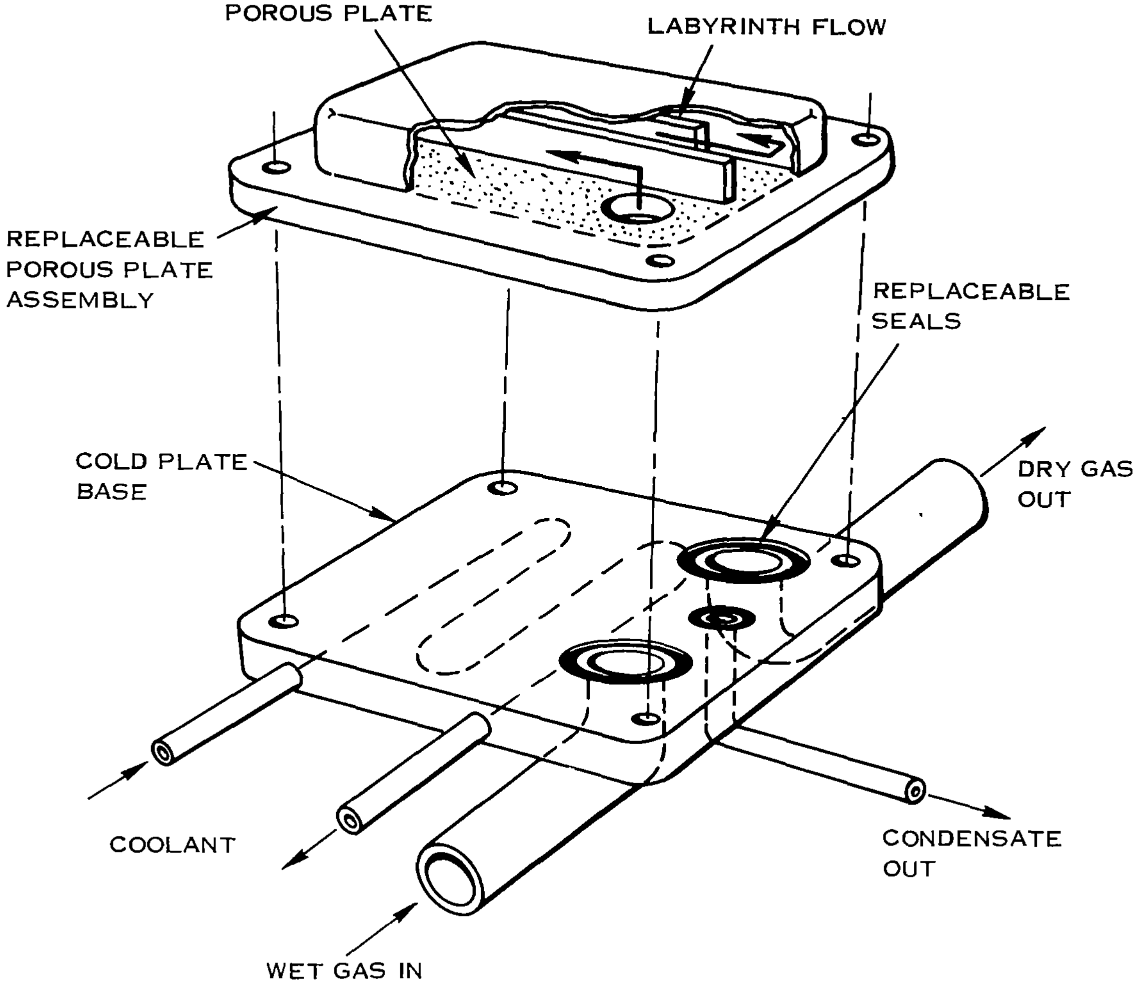


Figure 58. Maintainable Condenser

rates being processed. The high flow rate (1000 cfm), the nature of the fluid being processed, and equivalent weight considerations result in the selection of the low pressure drop hydrophobic/hydrophilic design concept. Potential problems are transfer disc clogging and failure of the differential pressure control.

Aerosol removal: Aerosols may be generated by sneezing, showers, heat exchanger carry-over, and by accidently released free moisture quantities passing through fans. Anticipated aerosol particle sizes are in the 10 to 100 micron range and will be removed by the particulate and bacteriological filters designed to remove 95% of particles greater than 0.3 microns. Three 750 cfm filter units are installed in the gas circulating system thus providing for a total processed flow of 2250 cfm. The filtered aerosols will be re-evaporated by the 50 percent relative humidity cabin air. Further discussion of the filtration system appears in the Bacterial Contamination Control Subsystem portion of the Atmospheric Contamination Control Section.

Deaeration: Maintenance of liquid cooled components and periodic new hardware replacements that will require line breaks together with leakages due to faulty or off-design operation will inevitably result in entrainment of air in the transport fluids. Dissolved gases in liquids will outgas when heated, therefore, process system water separators must be designed to preclude air inclusion in the fluid transfer lines.

The effects of entrained air in liquid transport lines are to:

1. Cause poor flow distribution in heat transfer equipment with a corresponding drop in efficiency.

2. Cause circulating pump cavitation.

3. Cause metering systems to give incorrect readings.

Figure 59 presents a sketch of a possible arrangement of hydrophilic and hydrophobic screens which will remove entrained air bubbles in a liquid line. The hydrophilic surface remains wetted and prevents the passage of air bubbles while the hydrophobic surface tends to remain dry, thus allowing the escape of gas.

Utilization of a small hydrophilic and hydrophobic screen device will produce the desired air separation effect; however, the problem with such a device is the degradation of the surfaces with time by contaminants in the water. It is anticipated that the water contained in the thermal transport circuit may be properly conditioned to extend separator life. The utilization of this device in the potable water circuit presents no problems due to the existence of an extremely high purity fluid. Frequent replacement of screen assemblies will be necessary for applications in contaminated lines such as urine, wash water, and atmospheric condensate.

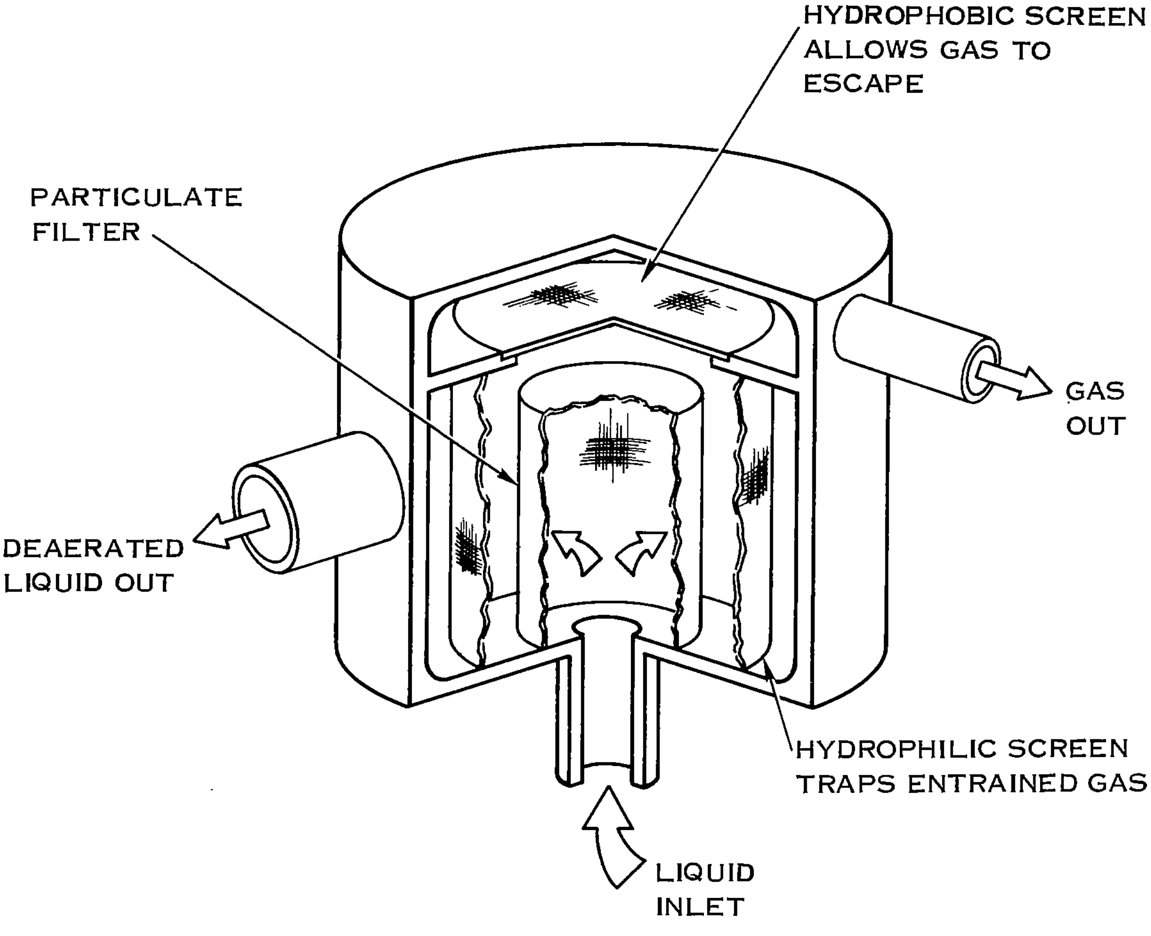


Figure 59. Liquid Line Deaerator

Degradation would tend toward changing hydrophobic surfaces to hydrophilic. This type of failure is in a "fail safe" direction since it can be identified by water carry-over in the air bleed port. The hydrophilic surface properties will also deteriorate with time but at a lower rate than the non-wetting side.

Recommendations. - While specific separation techniques are tentatively selected, it is recognized that the entire area of phase separation is considered pacing technology. Current experience with liquid/gas separation concepts demonstrates the need for extensive design and development effort to produce acceptable flight hardware. Development of phase separation units to achieve 500-day performance without maintenance is not considered to be a realistic goal in the development time available. Therefore, all separation equipment will require spares either for modular component or complete unit replacement.

CABIN TEMPERATURE AND HUMIDITY CONTROL CONCEPTS

To assure crew comfort, both cabin temperature and relatively humidity must be controlled and proper cabin ventilation must be provided. Cabin temperatures between 65°F and 75°F can be selected by the crew. Relative humidity is normally regulated to 55 ± 5 percent. Sensible and latent air loads are distributed in the two assumed vehicle compartments. A breakdown of the cabin air loads and anticipated ranges is as follows:

	Crew compartment	Equipment compartment
Sensible	6000-12 000 Btu/hr	12 000-24 000 Btu/hr
Latent	0-3000 Btu/hr	0-3000 Btu/hr

The difference in compartment thermal loads may be accomodated at minimum penalty by using multiple heat exchanger units in the compartment containing the larger loads. The exact number of units is specified in the individual candidate descriptions.

The candidate cabin temperature and humidity control concepts covered in this report consist of ten integral combinations of thermal, humidity, and water separation devices. These are summarized in table 22. Water separator concepts considered are shown in figure 57. The choice of power supply will not affect the selection since the power penalty for all three power supply designs is the same.

High air flow rates processed by the temperature and humidity control system provide a sizeable part of the circulation flow requirements. The variable flow fan system, which normally operates at reduced flow, requires more supplementary circulating fan flow than the reheat and the bypass systems. The separate condenser

TABLE 22

TEMPERATURE AND HUMIDITY CONTROL CANDIDATE SUMMARY

Concept	Water separator	Description
Air reheat	1. Integral wick 2. Face wick 3. Free moisture separator	Constant air flow condensing HX with reheat HX. Liquid flow modulation in condenser for RH control & in reheat HX for temp. control. (fig 60)
Variable speed fan	1. Integral wick 2. Face wick	Fan speed varied for temp. control, liquid flow modulation in condensing HX for RH control. (fig 61)
Air bypass	1. Integral wick 2. Face wick	Air bypassed around condensing HX for temp. control, liquid flow modulation for temp control. (fig 62)
Separate latent and sensible heat exchangers	1. Integral wick 2. Face wick 3. Free moisutre separator	Low flow condenser with water separator for humidity control, high flow dry HX for temp. control. (fig 63)

and cooler system provides considerably more flow than the reheat and bypass system. Appropriate additional or lower circulation flow penalties are applied to the total equivalent weight of the candidate systems as required to obtain the required circulation flow.

A condensing heat exchanger design using a face wick water separator and a variable speed fan for temperature control is selected for the AILSS for cabin temperature and humidity control.

Air Reheat

Figure 60 presents a sketch of a typical reheat concept using a condenser, a face wick water separator, and air reheater in series. In order to meet the individual cabin load variations, two units are located in the equipment and one unit is located in the crew quarters.

Airflow is constant through the system with the condenser providing all the maximum sensible heat load requirements at a 65°F cabin temperature. A non-condensing reheat heat exchanger is located downstream of the condenser for heating during low sensible heat load conditions and to obtain cabin temperatures up to 75°F. Cabin relative humidity is controlled by varying the coolant flow through the condensing heat exchanger. Cabin temperature is maintained by varying the reheater liquid flow.

Three water separator concepts are included in the reheat system evaluation (integral wick, face wick, free moisture separator). These water separators include a microporous water transfer device to prevent air carryover into the condensate collection system.

Absolute criteria. -

Performance: Individual control of cabin temperature and humidity is possible with a minimum of control interaction. The high airflow rate enables the cabin latent load upsets to be easily handled with a minimum variation in cabin relative humidity.

Safety: No safety problems exist since low temperature, low pressure water is used as the coolant fluid.

Availability/confidence: All three heat exchanger types have been built and flown in manned spacecraft programs. The 500-day performance of wetted fins (necessary for low core pressure drop) has not been demonstrated. Several free moisture water separator designs have been developed. The integral wick and face wick concepts, however, are of more recent origin and will require more development than the available free moisture concepts.

SUBSYSTEM: Cabin Temperature and Humidity Control

CONCEPT: Air Reheat/Integral, Face Wicking, and Free Moisture Separators

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999802 MTBF: 11 400 hr
(all designs)

Spares/Redundant (R) Units:

3 - Fan
1 - Cond. HX
1 - Reheat HX
14 - Water Transfer Disc
3 - Pump
2 - Humidity Control
3 - Temp. Control
2 - Temp. Control Valve
4 - Temp. Control Valve Actuator

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	48	3.15

EQUIVALENT WEIGHT (lb):	Integral Wick	Face Wick	Free Moisture Water Separator
Basic Unit	507	372	370
Expendables	0	0	0
Spares/Redundant Units	480	317	310
Electrical Power	500	610	786
Thermal Power	0	0	0
Radiator Load	151	184	238
Total Equivalent Weight	1638	1483	1704
POWER (Watts):			
Electrical	1110	1350	1746
Thermal	0	0	0
VOLUME (ft^3):	38	35	32

Figure 60. (Page 1 of 2)

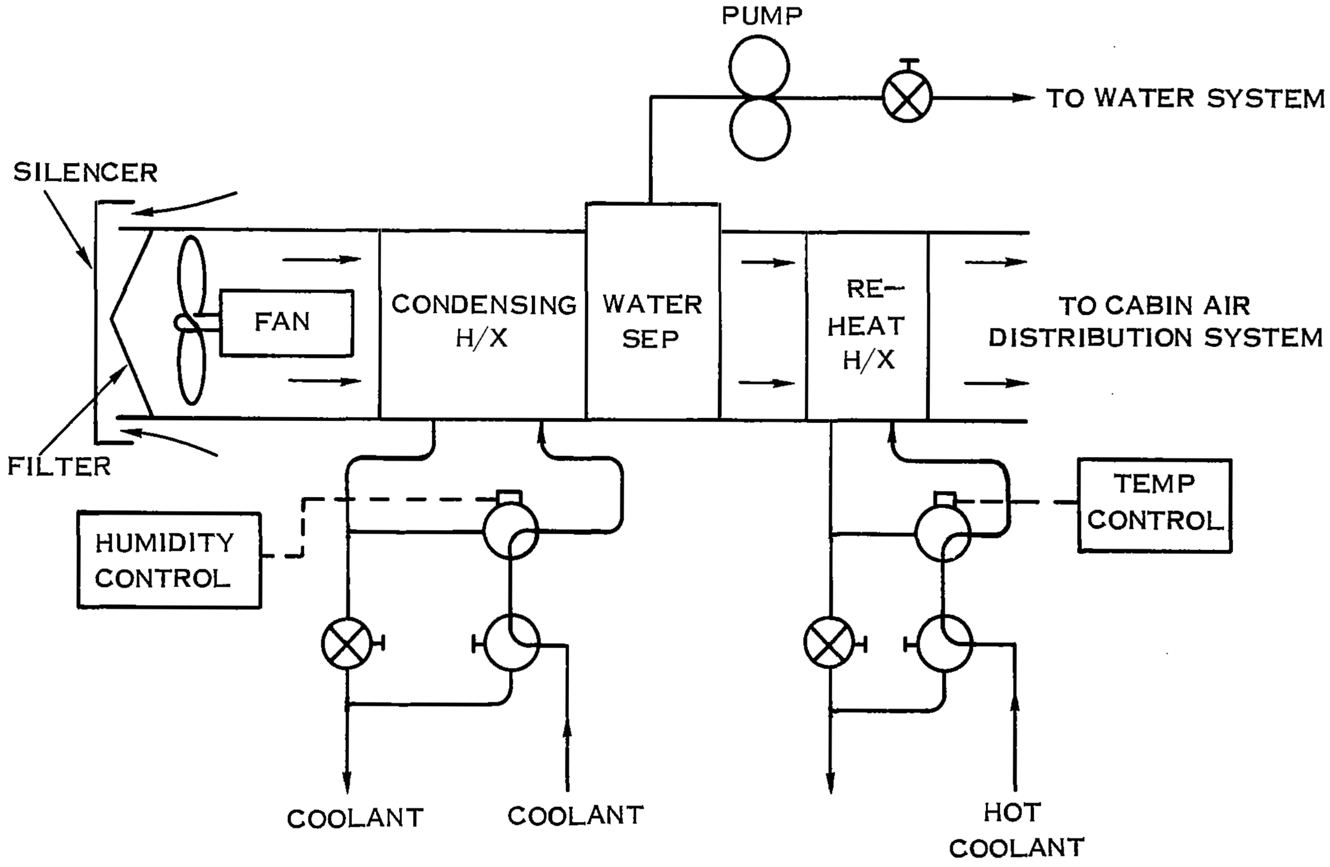


Figure 60. Condenser-Air Reheater Concept (Page 2 of 2).

Primary criteria. -

Reliability: The MTBF for this candidate is 11 400 hours. It is the same with all three water separator types and is influenced primarily by the use of six liquid loop temperature control valves.

Crew time: The operation of these designs is completely automatic. The microporous liquid transfer device used in all but the rotary separator concept is a limited-life item and requires scheduled replacement. Microbiological decontamination techniques have not been developed, but these should require some defined crew time. Since a down-time in excess of 30 minutes cannot be comfortably tolerated for any of the heat exchanger concepts considered in the section, the required spares are built in as a complete unit.

Replacement of the temperature control valves presents the greatest stress on the crew since it requires breaking into the coolant loop. Air inclusion in the coolant can present a potential heat exchanger operational problem.

Total equivalent weight: The design using a face-wick water separator is the lightest of the three designs. The fixed weight of the integral wick concept is high, and the fan power of the free moisture water separator concept has a large equivalent weight due to its high pressure drop and fan power.

Secondary criteria. - The integral-wick design presents a greater contamination problem than the other two designs. Decontamination of wicking integral with the heat exchanger core is more difficult since the wicks cannot be replaced. Interface problems exist, since the reheat concept requires two heat exchangers at different locations in the liquid circuit. This results in more plumbing than with the other concepts. Since noise and power consumption increase with fan pressure rise, the conventional heat exchanger/free moisture water separator concept presents more noise filtration problems than the other two designs.

Variable Speed Fan

This concept, shown in figure 61, provides temperature and humidity control in the same heat exchanger, and uses a variable-speed fan controlled by a cabin temperature setting. Cabin temperature is controlled by varying the airflow through the heat exchanger, while cabin relative humidity is regulated by varying the coolant flow.

Since airflow variations of four to one are required to meet all temperature and load conditions, the system pressure drop will vary by more than four to one. A condensing heat exchanger with a free moisture water separator concept is not applicable, since proper air flow distribution is not possible at the lower flow range. The water droplets are not dislodged from the heat transfer surface knife edges at the heat exchanger flow exit and, thus, flow blockage occurs. A fall-off in heat exchanger performance causes an increase in fan speed which blows out the water blockage. Subsequently, a flow increase overcools the cabin, restarting the cycle. The integral-wick and face-wick concepts, however, can operate with reduced airflow, since the water is drawn directly into the wicking and blockage of the flow path does not occur.

The 1000 cfm air-flow per unit (at maximum fan speed) is set by the largest cabin thermal load condition at a 65°F temperature condition. The variable-speed operation of the fan motor is obtained by varying both frequency and voltage as a function of temperature setting. This method is necessary to obtain efficient low-speed performance. As with the reheat system, two units are located in the equipment compartment and one in the crew compartment. The heat exchanger effectiveness of this concept is a conservative 82 percent.

Absolute criteria. -

Performance: The variable-speed motor system requires both air and coolant flow modulation to handle all conditions. The interaction of temperature and humidity control functions and the use of multiple heat exchanger units presents additional control complexities.

In order to prevent hunting (low-frequency oscillation) of the air and coolant flow controls, some interaction between the two flow controls is required. A change in the temperature control setting must be accompanied by a resetting of the coolant flow so that repeated overshoots do not occur. A detailed dynamic analysis must be performed on an actual system to fully define the control.

Since large flow variations occur with this system, air circulation flow must be determined at the minimum anticipated thermal control fan flow. As covered under Ventilation, an additional 1000 cfm must be provided by supplementary circulation fans to obtain the total required flow rate. The added power (56 watts) is charged to this concept.

Safety: No safety problems exist with this candidate.

Availability/confidence: No new concepts are necessary for implementation of these designs other than a fin coating which will maintain its wetability for 500 days. Etchings, applied ceramics, and spray-on coatings are currently under development with a good chance for successful development of at least one of the methods.

Primary criteria. -

Reliability: The MTBF for this concept, using either water separator type, is 11 400 hours, but the number does not accurately include possible chances of microbiological contamination. This is taken into account by considering the water transfer

SUBSYSTEM: Cabin Temperature and Humidity Control

CONCEPT: Variable Speed Fan/Integral and Face Wick Separators

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999813 MTBF: 11 400 hr
(all designs)

Spares/Redundant (R) Units:

3 - Fan
4 - Temp & Speed Control
1 - Cond. HX
14 - Water Transfer Disc
3 - Pump
2 - Humidity Control
2 - Temp. Control Valve
3 - Temp. Control Valve Actuator

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	48	3.15

EQUIVALENT WEIGHT (lb):	Integral Wick	Face Wick
Basic Unit	466	331
Expendables	0	0
Spares/Redundant Units	365	320
Electrical Power	424	533
Thermal Power	0	0
Radiator Load	135	169
	40	40
Total Equivalent Weight	1430	1393

POWER (Watts):		
Electrical	998	1241
Thermal	0	0

(Includes ventilation supplement)

VOLUME (ft^3):		
	35.5	31.5

Figure 61. (Page 1 of 2).

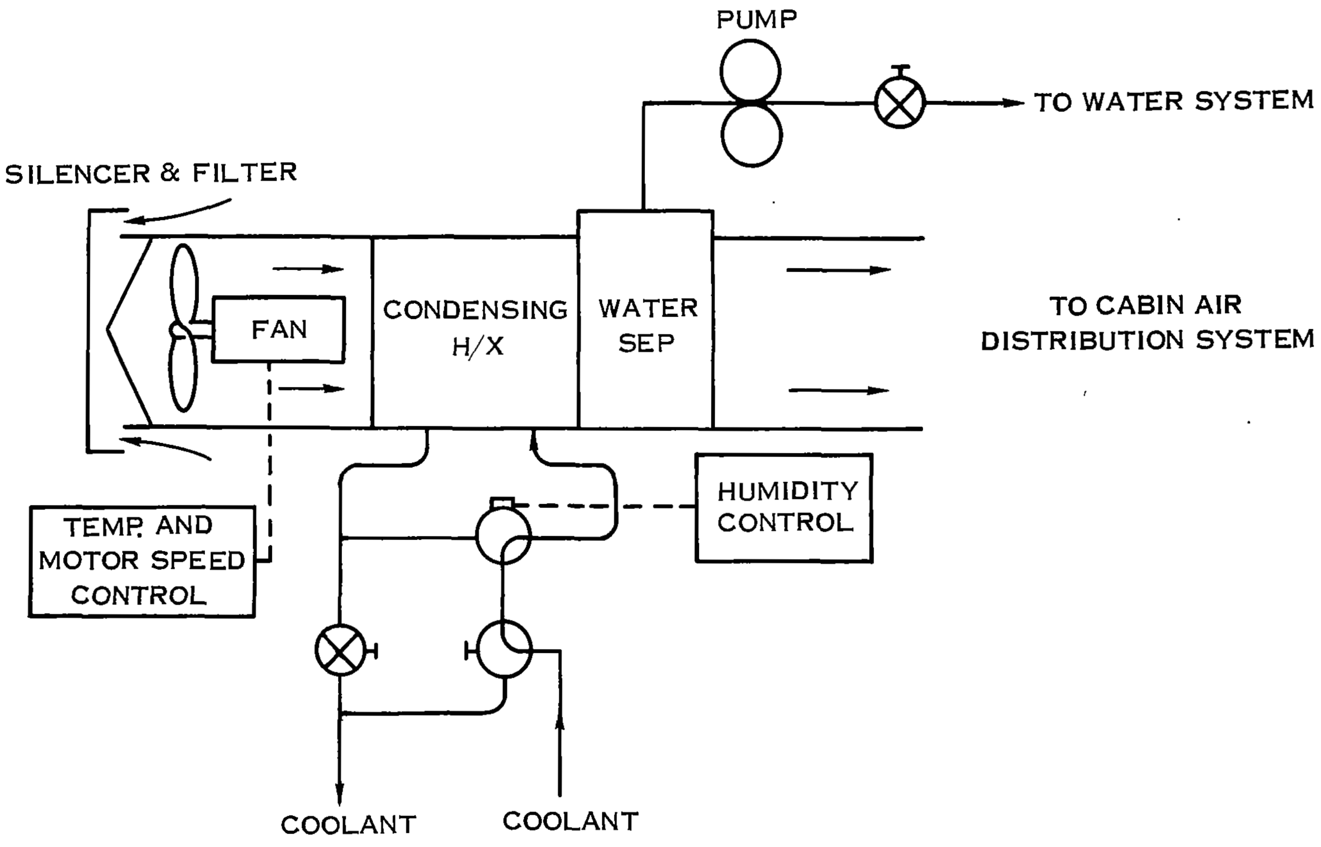


Figure 61. Variable Speed Fan Concept (Page 2 of 2).

devices as limited-life items. Although a breakthrough in long-life water transfer devices would eliminate the problem, it is not being counted on for the AILSS.

Crew time: The crew time includes unscheduled changes of the fan and temperature and humidity controls and scheduled maintenance of the water separator limited-life components.

Total equivalent weight: The integral-wick and face-wick concepts have relatively low penalties. The heat exchanger face wick compares favorably with the heavier integral-wick heat exchangers. An additional ventilation penalty of 40 pounds includes fan power equivalent, heat rejection, and fan weight.

Secondary criteria. - Contamination problems of the integral-wick concept involve both the possibility of decontamination and the subsequent disposal of a heat exchanger. This is not a problem with the face-wick concept, since the wick can be disposed of and a spare heat exchanger may be stored dry.

Although the fan flow cannot be counted on for full-time ventilation flow, the cost of additional recirculation fans is small. Only one liquid loop interface per unit is an advantage of this concept. This system has good flexibility aspects, since it does not depend on a high-temperature liquid source for temperature control. The integral-wick concept, however, does have limitations due to freezeup during cabin depressurization. Growth aspects are good, since an increase in liquid flow rate results in a considerable increase in latent load capacity. The noise of this system is the lowest of all concepts at normal cabin temperature settings of 70° to 75°F when the fan is running at reduced speed. Volume and power for this concept are low.

Air Bypass

This concept is very similar to the variable-speed fan concept. The maximum fan and coolant flows are the same. Heat exchanger air flow modulation is obtained by bypassing flow around the heat exchanger through a temperature-control-actuated bypass valve. Full fan flow is maintained at all times so that supplementary ventilation flow is not needed at high-temperature or partial-load conditions.

The integral-wick and face-wick water separators are considered with this concept. A sketch of the system is shown in figure 62.

Absolute criteria. - These ratings are identical to those for the variable-speed fan concept.

Primary criteria. - Reliability, crew time, and equivalent weight comments are similar to those for the variable-speed concept. Specific differences may be found on the data sheets. No ventilation penalty is charged to this concept, since the fan runs at full speed for all cases.

Secondary criteria. - The only significant difference between the bypass concept and the variable-speed fan concept is in system noise. Since the heat exchanger core provides some noise attenuation, opening of the bypass duct results in an increase in noise. Additional noise filtering is possible, but results in a significant increase in total equivalent weight.

Separate Condenser and Cooler

This concept, shown in figure 63, uses a separate condensing heat exchanger for humidity control, and a higher-flow noncondensing heat exchanger for cabin temperature control. Three hundred and fifty cfm are processed in the condenser unit and two thousand four hundred cfm in each of the sensible load heat exchangers. Relative humidity is controlled by varying the coolant flow into the noncondensing heat exchangers. A high airflow rate is required in the noncondensing cooler while providing a 65°F cabin temperature. Cabin temperature changes from high to low settings must be effected in a manner such that the heat exchanger coolant inlet temperature does not drop below the initial cabin dewpoint. This condition is obviated in the candidate design by maintaining coolant flow into the noncondensing heat exchanger at a temperature above the normal dewpoint range of 45° to 60°F.

The high flow requirement of this concept provides the additional flow required for ventilation; therefore, fewer circulation fans would be required. A ventilation fan and power credit is given to this concept.

Considering the two-compartment configuration, one condenser is located in each compartment with one sensible-load heat exchanger in the crew compartment and two in the equipment compartment. This best meets the 2:1 sensible-load distribution in the two compartments; latent load is the same in both.

The condenser may use the integral-wick, face-wick, or free-moisture-water-separator design, since a constant airflow rate is used.

Absolute criteria. -

Performance: The normally noncondensing sensible load heat exchangers are vulnerable to condensing during dewpoint upsets. Short-term upsets may be tolerated if nonactive face-wicking is used to prevent free moisture injection into the cabin. This is not a problem with the other candidates, because water separation is a normal part of their operation.

Safety: No critical safety problems exist. The possible free moisture additions to the cabin are as discussed above.

SUBSYSTEM: Cabin Temperature and Humidity Control

CONCEPT: Air Bypass/Integral and Face Wick Separators

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999830
(all designs)

MTBF: 10 200 hr

Spares/Redundant (R) Units:

3 - Fan
1 - Cond. HX
14 - Water Transfer Disc
3 - Pump
1 - Diverter Valve
4 - Diverter Valve Actuator
3 - Temp. Control
2 - Humidity Control Valve
3 - Humidity Control Actuator
2 - Humidity Control

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	48	3.5

EQUIVALENT WEIGHT (lb):	Integral Wick	Face Wick
Basic Unit	502	367
Expendables	0	0
Spares/Redundant Units	368	323
Electrical Power	397	508
Thermal Power	0	0
Radiator Load	136	153
Total Equivalent Weight	1403	1351
POWER (Watts):		
Electrical	882	1125
Thermal	0	0
VOLUME (ft^3):	45	41

Figure 62. (Page 1 of 2).

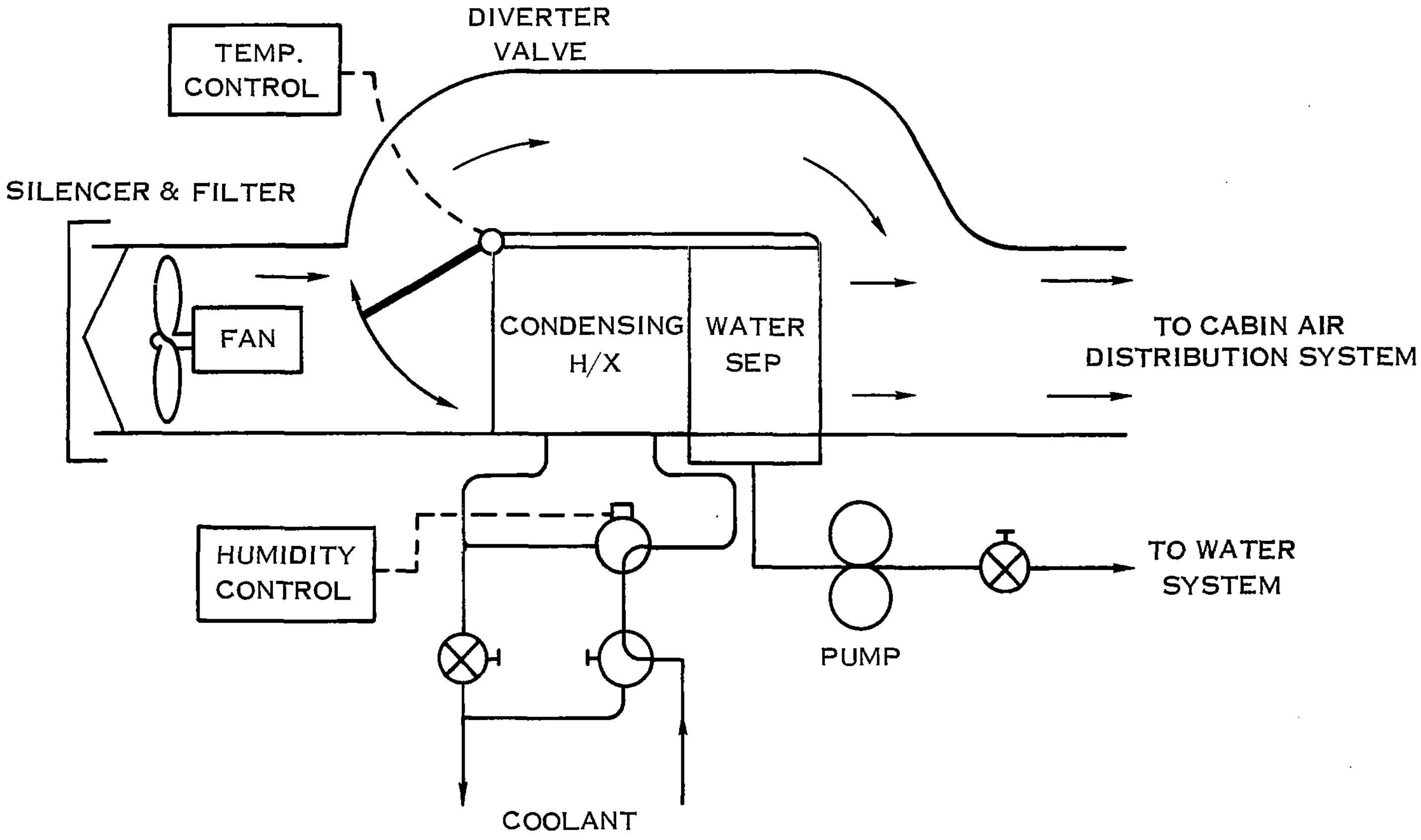


Figure 62. Air Bypass Concept (Page 2 of 2).

SUBSYSTEM: Cabin Temperature and Humidity Control

CONCEPT: Separate Condenser and Cooler/Integral, Face Wick, and Free Moisture Separators

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999799 MTBF: 12 980 hr
(all designs)

Spares/Redundant (R) Units:
2 - Fan, Humidity Control
3 - Fan, Temp. Control
1 - Cond. HX, Hum. Cont.
1 - Cond. HX, Temp. Control
10 - Water Transfer Disc.
3 - Pump
3 - Humidity Control
3 - Temp. Control
2 - Temp. Control Valve
4 - Temp. Control Valve Actuator

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	32	2.77

EQUIVALENT WEIGHT (lb):	Integral Wick	Face Wick	Free Moisture Water Separator
Basic Unit	870	843	840
Expendables			
Spares/Redundant Units	366	353	350
Electrical Power	503	529	574
Thermal Power	0	0	0
Radiator Load	130	138	152
Ventilation Credit	-73	-73	-73
Total Equivalent Weight	1796	1790	1843
POWER (Watts):			
Electrical	954	1014	1114
Thermal	0	0	0
(including ventilation credit.)			
VOLUME (ft^3):	58.5	57.5	57.0

Figure 63. (Page 1 of 2).

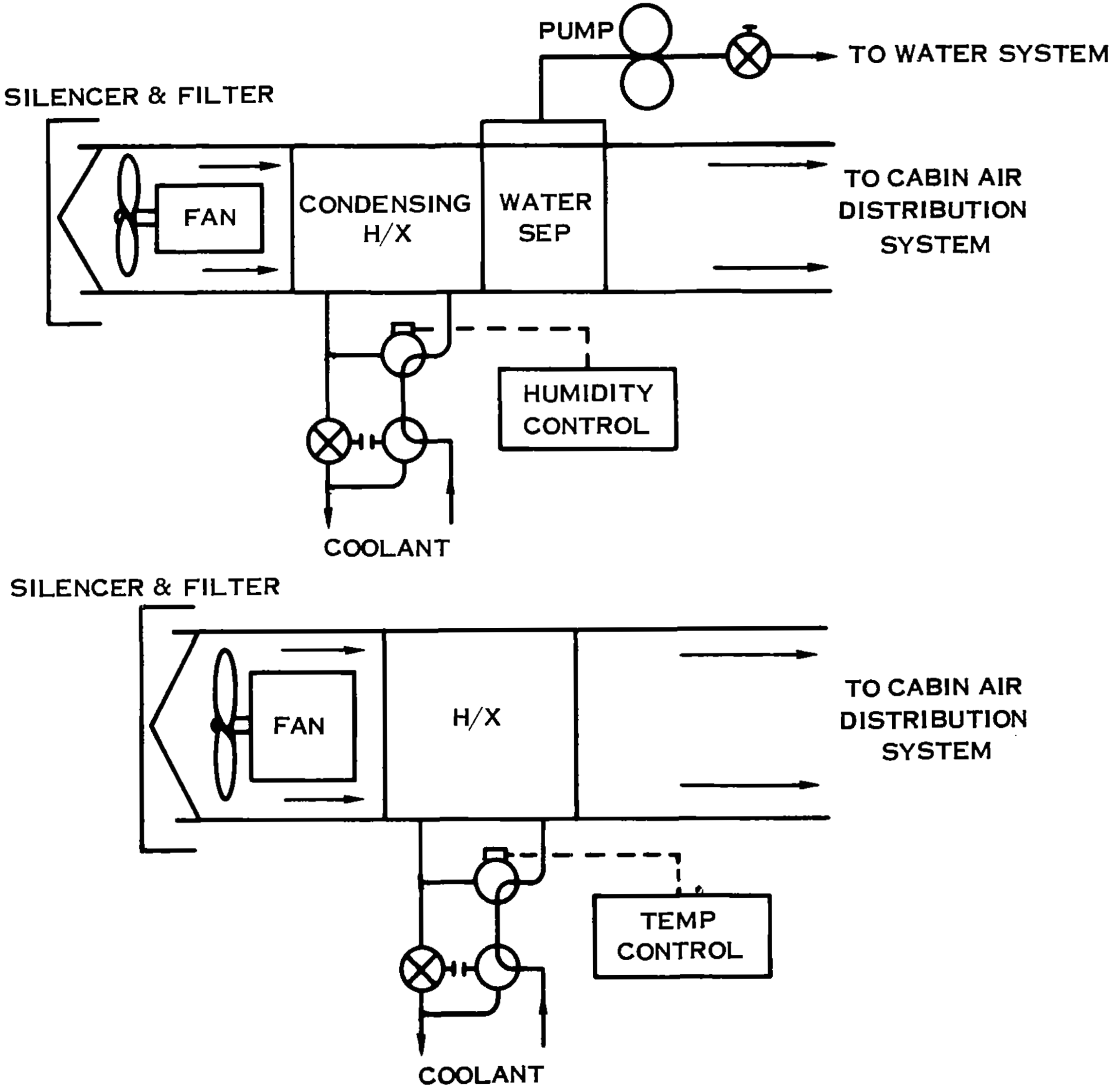


Figure 63. Separate Condenser and Cooler Concept (Page 2 of 2)

Availability/confidence: Except for the condenser fin coating problems common with the other concepts, only normal development problems are anticipated. This concept is used in both the Apollo Command and Lunar Modules.

Primary criteria. -

Reliability: This concept has a slightly higher MTBF than the other candidates.

Crew time: The maintenance time is about equal to that of the reheat systems. This time may be increased due to the possible crew attention required after a dewpoint upset.

Total equivalent weight: This system has the highest equivalent weight of all the candidates, even with credit given for the high ventilation flow capability (156 watts). The primary reason for this high weight is the very large noncondensing heat exchangers. This system weighs about 400 to 500 pounds more than the lightest candidate. An increase in the minimum cabin temperature (65° F) would be necessary before this system could become competitive in weight.

Secondary criteria. - The integral-wick condenser design is vulnerable to contamination problems that will be difficult to solve relative to the face-wick and conventional water separator designs. Interfaces are considered poor, since five heat exchangers require liquid loop flow. Flexibility is poor because the low flow condenser cannot handle large increases in latent load. The requirements of the noncondensing temperature control heat exchanger also limit flexibility.

Equipment Selection

Ten versions of the four temperature control systems are included in the selection matrix (table 23). Selection is independent of power plant type. The variable-speed fan/face-wicked heat exchanger concept is selected for all three power source designs. Table 24 presents a data summary for reference purposes.

Absolute criteria. - None of the candidates are rejected on the absolute criteria basis.

Performance: The reheat concept using face-wick or a free-moisture water separator rates Very Good on performance since it can best control temperature and humidity separately. The reheat system using an integral-wick heat exchanger is downrated to Good because of its freezing problem during cabin depressurization. All four versions of the variable-speed fan system and the bypass system are rated Good. Some interaction of the temperature and humidity control functions is possible, but this may be rectified by adding some sophistication to the controller. A Fair rating is given to the separate condenser and sensible-heat exchangers due to the possibility of free-moisture generation in the dry heat exchanger.

Safety: All candidates are rated Good on safety. There are no operational problems and the use of water in the coolant loop results in no cabin contamination problems. The selection of nonflammable wicking materials and water transfer disc materials is necessary for all concepts.

Availability/confidence: The integral-wick and conventional heat exchanger concepts have flown on the Apollo mission or are in current development. Development problems include wetted-fin development, water transfer disc life, and freezing during depressurization. There is good confidence that design solutions can be found for these problems.

Primary criteria. - Five candidates are rejected on primary criteria. They include the reheat concepts using the integral-wick and the free-moisture water separators, and the three separate condenser dry heat exchanger concepts.

Reliability: The MTBF ratings for all concepts are Good, because the range is between 10 200 and 12 978 hours, essentially equal to mission length. Addition of the variable-speed motor control and bypass actuator in the variable-flow concepts trades closely with the increased number of coolant flow valves and heat exchangers in the other two concepts.

Crew time: The significant contributors to crew time are the coolant flow control valves and the water transfer disks. These components must be purged of air after maintenance. Air entrainment in the coolant lines could result in serious operational problems. The reheat concepts with six valves and three transfer discs are rated Fair. A Good is given to the separate condenser and cooler candidates because of the reduced crew time with two rather than three water transfer devices. This concept could be improved further by using variable-speed temperature control fans at some increase in an already high equivalent weight. The valves on the three coolers may then be eliminated. The variable air flow concepts rate Good, based mainly on the lowest number of liquid loop valves.

Total equivalent weight: A Good rating is given to the four air-flow modulation concepts and to the reheat concept using a face-wick water separator. These candidates are within 100 pounds of each other and are considered essentially equal. The integral wick and the free moisture water separator designs of the reheat concept are given a Fair rating because they weigh about two hundred pounds more than those rated Good. The Poor ratings given the three separate condenser and cooler designs, as a result of high hardware weight, eliminate these designs from further consideration. The reheat concept utilizing integral wick and free-moisture water separation are also rejected at this level due to the Fair ratings given to crew time and equivalent weight.

Secondary criteria. - The variable-speed-fan concept using a face-wick water separator is selected after evaluation of the secondary criteria. The integral-wick heat exchanger concepts are rated Poor on contamination because of the difficult

TABLE 23
EVALUATION SUMMARY - CABIN TEMPERATURE AND HUMIDITY CONTROL

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts				
		Reheat			Variable speed fan	
CRITERIA / DESIGN		Integral wick	Face wick	Free moisture	Integral wick	Face wick
Absolute	Performance	Good	Very good	Very good	Good	Good
	Safety	Good	Good	Good	Good	Good
	Avail. /Conf.	Good	Good	Very good	Good	Good
Primary	Reliability	Good	Good	Good	Good	Good
	Crew Time	Fair	Fair	Fair	Good	Good
	Equivalent Weight	Fair	Good	Fair	Good	Good
		Eliminated		Eliminated		
Secondary	Contamination		Very good		Poor	Very good
	Interfaces		Poor		Good	Good
	Flexibility		Fair		Good	Good
	Growth		Good		Good	Good
	Noise		Fair		Very good	Good
	Volume		Very good		Very good	Very good
	Power		Good		Good	Good
			Eliminated		Eliminated	Selected

TABLE 23. - Concluded

EVALUATION SUMMARY - CABIN TEMPERATURE AND HUMIDITY CONTROL

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts				
		Air bypass		Separate condenser & cooler		
CRITERIA	DESIGN	Integral wick	Face wick	Integral wick	Face wick	Free moisture
Absolute	Performance	Good	Good	Fair	Fair	Fair
	Safety	Good	Good	Good	Good	Good
	Avaii./Conf.	Good	Good	Good	Good	Very good
Primary	Reliability	Good	Good	Good	Good	Good
	Crew Time	Good	Good	Good	Good	Good
	Equivalent Weight	Good	Good	Poor	Poor	Poor
				Eliminated	Eliminated	Eliminated
Secondary	Contamination	Poor	Very good			
	Interfaces	Good	Good			
	Flexibility	Good	Good			
	Growth	Good	Good			
	Noise	Poor	Poor			
	Volume	Good	Good			
	Power	Good	Good			
		Eliminated	Eliminated			

TABLE 24

TEMPERATURE AND HUMIDITY CONTROL DATA SUMMARY

Data Item		Reheat	Variable Speed	Air Bypass	Separate Condenser/Cooler
MTBF - hours		11 400	11 400	10 300	12 980
Crew Time - hours		51.5	51.5	51.5	35
Total Equivalent Weight-Pounds	Integral Wick	1 638	1 430	1 403	1 796
	Face Wick	1 483	1 393	1 351	1 790
	Free Moisture	1 704	—	—	1 843
Power-Watts	Integral Wick	1 110	998	882	954
	Face Wick	1 350	1 241	1 125	1 014
	Free Moisture	1 746	—	—	1 114
Volume-cu. ft.	Integral Wick	38	35.5	45	58.5
	Face Wick	35	31.5	41	57.5
	Free Moisture	32	—	—	57

decontamination procedures that are required. All other concepts rate Very Good. Interface aspects of the reheat system and the separate condenser and dry heat exchanger concepts are rated Poor because of the larger number of coolant loop interfaces. Line routing between the five or six units, with two compartments and other equipment between the heat exchanger locations, presents many problems. The two variable-airflow concepts rate Good on interfaces. The flexibility of the reheat concept is rated Fair since it depends on high reheater liquid temperatures within the thermal transport system which may not be available. The variable airflow concepts rate Good since they are basically self-contained. Growth is Good for all concepts. A Fair rating on noise is given the reheat system, using a face-wick water separator, due to high fan power. The variable-speed-fan concepts operate generally at a low-speed, so noise is rated Good. Volume is Very Good for the reheat and the variable-speed concepts. Power ratings are generally Good for all candidates passing the primary criteria.

Summary

The variable-speed-fan concept using a face-wick water separator shows Good or Very Good ratings through the three levels of selection criteria. Of the five candidates carried through to the secondary criteria, the four rejected candidates all rated Poor at least once, indicating significant deficiencies in the area of contamination, interfaces, or noise. Also of significance is the fact that the selected candidate, the variable-speed-fan concept using a face-wick water separator, has one of the lowest total equivalent weights of all the candidates considered, and no compromises were required in its selection.

Impact of Mission Parameters

Mission length. - Basic operation of the thermal control system is independent of mission length. Spares and water separator replacements would be reduced for shorter missions and conversely increased for longer missions. No change in the AILSS thermal control system selection would be necessitated by either a shorter or longer mission time.

Crew size. - Cooling requirements will, in general, vary with crew size, due to the direct variation of latent and sensible metabolic heat loads with the number of crew members. Other heat loads, from electronic equipment, etc., are expected to vary in some relation to the crew size; however, the exact relationship cannot be accurately established at this time. It is anticipated that changes in crew size will not alter the AILSS selection of the variable speed fan concept.

Power penalty. - A variation in power penalty between 300 and 750 pounds per kilowatt will have no influence on the concept selected for AILSS, since the variable-speed-fan total equivalent weight rating does not change in relation to the other candidates throughout this power penalty range. At increased power penalties, concepts using free-moisture separators become very noncompetitive due to excessive equivalent weights caused by the high power requirements.

For power-critical systems, the concepts using the least amounts of power are of interest. Integral-wick separators, because of their characteristic low pressure drops, inherently operate at relatively low power levels. The air-bypass concept utilizing the integral-wick separator requires 359 watts less than the selected variable-speed-fan concept (although the total equivalent weights are essentially the same). From a power-critical standpoint, this air-bypass concept appears most attractive; however, very undesirable poor secondary characteristics of contamination would have to be tolerated.

An alternate method of reducing the solar cell electrical power requirements in the atmosphere, temperature and humidity control subsystem is to reduce the cabin sensible cooling requirements. This may be accomplished by utilizing as much liquid cooling equipment as practical. A review of the Design 1 air cooled loads (see table 105, Design 1 Energy Balance) indicates that a 30 percent reduction in the air-cooled heat load is feasible. Assuming that fan power is proportional to the air-cooled loads, a 30 percent fan power reduction is therefore possible. This amounts to a reduction of 1241 watts to 869 watts for the selected variable-speed concept, a saving of 372 watts. If minimizing the power system is desirable, the air-bypass concept using an integral-wick heat exchanger would again be seriously considered, since a saving of 264 watts is realized and the total power consumed (618 watts) is 251 watts less than that required for the selected concept. Of course, the contamination problems must again be seriously considered.

In order to make a firm selection, the relative importance of power must be established and reflected in the selection criteria. Rather than of secondary importance, the power item would probably be considered as one of the primary criteria.

Resupply. - Resupply does not affect system selection, since only spare parts need be supplied.

Flight date. - All components in the atmosphere temperature and humidity control system require further development, but none of the problems are deemed unsurmountable. The quality and performance are expected to increase with development time. Flights with the selected concept are anticipated by 1975.

VENTILATION

Ventilation is necessary to distribute and circulate the air process flow. More specifically, the ventilation requirements cover the following:

1. Distribution (and collection) of thermal and humidity control air, CO_2 process flow, and trace contaminant and bacteria control flow.
2. Avoidance of hot and cold spots.
3. Simulation of free convection film coefficients for metabolic cooling.
4. Avoidance of water vapor, carbon dioxide, and trace gas pockets due to low diffusion rates.

These factors must be provided at minimum power with low noise levels and with the least disturbance to the crew.

In general, local airflow velocities of 50 fpm are adequate to provide the above requirements. Film coefficients of about 0.5 Btu/hr-ft^2 are produced over the crew (and air cooled equipment) without any awareness of a dynamic pressure force. Mass transport rates are increased such that gas mixing within the cabin may be effected in the order of one minute.

Although a specific compartment configuration definition is required for a proper ventilation system design, an estimate can be made of the hardware requirements. Each of the two compartments is taken as one-half of the total volume. Assuming a 5000-cubic-foot compartment volume, 25 feet in diameter by 10 feet high, a cross-sectional flow area of 500 square feet (parallel to compartment axis) exists. Furthermore, assuming a down-and-back flow path through the 500-square-foot dimension, a one-way flow area of 250 square feet is assumed. In order to obtain a 50-fpm flow velocity, a total of 12 500 cfm is required. Again, this is based on a simple cabin arrangement. The flow may be further divided to accommodate compartment and/or equipment locations.

The equipment process flow is 2500 cfm in the crew compartment (1000 cfm in the cabin heat exchanger, plus 1500 cfm from two bacteria control fans) and 2750 cfm in the equipment compartment (2000 cfm from two cabin heat exchangers and 750 cfm from the bacteria control fan). A simple air discharge outlet will produce a 1:1 induced-flow ratio due to the normal momentum exchange between the discharged airflow and the surrounding air. The process air flow, therefore, will contribute twice its actual flow to the required circulation rate. The remaining circulation flow requirement may be determined as follows:

1. In the crew compartment, the circulation flow required is:

$$12\ 500 - 2\ (2500) = 7500 \text{ cfm}$$

2. In the equipment compartment, the additional flow required is:

$$12\ 500 - 2\ (2750) = 7000 \text{ cfm}$$

This flow will be made up of supplementary flow provided by separate circulation fans designed to produce induced flow ratios of 3:1 to 5:1. A single 1500-cfm circulation fan located in each cabin will be capable of providing the 7000 to 7500 cfm supplementary flow requirement.

Although single 1500-cfm fans are assumed for this study, several smaller units, which the total flow adding up to 1500 cfm, may be used. Also, consideration of localized areas such as crew bunks will influence the design. The system schematics presented in the selected EC/LS systems section show the local fans as typical and a ducting arrangement only on the cabin heat exchangers.

The ventilation fan power required is calculated by assuming a 0.2-inch H_2O fan pressure rise and a combined fan-motor efficiency of 40 percent. The circulation power would then be 94 watts per compartment or a total of 188 watts.

HEAT TRANSPORT FLUID CIRCUIT

The liquid heat transport circuit serves all vehicle subsystems requiring heating or cooling. Although there are only a small number of items in the thermal control subsystem, the large number of interfaces with the other subsystems results in a rather complex situation. Design of the coolant circuits for the three system designs is arrived at by considering:

1. selection of heat transport fluid
2. required subsystem temperature and flow and degree of cascading desired
3. location of equipment in the cabins
4. equipment isolation requirements

Water is chosen as the intravehicular heat transport fluid for all three designs and for both low (36° to about 80°F) and high (150° to 210°F) temperature requirements. The selection of water for intravehicular use is based primarily on its nontoxic nature. Exposure of the coolant fluid is almost certain due to the development of a fluid leak, or spillage during the replacement of a component in a liquid line. Following the descriptions of the three heat transport system designs, a further discussion of fluid selection is presented.

Interface temperature requirements for all three power plant designs are shown in table 25. The amount of overlap of temperature requirements enables a series arrangement of components to be used, thus minimizing total flow. It is desirable to use the minimum coolant flow and obtain the highest radiator return temperature. This will reduce the radiator weight (included in the subsystem trades as a heat rejection penalty). Cascading of heat loads is possible in which waste heat from one subsystem may be used to provide heating requirements of another subsystem. The functional interdependence and resulting lack of operating flexibility is the price to be paid for such thermal optimization. In general, these arrangements have been avoided for AILSS critical subsystems. Equipment heating and cooling requirements are provided such that operation is independent of, or sensitive to, upstream load variations.

Physical locations of equipment and piping to and from components within the compartments must be taken into consideration. An internal cabin arrangement is not defined, but it is anticipated that a minimum of two compartments, separated by a pressure bulkhead, will be used. Specific equipment and subsystem locations are discussed under Configuration Considerations in the Selected EC/LS Systems section. The general approach is to minimize pressure bulkhead penetrations, and to keep piping short and simple.

The interfacing of the coolant loop with almost all other subsystems makes it imperative that provision for equipment maintenance not disrupt the entire thermal control circuit.

An investigation indicated that redundant loops do not provide the needed system reliability, but in fact may result in heavy, complex, and low-efficiency hardware. The most striking example lies in the care of a heat exchanger which, in a redundant system, would require three passes, one for the medium to be heated or cooled, and one for each of the redundant coolant loops. Such an item would have a lower efficiency, lower reliability, greater leakage potential, and a much higher weight than a two-pass heat exchanger for the same thermal load. Switching to the redundant pass does not solve the problem as the coolant is still free to leak. Resolution can only be attained by replacing the heat exchanger. Bypass valves on the coolant side allow continuous operation of the circuit during replacement.

Gross leakage is possible in only two areas, in heat exchangers which are discussed above, and in equipment connections. Damage to a tube connection occurs through abuse in breaking and making the connection. This problem is minimized by the use of welded connection throughout the loop up to and including the bypass and isolation valves. Tube connections are only used for components backed up by spares. The use of connections with replaceable seals should control leakage from the source to no more than a minute amount controllable by the humidity control subsystem.

TABLE 25

HEATING AND COOLING INTERFACE REQUIREMENTS

Subsystem	Design 1	Design 2	Design 3
Cabin heat exchangers	40°F cooling	40°F cooling	40°F cooling
CO_2 concentrator condensers	40°F, 60°F cooling	40°F, 60°F cooling	40°F, 60°F cooling
Water chiller & coolers	110°, 60°, 45°F cooling	110°, 60°, 45°F cooling	110°, 60°, 45°F cooling
Waste management system	——	Cool 1200°F air	——
Water reclamation motor	60°F cooling	——	——
Water reclamation condenser	——	55°F cooling	55°F cooling
Cold plates	70-80°F cooling	70-80°F cooling	70-80°F cooling
Water tank heater	——	160°F heating	160°F heating
CO_2 concentrator	——	200°F heating	200°F heating
Water reclamation heater	——	160°F heating	160°F heating
Food preparation Oven heating	——	180°F heating	——

It is thus projected that whatever advantage redundant cooling loops might appear to offer, a single loop can be designed to provide more efficient operation at less weight and with a higher reliability.

Design 1

A water coolant circuit performs the thermal control function in the solar cell-powered Design 1. A typical operating condition is shown on the flow chart in figure 64. Heating requirements are provided by electrical energy directly at the location required because there is no other process heat source available. The transport circuit only performs the cooling functions for the cabin temperature and humidity control heat exchangers, the CO_2 concentrator water condensers, the water reclamation system vapor compressor motor, electronic cold plates, potable water coolers and chillers, and the waste management systems.

The circuit water flow rate is 3600 lb/hr. This value is required to reject the cabin air-sensible and latent design loads, at a 65°F cabin temperature and 55 percent relative humidity (max). The remaining component arrangement is selected to minimize the interactions of the subsystems. The high coolant flow rate makes this possible to a large extent.

The heat sink shown is an intermediate heat exchanger used to transfer internal cabin water circuit heat loads to an external space radiator system circuit.

The space radiator heat sink contains a toxic low-freezing-point fluid and is therefore located external to the pressurized cabins. Radiator fluid into this heat exchanger is controlled to 34 ± 2°F, resulting in a water circuit outlet temperature of 38 ± 2°F. The low limit is set to prevent the freezing of water in the interloop heat exchanger and the higher limit is set to maintain a reasonably high sink temperature for thermal and humidity control.

Coolant water to the EC/LS system is first used for demand cooling of the drinking water from 60° to 45°F in the chiller. A maximum cooling load of 1800 Btu/hr occurs several times a day for a total of about one-half hour. The transient effect of the 0.5°F coolant temperature rise does not adversely affect the circuit operation temperature levels. It is much smaller than the normal sink temperature variations.

Coolant flow out of the chiller is divided among the three condensing cabin heat exchangers and the small condenser in the CO_2 concentrator delivery feed line. An uneven flow split is used to take advantage of the slightly different latent loads in two of the three cabin heat exchangers. The two heat exchangers in the equipment compartment share the maximum latent load of 3000 Btu/hr, while the single heat exchanger in the crew compartment handles the entire load.

Flow out of the two cabin heat exchangers and the CO_2 delivery condenser (all located in the equipment compartment) is joined and then used to condense steam in the CO_2 concentrator effluent air stream. This load is a 15-minutes on, 15-minutes

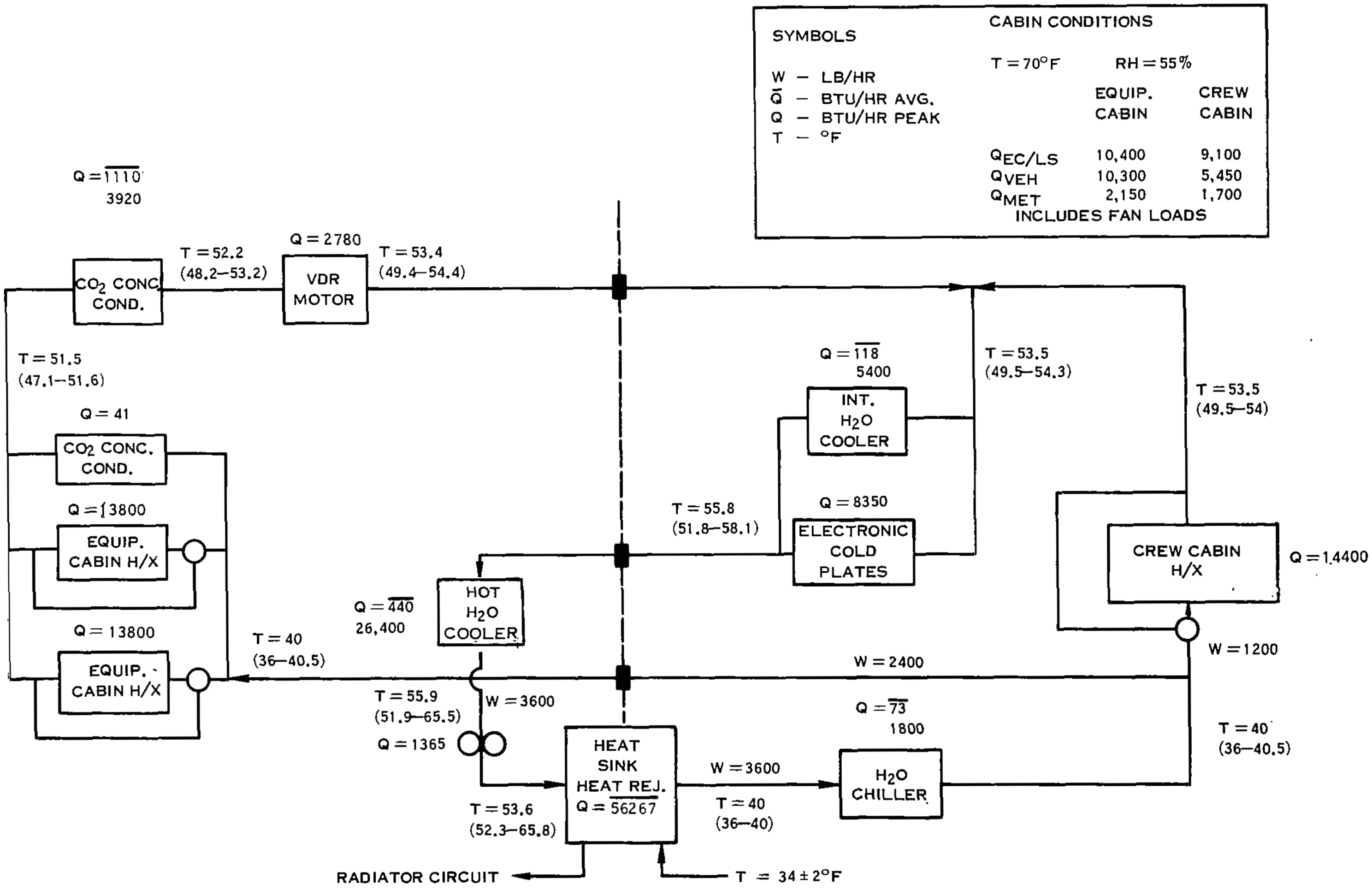


Figure 64. Design 1 Thermal Balance

off cycle, producing a transient temperature variation of slightly more than ± 1/2°F. The outlet coolant flow then cools the water reclamation system vapor compressor motor. This interface could be located in parallel with the CO_2 air stream condenser to minimize interaction, but since the degree of temperature variation is so small, the actual arrangement may be decided by the most convenient piping arrangement in the cabin.

The coolant line out of the vapor compressor motor penetrates the compartment bulkhead and is joined, within the crew compartment, with the coolant flow out of the third cabin heat exchanger. This particular series-parallel piping arrangement is not critical, but it is shown as an effect of the vehicle configuration on the piping schematic. An actual design must minimize the pressurized-wall penetrations and the amount of piping within the vehicle.

At this point, the coolant flow is again split for electronic cold plate cooling and for hot potable water cooling. The flow conditions into the cold plates (the liquid-cooled structure on which the heat-producing electronics are mounted) remain fairly stable. In addition to this, the flow and temperature margin is sufficient to effect close temperature control of critical electronic components as may be required. Bypass lines, regenerative loops, etc., may be located within the black box in which all loads are shown. These loads may also be located in several parts of either or both compartments. The parallel-located water cooler is used to cool 110°F potable water to 60°F, and requires about one-third of the available coolant flow. Waste management system air coolers are located downstream of cold plates.

Transient temperature variations are anticipated at both the cooler and the cold plates outlets. These variations plus other cumulative temperature variations through the coolant circuit could produce a total coolant temperature variation into the hot potable water cooler of about 55° to 75°F. This is quite tolerable, since the 160°F water to be cooled to 110°F allows sufficient control margin, even with the variable inlet temperatures. Additional temperature variations out of this cooler are of no consequence, since it is the last component in the circuit requiring thermal control.

The coolant circuit circulating pump is located downstream of the hot water cooler and just prior to the return to the interloop heat exchanger. This 400-watt pump is located at this point, and not at the minimum temperature point in the system, in order to provide the lowest sink temperature to the circuit.

Line losses are not shown on the flow chart, because they are dependent on the configuration, and at this stage only approximations can be made. Cabin heat load variations and circuit capacities are sufficiently large to accommodate any such losses.

Design 2

Design 2, the solar cell and radiosotope powered system, requires both a coolant circuit and a 200°F process heat cource circuit. The coolant circuit is similar to that of Design 1, with some difference in the water reclamation subsystem interface, with the addition of an air cooler in the waste management isotope circuit. The flow chart for Design 2 is shown in figure 65.

Coolant circuit. - Flow, as in Design 1, out of the radiator interloop heat exchanger first passes through the potable water chiller, and then through the three cabin heat exchangers and the CO_2 concentrator delivery line condenser. At the outlet of the two equipment compartment cabin heat exchangers and the CO_2 feed line condenser, the coolant flow is split. A portion of the flow enters the CO_2 concentrator process air return condenser, and the remainder enters the water reclamation system (VDR) condenser (a thermal distillation process is used in Design 2 rather than a vapor compression system as in Design 1). The condenser of the VDR is more sensitive to temperature than the vapor compressor motor and is therefore located in parallel rather than in series with the CO_2 concentrator condenser.

Flow of the VDR condenser and the CO_2 concentrator condenser joins the return flow from the cabin heat exchanger in the crew compartment. This flow then enters the potable water cooler and the cold plates which are located in parallel. Prior to entering the hot-water cooler, the coolant flow is passed through the waste management system air coolers. Isotope heat used in the vacuum decomposition system is transported by an air-circulation system. This heat is generated continuously at 1200°F and must be rejected during shutdowns and even during cabin depressurizations. Therefore, the air circuit must be run continuously and the contained heat must be rejected to the liquid-coolant circuit. Location of the waste management system air coolers does not affect the operation of the hot potable water cooler.

Heat process circuit. - An isotope-heated liquid circuit is provided to service the CO_2 concentrator steam generator, food preparation oven, potable water tank heating, and the water reclamation system evaporator heater. The temperature requirements within the loop vary from 200°F required in the concentrator steam generator to 150° to 160°F required in the VDR evaporator. The isotope is externally located and supplies slightly less than six kw of thermal energy. An isolated external heat transport system is selected to deliver heat to the 150° to 200°F water loop used to transport the EC/LS equipment process heat. As shown on the Design 2 flow chart, the high-temperature source is controlled by maintaining a 210°F isotope loop inlet to the isotope-to-water-loop heat transport fluid heat exchanger. Due to the transient nature of the process heat requirements, and also due to the variation in isotope energy output during its life, a heat sink must be provided for excess isotope output. A separate space radiator is selected for the isotope circuit. This

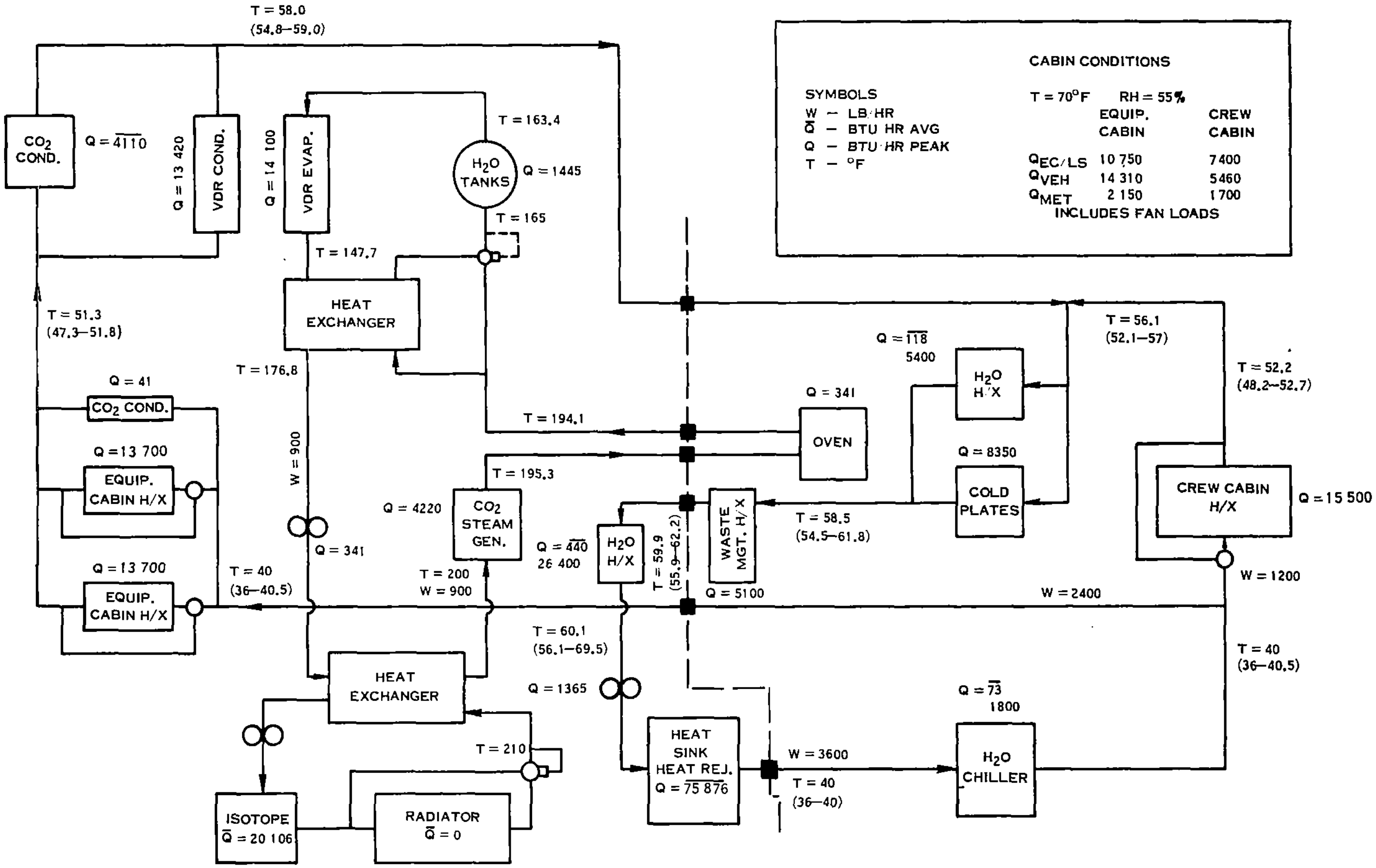


Figure 65. Design 2 Thermal Balance

serves two purposes: it provides a means for process heat temperature control, and it reduces the heat rejection penalty by allowing excess heat to be rejected at a high temperature.

The fluid used in the externally located isotope circuit is a silicone-base liquid which, in addition to its desirable high-temperature characteristics, has an adequate low-temperature freezing point for radiator use.

Water circuit pressure is held at 20 psia, giving a 5-psia margin on maximum vapor pressure. The 210°F control on isotope-loop temperature sets the maximum attainable temperature in the water circuit. In order to conserve energy, the separate high-temperature water loop does not interface directly with the low-temperature circuit. Although it is possible to operate both circuits using the same pump, the resulting flow mixing of the two circuits would result in a normal continuous heat leak to the low-temperature circuit. The resulting 350- to 400-pound heat rejection penalty more than justifies a separate, additional water pumping system. Although two sets of pumps must be used, it is possible to use one central accumulator system.

A 200°F water flow out the isotope interloop heat exchanger is used for CO_2 concentrator steam generation. The 15-minute on-off cycle is charged with a continuous heating penalty. Thermal storage could be used to smooth out the step-wave duty cycle, but the possible weight savings, if any, would not justify the additional complexity.

To obtain the 160°F temperatures required in the potable water tanks and in the VDR, a regenerative heat exchanger is added to the circuit. The temperature drop through this water-to-water heat exchanger is controlled to 170°F for inlet to the water tank heaters. Flow out of the tank heater coils enters the VDR evaporator heater, and then goes back through the regenerative heat exchanger, into the pumps, and back through the interloop heat exchanger.

The flow rate in the high-temperature water loop is 900 lb/hr. This rate is set by the water reclamation system evaporator heater requirements.

The local isotopes used in the waste management system (1200°F, 1.5 kw) and in the catalytic oxidizer (500°F, 224 watts) are air cooled and their output is ultimately transferred to the liquid loop. Catalytic oxidizer heat is dissipated directly to the cabin environment.

Design 3

Liquid circuit designs for the Brayton cycle-powered Design 3 are shown in figure 66. The Design 3 circuit is quite similar to Design 2, but uses Brayton cycle waste heat for thermal process energy. Differences exist in the location of the

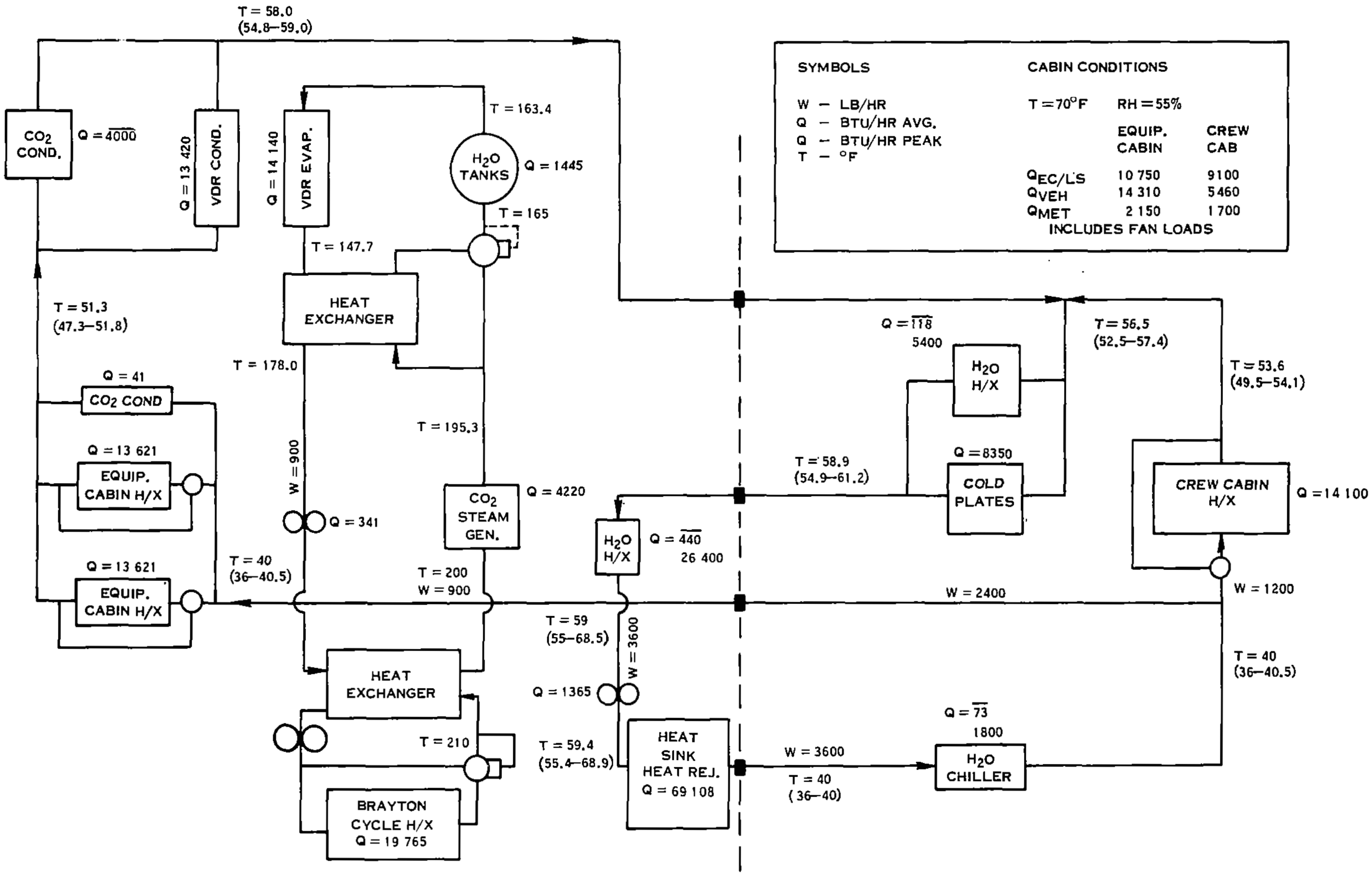


Figure 66. Design 3 Thermal Balance

heating circuit at the interface with the Brayton cycle, and the deletion of the oven heater.

Coolant circuit. - The water coolant circuit is identical to that of Design 2 at the chiller, the condensing cabin heat exchangers, the CO_2 concentrator condensers, the water reclamation system condenser, the warm water coolers, and the electronic cold plate interfaces. Flow out of the cold plates and cooler enters the hot potable water cooler as in Design 1. Flow through the circulating pump and the interloop heat exchanger completes the circuit. A small difference in the cabin heat exchanger loads exists, but this results in no schematic or subsystem changes.
or subsystem changes.

Process heat circuit. - The liquid circuit heating requirements are shown in table 25. Although a 375°F heat source is available, EC/LS heat requirements fall into the 150° to 200°F range. A water-circulating circuit is used inside the vehicle to service the CO_2 concentrator steam generator, the hot water tank heating, and the water reclamation system evaporator heater. A regenerative control method is used as in Design 2 to obtain the required process temperatures throughout the circuit at a minimum expenditure of energy.

The interface with the Brayton cycle heat source is effected externally through an intermediate circuit using a high-temperature fluid. Exposure of a water coolant fluid to a 375°F source would require a 200- to 250-psia pressure level to prevent boiling. Although this is practical for such an external circuit, it is anticipated that system downtime would result in water freezing. Therefore, a high-boiling-point, low-freezing-point fluid, obtained in silicone-based heat transport fluids, is required.

Heat may be extracted from the Brayton cycle primary heat rejection system on demand. The interface circuit has a Brayton cycle bypass which is used to control hot fluid into the interloop system to 210°F, the same temperature as in the Design 2 isotope system. During low or even zero heating demand periods, the control system bypasses the heat source. Excess heat is rejected back into the Brayton cycle radiator, thus eliminating the need for a supplementary radiator in the EC/LS or for heat rejection to the lower-temperature coolant circuit. Further Brayton cycle interface aspects are discussed in a paper by Kirkland and McKhonn. (Reference 8, Selected EC/LS Systems).

Alternate Systems

Both 1600°F and the 375°F heat transport systems were investigated for possible use in Designs 2 and 3, respectively, with other than the selected subsystems. This was necessary to properly evaluate the integration aspects of alternate candidates within the context of the subsystem trade-off sections.

High-temperature isotope heat is in fact used in Design 2 for the catalytic oxidizer, in the food preparation oven, for heating of the vacuum decomposition waste management system, for desorption steam in the ion exchange resin CO_2 concentrator, water reclamation system process heat, and for potable water tank heating. The catalytic oxidizer and the vacuum decomposition processes use air circulation for heat transport and therefore require no high temperature-liquid interface.

Brayton cycle waste heat is used in Design 3 for CO_2 concentrator desorption steam, water reclamation process heat, and for potable water tank heating.

Other possible high-temperature applications within the available temperature ranges include:

Subsystem	Temperature	Designs
CO_2 reduction system heating	1000° - 1600°F	2
Food preparation oven	375°F	3
Molecular sieve CO_2 removal	200°F - 375°F	2, 3
Water reclamation vapor pyrolysis	1100°F	2
Waste processing - vacuum drying	300°F	2, 3
Waste processing - decomposition and oxidation	500° - 1500°F	2

Although alternate possibilities existed, none of the other candidate subsystems using high temperature processes were selected. Safety and maintainability factors outweighed any total equivalent weight savings for all of these situations. Also, any single application would be charged with the inclusion of an independent thermal transport liquid heated system.

Fluid Selection

A heat transport loop fluid selection is necessary for both the low-temperature coolant loop used in all designs, and for a high-temperature process heat loop for the isotope and Brayton cycle Designs 2 and 3. Possible fluids considered in addition to water include nonwater fluids for use in the 400°F range, and fluids capable of practical operation at 1600°F. Selection of the space radiator heat transport fluid is also discussed.

Water. - Water at 200°F is selected as the heat transport fluid primarily because it is nontoxic. The most likely leakage failures will occur in the cabin heat exchangers. Should a toxic coolant be used, the fluid would be collected by the water separators and transferred to the water management subsystem, thus creating a severe contamination problem. Water provides two distinct advantages: 1) the contamination problem is eliminated (collected condensate is already assumed to be contaminated) and 2) minor leakage in the cabin heat exchangers can be tolerated almost indefinitely since coolant makeup during the mission can be obtained from the water management subsystem. Large leaks will produce free moisture to the extent of the accumulator volume and may be mopped up or vacuumed out of the air. While water temperatures in excess of 177 °F will flash into steam at 7.0 psia and present a burn hazard, a more severe hazard would be presented by 400 °F water or other high-temperature fluids. The only disadvantage of water stems from its maximum practical operating temperature, which is 177°F at 7 psia. Operation of the system at a temperature of 400°F would require a pressure of 300 psia to guarantee operation in the liquid range. This pressure represents a design safety factor added to the 247 psia vapor pressure of water at 400°F. Gross leakage or structural failure in such a pressurized system would result in steam ejection throughout the cabin, which would create a serious safety hazard in addition to a maintenance and handling problem.

a serious safety hazard in addition to a maintenance and handling problem.

With application to 400 °F heat transport systems, water still offers the most efficient operation with minimum power requirements. System pressurization represents the only drawback due to the associated steam production which would result from pressure failure or gross leakage. As 400 °F steam presents the same burn hazard as 400 °F liquid when free in the cabin, a pressurized system appears to be a small price to pay when compared to the contamination control equipment required to assure a safe environment with other coolants. Even this contamination control equipment cannot guarantee safe operation in all failure modes, nor can it protect against the contamination of certain adjacent subsystems. For these reasons, a pressurized water system appears to be the most attractive approach to 400 °F heat transport systems if required.

Nonwater fluids. - Use of fluids other than water offers system operation at low pressure but at the expense of efficiency and performance. Their use would produce a greater hazard for the crew through toxicity and, in some cases, flammability. As most of these coolants are either silicone base, organic, or fluorochemicals, this discussion is limited to these basic types. These fluids are used in a variety of industrial heat transport applications and are considered nontoxic by industrial safety standards assuming the work area is well ventilated and has a sealed and outside-vented heat transport loop. But in a closed-cabin spacecraft, vapor levels can reach toxic proportions. These vapors are difficult to remove and would require the development of special contamination control equipment to guarantee safe levels. Certain subsystems and components, such as porous plate water separators, are quite susceptible to contamination and pore clogging by these fluids. In the event of a gross leak failure, virtually all water separators would be clogged before the contamination could be returned to safe levels. This would require the use of additional solvents (i.e., charcoal), both in the water management and the cabin trace contaminant subsystems, to reduce and/or eliminate this additional contaminant. Special tankage is also required in conjunction with these systems to make up the lost coolant. The organic coolants are usually of the biphenyl and terphenyl variety. When these compounds are chlorinated, fire resistance is achieved at no sacrifice to thermal properties. These fluids can be used at low pressures (7 psia) and at temperatures in excess of 600°F. Although these fluids do not create fire hazards, toxicity is a problem along with high pumping power requirements.

The fluorochemicals are usually silicone based and can be made nonflammable, but this appears to lower the possible temperature service to an apparent maximum of 300°F. Operational temperatures in excess of 400°F can be achieved at low pressures but at the expense of flammability. This coolant is also quite volatile at elevated temperatures (49 percent weight loss at 392°F after 12 days). Operation of the nonflammable compounds at higher pressures is possible but not advantageous when compared to similar water systems. In general, toxicity, flammability, and high pumping requirements are the major drawbacks to this fluid approach.

<u>1600°F</u>. - The use of 1600°F isotope heat for heating requirements presents difficulties because of the complexity involved in obtaining a maintainable, safe, and reliable heat transport system. Potential liquid heat transport fluids are limited to liquid metals because of the extreme temperature requirements. Sodium, sodium-potassium, lithium, gallium, and bismuth-lead eutectics each have serious drawbacks through toxicity, contamination, or chemical activity with other cabin substances. Containment presents the most serious problem, because all of these fluids are corrosive to all but a few exotic materials, and even with these, special steps and equipment are required to control their corrosive activity.

System configurations can be either the open or the closed type. System reliability is met in the open system by a scheme of removal and replacement maintenance for failed equipment. Crew safety during component replacement can only be achieved by the development of a zero-gravity flushing and refill system. Even with the required emergency-only flushing equipment and redundant components, complete flushing of a liquid system in zero-gravity operation is difficult.

The closed system offers the best approach from a standpoint of crew safety, as the high-temperature system is never opened to the cabin atmosphere. System reliability is achieved through redundant equipment and parallel loops. All replaceable items used can be replaced external to the system. This makes electromagnetic pumps a good choice as they are externally replaceable. They are also more reliable than rotary pumps for this application because of the elimination of moving parts and the electric properties of the liquid metals. As the system is welded completely shut, metal corrosion represents the only critical failure mode. Overall system reliability is therefore limited by the unpredictability of the corrosive activity of the liquids over a period of 500 days.

The feasibility of using 1600°F heat transport systems for space vehicle applications is therefore restricted by the available fluids and the ability to incorporate these fluids into a safe, maintainable, and reliable system. Even if a nontoxic, chemically inactive, noncorrosive fluid were found, any containment failure would propose such a threat to crew safety that high-temperature heat transport systems within the cabin appear impractical for space use.

Gas cooling. - In previous studies of heat transport systems, consideration was given to liquid coolant systems only, disregarding the use of air as a coolant. In reality, air is the most widely used heat transport medium in the cabin and is also applicable to closed system high temperature loops, as they can be used at temperatures above the boiling point of liquid coolants. Because of their low density, gases are characterized by poor heat transfer properties and require high pressures to produce any efficiency. For example, helium at 100°F and 2000 psi requires 40 times the pumping power required for water to achieve the same removal rates. This ratio is greatly amplified for high temperatures as the pumping requirement for gas is proportional to the temperature squared while for liquids it decreases with temperature. This power penalty, together with high pressure requirements, generally renders gas systems impractical for large-capacity heat transport loops in space vehicles.

Cabin air as a high temperature heat transport fluid, however, is used in the catalytic oxidizer and in the waste management system. Since 3 cfm are required for the catalytic oxidizer and 12 cfm in the waste management system, the pumping power penalties are low enough to justify the use of gas over a high temperature liquid system.

Transport fluid-space radiator. - Many other studies have been performed and vehicles have been designed to use cabin-circulated heat transport fluids selected for space radiator performance. These fluids include the following:

1. FC - 75
2. H_2O/ethylene glycol solutions
3. H_2O/propylene glycol solutions
4. Freons
5. Monsanto Coolanol fluids, etc.

All have freezing points considerably below the 0°F necessary for optimum space radiator performance. Propylene glycol, which is the least toxic of the series, does not compete favorably with the other fluids as a radiator heat transport fluid.

In the selected system concept, the cabin water thermal transport loop interfaces externally to the cabin with the radiator loop containing one of the fluids listed above. A 4° to 6°F temperature results due to the interloop heat exchanger presence (assuming a 90 percent effectiveness). The penalty resulting from this temperature difference is assessed by the heat rejection penalty of the study, given as a function of heat rejection temperature. This results in a heat rejection system penalty increase of approximately 50 pounds, not considering the improved heat transport fluid characteristics of the water within the EC/LS equipment. This penalty is considered worthwhile because it eliminates a toxic material from the cabin and makes system maintenance practical.

WATER MANAGEMENT

CONTENTS

WATER MANAGEMENT

The function of the water management subsystem is to collect and purify waste water and to store and deliver potable water for use on demand. In performing this function, the subsystem is constrained by the contamination control requirement as follows: 1) The water produced by the subsystem must be sterile and free of organic and inorganic toxic material, 2) Stored water must remain sterile, 3) It must be possible to service the equipment routinely without contaminating the stored water, 4) Service operations, such as changing filters and removing sludge, should not contaminate the crew or the atmosphere, and 5) In the event of contamination of the water supply, there must be a means of complete and rapid subsystem sterilization.

The AILSS water management subsystem consists of facilities to collect and purify waste water derived from urine, washwater, and humidity condensate, and to store the resulting potable water in a sterile manner.

The major water reclamation equipment selected for the AILSS mission is vapor diffusion/compression for Design 1 and vapor diffusion for Designs 2 and 3. In all designs, all waste water is processed together in a single unit. The major factors influencing the selection of the two vapor diffusion concepts were:

1. best inherent sterility
2. low maintenance time
3. relatively low equivalent weight

The auxiliary equipment selected includes bacterial filters and high temperature (160°F) storage tanks to control bacterial contamination, and bladderless collection and storage tanks. The former were chosen because of their high positive effectiveness in controlling bacteria and because they do not contaminate the water. Bladderless tanks were chosen because of their high reliability and low maintainability requirements.

The delivery of potable water for use on demand implies supplying specific quantities for specified uses at the proper temperature. Table 26 shows a detailed breakdown of water use, rate of use, maximum use rate, and desired temperature.

POTABILITY REQUIREMENTS

Water potability requirements for space applications have been established by the Space Science Board (SSB) Ad Hoc Panel on Water Quality Standards for Long-duration

TABLE 26

WATER DELIVERY REQUIREMENTS *

Use	Temperature (°F)	Average (lb/day)	Peak (lb/hr)
Food & drink preparation			
Food preparation	160	10.29	120
Drinking & beverage preparation	45	52.62	120
Subtotal		62.91	
Washing machine			
Clothes washing	105	27.10	210
Utensile washing	105	8.00	210
Subtotal		35.10	
Personal Housekeeping			
Shower	105	50.00	240
Local body	105	13.50	240
Housekeeping	105	4.00	120
Subtotal		67.50	
Miscellaneous			
Electrolysis	160	1.84	0.08
Urinal flushing	160	54.00	240.00
Subtotal		55.84	
Total		221.35	

*All quantities are for a 70°F cabin.

Manned Space Missions. These standards are shown with those of the United States Public Health Service (USPHS) and the World Health Organization (WHO) in table 27. The Space Science Board defines microbiological potable water, tested under suitable conditions for aerobic and anaerobic microbial growth and on tissue cultures for cytopathic viruses, as that containing no more than 10 viable organisms per milliliter.

This specific requirement takes into account the fact that extraneous contaminants may be captured during the sampling procedure. It is also understood that in the testing of repeated samples of water, one abnormally high count of organisms in a set (of say five samples) may be rejected as spurious. Another feature of this requirement is that it is dependent on the testing facilities available: during ground testing of hardware, frequent tests for all three types of organisms -- viruses, aerobic, and anerobic microbes -- should be undertaken; during in-flight operation, such frequent testing will not be possible, and other criteria for sterility must be accepted. Thus the goal of this requirement, in its most stringent form, is to be used in ground evaluation studies of the hardware.

The second point that must be considered is the importance of nonliving organic contaminants in the water supply. Normally such materials would not be considered part of the microbiological contamination problem, with the exception of biotoxins. However, simple organic molecules, proteins, and cellular debris are substrates that can support the growth of many strains of microbes. It must be assumed that some viable organisms will find their way into the stored drinking water, and that they will then multiply on any organic residue that is present. Water recovery concepts which produce the lowest levels of organic contaminants are to be preferred from the point of view of biocontaminant control, even if pasteurization of stored water prior to consumption is standard practice, since heat-insensitive bioproducts resulting from growth in the stored water may be as undesirable as the organisms themselves.

Control Methods

For purposes of discussion, the water reclamation concepts can be divided into the following functions, each of which is physically associated with distinct components of the equipment. Other than the actual purification process, they are:

1. Pretreatment of waste water
2. Storage and delivery of purified water

Contamination hazards will be discussed for each function.

TABLE 27

POTABLE WATER STANDARDS

Compound or property	Space Science Board	United States Public Health Service	World Health Organization
Chemical (mg/l)			
Ammonia	—	—	0.50
Arsenic	0.50	0.05	0.05
Barium	2.00	1.00	1.00
Boron	5.00	—	—
Cadmium	0.05	0.01	0.01
Chloride	450.00	250.00	200-600
Chromium	0.05	0.05	0.05
Copper	3.00	1.00	1-1.5
Cyanide	—	0.20	0.20
Fluorine	2.00	1.70	1-1.5
Iron	Unobjectionable	0.30	0.3-1.0
Lead	0.20	0.05	0.05
Magnesium	—	—	50-150
Manganese	Unobjectionable	0.05	0.1-0.5
Nitrate	10.00	45.00	45.00
Selenium	0.05	0.01	0.01
Silver	0.50	0.05	—
Sulfate	250.00	250.00	200-400
Zinc	—	5.00	5-15
Alkyl benzene sulfonates (ABS)	No foam	0.50	0.5-1.0
Carbon chloroform extract (CCE)	—	0.20	0.2-0.5
Chemical oxygen demand (COD)	100.00	—	10.00
Phenols	—	0.001	0.001-0.002
Physical			
Turbidity (Jackson) max.	10.00	5.00	5-25
Color (Pt-Co) max.	15.00	15.00	5-50
Odor (TON)*	Unobjectionable	3.00	Unobjectionable
pH	—	—	6.5(7.0-8.5)9.2
Solids (ppm)** max.	1000.00	500.00	500-1500
Taste	Unobjectionable	—	Unobjectionable
Radiological (c/l)			
Radium-226-alpha	—	3.00	10.00
Strontium-90-beta	—	10.00	30.00
Gross beta emitters	—	1000.00	1000.00
Microbiological			
Coliform test (MPN)***	—	less than 2.2	less than 1.0
Total count/ml.	10.00	—	—

* Threshold Odor Number ** Parts Per Million *** Most Probable Number

Pretreatment

Urine, which represents an important portion of the input to the reclamation system, has two characteristics that have special impact on its reclamation treatment. Although it is essentially sterile when voided by a healthy person, it is an excellent growth medium for bacteria, and rapid bacterial contamination of the storage facilities is to be expected. Also, it contains a significant quantity of relatively volatile nitrogen compounds that break down under bacterial action and temperature ($\cong 120^\circ$F), releasing gaseous ammonia. Because both the bacteria and ammonia pose a contamination hazard, it has been found advisable to pretreat the urine to inhibit bacterial growth and to chemically fix the volatile ammonia. All the concepts considered in this study that process urine add a mixture of chromium trioxide and sulfuric acid to the waste water in the holding tanks to accomplish this. It is believed that these chemicals are the most effective available for this purpose.

Stored Water

Once sterilized, stored water will remain so as long as no leakage of contaminants occurs and no substrate is available for the growth of organisms. In practice, these two possibilities may be very difficult to prevent. In any case, it must be assumed that system failures will occasionally result in contamination of the water supply, and for this reason, provision must be made to 1) sterilize the stored water or, better still, keep the water sterile, and 2) permit temporary sterilization at the point of use (e.g., by an external final filter). A combination of these options is desirable.

Pasteurization and silver ion generation have been suggested as two permanent means of sterilizing stored water. The former, very effective in killing most organisms, would require a heating element in the storage tank capable of raising and holding the water temperature to 160°F for a period of 30 minutes, continuously, routinely, or upon the discovery of contamination.

Silver ion generators are available which will produce 100 ppb of silver ions with a unit weighing one pound (including silver supply and batteries with a 9000 hour life). The available evidence indicates that this level of silver ions in the water would not endanger the health of the crew. Claims for the effectiveness of silver ions generators are not universally accepted, and this method is not recommended for the AILSS system as the sole decontamination device. It may be considered as a possible supplementary method.

Other agents which could decontaminate the stored water include oxidizers such as chlorine or hypochlorite. The former may be too hazardous for use in the closed environment of a space vehicle for long missions. Hypochlorite will render the water unpalatable in high concentrations (50 to 100 ppm), but it is a reasonably effective bactericide at 10 ppm and its levels can be controlled easily. Corrosion is a possible result of such oxidizers.

The ad hoc panel took a strong stand on the question of having the capability to sterilize stored water: it was felt that a positive sterilizing step downstream of the purification point was mandatory and that pasteurization was the only proven method available (as of September 1967). Thus, the AILSS stores potable water continuously at 160°F, and, additionally, uses bacteria filters both up and downstream of the storage tanks to prevent contamination.

Finally, it is desirable to have the capability to sterilize the entire reclamation system with steam in the event of serious contamination problems. Such facilities are provided on the AILSS.

WASTE WATER DESCRIPTION

The waste waters processed are composed of urine, urinal flush water, humidity condensate, and washwater. In the subsequent concept designs, each waste water type or combination of waste water types is taken at its maximum daily average production rate. The maximum daily averages for urine and humidity condensate are a function of cabin temperature in the range of 65°F to 75°F. Maximum urine production, 29.7 lb/day, occurs at the lower temperature while the maximum humidity condensate production rate, 47.6 lb/day, occurs at the upper temperature. If both urine and humidity condensate are processed together, the corresponding maximum production rate, 73.3 lb/day, occurs at the upper temperature and is less than the sum of the individual maximum production rates.

To clarify this point, the five possible ways of grouping these waste waters for processing are shown below in table 28, along with the corresponding design processing rates. In all cases, the urinal water is composed of urine and urinal flush water. The amount of urinal flush water, incidentally, was determined by assuming one pound of hot (160°F) flush water per urination; however, the actual amount needed will depend on final equipment design.

All process units are sized for an eighteen hour a day processing time to provide a maximum repair time of 6 hours in any 24 hour period. Normally, the equipment would process 24 hours per day.

TABLE 28

MAXIMUM WASTE WATER RATES

Water Type/Process Grouping	Daily rate, lb/day	*Hourly rate
Urinal water	83.70	4.65
Humidity condensate	47.60	2.64
Washwater	102.60	5.70
TOTAL	233.90	12.99
Urinal water	83.70	4.65
Humidity Condensate & washwater	150.20	8.34
TOTAL	233.90	12.99
Urinal water & washwater	186.30	10.35
Humidity condensate	47.60	2.64
TOTAL	233.90	12.99
Urinal water & humidity condensate	127.30	7.07
Washwater	102.60	5.70
TOTAL	229.90	12.77
Urinal water, humidity condensate, & washwater	229.90	12.77
TOTAL	229.90	12.77

*Assumes 18 hours per day processing time.

Each of these waste waters presents a number of different contamination levels. The least contaminated water to be reclaimed is the humidity condensate. This water comes from the astronauts' perspired and respired moisture. The major contaminants found in this waste water as those scrubbed from the carrier gas stream in the humidity control heat exchangers. Table 29 shows the typical contamination levels for the condensate water.

Special note was made in the Atmosphere Contamination Control section of this report of the fact that the condensate was being depended on for control of the atmospheric concentrations of butyric acid and pyruvic acid. For complete control, these materials must be subsequently separable from the water by distillation. This appears to be a reasonable assumption because both exhibit relative volatilities with water of 0.08, i.e., water is about 13 times more volatile than either pyruvic acid or butryic acid. This leads to the conclusion that most of these two contaminants will remain in the residuum.

More heavily contaminated than condensate is the washwater. Typical washwater contamination levels are shown in table 30.

TABLE 29

TYPICAL CONDENSATE CONTAMINATION CHARACTERISTICS

Contaminant	Concentration (ppm)
Particulates	25
Dissolved solids	45
Total	70
COD	450 ppm
Odor	positive
Turbidity	positive
Color	positive (yellowish)
pH	7.1
Bacteria	positive (numerous)

TABLE 30

TYPICAL WASHWATER CONTAMINATION LEVELS

Dissolved materials	Concentration (ppm)
Chloride (NaCl)	340
Urea	100
Sebum	180
Lactic acid	75
Other	205
Subtotal	900
Particulates	1000
Detergent	1000
Total	2900
COD	1200 ppm
Odor	positive
Turbidity	positive
Color	positive
pH	4.8
Bacteria	positive (numerous)

Detergent selection is a critical factor that could easily influence the selection of the water management subsystem. Characteristics such as low foaming, no precipitation, easy removal, strong bactericidal action, and good cleaning qualities are all important, but they are not found in any single detergent material.

For this study, the detergent chosen was Rohm and Haas Triton DF-12, a nonionic, low foaming, biodegradable surfacant with good detergent properties. Though a low foamer, it does foam, and in low gravity environments this may cause trouble in the shower water separator and in the washer and dryer where liquid-gas interfaces are present. In this case, silicone base anti-foaming materials may be useful if added at the trouble points. Subsequent removal of anti-foamers has not been shown to date and might prove troublesome; development work in this area is indicated. Finally, it may be necessary to add an effective bactericide to the detergent to achieve bacterial control. Such a bactericide must be sufficiently removable so that it will not build up to levels that are toxic to the astronauts consuming the water. Because so many of these problems have not been satisfactorily resolved, the whole area of detergent selection or development is underscored as a pacing technology.

Urine is the most heavily contaminated by chemicals, even when diluted with urinal flush water, but its bacterial contamination, when fresh, is negligible. Approximate urinal water contamination levels are shown in table 31.

WATER BALANCE

Table 32 summarizes the spacecraft water balance at 70°F with respect to the water management subsystem. The values shown in this table require that the overall water recovery efficiency, η_{RE} (i.e., water recovered/water available) be:

$$\eta_{RE} = \frac{221.35 \text{ lb/day}}{223.00 \text{ lb/day}}$$

$$\eta_{RE} = 0.993$$

Most water reclamation equipment has been tested with urine because it is the most difficult waste from which to recover water, with the possible exception of feces.

Throughout this study it is assumed, unless otherwise noted, that all systems can recover water from all waste sources considered and produce a residuum with a solids concentration of about 50 to 55 percent. This is equivalent to a recovery efficiency with urine of approximately 95 to 96 percent, which appears reasonable on the basis of recent test results with several systems. Consequently, the total processing rate, which contains 224.50 lb/day of water and 1.50 lb/day of solids, would

TABLE 31

TYPICAL URINAL WATER CONTAMINATION LEVELS

Impurities	Concentration (ppm)
Organics	
Urea	8 900
Phenols	590
Amino acids	580
Lactic acid	360
Creatinine	280
Ammonia	180
Citric acid	180
Uric acid	180
Hippuric acid	140
Hydroxyliamine	100
Other organic acid	70
Vitamins	20
Miscellaneous	40
Subtotal	11 620
Inorganics	
Chloride (NaCl)	3 370
Sodium	1 070
Potassium	530
Phosphorous	320
Sulfur	280
Nitrates	140
Calcium	50
Magnesium	40
Subtotal	5 800
Gases	250
Particulates	460
Total	18 130

Note: Concentration shown are for a mixture of urine and urinal flush water at rates of 29.7 lb/day and 54 lb/day respectively.

TABLE 32

AILSS WATER BALANCE AT 70°F

Water source		Quantity (lb/day)
Human		
Urine		27.70
Sweat and respired moisture		38.70
Water in food waste		1.29*
Water in feces		2.25*
Equipment and processes		
Washwater		102.60
Urinal flush water		54.00
	Total	226.54
	Unrecovered	- 3.54*
	Total Available	223.00
Water requirements		
Food and drink		62.91
Washing		102.60
Urinal flush water		54.00
Electrolysis		1.84
	Total required	221.35

*Total water in food waste and feces is unrecovered

yield the required 221.35 lb/day of pure water. In the water reclamation system trade-offs, concepts not capable of meeting the 0.95 recovery rate of urine water are rejected.

In light of the high recovery efficiencies required, it is necessary to discuss the decision not to recover water in feces or food wastes. First of all, unlike urine which leaves the body essentially sterile, fecal material is laden with pathogenic microbial life. Of particular interest is the occasional occurrence in the feces of spores of clostridium botulinum. These spores are resistant to heat, cold, and bactericides.

Yet, given a suitable environment such as the water reclamation system, they can revert to their bacterial form. When this happens, their normal life processes include the excretion of botulinus toxin, one of the most potent poisons known and the cause of botulism poisoning. Therefore, it seems unreasonable to consider the recovery of fecal water. The same reasoning also applies to food wastes, which are normally processed in the same equipment as the feces and would therefore become equally contaminated.

WATER RECLAMATION SUBSYSTEM DESCRIPTION

The state-of-the-art processes capable of meeting the requirements for water reclamation fall into two broad categories: distillation and filtration. The practical distillation systems include various forms of evaporators and condensers. The filtration systems include such methods as electrodialysis, reverse osmosis, and multifiltration.

In the interest of clarity, table 33 lists the water reclamation process steps, their purposes, and their implementation. Table 34 lists the particular candidates studied and identifies the particular processes involved, including their implementation in the subsystems. All concepts are readily amenable to steam sterilization and this is provided for in the final selection. The subsystems are discussed in detail on the following pages.

One of the difficulties that arises in evaluating distillation systems is determining just what distinguishes one from the other. Clearly, pressure is one distinction. If the pressure is significantly below ambient, it is referred to as vacuum distillation; otherwise, it is just distillation. If the process takes place under a carrier gas, either stagnant or circulating, it is called evaporation, and if the vapor passes through a membrane, the term diffusion is used. There are also a number of additional processes or treatments that can be combined with the basic distillation process. Vapor compression is one that is used to permit condensation heat recovery by raising the condensation temperature of the vapor above the evaporation temperature and thus allowing the heat of condensation to provide the heat for evaporation.

A thermoelectric device, operating as a heat pump, can also be used for the same purpose as a vapor compressor. In this application, it has three major advantages over compression. The first is a potentially higher energy utilization in typical vacuum distillation applications. Compressors for such use are limited to efficiencies of 10-15%, which is roughly equivalent to a coefficient of performance (C.O.P.) of 4 to 6. Thermoelectric devices potentially can be made to operate with a C.O.P. of from 10 to 12, or from 2 to 3 times better energy utilization. The second advantage is that thermoelectric modules, because they need not be exposed to either vapor or waste water residuum, are more easily replaced without opening the fluid system

TABLE 33

WATER RECLAMATION PROCESSES

Process				Purpose	Implementation
Pretreatment				To fix volatile ammonia or destroy organics and kill bacteria	1. Chemical treatment 2. Electrochemical treatment
Separation	Distillation		Evaporation	To separate water from dissolved solids by changing its phase through heat addition, lowering its pressure, or both	1. Surface boiling in artifical "G" 2. Flash evaporation across expansion valve 3. Wick humidifier in gas stream 4. Evaporation through membrane
		Optional Steps	Vapor filtration	To stop bacterial and some organic carryover	Vapor permeable membrane
			Heat of condensation recovery	To reduce energy requirements by using heat of condensation to supply heat of evaporation.	1. Vapor compression 2. Thermoelectric heat pump
			Vapor pyrolysis	To oxidize organic vapors and incinerate bacteria	High temperature catalytic oxidation
			Condensation	To recover processed vapor in liquid form	1. Surface condensation and collection in artifical "G" 2. Porous plate condenser-separator 3. Condensing HX-porous plate separator 4. Condensing HX-rotating separator
	Filtration		Electrodialysis	To remove ionic species from water	Electric field across semi-permeable membrane
			Reverse osmosis	To remove water from ionic and organic species	High pressure across semi-permeable membrane
			Multifiltration	To remove low level organic and inorganic contaminants from waste water, particularly washwater and condensate	Charcoal filters, ion exchange resins, or both
Post-Treatment				1. To remove residual organics 2. To remove bacteria	1. Charcoal filters 2. Bacterial filters

TABLE 34 (Page 1 of 2)
WATER RECLAMATION CONCEPTS

Concept Process	Vapor distillation/ compression	Vapor distillation/ thermoelectric	Vapor distillation/ pyrolysis	Flash evaoration/compression/pyrolysis	Flash evaoration/pyrolysis	Closed cycle air evaporation
Pretreatment	Chemical	Chemical	None	None	None	Chemical
Separation Mechanism	Distillation	Distillation	Distillation	Distillation	Distillation	Distillation
Evaporation	Surface boiling under artificial "G" in rotating drum	Surface boiling under artificial "G" in rotating drum	Surface boiling under artificial "G" by rotating impeller	Flash evaporation across expansion valve	Flash evaporation across expansion valve	Evaporation from a wick to a closed loop circulating gas
Vapor filtration	No, but possible	No, but possible	No, but possible	Undefined, but probable	Undefined, but probable	No
Heat of condensation recovery	Yes, by vapor compression	Yes by thermoelectrics	No	Yes, by vapor compression	No	No
Vapor pyrolysis	No, but possible	No, but possible	Yes	Yes	Yes	No, but possible
Condensation	Surface condensation under artificial "G" in rotating drum	Surface condensation under artificial "G" in rotating drum	Porous plate condenser-separator	Condensing HX-porous plate separator	Condensing HX-porous plate separator	Condensing HX-porous plate separator
Post-treatment	Charcoal & bacterial filters	Charcoal & bacterial filters	Bacterial filters	Bacterial filters	Bacterial filters	Charcoal & bacterial

TABLE 34 (Page 2 of 2)

Concept Process	Open cycle air evaporation	Vapor diffusion/ compression	Vapor diffusion	Electrodialysis	Reverse osmosis	Multifiltration
Pretreatment	Chemical	Chemical	Chemical	Charcoal	None	None
Separation Mechanism	Distillation	Distillation	Distillation	Electric field force across semipermeable membrane	High pressure across semipermeable membrane	Adsorption on charcoal or ion exchange resin or both
Evaporation	Evaporation from a wick to an open loop circulating gas.	Evaporation - diffusion through membrane	Evaporation - diffusion through a membrane and stagnant gas passage.	Not applicable	Not applicable	Not applicable
Vapor filtration	No	Yes	Yes	Not applicable	Not applicable	Not applicable
Heat of condensation recovery	No	Yes, by vapor compression	No	Not applicable	Not applicable	Not applicable
Vapor pyrolysis	No, but possible	No, but possible	No	Not applicable	Not applicable	Not applicable
Condensation	Condensing HX-porous plate separator	Porous plate condenser-separator	Porous plate condenser-separator	Not applicable	Not applicable	Not applicable
Post-treatment	Charcoal & bacterial	Charcoal & bacterial filters	Charcoal & bacterial filters	Bacterial filters	Charcoal & bacterial filters	Bacterial filters

proper. Finally, they are more easily incorporated with a wider range of distillation schemes than a compressor. One example application is shown in the concepts that follow, but others are possible. The vapor diffusion concept is particularly adaptable, and even air evaporation, with which compression is not practical, can be adapted to the use of thermoelectrics. It is therefore recommended that a serious development effort be made to make thermoelectrics available for use in water reclamation applications.

To reduce or eliminate bacteria and to fix the volatile free ammonia that would otherwise carry over into the condensate, various chemical pretreatments are used. The most successful is a mixture of sulfuric acid and chrominum trioxide. Charcoal post treatments are also usually required to remove any residual organics that are present in the condensate. Another pretreatment process, applicable to any distillation or filtration process, electrochemically breaks down urea and other organics to N_2, CO_2, H_2, and H_2O. An intermediate treatment process, vapor pyrolysis, can also be used to eliminate all volatile carryover contaminants, including ammonia and bacteria. Pyrolysis can also be applied to the humidification systems, though with greater penalty and difficulty because of the necessity of heating and cooling large quantities of carrier gas as well as vapor. In addition, membrane barriers can be used to filter the vapor, and this procedure can be applied to nearly any distillation system. The membranes are also useful for low gravity gas-liquid interface control.

The filtration processes are more straightforward. Basically, they employ membranes to act as semipermeable barriers. In one approach, high pressure is used to force water through the membrane that holds back the contaminants much like a sieve. Another approach uses an electric field to move the contaminants through a membrane and out of the water. The latter is useful only for ionic contaminants and must be preceded by some form of organic removal process, such as the electrochemical pretreatment process mentioned earlier, or treatment with large quantities of charcoal.

Neither filtration process mentioned previously is suitable for water recovery from urine, but they can be used for other waste waters. A third filtration process, multifiltration, is also unsuitable for urine recovery but is useful for washwater and condensate reclamation. This process uses charcoal, ion exchange resins, or both to physically or chemically remove contamination from the water.

Vacuum Distillation/Compression

Vacuum distillation/compression refers to a vacuum distillation subsystem with some type of artificial gravity and intermediate vapor compression. The subsystem presented here employs chemical urine pretreatment, a rotary drum vacuum distillation unit with an integral vapor compressor, and a post-treatment section of bacteria filters and a charcoal filter. A data sheet and schematic of this subsystem is included as figure 67.

Waste water is received and stored in the pretreatment tanks, where a mixture of chromium trioxide and sulfuric acid from the chemical storage tanks is added to chemically fix the free ammonia and kill the bacteria. Two tanks are used; one receives waste water while the other discharges collected water to the still. The treated water feeds from the pretreatment tank into a circulation loop that includes the rotating still. As the waste circulates through the evaporator, the water vaporizes at near ambient temperature; a low pressure is maintained by a vent to space. In the compressor, the vapor pressure and temperature are raised above the levels in the evaporator so that a temperature difference exists between the condenser and evaporator. Thus, when condensation takes place, the heat of condensation is transferred by conduction to the evaporator and is therefore conserved. A hydrophobic screen and liquid filter is required at the compressor inlet to prevent contaminated fluid carryover into the condenser.

The condensate is continuously removed and pumped through a series of charcoal and bacteria filters. If either of the two conductivity sensors indicate unsatisfactory water, the processed flow is automatically diverted to the urinal. At the same time, the process feed valve is closed and a shutdown warning signal is given so that the necessary repairs may be made. Unless the failure is in the still itself, still rotation is maintained.

When one pretreatment tank is emptied, the feed valve automatically closes the empty tank and opens the other tank so that the processing continues without interruption. At the same time, the waste water feed is switched to the empty tank.

When the solids concentration in the circulation loop reaches 50 percent by weight as indicated by the solids sensor, the circulation loop residuum is automatically fed to the waste management system for disposal. As this happens, fresh waste water from the pretreatment tank is drawn into the circulation loop until the solids concentration reaches a predetermined low level. The residuum dump valve then closes and the processing continues.

Absolute criteria. -

Performance: Recovery efficiency for this subsystem is predicted to be 95 percent with undiluted urine. At this level of performance, it should be satisfactory for use in the AILSS. Water potability has been good but can undoubtedly be improved; a typical analysis is shown in table 35. Additional performance data is shown in figure 67.

Safety: This system is quite safe in normal operation. There does exist, however, a significant contamination potential if liquid-vapor interface control is lost because of a rotational failure. Subsequent repair work, which might necessitate opening the evaporator, would require great care to avoid contamination of the cabin and crew.

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Vacuum Distillation/Compression

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999258 MTBF: 13 600 hr

Spares/Redundant (R) Units:

1 - Check Valve
1 - Chem. Tank
1 - Chem. Injector
3 - Pump
2 - Regulator
2 - Sol. 4-way Valve
2 - Controller
3 - Conductivity Sensor
1 - Charcoal Canister
1 - Bacteria Filter Canister
3 - Water Pump
2 - Solids Sensor
2 - Sol. 3-way Valve
1 - Man. 3-way Valve
2 - Sol. Shutoff Valve
2 - Evap/Cond. Assy.
3 - Compressors Assy.

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	13.10	3.5

EQUIVALENT WEIGHT (lb):[a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	346	346	346
Expendables	289	289	289
Spares/Redundant Units	445	445	445
Electrical Power	452	452	452
Thermal Power	0	0	0
Radiator Load	137	137	137
Water Contingency Debit	+ 100	+ 100	+ 100
Total Equivalent Weight	1769	1769	1769

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):			
Electrical	1005	1005	1005
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	12	21	33

Figure 67. (Page 1 of 2)

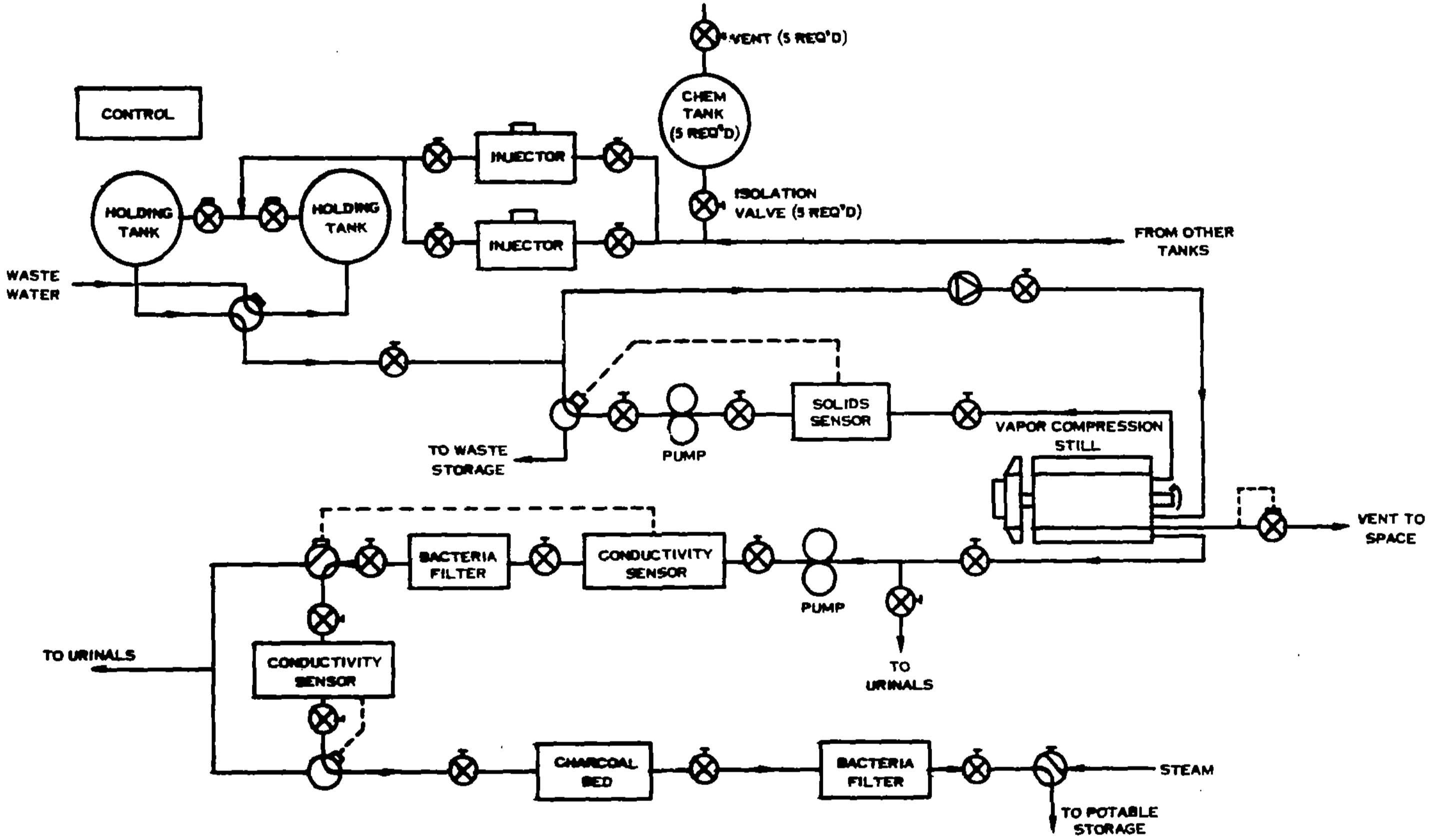


Figure 67. Vacuum Distillation/Compression Concept (Page 2 of 2).

TABLE 35
TYPICAL WATER ANALYSES

Criteria		Standard	Vacuum distillation/ *compression* (a)	Vacuum distillation/ *thermoelectric* (a)	Vacuum distillation/ pyrolysis (b)	Flash evaporation/ pyrolysis - flash evaporation/ compression/ pyrolysis (c)	Air evaporation, open & closed (b)	Vapor *diffusion*- vapor diffusion/ *compression* (b)	Electrodialysis (a)	Reverse osmosis (e)	Multifiltration (c, d)
Microorganisms, no/ml		10	——	——	0	0	——	——	——		0
Physical	Turbidity, Jackson U.	10	25	25	2	0.34	0	4	25	No reliable data available for the waste waters of interest	Clear
	Color, Chloroplatinate U.	15	5	15	5	<5	1	2	-		None
	Odor	U	111	9.2	None	None	-	-	-		None
	pH	5-8	8.1	8.0	5.3	7.5	7.0	6.5	7.6		7.2
	Conductivity, μmhos/cm.	1700	-	440	14	33	15.5	79.9	490		65
	Total Solids, mg/1	1000	86	217	10	20	0.008	70.0	1462		70
	Taste	U	-	-	-	None		-	-		Sat.
Chemical - *Inorganic*	Ammonia (NH_3), mg/1	0.50	0.025	15.0	0.4	-	1.32	1.51	15.0		neg.
	Arsenic (AS_3)	0.50	0.10	0.01	0.025	0.008	-	-	0.07		-
	Barium (B_4)	2.00	0.0006	0.101	0.08	0.0004	-	-	-		-
	Boron (B)	5.00	-	0.019	0.03	-	-	-	0.225		-
	Cadmium (Cd)	0.05	0.0003	0.016	0.005	0.02	-	-	0.020		-
	Chloride (Cl)	450.00	4.0	24.0	18.0	0.1	0.50	0.5	53.0		neg.
	Chromium (Cr)	0.50	*0.0001*	*0.003*	*0.021*	*0.002*	*0.01*	N.D.	*0.005*		-
	Copper (Cu)	3.00	0.0008	0.005	0.50	0.0008	0.01	0.056	0.010		-
	Cyan*ide* (Cn)	*0.20*	-	-	-	-	-	-	-		-
	Fluorine (F)	2.00	-	-	-	0.12	0	N.D.	-		-
	Iron (Fe)	U	0.0003	0.033	-	0.004	0.038	0.01	0.029		-
	Lead (Pb)	0.20	0.0006	0.016	0.045	0.004	-	-	0.020		-
	Magnesium (Mg)	125.00	0.12	7.8	-	-	-	-	-		-
	Manganese (Mn)	U	0.0001	0.048	-	0.004	0.05	0.078	0.005		-
	Nitrate (NO_3)	10.00	0.01	0.27	-	1	0.042	0.016	1.60		-
	Selenium (Se)	0.05	-	-	-	-	-	-	-		-
	Silver (Ag)	0.50	0.00001	0.002	0.005	0.004	-	-	0.001		-
	Sulfate (SO_4)	250.00	4.0	44.0	-	1.5	0	1.2	35		neg.
	Zinc (Zu)	5.00	0.003	0.030	-	0.004	-	-	0.040		-
Chemical-organic	Alkyl benzene sulfonate	0	-	0.02	-	-	0	-	-		-
	Carbon	10.0	-	40	-	-	-	-	985		-
	C.O.D.	100.0	18	75	23	7.2	-	-	2300		85
	Creatinine	0.1	-	-	-	-	-	-	-		-
	Phenols	0.001	-	-	-	0.05	-	-	-		-
	Urea	2.0	-	44	-	-	-	N.D.	125		-
Radiologic	Ra^{266} (α emitter), $\mu\mu$c	3	-	-	-	-	-	-	-		-
	Sr^{90} (β emitter)	10	-	-	-	-	-	-	-		-
	Gross β emitter	1000	-	-	-	-	-	-	-		-
Water Type			Urine - pretreated with hypochlorite & anti-foamer	Urine-pretreated with trimethylol *nitromethane*	Urine - no pretreatment specified	Urine - no pretreatment specified	Urine - pre-treated with chromic acid	Urine - pre-treated with chromic acid	Urine - no pretreatment specified		Humidity condensate from Air Force Simulator
Water Quantity			16.7 lb/hr.	3.5 lb (rate unspecified)	15.4 lb/day	0.6 lb/hr.	1.29 lb/hr.	0.2 lb/hr.	1.88 lb (rate unspecified)		0.132 lb/hr.

[a] AMRL
[b] Vendor supplied
[c] Vendor reports
[d] *Humidity condensate only*
[e] Washwater and humidity condensate only

U - Unobjectionable
N.D. - Not detected
- Indicates no test made

NOTE: The values shown in this table are for comparison against the standard, not for comparison between concepts.

Availability/confidence: The vacuum distillation/compression concept can, with a strong effort, be developed for a flight as early as 1974. Development is now well into the prototype development phase.

Stills for this concept have been developed by several companies. While the most recent stills represent prototype hardware, their mechanical performance has not been encouraging. Seal and compressor difficulties remain as problems. The maximum recovery efficiency achieved to date has been about 93 percent with urine.

Primary criteria. -

Reliability: The mean time between failures (MTBF) for this concept is 13 600 hours. Five chemical tanks (four out of five are required for mission completion) and redundant injectors must be installed, because maintenance will not be permitted in this section. With 32 additional miscellaneous spare components, the overall reliability has been calculated to be 0.999258.

Crew time: Scheduled maintenance of this unit involves regular replacement of the bacteria and charcoal filters. This operation requires steam purging of the unit before and after replacement and is estimated to require 131 hours per mission.

Unscheduled maintenance involves replacement of several miscellaneous parts subject to failure. Among these, the replacement of a compressor assembly, which involves disassembly of the still and the attendant difficulty in disposing of the residuum with loss of rotationally induced artifical gravity, is viewed as a particularly high stress operation. Whenever any such operations are performed, steam purging is required for sterilization before and after replacement. Unscheduled maintenance time is estimated to be 3.5 hours per mission.

Equivalent weight: The equivalent weights for this concept are shown on the data sheet. The weights shown are for a processing rate of 12.77 lb/hr. This system employs a residuum circulation loop with a solid sensor that, in effect, controls the overall recovery efficiency. A water contingency debit of 100 pounds is therefore charged against this concept to allow for a reasonable operating range of the sensor.

Secondary Criteria. - Under normal operation, this system will not contaminate the external systems, but since there is no positive bacterial control within the still, there is the possibility of bacterial contamination if the unit is opened for repairs. Interfaces are maintained with the waste management system and the power supply system. This system is fairly flexible in that it is not greatly affected by changes in cabin pressure, but gross changes in cabin temperature can alter the boiloff rate and greatly influence compressor performance. Because heat is conducted across a fluid boundary layer, the heat transfer rate is influenced by the solids concentration; marked improvement in recovery efficiency is quite expensive from a thermal point of view. Noise levels, considering the compressor, can be expected to be fairly high. Volume for the distillation units is low compared to their auxiliary equipment, so their overall volume is about average. Total electrical power if fairly low and steady.

Vacuum Distillation/Thermoelectric

This water reclamation system is another vacuum distillation process very similar to the vapor compression unit just discussed. The difference lies in the method of obtaining the heat of condensation. Instead of compressing the vapor to increase the temperature level, a thermoelectric device is used as a heat pump between the evaporator and condenser. The unit is therefore quieter and has less moving parts.

This system consists of a pretreatment section, a rotating drum with thermoelectric modules, and a post-treatment section. A schematic is shown in figure 68.

Waste water is received and stored in the pretreatment tanks where a mixture of chromium trioxide and sulfuric acid from the chemical storage tanks is added to chemically fix the free ammonia and kill the bacteria. Two tanks are used; one receives waste water while the other discharges collected water to the still. The treated water feeds from the pretreatment tank into a circulation loop that includes the rotating still. As the waste water circulates through the evaporator, the water vaporizes at a near ambient temperature; a low pressure is maintained by a vent to space. The vapor condenses at a slightly lower pressure and temperature on a surface in intimate contact with the cold junctions of a thermoelectric pile. This energy is then transferred to the hot junctions of the pile, which contact the evaporator surface, by means of electrical energy addition to the pile.

The condensate is continuously removed and pumped through a series of charcoal and bacteria filters. If either of the two conductivity sensors indicate unsatisfactory water, the processed flow is automatically diverted to the urinal. At the same time, the process feed valve is closed and a shutdown warning signal is given so that repairs may be made. Unless the failure is in the still itself, still rotation is maintained.

When one pretreatment tank is emptied, the feed valve automatically closes the empty tank and opens the other tank so that processing continues without interruption. At the same time, the waste water feed is switched to the empty tank.

When the solids concentration in the circulation loop reaches 50 percent by weight as indicated by the solids sensor, the circulation loop residuum is automatically fed to the waste management system for disposal. As this happens, more waste water from the pretreatment tank is drawn into the circulation loop until the solids concentration reaches a predetermined low level. The residuum dump valve then closes and processing continues.

Absolute criteria. -

Performance: Recovery efficiency for this system is predicted to be 95 percent with undiluted urine. At this level of performance, it should be satisfactory for use in the AILSS. Water potability has been good but can undoubtedly be improved; a typical analysis is shown in table 35. Additional performance data is found in figure 68.

Safety: This system is quite safe in normal operation. There does exist, however, a significant contamination potential if liquid-vapor interface control is lost because of a rotational failure. Subsequent repair work, which might necessitate opening the evaporator, would require great care to avoid contamination of the cabin and crew.

Availability/confidence: The vacuum distillation/thermoelectric concept can, with an unusually strong effort, be developed for a flight as early as 1976. Development of the basic equipment is well into the prototype stage, but the thermoelectric elements, for reasons to be explained later, are considered only in the research phase. No work is currently being done on this concept.

At the present state of the art, the individual thermoelectric elements have acceptably long life, but modules made up of such elements in series do not. To achieve satisfactory life performance, the same type of highly automated, rigidly controlled production techniques now used with semi-conductors would be required. Economically, this would require a very high cost or, alternatively, dependence on an unexpected upsurge in commercial usage.

Other problems also exist but these are mostly of a mechanical nature such as seals and, though serious, should be solvable in the stated development period. Recovery efficiency has been from 85 to 90 percent with urine, but 95 percent recoveries should be attainable.

Primary criteria. -

Reliability: The MTBF for this concept is 14 100 hours. Five chemical tanks (four out of five required for mission completion) and redundant injectors must be installed because maintenance will not be permitted in this section. With 32 spares, reliability is calculated to be 0.999358 for the 500 day mission.

Crew time: Scheduled maintenance of this unit involves regular replacement of the bacteria and charcoal filters. This operation requires steam purging of the unit before and after replacement and is estimated to require 131 hours per mission.

Unscheduled maintenance involves the replacement of several miscellaneous parts including the thermoelectric elements. Because the liquid-vapor interface control is

SUBSYSTEM: **Water Management - Reclamation**

CONCEPT: **Vacuum Distillation/Thermoelectric**

FLIGHT AVAILABILITY: 1976
(1970 go-ahead)

RELIABILITY: 0.999358

MTBF: 14 100 hr

Spares/Redundant (R) Units:

- 2 - Evap./Cond. Assy.
- 3 - Thermoelectric Module Assy.
- 1 - Check Valve
- 1 - Chemical Tank
- 3 - Cond. Pump
- 3 - Conductivity Sensor
- 1 - Chem. Injector
- 1 - 3-way Diverter Valve
- 3 - Feed Pump
- 2 - Solids Sensor
- 1 - Charcoal Canister
- 1 - Bacterial Filter Canister
- 2 - 3-way Sol. Valve
- 2 - Regulators, Vent
- 2 - Controller
- 2 - 2-way Sol. Valve
- 2 - 4-way Sol. Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	131.0	3.4

EQUIVALENT WEIGHT (lb):[a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	323	323	323
Expendables	289	289	289
Spares/Redundant Units	428	428	428
Electrical Power	422	422	422
Thermal Power	0	0	0
Radiator Load	119	119	119
Water Contingency Debit	100	100	100
Total Equivalent Weight	1681	1681	1681

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):			
Electrical	936	936	936
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	13	21	34

Figure 68. (Page 1 of 2)

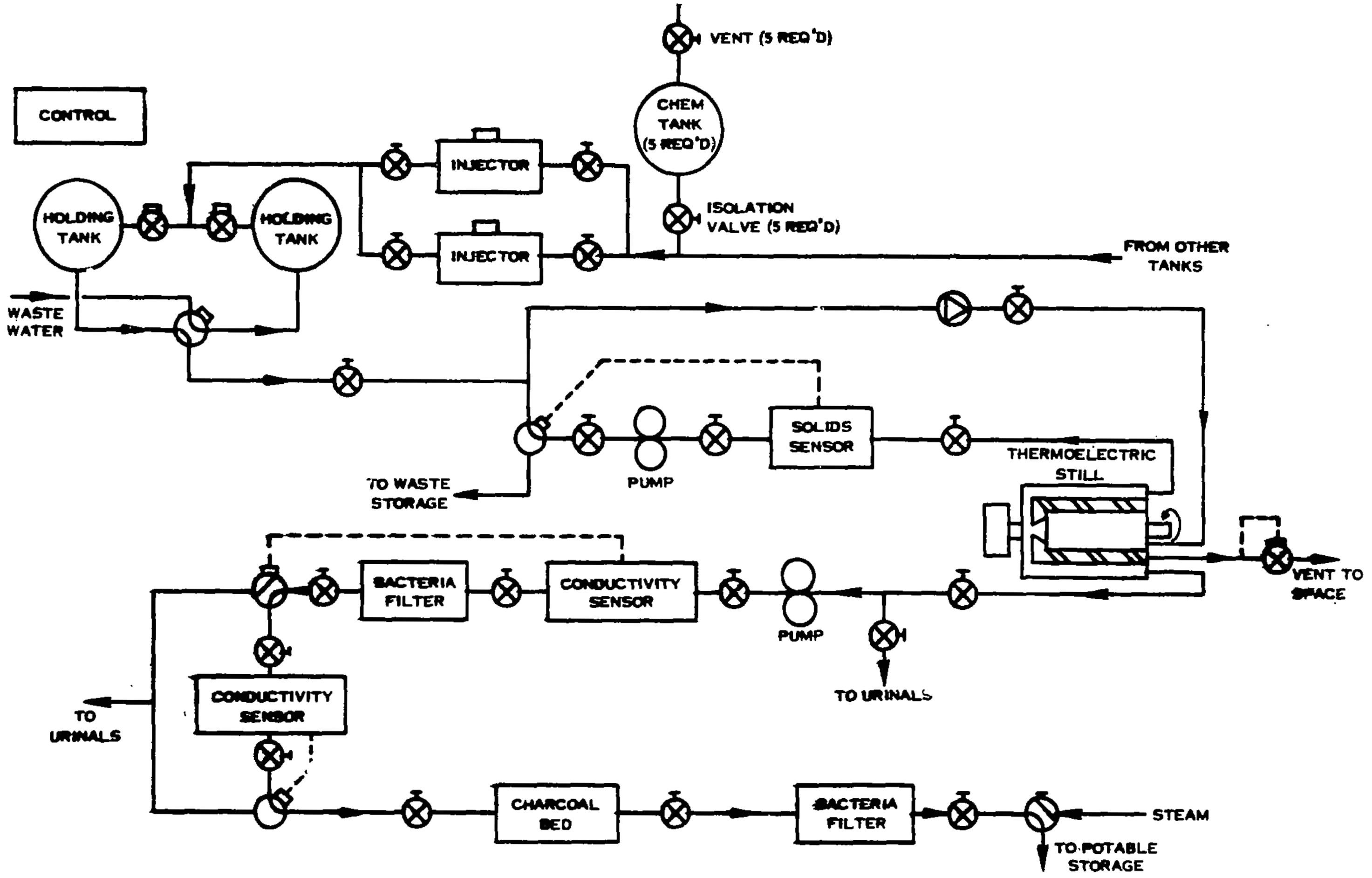


Figure 68. Vacuum Distillation/Thermoelectric Concept (Page 2 of 2).

induced by rotation of the unit, added crew stress will be present if any of these repairs require the stopping of still rotation. Whenever repairs are required, steam purging is necessary for sterilization before and after component replacement. These operations are estimated to require about 3.4 hours per mission.

Equivalent weight: The equivalent weights for this concept are shown on the data sheet. The weights shown are for a processing rate of 12.77 lb/hr. This system employs a residuum circulation loop with a solid sensor that, in effect, controls the overall recovery efficiency. A water contingency debit of 100 pounds is, therefore, charged against this concept to allow for a reasonable operating range of the sensor.

Secondary Criteria. - Under normal operation, this system will not contaminate external systems, but because there is no positive bacterial control within the still, bacterial contamination is a possibility if the unit is opened for repairs. Interfaces are maintained with the waste management system and the power supply system. This system is fairly flexible in that it is not greatly affected by changes in cabin pressure, but changes in cabin temperature can alter the boiloff rate. Because heat transfer occurs across a fluid boundary, it is influenced by the solids concentration, making a marked improvement in the recovery efficiency thermally quite expensive. The noise level should be low. The volume of the distillation unit is low compared to the auxiliary equipment, so, overall, the total volume is about average. Total electrical power is low and steady.

Vacuum Distillation/Pyrolysis

The vacuum distillation/pyrolysis water reclamation system uses vacuum distillation coupled with pyrolysis of the distillate vapor prior to condensation. This feature eliminates organic carryover and kills bacteria in one operation. Unlike vapor compression and thermoelectric vacuum distillation, it employs no means for recovering the latent heat of condensation, although this feature could undoubtedly be added, as could vapor pyrolysis on the other concepts. This system consists of urine holding tanks, and pretreatment section, an evaporator, the pyrolysis unit, a condenser, a condensate pump, a conductivity sensor, and a bacterial filter. A schematic is shown in figure 69.

Waste water is received and stored in the holding tanks, where a mixture of chromium trioxide and sulfuric acid from the chemical storage tanks is added to aid in bacteria control. Two tanks are used; one receives waste water while the other discharges collected water to the still. From the holding tanks, the waste water is fed into a circulation loop that includes the still. As the waste water circulates through the evaporator, it is vaporized at low pressure by the addition of heat. In Design 1, this heat is supplied by an installed electrical heater; in Design 2, it is supplied from an isotope-heated fluid loop; in Design 3, it is supplied from a fluid loop heated with Brayton cycle waste heat. Low gravity evaporator gas-liquid interface control is achieved by rotating a paddle-wheel impeller within the evaporator chamber.

From the evaporator, the vapor goes to a catalytic pyrolysis unit where it is heated to 1200° to 1600°F in the presence of oxygen. This process oxidizes all organic contamination carryover and incinerates any microbiological carryover. Heat to this unit is supplied from an electrical heater in Designs 1 and 3, and from an installed isotope source in Design 2. When the process flow through the pyrolysis unit is stopped due to system failure, a means of dissipating the heat from the isotope in Deisign 2 must be provided. This is accomplished by incorporating an additional separate gas circuit into the unit in parallel with the processing circuit. The equivalent weights shown later reflect the necessary pump, heat exchanger, ducting, and power penalties to accomplish this.

There also exists a low temperature pyrolysis unit that operates with a catalyst at about 300°F. While the advantages of lower power, lower weight, and improved operating safety are obvious, the performance of this unit does not yet meet a minimum standard for water purity, at least with respect to ammonia removal.

The vapor finally condenses in a separate porous plate condenser where the oxidized gases are vented to space. The condensate is continuously removed and pumped through a series of bacteria filters. No charcoal filters are used in this system because the pyrolysis unit removes the organics. If either of the two conductivity sensors indicates unsatisfactory water, the processed flow is automatically diverted to the urinal. At the same time, the process feed valve is closed and a shutdown warning signal is given so that the necessary repairs can be made. Unless the failure is in the evaporator itself, impeller rotation is maintained.

When one holding tank is emptied, the feed valve automatically closes the empty tank and opens the other tank so that processing continues without interruption. At the same time, the waste water feed is switched to the empty tank.

When the solids concentration in the circulation loop reaches 50 percent by weight as indicated by the solids sensor, the circulation loop residuum is automatically fed to the waste management system for disposal. As this happens, fresh waste water from the holding tank is drawn into the circulation loop until the solids concentration reaches a predetermined low level. The residuum dump valve then closes and processing continues.

Absolute criteria. -

Performance: Recovery efficiency for this system is predicted to be 95 percent with undiluted urine. At this level of performance, it should be satisfactory for use

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Vacuum Distillation/Pyrolysis

FLIGHT AVAILABILITY: 1974 (Designs 1 & 3), 1976 (Design 2)
(1970 go-ahead)

RELIABILITY: 0.999606 MTBF: 14 000 hr

Spares/Redundant (R) Units:

- 3 - Evaporator Assy.
- 2 - Pyrolysis Assy.
- 1 - Check Valve
- 3 - Water Pump
- 2 - 4-way Sol. Valve
- 1 - Chem. Injector
- 3 - Pump
- 3 - Conductivity Sensor
- 2 - Controller
- 2 - Heater Control
- 1 - 3-way Diverter Valve
- 2 - Condenser
- 1 - Bacterial Filter Canister
- 2 - Solids Sensor
- 2 - 3-way Sol. Valve
- 2 - O_2 Control Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	38	2.6

EQUIVALENT WEIGHT (lb):[a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	336	386	336
Expendables	155	155	155
Spares/Redundant Units	513	513	513
Electrical Power	2170	18	291
Thermal Power	0	301	0
Radiator Load	655	655	655
Water Contingency Debit	100	100	100
Total Equivalent Weight	3929	2128	2050

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):	Design 1	Design 2	Design 3
Electrical	4835	40	646
Thermal	0	4795	4189

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	11	18	29

Figure 69. (Page 1 of 2)

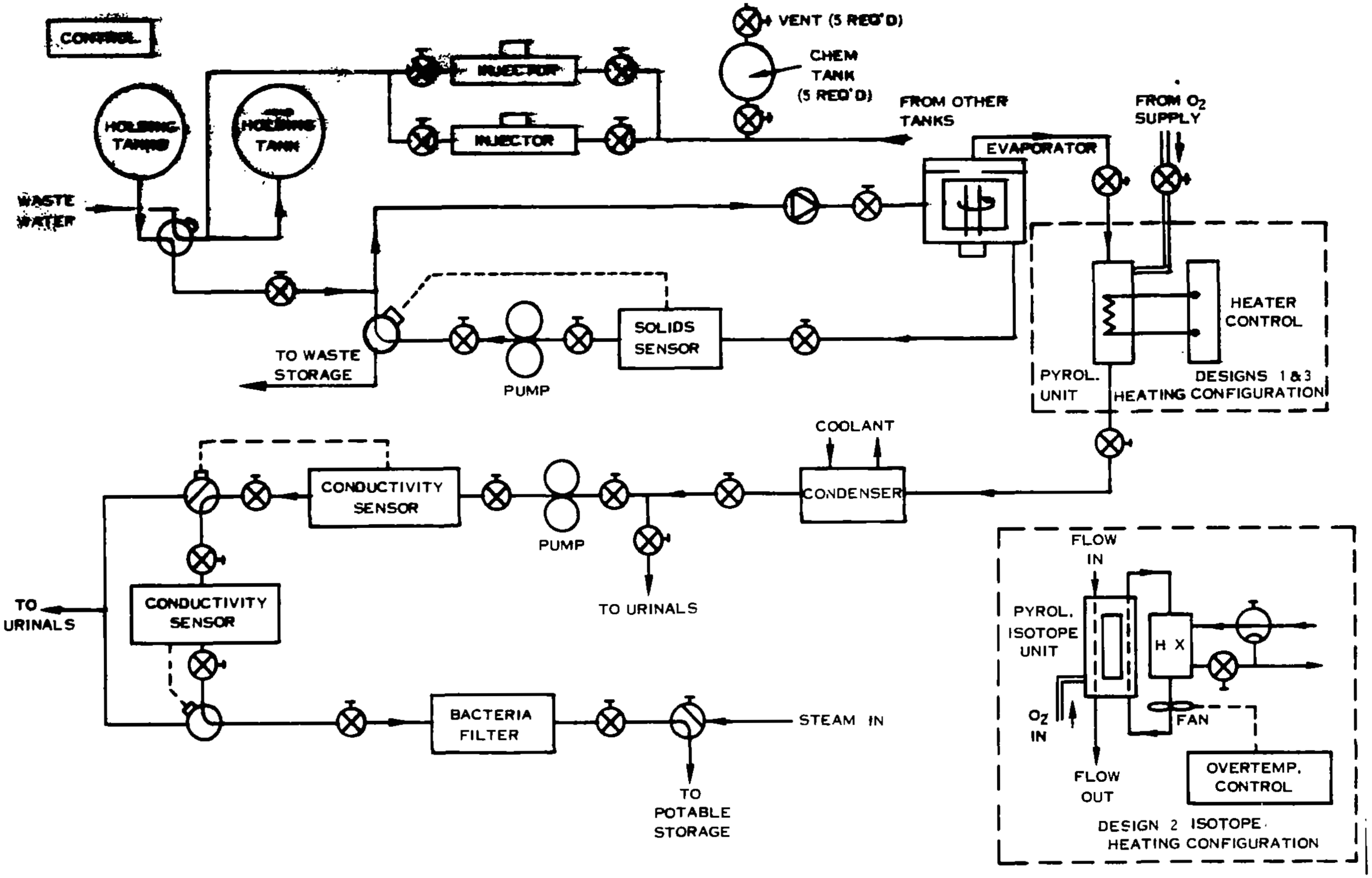


Figure 69. Vacuum Distillation/Pyrolysis Concept (Page 2 of 2).

in the AILSS. Water potability has been quite good; a typical analysis is shown in table 35. Additional performance data is shown in figure 69.

Safety: There are three possible safety problems associated with this subsystem. The first, the high temperature of the pyrolysis unit, poses a slight fire potential. The second, the use of installed isotope heaters in Design 2, presents a radiation potential. Neither, of course, makes the use of this subsystem prohibitive, but together they present added hazards that must be considered. There does exist, however, a significant contamination potential if liquid-vapor interface control is lost because of a rotational failure. Subsequent repair work, which might necessitate opening the evaporator, would require great care to avoid contamination of the cabin and crew.

Availability/confidence: Vapor pyrolysis as a vapor treatment technique can, with a strong effort, be developed for a flight as early as 1974. Development is now well into the prototype development phase.

The still utilized in this concept has been developed for use with radioisotopes It is somewhat simpler, with fewer mechanical problems, than the previously described vacuum distillation stills. Because of the geometric configuration, the still does not lend itself to the recovery of the heat of condensation. A separate condenser is used.

Pyrolysis, as a vapor treatment method, however, can be applied to any distillation system where it can serve to replace charcoal posttreatment.

Recovery efficiencies of 93% have been achieved.

Primary criteria. -

Reliability: The MTBF for this concept is 14 100 hours, five chemical tanks (four out of five required for mission completion) and a redundant injector must be installed because maintenance will not be permitted in this section. With 32 spares, the overall relaibility has been calculated to be 0.999606 for the 500 day mission.

Crew time: Scheduled maintenance of this system involves regular replacement of bacteria filters. These operations require steam purging before and after replacement, so the total time per mission is estimated to be 38 hours.

Unscheduled maintenance involves replacement of several miscellaneous parts. Because the liquid-vapor interface is controlled by induced fluid rotation, added crew stress will be present if any of these repairs requires stopping the impeller. Whenever repairs are made, steam purging is necessary for sterilization before and after component replacement. These operations are estimated to require about 2.6 hours per mission.

Equivalent weight: The equivalent weights for this concept are shown on the data sheet. The weights shown are for a processing rate of 12.77 lb/hr. This system employs a residuum circulation loop with a solids sensor that, in effect, controls the overall recovery efficiency. A water contingency debit of 100 pounds is therefore charged against this concept to allow for a reasonable operating range of the sensor.

Secondary criteria. - Under normal operation, this system will not contaminate external systems, but because there is no positive bacteria control within the still, bacterial contamination is possible if the unit is opened for repairs. Interfaces are maintained with the waste management subsystem, the power supply system, and the radioisotope heat source if that option is used. This system is quite flexible in that changes in cabin pressure or temperature do not affect it. Here too, because heat transfer takes place across a fluid boundary layer, it is influenced by the solids concentration, making marked improvement in recovery efficiency quite expensive from a thermal point of view. Noise levels should be low. The volume of this unit is low compared to the auxiliary equipment, and because there are charcoal filters the total volume is below average. Total electrical power is quite high, but there are no significant power peaks.

Flash Evaporation/Pyrolysis and Flash Evaporation/Compression/Pyrolysis

These two concepts differ only in the provision in one for recovering the heat of condensation by the method of vapor compression. Otherwise, these concepts are similar enough to warrant discussing them together.

Flash evaporation is a method of vacuum distillation employing advantageous features found in other systems, i.e., vapor pyrolysis and, in the compression version, vapor compression. Furthermore, it can provide an artificial gravity interface control with no moving parts and, therefore, dispenses with the need for rotating drums or impellers and the attendant seal problems. The system uses a closed urine liquid loop that includes a pump, heat exchanger, expansion valve, and flash evaporator-separator. The vapor loop includes a pyrolysis unit, and a heat exchanger that acts as a vapor condenser. In the compression version, a compressor is added and the two heat exchangers are replaced by a single regenerative heat exchanger. Schematics are shown in figures 70 and 71.

Waste water is received and stored in the holding tanks where a mixture of chromium trioxide and sulfuric acid from the chemical storage tanks is added to aid in bacteria control. Two tanks are used; one receives waste water while the other discharges collected water to the unit. Water enters the unit at the evaporator and is circulated through a loop that includes a pump, heat exchanger, expansion valve, and evaporator. A low pressure is maintained in the evaporator so that, as the pressurized waste fluid passes through the expansion valve, about 10 percent of the fluid is converted to vapor.

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Flash Evaporation/Pyrolysis

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999692 MTBF: 14 800 hr

Spares/Redundant (R) Units:

- 2 - Pyrolysis Assy.
- 3 - Flush Evaporator/Separator
- 3 - 3-way Sol. Valve
- 2 - Expansion Valve
- 3 - Feed Pump
- 3 - Water Pump
- 1 - Bacterial Filter Canister
- 2 - Controller
- 2 - Solids Sensor
- 3 - Conductivity Sensor
- 1 - Injector
- 1 - Man. 3-way Valve
- 2 - 4-way Sol. Valve
- 2 - O_2 Control Valve
- 1 - Heat Exchanger/Cond.

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	38	2.4

EQUIVALENT WEIGHT (lb): [a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	336	386	336
Expendables	155	155	155
Spares/Redundant Units	513	513	513
Electrical Power	2175	18	284
Thermal Power	0	300	0
Radiator Load	656	656	656
Water Contingency	100	100	100
Total Equivalent Weight	3935	2128	2044

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):			
Electrical	4845	40	631
Thermal	0	4805	4214

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	10	18	28

Figure 70. (Page 1 of 2)

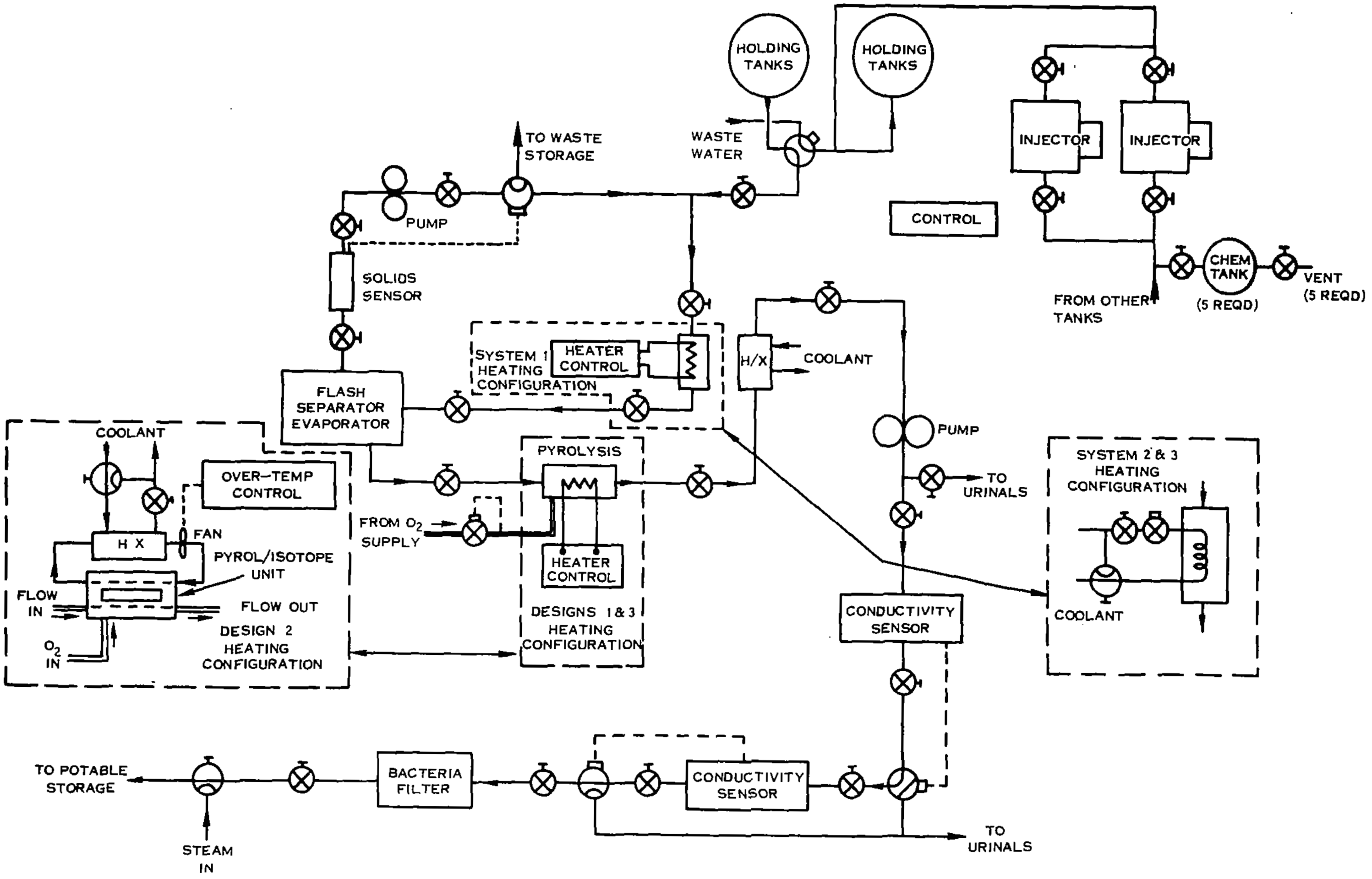


Figure 70. Flash Evaporation/Pyrolysis Concept (Page 2 of 2)

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SUBSYSTEM: Water Management - Reclamation

CONCEPT: Flash Evaporation/Compression/Pyrolysis

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999766

MTBF: 14 400 hr

Spares/Redundant (R) Units:

2 - Pyrolysis Assy.
3 - Flash Evaporator Assy.
3 - 3-way Sol. Valve
3 - Feed Pump
1 - Regenerative Heat Exchanger/Condenser
2 - Expansion Valves
3 - Compressors
3 - Water Pump
1 - Bacterial Filter Canister
2 - Controller
1 - Injector
2 - Solids Sensor
3 - Conductivity Sensor
1 - Manual 3-way Valve
2 - 4-way Sol. Valve
2 - O_2 Control Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	38	2.5

EQUIVALENT WEIGHT (lb):[a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	336	386	336
Expendables	155	155	155
Spares/Redundant Units	528	528	528
Electrical Power	948	683	948
Thermal Power	0	27	0
Radiator Load	288	288	288
Water Contingency Debit	+ 100	+ 100	+ 100
Total Equivalent Weight	2355	2167	2355

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):	Design 1	Design 2	Design 3
Electrical	2115	1519	2115
Thermal	0	596	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	10	19	29

Figure 71. (Page 1 of 2)

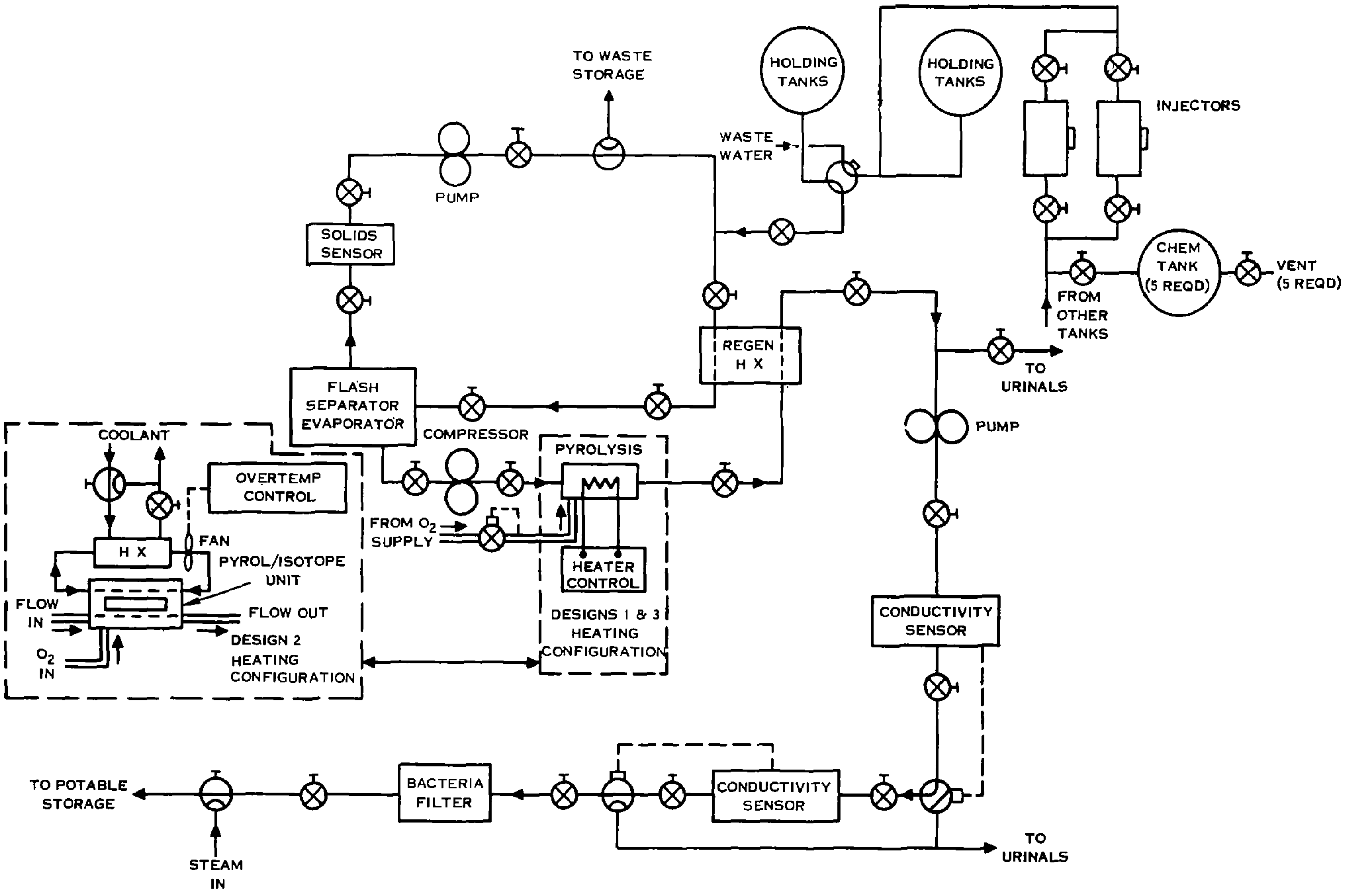


Figure 71. Flash Evaporation/Compression/Pyrolysis Concept (Page 2 of 2)

In the compression version of this concept, the vapor goes from the evaporator to a compressor and then to a catalytic pyrolysis unit. In the noncompression version, the compression step is omitted.

In the pyrolysis unit the vapor is heated to 1200° to 1600°F in the presence of oxygen. This process oxidizes organic contamination carryover and incinerates any microbiological carryover. Heat to this unit is supplied from an electrical heater in Designs 1 and 3 and from an installed isotope source in Design 2. When the process flow through the pyrolysis unit is stopped due to a system failure, a means of dissipating the heat from the isotope in Design 2 must be provided. This is accomplished by incorporating an additional gas circuit separate from but parallel to the processing circuit. The equivalent weights shown reflect the necessary pump, heat exchanger, ducting, and power penalties to accomplish this.

There also exists a low temperature pyrolysis unit that operates with a catalyst at about 300°F. While the advantages of lower power, lower weight and improved operating safety are obvious, the performance of this unit does not yet meet a minimal standard for water purity, at least with respect to ammonia removal.

After the pyrolysis unit, the vapor is condensed. In the compression version, it is condensed in the circulating loop heat exchanger, thereby conserving the heat of condensation. In the noncompression version, it is condensed in a separate heat exchanger and the heat of condensation is rejected to the radiators.

The condensate is continuously removed and pumped through a series of bacterial filters. No charcoal filters are used in this system because the pyrolysis unit removes the organics. If either of the two conductivity sensors indicates unsatisfactory water, the processed flow is automatically diverted to the urinal. At the same time, the circulation loop pump is stopped and a shutdown warning signal is given so that the necessary repairs can be made.

When one holding tank is emptied, the feed valve automatically closes the empty tank and opens the other tank so that processing continues without interruption. At the same time, the waste water feed is switched to the empty tank.

When the solids concentration in the circulation loop reaches 50 percent by weight as indicated by the solids sensor, the circulation loop residuum is automatically fed to the waste management system for disposal. As this happens, fresh waste water from the holding tank is drawn into the circulation loop until the solids concentration reaches a predetermined low level. The residuum dump valve then closes and processing continues.

Absolute criteria. -

Performance: Recovery efficiency for this system is predicted to be 95 percent with undiluted urine. At this level of performance, it should be satisfactory in the AILSS. Water potability has been good; a typical analysis is shown in table 35. Additional performance data is found in figures 70 and 71.

Safety: There are three possibly significant safety hazards associated with this system. The high temperature pyrolysis unit poses a slight fire potential while the Design 2 isotope heat source poses a possible radiation hazard. In addition to these, the pressurized circulation loop admits the possibility of an outward contamination leak. None of these prohibits use of this system, but they are additional problems that must be considered.

Availability/confidence: These concepts can, with a strong effort, be developed for a flight as early as 1977. Development is now in the research phase.

Nearly all of the components in these concepts are simple and straightforward in design. The evaporator-separator is the only one for which a zero gravity concept is lacking. The system, without compression, is currently undergoing development and has demonstrated 97.5 percent recovery efficiency in carefully controlled tests.

Primary criteria. -

Reliability: The estimated MTBF for the flash evaporation/compression unit is 14 400 hours. With 38 spares, the overall reliability is calculated to be 0.999766. The estimated MTBF for flash evaporation without compression is 14 800 hours; with 36 spares, the overall reliability is calculated to be 0.999692 for the 500 day mission. Urine solids buildup in the expansion valve may seriously degrade its operating life. Component replacement in the residuum line may present a contamination problem due to the presence of urea, ammonia, and microorganisms. Five chemical tanks (four out of five required for mission completion) and a redundant injector must be installed because maintenance will not be permitted in this section.

Crew time: Scheduled maintenance of these units involves routine replacement of the bacteria filters. This is a manual operation involving steam sterilization before and after replacement. The total mission time required for all these operations is 38 hours per mission.

Unscheduled maintenance involving replacement of the pyrolysis unit, pumps, and evaporator-separator in the flash evaporation/pyrolysis concept requires an estimated

2.4 hours per mission. Adding maintenance on the compressor in the flash evaporation/compression/pyrolysis concept brings the unscheduled maintenance time to 2.5 hours per mission. For all such operations, steam purging would be required.

Equivalent weight: The equivalent weights for these concepts are shown on the data sheet. The weights shown are for a processing rate of 12.77 lb/hr. These systems employ a residuum circulation loop with a solids sensor that, in effect, controls the overall recovery efficiency. A water contingency debit of 100 pounds is therefore charged against these concepts to allow for a reasonable operating range of the sensor.

Secondary Criteria. - Under normal operation, this system will not contaminate the external systems, but repairs to the liquid loop could pose a contamination potential. Interfaces are maintained with the waste management subsystem, the power supply system, and the radioisotope heat source if that option is used. The system is quite flexible in that changes in cabin pressure or temperature do not effect it greatly. Growth for the system is probably better than for other vacuum distillation systems, because boiling does not occur on a heat transfer surface. Thus, the practical heat transfer coefficient limitation caused by high solids concentration is less restricting. Noise level, because of the compressor, will likely be fairly high. The volume is less than with most systems since only bacteria filter post treatment is required. Power is relatively high but steady.

Closed Cycle Air Evaporation

Air evaporation is an ambient pressure distillation process in which a carrier gas is used to evaporate water from waste-water-saturated wicks and carry it to a condenser-separator for recovery. There are two basic schemes for doing this: the open cycle and the closed cycle. The closed cycle is discussed here, the open cycle in the following section. Figure 72 illustrates the closed cycle concept.

In this concept, waste water is collected in the pretreatment tanks, where a mixture of chromium trioxide and sulfuric acid from the chemical storage tanks is added to chemically fix the free ammonia and kill the bacteria. Two tanks are used; one receives waste water while the other discharges collected water to the evaporator wicks through a metering pump. The water then evaporates into a carrier gas (circulated past the wicks), which is usually of the same composition as cabin gas but may be different if desired. In any case, the carrier gas picks up water from the wicks and leaves the evaporator nearly saturated and at a reduced temperature. From there, it goes through a condensing heat exchanger where the vapor condenses and is separated from the gas. Finally, it is drawn back to the evaporator, after first passing through a heater.

The condensate is continuously removed and pumped through a series of charcoal and bacteria filters. If either of the two conductivity sensors indicates unsatisfactory water, the processed flow is automatically diverted to the urinal. At the same time, the process feed valve is closed and a shutdown warning signal is given so that the necessary repairs may be made.

When one pretreatment tank is emptied, the feed valve automatically closes the empty tank and opens the other tank so that processing continues uninterrupted. At the same time, the waste water feed is switched to the empty tank. This is accomplished with the use of two evaporators, one on-line and the other off-line. The spent wick in the off-line unit can be steam sterilized, dried, and outgassed to space before removal. This procedure eliminates any undue crew stress associated with wick replacement.

Absolute criteria. -

Performance: One of the main advantages of the air evaporation technique is that it is capable of recovering nearly 100 percent of the water from the urine. Because it also produces water of excellent potability (see table 35), its performance is markedly better than any other system.

Safety: This concept has two major safety hazards. During operation, conditions in the wick are ideal for bacterial growth. Should it be necessary to break into the gas loop for maintenance, a definite contamination hazard exists. Furthermore, the wicks used are flammable and their storage on board the spacecraft poses an undesirable fire hazard. Otherwise, this concept is as safe as any of the others considered in this study.

Availability/confidence: The closed cycle air evaporation concept can, with reasonable effort, be developed for a flight as early as 1974. Development is now well into the prototype development phase.

The closed cycle air evaporation system has completed a successful 28-day test in the NASA Integrated Life Support System. Air evaporation is the most highly developed water reclamation technique at the present time. Recovery efficiency of nearly 100 per-percent is readily achieved.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 20 000 hours. Five chemical tanks (four out of five required for mission completion) and redundant injectors must be installed, since maintenance will not be permitted in this section. With 37 additional spares, the overall reliability has been calculated to be 0.999447. This concept requires a condenser-separator with estimated life of 100 days; it is so designed that separator replacement will not require breaking into the coolant lines.

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Air Evaporation - Closed

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999447 MTBF: 20 000 hr

Spares/Redundant (R) Units:

1 - Wick Evaporator
1 - Chem. Tank
1 - Evaporator
6 - Condenser/Separator
1 - Diverter Valve
2 - Fan
1 - Charcoal Canister
3 - Feed Pump
2 - 4-way Sol. Valve
2 - 3-way Sol. Valve
1 - Chem. Injector
1 - 4-way Diverter Valve
2 - Feed Valve
1 - Check Valve
3 - Conductivity Sensor
1 - Bacterial Filter Canister
2 - Heater Controller
2 - Controller
3 - Pump
1 - Heater

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	207	1.8

EQUIVALENT WEIGHT (lb):[a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	260	260	260
Expendables	564	564	564
Spares/Redundant Units	250	250	250
Electrical Power	1498	21	21
Thermal Power	0	164	0
Radiator Load	450	450	450
Excess Water Credit	- 360	- 360	- 360
Total Equivalent Weight	2662	1349	1185

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):			
Electrical	3330	47	47
Thermal	0	3283	3283

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	12	64	76

Figure 72. (Page 1 of 2)

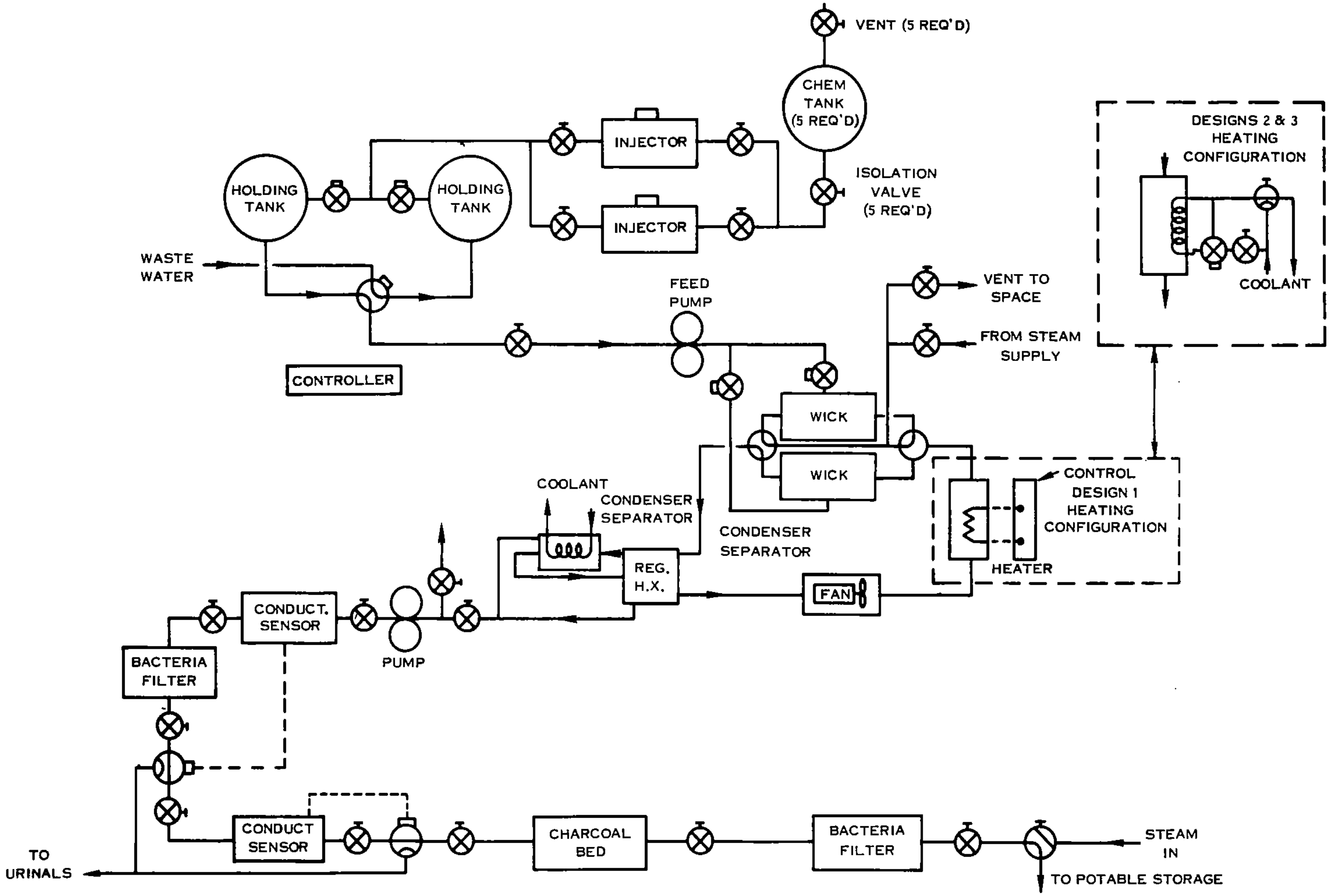


Figure 72. Closed Cycle Air Evaporation Concept (Page 2 of 2).

Crew time: Schedule maintenance involves replacement of the wicks, bacteria and charcoal filters, and a number of limited life items. These manual operations require steam purging for sterilization. All of these operations should require about 207 hours per mission.

Unscheduled maintenance involves replacing any of a number of miscellaneous items. Steam sterilization is required for any liquid-side replacement operation and for gas-side replacements. These repairs will take about 1.8 hours per mission.

Equivalent weight: The equivalent weights of this system are shown on the data sheets. The weights shown correspond to a processing rate of 12.77 lb/hr. This system enjoys a weight credit of 360 pounds, which represents the approximate reduction in the oxygen storage-electrolysis systems made possible by the electrolyzing of the additional water recovered by this system over that possible with the other water reclamation concepts (about 1.5 pounds of water per day).

Secondary criteria. - Contamination for this concept is a potentially difficult problem because, at the temperature levels present, the wick is a nearly ideal medium for bacterial growth. The system interfaces with the power system, waste collection system, and space. A certain amount of flexibility is possible due to the ability to reclaim essentially 100 percent of the water. Growth characteristics, however, are limited because of the relatively high expendables required. Noise levels should be somewhat less than average, while the volume requirements are considerably greater than average. Electrical power for Design 1 is quite high, but it is quite low for Designs 2 and 3.

Open Cycle Air Evaporation

The open cycle air evaporation concept is quite similar to the closed cycle except that it utilizes the spacecraft humidity control system as its gas loop. This arrangement has as its major advantages a low equivalent weight and a low electrical power requirement. Nearly all of the auxiliary equipment required for the closed cycle concept is required here, too.

Unfortunately, this concept poses serious safety problems. Because of the fact that the wicks are directly open to the cabin through the humidity control duct, there is no satisfactory way to guarantee that bacterial growth in the wick will not contaminate the cabin air. Further, even though a charcoal odor filter is usually included in the air duct, there is no way to prevent ammonia odors from getting into the cabin should they evolve from the urine in the wicks (charcoal is not a particularly good ammonia adsorbent).

Such a system was employed in a recent 60-day manned test and there was evidence that ammonia carryover did, in fact, occur. While no bacteriological problems were reported during this 60 day test, sufficient doubt justifiably exists concerning this point for a mission of nearly nine times that duration. Therefore, on the basis that it is inherently unsafe because of a cabin air contamination, open cycle air evaporation is rejected from further consideration because it fails to meet the AILSS safety requirements.

Vapor Diffusion and Vapor Diffusion/Compression

Vapor diffusion is an ambient pressure distillation process in which water evaporates from a membrane surface, diffuses through a narrow gas-filled gap, and condenses on a porous metal condensing-separating surface. The semipermeable membrane prevents the passage of solids and other contaminants, including microorganisms, into the condenser. The still is composed of several membrane evaporator-condenser modules. In addition, the system employes a urine preheater, a condenser coolant loop, a circulation tank, pumps, pretreatment tanks, and post-treatment equipment. A schematic is shown in figure 73. In modified form, a compressor is added to permit recovery of the heat of condensation. A schematic of this arrangement is shown in figure 74.

These concepts differ only in the provision for recovering the heat of condensation. Otherwise, the concepts are similar enough to warrant discussing them together.

Waste water is received and stored in the pretreatment tanks, where a mixture of chromium trioxide and sulfuric acid from the chemical storage tanks is added to chemically fix the free ammonia and kill the bacteria. Two tanks are used; one receives waste water while the other discharges the treated water into a circulation loop that includes the vapor diffusion still. As the waste fluid flows through the evaporator portion of the still, the water evaporates and diffuses first through a semipermeable membrane and then into a void space or gap. In the noncompression version, this gap is gas filled at slightly greater than ambient pressure. The vapor diffuses through the gap and condenses on the water porous plate condenser surface. In the compression version, the gap contains no gas and the vapor is drawn off, compressed, and returned to a gap on the opposite side of the evaporator (see figure 75). There it condenses, giving up the heat of condensation to the evaporating fluid. Power is all electrical in Design 1, but the heater is isotope powered in Design 2 and waste heat powered in Design 3. Because the membranes in these systems are limited life items, and because of the contamination problem attendant with individual membrane replacement, all membranes, including spares, are installed in a modularized unit. Five modules are provided; three for the mission and two for redundancy. When a membrane failure occurs, normally by clogging, a new module can be put on-line by simply closing the valves on the failed module and opening the valves on the new one. Each module contains a total of 25 square feet of membranes.

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Vapor Diffusion

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999248

MTBF: 16 000 hr

Spares/Redundant (R) Units:

1 - Chem. Tank
1 - Chem. Injector
2 - Heater Control
3 - Pump
3 - Conductivity Sensor
1 - Charcoal Canister
2 - 4-way Sol. Valve
2 - Diverter Sol. Valve
1 - Heater
1 - Check Valve
2 - Press. Regulator
1 - Bacterial Filter Canister
2 - Controller
2 - Solids Sensor
2 - Sol. Shutoff Valve
1 - Manual 3-way Valve
3 - Pump

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	56	2.3

EQUIVALENT WEIGHT (lb):[a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	459	459	459
Expendables	199	199	199
Spares/Redundant Units	112	112	112
Electrical Power	1940	20	20
Thermal Power	0	222	0
Radiator Load	587	587	587
Water Contingency Debit	+ 100	+ 100	+ 100
Total Equivalent Weight	3397	1699	1477

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):			
Electrical	4310	45	45
Thermal	0	4265	4265

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	13	9	22

Figure 73. (Page 1 of 2)

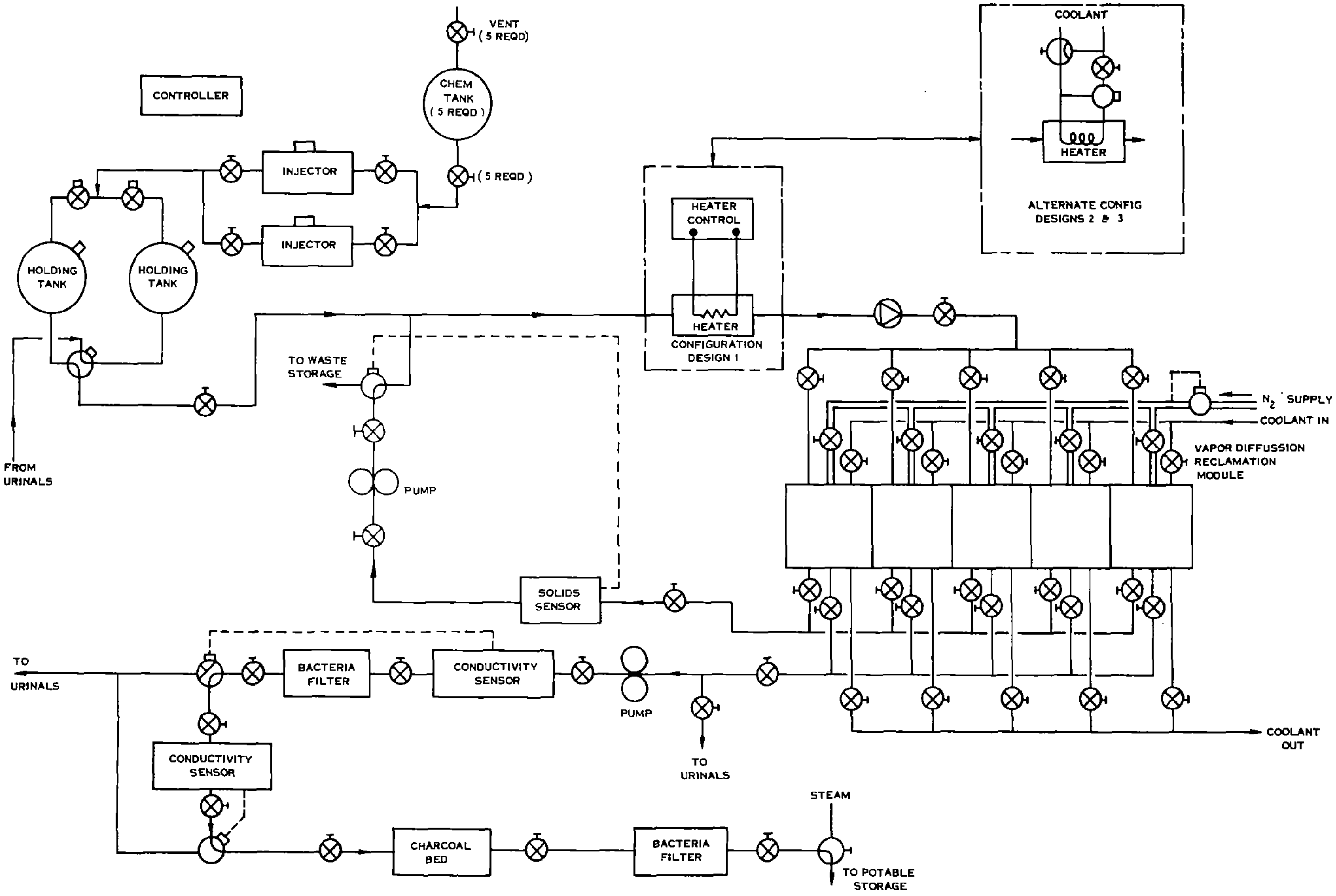


Figure 73. Vapor Diffusion Concept (Page 2 of 2)

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Vapor Diffusion/Compression

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999248

MTBF: 14 300 hr

Spares/Redundant (R) Units:

1 - Chem. Tank
1 - Chem. Injector
2 - Heater Control
3 - Pump
3 - Conductivity Sensor
1 - Charcoal Canister
2 - 4-way Sol. Valve
3 - Compressor
2 - Sol. Diverter Valve
1 - Heater
1 - Check Valve
2 - Press. Regulator
1 - Bacterial Filter Canister
2 - Controller
2 - Solids Sensor
2 - Sol. Shutoff Valve
1 - Man. 3-way Valve
3 - Pump

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	36	2.5

EQUIVALENT WEIGHT (lb):[a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	498	498	498
Expendables	199	199	199
Spares/Redundant Units	173	173	173
Electrical Power	736	600	600
Thermal Power	0	15	0
Radiator Load	222	222	222
Water Heating Credit	- 136	- 15	0
Water Contingency Debit	+ 100	+ 100	+ 100
Total Equivalent Weight	1792	1792	1792

[a] Corresponding to a processing rate of 12.77 lb/hr.

POWER (Watts):			
Electrical	1634	1334	1334
Thermal	0	300	300
Water Heating Credit	300	300	300
	1334	1334	1334

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	14	11	25

Figure 74 (Page 1 of 2)

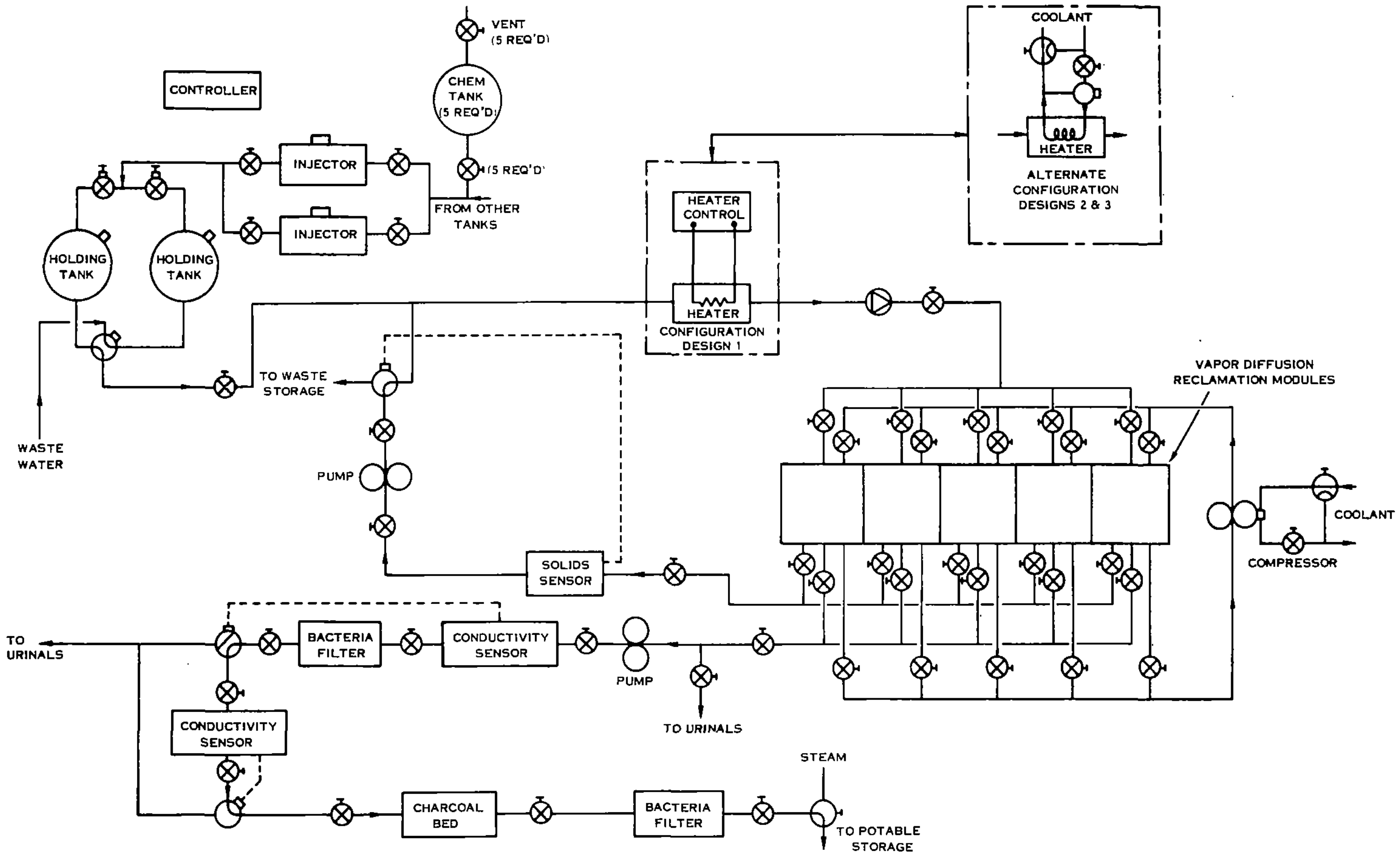
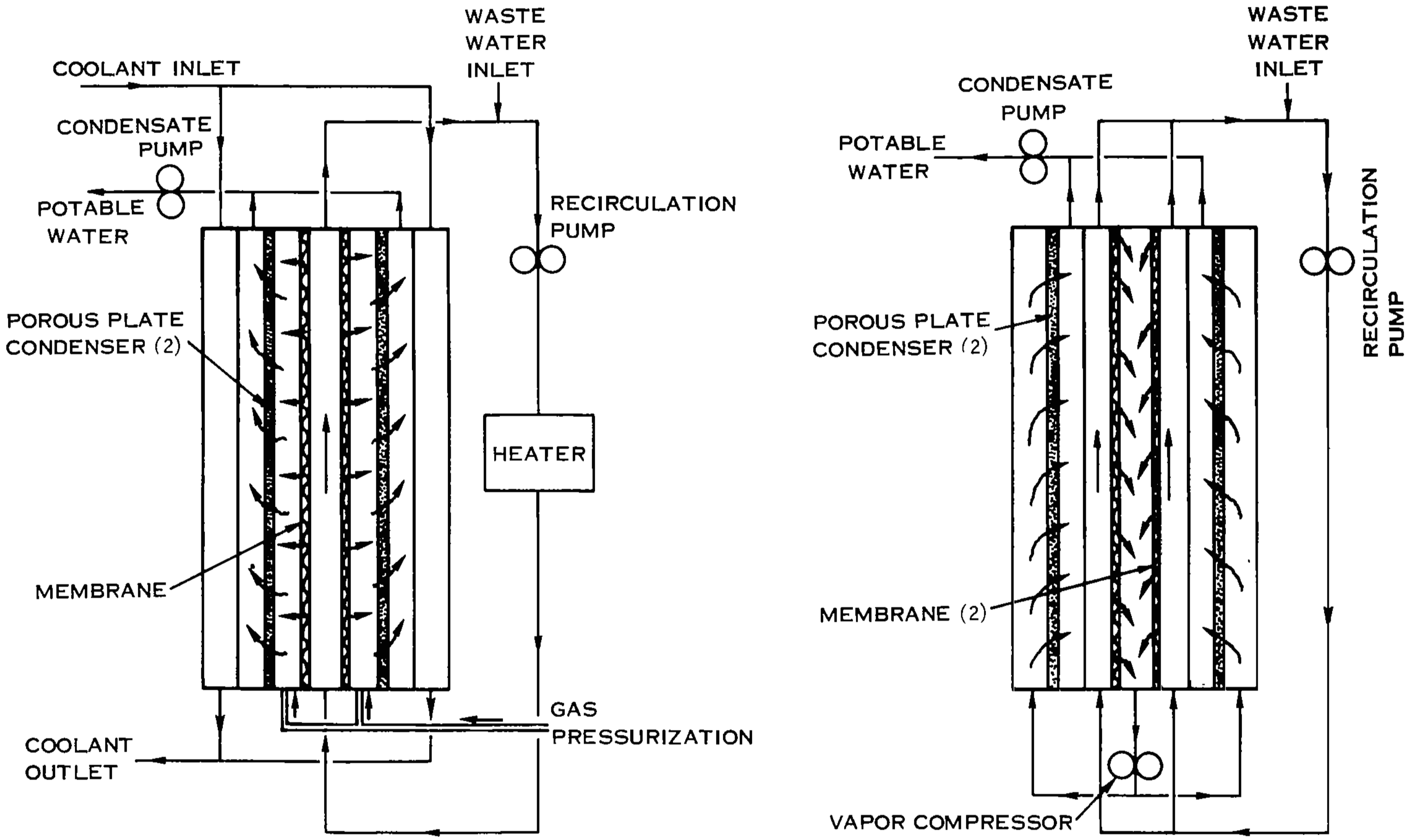


Figure 74. Vapor Diffusion/Compression Concept (Page 2 of 2).



TYPICAL VAPOR DIFFUSION MODULE ARRANGEMENT

TYPICAL VAPOR DIFFUSION/COMPRESSION MODULE ARRANGEMENT

Figure 75. Comparison of Vapor Diffusion Arrangements

The condensate is continuously removed and pumped through a series of charcoal and bacteria filters. If either of the two conductivity sensors indicates unsatisfactory water, the processed flow is automatically diverted to the urinal. At the same time, the process feed valve is closed and a shutdown warning signal is given so that repairs may be made. When one pretreatment tank is emptied, the feed valve automatically closes the empty tank and opens the other tank so that processing continues without interruption. At the same time, the waste water feed is switched to the empty tank.

When the solids concentration in the circulation loop reaches 50 percent by weight as indicated by the solids sensor, the circulation loop residuum is automatically drained to the waste management system for disposal. As this happens, fresh waste water from the pretreatment tank is drawn into the circulation loop until the solids concentration reaches a predetermined low level. The residuum dump valve then closes and processing continues.

Absolute criteria. -

Performance: Recovery efficiency for this system is predicted to be 95 percent with undiluted urine. At this level of performance, it should be satisfactory for use in the AILSS. Water potability has been good and can undoubtedly be improved: a typical analysis is shown in table 35. Additioal data is found in figures 73 and 74.

Safety: This concept poses no significant safety hazards. In fact, it offers a distinct safety advantage: The unit is essentially sterile throughout when in operation. This important feature of the vapor diffusion technique is brought about by the following factors:

1. The urine liquid is kept at a suitable pasteurizing temperature (150°F) during processing.

2. The membrane acts as an internal bacterial filter which prevents bacterial carryover.

In addition, the modular design employed obviates the necessity of ever having to open the unit for maintenance.

The additional radiation hazard posed by the isotope heat source in Design 2 is minimal. In fact, because it would obtain its heat through a heat transport loop from a remote source, it is considered to be intrinsically less hazardous than those concepts utilizing an individual installed isotope heat source.

Availability/confidence: Either vapor diffusion concept can, with a strong effort, be developed for a flight as early as 1977. Development is now in the early prototype development phase.

A prototype Vapor Diffusion still has undergone several thousand hours of testing, but membrane life is still the major problem requiring developing work. Recovery efficiencies of 98 percent have been achieved with urine.

Primary criteria. -

Reliability: The MTBF for this concept is 14 300 hours with compression and 16 000 hours without compression. Five chemical tanks (four out of five required for mission completion) and redundant injectors must be installed since maintenance will not be permitted in this section. Nine cells, which are limited life items, are required to meet the 500-day mission requirement. Six additional standby cells are required to obtain the desired reliability. The fifteen cells have been modularized. Each vapor diffusion module contains three cells and will not require maintenance. With 30 additional miscellaneous spare components (33 with compression), the overall reliability is calculated to be 0.999248.

Crew time: Scheduled maintenance of these units involves routine replacement of bacteria and charcoal filters. These manual operations include steam purging for sterilization before and after replacement. Total scheduled maintenance time should be about 38 hours per mission.

Unscheduled maintenance on the vapor diffusion concept involves replacement of pumps and possibly a number of miscellaneous items that are estimated to require 2.3 hours per mission. Adding compressor maintenance for the vapor diffusion/compression concept raises the estimate to 2.5 hours per mission. Steam purging is required for all such operations.

Equivalent weight: The equivalent weights for these concepts are shown on the data sheet. The weights shown are for a processing rate of 12.77 lb/hr. These systems employ a residuum circulation loop with a solid sensor that, in effect, controls the overall recovery efficiency. A water contingency debit of 100 pounds is therefore charged against these concepts to allow for a reasonable operating range of the sensor.

There is a water heating credit for the vapor diffusion/compression concept because this system delivers water at close to the storage temperature of 160°F. Thus, the heat required in the storage tanks (a point to be taken up later under the heading of Water Storage) is less than required for other concepts and results in a credit for this concept. This, of course, does not apply to the vapor diffusion concept.

Secondary criteria. - This system, under normal operation, will not contaminate external systems. It interfaces with the waste management subsystem, the power supply system, and the heat source. It is quite flexible, since it is unaffected by changes in either pressure or temperature. Its growth capabilities are on a par with those of most vacuum distillation systems. Noise levels should be much lower than with other systems because only two liquid pumps are operating. Volume is average. Electrical power is low, but heating requirements are high.

Electrodialysis

The electrodialysis water reclamation system uses alternate pairs of anion and cation semipermeable membranes to separate electrolytes from the water. Unfortunately, nonelectrolytes such as urea are not well removed. The driving force for the separation is an electrical field maintained across the membranes, which are placed between an anode and a cathode. Positively charged ions are drawn toward the cathode while negatively charged ions are drawn toward the anode. Their progress is hindered, however, by the membranes. The cations pass through the cation-permeable membranes but are stopped by anion-permeable membranes. Simultaneously, a reverse action traps anions behind the cation-permeable membranes. Thus, water in alternate channels (dilute channels) loses ions while the fluid in the other channels (concentrate channels) gains ions to form a concentrated liquid.

Urea, the major contaminant in urine, as well as the other nonelectrolytes, must be removed by an alternate process. Two such processes have been proposed: sorption on charcoal and electrochemical decomposition.

Regardless of the method used to remove nonelectrolytes, electrodialysis does not appear to offer a recovery efficiency high enough to warrant its consideration for AILSS. Although fairly good salt rejection can be achieved by keeping the concentrate channel concentration low, this can only be done at the expense of the overall vehicle water balance, which lowers the overall recovery efficiency. If the concentrate channel concentration is allowed to rise to an equilibrium level (200 000 ppm), the endosmotic water loss must correspondingly increase and this, along with other factors, prevents an acceptably high recovery efficiency. Information supplied by potential suppliers as well as government sources indicates that with the best possible projected membranes, the maximum recovery efficiency that can be expected is from 90 to 92 percent. On this basis, it appears that the electrodialysis concept does not provide satisfactory performance.

It is, therefore, rejected at the absolute level.

Reverse Osmosis

Reverse osmosis is a process that uses high pressure to force water from a solution through a semipermeable membrane into a less concentrated solution. Because the natural osmotic force tends to cause spontaneous movement of the water from the less to the more concentrated solution, this process, by pressurization of the less concentrated solution, reverses that flow and is therefore called reverse osmosis. The semipermeable membrane prevents the passage of solids and other contaminants, including microorganisms.

A reverse osmosis unit consists of a pressure vessel containing the semipermeable membrane. The membrane itself can take one of several forms depending on the material from which it is made and other considerations. For example, low permeability nylon has been used in the form of extremely small, spun tubes. The more common cellulose acetate is usually used in sheet form. In either case, the essential configuration is two parallel flow passages separated by the membrane. In addition to the reverse osmosis unit itself, the system employs a circulation pump, accumulator, holding tanks, post treatment filters, and a high (150 psia) pressure gas source. A schematic is shown in figure 76.

In this system, waste water consisting of wash water and condensate is received and stored in holding tanks. Two tanks are used; one receives waste water while the other discharges the water, at intervals, into the circulation loop which includes the accumulator and the reverse osmosis unit. After the loop is filled, the waste water is pressurized to 150 psia from a high pressure gas source through the accumulator and circulated around the loop. In the reverse osmosis unit, the high pressure forces the water through the semi-permeable membrane, leaving the solids in the circulation loop. Each module contains a total of five square feet of membrane. Power is required only for pumping and is all electrical in all designs.

The processed water is continuously removed and pumped through a series of charcoal and bacteria filters. If either of the two conductivity sensors indicates unsatisfactory water, the processed flow is automatically diverted to the urinal. At the same time, the process feed valve is closed and a shutdown warning signal given that repairs may be made. When one pre-treatment tank is emptied, the feed valve automatically closes the empty tank and opens the other tank. At the same time, the waste water feed is switched to the empty tank.

When the solids concentration in the circulation loop reaches a level equivalent to the desired water recovery efficiency, pressure is released and the contents of the loop discharged to the primary water recovery device. A fresh charge of waste water is then drawn in from the pre-treatment tank, the pressure reapplied, and processing resumed.

Absolute criteria. -

Performance: Because recovery efficiency with reverse osmosis is a function of pressure, it is not possible to obtain the high recovery efficiencies required of a single processing system without employing unacceptably high operating pressures. Thus, this concept was considered for use in series with some other system better suited to high recovery efficiencies. Furthermore, its use was restricted to washwater, condensate, or mixtures of washwater and condensate because the amount of water that can be recovered from urine is quite small at reasonable pressures. The final design utilizes an operating pressure of 150 psia to give a recovery efficiency of 80 percent for washwater.

Potability of water processed by this concept can be good, but adequate data for typical spacecraft washwater and condensate is lacking. Certain non-electrolytes such as urea (present in both washwater and condensate) appear to be difficult to remove by this method. Further, the ability of the concept to completely remove detergents is doubtful, although preliminary tests on a limited number of detergents have been very successful.

Despite these limitations and uncertainties, reverse osmosis is believed to be a possibly valuable adjunct to the spacecraft water reclamation system because of its relatively low weight and power penalty per pound of water processed.

Safety: Reverse osmosis is a relatively simple and safe system. For the waste waters considered for it in this application, the operating pressure of 150 psia is considered entirely acceptable, and although this process operates at essentially ambient temperature, significant bacterial control is expected because of the filtering effect of the membrane. There is, of course, a hazard posed should a leak develop in the high pressure side of the unit which handles the contaminated water.

Availability/confidence: Reverse osmosis is, with strong development effort, predicted to be ready for use by 1974. Current development is in the late research phase for membranes in spacecraft applications and in the late prototype development phase for hardware.

This concept is receiving considerable attention for commercial application utilizing brackish or sea water. Spacecraft development is at an early stage, however. Despite the basic simplicity of the overall process, the mechanism of water transfer and waste rejection by the membranes is a complex phenomenon. The success of these membranes in rejecting at least some salts offers some reason to project success in rejecting other materials as well. Problems of detergent rejection, non-electrolyte rejection, and life in a typical spacecraft waste water environment all require resolution.

Primary Criteria. -

Reliability: The estimated MTBF for this concept is 20 700 hours. With 26 spares, the overall reliability has been calculated to be 0.999571. The reverse osmosis module in this design operates at 50 percent of its rated pressure for about 50 percent of its rated life. A continuous outflow of the fluid concentrate must be maintained while the module is under pressure. If this flow stops, the water from the washwater will continue to permeate through the membrane until the concentrate

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Reverse Osmosis

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999571 MTBF: 20 700 hrs.

Spares/Redundant (R) Units:

- 3 - Circ. Pump
- 2 - R.O. Modules
- 3 - Conductivity Sensor
- 1 - Charcoal Filter
- 1 - Charcoal Cartridge
- 2 - Solids Sensors
- 1 - Bact. Filter
- 1 - Bact. Filter Cartridge
- 3 - 3-way Sol. Valve
- 2 - 4-way Sol. Valve
- 1 - Check Valve
- 3 - Pressure Regulator
- 3 - Controller

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	56	1.7

EQUIVALENT WEIGHT (lb): *	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	123	123	123
Expendables	73	73	73
Spares/Redundant Units	84	84	84
Electrical Power	36	36	36
Thermal Power	0	0	0
Radiator Load	11	11	11
Total Equivalent Weight	327	327	327

* Corresponding to a processing rate of 6.67 lb/hr.

POWER (Watts):			
Electrical	80	80	80
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	6	7	13

Figure 76. (Page 1 of 2)

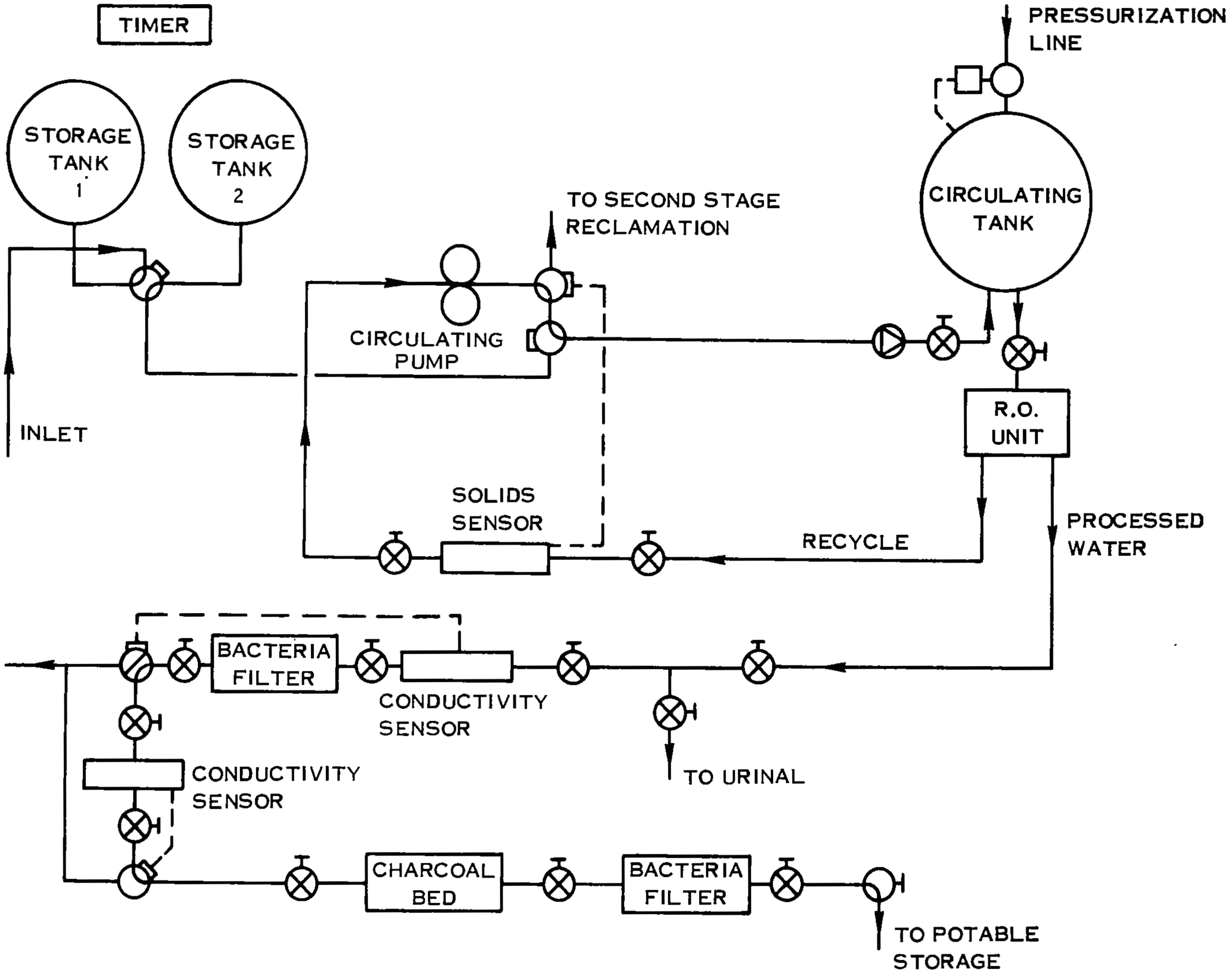


Figure 76. Reverse Osmosis (Page 2 of 2)

solution starts to precipitate, coating the membrane and clogging the spacer. Since the pressure is maintained independent of flow in the present concept, provisions are incorporated to automatically relieve the circulating tank pressure in the event of a pump failure.

Crew time: Scheduled maintenance of this unit involves routine replacement of bacteria and charcoal filters. These manual operations include steam purging for sterilization before and after replacement. Total scheduled maintenance time should be about 56 hours for the entire mission.

There is little unscheduled maintenance of the basic unit. Should a membrane failure occur, the entire module can be replaced. This procedure, and all other equipment repair, should require no more than 1.7 hours per 500 days.

Equivalent weight: The equivalent weights for this concept are shown on the data sheet. The weights shown are for a processing rate of 6.67 lb/hr which represents 80 percent of the combined washwater and humidity condensate flow rate. While this concept employs a solids sensor in a residuum circulation loop, no additional penalty is charged for a water contingency, because the residuum is sent on for further processing in the selected distillation systems used with this concept.

Secondary criteria. - This system, under normal operation, will not contaminate other systems, but the high operating pressure employed does pose an above-average threat of contamination in the event of a leak. It interfaces with the power supply system and with one other water reclamation system. Its insensitivity to changes in external temperature and pressure make it quite flexible, but its growth characteristics are somewhat limited both with respect to crew size and mission length. Noise levels should be quite low. Volume is average. Electrical power is low, and no heat is required.

Multifiltration

Multifiltration is a method of water reclamation in which waste water is filtered through various materials, mainly charcoal and ion exchange resins, to remove contaminants. While nearly any waste water can be treated in this way, a preliminary analysis indicated that the total equivalent weight required for urine or washwater is much greater than for any other system being considered. Thus, multifiltration was considered for condensate reclamation only. For this purpose, it consists of only charcoal and bacterial filters as shown in figure 77.

Water is received and stored in holding tanks. No pretreatment is required. Two tanks are used; one receives waste water while the other discharges collected water to the filters. The water is fed in a single pass through a bacteria filter (to protect the charcoal bed), a charcoal filter, and another bacteria filter. If either of the two conductivity sensors indicates unsatisfactory water, the process flow is automatically diverted back to the holding tanks. At the same time, the process feed valve is closed and a shutdown warning signal is given so that repairs may be made.

When one holding tank is emptied, the feed valve automatically closes the empty tank and opens the other tank so that processing continues uninterrupted. At the same time, the waste water feed is switched to the empty tank.

Absolute criteria. -

Performance: Recovery efficiency for this system is limited only by the water lost when the beds are replaced. If the bed is steam-purged to remove all ullage water and to sterilize the bed, it can be dried by cabin air after removal so the loss would rarely exceed one percent. Recovery efficiency may therefore be taken at 99+ percent.

Typical product water analysis is shown in table 35. Unfortunately, no extensive water analyses have been performed with any tested system. Those that have, as in the example shown, indicate satisfactory performance.

This system requires power only for pump operation and the conductivity sensor. In either case, in the context of this study, the power requirement is negligible. This is one of the advantages of the multifiltration system.

Safety: This system presents no significant safety problems.

Availability/confidence: The multifiltration concept can, with a strong effort, be developed for recovery of condensate for a flight as early as 1972. Development is now in the late prototype development phase. The components and materials required for this system are available and of sufficient simplicity so that no untoward problems are anticipated. A recovery efficiency in excess of 99 percent is possible with this system.

Primary criteria. -

The combined MTBF is 40 600 hours. With 17 additional spare components, the overall reliability has been calculated to be 0.999694.

Crew time: Scheduled maintenance involves the periodic replacement of the bacterial filters and the charcoal bed. For each change, the unit must be steam purged to sterilize it before placing it in operation. These operations should require about 128 hours per mission.

SUBSYSTEM: Water Management - Reclamation

CONCEPT: Multifiltration

FLIGHT AVAILABILITY: 1972
(1970 go-ahead)

RELIABILITY: 0.999695 MTBF: 40 600 hr.

Spares/Redundant (R) Units:

1 - Charcoal Canister	3 - Conductivity Sensor
1 - Bacterial Filter Canister	2 - Diverter Valve
3 - Pump	2 - Controller
2 - Sol. Valve	

CREW TIME (Hr/Mission):	Scheduled	Unscheduled
	128	0.9

EQUIVALENT WEIGHT (lb): [a]	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	113	113	113
Expendables	206	206	206
Spares/Redundant Units	43	43	43
Electrical Power	6	6	6
Thermal Power	0	0	0
Radiator Load	2	2	2
Total Equivalent Weight	370	370	370

[a] Data is for a flow rate of 2.64 lb/hr.

POWER (Watts):			
Electrical	12	12	12
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	4	8	12

Figure 77. (Page 1 of 2)

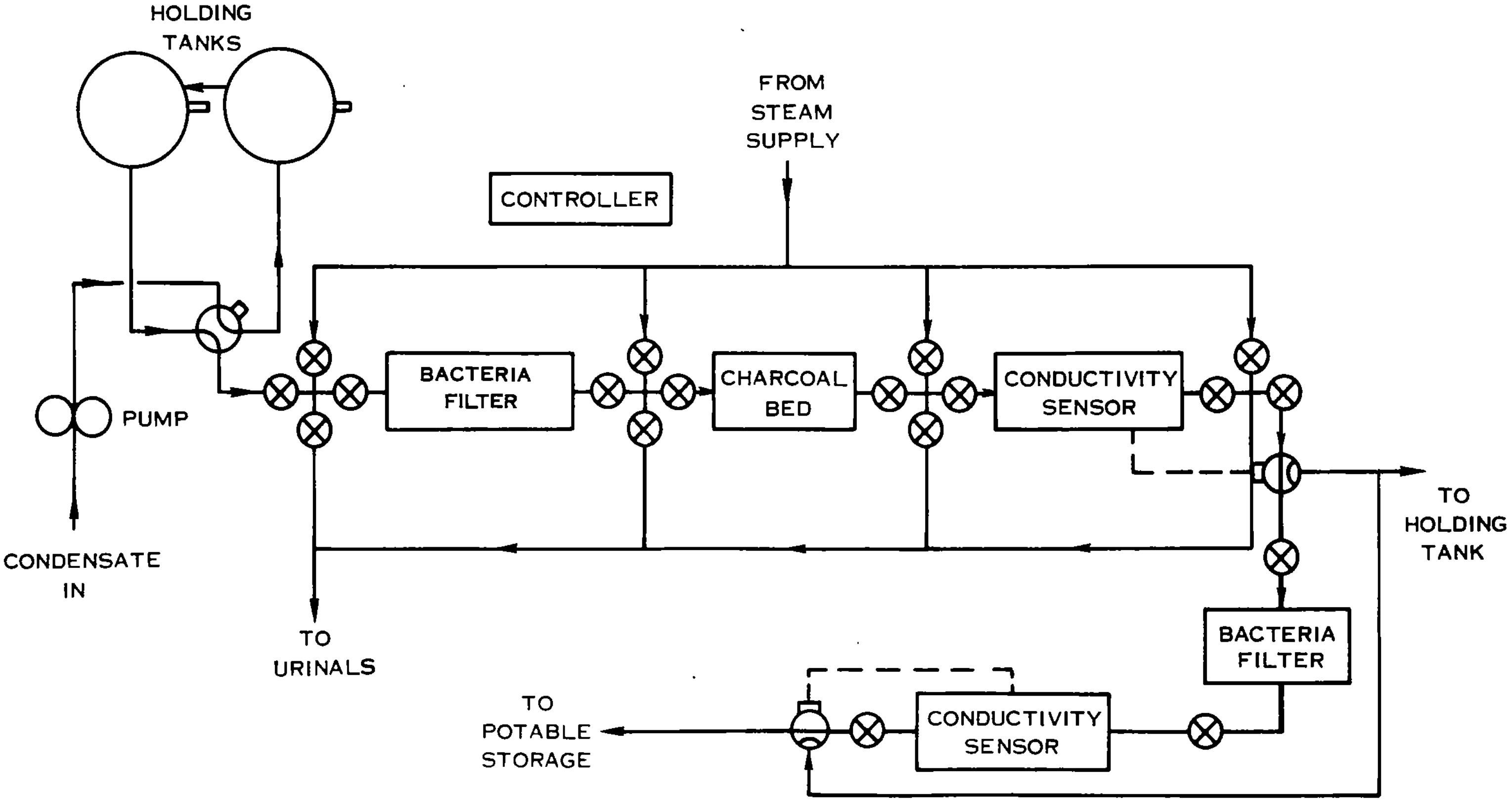


Figure 77. Multifiltration Concept (Page 2 of 2).

Unscheduled maintenance is estimated to be 0.9 hours per mission.

Equivalent weight: The equivalent weights of this system are shown on the data sheet. The weights correspond to a processing rate of 2.64 lb/hr, which is the humidity condensate flow rate.

Secondary criteria. - Contamination from this system should be low, provided it is operated correctly. It is quite flexible because the temperature and pressure are independent within normal design ranges. It cannot be made larger without significant increases in expendable weight. The noise level is low, but volume, because of the expendables, is high. Power consumption is low.

WATER RECLAMATION CONCEPT EVALUATION AND SELECTION

This section presents the evaluation ratings of the water reclamation concepts previously discussed and the selections for each power supply design.

For Design 1, the vapor diffusion/compression concept was selected. For Designs 2 and 3, the vapor diffusion concept was selected. In all three cases, the single major factor influencing the selection was the superior ability of these concepts to cope with the microbiological contamination problem.

Because of the five different ways in which the waste waters can be combined as discussed previously in the WASTE WATER DESCRIPTION section, the evaluation and selection of the water reclamation equipment must consider the use of a single reclamation unit processing all the waste water or a combination of reclamation units integrated as dictated by the other four ways in which the waste waters can be combined. For this purpose, any of the eight distillation concepts can be considered for processing all the waste water, while reverse osmosis can be considered for use with wash water and/or condensate, and multifiltration can be considered for use with condensate only.

Within this framework, there are a total of 112 possible integrated concepts that could be considered. Recognizing that any integrated concept must necessarily include a distillation concept to process the urinal water, it was decided to first evaluate and select a distillation concept for each design and then make the final evaluation and selection from a group of integrated reclamation concepts employing that distillation concept. This procedure is felt to be justified because the selection of any concept is made, in this study, not on the basis of a single criterion but rather on the basis of the thirteen AILSS criteria.

This simplification reduces the number of combinations to be considered to fourteen. After a closer examination, it was determined that there were, in fact, only five integrated concepts that could not be eliminated by inspection:

Distillation
All waste water processed by the distillation concept.

Distillation/multifiltration (c)
Urinal water and wash water processed by the distillation concept and condensate processed by multifiltration.

Distillation/reverse osmosis (c)
Urinal water and wash water processed by the distillation concept and condensate processed by reverse osmosis.

Distillation/reverse osmosis (w)
Urinal water and condensate processed by the distillation concept and washwater processed by reverse osmosis.

Distillation/reverse osmosis (w + c)
Urinal water processed by the distillation concept and condensate and wash water processed by reverse osmosis.

These, then, form a group of integrated concepts from which the final AILSS selection was made. Figure 78 shows schematically how these integrated concepts would be arranged.

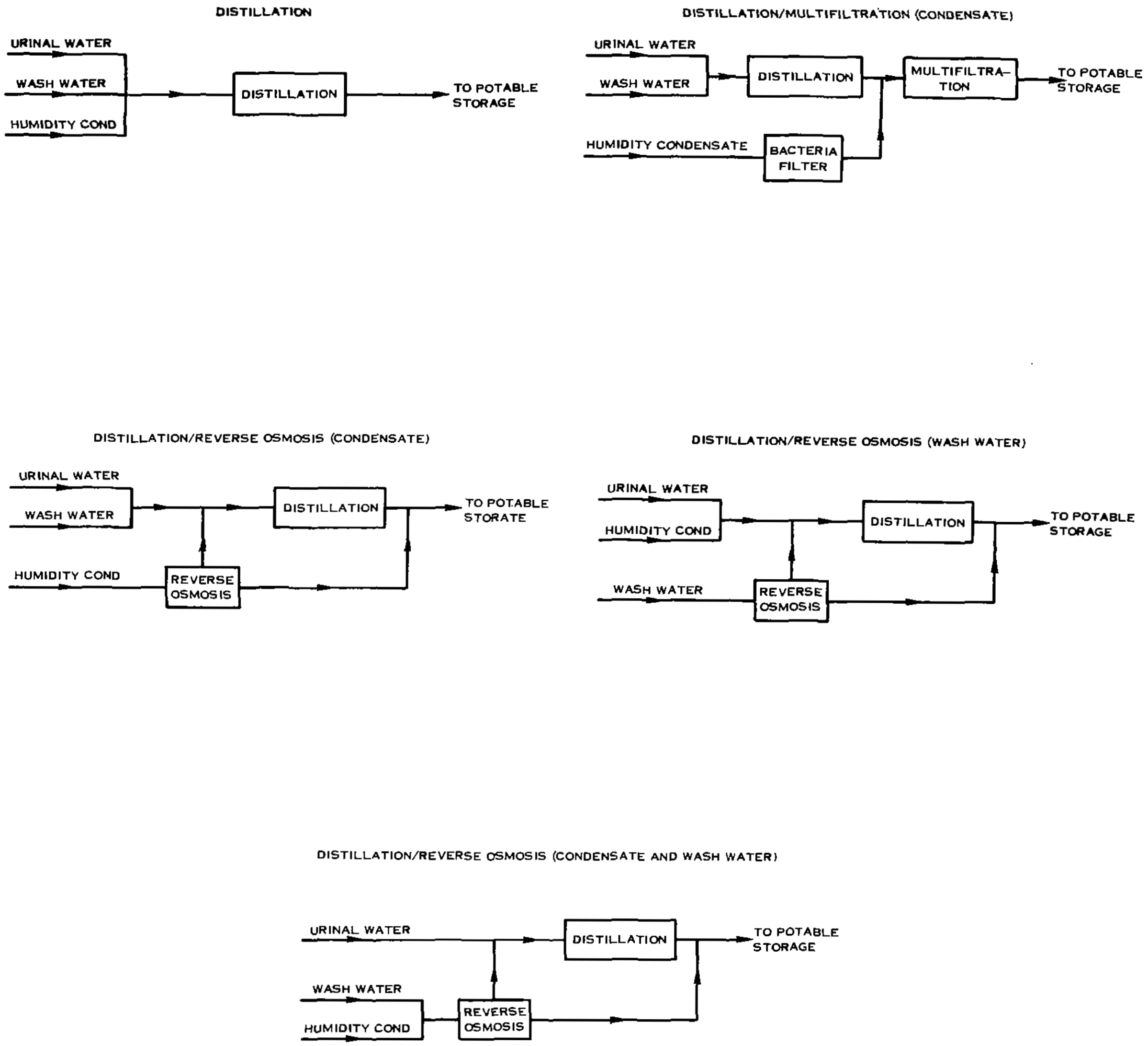
Distillation Concept Evaluation and Selection: Design 1

The ratings for these concepts are shown in table 36.

Absolute criteria. -

Performance: Throughout this section, the most important performance criterion is water potability: chemical and microbiological purity. From this standpoint, all concepts except two rate Good. Two concepts, however, show a much better potential for controlling microbiological contamination: vapor diffusion/compression and vapor diffusion. In these concepts, the combination of pretreatment, the 150°F evaporator temperature, and membrane vapor filter comes closest to providing positive microbiological contamination control. They are rated Very Good.

Safety: All concepts except three are rated Good on safety because of the general provisions made in each for sterilization prior to and following repair work. The closed cycle air evaporation system is rated Fair because of the fire and bacterial growth potential posed by the stored used and unused wicks. The two vapor diffusion concepts are rated Very Good because their inherent sterility poses fewer hazards from external leakage and because their modularized design obviates the necessity for internal repair.



DISTILLATION

DISTILLATION/MULTIFILTRATION (CONDENSATE)

DISTILLATION/REVERSE OSMOSIS (CONDENSATE)

DISTILLATION/REVERSE OSMOSIS (WASH WATER)

DISTILLATION/REVERSE OSMOSIS (CONDENSATE AND WASH WATER)

Figure 78. Integrated Concept Schematic Arrangements

TABLE 36 (Page 1 of 2)

EVALUATION SUMMARY - WATER RECLAMATION DISTILLATION CONCEPTS

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts														
		Vacuum distillation/ compression			Vacuum distillation/ thermoelectric			Vacuum distillation/ pyrolysis			Flash evaporation/pyrolysis			Flash evaporation/compression/pyrolysis		
CRITERIA	DESIGN	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Absolute	Performance	Good			Good			Good			Good			Good		
	Safety	Good			Good			Good			Good			Good		
	Avail./Conf.	Good			Fair			Good			Good			Good		
Primary	Reliability	Good			Good			Good			Good			Good		
	Crew Time	Poor			Fair			Good			Good			Good		
	Equivalent Weight	Very good	Good	Good	Very good	Good	Good	Poor	Fair	Good	Poor	Fair	Good	Good	Fair	Fair
		Eliminated			Eliminated			Eliminated			Eliminated			Eliminated		
Secondary	Contamination															
	Interfaces															
	Flexibility															
	Growth															
	Noise															
	Volume															
	Power															

TABLE 36 (Page 2 of 2)
EVALUATION SUMMARY - WATER RECLAMATION DISTILLATION CONCEPTS

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts								
		Closed cycle air evaporation			Vapor diffusion			Vapor diffusion/ compression		
CRITERIA	DESIGN	1	2	3	1	2	3	1	2	3
Absolute	Performance	Good			Very good			Very good		
	Safety	Fair			Very good			Very good		
	Avail./Conf.	Good			Good			Good		
Primary	Reliability	Good			Good			Good		
	Crew Time	Fair			Good			Good		
	Equivalent Weight	Fair	Very good	Very good	Poor	Good	Very good	Very good	Good	Good
		Eliminated								
Secondary	Contamination				Very good			Very good		
	Interfaces				Good			Very good		
	Flexibility				Good			Good		
	Growth				Good			Good		
	Noise				Very good			Good		
	Volume				Good			Good		
	Power				Very good			Very good		
					Elim.	Selected		Sel.	Eliminated	

Availability/confidence: The availability/confidence of all systems except vacuum distillation/thermoelectric is rated Good. Although the air evaporation system warrants a slightly higher rating because it has been successfully used in manned chamber tests, its difference over the other systems rated Good is considered small compared to the available development time. The vapor distillation/thermoelectric concept is rated Fair because of uncertainty about the development of reliable thermoelectric modules.

At the end of the absolute criteria evaluation, all distillation concepts are considered acceptable.

Primary criteria. -

Reliability: Because the MTBF of all concepts is in excess of the mission duration, and because there are not significant differences between them, all are rated Good. A summary of the MTBF's is given in table 37.

Crew time: The crew time for all but three concepts is rated Good. Vacuum distillation/compression is rated Poor because of the large number of bacteria filters that require replacement and because of the added problems of replacing the compressors on the rotating evaporator-condensor units. Vacuum distillation/thermoelectric and closed cycle air evaporation are rated Fair because of the large number of bacterial filters that require replacement. The rest of the concepts have significantly lower but very nearly equal scheduled and unscheduled maintenance time. They are rated Good. A summary of crew times is given in table 37.

TABLE 37

DISTILLATION CONCEPT - PRIMARY CRITERIA SUMMARY

Concept	MTBF, Hr	Crew time Hr per mission Scheduled/ Unscheduled
Vacuum distillation/compression	13,600	131/3.5
Vacuum distillation/thermoelectric	14,100	131/3.4
Vacuum distillation/pyrolysis	14,000	38/2.6
Flash evaporation/pyrolysis	14,800	38/2.4
Flash evaporation/compression/pyrolysis	14,400	38/2.5
Closed cycle air evaporation	20,000	207/1.8
Vapor diffusion	16,000	56/2.3
Vapor diffusion/compression	14,300	56/2.5

Equivalent weight: Because of the possibility of these concepts being integrated, as previously discussed, with either reverse osmosis or multifiltration, the total equivalent weight evaluation must be made over the range of processing rates associated with their use in the various integrated concepts discussed. The total equivalent weights, then, are determined as a function of processing rate and are shown for Design 1 in figure 79. The range of interest lies between a maximum of 12.77 lb/hr (if all waste water is processed together) and a minimum of 6.32 lb/hr (if only urinal water is processed). The ratings discussed below are for that range and do not change within that range.

Vacuum distillation/compression, vacuum distillation/thermoelectric, and vapor diffusion/compression rate Very Good because they efficiently conserve the heat of vaporization of the distillate. Flash evaporation/compression/pyrolysis, rated Good, would have been rated higher, but the pyrolysis unit requires a fairly large quantity of energy. None of the remaining systems provide for recovery of the heat of vaporization of the distillate, so that all but one rate Poor. The exception, closed cycle air evaporation, benefits from an excess water credit and is therefore upgraded to Fair.

Selection. - An examination of the primary criteria ratings shows that vapor diffusion/compression is equal to or better than any of the other concepts in reliability and crew time. Compared to those concepts with equal ratings under those criteria, it has significantly lower total equivalent weight. Coupling this with its better absolute criteria ratings, particularly its better microbiological control characteristics, leads to its choice as the Design 1 distillation concept.

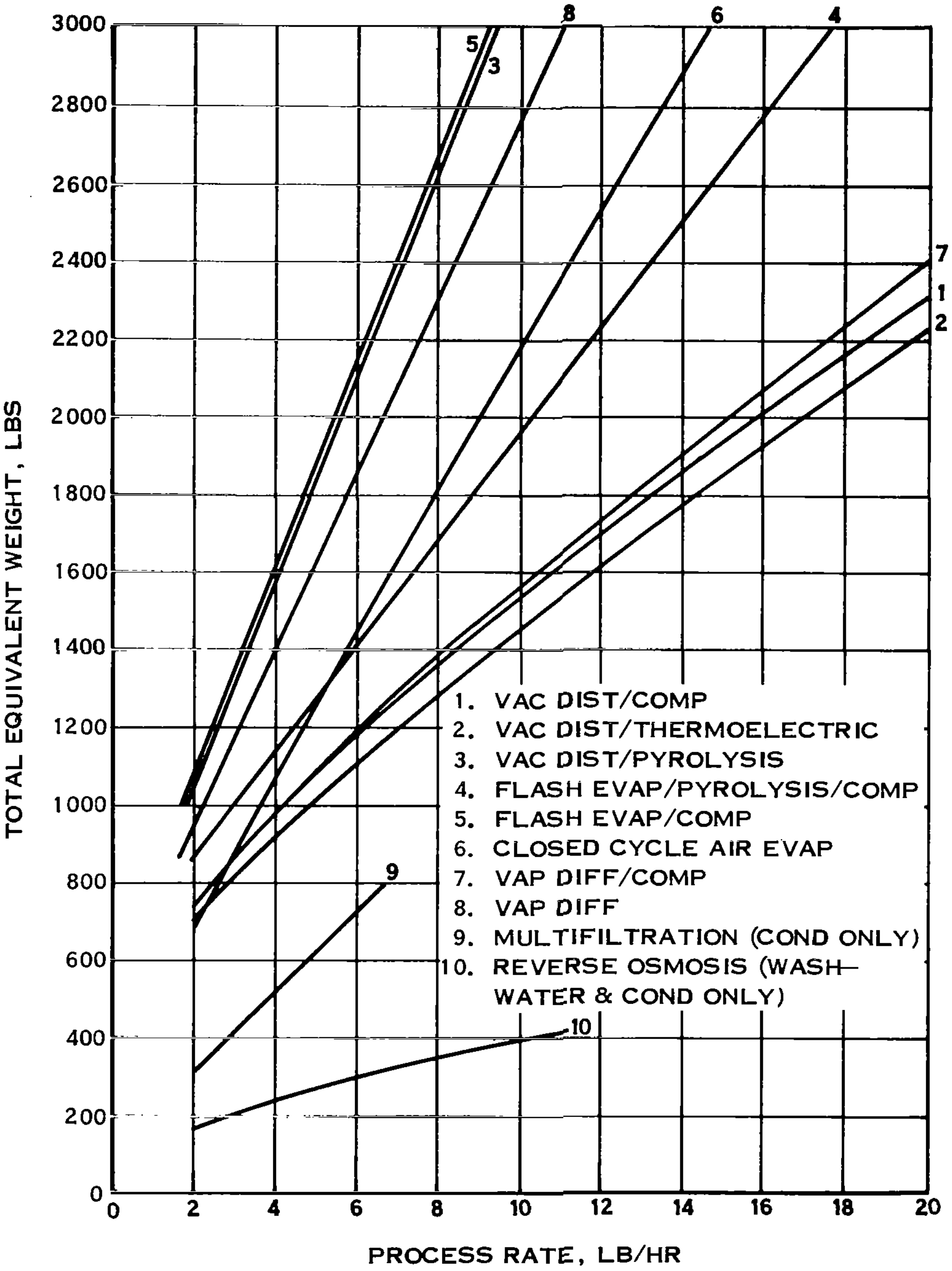
An examination of the secondary criteria ratings for this selected concept reveals no factors that would negate this selection.

Distillation Concept Evaluation and Selection: Design 2

A summary of the distillation concept ratings for this design is shown in table 36.

Absolute criteria. - All absolute criteria for this design are rated the same as for Design 1.

Primary criteria. - Reliability and Crew Time for this design are rated the same as for Design 1.



(ASSUMES URINE RATE@~ 30 LB/DAY EXCEPT AS NOTED)

Figure 79. Total Equivalent Weight Versus Process Rate (Design 1)

Total equivalent weight: Just as for Design 1, the total equivalent weight must be evaluated over the range from 6.32 lb/hr to 12.77 lb/hr. Figure 80 shows the total equivalent weights in the range of interest. The ratings apply to that range of processing rates.

For Design 2, the closed cycle air evaporation system rates Very Good, mostly because of the excess water credit. Vacuum distillation/compression, vacuum distillation/thermoelectric, and vapor diffusion/compression rate Good, demonstrating that this design places less emphasis on thermal power requirements. For the same reason, vapor diffusion rates Good although its thermal requirements are high. The remaining systems, all with pyrolysis units, rate Fair.

At the end of the primary criteria, three concepts, closed cycle air evaporation, vapor diffusion/compression, and vapor diffusion appear to be about equal on the basis of the primary criteria. The absolute criteria ratings for the two vapor diffusion, concepts however, are clearly better than for closed cycle air evaporation. The latter may therefore be eliminated, but an examination of the secondary criteria must be made for a final selection between the two vapor diffusion concepts.

Secondary criteria. - Contamination is rated equally for both concepts and is Very Good because of the high temperature of the circulating loop and the filtering action of the membranes. Vapor diffusion has one more interface, with the thermal control loop, than vapor diffusion/compression, for a rating of Good as compared to the latter's Very Good. Because of the similarity of these two concepts, flexibility and growth are equal and are rated Good. Vapor diffusion/compression is expected to have a somewhat higher noise level than vapor diffusion, due to the compressor. Therefore vapor diffusion/compression is rated Good while vapor diffusion is rated Very Good. The volume for both is less than any other concept and is rated Very Good. Vapor diffusion requires less electrical power than vapor diffusion/compression so that it is rated Very Good. Vapor diffusion compression is rated Good under power.

Selection. - The final overall ratings for the two vapor diffusion concepts are virtually identical. On the basis of significantly lower electrical power, vapor diffusion is selected over vapor diffusion/compression for Design 2.

Distillation Concept Evaluation and Selection: Design 3

A summary of the distillation concept ratings for this design is shown in table 36.

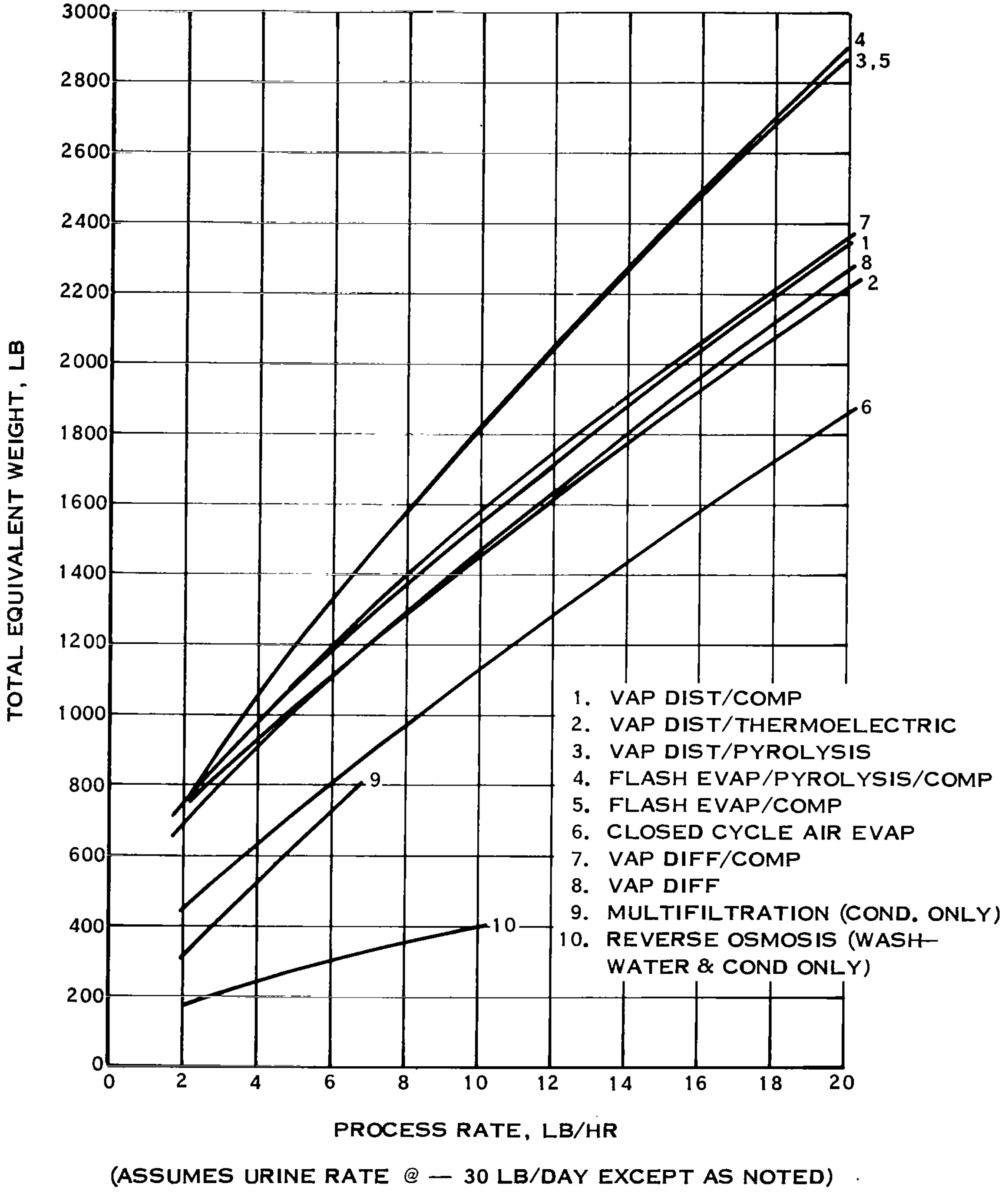


Figure 80. Total Equivalent Weight Versus Process Rate (Design 2)

Absolute criteria. - All absolute criteria for this design are rated the same as for Design 1.

Primary criteria. - All primary criteria, except total equivalent weight, for this design are rated the same as for Design 1.

Total equivalent weight: Just as for Design 1, the total equivalent weight must be evaluated over the range from 6.32 lb/hr to 12.77 lb/hr. Figure 81 shows the total equivalent weights in the range of interest. The ratings apply to that range of processing rates.

For this design in which thermal power is obtained at no penalty, the closed cycle air evaporation unit rates Very Good, again, mainly because of the excess water credit. Vapor diffusion, which requires high thermal power, also rates Very Good. Vacuum distillation/compression, vacuum distillation/thermoelectric, and vapor diffusion/compression while conserving thermal power, do it at the expense of electrical power and so, benefit less from available thermal power and rate only Good. Vacuum distillation/pyrolysis and flash evaporation/pyrolysis benefit from free thermal power, though not as much as vapor diffusion because of their pyrolysis units, and so, rate Good. Flash evaporation/compression/pyrolysis would also rate Good were it not for its compressor: it rates Fair.

Selection. - An examination of the primary criteria ratings shows that vapor diffusion is equal to or better than any of the other concepts in reliability and crew time. Compared to concepts with ratings equal to it under those criteria, it has significantly lower total equivalent weight. Coupling this with its better absolute criteria ratings, particularly its better microbiological control characteristics, leads to its choice as the Design 3 distillation concept.

A further examination into the secondary criteria ratings of this concept reveals no factors that would negate its selection.

Integrated Concept Evaluation & Selection: Design 1

For Design 1, the selected distillation concept was vapor diffusion/compression, so that in the integrated concepts evaluation it will be this distillation concept that is integrated with either multifiltration or reverse osmosis. Evaluation ratings for Design 1, which employs all solar cell power, are summarized in table 38.

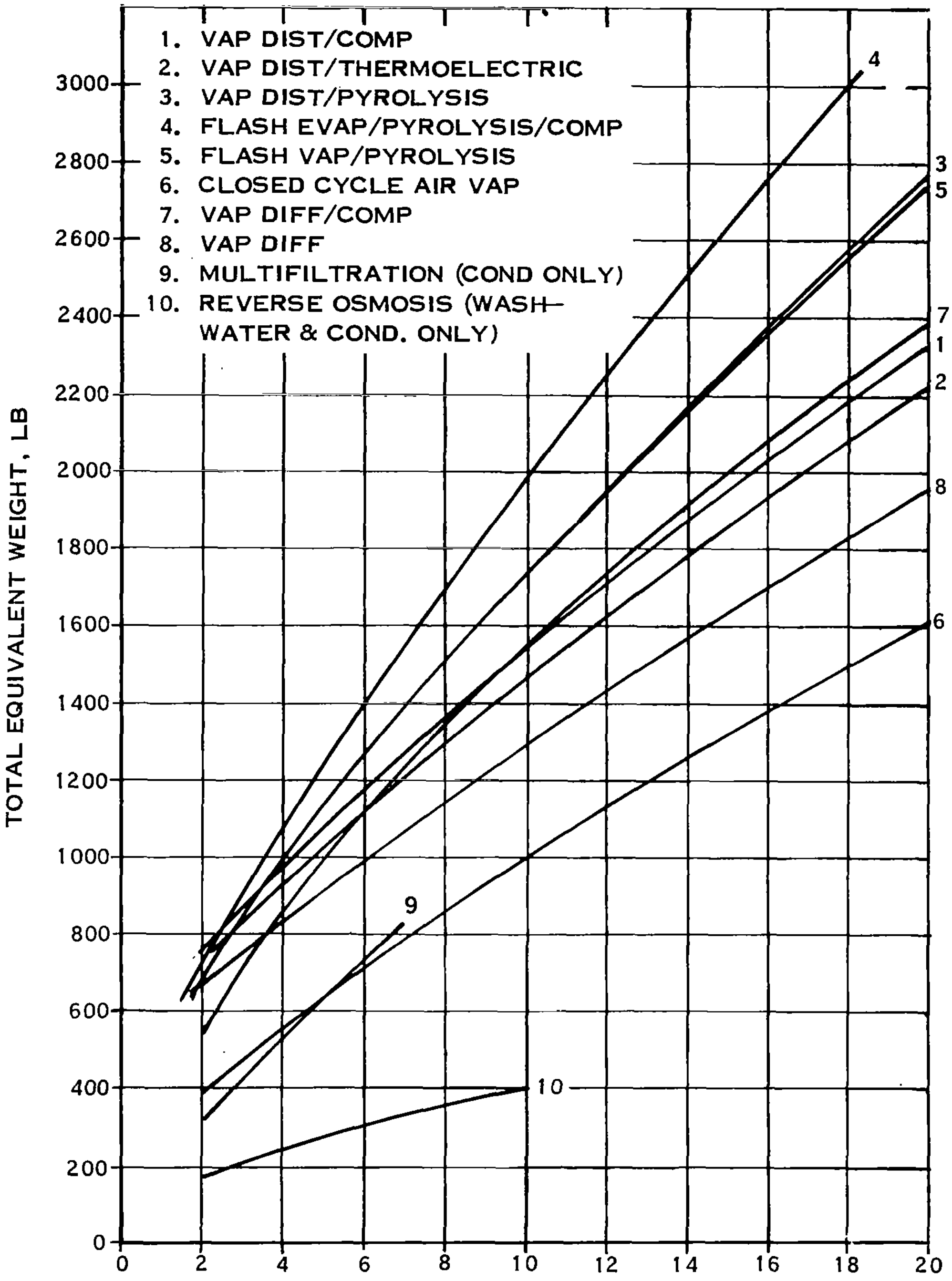


Figure 81. Total Equivalent Weight Versus Process Rate (Design 3)

TABLE 38
EVALUATION SUMMARY - WATER RECLAMATION INTEGRATED CONCEPTS

Power Supplies
Design 1 - Solar Cell
Design 2 - Solar Cell/ Isotopes
Design 3 - Brayton

		Candidate Concepts														
		Distillation			Distallation/ Multifiltration (Condensate)			Distillation/ Reverse Osmosis (Condensate)			Distillation/ Reverse Osmosis (Washwater)			Distillation/ Reverse Osmosis (Condensate and Washwater)		
CRITERIA	DESIGN	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Absolute	Performance	Very good			Very good			Very good			Very good			Very good		
	Safety	Very good			Fair			Good			Good			Good		
	Avail. /Conf.	Good			Good			Good			Good			Good		
Primary	Reliability	Good			Fair			Fair			Fair			Fair		
	Crew Time	Good			Fair			Good			Good			Good		
	Equivalent Weight	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Very good	Very good	Good
					Eliminated			Eliminated			Eliminated					
Secondary	Contamination	VG	VG	VG										G	G	G
	Interfaces	VG	G	G										VG	G	G
	Flexibility	G	G	G										G	G	G
	Growth	G	G	G										G	G	G
	Noise	G	VG	VG										G	VG	VG
	Volume	VG	VG	VG										F	F	F
	Power	F	VG	VG										VG	VG	VG
		Selected												Eliminated		

Absolute criteria. -

Performance: The performance rating for the distillation concept has already been established as Very Good in the distillation concept evaluation discussion. Because both reverse osmosis and multifiltration can individually be rated Very Good in performance, any combination of either of them with the selected distillation concept can be rated Very Good also.

Safety: The distillation concept was given a Very Good rating under safety because of the inherent bacteriological control associated with either vapor diffusion concept. Such inherent control, however, does not exist with either the reverse osmosis concept or the multifiltration concept. Consistent with the rating standard adopted for the distillation concepts, reverse osmosis would, individually, rate Good because, although it operates at essentially ambient temperature, its membrane acts as a bacteria filter. Multifiltration, however, must be downrated to Fair because, although no more unsafe in operation than most of the other concepts, replacement of the charcoal filters involves handling a potentially contaminated piece of equipment. The distillation/multifiltration (c) concept is therefore rated Fair, while the other integrated concepts involving reverse osmosis are rated Good.

Availability: The availability of the integrated concepts is determined by the availability of the latest available component. In all cases, the latest available concept is vapor diffusion/compression which, with strong effort, can be developed by 1977. Reverse osmosis can be available by 1974 and multifiltration by 1972. Therefore, all concepts are rated Good.

Primary criteria. - The pertinent primary criteria data are summarized in table 39.

Reliability: The reliability of the distillation concept is rated Good because the MTBF for vapor diffusion/compression is greater than the mission length. The MTBF of the other concepts is less than the mission length and therefore rates Fair.

Crew time: The majority of the scheduled crew time in all of these concepts involves replacement of the charcoal and bacteria filters. Fortunately, these components can be shared by the basic units involved in the integration, so that total scheduled crew time is not the sum of the individual unit scheduled crew times. Nevertheless, the distillation/multifiltration (c) concept requires more filter changes and hence has a scheduled crew time of almost double that of the other concepts. For this reason, it is rated Fair. The other concepts are rated Good.

Total equivalent weight: The total equivalent weights for Design 1 are shown in table 39. The variation of total equivalent weight as a function of process rate for all individual concepts is shown in figure 10-13. The basic reason the weights differ is because of the different types and flow rates of water being processed. On the basis of these weights, all concepts are rated Good except the distillation/reverse osmosis (w + c) concept, which rates Very Good.

Summary: At the end of the primary criteria, distillation/multifiltration (c), distillation/reverse osmosis (c), and distillation/reverse osmosis (w) can be clearly eliminated. The remaining two concepts, however, are essentially equal, so that examination of the secondary criteria is indicated.

Secondary criteria. - Contamination characteristics of the vapor diffusion concepts in the distillation concept are rated Very Good because of the inherent bacteria control. When integrated with reverse osmosisin distillation/ reverse osmosis (w + c), the rating drops to Good because the reverse osmosis concept, operating at lower temperature, is not as sterile and therefore presents a higher contamination potential.

Both concepts have the same interfaces with external systems and therefore are rated the same. On the basis used in rating all the concepts, both the distillation and integrated, the rating is Very Good.

Flexibility is rated the same for both concepts because the addition of reverse osmosis to the appropriate vapor diffusion concept does not substantially alter the sensitivity of the concept to variations in power source. Because the distillation concept, already representing an optimization around power source, is rated Good, both concepts are rated Good.

Both concepts are rated Good under growth because they are both membrane processes, requiring low expendable weight, and are relatively insensitive to changes in mission duration. Furthermore, both offer certain technological growth possibilities as membrane technology improves.

The overriding noise factor, in either concept, is the compressor on the vapor diffusion/compression unit. The reverse osmosis pump is relatively quiet. Both concepts are rated Good.

Compared to the vapor diffusion/compression unit with its installed redundant evaporator-condenser modules, the volume of the reverse osmosis unit is relatively small. Nevertheless, it requires a second set of collection tanks so that the distillation concept is rated Very Good, while the distillation/reverse osmosis (w + c) concept rates Fair.

The power required by the distillation concept is nearly double that required by the distillation/reverse osmosis (w + c) concept. The former is therefore rated Fair while the latter is rated Very Good.

Selection. - While both the distillation concept and the distillation/reverse osmosis (w + c) concept are quite close, the distillation concept is selected on the basis of significantly better safety, reliability, and contamination ratings. Design 1 therefore uses a vapor diffusion/compression system for all water reclamation.

Integrated Concept Evaluation and Selection: Design 2

For Design 2, the selected distillation concept was vapor diffusion, so that in the integrated concept evaluation it will be the distillation concept that is integrated with either multifiltration or reverse osmosis. Evaluation ratings for Design 2, which employs isotope thermal power and solar cell electrical power, are summarized in table 38.

Absolute criteria. - The absolute criteria ratings for Design 2 are the same as those for Design 1.

Primary criteria. - The primary criteria ratings for Design 2 are the same as those for Design 1. The pertinent primary criteria data is summarized in table 39.

Summary: At the end of the primary criteria, as before, the distillation/multifiltration (c), the distillation/reverse osmosis (c), and the distillation/reverse osmosis (w) concepts can be clearly eliminated. The remaining two concepts, however, are essentially equal so that examination of the secondary criteria is indicated.

Secondary criteria. - Most of the secondary criteria have the same ratings for Design 2 as for Design 1. The number of interfaces increases for Design 2 to include the thermal loop so that both concepts rate Good instead of Very Good as for Design 1. Also, because the vapor diffusion concept selected for Design 2 does not use a compressor, the noise level is reduced and both concepts are rated Very Good. Finally, the elimination of the compressor also reduces the electrical power required for the selected vapor diffusion concept, so that both concepts can be rated Very Good on power.

Selection. - Both concepts again are quite close in their overall ratings, but the preference must still lie with the distillation concept. Vapor diffusion is therefore selected for Design 2 on the basis of better safety, reliability, and volume characteristics.

Integrated Concept Evaluation and Selection: Design 3

For Design 3, the selected distillation concept was vapor diffusion, so that in the integrated concept evaluation it will be this distillation concept that is integrated with either multifiltration or reverse osmosis. Evaluation ratings for Design 3, which employs Brayton cycle power, are summarized in table 38.

TABLE 39

INTEGRATED CONCEPTS - DATA SUMMARY

Concept	Waste Water		MTBF, hrs			Crew Time, hrs				Total Equivalent Weight, lb			Electrical Power, watts		
							Unscheduled								
	Type	Flow, lb/hr	Design 1	Design 2	Design 3	Scheduled	Design 1	Design 2	Design 3	Design 1	Design 2	Design 3	Design 1	Design 2	Design 3
Vapor Diffusion/Compression	All	12.77	14 300			56	2.5			1792			1634		
Vapor diffusion				16 000	16 000			2.3	2.3		1699	1477		45	45
Combined			14 300	16 000	16 000	56	2.5	2.3	2.3	1792	1699	1477	1634	45	45
Vapor Diffusion/Compression	Urinal Water plus Washwater	10.35	14 300			56	2.5			1595			1270		
Vapor Diffusion				16 000	16 000			2.3	2.3		1495	1300		38	38
Multifiltration	Condensate	2.64	40 600	40 600	40 600	128	0.9	0.9	0.9	240	240	240	12	12	12
Combined			10 590	11 490	11 490	128	3.4	3.2	3.2	1835	1735	1540	1282	50	50
Vapor Diffusion/Compression	Urinal Water plus Washwater	10.88	14 300			56	2.5			1630			1350		
Vapor Diffusion				16 000	16 000			2.3	2.3		1540	1345		40	40
Reverse Osmosis	Condensate	2.11	20 700	20 700	20 700	56	1.7	1.7	1.7	190	190	190	26	26	26
Combined			8 458	9 025	9 025	56	4.2	4.0	4.0	1820	1730	1535	1376	66	66
Vapor Diffusion/Compression	Urinal Water plus Condensate	8.22	14 300			56	2.5			1410			1020		
Vapor Diffusion				16 000	16 000			2.3	2.3		1310	1145		30	30
Reverse Osmosis	Washwater	4.55	20 700	20 700	20 700	56	1.7	1.7	1.7	260	260	260	53	53	53
Combined			8 458	9 025	9 025	56	4.2	4.0	4.0	1670	1570	1405	1073	83	83
Vapor Diffusion/Compression	Urinal Water	6.32	14 300			56	2.5			1225			800		
Vapor Diffusion				16 000	16 000			2.3	2.3		1140	1010		22	22
Reverse Osmosis	Washwater plus Condensate	6.67	20 700	20 700	20 700	56	1.7	1.7	1.7	327	327	327	80	80	80
Combined			8 458	9 025	9 025	56	4.2	4.0	4.0	1552	1467	1337	880	102	102

Absolute criteria. - The absolute criteria ratings for Design 3 are the same as those for Design 1.

Primary criteria. - All primary criteria, except total equivalent weight, for this design are rated the same as for Design 1. The pertinent primary criteria data are summarized in table 39.

Total equivalent weight: For Design 3, the total equivalent weight rating of the distillation concept remains Good, but the rating for the distillation/reverse osmosis (w + c) concept drops from Very Good to Good. The reason that these concepts draw closer together in total equivalent weight is basically because thermal power is supplied at no penalty in Design 3, and the selected vapor diffusion concept requires mostly thermal power. The other concepts retain the same ratings as in Design 1.

Selection. - At the end of the primary ratings, the vapor diffusion distillation concept is selected for Design 3 on the basis of better safety and reliability ratings.

Summary

After considering possible waste waters combinations for processing and significant combinations of basic processing concepts for each of the three designs, the following concepts are selected for the AILSS mission:

Design 1 - All waste water processed together by a vapor diffusion/compression unit.

Design 2 - All waste water processed together by a vapor diffusion unit using isotope heat.

Design 3 - All waste water processed together by a vapor diffusion unit using Brayton cycle waste heat.

IMPACT OF MISSION PARAMETERS

Mission Length

An analysis of the effect of mission duration includes two major criteria: total equivalent weight and reliability. So far as total equivalent weight is concerned, no significant changes occur in the relative standing of any of the concepts for Designs 1, 2, or 3 over mission durations 100 to 1000 days.

From the standpoint of reliability, the relative ratings and, hence, the selections would not change for mission durations below about 600 days. Beyond that time, the ratings of the leading concepts would change from Good to Fair. In spite of this, vapor diffusion/compression still would be selected for Design 1 on the basis of the overall ratings. For Designs 2 and 3, beyond 600 days, closed cycle air evaporation becomes more attractive due to its high recovery efficiency, and the choice between it and the selected vapor diffusion concept becomes more difficult. Nevertheless, vapor diffusion would remain the recommended selection based primarily on its better bacteriological control characteristics.

An integration consideration concerning the water balance and therefore the water reclamation system is the quantity of excess water which may be made available to the total system. Electrolysis of excess water can provide significant quantities of oxygen for leakage make-up for long duration missions. Complete reclamation of all processed water would result in a 750 pound saving for a 1000 day mission. A possible approach to obtain this water would be to add a second stage of processing to the vapor diffusion unit, which would result in the complete recovery of all water processed. This unit could be a small air evaporation unit, with the product water reprocessed through the primary distillation unit. The significant weight saved should compensate for the increased complexity and slightly higher crew maintenance time.

Crew Size

Changes in crew size, so far as the selection of water reclamation equipment is concerned, can possibly cause a change in total equivalent weight and maintenance time evaluation. The changes in total equivalent weight can readily be seen by examining figures 79, 80, and 81. In reality, the total equivalent weights shown should be adjusted slightly to account for different urine pretreatment weight. However, this correction amounts to only 0.34 lb/man-day, and it may be ignored for the present purpose. The relationship between crew size and processing rate is given below:

3 men - 4.26 lb/hr 9 men - 12.77 lb/hr
6 men - 8.52 lb/hr 12 men - 17.03 lb/hr

In the range from six to twelve men, the relative total equivalent weight of the various concepts remains unchanged and within reasonable absolute difference limits. Thus, there is no reason to change the selection for any of the designs.

For crews larger than 12 men, however, a review of the integrated system indicates that incorporation of a reverse osmosis unit for washwater and condensate processing would be desirable because a significant total equivalent weight reduction could be made.

For small crews, differences in total equivalent weight become small and no change in the original selection results.

Power Penalty

Power penalty affects only total equivalent weight. Considering that in the selection of a distillation concept, this was not the deciding factor, only the grossest changes could be expected to influence the selection. However, considering integrated arrangements using reverse osmosis, significant power and therefore total equivalent weight savings are possible for increased power penalties.

For Design 1 there are no significant relative changes in the distillation system selection. The vapor diffusion/compression selection would remain valid over this entire range of power penalties. A nearly 800 watt power reduction is possible by using vapor diffusion/compression along with reverse osmosis. Therefore, at a power penalty of about 750 pounds per kilowatt a reverse osmosis unit would definitely be used because this would justify the added complexity and maintenance time.

For Design 2, assuming no change in solar cell penalty, there are three distillation concepts that change significantly in total equivalent weight in the range from 0 to 100 pounds per kilowatt for thermal power. These three are the large thermal power users: vacuum distillation/pyrolysis, flash evaporation/pyrolysis, and vapor diffusion. Of these, vapor diffusion shows the most marked change. Below about 25 pounds per kilowatt, its total equivalent weight rating would change from Good to Very Good. Above 60 pounds per kilowatt, the rating would drop to Fair. In this last range, a choice between vapor diffusion and air evaporation would be very difficult. Use of a reverse osmosis unit for washwater and condensate can reduce thermal requirements of the isotope by about 50 percent. Therefore, any significant increase in isotope power penalty would result in its selection for use with the vapor diffusion unit. Electrical power level of the Design 2 selection is so low that electrical power penalty changes have no effect.

In Design 3, changes in the electrical power penalty have essentially the same effects as those just discussed above for Design 2, and no changes in selection result.

Finally, for a power critical mission, the choice of vapor diffusion/compression for urinal water and reverse osmosis for condensate and washwater is clearly evident. Such a system requires nearly 200 watts less power and is about 100 pounds lighter than its nearest competitor.

Resupply

The influence of resupply capability on concept selection depends on its effect on three of the selection criteria: reliability, crew time, and total equivalent weight. If it is accepted that a certain weight of material must be launched into space to accomplish a certain mission, the question of resupply enters only if there is a restriction on initial launch weight. Under these circumstances, concepts with a high percentage of their weight in expendables giving a low launch weight might tend to appear more attractive. Because the weight of expendables and spares for all the water reclamation concepts is relatively similar, resupply capability does not influence the concept selections.

Flight Date

Although the nominal flight date for the AILSS mission is set at 1980 for this study, it is interesting to consider how changes in that date might affect the concept selections. Because the concepts studied (except electrodialysis which was rejected on the basis of performance as well as availability) could be available as flight qualified hardware by 1980, no change in the selections would result from considering launch dates beyond 1980. In fact, because both vapor diffusion and vapor diffusion/compression could be ready as early as 1977, no change in selection would be anticipated from that date on.

For launches earlier than 1977, however, other concepts would have to be chosen. An examination of the availability dates given in the concept selection sections of this report reveals that 1974 is the earliest date at which a complete flight qualified water reclamation concept could become available. Actually, three concepts are involved: vacuum distillation/compression, vacuum distillation/pyrolysis (Designs 1 and 3), and closed cycle air evaporation. Both reverse osmosis and multifiltration are also available by this date but, since neither is considered suitable for urine processing, they could only be used in conjunction with one of the three distillation systems mentioned. Considering the overall criteria evaluations, it seems apparent that the selection would be the closed cycle air evaporation concept for Designs 2 and 3 for the period between 1974 and 1976.

For Design 1, in the 1974 to 1976 period, the high total equivalent weight of the closed cycle air evaporation concept appears particularly unappealing. Nevertheless, considering other concepts available during that period, its generally better characteristics in the other criteria make it the most desireable choice. In order to overcome the weight problem, consideration could be made of utilizing reverse osmosis for washwater and condensate processing in conjunction with air evaporation utilized for processing both urine and the residuum from the reverse osmosis.

By 1976, two more concepts could become available: vacuum distillation/thermoelectric and vacuum distillation/pyrolysis (Design 2). Examination of the overall evaluation, however, reveals no factors that might change the previously suggested selections.

WATER STORAGE

Tankage

Tankage, particularly water tankage within the cabin, deserves mention as a special problem area simply because no tank concept has been advanced to date that appears to satisfy the requirements of good volume utilization (ratio of stored liquid volume to tank volume), adaptability to reasonably accurate quantity sensing, ease of maintenance, high cyclic life, and true zero-gravity operation. Additional constraints such as manual liquid expulsion (in an emergency), ease of flushing and cleaning, adaptability to gas purging of the liquid, internal fluid mixing, and ability to transfer heat are considered important but secondary.

Discounting design details, liquid tank concepts generally fall into two categories: bladder or diaphragm tanks, where the gas-liquid interface is positively maintained by a membrane; and bladderless tanks, where surface tension forces maintain the gas-liquid interface. Each of these are discussed in some detail below.

Bladder tanks. - Bladder tanks usually employ an elastomeric flexible membrane or bladder that serves to contain and position the water within the tank shell so that positive expulsion is always possible. They provide generally good volume utilization, a means of fairly accurate quantity sensing, and stable zero gravity control.

The basic disadvantage of this type of tank lies with the bladder itself. Even allowing for substantial state-of-the-art advances in flexing bladder (or diaphragm) design, it must always be less reliable than a static tank. The implications of having to spare and/or repair bladder-type tanks are far-reaching and include:

1. The high weight penalties resulting from use of repairable tanks or from carrying extra tanks and water to replace the failed unit.

2. The problem of how to expel water from a tank with a ruptured bladder prior to repair (bladder replacement), and providing yet another storage vessel to receive this expelled water.

3. The actual finding of a ruptured bladder, when the failure does occur, presents very real fault isolation problems to which the solution is not readily apparent.

Any tankage concept that requires maintenance is at an extreme disadvantage when compared to a tank concept where the reliability is identical to a structure with a high safety factor (virtually 1), and where no maintenance is anticipated.

Bladderless tanks. - Bladderless zero-gravity tanks make use of the surface tension forces at a liquid-gas interface which cause the liquid surface to assume a geometrical shape yielding the smallest surface area, generally a quasi-spherical segment within the boundaries of the tank. This type of tank appears to comply with most of the tank requirements described earlier and is therefore advanced for use in the AILSS. The biggest asset of bladderless tanks is that they exhibit a potential for such high reliability on long-duration missions that maintenance can be completely avoided. Their prime drawback, however, is that a true zero-gravity capability has yet to be demonstrated, particularly in the situation where small accelerations (from maneuvers in space) tend to exceed the present tank surface tension capabilities and result in floating liquid in the tank and loss of a positive interface.

Design concepts for this type of tank have ranged from relatively simple tapered cylindrical shapes (where the liquid will migrate to the smaller end) to spherical shapes with internal baffling ranging from simple to quite complex. The resistance to upsets (gravity loads away from the liquid outlet) is a function of liquid density, surface tension characteristics, and tank geometry. In general, the greater the height of liquid normal to a fixed surface area, the greater the pressure during an acceleration in that direction and, therefore, the greater the likelihood of the liquid breaking free and away from the outlet. The surface tension force also increases inversely as the span of the surface area. The purpose of internal baffling is to reduce a large area into many smaller areas, often with multidirectional acceleration resistance. At one concept extreme, then, a single cavity (i.e., tapered cylinder) tank would leave little resistance to accelerations, while at the other extreme, a wick-filled tank would have high resistance to accelerations, and it might not even need tank walls. As an example of a possible configuration, figure 82 shows a concept which incorporates a tapered cylindrical tank with simple conical baffles to resist small accelerations. This principle of the positive expulsion by surface tension phenomenon has been used on earth for some time, e.g., cigarette lighters and ball-point pens.

Another design consideration has to do with the venting of gas from the tanks. Basically, this requires control of the position of the gas bubble as well as of the liquid mass. While the problem is again one of controlling the interface, methods of assuring liquid at the outlet do not necessarily assure a coherent gas bubble. The same method of baffle design can, however, be used to accomplish this, or the vent tube opening can be hydrophobic. In this latter case, there still must be a single or a group of coherent bubbles. The most desirable configuration depends on the specific operating condition to which the tank will be subject and cannot be determined in general. At present, no bladderless zero gravity water tanks are available, but it is believed that such will be ready by 1980.

In summary, then, bladderless tanks are preferred over bladder tanks because of increased reliability and greatly reduced maintenance problems. They do pose a significant design problem, however, and more experimental work will be required to make them practicable. In view of the improved performance they appear to offer, such development is deemed entirely warranted and possible by the AILSS flight period time.

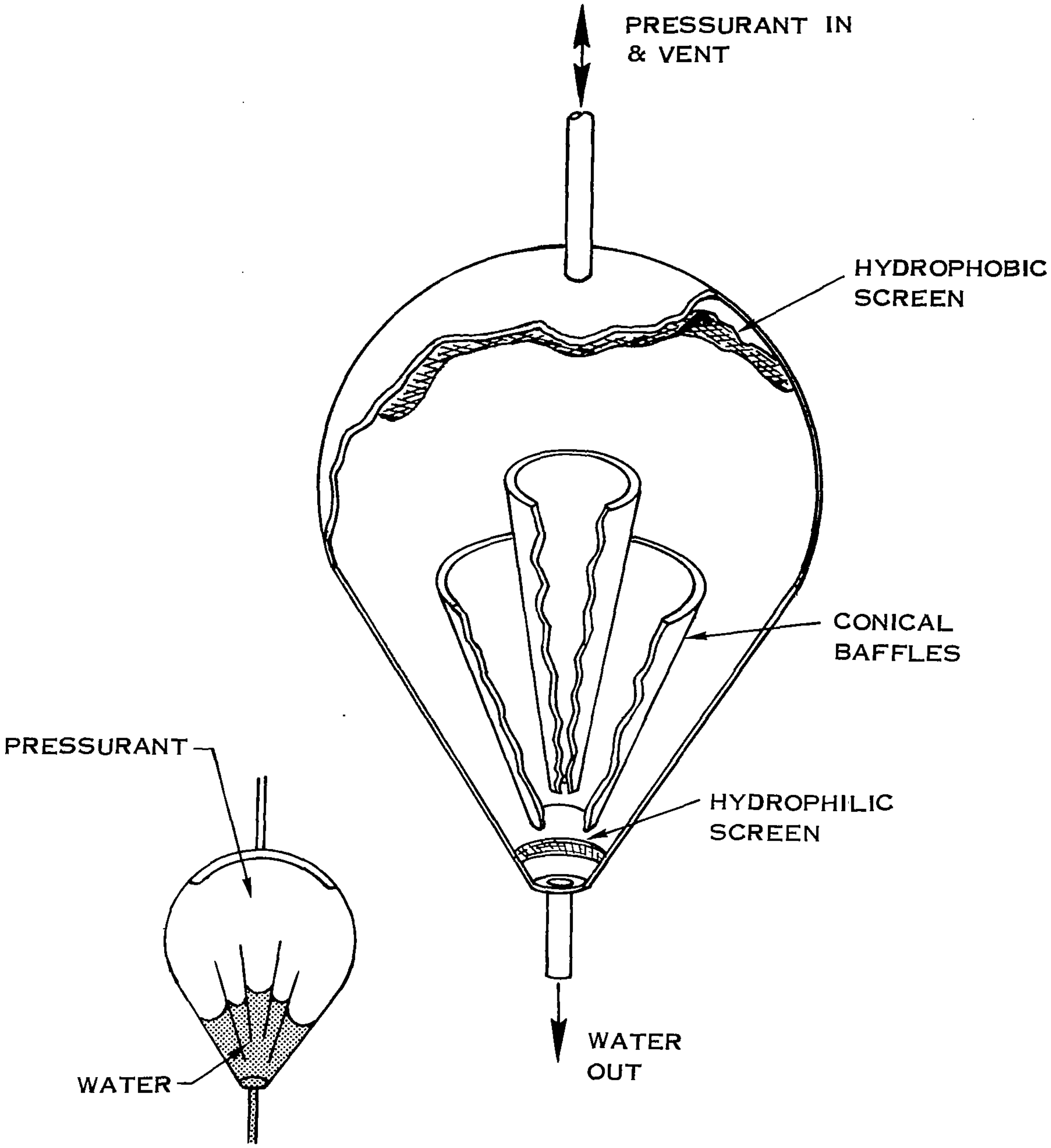


Figure 82. Bladderless Tank Concept

Potable Water Storage

The potable water storage tanks for the water management system serve to hold the potable water in an uncontaminated state until use. The tanks selected are the bladderless zero-gravity type.

In line with the recommendations for bacterial control, it is planned to provide these tanks with a heater and insulation to hold the contents economically at 160°F. This provides hot water at the maximum required temperature and keeps the stored water sterile. Each tank is also fitted with inlet and outlet bacterial filters.

The size and number of tanks is based on consideration of fill and drain times, failure cycles, and potable water testing requirements. These factors led to the selection of three 100-pound capacity tanks.

In addition to these tanks, a fourth tank is provided to bring the total available water contingency capacity up to 300 pounds. This contingency number was determined by assuming that the RQ could drop to 0.85 for up to half the mission length, that the solids sensor whose estimated range is ± 2.5 percent would operate on the low side for half the mission length, and that there would be up to 100 pounds of water lost for miscellaneous reasons. This additional tank also provides the functional capability of rejecting and reprocessing the entire contents of a potable water tank. Under these conditions, reprocessing would take about 32 hours, taking advantage of the difference between the design processing rate of 12.8 lb/hr and the normal collection rate of 9.3 lb/hr.

The amount of water required for firefighting for EC/LS equipment is estimated to be 200 pounds. Storage of this water is not provided in the EC/LS system because it represents only a part of the larger firefighting water requirement of the entire spacecraft, and because of its intended use it does not need to be maintained potable. It is not planned at this time to reprocess this water if used.

Collection Tankage

The collection tanks serve to collect all the waste water for delivery to the single distillation processing unit. They also serve as pre-treatment tanks. The same type of bladderless tank as used for potable water storage is used here.

For purposes of sizing, each tank must hold at least enough water for a six-hour downtime. In addition, each tank must be large enough to accept all water input while the other is draining over the next six-hour period. Since the drain time is two-thirds of the fill time, or four hours, each tank must have a 10-hour capacity. If allowance is made for the additional water used in one steamdown and a 15 percent contingency is included, the total capacity per tank is again 100 pounds.

SYSTEM DESCRIPTION

Because of the similarity between the overall power systems for each design considered, this discussion covers all three in a single discussion. All water quantities stated are for a 70°F cabin.

Used water is collected and fed to the water management subsystem at several points throughout the spacecraft. Urine is received at the urinal at the rate of 29.20 lb/day; the water content being 27.7 lb/day. For purposes of design, it is assumed that each of the nine crewmen will urinate six times a day. After each urination, an additional pound of hot (160°F) water will be manually injected into the urinal to flush away any residual urine. The total input received at the urinal is thus 83.20 lb/day.

Water used in the preparation of food and drink, in the washing machine, and for bathing is received in the main water collector which is connected to the urinal water separator in parallel with the urinals. The flow rate from these sources is 102.60 lb/day.

All cabin condensate resulting from crew sweat and respiration (38.7 lb/day) is also received in the main water collector. Thus, the total inflow to the reclamation system is 224.50 lb/day.

The average process rate through the system is 221.35 lb/day. On the average the liquor discharge from the vapor diffusion system will amount to 3.07 lb/day (including urine solids), and this will occur about every 2-1/4 days. From the vapor diffusion system, the purified water passes through an additional bacterial filter into a potable storage tank where it is heated to 160°F.

The potable storage tanks are as described previously. Each is provided with inlet and outlet bacteria filters to prevent the entry of bacteria from either direction. In addition, the water temperature is raised and held at 160°F. The energy required to raise and maintain all the stored water at 160°F is 965 Btu/hr or 283 watts. Immediately at the outlet of each tank, before the bacteria filter, a sampling tape is provided so that water may be withdrawn for testing purposes. The fill-hold-drain cycle is automatically controlled by timed capacity sensors coupled to solenoid valves. Water is delivered on demand for use at the temperature described in table 26.

Certain upsets have been anticipated in the operation of this system. Equipment failures requiring up to six hours of repairs are provided for by designing each reclamation system for 18 hours of normal operation per day. It is immaterial when the failure occurs during any given 24 hour period, because it is unnecessary to dump any tank. If the failure causes processed water to be rejected and diverted from potable storage by the conductivity sensor, the procedure is to shut the system down immediately. Once the failure is isolated and repaired, the affected part of the system can be purged, steam sterilized, and then returned to service.

WASTE CONTROL

CONTENTS

WASTE CONTROL

The objectives of the waste control subsystem (WCS) are to provide the following functions:

1. Collect, treat, and store and/or dispose of all solid and liquid wastes, and collect and transfer raw urine to the water management subsystem

2. Eliminate odors, aerosols, and existing gases

3. Sterilize waste matter to:

   a. Inhibit or eliminate micro-organism production

   b. Prevent production of gases (CO_2, CH_4, H_2, H_2S) in the wastes

   c. Prevent crew contamination if stored wastes escape into living areas

4. Reduce storage mass and volume of waste materials

The variety of wastes present, the differences in their physical characteristics (volume, density, composition, etc.), and the differing levels of micro-organism activity present significant problems in the selection of a waste control system. The waste categories and daily quantities for nine men, anticipated for the AILSS mission, are summarized in the following table:

	Solids (lb/day)	Liquids (lb/day)
Feces	0.99	2.25
Urine Residuum	1.53	1.53
Tissue Wipes	0.99	--
Food Packaging	1.81	--
Unused Food	1.21	1.53
Debris	0.08	--
Facial and Cranial Hair	Negligible	
Vomitus	Occurs at infrequent intervals	
TOTAL	6.61	5.31

TOTAL waste products = 11.92 lb/day

Solids - 55 percent

Liquids - 45 percent

The waste management system must be flexible enough to handle wet wastes such as feces, urine, unused food, and wet cloths as well as food containers, urine sludge (from the water reclamation system), fingernail clippings, hair, vomitus, and miscellaneous debris. Moreover, the nature of the waste products handled dictates that psychological and physiological factors be considered in addition to the standard evaluation criteria. Urine is initially sterile but it is rapidly colonized by micro-organisms that degrade urea and uric acid components to toxic ammonia gas. Efficient and immediate collection and treatment of the urine is required to eliminate the production of ammonia and to ensure a potable water when the urine is processed through the water reclamation systems. Other waste materials must be collected to reduce the particulate matter in the atmosphere. The accumulation of garbage and refuse on extended flights would be overwhelming unless appropriate steps are taken to reduce the volume, to store, or to destroy the materials. Food debris or unused rations are rapidly contaminated and colonized by micro-organisms, resulting in the production of fermentative and putrefactive gases and odors. Therefore, the solid waste matter must be sterilized or treated to inhibit the growth of the micro-organisms so health hazards do not develop and gases are not generated and dispersed into the atmosphere or within storage containers. These factors make it mandatory to eliminate the manual transfer of feces and fecal collection aids. Operation in zero gravity adds problems in the collection and transfer of waste products that are complicated by requirements related to odor, sanitation, convenience, psychological acceptance, and physiological suitability.

During flights of the Mercury and Gemini programs, fecal waste collection has been accomplished with a hand-held plastic bag containing a liquid chemical which was later manually kneaded with the feces to provide sterilization. Processes of this type were not considered for evaluation due to handling requirements, psychological considerations, and safety. Long term storage of untreated wastes in pressure vessels is rejected for safety considerations, and overboard dumping is limited to gas and vapor. Several waste management systems have been or are being developed that reclaim fecal water. As noted in the Water Management section, the recovery of fecal water is neither necessary nor desirable. This is due to the fact that metabolic oxidation of food hydrocarbons produces water in excess of that required to obtain a closed metabolic water and oxygen loop.

Waste control involves the functions of collection, transfer, treatment, and storage and/or disposal. The concepts evaluated here are methods of treatment, because the other functions are primarily a problem of integration with the treatment function.

Urine collection and transfer is evaluated separately, because that subsystem is isolated from handling other categories of waste matter. The motor driven centrifugal separator selected for removing urine from the process flow stream and transferring it to the water management system requires one pound of water for adequate flushing of the collection and transfer circuits after each use. The numerous obnoxious characteristics of the liquid waste processed by this urine/air separator dictate component replacement as the only feasible maintenance method. Even then, a flushing and sterilizing system must be provided to allow handling of the urine/air separator, solenoid valve, and pump.

LIQUID WASTE COLLECTION AND TRANSPORT

The objective of the urine management concept is to provide a means for collecting raw urine and transporting it to the water management subsystem where treating and processing occur. The collection and transfer must be accomplished under zero-gravity conditions while positively preventing the escape of urine to the cabin. This subsystem must be capable of being operated either separately or simultaneously with defecation.

Three basic concepts are available for the collection and transfer of raw urine:

1. Collector/bladder with manual transfer
2. Liquid/gas flow with sponge/bladder pressurized transfer
3. Liquid/gas flow with centrifugal phase separation/transfer

The third concept, liquid/gas flow liquid waste collector with a centrifugal phase separator/transfer device, is selected for integration with all the waste management systems considered.

Collector/Bladder with Manual Transfer

The collector/bladder concept utilizes the velocity imparted to the urine by the crewman to transfer the fluid to a bladder. A penis seal is provided at the collector to prevent urine from escaping to the cabin. A roller arrangement is required to ensure that no air is present in the bladder prior to urination and to transfer the urine to the water management subsystem. This is the most basic system available, and similar methods have been used in the Mercury/Gemini programs. It is psychologically unacceptable, however, and time consuming for long term missions.

Liquid/Gas Flow with Sponge/Bladder Pressurized Transfer

This second concept utilizes a blower that draws cabin air into the collector to provide a two-phase mixture during urination for zero-gravity transfer. The mixture is drawn through a particle filter to remove solid wastes, and a chemical disinfectant is added in a bacteria control unit. After passing through a selector valve, the mixture enters a reservoir containing a sponge-like substance within a nonpermeable membrane.

Capillary action retains the urine while the cabin air is drawn through the sponge and returned to the cabin after passing through a charcoal bed for odor removal. Urine transfer is accomplished by changing the selector valve to expose the sponge material to a lower-pressure tank. The differential pressure across the bladder squeezes the sponge, thereby transferring the urine. This concept requires careful selection of the bladder and sponge materials and is more feasible where urine can be dumped to space vacuum, thereby generating a higher differential pressure for transfer.

Liquid/Gas Flow with Centrifugal Phase Separation/Transfer

This concept employs a centrifugal fan (the common process flow fan for wet waste, dry waste, and urine collection) to draw air from the cabin through the urinal during urination. The urinal is provided with an adjustable diaphragm which is inserted after removing the sealing cap (each crewman is provided with his own diaphragm). Activation of the fan during urination provides positive transfer during zero-gravity operation. A motor-driven centrifugal separator is provided to separate the process flow air from the urine where it passes through the common system bacteria filter and odor removal bed before returning to the cabin. The pressure head generated by the centrifugal separator and a boost pump transfers the raw urine to the water management subsystem where treating and processing is performed. The urinal, flexible line, and separator are internally coated with teflon to prevent liquid adhesion. Provisions are made for water flush after each urination as well as prior to replacement of the separator and associated components (where steam sterilization is also utilized). A complete discussion of the water separation concepts is included for this and other applications in the Thermal Control sections.

Evaluation and Selection

The liquid/gas flow with centrifugal phase separation/transfer concept is selected because it provides the most positive collection and transfer commensurate with maximum reliability and minimum crew effort, and therefore is psychologically the most acceptable.

Maintenance of waste control candidates is hampered by the odors and other contaminants in the lines. Because of the potential dangers of opening the system to the cabin, a flushing and disinfecting system is required in many areas of the loop. Two examples were previously mentioned; the flushing of the urine separator and the autoclaving of the bacteria filter. One of the major advantages of this approach is that periodic cleaning of the system should reduce component failure and extent the time between required openings of the system. As almost every component in this type of system is exposed to internal contamination, isolation of components to be replaced will be a normal operation. Component isolation is obtained by use of inline valves and by eliminating connections between contaminated lines and clear potable water lines.

WASTE CONTROL CONCEPTS

The integrated vacuum decomposition process is selected for the three AILSS power supply system designs. Electrical process heating is used for Designs 1 and 3, the solar cell and the Brayton cycle systems. Design 2 employs isotope heat for processing. Waste products are heated under vacuum to 1200°F, with evolved gas products being vented overboard. Urine management utilizes a liquid/gas collector with a centrifugal phase separator and transfer device.

A minimum of two waste collectors and two urinals is provided in all waste control candidates to fulfill the needs of a nine-man crew. Both urination and defecation (separately or simultaneously) take place while seated on the waste collector. Foot restraints and a body restraining belt (similar to a seat belt) are provided to enable zero-gravity operation. A process flow fan is utilized to provide positive zero gravity waste transfer and to prevent odors, aerosols, bacterial, etc., from escaping to the cabin. In the instances of prolonged nausea, vomitus collection and transfer to the wet waste collector is accomplished by an adapter. The adapter essentially is a tube that can be fitted over the mouth of a sick crewman, thereby directing all waste into the collector, including stomach gases. A permanent adapter is presently available but the development of a throwaway model would eliminate the unpleasant time consuming cleaning operation in which adequate sanitation is difficult to achieve.

Each of the waste control candidates requires a process flow circuit consisting of an order removal filter, a bacteria filter, a process flow fan for zero gravity collection, urine collection and transfer components, a dry waste shredder and contamination control. This process flow circuit is common to all evaluated concepts. All items except the urine collection and transfer components will be discussed in general and should be regarded as applicable to all candidates.

Odor removal filters are required for odor and contamination control. A single rechargeable filter system is provided, because vacuum regeneration is not practical due to the small quantities of regenerable charcoal relative to the greater amounts of nonregenerable chemicals required. The odor removal chemicals are packaged in cartridges, and the replacement scheme utilizes a canister/cartridge with scheduled replacement. The filter contains predominantly lead dioxide (nonregenerable) for hydrogen sulfide removal with Barneby-Cheney types 213 and G.I. charcoal provided for removal of ammonia and phenol (and other hydrocarbons), respectively. Lead dioxide is recommended because it exhibits loading factors that are three times better than its nearest rival. Its use results in a system weight savings of approximately 1000 pounds. It does pose a problem, however, because the material is rather toxic and dusts easily, and, unless adequate precautions are taken, could enter the cabin proper. Preliminary attempts to eliminate the dusting problem have been encouraging.

Under these circumstances, it is believed that development of a nondusting lead dioxide material would yield a greater return much sooner than attempting to develop an as yet undefined sorbent.

The bacteria filter removes the micron-size bacteria from the process flow stream. As this filter is highly susceptible to clogging, a pressure drop reading will indicate when replacement is necessary. Scheduled replacement is unfeasible due to the unpredictable growth of the bacteria within the filter. Bacteria filter elements are housed in a structural container that is sealed by means of valving (while still in-line) and designed for replacement as a unit approximately every ten days. Although filter element replacement is the lightest weight method, the microbiological problems associated with it are significant enough to warrant the weight penalty of housing replacement.

When dry wastes (e.g., food containers) are collected, a shredder, which acts like a household garbage disposal unit, is temporarily attached to the waste collector. Steam purging is provided for periodic cleaning of the shredder when it is installed on the waste collector. It is removed and stowed after dry waste collection has been completed. Sealing caps and gate valves are provided so that the internal parts of the shredder are not exposed during storage. A debris collection attachment is included with the shredder to transfer those items not otherwise easily collected (miscellaneous debris, hair, fingernail clippings, etc.). This device consists of a collector nozzle and flexible hose. It functions like a household vacuum cleaner. All candidates evaluated possess identical vomitus and debris collection equipment, so a description of this equipment will not be repeated for each candidate.

The twelve waste control concepts evaluated are listed below:

1. Anaerobic Biodegradation
2. Aerobic Biodegradation
3. Gamma Irradiation
4. Beta Excited X-Ray Irradiation
5. Freezing of Wet Waste
6. Vacuum Drying Utilizing Separate Functions
7. Liquid Germicide Addition
8. Integrated Vacuum Drying
9. Integrated Vacuum Decomposition
10. Flush Flow Oxygen Incineration
11. Pyrolysis/Batch Incineration
12. Wet Oxidation

Candidates meeting the absolute criteria are further evaluated for each of the three AILSS power supply systems (designs 1, 2 and 3).

In the evaluation of waste control candidates, the primary criterion of crew time (stress) requires further amplification. Crew stress was subdivided into the two categories of collected waste elimination and equipment maintenance to emphasize those factors unique to waste control (although the evaluation chart combines the crew stress subdivisions into a single rating). Candidates were judged on their relative ability to eliminate collected waste, because the probability of recontamination of waste products (resulting in crew stress) generally varies inversely with the degree to which waste is eliminated. Since elimination of manual transfer of feces and fecal collection aids is an AILSS specification requirement, those candidates which inherently require one or more manual transfer operations were rejected due to their inability to meet the absolute criterion of performance. If required, all remaining candidates were modified to include integrated collection/treatment functions, eliminating manual transfer of feces and fecal collection aids.

Evaluation of maintenance requirements for the candidates considers both the time and the stress involved. Maintenance requirements for waste control candidates fall into three basic categories:

1. System operation
2. Scheduled replacement of items and components
3. Unscheduled replacement of failed items.

Daily system operation represents the major portion of maintenance in the systems. This operation is obtained by a combination of manual functions resulting in relatively high crew stress through time-consuming sequential operations. Thus, all waste control candidates are expected to result in high crew stress. Candidates, however, were rated on the relative crew stress produced. The operating time is noted on each candidate data sheet.

All candidates evaluated perform combined collection and process functions and employ dry collectors; that is, no flush water is used. Phase control is maintained by directed air jets located in the collector annulus.

Wet collectors require that water be reclaimed from the flush mixture. Reclamation of fecal water alone is not required by the AILSS metabolic and water balance, and with the atmospheric leakage assumed. Water reclamation of a fecal slurry, therefore, imposes a rather severe hardship on the reclamation system. Since fecal water recovery is not required for the AILSS, wet collectors are not considered.

Anaerobic and Aerobic Biodegradation

The biodegradation concept is a biological process in which organic waste compounds are used up by biota in supporting microbial metabolism either in the absence (anaerobic biota) or presence (aerobic biota) of free oxygen. The anaerobic (waste digestion) process utilizes oxygen derived from compounds in the waste products, is relatively slow, and results in the production of noxious gases such as H_2S, CO, and pyrimidines. The main digestor gases are CH_4 and CO_2, and pathogens tend to survive in this type of environment. Thus, anaerobic process is rejected for safety considerations (as well as availability/confidence due to lack of any substantial development effort). For these reasons the aerobic process appears to be the most attractive of the two biological processes. The aerobic method, which utilizes an external oxygen supply, is relatively rapid, and results in the production of end products (mostly CO_2) that are not noxious and do not support pathogens. Two principal aerobic processes are available; the activated sludge and the trickling filter processes. While both of these processes are used commercially in sewage treatment plants, little development effort has been encountered in adapting these processes to workable flight systems for spacecraft use. One source of information indicated that an aerobic biodegradation process being investigated utilized a novel variation of the trickling filter method, with the collection and treatment functions being integrated. Limited investigation showed, however, that a substantial development effort would be required before this concept would be competitive for a space application. The aerobic biodegradation processes are therefore rejected because of unacceptable availability/confidence.

Gamma Irradiation

A general laboratory type of gamma irradiator was evaluated to determine its suitability for waste management. The gamma irradiator has a rotating inner shield which contains a sample cavity. The inner rotating mass is surrounded by lead shielding. To operate the device, the sample is placed in the cavity and hand-rotated 180 degrees, placing the sample in view of the cesium-137 source. Source intensity varies from 1500 kR/hr at the source to 50 kR/hr at the center of the turntable (two inches away). Approximately 10 hours are required for irradiation (exposure time is dependent upon sample configuration and density). In order to ensure effective utilization of the source, it is necessary to place the sample as close to the source as possible. Use of a large sample cavity with unprocessed wastes (unshredded food containers, debris, bagged feces, etc.) requires a high-energy source to provide an effective kill across the chamber distance. This results in significantly increased shielding requirements. Thus it would be necessary to shred large-volume wastes, and provide further volume reductions by compacting daily wastes with a hydraulic press into a form conveniently acceptable to the sample cavity. All of this process must be accomplished automatically to prevent contamination of the cabin and crew by the waste material. The liquid that has been pressed from the wastes can be reprocessed (although with difficulty due to its high level of contamination). The wastes should be encased in plastic to provide increased handling acceptability and to prevent the possibility of recontamination. After the irradiation process has been completed, the sterilized packaged blocks of waste can be stored in the food compartment. Manual operations are required to transfer the packaged wastes to the irradiator and again to the storage compartment upon completion of the irradiation process. Due to the inherent requirement for manual transfer of feces and fecal collection aids, the gamma irradiation concept was rejected for its inability to meet the absolute criterion of performance.

Beta-Excited X-Ray Irradiation

The beta-excited X-ray irradiation concept utilizes a beta energy source (in the form of a flat sheet) which is backed on the rear face and sides with a beta energy absorber. The beta particles are emitted from the front face of the source and directed at an angled target material. This then gives off X-rays aimed at the wastes being treated. These highly directional X-rays now possess significantly greater penetrating power than the original beta energy and require significantly less shielding than gamma energy (principally due to the achieved directionality). The required collection equipment is identical to that used in the gamma irradiation process. While the beta-excited X-ray has received limited development work for dental X-ray equipment, its feasibility has not yet been demonstrated, even commercially. Thus, the beta energy irradiation concept was rejected on the basis of unacceptable availability/confidence as well as performance due to its inherent fecal handling requirements.

Freezing of Wet Waste

Freezing and storage of wet wastes at approximately -20°F inhibits production of micro-organisms and odors. The refrigeration system required may be provided by a low-temperature space radiator utilizing appropriate low freezing-point heat transport fluids.

Several inherent problems exist in such a system. First, a common collection and processing unit is not practical. Since the processed wastes must be held continuously at -20°F, problems will arise in preventing a heat up of the waste material during the collection mode. Second, manual transfer from the collector to the process unit will be required, and this is unacceptable. Longer batch collection times could be incorporated; however, germicides or some vacuum drying will be required to inhibit the formation of bacteria until the wastes are refrozen. Addition of an automatic transfer system would result in unnecessary hardware complexity. Third, failure of the freezing unit presents an extreme safety hazard in that considerable amounts of bacteria and contaminants will be produced. The addition of proposed hardware and procedures to eliminate some of these inherent problems presents no significant advantages over the liquid germicide or vacuum drying concepts.

In summary, manual handling is unacceptable, batching presents no advantages over the germicides or vacuum-drying concepts, an automatic transfer system presents many disadvantages over those systems that do not require transfer, and the concept in any arrangement presents an inherent safety hazard in that a failure of the freezing equipment results in production of considerable amounts of harmful bacteria and contaminants. Thus, freezing of wet waste was rejected because of performance and safety considerations.

Vacuum Drying Utilizing Separate Functions

Exposure of waste matter to heat/vacuum to reduce the original water content to 10 percent results in cessation of micro-organism activity and allows storage in a bacterioastatic condition. This concept utilizes a plastic bag (in conjunction with a fixed seat installation) for collection of waste that is sealed and manually transferred to a separate dryer after each use. Two waste collectors with a removable shredder attachment are provided. A hydrophobic patch is contained in the plastic collection bag to allow air to be drawn through during collection (to allow positive zero-gravity transfer and to prevent the escape of odors and gases to the cabin) and to allow vapors to escape during drying. Two dryers are provided for alternate collection and treatment modes (24 hour cycle). Drying is accomplished by applying thermal energy to the dryer can and venting it to space vacuum. After completion of the drying cycle, the solid residue remaining in the plastic bag (56 percent of total wastes processed) is manually transferred to a storage container. Since manual transfer operations are an inherent part of the vacuum drying concept utilizing separate functions, this candidate was rejected due to its inability to meet the absolute criterion of performance.

Liquid Germicide Addition

Chemicals suitable for bacterial treatment are either gases or liquids. The use of a gas such as ethylene oxide is rejected for safety reasons. Any gas leaks due to failure during treatment and/or storage would introduce these gases directly into the cabin atmosphere. The presence of sterilizing gases in the cabin would probably constitute a greater hazard to the crew than the escape of micro-organisms from the waste matter. Liquid chemical preservatives are available that provide positive killing action against all types of bacteria. Effective mixing of the chemical and germicide is critical in ensuring that a bacteriostatic mixture results. Several means of mixing are available other than the psychologically unacceptable manual kneading method (as used in Gemini). One approach is to mix the wet wastes with either urine or water to form a slurry to which the germicide is added. However, in order to be economical, the water (or urine) must be recovered from this process (in which case germicide addition would be unnecessary except for equipment sterilization). A second approach is to mechanically knead or blend the undiluted wastes with liquid germicide.

Incorporation of a strong biocidal agent throughout the excreta will kill the micro-organism population and maintain sterility in storage. Biocides have differing kill properties against microbial species such that the treatment concentration must be high enough to destroy the most resistant of the fecal organisms. In addition, the organic content and chemical constituents of feces tend to inactivate antimicrobial agents, requiring excessive doses. Use of a single disinfectant cannot be trusted. A multiple-biocide approach is much more rational and reliable.

A wide variety of chemicals are available for use as fecal disinfectants. These include quaternary ammonium compounds (Zepharin, Roccal); chlorinated and other derivatives of phenol (Lysol, Dowcides, Metasols); phenyl mercurial compounds (PMA, PMO, Super-Ad-It); chlorine and other halogenated compounds (HTH, Chloramine-T, Iodophors); sulfur-containing compounds (Drewicides, Thiostats); tin compounds (TBTO, TPTO); arsenical compounds (Vyñezene); and a multitude of other applicable industrial and pharmaceutical compounds.

Biocides present toxicological problems when used at high concentrations. Therefore, odor, inhalation toxicity, vapor pressure, irritation properties, and explosive and ingestive toxicity properties play a part in selecting a suitable disinfectant for fecal decontamination. A degree of risk will be present regardless of the ultimate choice. The mercurials and most chlorinated phenolics would be eliminated except under special storage conditions.

The photodynamic action of dyes in the presence of light is an acceptable biocidal activity that rapidly kills organisms. Most of the activity is limited to the gram-positive organisms and is greatly reduced in the presence of serum proteins. The triphenylmethane dyes are particularly effective bactericides (crystal violet, malachite green, parafuchsin), as well as the amino-acridine, proflavine. Proflavine has a wider bacteria spectrum than the triphenylmethanes. It is assumed for this study that a safe germicide will be available for this concept.

Absolute criteria. -

Performance: The germicide concept and system data are shown schematically in figure 83. A shredder is required to expose the surfaces of the food containers and other matter to the germicide to ensure sterilization. Because feces, tissue wipes, and urine sludge (from the water management system) do not require shredding, their collection is handled directly without the necessity of prior shredding.

The waste collectors are provided with separate blenders and germicidal metering equipment. The blenders (requiring about 150 watts) are utilized to ensure thorough mixing of the wastes and germicide. The collector gate valves are opened only during waste collection. When the containers are full, the tank is sealed, removed to storage, and replaced with an empty tank. Waste collectors are sized for replacement every 50 days.

SUBSYSTEM: Waste Control

CONCEPT: Liquid Germicide Addition

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY: 0.999954

MTBF: 36 400 hr.

Spares/Redundant (R) Units:

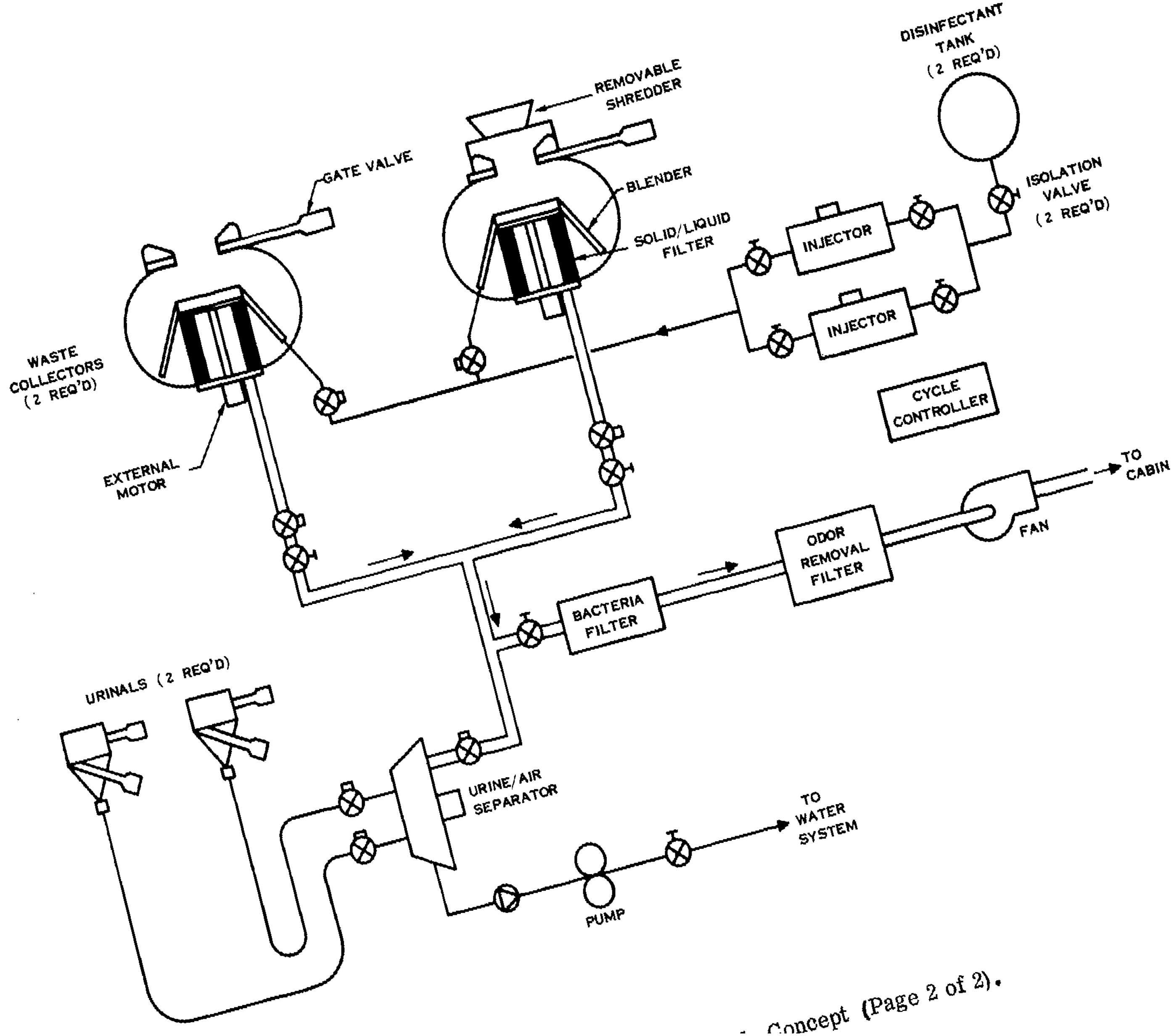
- 2 - Waste Collector
- 2 - Slinger Motor
- 2 - Solenoid Shutoff Valve
- 1 - Redundant Germicide Supply
- 1 - Urinal
- 2 - Urine/Air Separator
- 2 - Shredder
- 50 - Bacteria Filter-Exp.
- 1 - Bacteria Filter
- 1 - Check Valve
- 1 - Odor Removal Filter
- 20 - Odor Removal Filter-Exp.
- 2 - Process Flow Fan
- 2 - Urine Pump
- 3 - Cycle Controller

CREW TIME (Hr/Mission):	Scheduled	Unscheduled	Operating Time
	95	0.4	2695

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	71	71	71
Expendables	1798	1798	1798
Spares/Redundant Units	358	358	358
Electrical Power	135	135	135
Thermal Power	0	0	0
Radiator Load	40	40	40
Total Equivalent Weight	2402	2402	2402
POWER (Watts):			
Electrical	300	300	300
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
	333.2	35.2	368.4

Figure 83. (Page 1 of 2)



Concept (Page 2 of 2).

Safety: The ability of this candidate to effectively kill all microorganisms present is limited by the performance of the blending equipment, assuring a safe germicide. Isolated pockets of untreated waste present a potential crew hazard, because live microorganisms are being generated. In this event, however, the process flow equipment should limit their escape to the cabin. The presence of liquid germicides stored in concentrated form represents a crew hazard, because a tank or disinfectant line rupture or leak would introduce the germicides into the crew compartment.

Availability/confidence: The germicide concept has not been proposed or developed by any source (other than the crude systems utilized in early space flight). Three items require development. The dry waste shredder, common to all candidates, is one of the undeveloped items. Another item is the collector blender, which requires significant development effort, because it represents the key to this system's operation. The other item to be developed in this concept is the germicide, which must provide effective kill properties commensurate with minimum toxicity. The germicide-addition concept is presently in the early research phase. Normal development could result in suitable flight hardware by 1977.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 68 990 hours, With redundant disinfectant supply tanks and 21 additional miscellaneous spares, the overall subsystem reliability is calculated to be 0. 999954.

Crew time: While positive treatment of accumulated waste is provided, no reduction in waste weight or volume occurs in the liquid germicide concept. This is expected to produce a relatively high crew stress.

The liquid germicide system collects wastes, mixes them with a disinfectant, and stores the resulting mixture. This requires a large rotary-type collector. In addition to the common process flow components previously discussed, the liquid germicide addition concept, by utilizing rotary collection and processing equipment, possesses features that are common with the next evaluation candidate discussed (integrated vacuum drying). While rotary collection systems have different configurations (blenders, slingers, etc.) and applications, the maintenance problems are similar and will be discussed here. All of the rotary collection concepts require motors that are externally mounted on the collection unit and easily replaceable. Another common required feature is internal filters that pass process flow air while retaining liquids and solids. These filters are quite susceptible to clogging, and require replacement of the entire collection unit when insufficient process flow is available for positive waste transfer. Process flow fans are oversize for candidates employing rotary collection concepts to allow for flow degradation. Filter replacement is not feasible due to the nature of the collector contents. This replacement penalty (replacement of subsystem due to failure of one component) is applicable to all failures internal to the collection unit. Each collector is replaced when full and transferred to storage. Spare disinfectant tanks are plumbed into the system and used as required. The disinfectant system may also require flushing prior to maintenance, depending on the germicide chosen. A potent germicide may constitute a hazard and will have to be handled similarly to the urine pretreatment chemical described in the Water Management section.

Although the total mission time required for scheduled maintenance of the liquid germicide process is average for the candidates evaluated, the relative stress is high. This results from the fact that more than 40 percent of the scheduled maintenance time involves changing and replacing collection vessels. The large physical size and weight (332 lb each when full) may require two men when transferring the collector to storage, and this operation is expected to produce a high crew stress. Unscheduled maintenance for the liquid germicide process is a relatively low stress condition. Operating time is one of the lowest of the concepts considered (although the variation between candidates is not significant).

Equivalent weight: The equivalent weight of the germicide concept, including 24 waste collectors, is summarized on the data sheet of figure 83 for the three different power supplies.

Secondary criteria. - The presence of germicide stored in bladder tanks, in supply lines to the collectors, and diffused through the waste stored in the collectors constitutes a potential source of contamination.

The germicide system contains the fewest interfaces of all the candidates evaluated. It has only one interface with the pressure supply for the germicide tanks. The electrical interface is similar to those of the other candidates which require some electrical components (fans, shredders, etc.), except it has one additional component, the blender. Flexibility is limited by the ability to develop germicides which can handle all waste categories expected to be present on any space mission.

Little growth is possible with the germicide concept, because capacity is limited by the number of collection vessels and the supply of germicide present. Other than the components all candidates have in common, the germicide system possesses three motor-driven blenders which are operated intermittently. The blenders are expected to have a relatively high noise level, and, although the blender noise will be deadened by the storage containers, the externally mounted motors may require noise suppression devices. The quality of the power-consuming components (i.e., their frequency of utilization and levels affecting the power generation system) is average among the evaluated candidates. The estimated total volume of the germicide system, including storage containers, is shown on the data sheet of figure 83 and is one of the highest system volumes.

Integrated Vacuum Drying

This method of treatment consists of vacuum drying of waste matter to 10 percent water, by weight, to stop microorganism activity, permitting safe storage. Elimination of manual transfer operations is achieved by collecting, treating, and storing wastes in a common container. After each defecation (or collection of other waste categories), a gate valve seals the container which is then opened to space vacuum. Heat transferred to the container allows dehydration of the fecal matter. Inefficient packing of the fecal matter, however, results in drying times that are dependent upon the packing configuration and fullness of the container. Moreover, the waste transfer and odor control fan must be sized to pass an adequate air flow through the container when it is full. Efficient operation is provided by adding a motor-driven slinger (requiring about 30 watts) to break up the fecal matter and centrifugally transfer it to the container walls (shown schematically with related system data in figure 84). Because a good heat transfer surface is now provided, application of a thermal energy source to the container is not required. Addition of a slinger reduces the time to achieve 90 percent drying from 20 to 4 hours.

Higher-temperature (300°F) vacuum drying operation is possible and has the advantage of providing better bacteria control during each cycle. The higher temperatures, however, cause partial decomposition of waste material and considerably increase the odor control problem. Further elevation of the process temperature to 1200°F will result in much greater waste decomposition, and the process is then considered a vacuum decomposition process, considered as the next candidate. For this reason, the 300°F vacuum drying process, which offers no real advantage over a low-temperature system and in fact may create additional problems, is not treated as a separate candidate.

Absolute criteria. -

Performance: The unique features of the integrated vacuum drying concept are the use of a slinger to break up wastes and provide efficient drying, and incorporation of a vacuum pump to reduce oxygen and nitrogen losses. In addition to eliminating the requirement for direct container heating, the slinger ensures good utilization of vessel volume. A filter is required to retain solids and liquids but allow for the passage of process air flow. The process flow fan must be oversized to allow for flow degradation as the container is filled. Two waste collectors are used which have provisions for shredder attachment during dry waste collection. A vacuum pump is incorporated to reduce cabin air loss. Ullage pumpdown to 1.0 psia prior to vacuum exposure reduces air loss leakage to approximately 0.40 lb/day, thereby saving approximately 1600 lb of cabin air over a 500-day mission. Waste collection containers are sized for 50 days and are replaced on scheduled basis.

Safety: Isolated pockets of undried waste present a potential crew hazard, because live microorganisms would be generated. A rupture of a collector or loss of collector sealing which would introduce waste into the cabin also would represent a potential crew hazard.

Availability/confidence: The availability of this concept is high, similar hardware having been fabricated and used successfully for 47 days in a manned chamber test.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 25 200 hours. With 27 spares, the overall subsystem reliability is calculated to be 0.999860.

Crew time: The integrated vacuum drying system reduces the weight of collected wastes to approximately 60 percent of the original. The presence of dried waste is expected to produce relatively high crew stress. No direct handling of wastes is required, however, because the vacuum drying process occurs directly in the collection vessel where the dried waste is stored.

This system collects and stores wastes in large rotary collectors as previously discussed. The gate valves on the collectors must hold against a space vacuum with a contamination potential present. The manually actuated valve is similar in configuration to the present ILSS molecular sieve valves (disc valves) due to the similarity of functions. Replacement is achieved through flange mounting and seating to the canister with flexible ducts for process flow. To enhance vacuum sealing, a particulate filter is required upstream of the valve to limit contamination to acceptable levels. The bacteria filter should be adequate for this function. Valve leakage requires replacing the entire unit. A leak prevents the vacuum pump from pulling the pressure in the chamber down to the crossover pressure (to space vacuum). This acts as a built-in safety feature. The pump never allows leakage to space, and it indicates the pressure of a leak with its failure to shut off.

Vacuum pump replacement does not require system downtime, because the collector can be cycled directly to space vacuum at the expense of up to 10 cubic feet of cabin air.

Scheduled maintenance time for the integrated vacuum drying process is about average for the candidates evaluated. The stress factor, however, is significant, since a large percentage of time is utilized for the removal and replacement of the waste collectors. The large physical size and weight of the waste collectors (238 lb each when full) will probably require two men for removal and stowage, and this

SUBSYSTEM: Waste Control

CONCEPT: Integrated Vacuum Drying

FLIGHT AVAILABILITY: 1974
(1970 go-ahead)

RELIABILITY: 0.999860

MTBF: 25 200 hr

Spares/Redundant (R) Units:
- 2 - Waste Collector
- 2 - Slinger Motor
- 2 - Urine Pump
- 2 - Solenoid Shutoff Valve
- 2 - Pressure Switch
- 1 - Urinal
- 2 - Urine/Air Separator
- 2 - Shredder
- 2 - Solenoid 2-Way Valve
- 1 - Check Valve
- 2 - Vacuum Pump
- 1 - Odor Removal Filter
- 20 - Odor Removal Filter-Exp.
- 2 - Process Flow Fan
- 1 - Bacteria Filter
- 50 - Bacteria Filter-Exp.
- 3 - Cycle Controller

CREW TIME (Hr/Mission):	Scheduled	Unscheduled	Operating Time
	90	0.8	2695

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	82	82	82
Expendables	1685	1685	1685
Spares/Redundant Units	239	239	239
Electrical Power	86	86	86
Thermal Power	0	0	0
Radiator Load	0	0	0
Total Equivalent Weight	2092	2092	2092
POWER (Watts):			
Electrical	190	190	190
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Designs 1, 2 and 3	332.0	35.6	367.6

Figure 84. (Page 1 of 2)

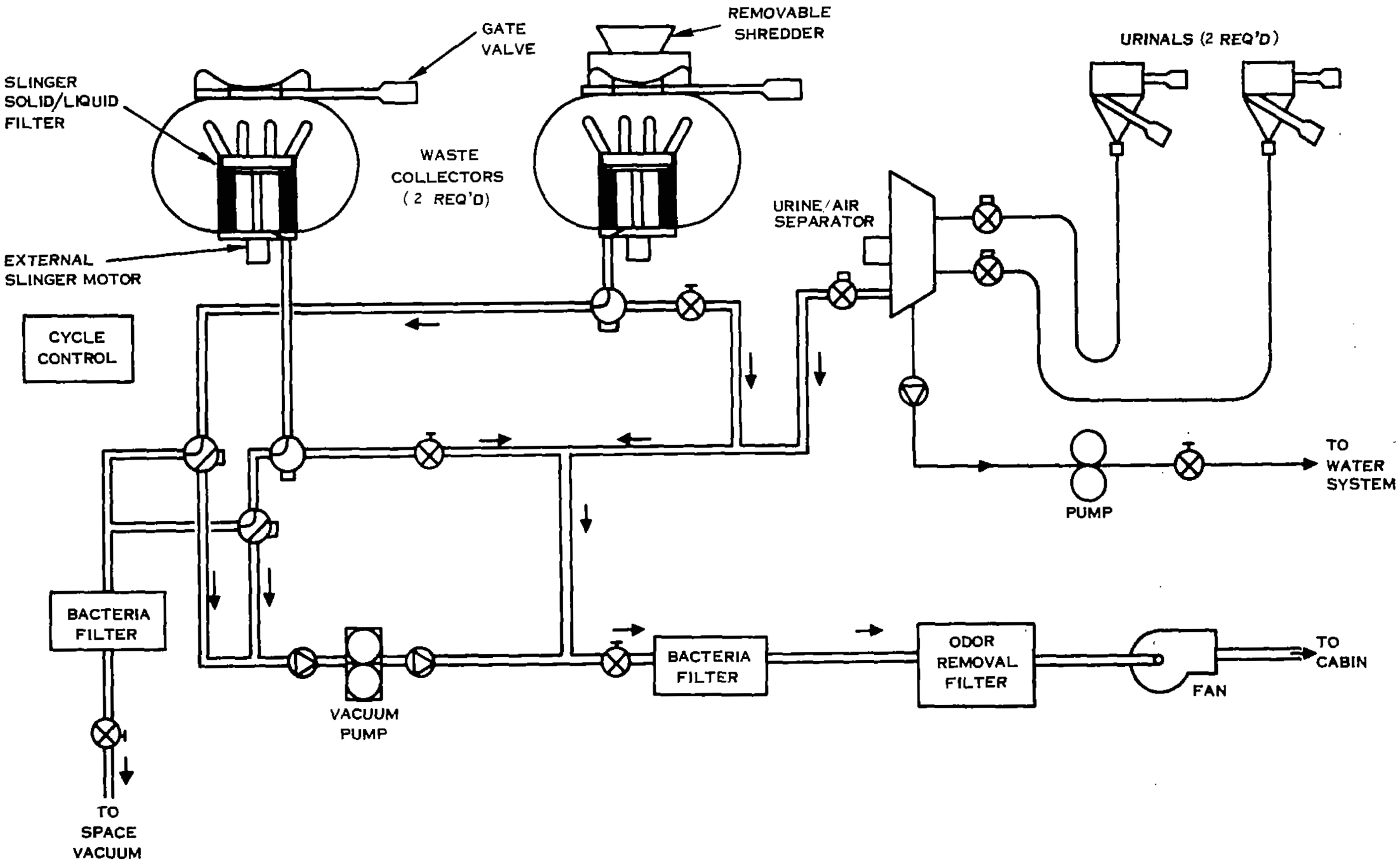


Figure 84. Integrated Vacuum Drying Concept (Page 2 of 2).

operation is expected to produce a relatively high crew stress. Unscheduled maintenance time for the integrated vacuum drying concept is one of the lowest of the concepts considered. The integrated vacuum drying process possesses one of the lowest operating time requirements (although the variations among candidates is not significant).

Equivalent weight: The total equivalent weight of the integrated vacuum drying system, including 21 waste collectors, is summarized on the figure 84 data sheet.

Secondary criteria. - Contamination from collection vessel leakage or incomplete drying of fecal material is possible.

In addition to electrical power requirements, two interfaces are required. A vacuum line is necessary to achieve drying, and a coolant supply is required for the vacuum pump condenser/separator.

While the integrated vacuum drying concept can treat all waste categories, the system is somewhat limited by cabin-to-collector heat transfer, thus reducing flexibility. The capacity of the drying system is limited by the total collection volume available. Little growth possibilities are apparent. In addition to the common components required by all candidates, the integrated vacuum drying system requires slinger motors and a vacuum pump. These components, although operated intermittently, are expected to produce a relatively high noise level. The total volume of the integrated vacuum drying concept, including all required collection vessels, is shown on the data sheet of figure 84. This represents one of the highest system volumes. The quality of required power consumption is considered average among the candidates evaluated.

Integrated Vacuum Decomposition

The integrated vacuum decomposition concept utilizes vacuum and high temperature to decompose waste materials into gaseous products which can be exhausted to vacuum. The chamber is subsequently allowed to cool down, with the residue (approximately 12 percent of total wastes processed) being vacuumed from the chamber at the completion of the cooldown period. Although no oxygen is required for vacuum decomposition, the power required to sustain the process for twelve hours is significantly greater than that required for pure incineration. The integrated vacuum decomposition concept is shown schematically in figure 85.

Four waste collector/incinerators are provided, of which two are alternately available for collection during any 24-hour period. The remaining two units are used to simultaneously eliminate wastes during the first 12 hours of the cycle, with the remaining 12 hours of the cycle provided for chamber cooldown. Incinerable collection bags with a hydrophobic patch (to retain liquids and solids yet pass process flow) are provided for the waste collector/incinerators. This method eliminates the maintenance and microbiological problems of filter replacement, since clogging is not anticipated with collection bags which are replaced every 24 hours. It may be possible with proper baffling in the collector, to eliminate the collector bags thereby reducing crew time. For this study, however, the use of the bags was retained. Dry waste collection is common to all candidates. A shredder is employed which is manually attached to one of the waste collectors when dry waste collection is required. A debris collection attachment is provided to be used in conjunction with the shredder when the collection of hair, fingernail clippings, paper, and miscellaneous debris is required.

Absolute criteria. -

Performance: The concepts for Designs 1 and 3 are identical and employ electrical heating with chamber cooldown provided by directing process flow air around the internal chamber of the waste collector/incinerators prior to exhausting to the cabin. A chamber cooling bypass loop is utilized so that the entire 12-hour cooldown period can be used, thereby allowing the process flow air being used for cooling to be dumped directly to the cabin. Thus, heat rejection is provided via the thermal control system without necessitating the incorporation of a separate heat exchanger loop.

The radioisotope heating arrangement for Design 2, due to the continuous thermal output of the isotope source, requires a separate thermal control concept. A general radioisotope heating and cooling method is shown in figure 86. This figure illustrates the Design 2 components which are required in addition to those shown on the general schematic (figure 85). Figure 86 applies not only to the integrated vacuum decomposition concept for Design 2 but also to the Design 2 configurations for candidates that follow. During the initial treatment step of the decomposition process, the isotope bypass valve is closed, the process flow circuit solenoid valves for the units undergoing the decomposition processing are opened to cabin, and the chamber pressure of these same units is allowed to build up until the entrained water in the waste is vaporized (15 psig and 250°F). The vacuum valve (figure 85) is then opened and the vapor is flashed to space. With the vacuum valve still in the open position, heating is continued until the chamber reaches 1200°F. Redundant fans are provided which operate continuously (one at a time) to draw air from the cabin, circulate it past the isotope, and deliver it to the chambers being heated (or return it to the cabin via a heat exchanger that provides isotope cooling). After heating the decomposition chambers, the process air flow is directed to separate heat exchangers prior to cabin re-entry. Chamber cooling is provided by opening the isotope bypass valve, repositioning the decomposition chamber process flow circuit solenoid valves for closed-loop operation, and actuating the individual circulation fans. Twelve hours are provided for chamber cooling, after which the ash residue is vacuumed from the chamber.

Testing accomplished during 1961 and 1962 on a three-man, 14-day laboratory system has shown that vaporization and pyrolysis of the plastics in the wastes results

SUBSYSTEM: Waste Control

CONCEPT: Integrated Vacuum Decomposition

FLIGHT AVAILABILITY: 1976
(1970 go-ahead)

RELIABILITY:			MTBF:	
	Designs 1 & 3	0.999317	Designs 1 & 3	14 000 hr
	Design 2	0.999329	Design 2	10 400 hr

Spares/Redundant (R) Units:

- 2 - Shredder
- 1 - Bacteria Filter
- 50 - Bacteria Filter-Exp.
- 1 - Urinal
- 2 - Urine/Air Separator
- 2 - Urine Pump
- 2 - Process Flow Fan
- 3 - Cycle Control
- 3 - Solenoid Shutoff Valve
- 1 - Check Valve
- 1 - Ash Collector Fan
- 1 - High Temp. Shutoff Valve (R)
- 4 - High Temp. Shutoff Valve
- 1 - Odor Removal Filter
- 20 - Removal Filter-Exp.
- 1 - Urine Check Valve

Designs 1 & 3 Only

- 1 - Incinerator Heater (R)
- 2 - Heater Control

Design 2 Only

- 2 - Heat Exchanger
- 1 - Cooling Fan (R)
- 3 - Cooling Fan
- 3 - Solenoid 3-Way Valve
- 1 - Solenoid Shutoff Valve
- 1 - Check Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled	Operating Time
Designs 1 & 3	105	2.2	2945
Design 2	105	2.9	2945

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	354	489	354
Expendables	920	920	920
Spares/Redundant Units	106	126	106
Electrical Power	630	144	630
Thermal Power	0	60	0
Radiator Load	39	203	39
Total Equivalent Weight	2049	1942	2049
POWER (Watts):			
Electrical	1400	320	1400
Thermal	0	1200	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Designs 1 & 3	127.1	2.9	130.0
Design 2	129.2	3.7	132.9

Figure 85 (Page 1 of 2)

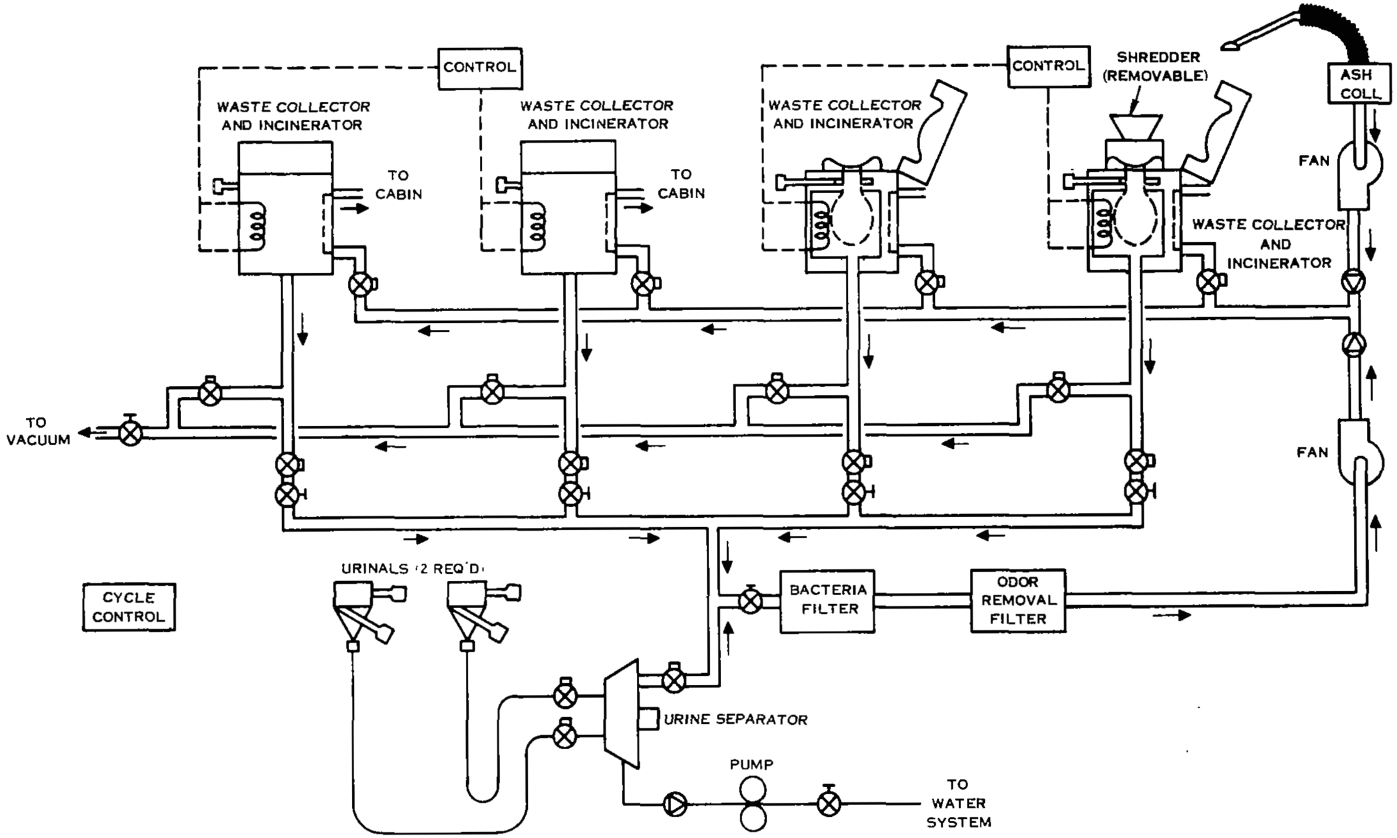
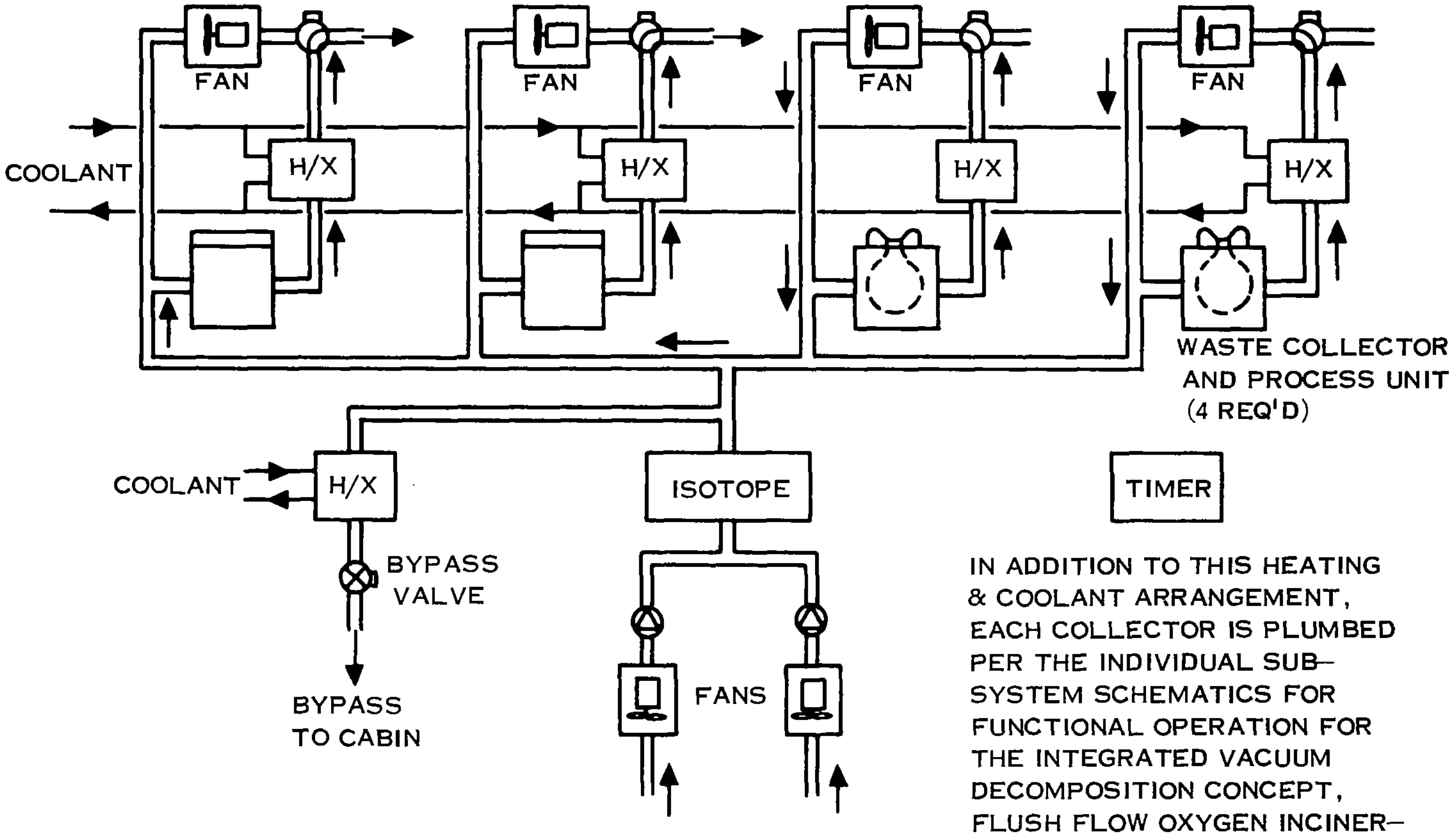


Figure 85. Integrated Vacuum Decomposition Concept (Page 2 of 2).



IN ADDITION TO THIS HEATING & COOLANT ARRANGEMENT, EACH COLLECTOR IS PLUMBED PER THE INDIVIDUAL SUB-SYSTEM SCHEMATICS FOR FUNCTIONAL OPERATION FOR THE INTEGRATED VACUUM DECOMPOSITION CONCEPT, FLUSH FLOW OXYGEN INCINERATION CONCEPT, PYROLYSIS/BATCH INCINERATION CONCEPT, AND THE WET OXIDATION CONCEPT.

Figure 86. Radioisotope Heating Arrangement.

in the formation of solidifying fractions. If these materials are allowed to condense, the chamber exhaust tubes eventually clog. Thus, the gases must be rejected at a high temperature (with the vent line to vacuum heated). Heat recovery between the inlet and the outlet gases is limited. Moreover, the presence of these fractions in the exhaust gases precludes the recovery of water and oxygen. Therefore, the products of the decomposition processes should be dumped overboard without attempting heat and/or byproduct recovery.

Safety: Potential safety hazards are not apparent in the components of the integrated vacuum decomposition process or in its operation for system Designs 1 and 3. The existence of plumbing for the distribution of process flow air for 1200°F heating represents a slight safety hazard for the Design 2 concept. It is assumed that adequately shielded isotopes will be available which do not present any safety hazard. A more significant safety hazard in Design 2 would be the loss of isotope cooling resulting from a fan failure. A loss of isotope cooling would rapidly increase the isotope source temperature until its melting point was reached. Further temperature increases would melt the isotope shielding and produce a severe safety hazard. Redundant fans are utilized to eliminate the danger of a fan failure resulting in isotope overheating. Ducting is provided so that process flow air can be recirculated, thereby providing isotope cooling in the event of compartment depressurization.

Availability/confidence: Development effort has indicated the feasibility of this concept. The integrated vacuum decomposition concept for Designs 1 and 3 is in the early prototype development phase, and flight hardware is expected during 1976 with normal development progress. Flight hardware for Design 2 is anticipated by mid-1977.

Primary criteria. -

Reliability: The MTBF for the Design 1 and 3 systems is estimated to be 14 000 hours. The exposure of the vacuum vent valve to high temperature may compromise inherent reliability. Redundant valves are installed in the vacuum vent line. With redundant heaters and 26 additional spares, the overall reliability is calculated to be 0.999317. The system for Design 2 possesses an inherent reliability of 10 400 hours, MTBF. Redundant isotope cooling fans and 34 additional spares are required to achieve an equivalent reliability.

Crew time: Since collected wastes are processed within a 24-hour period, and process residue consists of a sterile ash which is later vacuumed from the chamber, crew stress due to the presence of wastes is expected to be very low. The integrated vacuum decomposition process (for all system designs) possesses a relatively high scheduled maintenance time requirement. This is due primarily to the fact that the high residue quantities require frequent ash collection filter replacement.

Although total system operating times do not vary significantly among the candidates evaluated, the integrated vacuum decomposition process has one of the highest operating time requirements.

Equivalent weight: The total equivalent weight for the integrated vacuum decomposition process is the lowest of any of the candidates and is summarized in figure 85.

Secondary criteria. - The positive treatment of collected wastes and the absence of manual handling and storage requirements eliminate the potential areas of contamination. Each of the system designs possesses two interfaces. The system Designs 1 and 3 have electrical heating and vacuum interfaces, while the system Design 2 interfaces are vacuum and thermal heat supply. Significant flexibility can be achieved, since the process can handle variations in waste composition and type with little or no effect upon performance. Since cycle time can be decreased by providing for more rapid chamber cooldown, increased (or decreased) capacity can be easily provided. Furthermore, the overall growth potential is not limited by expendable supply requirements. The Design 1 and 3 concepts are expected to produce a relatively low noise level. A somewhat higher noise level is expected in the Design 2 system, since noise suppression of the exhausting process flow air cannot be as effective as that provided by the decomposition chamber itself without a significant weight penalty. The total system volume of the integrated vacuum decomposition process is summarized on the data sheet of figure 85. The power quality of this process for Designs 1 and 3,due to its high level and cyclic nature, is one of the poorest of the candidates evaluated. The Design 2 concept minimizes the effect on power generation equipment and produces a relatively good power quality.

Flush Flow Oxygen Incineration

Incineration is the complete oxidation of wastes using either pure oxygen or oxygen diluted with an inert gas such as nitrogen. The incineration process consists of two steps, the first being common to all incineration processes considered. After the wastes are collected and sealed in the chamber (with the vacuum valve remaining closed), heat is applied for a specified time period (usually 30 minutes) or until a predetermined internal pressure is reached (approximately 30 psia). This is performed to ensure vaporization and sterilization of the gas and vapor to be exhausted to space vacuum, and to dry the waste so that combustion can follow. After venting the sterile gas and vapor to space vacuum, the vent valve is left open. Heat is applied to bring the incineration chamber temperature to 1000°F, while a controlled flow of oxygen is continuously supplied to the chamber. The incineration process continues for approximately 12 hours and results in a 97 to 99 percent reduction in the processed waste. The residue remaining is a dry powder which is vacuumed from the chamber after a twelve-hour cooldown period.

The flush flow oxygen incineration process is shown schematically in figure 87 with related candidate data appearing on the data sheet. Four waste collector/incinerators are provided, of which two are alternately available for collection during any 24-hour period. The remaining two units are used to simultaneously eliminate wastes during the first 12 hours of the cycle, with the remaining 12 hours of the cycle provided for chamber cooldown. Incinerable collection bags with a hydrophobic patch (to retain liquids and solids yet pass process flow) are provided for the waste collector/incinerators. This method eliminates the maintenance and microbiological problems of filter replacement, since clogging is not anticipated with collection bags which are replaced every 24 hours. Dry waste collection is common to all candidates. A shredder is employed which is manually attached to one of the waste collectors when dry waste collection is required. A debris collection attachment is provided to be used in conjunction with the shredder when the collection of hair, fingernail clippings, paper, and miscellaneous debris is required.

Absolute criteria. -

Performance: The concepts for Designs 1 and 3 are identical and employ electrical heating with chamber cooldown provided by directing process flow air around the internal chamber of the waste collector/incinerators prior to exhausting to the cabin. A chamber cooling bypass loop is utilized so that the entire 12-hour cooldown period can be used, thereby allowing the process flow air being used for cooling to be dumped directly to the cabin. Thus, heat rejection is provided via the thermal control system without necessitating the incorporation of a separate heat exchanger loop. The heating concept for Design 2, using an isotope source, is exactly the same as previously described for the integrated vacuum decomposition isotope system.

Safety: Potential safety hazards, except for the presence of high pressure oxygen, are not apparent in the components or in their operation for system Designs 1 and 3. The system for Design 2 possesses several inherent safety problems. The existence of plumbing for the distribution of process flow air for the 1000°F heating requirements represents a slight safety hazard, but it is assumed that adequately shielded isotopes will be available which do not present any safety hazard. A more significant safety hazard in the system for Design 2 would be the loss of isotope cooling resulting from a power failure. This problem is discussed for the integrated vacuum decomposition process under absolute criteria.

Availability/confidence: A three-man, 14-day prototype incinerator was developed during 1961-62, and testing has indicated the feasibility of this concept. The flush flow oxygen incineration concept for Designs 1 and 3 is in the early prototype development stage, with flight hardware expected during 1977 with normal development progress. Flight hardware for Design 2 is anticipated by mid-1978. An incinerator is currently being developed for NASA/Ames using both electrical and microwave energy. However, nsufficient data prevented its consideration.

SUBSYSTEM: Waste Control

CONCEPT: Flush Flow Oxygen Incineration

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY:		MTBF:	
Designs 1 & 3	0.999278	Designs 1 & 3	12 472 hr
Design 2	0.999290	Design 2	9 500 hr

Spares/Redundant (R) Units:
- 2 - Shredder
- 1 - Bacteria Filter
- 50 - Bacterial Filter-Exp.
- 1 - Urinal
- 2 - Urine/Air Separator
- 2 - Urine Pump
- 2 - Process Flow Fan
- 3 - Cycle Control
- 4 - Solenoid Shutoff Valve

(Common)
- 1 - Check Valve
- 1 - Ash Collector Fan
- 1 - High Temp. Shutoff Valve (R)
- 4 - High Temp. Shutoff Valve
- 1 - Odor Removal Filter
- 20 - Odor Removal Filter-Exp.
- 2 - Oxygen Regulator

Designs 1 & 3 Only
- 1 - Incinerator Heater (R)
- 2 - Heater Controller

Design 2 Only
- 2 - Heat Exchanger
- 3 - Solenoid 3-Way Valve
- 1 - Cooling Fan (R)
- 1 - Solenoid Shutoff Valve
- 1 - Check Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled	Operating Time
Designs 1 & 3	65	2.4	2945
Design 2	65	3.2	2945

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	372	507	372
Expendables	2205	2205	2205
Spares/Redundant Units	120	140	120
Electrical Power	450	144	450
Thermal Power	0	0	0
Radiator Load	30	139	30
Total Equivalent Weight	3177	3135	3177

POWER (Watts):			
Electrical	1000	320	1000
Thermal	0	0	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Designs 1 & 3	123.3	3.2	126.5
Design 2	125.4	4.0	129.4

Figure 87 (Page 1 of 2)

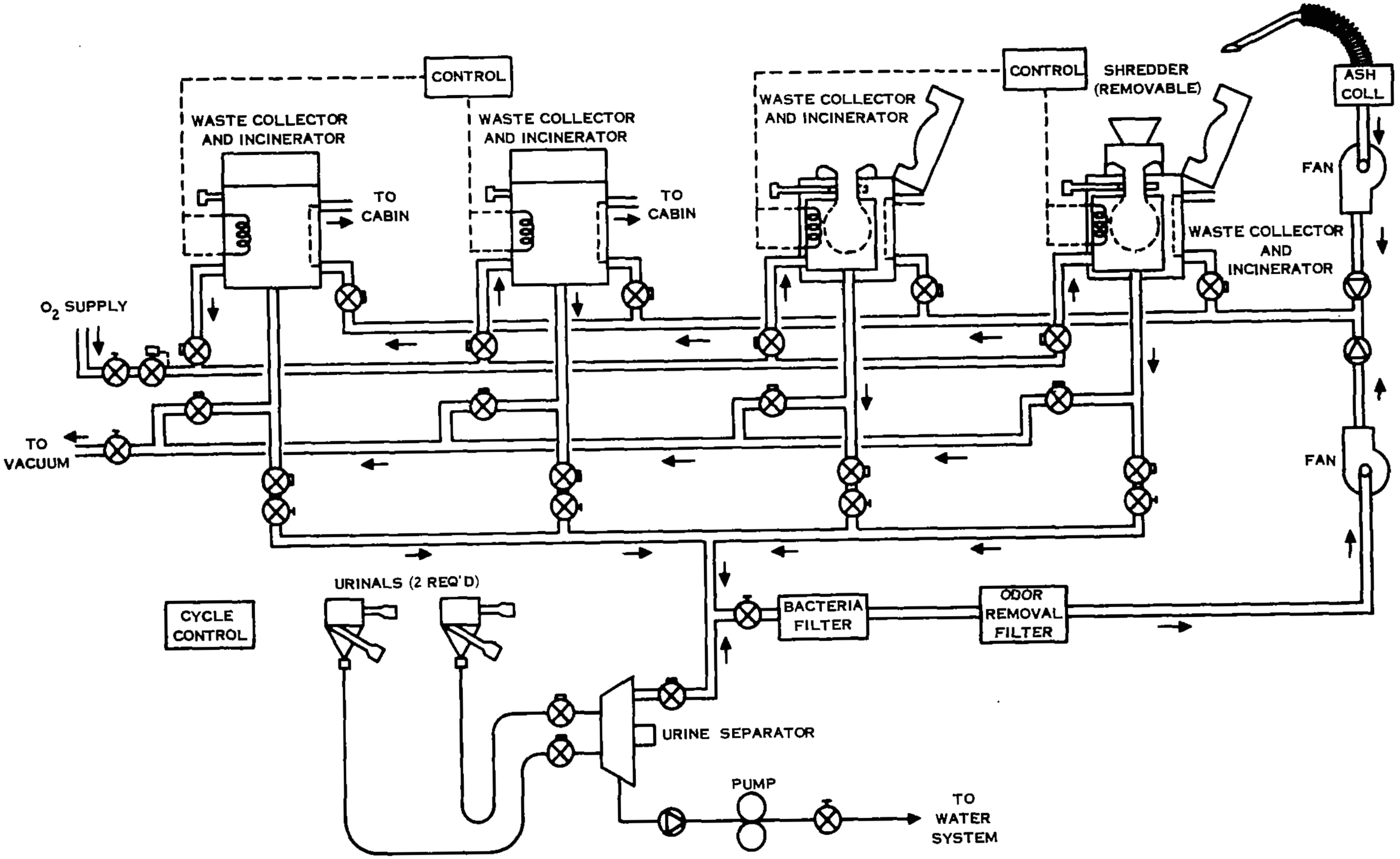


Figure 87. Flush Flow Oxygen Incineration Concept (Page 2 of 2).

Primary criteria. -

Reliability: The MTBF for Designs 1 and 3 is estimated to be 12 472 hours. With redundant incinerator heaters, vacuum vent valves, and 28 miscellaneous spares, the overall reliability is calculated to be 0.999278. The Design 2 concept possesses an MTBF of 9500 hours. Redundant isotope cooling fans and 36 additional spares are required to achieve an equivalent reliability.

Crew time: Since collected wastes are processed within a 24-hour period, and the process residue consists of a sterile ash which is later vacuumed from the chamber, crew stress due to the presence of wastes is expected to be very low. The crew time involved in scheduled maintenance of the flush flow oxygen incineration process for all system designs is one of the lowest of all candidates evaluated. The unscheduled maintenance time for all system designs, however, is one of the highest for the systems evaluated. Design 2 possesses significantly higher unscheduled maintenance requirements than the other system designs due to the complexity of the chamber heating and cooling circuit.

Equivalent weight: The total equivalent weight and its constituents for the flush flow oxygen incineration process are summarized on the data sheet of figure 87 for the three power supply designs.

Secondary criteria. - The positive treatment of collected wastes and the absence of manual handling requirements eliminates potential areas of contamination. Each of the system designs possesses three interfaces. Designs 1 and 3 have electrical heating, oxygen supply, and vacuum interfaces, whereas the Design 2 system interfaces are oxygen supply, vacuum, and coolant. Significant flexibility can be achieved since the process can handle variations in waste composition and type with little or no effect upon performance. Since cycle time can be decreased by providing for more rapid chamber cooldown, increased (or decreased) capacity can be easily provided. However, the overall growth potential is limited primarily by the availability of oxygen for processing. A noise comparison between the evaluated candidates is based upon relative differences (i.e., ignoring the noise levels of components common to all candidates such as process flow fans, urine/air separators, shredder, etc.). The concept for Designs 1 and 3 is expected to produce a relatively low noise level, since the major source of noise, the process flow air exhaust, is effectively muffled by the incinerator. Since Design 2 has a separate cooling circuit, the process flow air is exhausted to the cabin through a separate noise suppressor (muffler). This is expected to produce a slightly higher noise level. The total system volume of the flush flow oxygen incineration process is summarized on the data sheet of figure 87. The power quality of this process for Designs 1 and 3, is due to its high level and cyclic nature, relatively poor. Design 2 minimizes the effect on power generation equipment and produces a relatively good power quality.

Pyrolysis/Batch Incineration

Absolute criteria. -

Performance: The pyrolysis/batch incineration concept utilizes a three-step process to minimize oxygen supply quantities. The wastes are first heated to 250°F and held at this temperature for 30 minutes to ensure sterilization. The vent valve is then opened and the water is flashed to space as a vapor. The chamber is then heated to 1200°F, with the vacuum valve remaining open, and the wastes are pyrolytically decomposed (vacuum decomposition) and the gases vented to space. At the end of the pyrolysis process, the vent valve is closed, the chamber is charged with oxygen, and several batch incinerations are performed (maximum chamber pressure is 200 psia). The batch incineration step reduces the ash residue from 12 to 2 percent of the total wastes processed. After the final venting to space, the chamber is allowed to cool down and the residue is vacuumed from the chamber. The pyrolysis/batch incineration process is schematically identical to the flush flow oxygen incineration process (figure 87) for all system designs. Waste collection, cycle operation, and chamber heating and cooling are also identical to the candidate previously discussed, so a description of these processes will not be repeated. The data for this concept is shown in figure 88.

Safety: Safety considerations for the pyrolysis/batch incineration process are similar to those presented for the flush flow oxygen incineration process.

Availability/confidence: While the three-step pyrolysis/batch incineration process has received little development effort, the required equipment is similar to that used in the flush flow oxygen incineration concept. A two-man system utilizing a single radioisotope source has been designed for the Atomic Energy Commission. The pyrolysis/batch incineration concept for Designs 1 and 3 is in the early prototype development stage, with flight hardware expected during 1977 with normal development progress. Flight hardware for Design 2 is anticipated by mid-1978.

Primary criteria. -

Reliability: The MTBF's for Designs 1 and 3 are estimated to be 12 472 hours each. With redundant incinerator heaters, vacuum vent valves, and 28 miscellaneous spares, the overall reliability is calculated to be 0.999270. The Design 2 concept possesses an MTBF of 9500 hours. Redundant isotope cooling fans and 36 additional spares are required to achieve an equivalent reliability.

Crew time: Crew stress considerations for the pyrolysis/batch incineration concept are similar to those of the flush flow oxygen incineration process, since crew time requirements for scheduled and unscheduled maintenance as well as operating time are identical for both processes. Thus, no difference in crew stress is anticipated between the two candidates.

SUBSYSTEM: **Waste Control**

CONCEPT: **Pyrolysis/Batch Incineration**

FLIGHT AVAILABILITY: 1977
(1970 go-ahead)

RELIABILITY:			MTBF:		
	Designs 1 & 3	0.999278		Designs 1 & 3	12 472 hr
	Design 2	0.999290		Design 2	9 500 hr

Spares/Redundant (R) Units: (Common)

- 2 - Shredder
- 1 - Bacteria Filter
- 50 - Bacteria Filter-Exp.
- 1 - Urinal
- 2 - Urine/Air Separator
- 2 - Urine Pump
- 2 - Process Flow Fan
- 3 - Cycles Control
- 4 - Solenoid Shutoff Valve
- 1 - Check Valve
- 1 - Ash Collector Fan
- 1 - High Temp. Shutoff Valve (R)
- 4 - High Temp. Shutoff Valve
- 1 - Odor Removal Filter
- 20 - Odor Removal Filter-Exp
- 2 - Oxygen Regulator

Design 1 & 3 Only

- 1 - Incinerator Heater (R)
- 2 - Heater Controller

Design 2 Only

- 2 - Heat Exchanger
- 3 - Solenoid 3-Way Valve
- 1 - Colling Fan (R)
- 3 - Cooling Fan
- 1 - Solenoid Shutoff Valve
- 1 - Check Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled	Operating Time
Designs 1 & 3	65	2.4	2945
Design 2	65	3.2	2945

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	372	507	372
Expendables	1297	1297	1297
Spares/Redundant Units	120	140	120
Electrical Power	630	144	630
Thermal Power	0	60	0
Radiator Load	39	203	39
Total Equivalent Weight	2458	2351	2458
POWER (Watts):			
Electrical	1400	320	1400
Thermal	0	1200	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Designs 1 & 3	91.5	3.2	94.7
Design 2	93.6	4.0	97.6

Figure 88 (Page 1 of 1)

Equivalent weight: The equivalent weight for the process is summarized in figure 88 for the three power supply designs.

Secondary criteria. - The ratings of the pyrolysis/batch incineration process with respect to secondary criteria are nearly identical to the previous concept. The only exception is that, since the pyrolysis/batch incineration process does not materially benefit from the heat of combustion of the waste products, additional electrical heat must be added (over the flush flow oxygen incineration process). Thus, the power quality for this candidate is somewhat poorer.

Wet Oxidation

Absolute criteria. -

Performance: Wet oxidation is a moderate temperature, high pressure catalytic process (500 to 600°F and 1200 to 2000 psia) used commercially on a large scale in industrial sewage treatment plants. The wet oxidation process (known as the Zimmerman process) employs an insulated chamber similar to the incineration and decomposition concepts. Waste treatment is accomplished by charging the chamber with 500 psia oxygen at ambient temperature and applying heat to bring the chamber up to oxidation temperature. The final pressure and temperature are approximately 1750 psia and 550°F respectively. A study on the feasibility of small-scale wet oxidation systems has shown that the use of a base metal oxide catalyst increases not only the rate of reaction but also the quality of the end products, and is thus highly desirable. The process effluent consists of a dark organic ash and a clear-to-pale liquid consisting mostly of water containing carbon dioxide and traces of acetone vapor, carbon monoxide, hydrogen, and nitrogen. No sulfur compounds were detected in the liquid effluent. The oxygen required (approximately 0.05 lb per pound of wet waste) can be obtained by electrolyzing the product water. This water, however, is not potable and would even require processing prior to electrolysis.

A wet oxidation system is shown schematically in figure 89 with related system data. Oxygen is assumed to be stored in gaseous form at 3000 psi rather than obtaining it from electrolyzed product water. A compressor is used to boost storage tank pressure to 1200 psia toward the end of the mission. Oxygen storage eliminates the need for an electrolysis cell, thereby providing significant increases in safety, reliability, crew time, and interfaces at the expense of equivalent weight. A stirrer and motor can be employed in the oxidation chamber to ensure that sufficient oxygen is dissolved in the wastes undergoing oxidation, thereby increasing the rate of reaction. However, the mechanical problems of employing a stirrer/motor penetration in the chamber (with the resultant decrease in system reliability) are considered to be too large, and the use of such equipment does not produce gains sufficient to warrant its incorporation.

SUBSYSTEM: Waste Control

CONCEPT: Wet Oxidation

FLIGHT AVAILABILITY: 1980
(1970 go-ahead)

RELIABILITY:	Designs 1 & 3	0.999385	MTBF:	Designs 1 & 3	16 000 hr
	Design 2	0.999397		Design 2	11 600 hr

Spares/Redundant (R) Units:

2 - Shredder
1 - Bacteria Filter
50 - Bacteria Filter-Exp.
1 - Urinal
2 - Urine/Air Separator
2 - Urine Pump
2 - Process Flow Fan

3 - Cycle Control
4 - Solenoid Shutoff Valve
1 - Odor Removal Filter
20 - Odor Removal Filter-Exp.
1 - Urine Check Valve
2 - Oxygen Regulator
2 - Compressor

Designs 1 & 3 Only
1 - Incinerator Heater(R)
2 - Heater Control

Design 2 Only
2 - Heat Exchanger
1 - Cooling Fan (R)
3 - Cooling Fan
3 - Solenoid 3-Way Valve
1 - Solenoid Shutoff Valve
1 - Check Valve

CREW TIME (Hr/Mission):	Scheduled	Unscheduled	Operating Time
Designs 1 & 3	155	1.7	2860
Design 2	155	2.4	2860

EQUIVALENT WEIGHT (lb):	Design 1 (Solar Cell)	Design 2 (Solar Cell/Isotopes)	Design 3 (Brayton)
Basic Unit	1053	1214	1053
Expendables	1428	1428	1428
Spares/Redundant Units	105	127	105
Electrical Power	405	171	405
Thermal Power	0	35	0
Radiator Load	63	159	63
Total Equivalent Weight	3054	3134	3054

POWER (Watts):

Electrical	900	380	900
Thermal	0	700	0

VOLUME (ft^3):	Installed	Spares/Expendables	Total
Designs 1 & 3	148.6	2.8	151.4
Design 2	150.7	3.6	155.3

Figure 89 (Page 1 of 2)

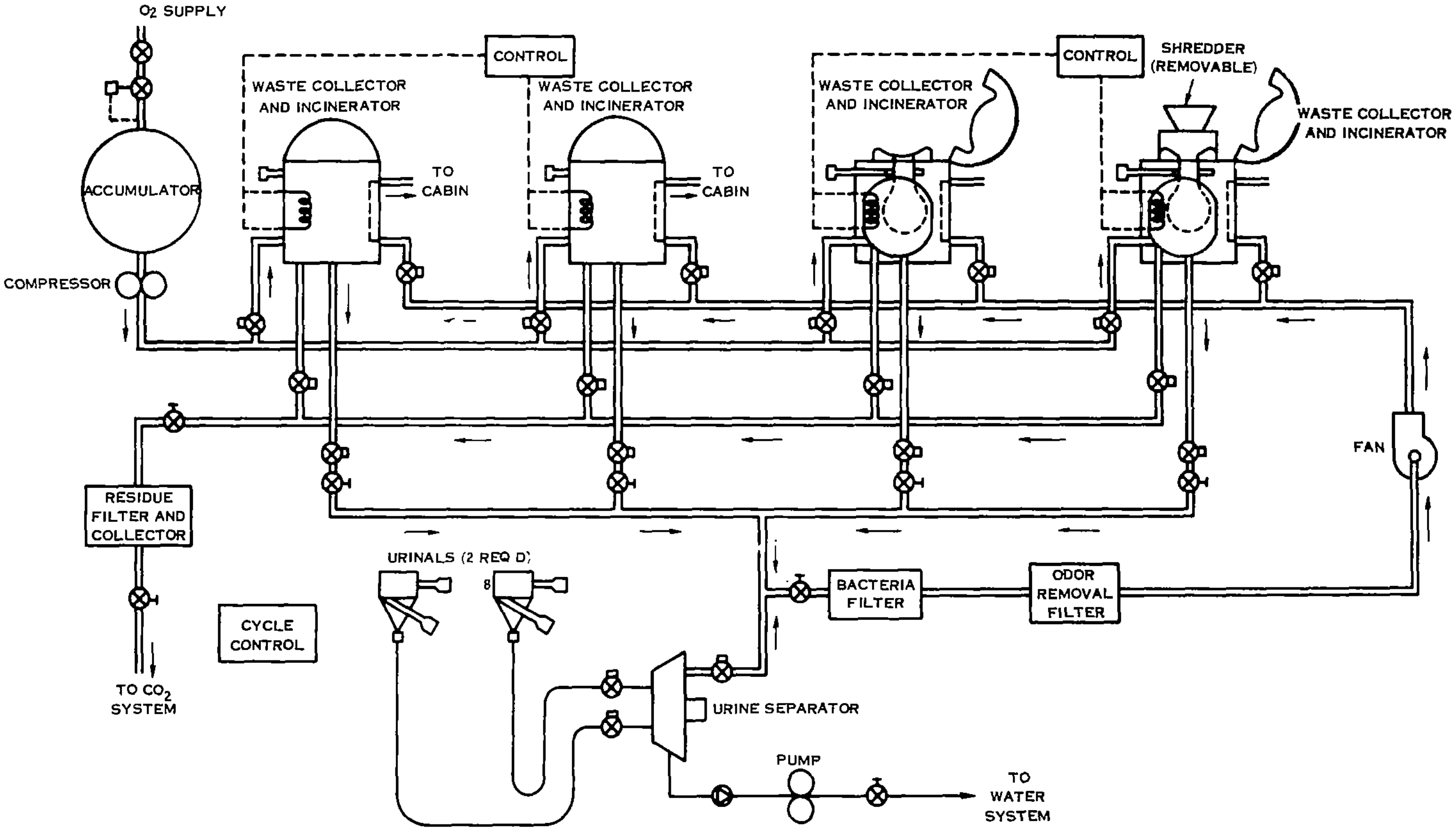


Figure 89. Wet Oxidation Concept (Page 2 of 2).

The components and their operation, cycle operation, and chamber heating and cooling are similar to those of the two previous candidates as well as the integrated vacuum decomposition system. The primary difference in the wet oxidation process is the method employed for residue expulsion and filtration. Each chamber is provided with an orifice for a pressure bleed to the carbon dioxide concentration and reduction subsystems. A filter housing with replaceable cartridges is used to remove solid residue from the effluent. Solid residue quantities are expected to be approximately 20 percent of the total wastes processed. The unfiltered effluent, consisting primarily of carbon dioxide and water, is delivered to the separator. Carbon dioxide is delivered to the concentrator and the water portion of the effluent is delivered to the water management subsystem for processing. Since this water is neither required nor desired, this is a questionable advantage.

Safety: Safety considerations are similar to those described for the flush flow oxygen incineration process. The requirement for a high pressure process operation is expected to impose additional safety hazard.

Availability/confidence: While the feasibility of wet oxidation for spacecraft waste control has been demonstrated, substantial effort is required to reduce it to working flight hardware. Practical means of effluent expulsion and filtration, integration with other subsystems, and further reductions in residue quantities have received little attention and will require development effort. Operation under zero gravity conditions remains to be demonstrated. The wet oxidation concept for Designs 1, 2 and 3 is expected to produce flight hardware by 1980 with concentrated development efforts.

Primary Criteria. -

Reliability: The MTBF for the Design 1 and 3 systems is estimated to be 16 000 hours. With redundant incinerator heaters and 23 miscellaneous spares, the overall reliability is calculated to be 0.999385. The system for Design 2 possesses an inherent reliability of 11,600 hours, MTBF. Redundant isotope cooling fans and 31 additional spares are required to achieve an equivalent reliability. The increase in MTBF over that of the flush flow oxygen incineration concept results from elimination of the high temperature vacuum valves.

Crew time: Since collected wastes are processed within 24 hour period, and process residue consists of a sterile ash which is later vacuumed from the chamber, crew stress due to the presence of wastes is expected to be very low. The wet oxidation process (for all system designs) possesses the highest scheduled maintenance time requirement of all the candidates evaluated. This results primarily from frequent ash filter replacement (100 times per mission) due to the high percentage of residue. Unscheduled maintenance time requirements are average among the concepts considered (with the system for Design 2 being significantly higher).

Secondary criteria.- The positive treatment of collected wastes and the absence of manual handling requirements eliminate potential areas of contamination. Each of the system designs possesses three interfaces, of which oxygen supply and subsystem interfaces are common to both. The remaining interfaces are electrical heating for Design 1 and 3 and coolant for Design 2. Flexibility is somewhat limited by the fact that solid residue quantities and effluent purity are, to some extent, dependent upon the composition and type of the collected waste. Offsetting this, however, is the high degree of overall flexibility resulting from the integration potential of utilizing the process end product. The processing time for the wet oxidation concept is expected to be about two hours. Thus, by decreasing chamber cooldown time, several cycles can be run daily, thereby providing significant growth potential. Overall growth, however, is limited by the available supply of oxygen. Designs 1 and 3 are expected to have a relatively low noise level. A somewhat higher noise level is expected in the Design 2 system since noise suppression of the exhausting process flow air cannot be as effective as the incinerator chamber itself without a significant weight penalty. The total volume of the wet oxidation process for all system designs is summarized on the data sheet of figure 89. The power quality for the system 1 and 3 designs is approximately average among the candidates evaluated. Design 2 minimizes the effect on the power generation equipment and produces a relatively good power quality.

Evaluation and Selection: Design 1

The integrated vacuum decomposition concept is selected for Design 1.

Absolute criteria. - Of the twelve specific concepts evaluated, six are rejected due to their inability to meet the absolute criteria. These are anaerobic biodegradation, aerobic biodegration, gamma irradiation, beta excited x-ray irradiation, freezing of wet waste, and vacuum drying utilizing separate functions. The absolute criteria categories with the corresponding ratings for the six rejected candidates are shown in table 40. The reasons for rejection are listed below:

1. Anaerobic Biodegradation
   Safety - production of noxious gases
   Availability/confidence - lack of development

2. Aerobic Biodegradation
   Availability/confidence - lack of development

3. Gamma Irradiation
   Performance - inherent fecal handling requirements

4. Beta Excited X-ray Irradiation
   Performance - inherent fecal handling requirements
   Availability/confidence - feasibility not demonstrated

TABLE 40
EVALUATION SUMMARY - WASTE CONTROL, UNACCEPTABLE CANDIDATES

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Biodegradation		Irradiation		Other Concepts	
		Anaerobic biodegradation	Aerobic biodegradation	Gamma Irradiation	Beta excited x-ray Irradiation	Freezing of wet waste	Vacuum drying utilizing separate functions
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Good	Good	Unacceptable	Unacceptable	Fair	Unacceptable
	Safety	Unacceptable	Fair	Fair	Fair	Unacceptable	Fair
	Avail./Conf.	Unacceptable	Unacceptable	Fair	Unacceptable	Good	Very Good
		Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated
Primary	Reliability						
	Crew Time						
	Equivalent Weight						
Secondary	Contamination						
	Interfaces						
	Flexibility						
	Growth						
	Noise						
	Volume						
	Power						

5. Freezing Wet Waste
   Performance - inherent fecal handling requirements
   Safety - production of contaminants (freezing unit failure)

6. Vacuum Drying Utilizing Separate Functions
   Performance - inherent fecal handling requirements

Of the remaining concepts, as shown in table 41, all are rated equally on performance because they are all capable of meeting the AILSS requirements. The integrated vacuum decomposition concept is rated Good on safety while all other concepts are rated Fair. This is because it effectively eliminates accumulated waste and sterilizes itself every 24 hours and therefore does not require germicide or high pressure oxygen which could be a potential safety hazard.

Primary criteria.- The reliability of the liquid germicide and integrated vacuum drying system is much higher than that of the other candidates because the collecting units are changed periodically. This of course results in a slightly higher crew stress which offsets the ash handling requirements of the decomposition and incineration systems.

A total equivalent weight summary for the various concepts is shown in table 42. The integrated vacuum decomposition concept has the lowest weight and is followed very closely by the integrated vacuum drying concept. The weights for the wet oxidation and flush flow oxygen incineration concepts are significantly higher than the other concepts due to oxygen requirements and are rated Poor. This rating together with lack of outstanding characteristics eliminated these two concepts from further consideration. The other candidates have reasonable primary characteristics and so the secondary criteria are examined.

Secondary criteria.- Four candidates remain after completion of the primary criteria evaluation. These are integrated vacuum drying, liquid germicide addition, pyrolysis/batch incineration, and integrated vacuum decomposition. The liquid germicide and integrated vacuum drying concepts, which store treated waste, are rated Poor relative to the other concepts in contamination due to the possibility that waste material might not be treated completely. They also have volumes which are three times larger than those of the other two concepts. Growth potentials for these two concepts are only fair. These factors resulted in elimination of the liquid germicide and integrated vacuum drying concepts.

A comparison of the secondary characteristics of the two remaining Design 1 candidates shows that the integrated vacuum decomposition concept has a slightly better overall rating than the pyrolysis/batch incineration process. The integrated vacuum decomposition concept also possesses better interface and growth characteristics but a slightly larger overall volume. Both concepts' power requirements are

TABLE 41
EVALUATION SUMMARY - WASTE CONTROL

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts					
		Liquid germicide addition	Integrated vacuum drying	Integrated vacuum decomposition	Flush flow oxygen incineration	Pyrolysis/ batch incineration	Wet oxidation
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Good	Good	Good	Good	Good	Good
	Safety	Fair	Fair	Good	Fair	Fair	Fair
	Avail./Conf.	Fair	Very Good	Good	Good	Good	Fair
Primary	Reliability	Very Good	Very Good	Good	Good Fair Good	Good Fair Good	Good
	Crew Time	Good	Good	Very Good	Very Good	Very Good	Good
	Equivalent Weight	Good	Very Good	Very Good	Poor	Good	Poor
					Eliminated		
Secondary	Contamination	Poor	Fair	Very Good		Very Good	Eliminated
	Interfaces	Very Good	Good	Good		Fair	
	Flexibility	Fair	Good	Very Good		Very Good	
	Growth	Fair	Fair	Very Good		Good	
	Noise	Good	Fair	Very Good		Very Good	
	Volume	Poor	Poor	Good		Very Good	
	Power	Good	Good	Fair/V.G./Fair		Fair/V.G./Fair	
		Eliminated	Eliminated	Selected		Eliminated	

TABLE 42

DATA SUMMARY - WASTE CONTROL

Concept	Design	Total Equivalent Weight (lbs)	MTBF (hrs)	Crew Time (hr/mission)			Volume (ft^3)	Power (watts)
				Scheduled	Unscheduled	Operating Time		
Liquid Germicide Addition	1	2042	36,400	95	0.4	2695	368.4	300
	2							
	3							
Integrated Vacuum Drying	1	2092	25,200	90	0.8	2695	367.6	190
	2							
	3							
Integrated Vacuum Decomposition	1	2049	14,000	105	2.2	2945	130.0	1400
	2	1942	104,000		2.9		132.9	320
	3	2049	14,000		2.2		130.2	1400
Flush Flow Oxygen Incineration	1	3172	12,472	65	2.4	2945	126.5	1000
	2	3135	9,500		3.2		129.4	320
	3	3177	12,472		2.4		126.5	1000
Pyrolysis/Batch Incineration	1	2458	12,472	65	2.4	2945	94.7	1400
	2	2351	9,500		3.2		97.6	320
	3	2458	12,472		2.4		94.7	1400
Wet Oxidation	1	3054	16,000	155	1.7	2860	151.4	900
	2	3134	11,600		2.4		155.3	380
	3	3054	16,000		1.7		151.4	900

the same. A reexamination of the primary characteristics of the two contenders shows that the integrated vacuum decomposition process requires slightly more crew time due primarily to the higher scheduled maintenance time resulting from 50 ash collection filter replacements per mission versus 10 for the pyrolysis/batch incineration process. However, integrated vacuum decomposition possesses a significant weight advantage over the pyrolysis/batch incineration concept (in excess of 400 lb) and is inherently safer because it does not require high pressure oxygen for operation. As a result, the integrated vacuum decomposition concept is selected for the AILSS mission.

Selection.- Based on the above evaluation, the integrated vacuum decomposition candidate is selected because of its inherently safe characteristics, light weight, low volume, and good secondary characteristics.

Evaluation and Selection: Design 2

The vacuum decomposition concept is selected for Design 2. All process heat for Design 2 concepts is provided by isotope heat.

Absolute criteria.- The rating of all the candidate concepts is the same as discussed for Design 1 above.

Primary criteria.- Primary ratings of all the candidate concepts remain the same as discussed for Design 1 above, except for the reliabilities of the incineration and decomposition systems, which are reduced due to the added complexity of the isotope interfaces. However, with the availability of thermal waste heat the power requirements, and therefore total equivalent weight, are reduced significantly for the integrated vacuum decomposition and incinerations concepts. Resultant changes in total equivalent weight are shown in table 42. Flush flow oxygen incineration and wet oxidation are again eliminated because of high weight and no other outstanding characteristics. The remaining candidate concepts are further evaluated in regard to the secondary criteria.

Secondary criteria.- Secondary criteria ratings of the remaining concepts are identical to those for Design 1 except for power. With the availability of isotope heat, the integrated vacuum decomposition and pyrolysis/batch incineration requirement for power is reduced significantly, improving the ratings. As a result, relative ratings of the candidates remain the same and the integrated vacuum decomposition system is again selected because of its safety, minimum weight, and outstanding secondary characteristics.

Selection.- The integrated vacuum decomposition concept is selected for the AILSS mission because it offers a minimum equivalent weight and exceeded the two remaining runner-up candidates in the secondary criteria evaluation.

Evaluation and Selection: Design 3

The integrated vacuum decomposition concept is selected for the Design 3 system. Since process heat is limited to 375°F for design, electrical heating is necessary for all high temperature concepts. Therefore, the evaluation and selection process for the Design 3 concept is identical to that made in the Design 1 evaluation and selection.

Evaluation and Selection Summary

The integrated vacuum decomposition concept best meets the AILSS criteria and is selected for Designs 1, 2 and 3. It provides a safe method of disposing of waste material, with minimum weight and low volume.

Although the integrated vacuum decomposition process was investigated during 1961 and 1962, and a laboratory prototype was built and tested, little development has been achieved following this contract. System feasibility has been adequately demonstrated, so further effort should be directed primarily toward system optimization and reduction of maintenance time. This includes investigating and sizing a system to handle shredded wastes, along with feces and other wet wastes, as well as ensuring long term operation without outlet tube clogging. Pacing technology areas are not apparent in this concept, and with concentrated development effort, hardware is expected to be available for the AILSS mission.

IMPACT OF MISSION PARAMETERS

Mission Length

Mission duration extension beyond 500 days does not change the AILSS selection (integrated vacuum decomposition) until a mission length of approximately 900 days is reached. At this point, it appears desirable to modify the vacuum decomposition concept or consider other concepts such as wet oxidation that would permit reclaiming oxygen for use in cabin leakage make-up by reclaiming some or all of the wet wastes. This would result in a lower stored oxygen requirement with the differential credited to the waste management system. Higher vehicle leakage rates would have the same effect as a longer mission, i.e., the total oxygen for leakage make-up would be higher and waste control concepts based on oxidation would become more attractive.

For AILSS type missions or longer, the integrated vacuum decomposition concept is also attractive because its weight advantage increases over those concepts requiring large storage containers such as liquid germicide or integrated vacuum drying.

For missions shorter than 500 days, the vacuum drying system becomes more competitive, and at 200 days, it shows a 400 pound total equivalent weight advantage over vacuum decomposition. This weight decrease is sufficient to override the superior secondary characteristics of the vacuum decomposition concept for short duration missions.

Crew Size

Crew size changes, either greater or less than nine men, are not expected to exert any significant influence upon the waste control candidate selection provided the present waste control requirement of always having two collectors available for use remains unchanged. Since the effects of crew size on system weight is a most important primary consideration in the concept evaluation, a comparison of these approximate weights for a 6, 9, and 12 man crew is presented below for the selected integrated vacuum decomposition concept and the three runner-up candidates for design 1 and 3.

	6 Man Crew Approx. System Weight (lbs.)	9 Man Crew Approx. System Weight (lbs.)	12 Man Crew Approx. System Weight (lbs.)
1. Integrated Vacuum Decomposition (Selected)	1480	2049	2618
2. Integrated Vacuum Drying	1500	2007	2514
3. Liquid Germicide Addition	1660	2402	3144
4. Pyrolysis/Batch Incineration	1740	2458	3176

The tabulation shows that the relative weights are not significantly changed when evaluating the four waste control concepts for either the 9 or 12 man crew. Therefore, the nine man crew selection (integrated vacuum decomposition) is valid for the increase or decrease in crew size provided the two usable collector requirement exists.

If the nine man requirement for two usable collectors was relaxed to only one usable collector for a six man crew (or less), collector weight is decreased and the integrated vacuum decomposition concept selection is more valid. With the AILSS assumptions, the incineration/decomposition processes required four collectors (two for collection and two for processing), while the high expendable candidates such as integrated vacuum drying and liquid germicide addition provided two collectors.

Conversely, requiring more than two waste collectors available at all times for crew sizes of twelve or more men could penalize the incineration/decomposition concepts on the basis of weight and could upset the selection of the integrated vacuum decomposition candidate for this application.

However, as long as the basic AILSS assumptions do not change, crew size will not have an appreciable effect on the waste management control system selected.

Power Penalty

A summary of the power requirements for the six waste control concepts evaluated in accordance with the AILSS primary and secondary criteria is shown below.

	Design 1 Power (Watts)	Design 2 Power (Watts)	Design 3 Power (Watts)
(Selected) 1. Integrated Vacuum Decomposition	1400	320	1400
2. Pyrolysis/Batch Incineration	1400	320	1400
3. Flush Flow Oxygen Incineration	1000	320	1000
4. Wet Oxidation	900	380	900
5. Liquid Germicide Addition	300	300	300
6. Integrated Vacuum Drying	190	190	190

Initially, when considering designs 1 and 3, the power requirement chart shows that an increase or decrease in the power penalty will have the greatest effect upon the integrated vacuum decomposition and the pyrolysis/batch incineration concepts. The chart further lists the remaining concepts in the order of decreasing effects caused by changes in power penalty. A significant increase in power penalty of 50 percent or greater could change the AILSS selection to the integrated vacuum drying waste control concept. No change in the AILSS waste control selection will be necessitated by a power penalty decrease of 50 percent or greater. Therefore, a power penalty increase approaching 50 percent is necessary before considering any reversal of the current concept selections.

If a power critical electrical system is utilized for designs 1 and 3, the low power consumption systems such as the integrated vacuum drying and the liquid germicide addition candidates would appear most attractive. The integrated vacuum drying concept is selected, however, after consideration of the poor contamination characteristics associated with the liquid germicide addition system.

When considering the design 2 waste control evaluation, the power requirements chart shows that the required power for all systems is relatively low and within the same approximate range. It is obvious that an increase or decrease in the power penalty will not change the AILSS selection of the integrated vacuum decomposition candidate.

Resupply

The necessity of periodic resupply capability will have the greatest effect upon those concepts which have the greatest ratio of expendables to fixed weight such as integrated vacuum drying, liquid germicide addition, and flush flow oxygen incineration. Missions that provide resupply capabilities afford the advantages of reducing the launch weight and increasing the number of waste control concepts that can be considered for final selection. The disadvantages associated with this mission concept are the increases in total mission weight, cost, and crew size required to shuttle waste collectors back and forth through space. The incorporation of resupply to the AILSS mission would certainly influence the selection of the integrated vacuum decomposition concept for designs 1, 2 and 3. Integrated vacuum drying allows launch weight to be decreased at no increase in total weight in orbit at 500 days.

Flight Date

An earlier or later launch date would dictate the type of waste control concept to be selected based on availability. The AILSS mission launch date was projected for 1976 to 1980. The earlier launch date limit (1976) was established in anticipation of having fully developed flight hardware for the selected integrated vacuum decomposition concept. The integrated vacuum drying candidate is expected to produce the first fully developed spacecraft waste control system in 1973; therefore, this becomes the earliest possible launch date for a system of this type. An extension of the launch date beyond the 1980 limit would make available all the fully developed waste control systems utilized in the AILSS evaluation plus any advancements in the state of the art. It is quite possible that a change in the AILSS selection could be made at this time.

CREW PROVISIONS

CONTENTS

CREW PROVISIONS

The crew provisions subsystem consists of the equipment and supplies needed for food and feeding, personal hygiene, whole body cleaning, clothing, and several other considerations.

Unlike other life support subsystems, crew acceptability is of paramount importance for the crew provisions subsystem. Thus the basic objective here is to select concepts that are psychologically acceptable to the crew but still represent a sound engineering approach. Alternative concepts sometimes have lower weight, power, and volume than a particular selection, but selecting such concepts would result in an undesirable amount of crew psychological stress.

FOOD AND FEEDING

Freeze-dried food is selected for the basic AILSS diet because it is the only concept that is both psychologically and nutritionally acceptable and has satisfactory weight. It is anticipated that a complete diet will incorporate other desirable food types to supplement this basic diet. Nonoral feeding techniques such as intravenous feeding and the recently developed technique of dimethyl sulfoxide-assisted through-the-skin feeding are not considered here because of obvious psychological problems.

A diet adequate to sustain the crew throughout the AILSS mission must provide approximately 2600 kilocalories of energy per man per day, with adequate quantities of proteins, fats, carbohydrates, minerals, and vitamins. Exact caloric requirements for the crew should be based on actual crew body weight, age, height, and level of activity for the specific mission.

The revised 1963 recommendations of the Food and Nutrition Board of the National Academy of Sciences-National Research Council on Dietary Allowances (Reference 9 and the following table) have served as the model for the AILSS diet. Protein, fat, and carbohydrates will supply substantially all the calories required. The diet should provide (not merely contain) the following nutrients, for a typical AILSS crew member defined as a male, age 35 to 55, weight 154 lb, height 69 inches:

Kilocalories	2600
Protein	70 gm
Calcium	0.8 gm
Iron	10 mg

Vitamin A	5000 International Units
Thiamine	1 mg
Riboflavin	1.6 mg
Niacin	17 mg equivalent
Ascorbic acid	70 mg

The protein level is 70 grams, based on NAS-NRC studies. Although fats provide a high caloric density per unit weight, the amount of fat in this diet is limited to 82 grams (30 percent of the calories) to avoid problems of storability, reconstitution, palatability, and possible medical effects. The remaining calories are supplied by carbohydrates. Vitamins and minerals are supplied by the food and dietary supplements as required.

The metabolized diet constituents are as follows:

	Wt. (gms)	Kilocalories	Calories (%)
Protein	70	300	12
Fat	82	780	30
Carbohydrates	364	1520	58
		2600	

If completely consumed, the selected diet will result in the following calculated metabolic balance:

O_2 consumed	1.68 lb/man/day
CO_2 output	2.05 lb/man/day
Metabolic water	0.7 lb/man/day
Respiratory quotient	0.89

In addition to the physiological requirements, the diet must be acceptable to the crew, be easy to prepare, and remain free of degeneration in taste or bacterial content when stored for the duration of the mission. Several diets have been examined, with the result that the basic trade-off is between acceptability and total equivalent weight.

A large number of diets and diet combinations are available which satisfy the AILSS requirements. For example, the nutritional needs of the crew could be supplied by two chemical meals a day and one freeze-dried meal, or by a freeze-dried diet made up of bite-size pieces eaten dry. The diets evaluated here are intended to provide basepoints that can be used to evaluate the effects of the many possibilities.

Food preparation method and eating technique are poorly defined. Existing approaches are available but new and more advanced techniques would allow eating in a more normal way (eliminating for example the plastic squeeze tube). Such techniques should reduce the preparation and eating time and result in food with a more normal appearance and texture. Proposed eating techniques are discussed under each diet type.

The basic diet types to be considered here are:

1. Dried
2. Frozen
3. Freeze-dried
4. Liquid
5. Chemical

In evaluating these diets, the performance criterion includes and emphasizes crew acceptability, in addition to considering mechanical hardware aspects. Crew acceptability is based on such factors as variety, flavor, and texture.

Dried Diet

The dried diet consists of food items dried by conventional means. Many of the items are in powdered and compact form. Drinks are reconstituted from dried or prepared mixes.

Dried food is eliminated from further consideration for the AILSS because it does not meet the absolute performance requirements due to crew unacceptability for a 500-day mission. If carried through the complete trade, this diet would be rated the same as the freeze-dried diet on all the other characteristics except availability, where it would require less development.

Frozen Diet

The frozen foods diet is based on use of standard commercially available food products, except that they are frozen and packaged for an AILSS-type mission. This diet consists of a combination of precooked frozen main dishes, desserts, soups, and baked goods. This diet is different from others in that all the original water content of the food is frozen with it. In addition, drink powders, snack items, cookies, cereal cubes, and other items that normally can be carried dry constitute a part of this diet. Frozen portions of this diet are stored in foil containers which also provide a moisture barrier and a cooking and eating container for the food. Concentrated frozen drinks mixed with water are contained in expandable multilaminate containers similar to those currently in use. Foods eaten dry are contained in wrappers for protection against atmospheric oxygen or moisture and are stored at ambient temperature. The frozen foods are prepared in their storage containers by oven heating. Frozen drinks are thawed and mixed with water. Hot and cold powdered drinks are mixed with water at 160°F and 45°F, respectively, for consumption. Snack bits are consumed without preparation.

All cooked solid and semisolid items can be eaten with either standard eating utensils or a special tool with a food-holding device. Solid snack-type foods are eaten in bite-sized pieces to avoid crumbing and are dispensed from packages. Liquids are consumed from disposable squeeze-type containers or reuseable rigid containers with a piston or bellows for dispensing the fluid through a mouthpiece. A dishwasher is provided to clean the utensils. Should the refrigeration facility fail, the frozen food will become inedible. In this case, the nonfrozen items in the diet can still be consumed, resulting in a much reduced calorie intake (estimated at 1300 kilocalories). The frozen diet evaluation considers only a two-week 2600 kilocalories per man-day contingency food supply to compensate for a small amount of food deterioration.

Absolute criteria. -

Performance: Frozen foods rate high on crew acceptability. With recently developed direct-contact liquid refrigerant freezing techniques, taste and general quality should be close to that of fresh food. Acceptability, however, declines with food deterioration in storage.

Safety: The safety characteristics of the frozen food diet are principally limited by the possibility of freezer failure. To maintain crew safety at a high level, a complete backup food supply would be required. Also, the freezer coolant liquid would be a toxicity hazard if accidentally released into the atmosphere, although cooling by direct radiation to space might be practical.

Availability/confidence: The availability of the frozen diet is good since the basic frozen food items are available. Some development work is required to determine the most economical combination of freezer temperature and packaging material to arrive at an optimum storage condition and to insure survival of the food over the full mission period.

Primary criteria. -

Reliability: The reliability of the frozen food diet is dependent upon the freezer. Hardware reliability can be improved by the use of modular freezers so that in the event of freezer failure only a portion of the diet spoils. Another reliability problem is the possible spoilage of food without freezer failure. Spoilage or flavor loss could occur due to bacterial contamination or long storage. These factors could result in slow deterioration of individual food items rather than a complete failure of the entire frozen food supply. On a 500-day mission, such deterioration could result in the partial loss of some food items near the end of the mission.

Crew time: The crew time factor is moderately high. It is estimated that preparation and cleanup time amounts to seven man-hours per day. Crew maintenance time includes estimated freezer maintenance time. Of all the food types considered, however, the frozen foods diet is the only one requiring maintenance of the storage facilities.

Equivalent weight: The equivalent weight makeup of the frozen diet for Designs 1 and 3, with no credit for contained water, is as follows:

Food weight (3 lb/man-day)	13 500 lb
Total packaging weight	1 370
Storage weight	4 700
Preparation and consumption equipment	100
Washer-dryer weight	46
Power penalty (oven, washer-dryer)	406
Food contingency, 3%	587
Total	20 709 lb

The Design 2 weight is almost the same, 20 338 pounds, the difference resulting from the lower oven and washer-dryer power penalties.

The high food weight results from 6390 pounds of contained water. The highest credit for this water could be obtained in conjunction with a modified Sabatier-methane dump oxygen generation concept, which was not selected for the AILSS. The excess water from the food would be electrolyzed to provide oxygen for the crew and hydrogen for CO_2 reduction, permitting dumping of nearly half the generated carbon dioxide to space and eliminating the need for oxygen to compensate for vehicle leakage. The resulting equivalent weight credit of 1100 pounds, however, does not reduce the frozen food concept's equivalent weight nearly enough to make it competitive.

For the AILSS, which is fully regenerative with regard to oxygen, CO_2 cannot be dumped and the credit for water contained in the food is even less, because the system water balance is complete without it. As the food is consumed, the water would enter the life support system as urine. Additional water for food preparation would be unnecessary, reducing water supply requirements so that some urine would not have to be processed to recover water. The resulting reduction in water processing rate by the AILSS would save only about 100 pounds of water management system equivalent weight, included in the following equivalent weight tabulation.

Thus, depending on the oxygen generation approach, the net total equivalent weight for the Design 1 or 3 frozen diet is as follows (the Design 2 weight is 371 pounds lower, as previously discussed):

	Sabatier with Partial CO_2 Dump	AILSS Closed Loop O_2 Regeneration
Frozen diet equivalent weight	20 709 lb	20 709 lb
Contained water credit	1 100	100
Frozen diet net equivalent weight	19 609 lb	20 609 lb

Secondary criteria - Contamination is only fair because in the event of a freezer failure the cabin atmosphere could be contaminated by bacteria from spoiled food. Disposal of unused food also causes a potential contamination hazard. The frozen foods diet interfaces with three subsystems. The interfaces are with the waste management system for the disposal of packaging, the atmospheric control system as mentioned under contamination in the event of food spoilage, and the thermal control system for the maintenance of freezer temperature and for food preparation. The flexibility of the frozen foods diet is fair. The use of freezers to keep large amounts of food limits the storage and operation of other systems and offers no apparent advantage or alternate use for the freezers when empty. Growth is only fair because the addition of crew members or the increased duration of the mission would require direct proportionate increases in the weight of both the frozen foods and the storage system. The volume of the frozen foods system is poor. Food and packaging volume is 660 ft^3, additional storage volume is 200 ft^3, and prepration equipment occupies 4 ft^3, for a total volume of 864 ft^3. The power to operate the oven is estimated as 700 watts.

Freeze-dried Diet

The freeze-dried diet discussed here is currently used in space flights, with one exception: the ability of a number of items to retain their normal size and consistency, such as freeze-dried steak, shrimp, and chicken. Items of this type add to the acceptability of freeze-dried products.

Freeze-dried food is prepared by quick freezing followed by vacuum sublimation of the frozen water content. This process preserves the basic food structure and most of the taste, by preventing loss of flavor oils. Food is stored at ambient cabin conditions in appropriate containers with air and moisture barriers.

Food items in whole form require rehydration and heating to a palatable eating temperature. This is done through rehydration with hot water (160°F) in the package and placement of the package in an oven. A metering unit adds water at a preselected temperature to the food contained. Freeze-dried foods of smaller piece size are reconstituted in hot water and should stay warm long enough for consumption. Drinks are reconstituted with hot or cold water in a zero gravity drinking device.

Whole reconstituted freeze-dried foods and some solid foods are eaten from the packaging container with modified reusable, food-holding eating utensils. Bite-size snack items are eaten as is from the packaging container. Liquids are consumed from a reusable container having a mouthpiece and a piston or bellows to force the liquid out. The drinking device and the reusable eating utensils are washed in a dishwasher.

The freeze-dired diet may be supplemented with whole-moisture foods for diet variety. Ham, chicken, spagetti, lobster, or other full-moisture foods can be carried in a suitable container. Although this approach is not included in the evaluations, the preparation equipment, eating utensils, and oven are compatible.

Absolute criteria

Performance: The freeze-dried diet is nutritious and does not deteriorate in storage. Compared with frozen food, it does not usually taste as much like fresh food, but its flavor and related qualities are still quite acceptable.

Safety: Freeze-dried foods have been stored for several years without any serious deterioration in bacteria content or in taste. In instances where the packaging breaks, there may be some degradation in food quality, although this would take place over several weeks. The deterioration of some of the food items would result in use of the contingency food supply and perhaps a restricted calorie intake.

Availability/confidence: Freeze-dried foods are carried on current and planned space missions. There are a variety of foods which have been developed and are available. Further development of freeze-dried foods is required for production of whole food items which are attractive and tasty. The constant use of a paste-consistency food squeezed from a tube is not acceptable for a long space mission. Sources that have been questioned believe it is possible to develop food items in whole form that can be eaten with utensils.

Primary criteria. -

Reliability: There is a low probability of food supply spoilage. Failure of the oven or eating utensils would result in operating in a degraded but effective mode of operation, that is, eating cold food. Failure of the unit providing water for the food would be a more serious problem resulting in another degraded mode of operation. However, if drinking water could be obtained from another source, the foods could be eaten dry.

Crew time: Time for the actual steps in adding water to the food items requiring rehydration, mixing the food, heating, cleanup, and disposal of waste food and packaging (but not including eating) is estimated at five man-hours total crew time per day. Maintenance times are negligible.

Equivalent weight: The equivalent weight makeup of the freeze-dried diet is shown in the following table. Note that the ratio of packaging weight to food weight is high because the food contains no water and must be prepared in its own container, requiring sturdy construction. The high storage weight is necessary for support and protection.

	Designs 1 & 3 (lbs)	Design 2 (lbs)
Weight of primary food supply at 1.58 lb/man/day	7 110	7 110
Contingency, 3%	309	309
Packaging weight	900	900
Storage weight	2 300	2 300
Power penalty (oven, washer/dryer)	58	5
Preparation equipment weight	25	25
Washer/dryer weight	46	46
Total equivalent weight	10 748	10 695

Secondary criteria. - Freeze-dried diets are not prone to contamination. Anticipated low spoilage rates and adequate packaging keep contamination of the atmosphere or any other system low.

Overall interface problems of the freeze-dried diet are minimal. The interface with waste management is in terms of fecal output rates and is about the same as a fresh diet. Hot water at a temperature of up to 160°F must be supplied for drink preparation and food reconstitution.

Flexibility is good. The diet can be eaten as needed, and a good packaging technique for combining the various food items will allow selection and variation in the diet according to taste. For any change in crew size or mission duration, proportional increases in the moderate food supply weights and volumes will be required. Little noise is associated with freeze-dried food preparation. Volume is relatively low. Total volume at the start of the mission is 520 ft^3 for food and packaging, 160 ft^3 additional storage, and 3 ft^3 for preparation equipment, for a total volume of 683 ft^3.

The power requirement is 100 watts for oven operation and 90 watts for dishwashing. It is assumed that only one of these units will be used at one time.

Liquid Diet

The liquid diet is a nutrient-defined diet composed of purified food substances. The United States Army Natick Laboratories Diet No. 1, which is typical, consists of sodium caseinate, corn starch, sucrose, vegetable oils, flavoring, and emulsifier. It is prepared by mixing with water, but can be dried and ground into a powder. This powder could then be rehydrated prior to crew consumption.

This food can be packaged in large quantities and dispensed in meal amounts. Preparation consists of adding water from a metering dispenser to a reusable container. The water is mixed with the food powder with a blender. No hot water or heating is necessary. Consumption is in liquid form at ambient temperature from a liquid dispenser.

Absolute criteria. -

Performance: Initial low acceptability of this diet will become even lower due to monotony. Even the use of several flavors is not expected to help. With low acceptability, it can be expected to have an adverse effect on crew attitude and health, and must be considered unsatisfactory.

No information is available on long-term (500-day) storage of the diet compounds. If browning (a reaction between protein and glucose) takes place, it could be overcome by addition of a preservative or by separate storage of the caseinate until rehydration.

Safety: As with the other diets discussed, the alternative in the event of a total food supply failure is a mission abort or crew starvation. No information is available on long-term storage of this diet.

Availability/confidence: Several diets of this general type are available. However, decomposition during long duration storage must be eliminated. Further development would also be required in acceptability. New methods of flavoring, coloring, and preparation might improve the current low acceptability of this diet.

Chemical Diet

The chemical diet is a combination of nutrient chemicals, amino acids, and vitamins. A typical formulation consists of glucose, ethyl linoleate, a group of mineral salts, a group of amino acids, and a group of vitamins. The diet may be stored in dry powder form and mixed with water just prior to crew consumption.

The chemical diet is unique in that it is almost completely digestible. As a result, fecal elimination is sharply reduced, although this would benefit the waste control subsystem only slightly. The major advantage of this diet would be low weight.

Absolute criteria characteristics are very similar to those of the liquid diet, previously discussed. Thus, the chemical diet also has unsatisfactory performance because of poor crew acceptance for a 500-day duration.

Evaluation and Selection: Designs 1, 2, and 3

Selection of the freeze-dried diet is based on its psychological and nutritional values, safety, availability, and reliability. Ratings are shown on the evaluation summary, table 43.

Absolute criteria. -

Performance: The frozen diet is rated Very Good because it meets all requirements of nutrition, storage capability (assuming an unfailing, low temperature freezer), flavor, variety, and related qualities. The freeze-dried diet does not score as high on crew acceptance and rates Good. The dried diet offers little variety and is therefore Unacceptable. The chemical and liquid diets have poor flavor variety and crew acceptability and are considered Unacceptable.

Safety: Potential spoilage effects of freezer failure give the frozen diet a Fair rating. The dried and freeze-dried diets do not deteriorate in storage and are rated Good. Long-term storage problems with chemical and liquid diets such as browning reactions have been identified, and they are rated Fair.

Availability/confidence: Frozen and dried diets need little modification from forms now available and are rated Very Good. Development of a low-temperature freezer should pose no problem. The freeze-dried diet requires more development work and rates Good. The liquid and chemical diets need considerable development and evaluation, and their availability is judged Fair.

Summary: The dried, chemical, and liquid diets have Unacceptable absolute criteria ratings and are eliminated from further consideration. Frozen and freeze-dried diets score very well.

Primary criteria. -

Reliability: Reliability of the frozen diet is limited by reliability of the freezer, which is judged Fair. The freeze-dried diet has no reliability problems and is rated Very Good.

TABLE 43
EVALUATION SUMMARY - FOOD AND FEEDING

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts				
		Frozen	Freeze-dried	Dried	Liquid	Chemical
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Very Good	Good	Unacceptable	Unacceptable	Unacceptable
	Safety	Fair	Very Good	Very Good	Fair	Fair
	Avail./Conf.	Very Good	Very Good	Very Good	Fair	Fair
				Eliminated	Eliminated	Eliminated
Primary	Reliability	Fair	Very Good			
	Crew Time	Fair	Good			
	Equivalent Weight	Poor	Good			
		Eliminated				
Secondary	Contamination		Very Good			
	Interfaces		Good			
	Flexibility		Good			
	Growth		Good			
	Noise		Good			
	Volume		Good			
	Power		Good			
			Selected			

Crew time: Crew time for the frozen diet not only includes thawing and preparation, but also freezer maintenance. It is rated Fair. Freeze-dried diet preparation is relatively short and is rated Good.

Equivalent weight: AILSS total equivalent weight values (Design 1 or 3) are as follows:

Frozen diet	20 609 lb
Freeze-dried diet	10 748

While the Design 2 weights are different, the difference is negligible. The frozen diet contains considerable stored water, but the resulting credit for reduced load on the water management or oxygen generation systems is only about 1100 pounds at most. For comparison, the liquid diet, which was judged Unacceptable on performance, would weigh 7829 pounds.

Summary: The freeze-dried diet rates well on primary criteria. The frozen diet is unacceptable because of its high weight.

Selection. - Crew acceptance eliminated most of the candidate diets at the absolute criteria level. The frozen diet was eliminated at the primary criteria level because of excessive weight. This leaves only the freeze-dried diet. Fortunately, the freeze-dried diet has very satisfactory secondary criteria ratings, as shown in the evaluation summary table, and it is therefore selected for the AILSS.

Use of a mixed diet was not considered here because of the infinite number of possible combinations. Nevertheless, in actual use the basic freeze-dried diet would probably be modified to include a number of dried and vacuum-packaged items. The expanded variety of an occasional vacuum-packed ham, for example, would increase crew acceptance considerably.

Impact of Mission Parameters

Mission length. - Mission duration may be decreased to a point where the dried and chemical diets are acceptable to the crew. One of these diets would then be selected because of low crew time and weight. However, maximum acceptable mission duration for one of these diets is well under one year. For missions exceeding 500 days, the situation described for the AILSS is unchanged. Thus, the freeze-dried diet would be selected for any long-duration mission.

Crew size. - Because equivalent weight of all diets is very nearly proportional to crew size, changing crew size does not cause a qualitative change in weight relationships. The freeze-dried selection is therefore applicable to any crew size, for the same reasons it was selected for the nine-man crew.

Power penalty. - Power equivalent weight is such a small part of the total equivalent weight of all diets that power penalty has no influence on diet selection. The selected freeze-dried diet also applies to a mission where power availability is limited.

Resupply. - Initial launch weight is very nearly proportional to resupply period length. As resupply frequency is increased, frozen diet weight is reduced the most. However, the qualitative relationship among diet weights is unchanged, and the freeze-dried diet would therefore be selected, regardless of resupply.

Flight date. - The freeze-dried diet selected for the AILSS applies to any similar mission after 1975. For an earlier mission, a less complete freeze-dried diet would be heavily supplemented with dried diet items. Following 1980, new food storage methods will probably be used to supplement the freeze-drying technique. Irradiation could replace vacuum packaging or freezing. Osmotic drying, which removes only unbound water, will undoubtedly be used to preserve food texture while still removing most of the water.

PERSONAL HYGIENE

Personal hygiene is both a functional and a psychological necessity on long-duration missions. That is, it is needed both to prevent mouth and skin disease and to provide a psychological link with earthbound habit patterns and attitudes. Personal hygiene may be divided into the four areas: grooming, dental hygiene, selective body cleaning, and whole body cleaning. The first three areas are discussed briefly in this section, while whole body cleaning receives more detailed consideration in the following section.

Grooming

Grooming consists of removing long finger and toe nails and excess hair plus small amounts of dried skin which may accumulate from time to time. The equipment must be designed to collect this material before it can drift free in the cabin. Hardware concepts of the type discussed briefly in the following paragraphs are under development by several companies.

A sealed box with a transparent top is used for collecting finger and toe clippings. This box has an air stream hose leading to the waste management subsystem and a set of holes with cuffs for inserting the hands or feet. The box is collapsible for storage when not in use.

Hair cutting is accomplished by means of an electrically driven clipper. The clipper has a vacuum collector for preventing loose hairs from entering the cabin atmosphere. A flexible air stream hose removes the hair particles from the collector for delivery to the waste control subsystem.

Shaving is accomplished with an electric razor (each crewman having his own) modified to collect facial hairs in the shaver head during the shaving process. On completion, the shaving debris is released into the waste control subsystem collector, using the enclosed nail clipping box to prevent its escape into the atmosphere.

Dental Hygiene

Dental hygiene is practiced after each meal to maintain the teeth free of cavities, reduce plaque buildup, and prevent gingivitis. It is recommended that the diet include a number of solid foods requiring chewing in order to prevent softening of the gums and loosening of the teeth. However, proper dental stimulation through brushing will assist in maintaining good tooth emplacement.

Dental hygiene equipment includes an electric toothbrush, a liquid dentifrice, a water delivery unit, and a waste collection unit.

The liquid dentifrice is delivered to the toothbrush directly from its storage container. The crewman inserts the toothbrush unit into his mouth and activates the electric motor. When brushing is completed, water is delivered directly to the mouth for rinsing. To collect the expectorate, an adaption tube is inserted in the waste water collection system. This tube has a mouthpiece with an air stream device which sucks up the mixture of water, saliva, dentifrice, and dental debris for delivery to the water recovery system. A liquid dentifrice has been selected to prevent buildup of pastes in the collection tube. An ingestible dentifrice was considered for this application; however, it was not selected because of the anticipated greater crew stress and because of possible medical problems relating to long-term ingestion of the dentifrice.

Selective Body Cleaning

No detailed evaluation was made of concepts for selective body cleaning. While alternatives exist (for example, doing no selected area washing and applying a bacteriostatic liquid or cream; or using ultraviolet sterilization), the practical way to clean small body areas is with reusable wet wipes. None of the other approaches can be expected to fully satisfy performance requirements.

The reusable wet wipes provide good flexibility in selection of the body area to be washed. While other approaches may hold down the bacteria content, they are definitely not as satisfying, despite lower possible weight and power or higher ratings for other evaluation criteria. The wipes are also usable for general purpose cabin cleanup, discussed later under "General Housekeeping".

Impact of Mission Parameters

Mission length, crew size, power penalty, resupply, and flight date changes are not expected to influence selected personal hygiene techniques other than whole body cleaning, which is discussed later.

WHOLE BODY CLEANING

This portion of the AILSS study evalutes conceptual designs for a whole body bath or shower concept. The selected concept is a head-in shower. Although the concept of reusable wipes appears to be very competitive in terms of AILSS tradeoff criteria, the shower is chosen because of extra emphasis on its superior thoroughness in cleaning all body areas and its superior psychological acceptability.

Whole body cleaning must remove body surface contaminants from external sources such as food and dirt as well as natural body products such as sebum, sweat, desquamated epithelium, microbial growth, and fecal matter and other body opening residues. Upon completion, the skin must be left dry with satisfactory bactericidal properties.

The following whole body cleaning concepts are considered here:

1. Shower
2. Reuseable body wipes
3. Disposable body wipes
4. Automatic sponge
5. Immersion bath
6. Sauna

Evaluation of these concepts is made on the basis of a body wash each day, except in the case of the shower where a wash every three days is used because of the shower's greater effectiveness in the removal of body skin residues. The weight penalty for water reclamation is estimated at 7.7 lb/lb of water reclaimed per day. This is an average penalty for all three designs. The actual penalty ranges from 7.2 to 8.1 lb/lb water recovered per day.

Shower

A head-in air stream concept is selected for the zero gravity shower evaluation. Not only is it psychologically more satisfying, but it is the best method of cleaning the scalp, obviating the need for a separate operation. An alternative approach is the head-out concept. The principal thought behind a head-out concept is avoiding suffocation or drowning. However, neck dams are required which are in themselves potential safety hazards, and additional complexity is necessary for face and hair cleaning, which cannot be accomplished using this concept. With the proposed head-in concept, air flow is continuously circulated over the crewman and water is directed from a hand-held shower head. The air flow eliminates drowning or suffocation problems by keeping the water away from the nose and mouth area.

Figure 90 shows the zero gravity shower concept, a cylindrical stall about 30 inches in diameter and 80 inches long. The crewman enters nude and uses stirrups and restraint straps to retain orientation in the air-water stream while keeping his hands free for washing. Warm water from a hand-held shower head is sprayed onto the body and is carried away from the head by a 1000 cfm air stream. This recirculating air stream is heated as it passes through the fan and its temperature is controlled, after warm-up, by a timer actuated valve that bleeds cabin air. The water is removed from the air stream by a separator. Detergent is released by a trigger on the shower head, and a washcloth provided for local scrubbing serves as a body wash backup if the shower fails. A separate water collector-blower circuit removes local water accumulation and aids drying. When the water is turned off, the warm air stream is used for drying, which is completed with a towel. Water use for the shower is based on a 0.5 gallon per minute flow, with four minutes of water used for each shower.

Absolute criteria. -

Performance: Cleaning, bactericidal action, and rinsing are potentially thorough for all body areas. For most Americans, the shower is the ultimate in psychological acceptability and is often a normal part of their daily routine. It provides simultaneous relaxation and stimulation, an almost instantaneous sense of cleanliness, and a feeling of well-being.

Safety: A primary safety consideration is bacterial contamination. Due to the complex equipment, the possibilities of bacterial contamination in the shower system are somewhat higher than with the sponge bath method. However, the hazard is reduced by use of bactericide in the water, a clean water rinse, and periodic shower cleaning.

Availability/confidence: The shower concept presented here is within the current

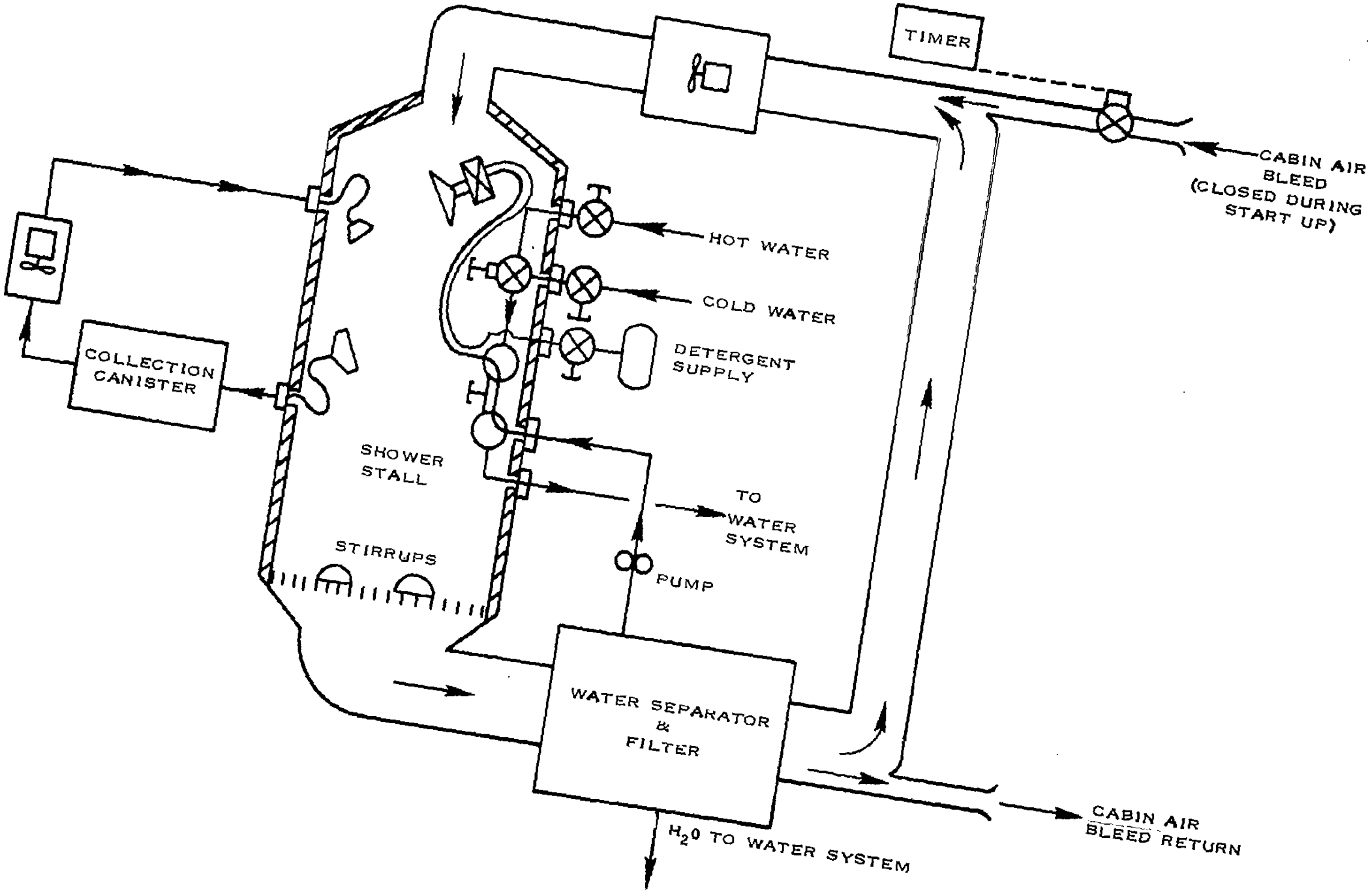


Figure 90. Shower.

state of the art and requires only limited integration development. It could be available for a flight as early as 1975.

Primary critiera. -

Reliability: MTBF for this concept is estimated to be 386 000 hours. The overall subsystem reliability is calculated to be 0.9999876 using the following spares: 1 fan (each type), 1 water separator, 1 temperature control valve, 1 pump, 1 timer, 1 valve actuator, and 1 water shutoff valve.

Crew time: The time required for a shower using the air stream shower concept is estimated at 8 minutes for all operations with 4 minutes of actual shower time. Routine maintenance is limited to periodic cleaning of the inside of the compartment and monthly replacement of the two filters. This is estimated to require 36 man-hours per mission. Corrective maintenance is limited to nonscheduled replacement or repair of the unit water pump, air-water separator, fan, and temperature controls. The total corrective maintenance is estimated to be three man-hours per mission.

Equivalent weight: The weight values for the shower are as follows:

Shower weight	195 lb
Spares weight	52
Weight penalty --- water reclamation (50 lb H_2O/day)	385
Weight penalty --- power	76
Total equivalent weight	708 lb

The power penalty is based on a battery storage system designed to deliver 700 watts for 0.5 hours per day (350 watt-hours), assuming a battery weight of 0.05 lb per watt-hour, a 30 percent discharge ratio, and a 50 percent electrical charging efficiency.

Secondary criteria. - Both air and water processing systems are designed to handle any resulting microbial contaminants. The shower has direct interfaces with the water management system but also puts thermal and humidity loads on the atmosphere control system. The shower is flexible because it provides backup washing machine or dryer capability if this equipment fails. Growth characteristics are good, because the shower can be designed for any crew use schedule including consecutive use by several crew members if desired. With its large air flow and water spray, this concept has a high noise level during use, which is approximately eight minutes. Volume is high, with 42 ft^3 (collapsible to 18 ft^3) for the shower chamber, 5 ft^3 for the air system and 1 ft^3 for the water system, for a total of 48 ft^3. Instantaneous power is 700 watts, and a battery is required to reduce this to the more satisfactory level of 29.2 watts continuous. The 76 pound power penalty includes battery weight.

Reusable Body Wipes

The reusable body wipes are 10-inch squares of woven fabric stored dry and moistened as required with water and bactericide. When a wipe becomes soiled, it is rinsed in a unit which removes the water from the wipe by utilizing a mechanical squeezer and an air stream flow. A fresh supply of water is introduced to moisten the cloth. The excess free water is then removed by the air stream, after which the wipes are removed for further use. Periodically, the wipes are washed in the clothes washer/dryer unit. An air-water separator is used to remove the water from the air-water flow. A towel is used to dry the skin. Figure 91 is a block diagram of this system.

Absolute criteria. -

Performance: Cleaning and bactericidal action are potentially through, but this requires considerable attention by the crewman. A crewcut is mandatory for adequate scalp cleansing. This concept bathes one portion of the body at a time, so it is not entirely satisfactory as a whole body bath. Psychologically, the wipes provide a sense of refreshment, but there is no relaxation and washing becomes a chore. A 30-day test at Hamilton Standard conducted with commercial disposable wipes showed that once the shower habit was broken, wipes were acceptable.

Safety: Safety of the reusable wipes is very high. The only safety consideration is the possibility of microbial buildup on the wipes or in the moistening unit. This will be taken care of by use of a bactericide in the water and by using the pickup streams for drying.

Availability/confidence: The techniques and equipment for reusable body wipe bathing are currently available and will require little development.

Primary criteria. -

Reliability: The MTBF for this concept is estimated to be 636 000 hours. The overall subsystem reliability is calculated to be 0.999803 when supported with the following spares: 1 detergent tank, 1 check valve, 1 water separator, 1 pump, and 1 fan.

Crew time: The time required for whole body cleaning (including hair) is estimated at 15 minutes/man for all operations involved. No routine maintenance is required other than cleaning the washing machine, which takes three hours for the mission.

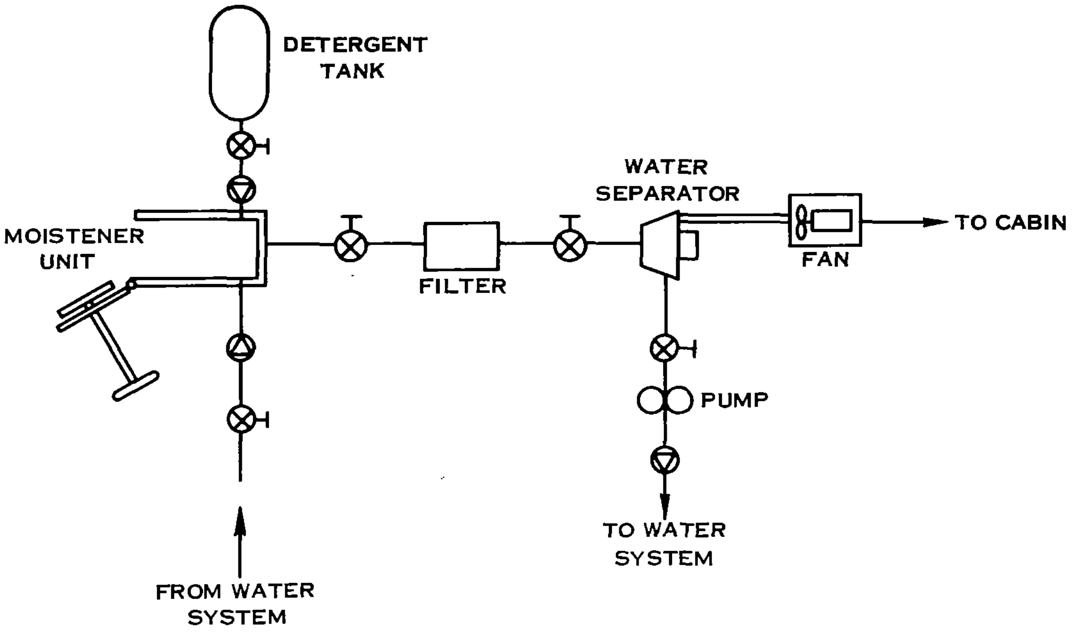


Figure 91. Reusable Body Wipe Moistener Unit

Equivalent weight: Total estimated equivalent weight for the system is 234 pounds. This is made up as follows:

Basic weight of wipes (50)	2 lb
Water management system (20 lb H_2O/day)	154
Moistening unit, fan, separator	20
Power penalty (130 watts)	58
Total equivalent weight	234 lb

Secondary criteria. - Use of reusable wipes for body bathing has no effect on contamination level of the cabin atmosphere. Using a biocidal agent in the body wash and drying the wipes after use keeps the bacterial contamination levels low in the wipes themselves. Contaminants must be delivered to the water management subsystem at a point where they are anticipated and can be processed out. This interface with the water management subsystem is the primary interface. Water requirements are 20 lb of water per day at 105° F. Since the reusable wipes provide a backup for cabin cleaning and for local body area washing (such as face and hands) their flexibility is considered good. The growth of this approach is limited only by the capability of the water management subsystem and scheduling of the use of the moistening unit. The noise level of the water pickup fan is about 30 db, which is considered very good. The reusable wipes also have very low volume requirements: 0.8 cubic foot for a supply of 50 wipes, 0.1 cubic foot for the squeezer-moistener unit, and 1.0 cubic foot for the air-water separator, for a total of 1.9 cubic feet. The peak power requirement for this method of whole body washing is 130 watts of power used in the water pickup fan. Peak water volume is 0.6 gallons per minute delivered at 105° F.

Disposable Body Wipes

Disposable wipes can be either premoistened or moistened during use. Either way, they are wet when discarded, and a corresponding water storage penalty must be charged. Disposable wipes are psychologically similar to reusable wipes, and absolute and primary criteria evaluations are also the same, except for weight. Total equivalent weight is 2250 pounds for the mission. This applies to disposable wipes, whether they are premoistened or not, because it includes the water "stored" in premoistened wipes or a water storage penalty to compensate for water lost when individually moistened dry wipes are discarded.

Common commercial wipes are out of the question, because of accumulation of alcohol in the atmosphere and excessive loading of the atmospheric contaminant control system. For any type of disposable wipes, disposal itself would be a serious problem. If used wipes were stored, they would present a bacterial hazard and would occupy more than their original volume. If destroyed, they would place a considerable load on the waste management system. Dumping to space would probably have to be considered. Storage was assumed for this evaluation.

Automatic Sponge

The automatic sponge (figure 92) has water delivery and pickup lines leading to a hand-held head with a sponge at the water delivery point. A housing connected to a low pressure source surrounds the sponge and acts as a pickup for the water as it is deposited on the skin by the sponge. The hand-held unit is moved over the body for cleaning local areas. Addition of detergent to the water is controlled by the crewman, who also controls the temperature of the water. At the pickup end, an air-water separator is used to remove the used water for delivery to the water management system. The sponge head is removable and can be cleaned in the clothes washer. Sufficient sponge heads are provided to allow a clean sponge for each body wash. If the water supply or pickup units fail, an alternate mode of operation for the automatic sponge is to use only the sponges wetted in the clothes washer.

Absolute criteria. -

Performance: Cleaning and bactericidal action of the automatic sponge are entirely adequate. However, the body is bathed one part at a time, so that this concept is not entirely satisfactory as a whole body bath. Psychologically, the sponge provides an ease of application that allows a degree of relaxation and enjoyment. However, it does not approach the ultimate in this respect, because only part of the body is exposed to the cleaning process at any one time.

Safety: A bactericide in the water, periodic washing of the sponges, and rinsing of the feed and pickup lines keep microbial accumulation and buildup in the sponge head and lines at a safe level.

Availability/confidence: a device highly similar to this concept has been developed, but additional human engineering is needed.

Primary criteria. -

Reliability: MTBF for this concept is estimated to be 640 000 hours. Overall reliability for this concept is calculated to be 0.999910 using the following spares: 1 fan, 1 water separator, 1 pump, 1 check valve, and 1 detergent tank.

Crew time: Crew time is low. The whole body cleaning requires 15 minutes per man. There is no maintenance other than routine rinsing and cleaning.

Equivalent weight: The total equivalent weight for the automatic sponge is 261 lb, made up as follows:

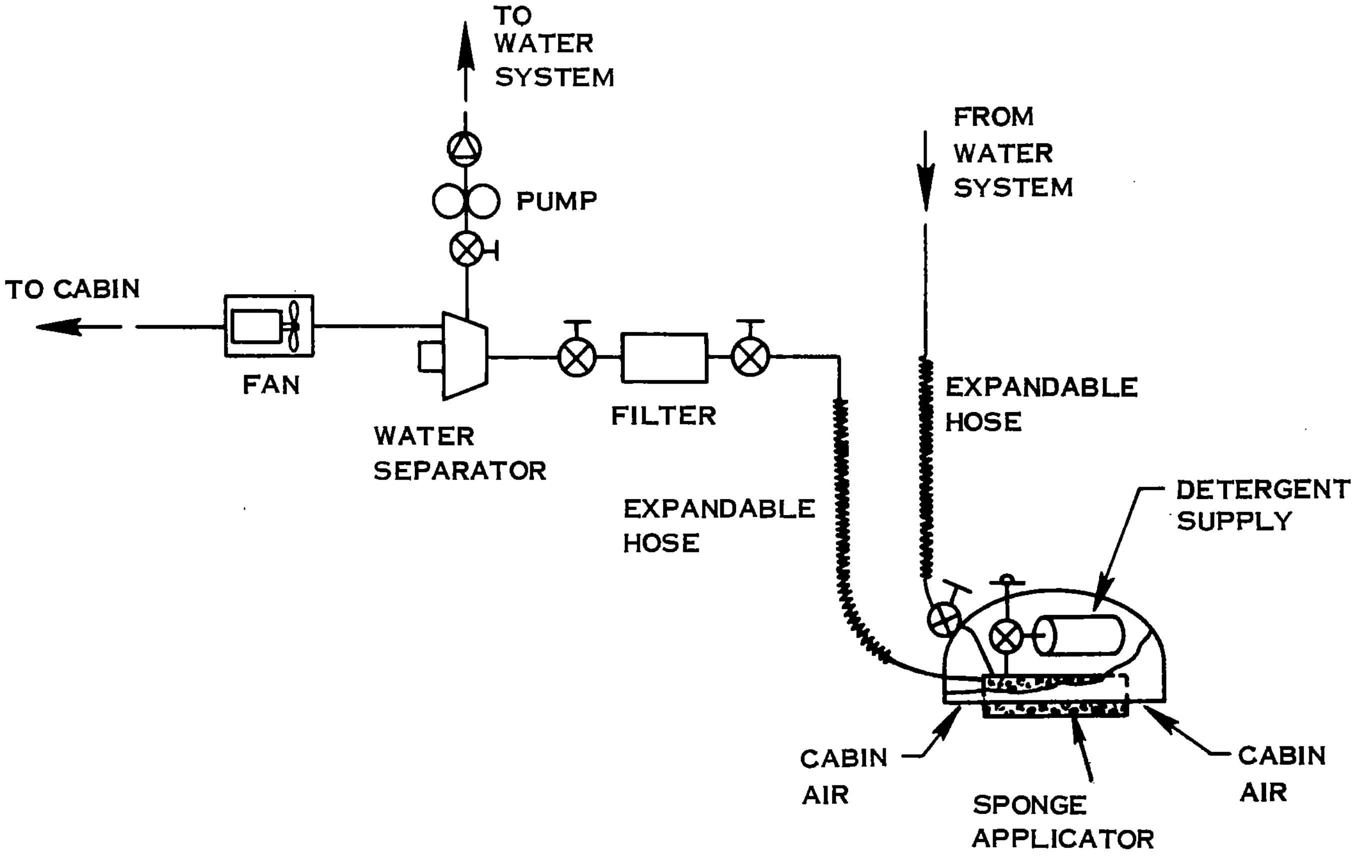


Figure 92. Automatic Sponge

Water management subsystem (at 20 lb H_2O/day)	154 lb
Sponge head, hose, separator	30
Power penalty (at 130 watts)	75
Weight of spare sponges	2
Total equivalent weight	261 lb

Secondary criteria. - The primary interface is with the water management subsystem. An interface also exists with the atmospheric control subsystem in the use of an air stream to collect the water. This poses no demand on the cabin air conditioning equipment, however, except for a slight increase in cabin moisture. The automatic sponge provides a means of cabin cleaning and a means of washing smaller body areas such as the face and hands and is therefore quite flexible. The growth capacity of this concept is limited only by the water system and the scheduling of use. Noise is low, the principal source being the air pickup at the water separator. Automatic sponge volume consists of 0.25 ft^3 for shower head and lines, 1.0 ft^3 for water separator and pumps, and 0.5 ft^3 for 10 spare shower sponge heads, for a total of 1.75 ft^3. The automatic sponge requires a peak power input of 130 watts.

Immersion Bath

The immersion bath concept consists of a plastic suit having pads of sponge material on the inner surface. After the crewman dons the suit, water is introduced through lines from the water management subsystem. Sufficient water is provided (approximately 3 liters) to moisten the sponge areas of the suit. Washing action is obtained by rubbing the sponge areas over the body. Upon completion of bathing, the water is worked down and pumped out of the suit. One suit is to be used by all crewmen, and it requires washing in the laundry unit.

Absolute criteria. - Cleaning action is inadequate without considerable effort. In addition, adequate rinsing of waste products from sponges is impractical. Moreover, although the entire skin surface is wetted simultaneously, the head is omitted, making the concept somewhat unsatisfactory as a whole body wash. The immersion bath has mixed psychological acceptability. It permits a relaxing soak period, but washing and water disposal take considerable effort.

These problems combine to produce unacceptable performance, and no further consideration is given to the immersion bath concept.

Sauna

The sauna is an enclosure in which the crewman remains while steam or hot dry air is introduced.

This concept is psychologically very acceptable. Its action is passive, allowing complete relaxation. Yet, its aftereffect is a feeling of exhileration and well-being if sufficient cooling is provided.

Nevertheless, the sauna is inherently unacceptable as a zero gravity cleaning device because dirt and sweat residue would remain on the skin surface. Thus, the sauna "bath" itself would have to be followed by one of the body cleaning techniques previously described. Such a combination would have attractive features, but cooldown and crew time would be problems.

Evaluation and Selection: Designs 1, 2, and 3

The shower concept is selected for its superior crew acceptability. Ratings of all concepts are shown on table 44, and data on the candidate concepts are shown on table 45.

Absolute criteria. -

Performance: The shower has superior performance in terms of crew acceptability and cleaning thoroughness; it is rated Very Good. Reusable wipes, disposable wipes, and automatic sponge are more localized in application and do not have the same flushing action as the shower, and they are less acceptable to the crew; they are rated Fair. Cleaning action of the immersion bath and the sauna are inadequate, and their performance is therefore rated Unacceptable.

Safety: If the shower is not adequately cleaned, it is a likely bacteria growth site; assuming adequate housekeeping, however, it is rated Good. Reusable wipes, disposable wipes, and automatic sponge have no special safety problems and rate Very Good. The immersion bath provides a potential bacterial growth site and is rated Fair, while the sauna entails some danger of heat exhaustion and also rates Fair.

Availability/confidence: The shower is a proven concept, but it needs further development and is rated Good. Development of reusable and disposable wipes and of the automatic sponge concept is well advanced, meriting a Very Good rating. The immersion bath requires considerable development and rates Fair, while the sauna could be easily adapted to aerospace use and rates Good.

TABLE 44
EVALUATION SUMMARY - WHOLE BODY CLEANING

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		CANDIDATE CONCEPTS					
		Shower	Reusable wipes	Disposable wipes	Automatic sponge	Immersion bath	Sauna
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Very good	Fair	Fair	Fair	Unacceptable	Unacceptable
	Safety	Good	Very good	Very good	Very good	Fair	Fair
	Avail./Conf.	Good	Very good	Very good	Very good	Good	Good
						ELIMINATED	ELIMINATED
Primary	Reliability	Very good	Very good	Very good	Very good		
	Crew Time	Very good	Good	Good	Good		
	Equivalent Weight	Fair	Very good	Poor	Very good		
				ELIMINATED			
Secondary	Contamination	Good	Good		Good		
	Interfaces	Fair	Good		Good		
	Flexibility	Good	Very good		Good		
	Growth	Good	Good		Good		
	Noise	Fair	Very good		Good		
	Volume	Fair	Very good		Very good		
	Power	Fair	Good		Good		
		SELECTED*	ELIMINATED		ELIMINATED		

*Performance given extra emphasis - see text.

TABLE 45
DATA SUMMARY - WHOLE BODY CLEANING

Concept	MTBF Hours	Crew Time			Total Equivalent Weight Pounds	Electrical Power Watts
		Operation Minutes/use	Period Days/use	Maintenance Hours/mission		
Shower	386 000	8	3	39	708	29*
Reusable Wipes	636 000	15	1	3	234	130
Disposable Wipes	No anticipated failures	15	1	0	2250	130
Automatic Sponge	640 000	15	1	0	261	0

*With energy storage battery; without battery peak power is 700 watts

Summary: Most of the concepts have acceptable and superficially equivalent ratings. However, giving added importance to performance makes the shower concept superior. Performance of the immersion bath and sauna is inadequate, and these concepts are not considered further.

Primary criteria. -

Reliability: All MTBF values far exceed mission duration, and all concepts are therefore rated Very Good.

Crew time: The shower concept requires relatively little use time and is rated Very Good. Other concepts need over five times as much total time for normal use and are still not as satisfying. However, these concepts do require considerably less routine maintenance than the shower and are rated Good.

Equivalent weight: Reusable wipes and automatic sponge are rated Very Good, the shower is considerably heavier and rates Fair, and disposable wipes are very heavy and rate Poor.

Summary: Reusable wipes and automatic sponge have the best primary ratings. Ratings of the shower are equally acceptable except for weight, which is high. The weight penalty for disposable wipes, based on no water recovery, is unacceptable, and this concept is not considered further.

Secondary criteria. - All concepts return contaminated water to the water management system, but that system is designed to control the contamination, and all concepts are therefore rated Good. In addition to this water management interface, the shower has considerable effect on the temperature and humidity control system and is rated Fair, while the reusable wipes and automatic sponge concepts are rated Good. All concepts are flexible in that they can be used to clean utensils and/or clothes and/or cabin walls, but the reusable wipes concept combines great mobility and is rated Very Good, while the other concepts are rated Good. No concept has outstanding growth potential and all are rated Good, although phychological acceptability of the shower becomes still more important for longer missions. A high air and entrained water flow rate makes the shower quite noisy during use, but this use is brief and not too frequent (eight minutes, three times each day) and so the shower is rated Fair. The automatic sponge is used more often but is quieter and is rated Good. Reusable wipes are virtually noiseless and rate Very Good. The shower rates Fair on volume, while the other concepts take far less space and rate Very Good. All concepts require intermittent power, but the shower needs a much higher level or an energy storage device and rates Fair, while the other concepts are rated Good.

Selection. - The reusable wipes concept has the best overall ratings, but for a long duration mission a shower is far more acceptable to the crew. The automatic sponge concept represents a compromise, with overall ratings very nearly equal to those of reusable wipes. However, crew acceptability in this area should not be compromised, and the shower concept is therefore selected.

Impact of Mission Parameters

Mission length. - Mission duration has a significant effect on the disposable wipes concept only, because its weight consists almost entirely of expendables. For missions of more than 500 days, its weight continues to be excessive. As mission length is decreased, weight of the disposable wipes concept remains excessive until about 150 days duration. For shorter missions, its weight is acceptable but still higher than that of reusable wipes, except for very short missions. All other concepts maintain the same relative positions, regardless of mission duration. Thus, the shower remains the selected concept for shorter or longer mission durations except for missions of less than 150 days, where wet wipes are a likely choice.

Crew size. - Crew size has some influence on concept selection. However, for larger crews the shower requires more energy per day and the equivalent weight advantage of a battery decreases until acceptability of its total equivalent weight becomes questionable. However, its psychological advantages make the shower a likely choice for any size crew.

Power penalty. - Decreasing the power penalty reduces the shower's incremental weight penalty, making it a somewhat more attractive selection. Increasing the power penalty makes the shower concept less attractive, until at double the AILSS power penalty, its weight may be considered excessive and the automatic sponge may be a more desirable choice, unless an energy storage battery is used. Prewetted disposable wipes, although extremely heavy, require no power and would therefore be the choice for a mission where power availability was sufficiently critical.

Resupply. - Weight of the disposable wipes concept approaches zero as resupply frequency is increased. However, its weight becomes lowest only with a resupply period of less than 60 days, and its weight advantage at 30 days is less than 150 pounds. Consequently, selection of disposable wipes instead of the shower concept is unlikely, except for resupply periods of less than 60 days.

Flight date. - The selected shower concept is available for any flight after 1975. For earlier flights, the automatic sponge concept is a better choice than reusable wipes, because of better crew acceptance.

CLOTHING

The clothing provided for the nine crewmen must be comfortable, provide the proper thermal insulation, and be compatible with the AILSS atmosphere.

This study includes an investigation of both launderable and disposable clothing, and a trade-off between these two concepts.

This study is based on a trade study done by the Clothing and Organic Materials Division of the United States Army Natick Laboratories for the NASA Langley 90-day ILSS mission. This data was updated based on the AILSS mission requirements and penalties. Additional information to update the Natick study has been obtained from NASA's Manned Spacecraft Center and the United States Air Force Materials Laboratory, Wright-Patterson Air Force Base.

The clothing style selected for use in this study is based on that used in the Natick Laboratory studies (see figure 93). Various styles and colors could be used to break the monotony and identify crewmen, and these changes would have little effect on the trade-off conclusions.

This clothing trade study is based on the following assumptions:

1. A minimum of three sets of clothes is provided, two sets to be worn and one set as a spare.

2. Clothes will be worn a minimum of one day for undergarments and nine days for outer garments. This relatively long outer garment wear period is based on the "clean room" environment in the AILSS vehicle.

3. The clothing will consist of two pieces of underwear, a short-sleeve undershirt and undershorts; two pieces of outer wear, long-sleeve shirt and pants; and two socks with cushion soles for each crewman.

4. A set of clothing is defined as the complete clothing requirement for one man as worn during one 24-hour period, consisting of two outergarments, two undergarments, and two socks. The same undergarments are used for sleeping and daily use. The combinations of underwear, socks, and outergarments should have a clo (0.88°F-ft^2-hr/Btu) value of between 1.0 and 1.5; a moisture permeability index (I_m) of between 0.5 and 0.6; and the ratio of I_m to Clo should be at least 0.4. The material must have a high enough vapor permeability to allow a crewman to work at a metabolic rate of 1200 Btu/hr without heat storage. For short-term work rates above 1200/hr, the outer garment should be removable and the undergarment should allow a crewman to work at a metabolic rate of

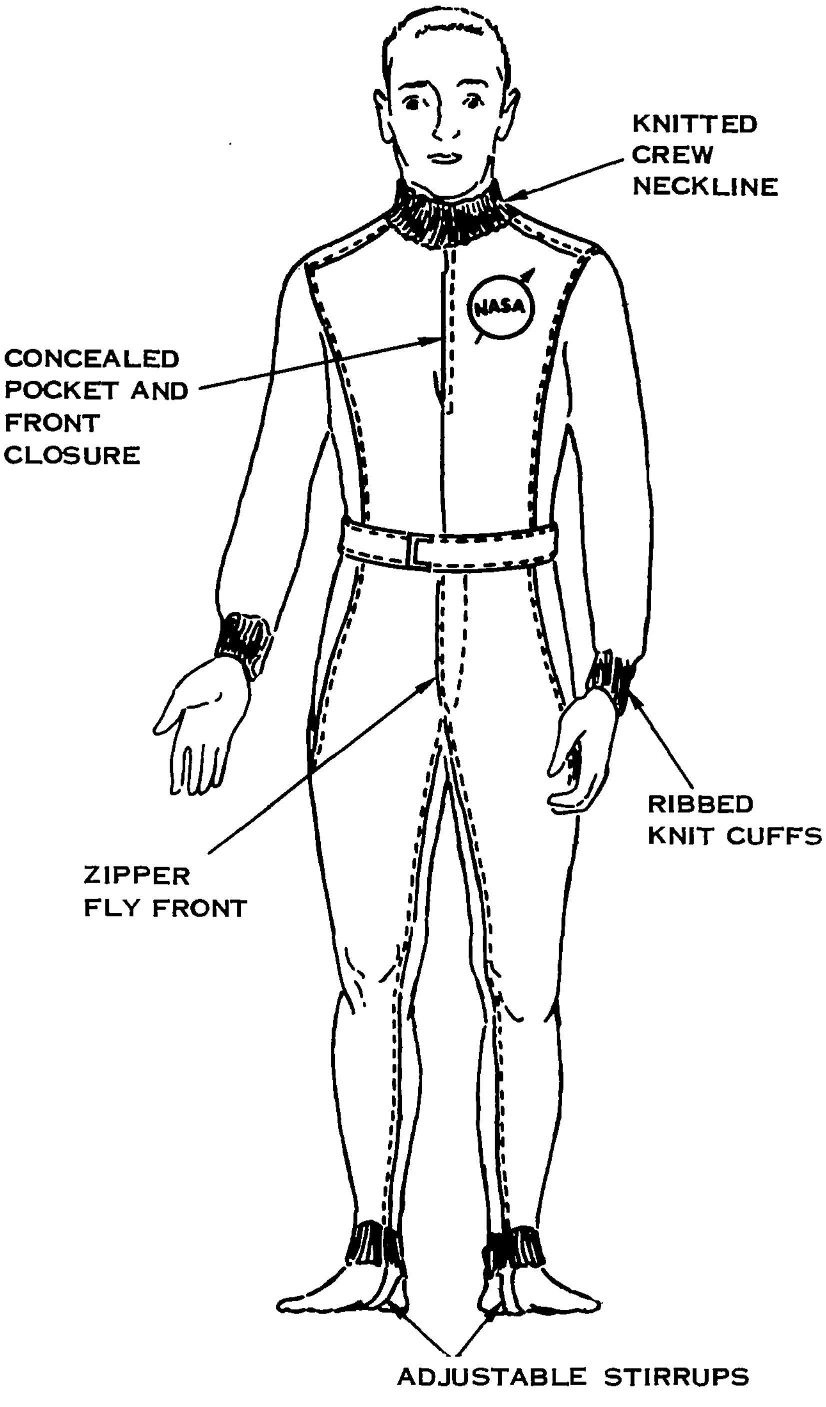


Figure 93. Natick Concept Constant Wear Garment

2500 Btu for periods of up to one hour without requiring the crewman to store more than 600 Btu. Furthermore, the garments should be capable of being worn under a pressurized space suit.

The material should be designed to be fire and high-temperature resistant. For emergencies or equipment failure outside of the crew compartment, fireproof and chemical-resistant clothing should be provided. The actual definition of these garments is outside the scope of this report: however, the following trade-off was performed between disposable and reusable clothing for everyday wear within the cabin.

Disposable Clothing

Disposable clothing is designed to be worn for a limited time period and then discarded in the waste management system or repackaged and stored until the end of the mission. Either method of disposal would be a problem, because of the added load on the waste management system or because of the difficulty of repacking the clothes in their original storage volume. For this trade study, disposable clothing is assumed to consist of a nonwoven fabric of approximately three ounces per square yard constructed to conform to the style requirements of the AILSS. The weight includes an allowance for fireproofing and bactericide. Disposable clothing can also be made of woven, knit, or foam material,which would require appropriate adjustments in clothing weights.

Crew acceptability is somewhat limited by the necessity for an extremely light weight, low volume material. This may require some sacrifice in qualities such as texture. This disadvantage is partly compensated by the potential variety of styles, colors, and patterns that would break monotony and provide crew member identification.

Disposable clothing is to be worn in accordance with the schedule noted earlier. The clothing is packaged before use and stored in the same package after use.

Absolute criteria. -

Performance: Disposable clothing can be easily developed to meet AILSS comfort requirements.

Safety: With adequate development work the disposable clothing will be safe. A fireproofing compound can be added to the bonding resin or coated on the surface of the fibers. No data is available on the outgassing of toxic gases and odors from disposable clothing. Thus, the advisability of storage is somewhat doubtful.

Availability/confidence: Disposable clothing made from materials meeting the fire and safety requirements is within the state-of-the-art, but development work is required in the selection and treatment of these materials.

Primary criteria. -

Reliability: The reliability of disposable clothing is considered very good. No cleaning equipment is required, and the clothes would always be available in a clean useable form. A mending and patching kit should be carried along to make clothing repairs.

Crew time: The crew time associated with disposable clothing is relatively low. Crew time for nine men is estimated at 0.25 man-hours per day for disposal of the clothing. No routine maintenance is required. Corrective maintenance in the form of repairing rips and tears is approximately 15 man-hours for the mission.

Equivalent weight: Disposable clothing has high equivalent weight. Using the same changing schedule as recommended for reuseable clothing, (that is, change underwear every day and outer garments every 9 days), requires 500 sets of underwear and socks and 55 sets of outer garments. This amounts to 100 pounds of underwear and socks and 55 pounds of outer garments per man, for a nine-man total of 1395 pounds of clothing. Packaging and storage facilities add an estimated 425 pounds for a total weight of 1820 pounds.

Secondary criteria. - Contamination is uncertain. The shedding rates of the clothing fiber into the cabin atmosphere are unknown. There is no interface with another system except for the possible shedding of fiber or bacteria into the cabin. Flexibility is good. The clothing can be interchanged or worn for longer periods than planned, if required. Growth is limited because disposable clothing weight is proportional to mission duration. There is no noise with disposable clothing because cleaning facilities are not required. Volume is estimated to be 345 cubic feet. There is no power requirement associated with disposable clothing.

Reuseable Clothing

The wear schedule for reuseable clothing is the same as for disposable clothing; that is, outer garments are worn for nine days, underwear and socks are changed daily.

The most serious problem associated with reuseable clothing is washing. An automatic combination washer/dryer is sized to handle the total washing requirements in three loads. The clothes basket in the unit rotates continuously while a water jet is directed against the clothes to provide a washing and tumbling action. The daily clothes wash is done in loads of approximately 2.3 lb each. The wash-water has a 0.1 percent concentration of detergent and is spray-circulated over the clothes to produce the washing action. The clothes are then spun at a high rpm to extract the detergent solution. Rinsewater, containing a bactericide, is then sprayed on the clothes to bring the detergent solution down to a low concentration of bacteria. Upon completion of the rinse, the clothes are spin-dried and finally air-dried.

There has been almost no development of new cleaning techniques for use in space vehicles. The use of ultrasonic cleaning which is common in aerospace clean rooms should be investigated. Also, the use of ultraviolet radiation or other high energy radiation for bacterial control could be used. The destruction of bacteria and removal of moisture could prolong the time between washings, or cleanings, to weeks instead of days. This possibility should be investigated for possible application in the AILSS.

Reuseable clothing made of Nomex (an especially suitable nylon) is used for the study evaluation; however, the use of a different material such as PBI (polybenzimidazole, a high temperature and burn resistant material) would not affect the results. Beta cloth, which is fireproof and has been used extensively for the external layer of space suits, is rated higher in safety than Nomex; but as a result of the hazard of the Beta glass particles in the air and on the skin, its use for this application is not acceptable for the AILSS.

Absolute criteria. -

Performance: The clothing is worn according to the clothing schedule noted under the assumptions. When clothes become soiled, they are cleaned and dried in the washer/dryer. Clean clothes are stored with personal effects until reused. In the event of washer/dryer failure, the clothes can be washed in the body shower with considerably more crew time and crew stress. Reuseable clothing should be highly acceptable to the crew. It can be made extremely comfortable without much effect on total weight. The only potential problems are long term monotony and changes in properties such as elasticity.

Safety: In flame tests at atmospheric pressure, Nomex material is self-extinguishing. It is expected that the addition of a flame-retardant material would allow Nomex to pass the NASA category C fire criteria under AILSS environmental conditions.

Availability/confidence: Availability of reuseable clothing is good. Although clothing made of Nomex does not meet the fire criteria, other fibers that do are being developed and will be available for the flight period. Specifically, PBI is a material with characteristics that appear to be suitable for the AILSS environment and for the clothing under consideration.

The washer/dryer is not currently available; however, development of a zero-gravity machine suitable for the AILSS is feasible.

Primary criteria. -

Reliability: Reliability of reuseable clothing is limited by use of a washer/dryer.

Launderable clothing made of Nomex has been successfully tested under wear conditions that include a considerable margin of safety in the AILSS cycle. Adhesive patches and a sewing kit can be used to repair rips and tears.

Crew time: Operating time per day for washing crew clothing according to the washing schedule is 0.5 man-hours. Maintenance times for the mission are estimated to be:

Scheduled maintenance (cleaning and decontamination)	72 man-hours
Unscheduled maintenance	2 man-hours

Equivalent weight: The equivalent weight for reuseable clothing is relatively low. Clothing weight is as follows:

Clothing (Garments/man)	Weight for 9-man crew (lb)
Two-piece suit (3 at 1 lb/each)	27.0
Undershirt (3 at 0.21 lb/each)	5.7
Undershorts (3 at 0.21 lb/each)	5.7
Socks (6 at 0.085 lb/each)	4.6
Total equivalent weight (clothing)	43.0

Clothing weight is a small part of total equivalent weight, which is summarized in the following table:

Clothing	43
Washer/dryer	90
Water penalty	209
Power penalty (320 watts)	186
Pump and Fans	20
Total equivalent weight	548

Secondary criteria. - Reusable clothing has little contamination potential. Washing the clothes in water with a bactericide lowers bacterial levels and reduces free lint which might escape into the cabin atmosphere. The primary interfaces of the clothing system are with the water management and the atmospheric control subsystems. Interface parameters with water management are the water delivery requirements and the disposal of used washwater with cleaning agent. Depending on the concept selected, the cleaning agent is extremely important. This item is discussed later in this section in more detail. For clothes drying, ambient air is required. The air is returned to the atmospheric contamination control system at a temperature of 100°F and a dewpoint of 65°F.

Flexibility is high: The interchangeability of clothing among crew members is easier with knit material which has some stretch. The limiting factor is the similarity in sizes among the crew members. In the event of washer/dryer or water system failure the clothes can be worn for a longer time at some increase in crew stress.

Growth potential is very good with weight nearly independent of mission duration. The limiting factor in growth is the capacity of the washer/dryer unit. Since this unit is idle a large portion of the time, its capacity can be increased by using more water and power. The chief noise source is the washer/dryer. With adequate sound deadening, it should be possible to keep this noise to a low level (45 dB). Specific volumes for the reuseable clothing system are 5.2 ft^3 for the clothes, 8.0 ft^3 for the washer/dryer, and 2.0 ft^3 for pumps, fans, and ducts, for a total of 15.2 ft^3. Washer/dryer power is 320 watts during operation.

Evaluation and Selection: Designs 1, 2, and 3

Selection of reuseable clothing is based on the ratings shown on the evaluation summary, table 46.

Absolute criteria. -

Performance: Both disposable and reuseable concepts are adequate, despite minor drawbacks, and are rated Good.

Safety: Both concepts are quite safe and are rated Good.

Availability/confidence: Disposable fabrics are currently available and rate Very Good, although further weight reduction is highly desirable and disposal may be a problem. Reuseable fabrics available today may be adequate, but dependence on washer/dryer development limits the rating to Good.

Primary criteria. -

Reliability: Disposable clothes are highly reliable, with routine replacement whether or not fabric is damaged, and they are rated Very Good. Reuseable clothing is dependent on washer/dryer reliability and rates Fair.

Crew time: Despite automatic operation of the washer/dryer, disposable clothes require considerably less crew time than reuseable clothes, and the ratings are Good and Fair, respectively.

Equivalent weight: Disposable clothes are very heavy (1820 pounds) and are rated

TABLE 46
EVALUATION SUMMARY - CLOTHING

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts					
		Disposable clothing			Reuseable clothing		
CRITERIA	DESIGN	1	2	3	1	2	3
Absolute	Performance	Good			Good		
	Safety	Good			Good		
	Avail./Conf.	Very good			Good		
Primary	Reliability	Very good			Fair		
	Crew Time	Good			Fair		
	Equivalent Weight	Poor			Very good		
		Eliminated					
Secondary	Contamination				Good		
	Interfaces				Fair		
	Flexibility				Very good		
	Growth				Very good		
	Noise				Fair		
	Volume				Good		
	Power				Fair		
					Selected		

Poor. Reuseable clothes weigh far less (548 pounds) and are rated Very Good, including a washer/dryer penalty. Note, however, that equivalent weight is largely dependent on the wear cycle. The longer the garments are worn before changing, the smaller the difference in equivalent weight between disposable and reuseable clothing. The point where both concepts are approximately equal in weight occurs at a wear period of one week for undergarments and three weeks for outer garments. This wear period is believed to be psychologically unacceptable to the crew. Equivalent weights are identical for Designs 1, 2, and 3.

Selection. - The Poor equivalent weight rating of disposable clothing eliminates that concept from further consideration. Secondary criteria ratings of reuseable clothing are satisfactory, and that concept is therefore selected for the AILSS.

Impact of Mission Parameters

Mission length. - Weight of disposable clothing increases linearly with increasing mission duration, while weight of reuseable clothing is nearly constant. Thus, for missions of 200 days or less, disposable clothing is the proper selection. For longer missions, the weight of disposable clothing is excessive and reuseable clothing should be selected.

Crew size. - Weight of disposable clothing is proportional to crew size. For reuseable clothing, clothing weight and water penalty are approximately proportional to crew size, but washer/dryer equipment weight and power penalty are nearly constant. The resulting equivalent weight breakeven point occurs between two and three men, so that disposable clothing would be selected for one or two man crews, and reuseable clothing would be selected for larger crews.

Power penalty. - Changing power penalty affects the weight of the reuseable clothing concept because of washer-dryer power and water processing power. However, this effect is not sufficient to disqualify the selected reuseable clothing concept for any reasonable power penalty. Disposable clothing requires no power and would be selected for a mission where power is sufficiently critical.

Resupply. - Initial launch weight for disposable clothing is inversely proportional to resupply frequency, while launch weight of reuseable clothing is little affected by resupply. Thus, for a resupply period of 150 days, initial launch weights of the two concepts are equal. Therefore, disposable clothing may be desirable for resupply periods up to 150 days.

Flight date. - Availability of reuseable clothing is limited by development of the washer/dryer, which is expected to be available for a 1977 flight at the earliest. Disposable clothing must be used for earlier missions, despite high weight and the disposal problem.

OTHER CONSIDERATIONS

The crew provisions system must provide a number of items for crew comfort and health not covered under the major headings of this report. One such consideration is the requirement for miscellaneous supplies. These include toilet paper, facial tissues, lens wipes, deodorant, and dental floss. The total weight of these items is estimated at 200 pounds. The items will be used in a normal way and disposed of in the waste management subsystem.

Other requirements exist to assure proper exercise for the crew to help maintain bone structure and muscle tone during 500 days of zero gravity conditions. Isometric exercises form one readily available group of exercises requiring little or no equipment. An Exercycle type of machine, requiring a crewman to work at a high metabolic rate to maintain circulatory and respiratory system health, is recommended. A device that requires lifting work against a spring or friction load is required to maintain back and upper torso muscles. If space allows, a centrifuge to create an artificial gravity field might be desirable to retard cardiovascular deconditioning of the crew.

Crew recreation is an important consideration in maintaining a healthy crew psychological condition. One major form of recreation is reading. Use of microfilm chips for storage of books is an excellent means of providing reading material. The same microfilm system can be used for storing maintenance manuals and other technical data. Four readers should be provided for projecting the microfilm chips and to supply the crew with readers on demand. Music can be supplied by high density magnetic tapes. Television can be supplied through special transmission from earth. Television tape cartridges may also prove practical.

Detergent

A cleaning agent is required for use in the water used for body washing, clothes washing, dish washing, and general cabin cleaning tasks. The cleaning agent should meet the following requirements:

1. Good surfactant
2. Nonflammable by itself or on clothing
3. Low foaming
4. Nonclogging to water management system membranes
5. Nonprecipitating
6. Nonallergenic

7. Nontoxic in use concentration
8. Not gas producing or odor producing
9. Effective in low concentrations
10. Good bacterial action

Three general categories of detergents are available: anionics, cationics, and nonionics.

The anionics include soaps and many of the synthetic household detergents. As a class they are ruled out, because, although they are effective in low concentrations, they foam to a degree that would cause trouble in use. Additionally, some detergents (soap in particular) are precipitating and would clog membranes.

Cationics are good bactericides but are not good detergents. In addition, they produce foaming and can be allergenic and irritating to the eye.

Nonionic detergents generally meet the system handling requirements. They are low foaming at temperatures above their cloud point (cloud point is defined as the temperature at which all solutions, except very dilute ones, become turbid and eventually form two phases). They are good surfactants, are effective in low concentrations (0.1 percent), will not clog membranes, and are nonprecipitating. They are not bactericidal; in fact, they tend to be biodegradable. The toxicity, allergenic properties, irritability, flammability characteristics in use concentrations are not known. Because of their desirable properties, however, the nonionics are recommended as the basic detergent with the additional recommendation that long term toxicity, allergenic properties, flammability, etc., be investigated thoroughly.

The detergent selected as a prototype nonionic for use in the AILSS is Triton DF-12 manufactured by the Rohm and Haas Company. Like most nonionics, this is a liquid, has a mild odor, and has a specific gravity of 1.055. The cloud point is 51° to 66°F, which should reduce foaming problems to a minimum. It is a good surfactant at 0.1 percent concentration. In concentrated form, it is slightly toxic, can cause mild skin irritation, and quite probably is flammable, although the manufacturer was unable to supply information on this point. In dilute solution, these characteristics are unknown and require further investigation. This detergent is expected to be compatible with the water management system, but verification will be necessary.

Bedding

The sleeping area is combined with the personal quarters to provide a six-sided area where the crewman can be alone for privacy or sleeping. This area includes one solid wall containing outlet air ducts to maintain temperature and humidity, a mounting for a light, an inlet communications system, headphones for listening to music, a restraint system to maintain the crewman in a sitting or prone position, and a storage area for personal belongings. The other five sides are fabric, with the side perpendicular to the hardwall serving as the sleeping area. This is to ensure that the controls on the solid wall are accessible to the crewman fastened into the sleeping restraint system. The wall on which the crewman sleeps contains a soft material, either a fireproof foam or a felt-like material. The crewman is restrained against this cushion with a lightweight open-mesh material. The walls are a strong durable fabric that has been coated to reduce light reflections, absorb sound, and resist humidity. Attenuation of communications and other crew-caused noise is particularly important for satisfactory sleeping conditions. These walls could be made of Armalon (DuPont Teflon-coated fiberglass or Nomex), Temp-R-Glass (The Connecticut Hard Rubber Co. Teflon-coated fiberglass), Teflon-coated Beta cloth (Owens Corning Fiberglass Co.), or any other coated fireproof fabric.

General Housekeeping

Implements such as tools as well as surface areas in the cabin must be kept clean for aesthetic, health, and material durability reasons. Release of particulate matter can become an atmospheric control problem. Filters and absorbent material must be decontaminated, discarded, or stored under microbiologically safe conditions. Sanitization or disinfection of surface contamination on nonexpendables should effectively reduce microbial populations by 99 percent or better. Design simplicity to ensure cleanability and use of nonbiodegradable materials in critical areas is an important adjunct to all decontamination procedures.

Limited use control methods. - For tools and small parts cleaning and microbiological decontamination, ultraviolet radiation, wet or dry heat, and chemosterilants are considered.

Ultraviolet radiation: Radiations in the ultraviolet region, especially at 2500 to 2700 angstroms, are effective microbicidal agents. Their general use as a compartment disinfectant, however, is not possible due to the harmful biological effects of the radiations as well as production of ozone and prohibitive power requirements for multiple ultraviolet lamps. A chamber with the ultraviolet lamps enclosed is practical for disinfection of small items (tools, filters, parts, etc.) when vented to space vacuum for discharging ozone. The standard ultraviolet lamp has a power requirement of 40 watts and a life expectancy of 4000 to 15 000 hours. Used intermittently, the lamps should last through the mission at peak levels of performance. Double or triple replacement lamps should be carried for emergencies.

Heat (wet or dry): The use of heat for sanitization or sterilization is well established as an effective and reliable procedure. It is impractical to use this procedure as a general compartment decontamination method, but it is useful for sterilization of small items at 350 °F for one to two hours. Ovens are commercially available. The power requirement for a one-cubic-foot oven is 550 watts, while a three-cubic-foot oven requires 1000 watts. Corresponding weight varies from 66 pounds to 105 pounds.

Chemosterilants: Gaseous chemosterilants such as ethylene oxide and betapropiolactone are explosive, corrosive, or toxic and cannot be considered for the AILSS mission.

Selection: The heat method is recommended for decontaminating tools and small parts. This method will be implemented with an oven or autoclave.

General use control methods. - Candidates for cleaning and control of microbiological contamination in the cabin are disinfectants, biocidal aerosols, and vacuum cleaning.

Disinfectants: Commercially available disinfectants used for institutional or home disinfection of microbial contaminants are effective and reliable control agents when properly selected and used. The more useful compounds include phenolic-containing, chlorine-containing, quaternary ammonium compounds, and the antibiotics (e.g., Lysol, Roccal, CT41, Neomycin). Sponges or cloths wetted with solutions of these compounds are applied to the surfaces to kill accumulated micro-organisms. The phenolics have a continuing residual action and a strong odor. The chlorine-containing compounds produce chlorine as a residual. The quatenary compounds are less odorous and also somewhat less toxic, although they are likely to be flammable. The antibiotics are nonflammable, are effective bactericides, have little odor, and release no gas. A possible problem, however, exists in the buildup of resistant micro-organism strains.

Biocidal aerosols: These disinfectants packaged as aerosols spray finely dispersed mists on surface areas to control micro-organism buildup. The main objection to this method is the introduction of particulate droplets into the atmosphere which can be inhaled by the crewman and cause pulmonary complications. It also introduces propellant-type gases (freon) into the atmosphere.

Vacuum cleaner: A simple method of reducing contamination levels is to use a vacuum cleaner prior to cleaning with disinfectants. This method can eliminate 60 to 96 percent of the surface micro-organisms, especially those carried by dust or other particulate matter. The air from the vacuum cleaner can be passed through the atmospheric control subsystem for the entrapment of micro-organisms and particulate matter on filters or oxidation in the catalytic burner. This method cannot, in itself, provide a complete answer to the problem.

Selection: Methods of surface area decontamination are judged according to micro-organism kill efficiency, reliability, safety, power requirements, and availability. The choice of a disinfectant principally involves consideration of toxicity and odor problems in a closed system. A common household cleaner such as Lysol is acceptable and a prime choice because of its residual activity. For housecleaning purposes in the AILSS, the two methods recommended are:

1. For pickup of the dry cabin contaminants, a vacuum cleaner is recommended. This would be used periodically on all cabin surfaces and on special requirement when an unusually high atmospheric bacterial level is encountered.

2. For cleaning cabin walls, floors or other surfaces to remove vomitus, food, urine, or other bacteria-supporting media, wet wipes are recommended. The wipes are dampened with water containing detergent and a disinfectant (such as Lysol) and used to wipe the cabin surfaces. Soiled wipes are washed and dried in the washer/dryer unit and then stored for reuse.

Crew Provisions Subsystem Management

The limited available resources mean that crew provisions must be carefully managed. To do this, bookkeeping must be performed to allocate system resources where they are most needed. For example, the food supply is set at the beginning of the voyage. In the event of spoilage of a portion of the food supply, the remaining supply must be reallocated; also, the water supply allocation may be changed because of crew need or desire. The accounting system should monitor the resources available, allocate these to the crew members, make adjustments according to a preset list of priorities, and inform the crew of the status of the allocations. This system should be flexible so that in the event of a change in priorities or an unexpected change in supply, the allocation system can be modified. This bookkeeping function can be performed by the onboard computer with appropriate readouts and inputs made by the crew.

SUMMARY

A freeze-dried diet is the best approach to food and feeding. This basic technique should be supplemented with dried and vacuum-packaged items. Newer techniques such as irradiation and osmotic drying should also be further investigated.

Personal hygiene consists of grooming, dental hygiene, selective body cleaning, and whole body cleaning. Grooming equipment includes vacuum devices for collecting nail and hair clippings, an electric hair clipper, and electric razors. Dental hygiene is accomplished with an electric toothbrush, using a liquid dentrifice. Reuseable wipes are provided for selective body cleaning.

A head-in shower is selected as the best approach to whole body cleaning primarily on the basis of psychological acceptability and cleaning thoroughness. These advantages compensate for relatively high equivalent weight.

Reuseable clothing is selected for its great weight advantage and greater comfort. This clothing concept requires development of an effective washer/dryer device.

Other considerations include miscellaneous provisions, detergent, bedding, general housekeeping, and subsystem management. Miscellaneous provisions include various materials such as facilities for exercise and equipment for recreation. An aerospace detergent has a stringent set of requirements to meet, and a nonionic type such as Triton DF-12 is selected as the best choice. A restraint type "bed" integrated into personal quarters is recommended. Tools and small parts are thermally sanitized in an oven. For general housekeeping, use of both vacuum cleaning and disinfectant cleaning of cabin surfaces is recommended. Crew provision subsystem management is needed for inventory control of all expendable materials used in the subsystem.

INSTRUMENTATION AND CONTROL

CONTENTS

INSTRUMENTATION AND CONTROL

The instrumentation and control subsystem (ICS) consists of the necessary sensors and instruments, with appropriate signal conditioning and controls, to provide the capability of controlling, monitoring, and locating and analyzing problems in the EC/LS system during any mode of operation.

GENERAL APPROACH

The criteria used in defining the ICS requirements were chosen to provide adequate instrumentation for monitoring and fault isolation, and to provide a control system requiring a minimum amount of crew time consistent with good reliability.

Instrumentation hardware conditions the output signals from the subsystem sensors such as pressure transducers, flow transducers, voltage sensors, current sensors, temperature transducers, etc. to provide a standard level and form of output (that is, a 0 to 5 Vdc signal) to be used for caution and warning devices, displays, telemetry, and fault detection. Special instruments used for the measurement of atmosphere and potable water acceptability are designed to provide this standard output signal.

The number and placement of the subsystem sensors are based on data requirements for control, fault detection alarm, fault isolation, crew readout, and telemetry.

For purposes of control, the sensors are placed to satisfy the specific control functions as required by the selected subsystem concepts.

For fault detection alarm, sensors are placed as required by the fault detection routine, which consists of two levels of indication: warning and caution. The warning indication is a first level alarm which indicates critical failures requiring immediate attention to ensure crew safety and is activated by sensors placed directly into the subsystem plumbing. The caution indication is a second level alarm indicating failure conditions which do not require immediate corrective action, such as just out-of-specification conditions or gradually degrading measurements, and is activated by signals obtained from control sensors and/or cabin-installed special instrument sensors.

For fault isolation, parameters not already monitored for control and/or fault detection and required for the fault isolation routine are instrumented. These parameters, in addition to those for control and fault detection purposes, are continuously monitored as part of the fault isolation routine for isolating each failure symptom to the replacement level.

Functional parameters required for crew information, are instrumented for continouus crew readout. Examples of the parameters required are oxygen quantity, cabin temperature, cabin pressure, and water temperature. The same functional parameters used to provide continuous crew readout will be instrumented for telemetry transmission out of the system.

As an example for the O_2 generation, CO_2 concentration, and cabin pressure control subsystems, 84 sensors are used as follows:

	Subsystem		
Requirements	O_2 generation	CO_2 concentration	Cabin pressure control
Control	30	9	2
Fault detection alarm - warning	--	--	3
Fault detection alarm - caution	14	6	-
Fault isolation	5	10	2
Crew readout	--	1	2
TOTAL	49	26	9

Although each sensor is placed to meet one of the requirements for control, fault detection alarm, fault isolation, or crew readout, actual sensor redundancy is avoided whenever possible and reliability is enhanced by means of overlapping and supporting measurements. This approach offers more information for a given number of sensors and provides some protection against simultaneous failure of identical sensors in an upset condition. The size and complexity of the AILSS, therefore, together with the requirements for fault isolation to the replaceable component level and the necessity for some degree of redundancy, indicate that 223 sensors are required. They are distributed as follows:

Water management	55
Waste reclamation	13
O_2 high pressure storage	9
N_2 high pressure storage	8
Cabin pressure control	9
O_2 generation	49
CO_2 concentration	26
Cabin temperature and humidity control	22
Coolant loop	12
Crew provisions	2
Trace contaminant control	18
Total	223

Included in the above total are 42 speed sensors (for rotating machinery) and valve position indicators which are built into the equipment. While they do provide readouts, they are not otherwise considered as separate sensors.

COMPLEXITY TRADE-OFF

The AILSS maintenance philosophy of isolating faults to the replacement level, together with the necessity for operational and performance data and for overlapping and supporting measurements, dictate that approximately 223 sensors must be installed in the system hardware. The data obtained from these sensors and instruments must be processed for control, fault detection, fault isolation, crew readout, storage, trend analysis, and telemetry. A trade-off study was conducted to determine the equipment required to provide a convenient means of managing this data. To determine the degree of complexity of this equipment, the ICS concepts considered include extreme levels of complexity as well as several intermediate levels independent of the AILSS maintenance philosophy.

Candidate Descriptions

The candidate levels described below are shown in figure 94.

Level 1. - control sensor. - Level 1 contains the minimum instrumentation possible. The sensors are installed to meet system control requirements only. It is assumed that the life support system will work to design specification for 500 days. If troubleshooting is required at all, it is performed by manual inspection. No telemetry interface is provided.

Level 2. - control and operation sensors. - Instrumentation is limited to mechanical-type visual indicators. The sensors are installed to meet the fault detection requirements, but there are no interfaces and signal conditioning is not provided. When the crew notices a problem, a portable multipurpose instrument is used to make troubleshooting measurements at the installed sensors. No telemetry interface is provided.

Level 3. - control and operation sensors interfaced. - Level 3 contains all control and fault sensors plus special instrumentation for the measurement of atmosphere and potable water conditions with readouts for each parameter. The sensors are inter faced to provide a common output level for continuous monitoring. The displays are installed for major parameters to inform and warn the crew. Automatic fault detection is provided, but the fault isolation routine is completely manual requiring manual measurements from operational fault isolation instrumentation. A telemetry interface is provided for major parameters.

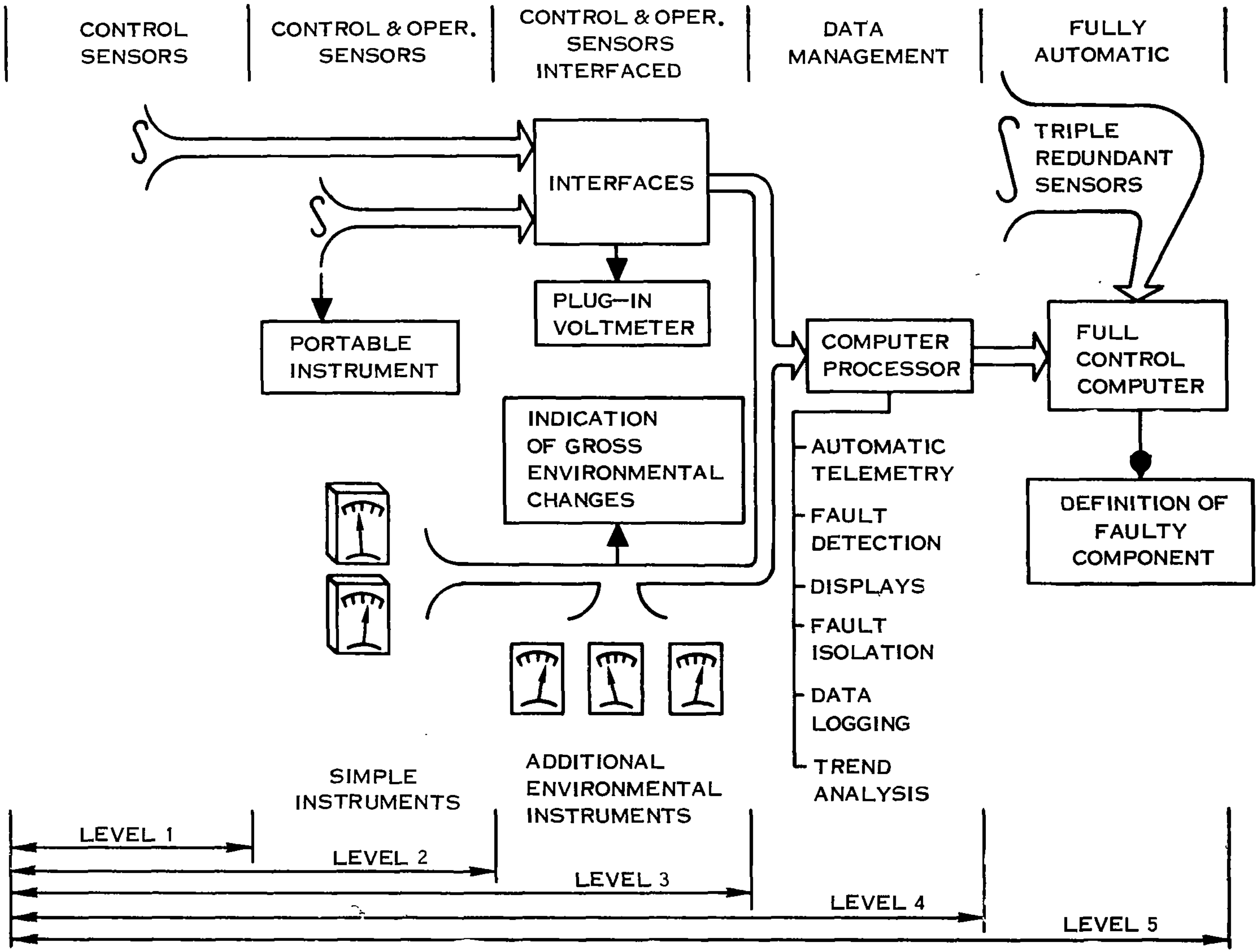


Figure 94. Instrumentation and Control Candidate Levels.

Level 4. - data management. - Level 4 contains all the level 3 sensors interfaced and connected to automatic data management processing circuitry. The displays are installed as required to inform and warn the crew. The crew has partial control over the displays and measurements, but fault warning is automatic with displays indicating probable faults. Automatic control is by independent loops.

Level 5. - fully automatic. - Additional sensors plus sensor redundancy, obviating the need for replacement, are incorporated to implement an increased level of system complexity and fault analysis. There are no manual controls and a single display tells the crew if a component change has been made or if manual maintenance is required.

Trade-off Discussion

Table 47 summarizes the evaluation of the characteristics considered in evaluating the five levels of instrumentation and control. The following is a discussion of the reasoning applied in preparing this table.

Absolute criteria. -

Performance: The candidates are rated for performance on the basis of relative usefulness to the crew. Level 1 is rated unacceptable for performance for two reasons. First, it does not meet the telemetry requirements. Second, it is not capable of meeting the requirements necessary to allow the AILSS mission to be completed. Level 2 is rated unacceptable for performance because it does not meet the telemetry requirement. Levels 3, 4, and 5 meet the performance criteria and are capable of operating for 500 days with maintenance.

Safety: Level 1 is classified also unacceptable for safety, because a reliability analysis indicates that approximately 8 failures will occur during the 500-day mission. The system, then, is not failure free. Human inspection, although useful, cannot replace installed sensors as a source of fault indication information.

Level 2 is rated unacceptable for safety, because it provides no assistance to the crew in isolating failures, and repair cannot begin until some major fault indication is analyzed. This procedure is potentially hazardous.

Level 3 is downgraded in safety, because even though it provides automatic fault detection alarm, the fault isolation routine is completely manual and time consuming and could present a potentially hazardous condition for the crew.

Level 4 provides virtually instant warning of critical hardware or instrumentation failures. Full and accurate fault isolation and operational information is made available to the crew.

TABLE 47
EVALUATION SUMMARY - ICS COMPLEXITY LEVEL

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Level 1	Level 2	Level 3	Level 4	Level 5
		Control sensors	Control & operational sensors	Control & oper. sensors interfaced	Data management	Fully automatic
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Unacceptable	Unacceptable	Good	Good	Very good
	Safety	Unacceptable	Unacceptable	Fair	Very good	Good
	Avail./Conf.	Very good	Very good	Very good	Very good	Fair
		ELIMINATED	ELIMINATED			
Primary	Reliability			Fair	Fair	Fair
	Crew Time			Fair	Good	Very good
	Equivalent Weight			Good	Good	Fair
				ELIMINATED		ELIMINATED
Secondary	Contamination				Good	
	Interfaces				Good	
	Flexibility				Good	
	Growth				Good	
	Noise				Very good	
	Volume				Good	
	Power				Good	
					SELECTED	

Level 5 is slightly downgraded in safety because of the increase in system complexity relative to Level 4, and because of the remote possibility that if it should be irreparably damaged it has no provision for AILSS operation in a manual control mode.

Availability/confidence: Only level 5 is rated less than very good on availability/confidence. The sensor, logic, and actuator requirements to implement level 5 become very difficult, because the operating range of every parameter must be programmed and rigidly adhered to throughout the mission. Sensor accuracy would have to be adequate for leak detection, and long-term integration of flows and linear actuators of better reliability than now available would be required.

Primary criteria. -

Reliability: The reliabilities of levels 3, 4, and 5 are rated essentially the same. Since they all have MTBF's of less than 12 000 hours, they are rated fair.

Crew time: The candidates that by definition require no crew time are rated best on this criterion. Level 4 has a low scheduled crew time requirement, but the measurement and control options require a small amount of time. Level 3 utilizes a manual fault isolation routine which can be time consuming and involves higher crew stress. Level 3 is rated fair for this reason. Level 5 is completely automatic and therefore requires little crew involvement and is rated very good.

Equivalent weight: The candidates are rated on the basis of relative complexity and power. Sensor weight makes up a significant portion of the three upper levels because the circuitry is relatively light. This tends to reduce the percentage of weight difference between levels 3 and 4, but this increases the level 5 weight difference because of the threefold increase in its sensor requirements. Level 5 is rated fair for this reason.

Subsystem Selection

The selection of a suitable level of instrumentation can be made on the basis of primary criteria. Candidate levels 1 and 2 are rated Unacceptable under absolute criteria and are excluded from further consideration. The difference in crew time and equivalent weight between the remaining candidates results in the selection of level 4 as the most suitable for this application. An inspection of absolute and secondary criteria verifies this selection.

It is recognized that a nearly infinite range of possibilities exists in defining the ICS. However, a consideration of additional levels of intermediate candidates, such as the installation of some fraction of the necessary sensors or the automation of some functions while omitting others, probably would not change the results of this study.

The selection of candidate level 4 reflects a degree of development one phase beyond the system concepts applied in current space vehicle designs, and level 4 has the performance capability that is necessary for completion of the AILSS mission.

Subsystem Summary

A schematic of the selected instrumentation subsystem is illustrated in figure 95. The basic functions of the ICS are summarized below:

Control. - Wherever possible, control is accomplished by individual automatic valve and switch control loops within each functional subsystem. This removes the possibility of a single failure in a centralized control system disabling several subsystems. It also provides the greatest degree of modularity at the subsystem level.

Data sources. - The data sources consist of several specialized instruments, such as cabin pressure and humidity meters, as well as the sensors mounted directly within the subsystems. In many cases the instruments provide the required 0 to 5 volt low impedance signals, but each sensor requires suitable signal conditioning for conversion, normalization, and impedance transformations. Selected parameters are normally displayed for crew use, and the rest are available by manual selection. All signals are digitized for storage and use by the computer in system performance evaluation and fault isolation.

Central processor. - The input of the data sources is handled by a central processor consisting of those computers which process sensor signals, subsystem faults, and data trends for system control, monitoring, warning, and fault analysis.

Fault isolation. - Any sensed fault results in the activation of a fault light and audible alarm as required for crew safety. This is automatic, as is activation of the fault isolation routine, but manual override features are included. The fault isolation routine, once activated, continues until the defective replaceable component is identified or until manual intercession is required.

Execution of the fault isolation routine is keyed to the excitation of a fault indication light. An out-of-limits condition in any of the continuously displayed special instruments will activate a malfunction indication, as will an out-of-limits condition occurring in any of the continuously monitored parameters which respond to the condition of a complete subsystem or a particular critical parameter. The critical parameters give an earlier warning of equivalent malfunction than the slower cabin instruments. This warning indication is used as a first level alarm which directs immediate attention to the appropriate subsystem. In this way, fault isolation and rectification is, in many cases, implemented on a nonemergency basis.

Tape storage. - Tape storage is provided by a tape deck, and it is used for

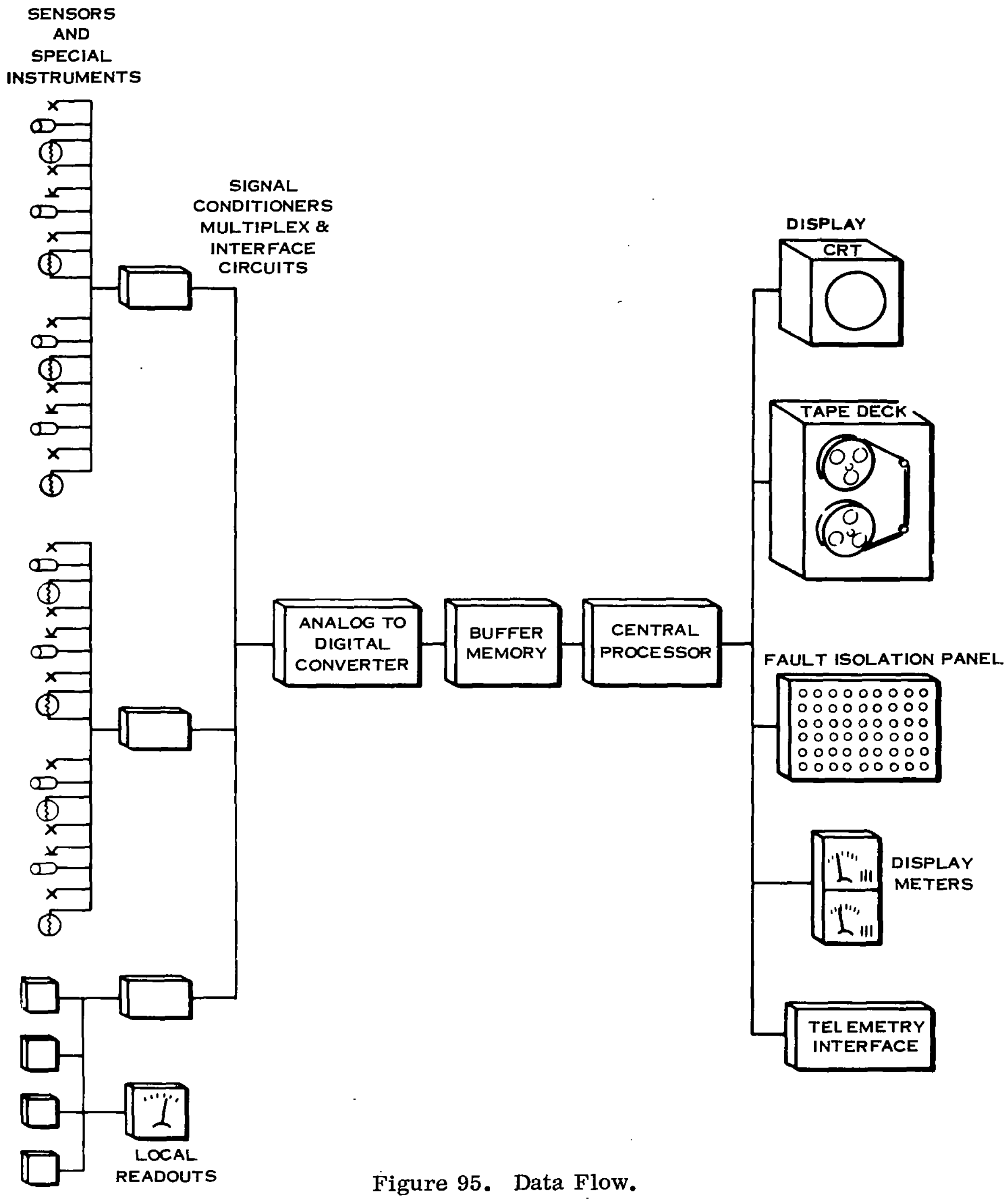


Figure 95. Data Flow.

data logging and telemetry time scaling. The availability of a tape deck makes it possible to obtain a trend analysis of any parameter as required, which is a valuable analytical tool in the fault isolation routine.

Telemetry. - The telemetry requirements are met by conducting information, in digital form, out of the system, Lines are time-shared, and an identification code accompanies the digital representation of each parameter. Data are available for transmission either in real-time or from tape storage. The digital information is in parallel format but is suitable for conversion to serial form for RF transmission.

Weight, Power, and Volume Summary

Table 48 summarizes a preliminary estimation of the weight, power, and volume requirements of the selected ICS subsystem.

TABLE 48

ICS WEIGHT, POWER, AND VOLUME SUMMARY

	Weight (lb)		Power (Watts)		Volume (in^3)	
Instrument Section	Installed	Spares	Peak	Average	Installed	Spares
Sensors	40.0	14.0	30.0	30.0	800	280
Signal Conditioning	6.0	3.0	10.0	10.0	400	200
Special Instruments						
Cabin Pressure	2.0	2.0	1.0	1.0	60	60
Cabin Temperature	2.0	2.0	1.0	1.0	60	60
Atmos. Constituents	6.5	6.5	3.7	3.7	400	400
Combustible Gases	2.0	2.0	30.0	30.0	80	80
Gas Chromatograph	10.0	---	40.0	2.0	4000	---
Water Conductivity	4.0	3.0	2.0	2.0	120	90
Cabin Dew Point	3.0	2.0	6.0	6.0	60	40
Ambient Radioactivity	2.0	---	1.0	1.0	60	---
Status Panels	25.0	---	5.0	5.0	4000	---
Lights and Audible Alarm	5.0	---	1.0	Negligible	250	---
CRT	9.0	---	25.0	5.0	400	---
Tape Deck	25.0	25.0	25.0	Negligible	2500	2500
Central Processor	5.0	---	25.0	25.0	250	---
Totals	146.5	59.5	205.7	121.7	13,400	3710
	Total wt = 206.0				(7.78 ft^3)	(2.15 ft^3)

CENTRAL PROCESSOR AND DATA MANAGEMENT

The central processor and data management system is described in the following paragraphs. A block diagram of this system is shown in figure 96. Computer aid is necessary to minimize the actual crew time required for the processing of sensor signals, subsystem faults, and environmental parameter trends sent for system analysis and monitoring. A single processor computer capable of performing these functions simultaneously would need to be a high speed parallel operator requiring high power consumption and interconnections as well as a high degree of complexity, since parallel data processing carries full word bits through multiple wiring. A more flexible system would utilize simple basic computer modules for serial processing. Proper programming would allow a number of instrumentation and control applications. Although slower than parallel, serial processing does much to reduce the number of circuit inter-connections that frequently limit the complexity of building-block modules. In addition, it allows the use of metal semiconductor (MOS) integrated circuitry, which is available in more complex forms than bipolar circuitry.

The central processor configuration, consisting of three computers, is the most advantageous. The three computer functions are:

1. Data management and control
2. Fault detection and isolation
3. Display and trend analysis

Provision is built into the system to periodically compare system operation against design limits. These individual comparisons can be completed in approximately 64 microseconds, and all critical parametric comparisons can be accomplished in less than one second.

Control Processing and Data Management

A central processor status panel, containing central processor, tape deck, and centralized display and control panel, is provided as the major crew/system interface. A cathode ray tube and fault light displays, as well as meters and necessary manual controls, are installed in this rack.

Data management is the supply of signal information to each remote subsystem display and to the storage register. Each remote display allows readout information at the subsystem location. Those control functions requiring ground station monitoring are sent to telemetry.

Control functions are accomplished by independent control loops within each

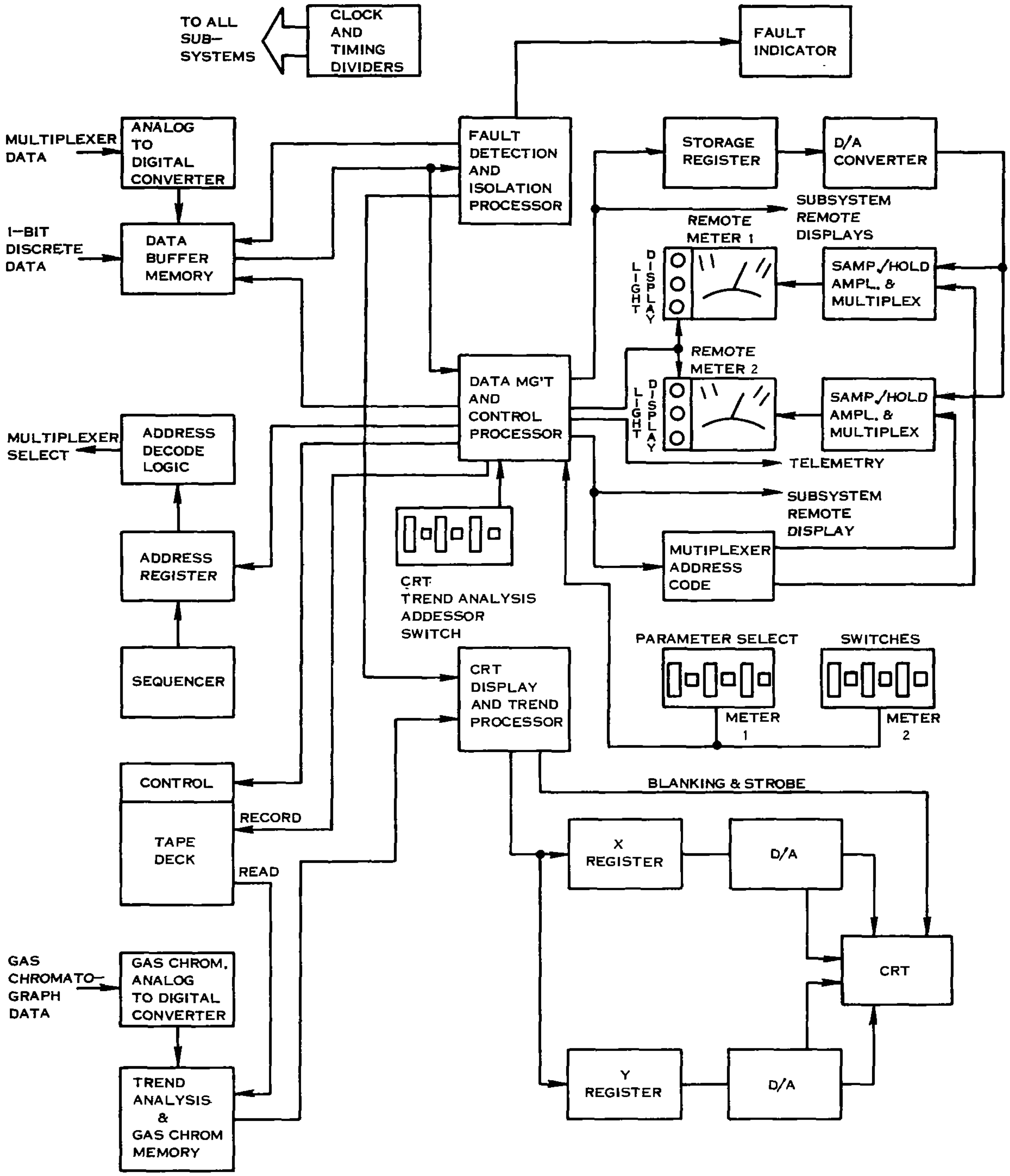


Figure 96. Control Processing and Data Management

subsystem. These loops retain the advantages of subsystem modularity and avoid the possibility of a processor failure disabling the life support processing system. Data flow and control processing are available for any control function requiring computation. A central block oscillator with suitable divider and decoding circuitry is available to meet system timing requirements. In the event of clock failure, repair is by replacement of a plug-in circuit card.

The control function includes an entire subsystem status panel display, as well as a central processor status panel. Wherever possible, a schematic-type status panel is provided, and when manually operated valves are required, they are located nearby. Valve positions are indicated by valve handle orientation to a reference.

Solenoid valve positions are indicated by backlighted valve symbol inserts in the display panel schematic. These valve position indicator (VPI) inserts are excited by mechanical actuation of a microswitch, thus ensuring that valve position, and not applied power is verified. Valve position indicators will show positive position for either an electrical or manual actuation.

Meters, switchable to read any parameter from the central processor, are provided on each subsystem panel to aid in determining subsystem status. An additional three-light display indicates whether the measured parameter is high, low, or within specification.

Fault Data Processing

Appropriate parameters are compared periodically against upper and lower limits as a continuous test of system performance. The cyclical nature of some subsystems prevents the testing of all parameters in this manner but, if necessary, a single limit or variable limits can be used. If a parameter goes out of specification limits for two successive cycles, the fault isolation routine is activated, fault data are presented at telemetry and two-meter display outputs, and a fault light and audible alarm are activated. If a change or shutdown is required, the data buffer memory is switched to a read/restore mode and bypassed by incoming data. This allows storage of data from the last second of operation for use in fault isolation analysis.

With the possible exception of fault isolation, the responses described above are a matter of routing data in predetermined manner in response to a signal, and these responses are accomplished by the fault detection and data flow processors. Fault isolation, which can tax the deductive reasoning powers of a human technician, is less adaptable to automation. Subsystem hardware design and sensor placement must be planned to make this task possible. Two approaches to fault isolation are considered. They are the chart implementation and multiple list techniques.

Chart implementation. - Typically, a fault isolation routine is patterned after the instictive human troubleshooting technique in which a theory is formed, based on some piece of information. A verifying test is then made, and, if necessary, the theory is modified. A series of such steps leads to the isolation of the faulty component. For a particular piece of equipment, a logical troubleshooting chart can be generated that assists the technician in this procedure. In this technique, the automatic implementation of such a chart is the basis for a fault isolation computer program.

Multiple list. - A second technique, which allows more use of human judgment while providing similar information, is considered for this application. In operation, any out-of-specification parameter results in a CRT display listing the parameter, its condition, (too high or too low), and a list of all possible components that could cause this condition through failure or degradation. A component failure, assuming proper sensor placement, results in the generation of several such lists, and only the faulty component appears on every list. The frequency of appearance of each component is indicated on the CRT.

Selection considerations. - In a textbook fault isolation operation, the chart implementation technique produces the desired display of faulty component identification with no superfluous information. The multiple list calls out the same component as the most likely cause of the malfunction but lists others. A number of potential problems, however, make it likely that human intervention will be required in fault isolation. In that event, the multiple list technique provides considerable information even though the automatic procedure cannot be completed. Either method is backed up by a manual troubleshooting chart (of the type described previously) for use with the two-meter display.

Problems associated with any fault isolation method include the following:

1. In the instance of gradual component degradation, there must be one parameter that first goes out-of-specification. At this time there is not enough information available to complete an automatic fault isolation routine. If the parameter should be one that causes a subsystem mode change or shutdown, no additional out-of-specification information can be obtained.

This problem is met by placing the tightest limits on the parameters that do not cause a mode change, allowing a full cycle of data accumulation after the first sensing of an out-of-specification parameter, and providing a capability of manually tightening the limits in a retest of data stored in the buffer memory to determine if other parameters are bordering on out-of-specification operation. The second of these features also eliminates fault warnings caused by single noise spikes. Trend analysis of the out-of-specification parameter, as well as related parameters, provides a backup source of information.

2. Multiple component failures present an isolation problem regardless of the troubleshooting technique. It is assumed that simultaneous random failures will be very rare and that the possibility of dependent failures will be recognized in advance and reflected in the fault isolation program. The multiple list technique provides all the information necessary to repair both kinds of failures but requires some human interpretation. The chart technique requires that two separate chart branches be followed to completion.

The availability of additional information for failure analysis makes the multiple list presentation the more desirable and it is therefore selected for AILSS application.

Display and Trend Analysis

Three types of display (and alarm) equipment provide continuous monitoring of parameters. Information is presented by Panel Mounted Meters, Indicator Lights and Warning Tones, and Graphical and Alphanumeric Display.

Panel meters. - Parameters to be monitored in such a way that information is continuously available to the crew are displayed on panel-mounted meters. These meters are used for both local readouts at the subsystem and compartment level and on the central status panel. Local readouts, at the point of measurement, are taken directly from sensor interface circuitry. The sensors for this application are not multiplexed to interface circuitry. The outputs of the interface circuits are multiplexed to the analog-to-digital converter, however, in addition to providing the required meter drive signal.

All remote readout meters receive data from the central processor in digital form. A common storage register and a digital-to-analog converter are installed at the readout location. Each meter is provided with a sample-and-hold circuit that receives updated signals during a period of less than one second.

Two meters on the central status panel are capable, by switching, of reading any sensed parameter using continuously updated information from the central processor. The use of two meters for this application provides the capability of testing for correlation between two fluctuating parameters. Secondary benefits are the redundancy and self-test capability provided by duplication. To reduce spare storage requirements, the meters used are all of the same type with replaceable face plates.

Indicator lights and audible warning. - Light displays are used as equipment power indicators, backlighting for subsystem status panels, and (in conjunction with an audible alarm) malfunction warnings. Neon lamps are used where continuous operation is required, with brighter incandescent lamps used for warning. Lamp panels are continuously monitored for filament failure by means of a warning circuit which activates a warning lamp in the event of an open filament failure in any lamp. The faulty lamp is identified by means of a test switch. An audible alarm system consisting of a signal generator and loudspeakers serves to direct crew attention to the warning lamp panel if any equipment malfunction should occur.

Graphical and alphanumeric displays. - Two techniques, paper printouts and cathode ray tubes, are considered for the display of graphical and alphanumeric information. Paper printouts of data are rejected because of problems in maintenance, reliability, trace contaminant generation, paper and chemical storage, and waste management. The cathode ray tube (CRT) type of display is selected to provide the readouts normally requiring paper.

As an example, the gas chromatograph is normally operated daily for detection of excessive trace contaminant levels. Detector outputs are digitized in increments of a few seconds, with the binary number output representing the integrated output level over each conversion period. Binary data are stored for playback in a compressed time mode using the trend analysis memory and CRT display. If necessary, signal averaging techniques may be applied to the chromatograph data for long-term evaluation of trace contaminant levels. A time strobe is provided for accurate determination of retention times. The control processor is used for the integration of area under portions of the output curve.

Trend analysis of any parameter may be performed as required. The procedure consists of transfering historical data for the selected parameter from magnetic tape to the trend analysis memory. A CRT plot of parameter history (figure 97) is then presented along with the normal operating limits for the parameter being monitored. Operator time is required only for switch selection of the parameter to be analyzed and interpretation of the CRT presentation. Trend analysis information as well as any other data from magnetic tape storage is available for telemetry as required. To provide an uninterrupted recording of historical data, a priority interrupt signal returns the tape machine to the proper position and record mode at the times that it is scheduled to record new data.

Considerable work is being done on the development of a substitute for the CRT. Electroluminescent, liquid crystal, light-emiting diode matrix, neon cell matrix, and laser displays are among those being investigated for this purpose. Because of the volume requirement of installed and spare cathode ray tubes, an improved display device will be incorporated when availability allows. In this report it is assumed the CRT utilizing electrostatic deflection will be viewed for trend analysis, fault isolation, and chromatograph information. Both current status and tape-stored historical information are available for display.

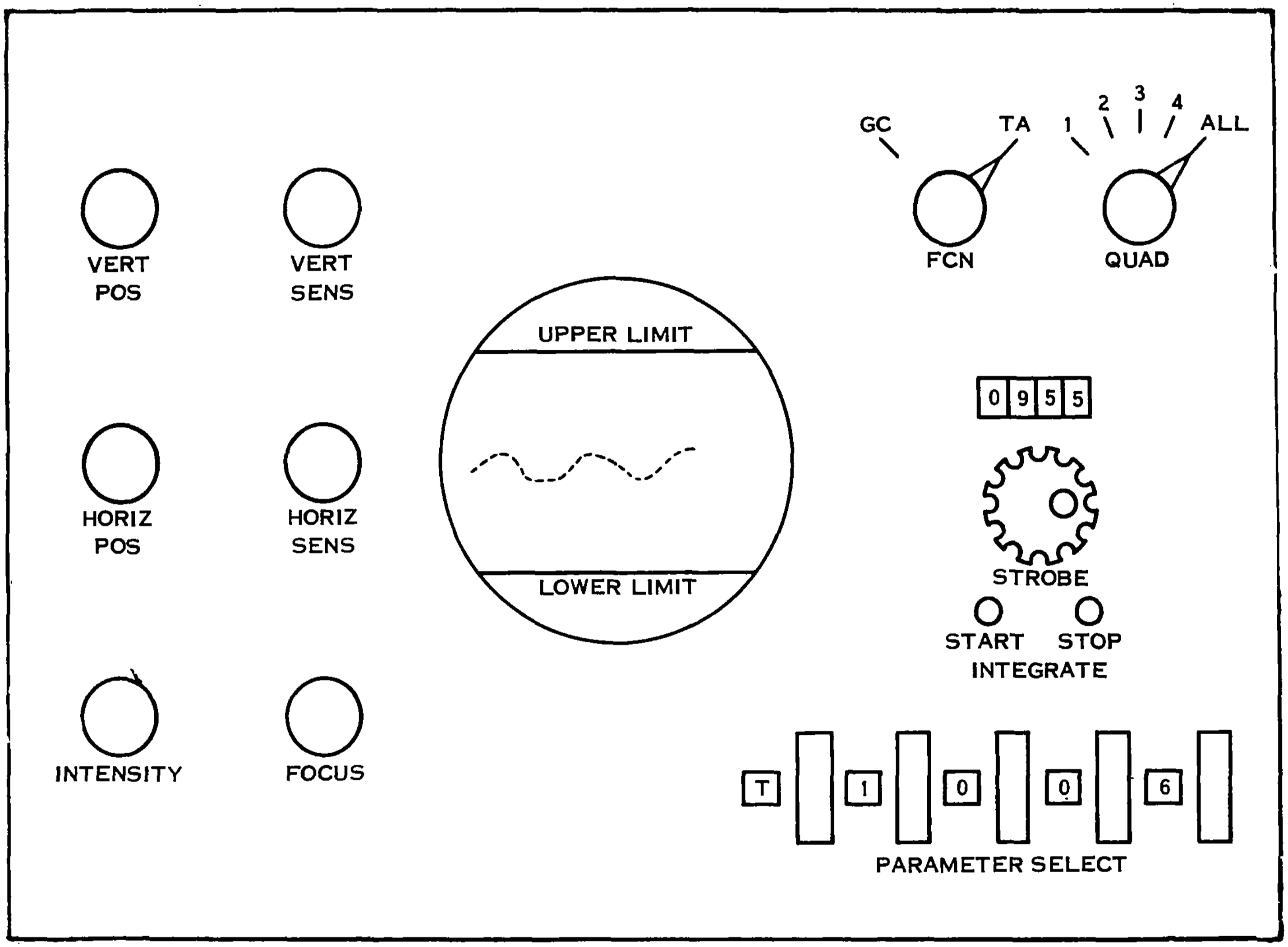


Figure 97. Gas Chromatograph Trend Analysis

Basic Computer Module

The basic computer around which this system is designed is a small, general purpose digital device (figure 98). Three such components are selected to perform the three major processing functions. The computer shown in the block diagram is a general configuration and will be optimized for the AILSS application. An index register and a small amount of additional logic, for example, will allow more efficient comparison of operations for fault detection. The data buffer memory provides read/write memory capability in the fault detection/isolation processor.

The use of several simple computers rather than a single, complex, central unit has been established in current proposed aircraft in which individual computers control navigation, flight control, engine fuel controls, display, fire control, and other functions.

The AILSS fault detection computer is the same processor that isolates the faults. The only modification required is an enlarged read-only memory capacity, which can be done with one additional printed circuit card. The use of machines identical to the fault detection/isolation computer, for display processing and for data management and control, requires programming effort only with no additional hardware design.

Since the three computers used in this application are identical, the software or programming for each function is included in each computer. Simple switching allows an installed or spare computer to be used for any function. The use of a computer in this manner makes it possible to effect major functional changes in the subsystem by merely modifying the program stored in the read-only memory. For a development program, a read/write memory, in which the stored program can be modified by the user, might be chosen, allowing keyboard access or the use of tape-stored multiple programs. A number of serial machines with characteristics similar to those required for AILSS application have been developed. Serial machines have performance times in the microsecond range and all three computers are identical except for the stored program being used.

Each computer, consisting of a small circuit board, is installed at the central status panel and is accessible for plug-in replacement of computers and memories. The crew time during normal operation is only that required to switch to the information sources from which data are required. Repair is on a plug-in replacement basis at the computer and memory levels.

Permanent storage of the program, limits, and curves is accomplished by means of nondestructive readout (NDRO) random access memories. Temporary scratchpad storage is provided by a shared, random access semiconductor memory of the same

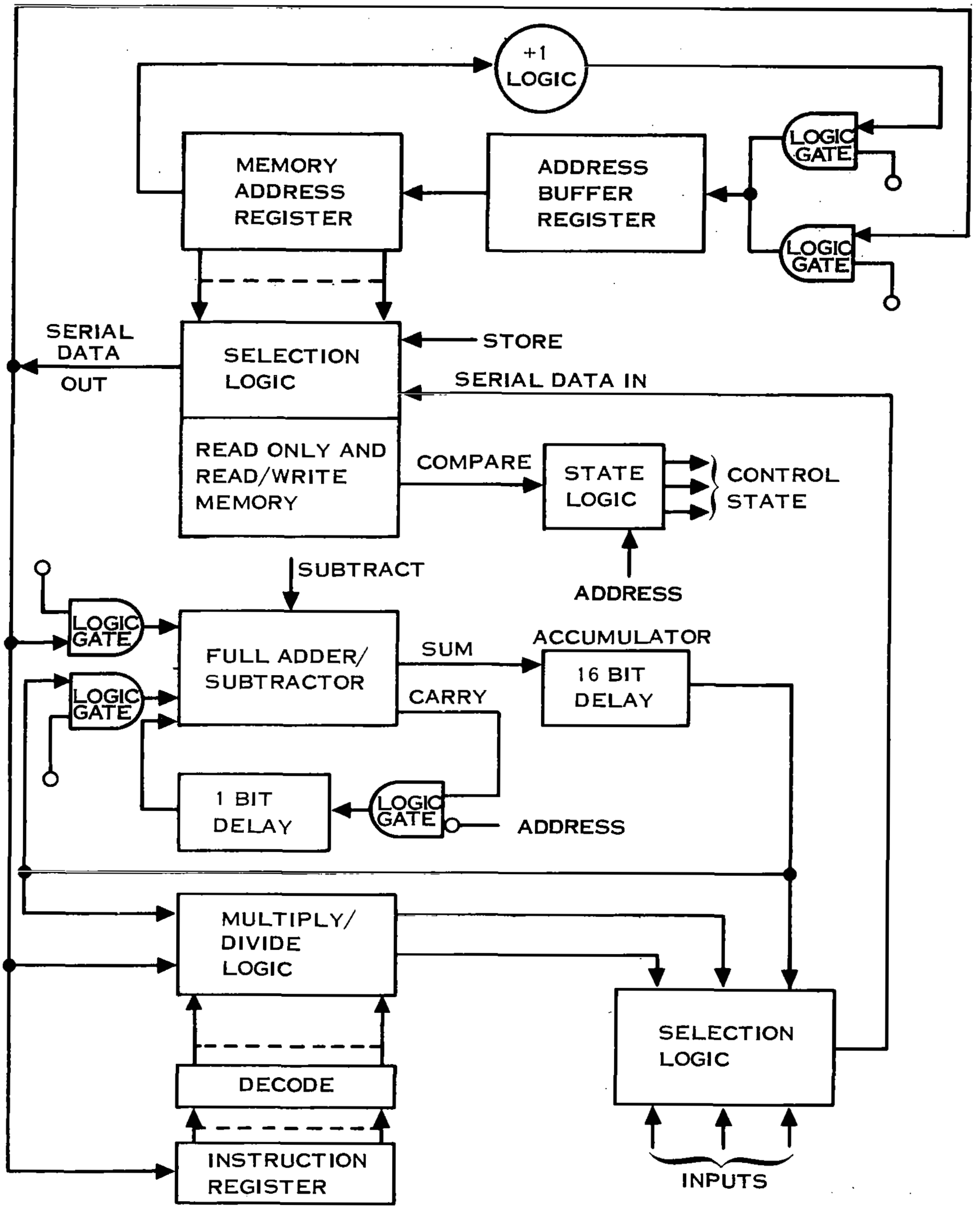


Figure 98. Typical Serial Digital Computer

type used for data buffer and trend analysis storage. There are, then, three machines, each with its own NDRO memory and read/write memory.

During normal operation, all sensors are continuously scanned (routine operation) by the multiplexer. All appropriate signals are tested for out-of-limit conditions and automatic fault isolation routine is implemented in the event of fault detection.

Experimental or developmental hardware is not required for this computer application, because current state-of-the-art hardware is adequate. It is anticipated that components combining smaller size and improved performance will be available at the time of final design. The present integrated circuit state-of-the-art makes possible a design at this time which would not be obsoleted by the long time factor between planning and actual flight. In general, it can be stated that a small digital computer, made of integrated circuit chips mounted on one-square-inch ceramic substrates, can now be built on one or two printed circuit cards. This use of medium-scale integrated chips on similar substrates will reduce the size of such a machine to perhaps five cubic inches. Large-scale integration, which is just becoming practical, makes it possible to further reduce the size to the single substrate or chip level.

SIGNAL CONDITIONING

The function of the signal conditioning circuitry described here is to generate electrical signals, analogous to the parameters being monitored, and to convert these signals to a standard dc voltage level and then to binary numbers that are stored for use by the central processor. Analog multiplexing of instrument and sensor outputs to shared interface circuits, and further multiplexing of interface outputs to a single analog-to-digital converter, results in significant wiring and circuitry savings. Figure 99 is a block diagram representation of the sensor and signal conditioning areas, including special instruments.

Simplified schematics of typical sensor interface circuits are shown in figure 100. The choice of amplifiers and actual circuit designs is largely determined by the accuracy requirement in each application. The operational amplifiers represented by triangular symbols in the schematics are integrated circuits requiring no external frequency compensation. The types currently available are approximately 0.35 inch in diameter and 0.2 inch high. An entire interface circuit typically uses one square inch of circuit board area. Dual amplifiers are available at present, and it is anticipated that flat packs containing four amplifiers will be available for this design.

In order to reduce circuitry and wiring to a minimum, a technique is used in which interface circuitry and multiplexers (figure 101) are installed in substations located in each subsystem. A centrally-located analog-to-digital converter is time-

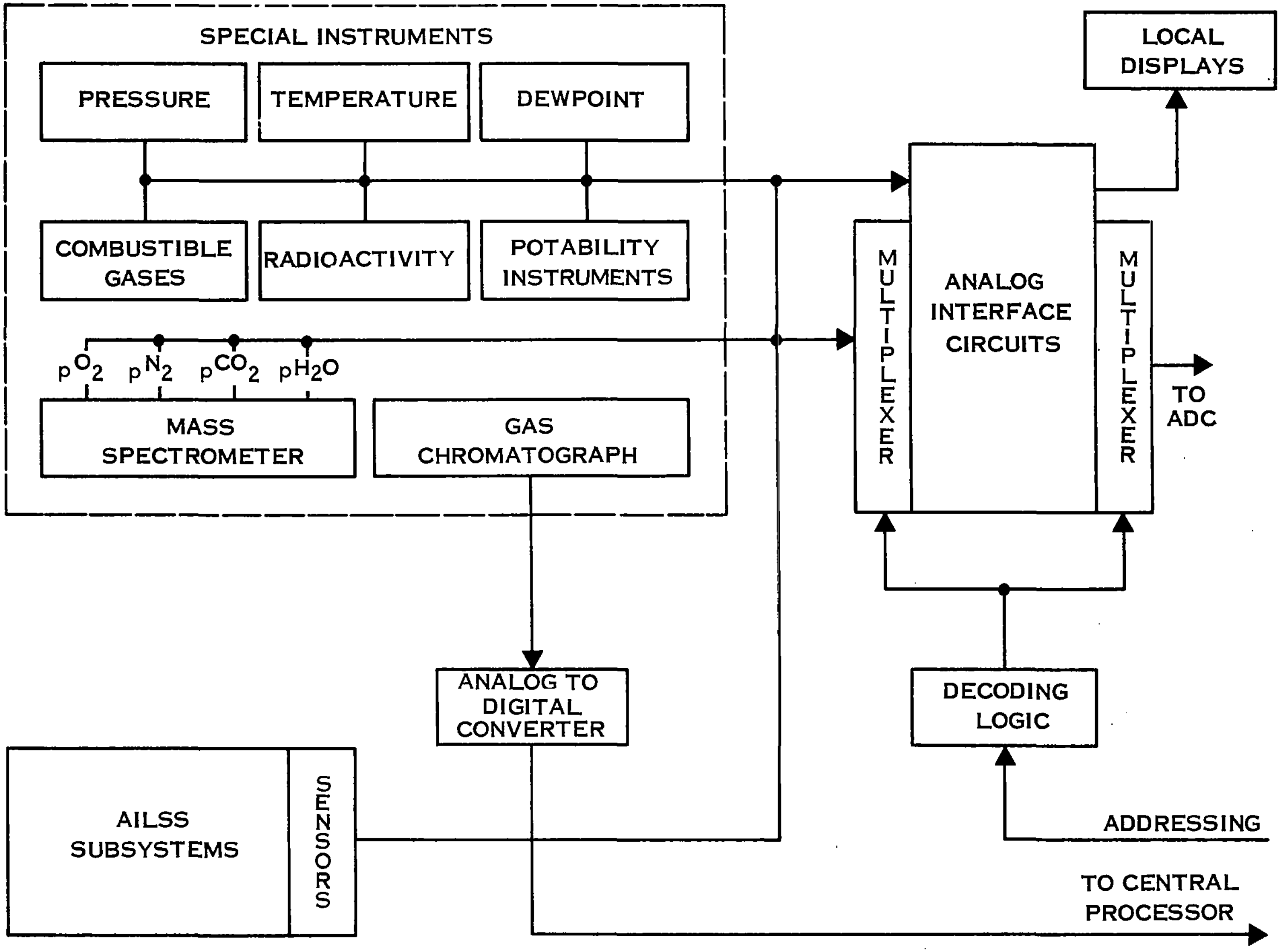
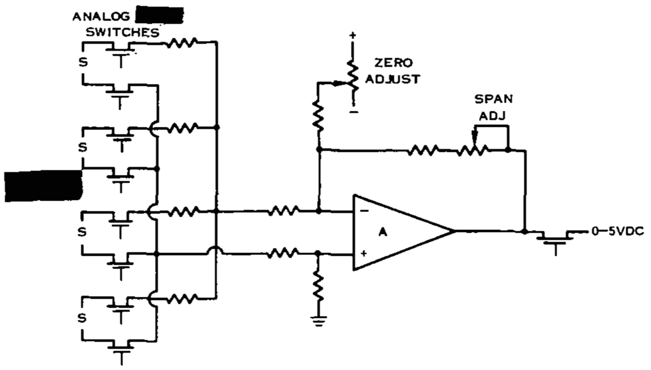
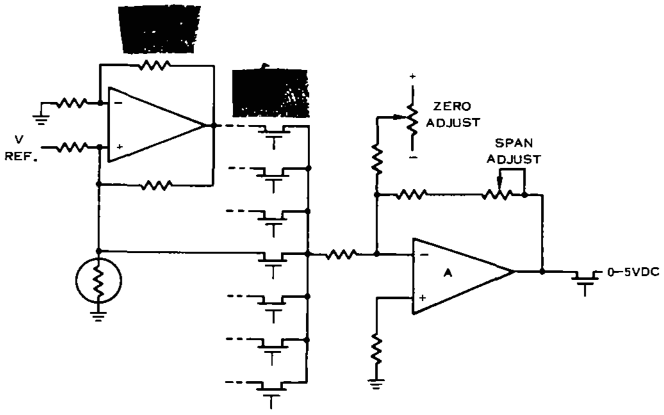


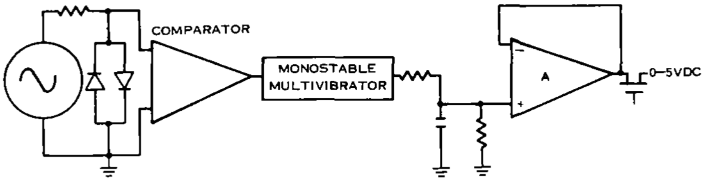
Figure 99. Sensor and Signal Conditioning Diagram



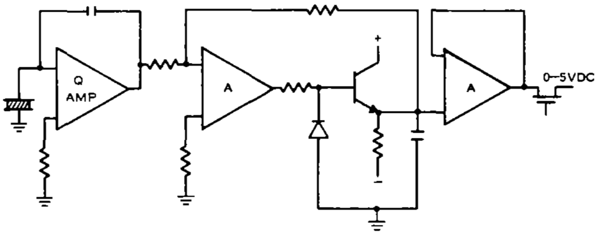
DIFFERENTIAL SOURCE INTERFACE



RESISTANCE PROBE INTERFACE



FREQUENCY TO DC CONVERTER



CHARGE AMPLIFIER PEAK DETECTOR

Figure 100. Typical Sensor Interface Circuits

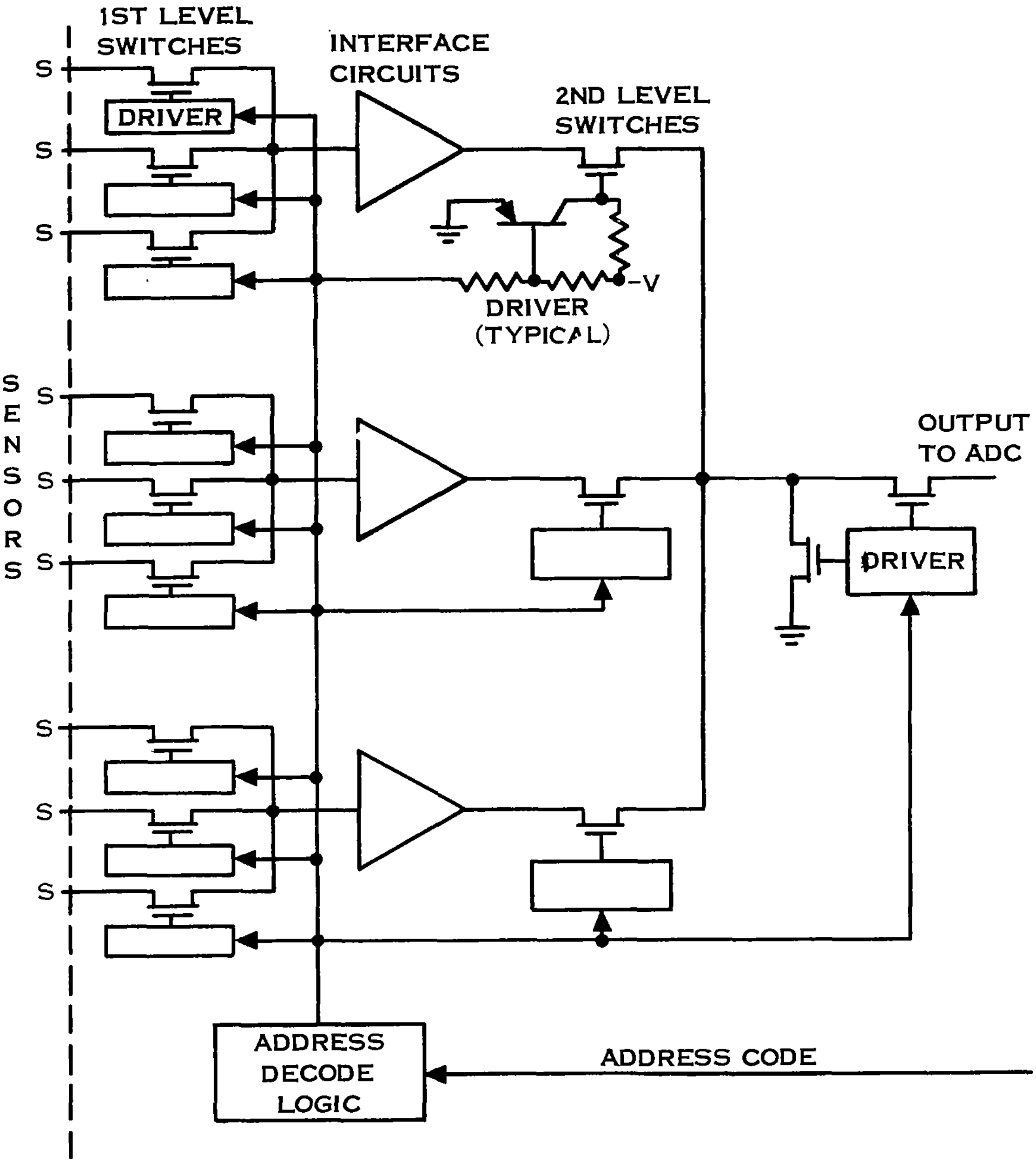


Figure 101. Substation Electronics

shared to convert all analog parameters to binary form for storage and computation. Information is transmitted from the substations to the analog-to-digital converter in multiplexed analog form, using one pair of conductors.

In operation, each transducer output is multiplexed to an interface circuit for conversion to a 0- to 5-volt, low impedance signal. Each signal is connected to an analog switch. The switches, controlled by the data memory address register, provide a second stage of multiplexing to the central analog-to-digital converter. As each signal is converted to a binary number (word), it is stored in the data memory for use by the processor. Data may be read from the memory during the conversion time of the analog-to-digital converter.

Discrete on-off signals representing valve or switch positions are transmitted serially over a second conductor pair and stored in the data memory as one-bit words. Each memory word location stores a bit of information for each bit of word length. A 1024-word 8-bit memory, for example, is capable of storing 900 8-bit words representing analog sensor outputs and 992 1-bit words of discrete level data. All stored data are updated at intervals of slightly less than one second.

The signal conditioning circuitry described is all solid state and can be implemented with currently available hardware. It provides the speed and accuracy of the measurement required for the monitoring and control functions associated with the AILSS and lends itself to improvement as better hardware becomes available. No scheduled maintenance is required for 500 days of continuous operation, but calibration must be performed after a component change.

Critical parameters are not multiplexed at the sensor interface level so that; in the event of a complete digital system failure, analog readouts of these parameters may still be obtained.

Except for the line voltage applied to power supply inputs, no safety hazards exist in the sensor or the signal condtioning areas. Operating voltages are typically from 5 to 25 Vdc, and protection is provided against excessive currents.

As stated previously, the circuitry described can be implemented by using present technology. Control systems having many of the same characteristics and requirements are currently being developed.

It is anticipated that, at the time of detailed design, nearly all of the circuitry will be available in monolithic integrated form to replace the hybrids currently used in some areas. This reduces the number of interconnections required and provides a corresponding increase in reliability.

Leakage and high on-resistance of currently available analog switches limit the number of sensors that can be multiplexed to one interface circuit. Constant improvements are being made in these devices, and it is anticipated that multichannel monolithic MOS switches will make possible a considerable reduction in size as compared to present systems.

The reliability of the electronics is a function of the number of connections and of the number and types of components. Figure 102 illustrates the effect on connection and component count of multiplexing at various points in the signal paths. Using, for purposes of illustration, three sensor outputs to be addressed individually and converted to 3-bit numbers in an output register, the connection and component counts are as indicated below.

System	Components	Connections
A	20	84
B	18	50
C	12	38

In the actual AILSS design, utilizing many sensors and a longer word length, this multiplexing technique becomes even more attractive. A second stage of multiplexing, at the outputs of the interface circuits, will allow optimum use of this technique with the hardware that will be available when the detailed design work is done. A savings in volume, weight, and cost contribute to the value of this approach. No limited-life components are included in the design.

Operation of the signal conditioning circuitry is controlled by a central processor that requires no crew time during normal operation. The maintenance troubleshooting time is minimized by means of a standard signal injection technique at both the analog and digital levels. This technique is implemented by connecting one channel of each multiplexer to a reference voltage. When these channels are addressed, they should, of course, produce a known binary number output. Any deviation in the output number indicates a malfunction in that signal path. The addresses in which the wrong numbers appear give an indication of the fault location. The central processor interprets this information and displays the results as part of its fault isolation routine. Circuitry is on replaceable circuit boards to allow rapid repair.

In the initial design phase, the technique described is suitable for any number of transducer channels and any reasonable degree of accuracy. The choice of data and addresses word lengths places a limitation on the number and accuracy of data channels so that conservative design is required to allow some growth capability.

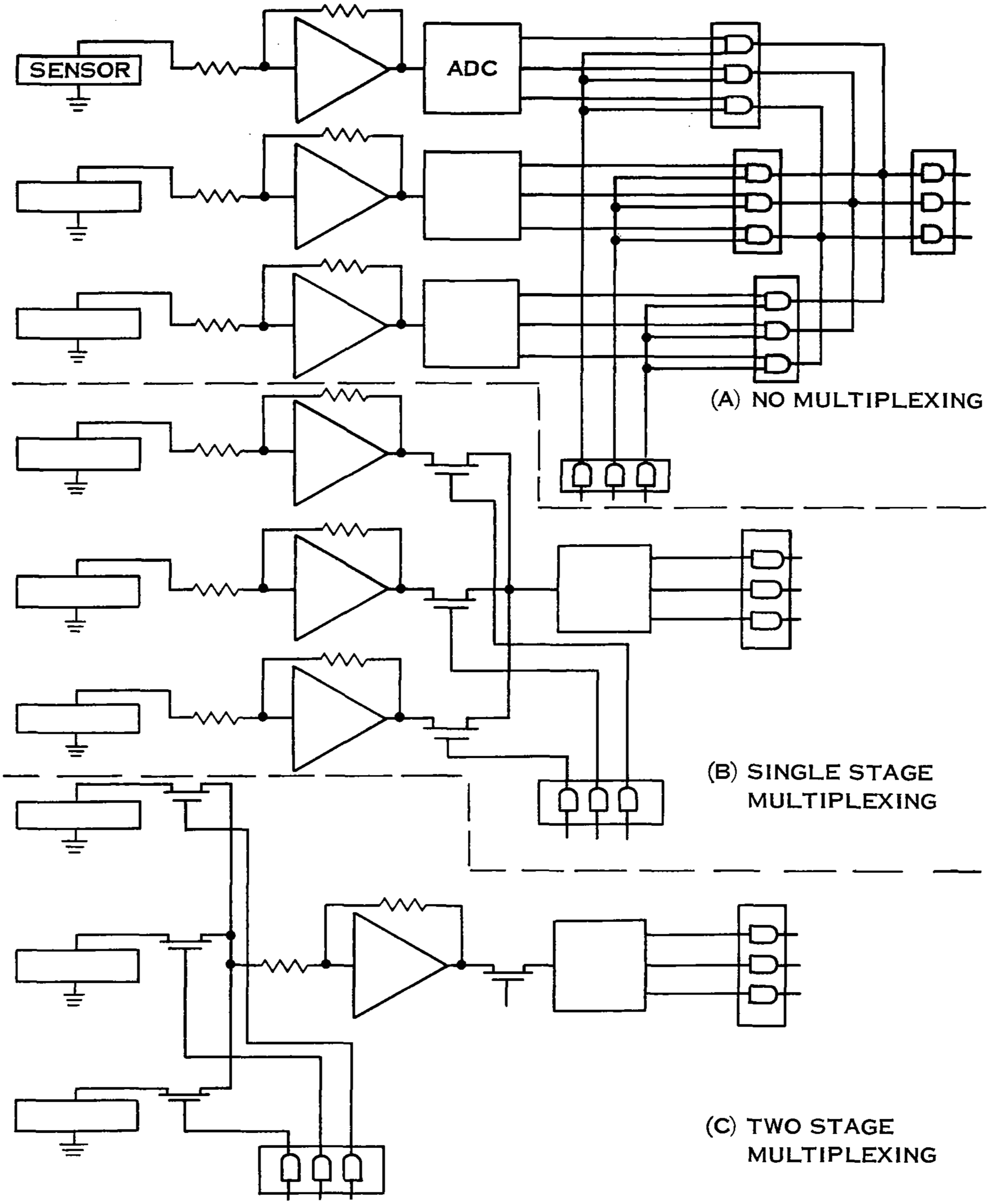


Figure 102. Multiplexing Level Effect

SENSORS AND INSTRUMENTS

Sensors installed directly in the AILSS subsystems are conventional and are used for control. They are also used by the central processor as part of the fault detection and isolation routine. The specific sensors primarily are for temperature, pressure, fluid flow, and electrical sensing.

Instruments consist of sensors and circuitry used for continuous monitoring of water potability and cabin atmosphere, with a separate readout for each parameter. Although these instruments are not connected directly to any AILSS subsystem for sensing, their output signals are used for control in some instances, and by the central processor in performing fault detection and isolation.

Table 49 summarizes the parameters to be monitored, the media, the selected method or instrument, and the monitoring period.

Temperature

Temperature sensors are chosen to provide the necessary accuracy and temperature range. They may be divided into three classes: high temperature and moderate accuracy, narrow temperature range and moderate accuracy, and extreme accuracy for any temperature range. For the high temperature and moderate accuracy classification, the thermocouple type is considered acceptable. For a narrow temperature range and moderate accuracy, the most applicable sensor is a thermistor modified by series and parallel resistor networks to give acceptable linearity over the specification range. For extreme accuracy, a platinum resistance probe is used to obtain the necessary accuracy and stability.

Pressure

Pressure sensors are either conventional bonded strain-gage or differential transformer pressure transducers. All the above types are suitable, and selection would be on the basis of detail specifications conformance and system compatibility. Partial pressures are measured by individual electro-chemical devices.

Fluid Flow

The fluid flow sensors would normally be of the free-turbine, magnetic rate

TABLE 49

SENSORS AND INSTRUMENTS

Parameter measured	Media	Selected method instrument	Monitor period
Electrical	Voltage/current	Voltage & current sensors	Continuous
Fluid flow	Liquid	Free-turbine/magnetic pickup	Continuous
Total pressure	Air/liquid	Pressure transducer	Continuous
Temperature	Air/water	Temperature transducer	Continuous
O_2 partial pressure	Air	Individual Sensor or Mass spectrometer	Continuous
N_2 partial pressure	Air		
CO_2 partial pressure	Air		
H_2O partial pressure	Air		
Combustible gases	Air	Combustible gas detector/ heated catalyst sensor	Continuous
Total hydrocarbons & methane	Air	Measured both as trace contaminant & combustible gas	Continuous
Trace contaminant	Air	Gas chromatograph	Periodic
Dewpoint	Air	Cold mirror hygrometer	Continuous
Radioactivity	Air/water	Geiger-Muller counter	Continuous
Microbiological:			
Physical	Air or Liquid sample	Volume displacement/ Coulter counter	Periodic
Chemical	Air or Liquid sample	Bioluminescence/Luminscent biometer	Periodic
Biological	Air or Liquid sample	Standard growth/ microscope	Special
Water Potability:			
Physical	Liquid sample	Physiological senses	Routine
COD	Water	Carbonaceous analyzer/ Total organic carbon analyzer	Routine
pH	Water	pH meter	Continuous
Conductivity	Water	Conductivity meter	Continuous
Microbiology	Water	Bioluminescence/Luminscent biometer, same as microbiological/ chemical monitor	Routine
Toxic metals & chemicals	Water	Spectrophotometer	Special

pickup classification. The electrical output of these sensors is a signal rate that is proportional to fluid flow. The measurement of pressure drop accross an orifice provides an alternative for some applications.

Electrical

The electrical sensors provide voltage and current signals from controlled outputs and limit micro-switches on solenoid-operated valves.

Atmospheric Constituent Measurement

A sensor system capable of providing adequate accuracy and service life in the measurement of partial pressures of O_2, N_2, H_2O, and CO_2 is the mass spectrometer-based instrument of the type developed by Perkin-Elmer and Beckman. Local displays are provided for each of the four gases, and each output is used in digital form by the central processor as well as for the local partial pressure control loops.

Drift in the instrument occurs in such a way that all output signals change by the same percentage, and the ratios of output signals remain constant. This feature allows two easy tests of instrument operation and calibration. By summing the output signals in a properly scaled operational amplifier, a total pressure signal may be obtained (minus a small trace contaminant partial pressure). Comparison with the total pressure obtained by the independent cabin pressure instrument gives an indication of instrument operation. A second comparison, H_2O partial pressure with the independently measured atmospheric dewpoint, provides a crosscheck in the event of disagreement in the first test. This test capability is well worth the expense of redudant instrumentation because of the importance of the accurate sensing of these parameters. The two reference measurements are simple and stable.

One instrument is undergoing further development to add the capability of measuring CH_4 and total hydrocarbons. The total hydrocarbon collector is designed to totalize a mass to energy range that may be proportional to total hydrocarbons. The CH_4 and total hydrocarbon measurements are valuable additions to the instrument and will be utilized if available for this application.

The instrument has been used in the O_2 and N_2 pressure control loops in the 60-day manned chamber test conducted by McDonnell-Douglas. Its measurement accuracy is 1 percent for O_2 and N_2 and 2 percent for CO_2 and H_2O. The detectable limit of H_2O and CO_2 is 0.2 torr. The instrument weight is 6.5 lb, volume 0.116 ft^3, and power consumption 3.7 watts. The addition of the measurement capabilities mentioned does not significantly change these figures. Either instrument is recommended for the AILSS for measurement of partial pressures of O_2, N_2, H_2O, and CO_2.

Combustible Gas Measurement

Combustible gas detection instruments make use of a heated catalyst sensor. In operation, the reaction of oxygen and combustible gases on the surface of the catalyst causes a temperature rise, unbalancing a temperature-sensitive bridge. The resulting electrical signal is processed and read out as a percentage of the lower explosive limit (LEL).

Instruments of the type required for this application are manufactured by General Monitors, Inc., and Mine Safety Appliance, Instrument Division. The sensors are installed in moving air streams for zero-gravity operation so that there is no reliance on convective flows. An instrument is placed in each compartment. Each instrument provides a local readout as well as sending data to the central processor. The readings are normally on a 0 to 10 percent LEL scale. Provision is included for switching to 0 to 100 percent LEL scale. Calibration is required at 30-day intervals by an integral calibration circuit and, as required, by application of a test gas.

Instrument weight is estimated to be two pounds and power consumption about 30 watts. No hazard is associated with operation of the equipment, and crew time is a few minutes per month for a routine calibration check. Because of the variation in the LEL of different gases, calibration is to the gas having the lowest LEL.

This instrument is presently in the development phase and should be qualified for flight by 1970.

Total Hydrocarbon and Methane Measurement

Independent measurement of total hydrocarbons in addition to combustible gas measurement is desirable. There is, however, a safety hazard associated with the hydrogen flame required by total hydrocarbon sensors. For this reason, and because hydrocarbons are measured both as combustible gases and as trace contaminants, no special instrument is included for the measurement of total hydrocarbons. The mass spectrometer discussed previously, however, is undergoing development to provide a measurement of total hydrocarbon concentration as well as methane.

Trace Contaminant Measurement

There is no generally accepted definition of contaminant measurement requirements. Even though some compounds consistently appear on lists of contaminants, no definitive list of contaminants with appropriate measurement levels has been generated.

The measurement technique outlined here is based on the assumption that a suitable contaminant control system can be designed and that such a system will be proven by test to be adequate contaminant buildup and predictable upsets. The basic problem, then, is to assure that the control system will work properly. As a secondary problem, it is necessary to assure that some fault, such as severe equipment overheating, will not generate contaminants at a rate exceeding the design limits of the control system.

Eighteen contaminants, listed in the Atmospheric Contaminant Control section of this report, are chosen for the secondary measurement. A concentration of 0.10 ppm (parts per million) is specified as the minimum measurable level for each component. Although prolonged exposure to a complex mixture of contaminants at this level should be avoided, the ability to detect and identify gases at a concentration of 0.10 ppm makes it possible to act soon enough to keep exposure time low. The presence of any one component at this concentration is acceptable. Measurements are made alternately at the inlet and outlet of the trace contaminant control subsystem as a means of testing subsystem operation.

A dangerous limitation of the trace contaminant measurement capability is the possibility of a large number of compounds, at concentrations just below the detectable threshold, being dangerous in combination. The possibility that some fault could cause this condition, without any one compound exceeding the measurable limit, seems extremely remote. The detection and identification of one compound gives the crew an indication of a fault. If, having been warned, the crew is unable to make a correction, an additional measurement capability would not be of any great assistance. Improvements in measurement state-of-the-art will be reflected in the final instrument selection.

Three methods of measurement - gas chromatography, mass spectrometry, and infrared intereference spectrometry - are considered for this application.

Gas chromatography. - Gas chromatography is, at present, nearest the state of development required for AILSS trace contaminant measurement. References have been found to two multicolumn gas chromatographs built to meet application requirements in recent years.

One instrument, using a special molecular sieve, carbowax, and Apiezon columns, has been found capable of detecting 1 x 10^{-9} mole quantities of 24 trace contaminant compounds as well as oxygen, nitrogen, and water. A second instrument reported in the November, 1967, issue of Aerospace Medicine uses three columns and three cross-section ionization detectors. It has detected trace levels of a number of other contaminant compounds. Columns in this instrument are packed with molecular sieve 5A. They are teflon-coated with a liquid phase of 60 percent Amine 220 and 40 percent Carbowax 4000, and a mixture of 10 percent Carbowax 20M with Chromosorb G.

Current laboratory chromatographs are capable of detecting levels of all the compounds listed in the trace contaminant control section of this report. It is anticipated that 1973 technology will make possible at least this performance in miniaturized instruments designed for space applications.

The potential safety hazards of the gas chromatograph are in the areas of high pressure storage of carrier gas and radioactivity in the detector ionization source. The pressure hazard was minimized in one of the instruments mentioned by proof-testing the 6000-psi titanium pressure vessel at 9000 psi and by releasing pressure prior to reentry with an explosive-actuated dump valve which also served as a rupture disc if the pressure exceeded 9000 psi.

Radioactivity of the detector ionization source is from a tritium beta source. Adequate shielding for the low energy radiation is provided by plastic structural members of the ionization chamber and the surrounding package. It is not necessary to open the ionization chamber in flight, and only massive damage to the instrument would expose the source. Nonradioactive detectors are available, but they have the disadvantages of low sensitivity and/or a requirement for hydrogen flames with associated gas storage requirements, poor stability, complex peripheral equipment, poor reliability, and large volume.

The compounds referred to are difficult to measure in 100 ppb concentrations, and some development work is required on a gas chromatograph for this application. Miniaturization of basic-process chromatographs has been accomplished, however, and no breakthough is required for development of a useful instrument for this application. This method of trace contaminant measurement is presently in the development phase and could be qualified for flight by 1973.

Mass spectrometry. - Miniaturized mass spectrometers have not been developed for flight measurement of trace contaminant gases. At least two instruments suitable for spacecraft use, however, have been developed for monitoring O_2, N_2, CO_2, and H_2O levels. Both instruments discussed previously for atmospheric constituent measurement use multiple collectors for simultaneous continuous monitoring of several gases. Both are magnetic deflection types miniaturized for space applications.

One instrument uses 12 collectors, but test results have only been published for the four gases. Laboratory-type mass spectrometers of current design, used with cryogenic traps, are capable of measuring atmospheric trace contaminants to concentrations of less than one ppm.

The analysis of mass spectra is complicated by the fact that double charges occur, molecules are fragmented in the ionization chamber, and isotopes of the various elements are present, resulting in a spectrum of particles of various masses for each compound rather than a single peak. Although each compound has a unique spectrum, analysis of a complex mixture results in an output requiring considerable computation in order to determine the componennts of the mixture. Computers are now used in order to avoid the tedious manual computations otherwise required. Interpretation of more mixtures becomes very difficult without computer assistance.

Although only 18 compounds have been chosen for measurement, these must be analyzed in the presence of hundreds of other possible contaminants. As the contaminant mixture becomes more complex, the need for preparation of the components to be measured by the mass spectrometer increases. With mixtures of the complexity likely to appear in the AILSS, the mass spectrometer becomes a sophisticated detector for a gas chromatograph. Although this combination of instruments is practical, it is not needed to meet the measurement requirements outlined previously.

Infrared intereference spectrometry. - The intereference spectrometer presents almost the same spectrum analysis problem as the mass spectrometer. In this instance, however, the spectrum takes the form of small variations in a very irregula baseline curve, and the desired data absorption bands tend to be masked by background bands. There is, then, a requirement for interpretation of instrument output before analysis can begin. It would be possible, with a dual-beam dual-detector instrument, to use background cancellation in order to reduce this problem. This technique would require identical source and detector spectral characteristics as well as drift tracking in order to be effective. Lower basic sensitivity as well as a number of the problems listed for the mass spectrometer results in unacceptable performance ratings for this instrument at this time. This method could be developed for flight as early as 1978, and is presently in the breadboard phase.

Selection: trace contaminant measurement. - Table 50 summarizes the selection ratings.

Absolute criteria: The interference spectrometer instrument is rejected for the AILSS mission because its performance is not acceptable. The other two candidates, the mass spectrometer and the gas chromatograph, met the basic absolute requirements although they have significantly different relative ratings.

TABLE 50
EVALUATION SUMMARY - TRACE CONTAMINANT INSTRUMENTATION

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts		
		Mass spectrometer	Gas chromatograph	Interference spectrometer
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3
Absolute	Performance	Fair	Very good	Unacceptable
	Safety	Good	Fair	Very good
	Avail./Conf.	Fair	Very good	Fair
				Eliminated
Primary	Reliability	Fair	Fair	
	Crew Time	Good	Good	
	Equivalent Weight	Good	Good	
		Eliminated		
Secondary	Contamination		Very good	
	Interfaces		Good	
	Flexibility		Very good	
	Growth		Good	
	Noise		Very good	
	Volume		Good	
	Power		Fair	
			Selected	

The performance of the mass spectrometer is downgraded because of its heavy dependence on the preconcentrator for the separation of complex mixtures. It is assumed that the AILSS atmosphere will contain trace levels of hundreds of compounds because available lists indicate that this can be expected. Inadequate separation of components in this application results in degraded if not unusable equipment performance.

With regard to safety, the gas chromatograph is rated Fair because of the need for high pressure, stored helium and the low energy radioactive ionization source for the detector. The mass spectrometer is downgraded because of a high voltage shock hazard. This hazard has been effectively managed in the past and is regarded as less important than the performance and availability characteristics of the candidate methods.

Basic instruments of both types are either available now or may be safely anticipated. The preconcentrator required for the mass spectrometer, however, is less readily available. It appears likely that, in addition to the concentration function, it must be nearly equal to a gas chromatograph in separation capabilities. It seems unlikely that this performance can be achieved without actually using a gas chromatograph.

Primary criteria: A review of the primary criteria for both candidates produces identical ratings.

As a result of the identical ratings on the primary criteria, the absolute criteria relative ratings are reviewed, and the gas chromatograph is selected. This selection is based on the significantly better performance of the gas chromatograph and the higher probability of obtaining an instrument suitable for the AILSS mission. A review of secondary criteria indicates there is no reason for reconsidering the selection.

A gas chromatograph proposed by Beckman is considered representative of the flight instrument. The package dimensions are 7" x 6 3/4" x 8 1/2" and package weight is nine pounds, excluding stored carrier gas. Power dissipation is 40 watts peak and 7 watts average over its 120-minute measurement cycle.

The helium carrier gas is stored at 4000 psi in six-inch titanium spheres, each containing enough gas for 150 cycles. Measurements are made at the inlet and outlet of the contaminant control subsystem at 24-hour intervals in routine operation. In the event of crew illness or unusual odors or other indications of contaminant buildup, interim measurements will be made.

Instrument operation is controlled by an electronic programmer. The crew time is held to a minimum. Calibration is by injection of gas samples with known contaminant concentration. The analog output signal of the chromatograph is converted to digital form, in increments of a few seconds, for storage on tape and in the trend analysis memory. At the completion of a measurement cycle, data are available in a compressed time mode for analysis and on any desired time scale for telemetry.

Dewpoint Instrumentation

Dewpoint instrumentations of both the cold mirror and the aluminum oxide type are considered for this measurement.

The aluminum oxide sensor consists of an aluminum strip, anodized by a special process to provide a porous oxide layer. A very thin layer of gold is evaporated over this structure. The aluminum base and the gold layer from the two electrodes of what is essentially an aluminum oxide capacitor. Water vapor transports through the gold layer an equilibrates on the pore wall. The number of molecules absorbed on the oxide structure determines the conductivity of the pore wall. Each value of pore wall resistance provides a distinct value of electrical impedance, which in turn is a direct measure of the water vapor pressure.

The cold mirror dewpoint instrument consists of a thermoelectric dewpoint hygrometer and associated controls and temperature readout circuitry. In operation, a sample of gas is directed into the hygrometer chamber, consisting of a thermoelectric cooling module with mirror surface and optical sensing configuration, and power is applied to cool the mirror. Light emanating from a lamp is reflected by the mirror to a photoresistor. The photoresistor feeds a control which continues to cool the mirror to a point where condensation forms on its surface. The control continually adjusts itself in order to maintain a constant dew layer thickness on the mirror surface. When the dew on the mirror is of constant thickness, it is in equilibrium with the partial pressure of the water vapor, and the temperature of the mirror is at the dewpoint temperature.

The aluminum oxide instrument can be developed for flight in 1974, whereas the cold mirror instrument is estimated as early as 1970. Both instruments are presently in the prototype development phase.

The cold mirror dewpoint instrument is selected for use in the AILSS mission, as vendor information indicates that the aluminum oxide type does not provide adequate stability for this application.

Radioactivity Instrumentation

Measurement techniques for ambient radioactivity will be determined when the sources of radioactive contamination are defined. The basic instrument is a Geiger-Muller counter or scintillation counter. If identification of isotopes is required, a scintillation detector using a thallium-activated sodium iodide crystal coupled to a multichannel pulse height analyzer will be used.

Microbiological Monitors

Microbiological monitoring is required to ensure a safe, habitable environment and a potable water supply for the crew. The various life support subsystems place different demands on the microbioligical monitoring equipment. The potable water supply must be continuously monitored while the atmosphere must be checked at frequent intervals.

The criteria listed below are used to judge the qualifications of the microbiological monitors. No single monitor meets all the requirements; therefore, a multiple choice is necessary.

1. Space application - operate in zero-gravity environment
2. Speed - rapidly determine microbial presence
3. Sensitivity - detect critical levels of micro-organisms
4. Accuracy - determine levels without significant errors
5. Automation - function automatically
6. Specificity - detect living micro-organisms
7. Reliability - operate for mission duration
8. Identification - identify micro-organisms

The methods for detection of micro-organisms are physical, chemical, and biological procedures. The physical method is used to detect the presence of the contaminants, the chemical to detect the viable organisms, and the biological to detect and identify the type of organism.

These methods are evaluated according to the established criteria listed above. The groups and their promising candidates are presented in table 51. Other procedures were studied in addition to the methods listed but are not discussed here. These include molecular sieve columns, electrophoresis, partichrome analysis, polarimetry, cytopathology, and centrifugation. The methods chosen for description: 1) are designed specifically for spacecraft use or are developed flight hardware, 2) are proven devices capable of performing some monitoring function significantly better than related devices, or 3) may not be available but employ a technique which shows good potential for performing a monitoring function.

TABLE 51

MICROBIOLOGICAL MONITORING METHODS

Type	Method	Space application	Speed	Sensitivity	Accuracy	Automation	Specificity	Reliability	Identification	Flight Availability
Physical	Light scattering	G	VG	VG	VG	VG	NS	G	NS	1975
	Volume displacement	G	VG	VG	VG	VG	NS	G	NS	1971
	Electron microscope	F	G	F	F	F	NS	F	NS	1980
	Light microscope	VG	VG	F	G	F	NS	G	NS	1971
Chemical	Antibodies	G	F	VG	G	F	VG	G	VG	1978
	Bioluminescence	G	VG	VG	VG	VG	VG	F	NS	1976
	Chemiluminescence	G	VG	VG	VG	VG	NS	G	NS	1976
	Gas chromatography	F	G	VG	G	VG	VG	G	G	1977
	Phosphorescence	G	VG-F	G	G	G	NS	G	NS	1979
Biological	Bioturbidity	G	F	VG	VG	F	VG	G	NS	1976
	Substrate change	G	F	F	F	G	G	G	NS	1978
	Respiration	G	F	F	F	G	VG	G	NS	1978
	Enzyme activity	G	F	F	F	F	VG	G	NS	1978
	Infrared detection	G	G	F	F	G	G	G	NS	----
	Standard growth	VG	F	VG	VG	G	VG	VG	G	1975

NOTE:

VG = Very good
G = Good
F = Fair
NS = Nonspecific

Physical devices: -

Light scattering: Microbia particles can be detected by light scattering devices, or nephelometers, in the atmosphere or in liquids. The procedure is nonspecific but rapid, sensitive, automated, and available.

Volume displacement: Electronic volume displacement counters are well known for pollution studies or particulate matter. The nonspecific counting and sizing of particles can be used for presumptive evidence of microorganism presence by monitoring the 0.5 to 5 micron range. Various bacterial monitors grow the microbes in a liquid nutrient and perform comparative counts to establish organism contamination. The procedure is rapid, sensitive, automated, and available, but nonspecific.

Electron microscope: Examination using the electron microscope is possible. However, size and power requirements are large, and sample preparation is too complex for use in a spacecraft on a routine basis.

Light microscope: The light microscope in its simplest design is lightweight (less than ten pounds), has lower power requirements (intermittent use of a 6-volt source), and is reliable. For counting purposes, it is insensitive to viable organisms and would require a concentration of water or atmosphere samples. It would be very useful in examining colonies of micro-organisms, and for reasonable applicability, zero-gravity staining procedures must be developed. Microbiological stains permit the rough categorization of some organisms, but its specificity is still limited.

Chemical devices. -

Antibodies: Preflight prepared fluorescent antibodies react with specific microorganisms and are detected by fluorimetric procedures. Virus and toxin detection can also be performed. The technique is rapid, sensitive, accurate, and available. It does not distinguish between living and dead microbes. However, antibodies for each organism are required.

Bioluminescence: Biological luminescence is based on the detection of light emitted by certain enzymatic reactions with specific bioproducts as cofactors. The two cofactors currently detected are adenosine triphosphate, or ATP, (using a firefly luciferase) and flavine mononucleotide, or FMN, (using a bacterial luciferase). Both ATP and FMN are found in all living cells, and detection of either in a sample is presumptive evidence of the presence of organisms. The method is sensitive, specific, rapid, automated, and accurate. It is the most promising of the monitoring procedures.

Chemiluminescence: A recent chemical method uses the reaction of a luminescent chemical (luminal) with cellular extracts. The technique is similar to the bioluminescent method described above. The procedure is rapid, accurate, and fairly sensitive. The chemical also reacts to oxidizing agents and free radicals, thus reducing specificity. The technique shows excellent speed, good sensitivity, and accuracy. The test distinguishes viable organisms. Complete automation can be attained.

Gas chromatography: This technique fingerprints micro-organisms by the relative amounts of component cellular organic molecules present. The method is still in the research phase. Presently a pure culture of an organism is required: mixtures cannot be analyzed. If the fingerprints of closely related strains can be distinguished by this method, it would be a relatively rapid (less than 1 hour) method to identify contaminant colonies. It is because of this potential that the technique is considered here.

Phosphorescence: This method is similar to the preceding one in that a fingerprint is obtained from a culture of micro-organisms. In this case, the culture is irradiated and the decay pattern of the phosphorescence (or fluorescence) is measured. The same considerations hold as for gas chromatography, but the technique is less sensitive and does not show as great a distinction between strains.

Biological devices: -

Bioturbidity: As organisms multiply in a liquid culture, their growth can be followed by monitoring the turbidity of the sample, by observing the increase in light scattered or by the culture or the decrease in transmitted light. Devices to make turbidimetric measurements of growth have been designed for automated use in spacecraft. These instruments are quite sensitive, but the accuracy of measurement if low because the growth may not begin immediately after inoculation and back extrapolation, therefore, is not reliable. The devices are automatable.

Substrate change: The pH of a growing culture will vary, and this variation can be measured automatically and continuously as an indication of growth. Devices have been designed employing this technique for space missions. As with the turbidity method, detection is slow and inaccurate and depends on selecting the proper growth medium for a particular organism.

Respiration: A Geiger-Mueller tube is used to detect $C_{14}O_2$ evolved by growing organisms in a medium containing a variety of C_{14}-labeled carbon sources. This is an automated technique designed for use in the Gulliver device to detect extraterrestrial life. Comments relating to speed, sensitivity, accuracy, and choice of proper growth medium are similar to the bioturbidity method.

Enzyme activity: This technique detects enzyme activity in a culture grown from a contaminated sample. Devices are available (the Multivator) in which phosphatase activity is automatically detected when phosphate is split from a fluor-phosphate compound. The compound becomes fluorescent only when the phosphatase is removed, and this can be followed with a fluorimeter. Comments relating to monitoring criteria are similar to the bioturbidity method.

Infrared detection: Bacteria liberate heat as a result of their metabolic activity. A sensitive infrared detector should be able to detect living organisms rapidly and with good accuracy. The developmental status of devices employing this technique is not known, but it is included in these considerations because of its potential capability.

Standard growth: The standard method of detecting bacterial contaminants in water or air is to filter a sample through a microbial membrane and expose the membrane to a growth medium. After incubation, colonies are visible on the membrane. This technique is very slow but sensitive. If replicate samples collected on different membranes are exposed to several different media and different growth conditions, some identification by genus is possible. The variety of media required to distinguish between organisms is large, and a restricted subset would probably have to be selected to make the essay practical. The method is a required routine analytical procedure to carry on any mission.

Another approach is a bacteria growth monitor, which utilizes growth in a solid (agar) medium inside a capillary tube. As the colonies reach a minimal size, they scatter sufficient light to be detected by photometrically scanning the capillary. This technique gives an estimate of the number of viable organisms in the original sample. Development time is about the same as for the liquid culture method. This technique avoids the use of liquid cultures but has disadvantages associated with preparing the agar filled capillaries.

Selection: microbiological monitor. - Because no candidate excels in all the microbiological monitoring functions, and because the monitoring requirements for the various EC/LS subsystems differ, the selection process leads to the use of a group of methods.

Volume displacement: The volume displacement method is the most rapid general technique for detecting microbiological contaminants. It is automated and essentially ready to fly. This method detects a time-dependent increase in particle size ratios, which is evidence of growth.

Bioluminescence: The bioluminescent technique is the current method of choice for demonstrating the presence of viable organisms. The main drawback of this method is the six-month life expectancy of firefly luciferase in storage. Bacterial luciferase may be similarly unstable. If modification or additives cannot extend the life of the enzymes, the procedure is not feasible for the AILSS mission. However, bacterial cultures can be carried for enzyme extraction in flight.

Standard growth: The standard growth procedure is included because of its flexibility and ease of operation. It offers a means of examining micro-organisms directly. A microscope is required for the examination. The membrane procedure is recommended by the Space Science Board.

Other considerations: Microbiological monitors for spacecraft use have evolved rapidly, and improvements in available designs can be expected. Areas remain, however, where better methods, perhaps totally new ones, are needed. One area in particular, the identification of micro-organisms, is currently plagued by lack of a rapid and sensitive procedure. The standard microbiological screening procedure for bacteria and fungi requires long growth times and many test media; the antibody approach requires preselection of types to be detected and may not be completely specific at the species level. A device which could rapidly fingerprint small numbers of any type of micro-organisum is needed to fill the gap. Gas/liquid chromatography and ultraviolet laser phosphorescence should be further developed for this purpose.

Another problem area is the detection and identification of viruses, which are restricted to antibody techniques and tissue culture. Gas chromatography also shows some promise here.

Techniques for stabilizing biological materials, especially enzymes, for periods of two years or more would permit the development of more techniques similar to the bioluminescent method. The demonstration that luciferase can be kept in an active state for the 500-day mission is an important step to be taken. Chemiluminescence is another method which is promising and should be investigated.

Water Potability Monitors

The parameters indicative of water pollution and/or potability as well as measuring devices useful in determining the levels of contamination are discussed in the Water Management section. The following paragraphs discuss the instrumentation required to establish water potability.

Organoleptic evaluation. - Drinking water must be acceptable to the astronauts. The physiological senses, acting as analytical instruments, establish turbidity, color, odor, taste, and other parameters of drinking water standards. Space flight, however, can affect organ sensitivity or function. Therefore, supporting instrumentation can be of value.

Chemical oxygen demand (COD). - The organic contaminants in water undergo chemical reaction, with rapid depletion of oxygen. Direct reading oxygen analyzers can be adapted to COD determinations. The units are self-generating, and require no power themselves.

Recent combustion/infrared techniques measure either total carbon or chemical oxygen demand. The units are a carbonaceous analyzer, which oxidizes organics to carbon dioxide, and a total organic carbon analyzer.

Conductivity. - The specific conductance measurement is the result of the actual and relative concentrations of ionic species in solution, which reflects mainly the inorganic content of the water. Conductivity must be measured along with pH, for it is only valid with a pH of 6-9, beyond which the measurement is more influenced by hydrogen and hydroxlions than by other ions present.

Water conductivity is measured by sensing alternating current between two inert probes installed in the pipe carrying potable water to the storage tank. The probes provide an electrical connection to a column of water acting as a resistor in a non-conductive pipe section. This resistor is connected as one leg of an AC bridge. The output voltage of the bridge is a function of water conductivity and is amplified, rectified, and filtered to obtain a DC voltage. The use of AC excitation reduces electrode degradation and liquid polarization. This concept is presently in the development phase and can be ready for flight by 1973.

Another type of instrument used for solution conductivity is the toroidal conductivity analyzer. In this system, a noncoducting tube, with a solution contact made at each end of the tube, wired closed to complete the loop, is placed through a toroidal coil. With an applied AC voltage on the toroid, the output seen at the ends of the flow-through tube is proportional to the conductivity if the solution. This concept is presently in the early breadboard phase and could be available for flight by 1972.

The toroidal conductivity analyzer has been chosen for the AILSS mission because electrodes are not required in the solution which increases reliability.

The output of the conductivity meter is displayed and multiplexed in the same way as the atmospheric monitors. There is also valve control circuitry to divert the water for reprocessing in the event that conductivity rises through a predetermined limit. This prevents contamination of stored potable water if the processor should malfunction.

The determination of the acid or alkaline strength of a solution is performed accurately by an electrometric pH meter. This meter has a 1.3 watt power requirement and can operate on single or continuous automatic cycles.

Microbiology. - The determination of the microbiological quality of drinking water is a paramount importance. The specific instrumentation required is discussed in the preceding Microbiological Monitors section.

Special analysis. - The long-term ingestion of reclaimed water, however, requires the elimination of toxic cationic and anionic moieties. On occasion, the water should be tested for the heavy metals, complex organic compounds, or other chemical ions. Ground tests will establish the incidence of toxic materials in processed water prior to flight, but tests should be performed during the mission. A sudden onset of illness after ingesting water is presumptive evidence of metal poisoning. The techniques considered for performing special analytical tests are discussed below.

Atomic aborption or flame photometry: These techniques are similar in nature Flame photometry measures emitted energy; atomic absorption measures absorbed energy. For metallic elements, atomic absorption is the more suitable procedure. Both atomic absorption and flame photometry are available in one unit but not as flight hardware. The open flame required in flame photometry is considered unacceptable.

Mass spectrometry: The passage of ions through electrical and magnetic fields results in varied radii or curvature. By fixing the radius and adjusting the voltage or strength of the magnetic field, particles can be collected and/or recorded. However, application of mass spectrometry to water samples will require special techniques. This technique is presently in the research phase, and is estimated to be developed for flight by 1983.

Spectrography: The emission spectra produced by the excitation of metallics in an electrical arc are recorded for analysis. The spectrograph detects most metallic ions and some nonmetallics. The arcs for the determinations, however, present a possible unacceptable safety hazard.

Spectrophotometry: Sample analysis is performed by spectrophotometric measurement of the absorption of visible, infrared, or ultraviolet light. Depending on the type of light used and the instrumentation, practically all measurements for compounds of properties listed in table 27 can be performed. Difficulties arise with the utilization of specimen cells in zero-gravity as well as in some pre-analytical procedures. This technique is presently in the prototype phase and could developed for flight as early as 1976.

Standard wet chemistry: Standard methods of wet chemistry are available for separation and identification of water contaminants. The procedures are time consuming and require adaption to a weightless environment.

Chromatography: Paper-strip chromatography separates inorganic cations and anions, which are then developed by special reagents for identification purposes. This method is currently in the prototype phase, and could be developed for flight by 1975.

A simplified technique by Elbech and Gabra (Chemist-Analyst; 52 (2): pp 36-40) can be adapted to space flight requirements. Other schemes are available for organic materials, including gas and gas/liquid chromatography.

Selection - special analysis: Spectrophotometric analysis is selected for its ability to analyze water samples for potability parameters. The following discussion summarizes the information considered in this evaluation. The evaluation is shown in table 52.

Six techniques are considered for performing special analytical tests to determine the presence of toxic heavy metals and other chemicals affecting the safety of water for drinking purposes. NMR spectroscopy, polarography, and electroanalysis were considered briefly, but their basic characteristics preclude their use in spacecraft within the AILSS mission period.

All of the candidates meet the AILSS absolute criteria with the exception of atomic absorption and spectrography, which do not meet the safety criteria due to their open flame or carbon arc and are therefore eliminated.

With regard to primary criteria, all candidates rate Good on reliability, except for mass spectrometry, which rates Fair due to a lower MTBF then the other candidates. On crew time, both the wet chemistry and paper chromatography concepts, assuming sufficient development for space application, require considerably more crew time and training compared to the other two candidates. All four candidates had comparable equivalent weights.

On the basis of primary criteria, the spectrophotometry concept is selected because of its higher overall rating. A review of the secondary criteria shows satisfactory characteristics.

Development work on the spectrophotometry concept is required in the areas of zero-gravity sample preparation and pre-analytical procedures to obtain hardware acceptable for use in space. Other than this, the methodology of the concept is within the present state of the art.

Summary. - The following units are recommended for the determination of water potability on the AILSS:

TABLE 52
EVALUATION SUMMARY - SPECIAL ANALYSIS TECHNIQUES FOR WATER POTABILITY

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Candidate Concepts					
		Atomic absorption	Mass spectrometry	Spectrography	Spectro- photometry	Standard wet chemistry	Paper Chromatography
CRITERIA	DESIGN	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Very good	Fair	Very good	Good	Good	Good
	Safety	Unacceptable	Good	Unacceptable	Good	Fair	Good
	Avail./Conf.	Fair	Good	Good	Good	Good	Good
		Eliminated		Eliminated			
Primary	Reliability		Fair		Good	Good	Good
	Crew Time		Good		Good	Fair	Fair
	Equivalent Weight		Good		Good	Good	Good
			Eliminated			Eliminated	Eliminated
Secondary	Contamination				Good		
	Interfaces				Good		
	Flexibility				Good		
	Growth				Good		
	Noise				Very good		
	Volume				Very good		
	Power				Very good		
					Selected		

Routine Analysis:

1. Organoleptic evaluation
2. COD analyzer
3. Conductivity meter
4. pH meter
5. Microbiological monitors (discussed in the Microbiological Monitors section); These are volume displacement, bioluminescent and standard growth techniques.

Special analysis:

Spectrophotometer

Recommendations

The following are considered to be areas which require additional research and development.

1. Development of satisfactory automated test units that measure pH, chlorides, temperature, oxygen, and conductivity.

2. Investigation of indicators of pollution and their relationship to the potability of water.

3. Investigation of a multiple monitoring system with routine analytical instruments.

4. Reduction to flight hardware of the carbonaceous analyzer and/or the total organic carbon analyzer.

5. Investigation of laser excitation in spectrographic analysis as a technique for heavy metal determination.

INSTRUMENT CALIBRATION

Calibration may be defined as a comparison of instruments, one of which is a standard of known accuracy, to detect, correlate, and/or adjust any variation of the instrument being checked. Normally, calibration is accomplished in a laboratory under controlled conditions. Highly skilled personnel are utilized, and routine procedures are followed. The AILSS application is not routine, however, and variations of the calibration concept are utilized.

Calibration in a zero-gravity environment presents many undefined areas that require considerable study. It is assumed the general AILSS instrumentation requirements are such that operational checks rather than complete rigorous calibrations will suffice for most instrumentation.

All proposed monitoring equipment must be initially evaluated under simulated spacecraft conditions to:

1. Ensure that the equipment adequately performs the monitoring task
2. Determine the degree and frequency of the operational check effort necessary to maintain instrumentation accuracy.

One approach in satisfying the need to verify instrument accuracy is to carry and/or derive onboard reference standards to be used to validate spacecraft instrumentation. A second technique includes the use of highly accurate instruments, with known long-term stability and accuracy. This minimizes the need for calibration and, in certain instances, completely negates it. This approach requires considerable effort to define the spacecraft hardware, accuracy requirements, and degree of required redundancy.

Electrical Calibration

The following techniques are used to provide electrical calibration capabilities.

Voltage. - The spacecraft power supply is used as the basic source to obtain a reference voltage. A solid-state voltage regulator is used to transform the spacecraft voltage into a usable reference standard. To obtain the greatest accuracy, the regulator is maintained at a constant temperature.

Resistance. - Very stable precision resistors are utilized as resistance references.

Variations in resistance values due to either ambient or self-heating temperature changes are minimized by derating the accuracy value of the resistors from actual requirements.

Current. - A standard reference current is obtained by using the reference resistors in conjunction with the reference voltage.

Pressure, Temperature, Flow, and Test Gas

Pressure . - Pressure transducers with a high accuracy and stability are available and are used as reference standards as well as operational monitors.

Temperature. - Temperature is monitored by means of stable platinum resistance thermometers and/or platinum-platinum rhodium thermocouples for calibration purposes. These temperature measuring devices are known to exhibit high stability over long periods of time. If a check is required, however, the basic spacecraft systems may be used to provide a series of single temperature test points. Liquid nitrogen at the boiling point provides a single temperature calibration point. In a similar manner, potable water may be frozen and remelted to provide a second temperature test point by utilizing the melting point of H_2O. The exact temperatures of the boiling liquid nitrogen and melting ice may be calculated quite simply if the pressure is known. In this manner, it is possible to use some of the fundamental characteristics of the spacecraft to provide suitable standards that are derived on board, thus saving weight, complexity, and cost.

Flow metering standards . - It is assumed that all onboard flowmeters are of a variety to minimize the need for frequent or extensive recalibration. In general, the head loss meters fill this need. Orifice plates are used for large flow rates. The plate is checked dimensionally by merely inspecting its diameter and contour. For lower flow rates, laminar flowmeters are used. A reference flowmeter is maintained to periodically cross-check all low flowmeters. To obtain a voltage analog signal, the orifice or laminar flowtubes probable will be used in conjunction with differential pressure transducers.

Test gas. - Equipment such as CO_2, O_2, and N2 analyzers and gas chromatographs require introduction of a gas of known concentration to verify their operation and accuracy. Bottled gases with known trace contaminants are available. Storing gas for periods of about four months, however, may result in changes in contaminant concentration. This may be due to mechanisms such as container outgassing, catalytic action of the gas container, or by selective adsorption or absorption by the container. A study should be initiated to determine the materials best suited for gas storage.

ELECTROMAGNETIC INTERFERENCE

Probably the most important advantage to be gained from planning instrumentation at the time of system planning is the ability to assure electromagnetic compatibility. Instrumentation added as an afterthought seldom provides completely satisfactory operation and usually costs more than if it had been planned as a part of the system.

EMI engery transfer (noise) passes through several media, conducted noise can be caused by cable induction, common power source coupling, switching pertubations and incompatible filter marriages causing ringing.

Radiated noise can be impressed on susceptible circuits through case penetration and free space transmission. The degree of energy transfer effected is a function of the consideration given to cable selection, use and routing, grounding, shielding, packaging, and actual circuit design. An approach to the grounding, wiring, shielding, suppression, and filtering for the AILSS is given to serve as a guide for the system. Detailed component and system design and test work will follow good EMI engineering practice to assure low radiated noise, compatibility within the system, and low susceptibility to externally generated noise.

Grounding

The grounding system for the AILSS involves the judicious use of both the multipoint and single-point grounding systems. The grounding system design must minimize or eliminate any coupling into low frequency, low level circuits such as the sensors; reduce radiation and coupling from circuits with radio frequency components; and preclude the development of inter- and intra-equipment potentials that can cause sensitive malfunction or degradation.

Wiring

Wiring coupling is a great contributor to noise problems in densely packaged equipment and in cable bundles. Wire-to-wire capacitance (in addition to mutual inductance) transfers energy and increases the noise. Hence, if high dielectric constant insulation (such as Teflon) is used, this noise level is reduced.

It is important, however, that the packaging be such that the combination of the ground plane return and point-to-point wiring is used for the computer. Cans used for the chips must be grounded to the ground plane (chassis) in addition to the returns. If possible, voltage busses will be provided for power supply voltages for the computer circuits. If such busses are supplied, insulation between the bus and chassis will be used to provide capacitance to ground for noise bypassing with the bus used to reduce $L\frac{di}{dt}$ generation.

Externally routed wiring (and internal wiring) is routed and grouped to minimize EMI coupling. AC input from the generator is routed through a separate connector over twisted wiring. Sensor wiring is divided into two groups via separate connectors to separate low and high level signals. Actuator drive signals are routed over shielded twisted pairs via a common connector.

Shielding

The necessity for an integrally constructed, shielded housing is apparent, because the equipment must neither radiate nor be susceptible to EMI levels. The internal construction of the AILSS is such as to provide internal isolation via barrier shielding between power supply, computer, and interfacing circuits.

In general, then, it is preferred that the housing be constructed of non-anodized or conductive material finished with Iridite or Alodine to provide conductivity with corrosion protection. Where access is not required, the housing is seam welded. Where access plates or covers are used, the plates and covers are affixed by screws, and the plates are mounted via r-f gaskets on clean surfaces. Connectors have conductive mounting surfaces and are mounted via metal gaskets with neoprene-like impregnant on clean surfaces.

Suppression and Filtering

The numerous switching functions required within the AILSS present a need for RFI and line transient suppression. Externally generated interference must be attenuated by power and signal line filters. The definition of suppression and filter circuitry must be determined by calculation as design data become available. The performance, analytical, and design criteria set forth in applicable military specifications will be observed in the design phase. MIL-STD-461, MIL-STD-462, MIL-STD-463, MIL-B-5087B, and MIL-C-5541, for example, will be utilized in design work performed at that time.

SELECTED EC/LS SYSTEMS

CONTENTS

SELECTED EC/LS SYSTEMS

GENERAL DISCUSSION

The results of subsystem synthesis to meet the total system requirements for the three designs defined in the specification portion of the Conduct of Study section are presented in this section. Three EC/LS system designs are defined which are tailored for the three electrical/thermal power supplies stated in the general mission requirements. A fourth system is also presented which with modifications, will be compatible with any of the three power supply types. Each of the three specific designs are presented as complete systems. The fourth system is a flexible one, and it must be viewed as a baseline for integration with each power supply. Table 53 presents a summary of the four EC/LS subsystem designs. A total equivalent weight and power summary of all designs is shown in table 54.

Except for the implementation of particular heating requirements, the three selected EC/LS designs are very similar. This is because of essentially similar weight penalties assigned to the power sources and because importance is placed upon reliability and crew stress in the subsystem selections. Another factor that contributes heavily to the similarity of the selection is the study conclusion that high-temperature, toxic heat transport fluids should be avoided within the pressurized cabin. Subsystem selections using high-temperature process fluids scored low on maintainability, and candidates are favored whose thermal needs are provided by either direct electrical or isotope heat, or by heat from a low-temperature heat transport fluid (200°F).

Power Supplies

At this point, it is desirable to review the three defined power supplies so that the differences in the selected systems for Designs 1, 2, and 3 are clearly understood. Present estimates of future solar cell and Brayton cycle electrical power penalties show, within a ±10 percent variation, remarkable agreement. Solar cell orbital penalties are projected to range between 458 lb/kW and 404 lb/kW for an earth orbital altitude of 250 to 300 miles. For Mars radius free flight, the estimated penalty for solar cells was 433 lb/kW, and the same value was estimated for Brayton cycle electrical power. Therefore, equivalent weight penalty for both the solar cell system designed for long duration flight and the Brayton cycle system is defined as 450 lb/kW. It is assumed that both electrical power generation systems deliver both 28 vdc and 110/220 3-phase ac power. No extra power conditioning charge is used in this study. The following is a description of the power system for each design.

Design 1. - With a solar cell power supply, this system must use either electrical resistance heating for thermal power, or the heat content of the thermal transport fluid at electronic equipment cold plate outlet temperatures (limited to 100°F). All power used is charged a penalty of 450 lb/kW.

Design 2. - This design uses solar-cell-generated electrical power also at a power penalty of 450 lb/kW. High temperature thermal power is made available in this system by radioisotope heat sources at an equivalent weight penalty of 50 lb/kW required. Local individual isotope heat sources and/or a central isotope heated transport circuit is available. Isotope source temperatures of up to 1600°F are possible, but liquid heat transport fluid temperatures above 200°F are not used in any of the subsystems selected. 1200°F isotope heat is used in the Waste Management subsystem but cabin air is used as the heat transport medium. Wherever a choice between electrical and isotope heating exists, isotope heating is preferred to minimize solar cell electrical power generation requirements.

Design 3. - Design 3 uses electrical energy provided by a Brayton cycle system at 450 lb/kW. Waste heat at the Brayton cycle radiator inlet is available to the EC/LS at 375°F, although only 200°F fluid is used in the system by using a liquid-to-liquid heat exchanger located outside of the cabin. A zero equivalent weight penalty is assumed for thermal energy used in the EC/LS system. The heat transport equipment weight is considered to be equivalent to the reduction in the Brayton cycle radiator weight to remove this heat. This thermal energy subsequently is degraded through use in the EC/LS processes and is rejected at a lower temperature (40 to 70°F) in the EC/LS radiator. A heat rejection penalty is charged for all heat rejected in the EC/LS radiator, regardless of the heat source. This is true for Designs 1 and 2 as well as 3.

SYSTEM INTEGRATION

Some broad aspects of system integration or synthesis are discussed in the Water Management and the Thermal Control section. More specific integration details of the three designs are included in this section. Actual integration of all four EC/LS designs (including synthesis of EC/LS subsystems and integration with the total vehicle) must consider in detail the following four factors.

1. Materials balance - required to define ranges and exact quantities not detailed in the general specification.

2. Energy balance - required to assure that all thermal and electrical quantities have been accurately included.

3. Subsystem interactions - considered to identify and define subsystems and vehicle operational interfaces.

4. Configuration considerations - included in a general sense to assure that vehicle and EC/LS hardware are compatible.

Design 3	Design 4
Water coolant loop providing 38 ± 2° F from radiator loop HX. Central 200° F water loop heated by Brayton cycle waste heat used for process heating	Coolant loop identical to Design 1, except waste control coolers as in Design 2. Central 200°F loop optional with isotopes or Brayton cycle heat.
Same as Design 1.	Same as Design 1.
Same as Design 1.	Same as Design 1.
Same as Design 1.	Same as Design 1.
Same as Design 2.	Catalytic oxidizer configuration as in Design 2 with electrical or isotope heater. Same sorbents.
Steam desorbed resin CO_2 sorbent. Steam purge regeneration. Central Brayton cycle waste heat loop generates steam.	Same as Designs 1, 2, &3, except optional 200°F heat process loop heating for steam generator in isotope and Brayton use.
Same as Design 1.	Same as Design 1.
Same as design 1.	Same as Design 1.
Same as Design 1.	Same as Design 1.
Vapor diffusion still for urine, flush, wash, & condensate H_2O. Heat of evaporation from Brayton heat loop, condenser in coolant loop.	Vapor distillation/compression still as in Design 1. Option to use multifiltration of condensate to reduce Design 2 power.
H_2O heated to & held at 160° F by Brayton heat loop. Demand cooling for consumption.	H_2O tanks held at 160°F by electrical heat or by 200°F heat process loop for isotope or Brayton use.
Vacuum decomposition of wet & dry wastes at 1200° F using electrical heat. Ash residue storage.	Same as Design 2, except optional electrical or isotope heat source.
Same as Design 1.	Same as Design 1.
Same as Design 1.	Same as Design 1.

TABLE 53

SUBSYSTEM SELECTION SUM

Subsystem	Design 1	Design 2
Thermal control	Water coolant loop providing 38 ± 2° F from radiator loop HX. Loop interfaces with all subsystems requiring process cooling.	Water coolant loop providing 38 ± 2° F from radiator loop HX. Central 200° F water loop heated by radioisotope used for process heat.
Cabin temperature & humidity control	Condensing HX's for temp & RH control. Variable speed fan for temp & coolant modulation for RH. Maintainable facewick H_2O separator.	Same as Design 1.
Ventilation	Separate circulation fans supplemented by cabin HX fans & bacteria control fans.	Same as Design 1.
Bacteria control	Separate fan units with high ΔP. Replaceable 0.3 micron filters.	Same as Design 1.
Trace contamination control	Central chemical sorbent canister for NH_3 control & electrically heated catalytic oxidizer with pre & post filter.	Central chemical sorbent canister for NH_3 control and local isotope heated catalytic oxidizer with pre & post filters.
CO_2 control & concentration	Steam desorbed resin CO_2 sorbent. Electrically generated steam purge regeneration.	Steam desorbed resin CO_2 sorbent. Steam purge regeneration. Central isotope heat transport loop used to generate steam.
Oxygen generation	Solid electrolyte reduction of CO_2 & H_2O. CO byproduct reacted to CO_2 & carbon (collected as solid) over catalyst.	Same as Design 1.
O_2 & N_2 storage	High press. (3000 psi) filament-wound bottle storage - one N_2 tank, four O_2 tanks.	Same as Design 1.
Pressure control	Total press. regulated by O_2 & N_2 inflow for leakage makeup. O_2 partial press. controlled by H_2O addition to solid electrolyte.	Same as Design 1.
Water reclamation	Vapor diffusion/compression still for urine, flush, wash, & condensate H_2O.	Vapor diffusion still for urine, flush, wash, & condensate H_2O. Heat of evaporation from isotope loop, condenser in coolant loop.
Potable water management	H_2O held at 160° F by electrical heat for bacteria control. Demand cooling for consumption.	H_2O heated to & held at 160° F by isotope heat loop. Demand cooling for consumption.
Waste management	Integrated vacuum decomposition of wet & dry wastes at 1200° F (electrical heat) with ash residue storage.	Vacuum decomposition of wet & dry wastes at 1200° F. Single local isotope used to heat four collector/incinerators. Ash residue storage.
Crew provisions	Zero-G full body shower wash, freeze-dried foods heated electrically. Reusable clothing with washing facilities.	Same as Design 1, except food heated by isotope heat in 200° F heat process loop.
Instrumentation	Local process control. Central computer for display. Data management, & trend analysis, automatic fault warning, telemetry.	Same as Design 1.

TABLE 54

TOTAL EC/LS EQUIVALENT WEIGHT AND POWER SUMMARY

	DESIGN 1 Solar Cell	DESIGN 2 Solar Cell/ Isotope	DESIGN 3 Brayton Cycle Waste Heat	DESIGN 4		
				Solar Cell	Solar Cell/ Isotope	Brayton Cycle Waste Heat
Power (Watts)						
Electrical	10 339	6 445	7 822	10 595	8 174	9 621
Thermal	0	7 638	5 814	0	3 064	1 340
Power Equivalent Weight (lb)						
Electrical	4 655	2 900	3 520	4 760	3 680	4 330
Thermal	0	382	0	0	153	0
Heat Rejection Weight (lb)	988	1 763	1 482	1 146	1 436	1 214
Hardware and Expendables Weight (lb)	20 110	20 132	20 001	21 120	20 284	20 205
Total Equivalent Weight (lb)	25 153	25 177	25 003	27 026	26 553	25 749

Electrical Power Penalty - 450 lb/kW
Radioisotope Power Penalty - 50 lb/kW
Brayton Cycle Waste Heat - No penalty
Radiator Penalty - 135 lb/kW
Isotope Radiator Penalty - 50 lb/kW
Weight includes Spares and Expendables

Following a discussion of the preceding factors, the four EC/LS designs are described. In order to minimize repetition of the common integration factors, the following format is used:

1. Design 1, using solar cell electrical power and electrical heating, is presented by describing all subsystems areas.

2. Design 2, using solar cell electrical power and isotope-supplied thermal power, is presented by noting the differences from Design 1. Reference to the Design 1 description is made on common factors.

3. Design 3, using Brayton cycle electrical power and cycle waste heat, is treated in a manner similar to Design 2.

4. Design 4, compatible with all of the power supplies, is presented with reference to each of the power supplies as applicable.

Materials Balance

The AILSS design is based on a closed metabolic process loop, with the exception of food supply. Figure 103 presents a general materials balance for a nine-man crew. Several factors affect the balance, including environmental effects such as temperature and relative humidity, and physiological effects such as diet and a possible shift in the RQ ratio (the ratio of CO_2 volume exhaled to O_2 consumed). System considerations also affect the balance. AILSS vehicle oxygen leakage is treated independent of the metabolic quantities, but, as discussed below, the gaseous storage facilities can be included as an integral part of the balance.

Material quantities are presented in the specification as maximum rates and/or ranges. These are usually adequate for initial subsystem definition, but they must be elaborated upon for total system integration considerations.

The following discussion presents the analysis and the rationale used in closing the AILSS mass balance.

Water balance. - The balance shown in Figure 103 is given for a 70° F cabin temperature. Since respiration, perspiration, urine, and water consumption rate vary with cabin temperature, a nine-man water balance is presented below as a function of cabin temperature (T_{cab}).

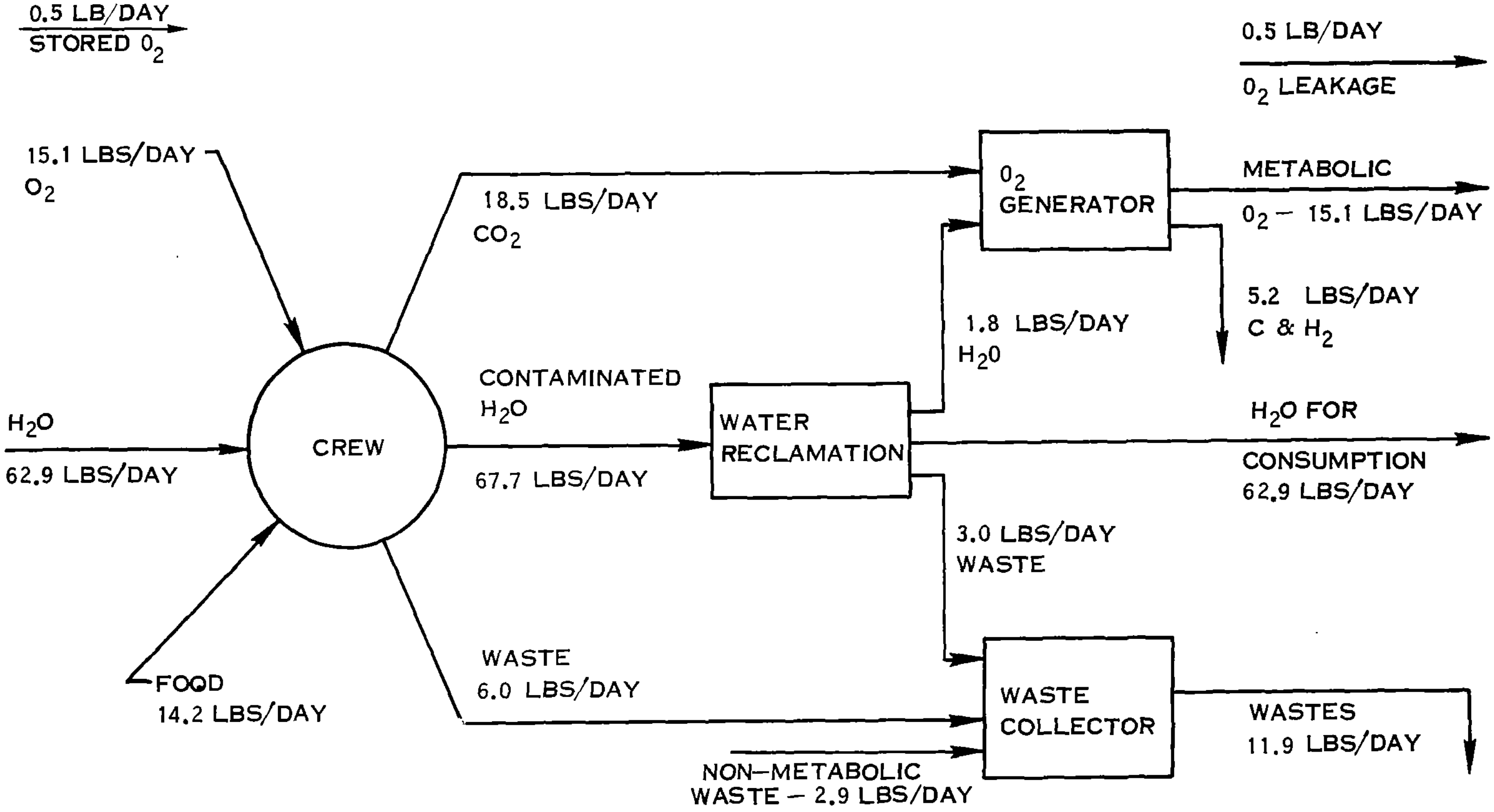


Figure 103. AILSS Materials Balance

Input (lb)	T_{cab} (°F)		
	65	70	75
Food and drink	59.51	62.91	69.81
In-Food	0.67	0.67	0.67
Metabolic water	6.36	6.36	6.36
	66.54	69.94	76.84

Output (lb)	T_{cab} (°F)		
	65	70	75
Resp./persp.	33.30	38.70	47.60
Urine	29.70	27.70	25.70
Food waste	1.29	1.29	1.29
Fecal H_2O	2.25	2.25	2.25
	66.54	69.94	76.84

This temperature effect is attributed to a change in the metabolic heat latent/sensible split due to heat transfer variations. Increased perspiration rates are accompanied by reduced urine rates and require additional water consumption. Wash water is not included in this balance since it is not metabolically consumed.

Of the total water output, only the amount consumed in food and drinking is required to be reclaimed. As discussed below, however, there is insufficient oxygen content in the reduction CO_2 to provide the metabolic oxygen requirements. Part of the excess water output is therefore required for oxygen generating by water electrolysis. Considering only the metabolic processes, additional water in excess of that required for consumption or oxygen generation may be discarded.

Oxygen balance. - For the AILSS selected diet of 2600 Kcal/man day, an average RQ of 0.89 is predicted. Oxygen consumption and carbon dioxide production in pounds/day is therefore:

O_2 consumption = 1.68 lb/man/day

CO_2 production = 2.06 lb/man/day

Sensitivity of these and other metabolic parameters for 2600 Kcal/man day due to RQ variations is shown in Figure 104.

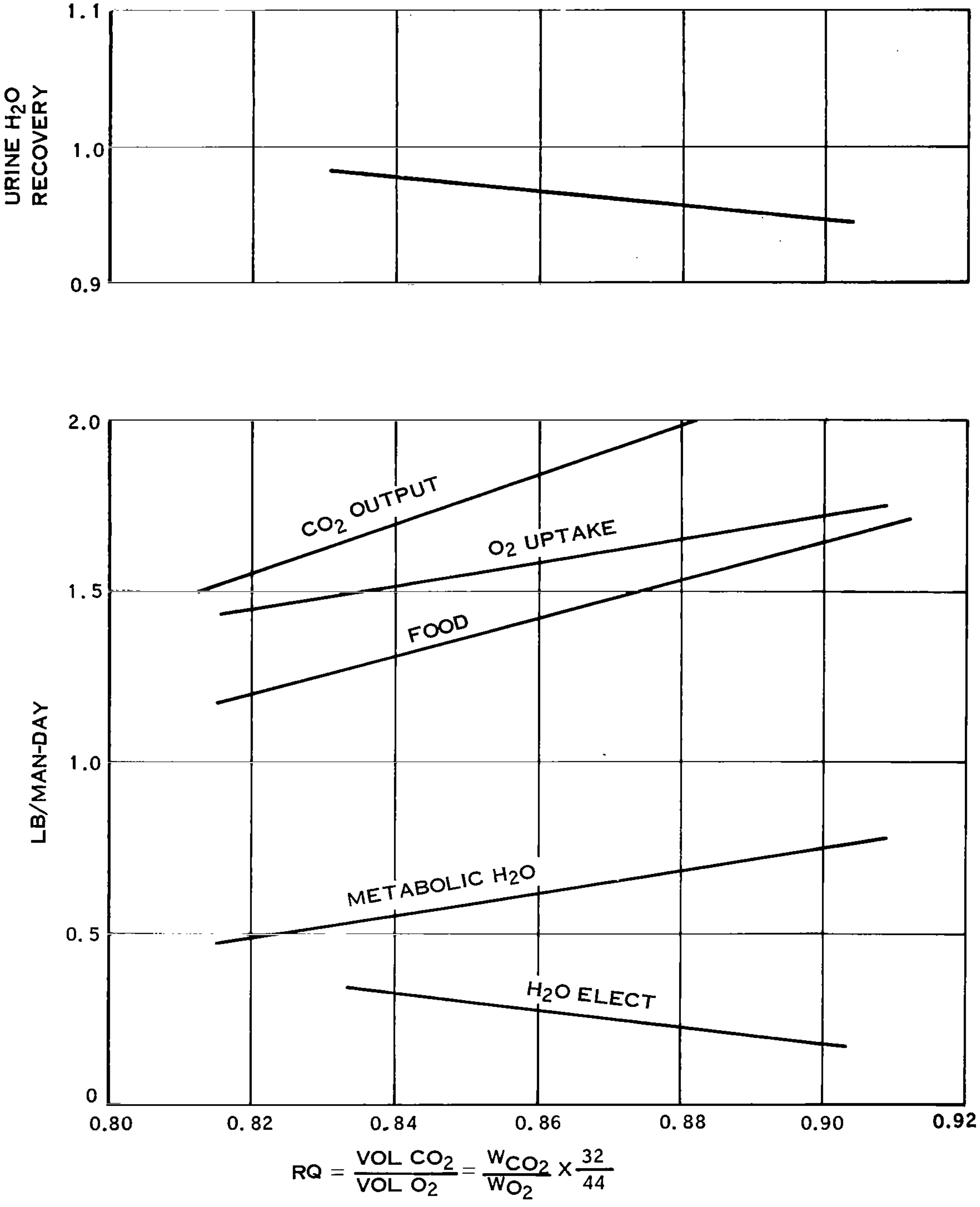


Figure 104. R.Q. Sensitivity at 2600 kcal/man-day

With a 100% reduction of CO_2 to oxygen and carbon, in a nine-man closed system oxygen recovered is 32/44 x 18.54 lb. The oxygen deficiency is then 15.12 - 13.48 = 1.64 lb/day. This may be supplied by electrolyzing 1.64 x 18/16 = 1.84 lb of water/day. This water is provided by the water management subsystem.

Additional oxygen is required for vehicle leakage and repressurization and is provided in the AILSS by high pressure gas storage. Actually, several mass balance possibilities exist which can include the makeup of vehicle oxygen leakage. Oxygen leakage may be made up by the electrolysis of stored or reclaimed waste water as previously discussed. Oxygen stores then would only be necessary for repressurization. This option is discussed in more detail in the Oxygen and Nitrogen Storage section.

Nitrogen is not involved in the metabolic processes in sufficient quantities to be considered, and it must be supplied by a storage system primarily for leakage makeup.

The oxygen deficit may be made up by carrying additional stored oxygen, normally used only for leakage to supply all or part of the 1.64 pounds per day of oxygen required to supplement the oxygen in the carbon dioxide. In this case, the 1.84 pounds per day of water need not be electrolyzed.

Contingency requirements. - Should a lower RQ of 0.85 occur during the AILSS mission, and assuming waste water is discarded, 95 percent urine water recovery efficiency will not be adequate for a balance. At an RQ of 0.85, a 0.41 lb/day water deficit will result. This reduction in water production will result in a corresponding reduction of water available from condensation of respiration and perspiration water. Should this condition occur for 500 days (highly unlikely), a net water loss of 205 pounds will occur.

Additional water losses are possible and must be considered in the water management design. As discussed in the water management section, a 300-pound contingency is provided to make up for effects of RQ shifts, water carryover in the vapor diffusion still residuum dumps, and anticipated amounts of nonrecoverable contaminated water possibly containing fecal water. Methods other than storage are possible to provide a contingency. They include 1) a high RQ diet, and 2) different water reclamation system selections. These alternate approaches are discussed in the subsequent paragraphs.

High RQ diet: The selection of a diet giving a higher RQ of 1.0 would favorably influence the water balance. A total of four hundred pounds of additional oxygen would be available from the collected CO_2 under this condition, thus decreasing the amount of water required for electrolysis.

Subsystem selection: An approach to eliminate the possibility of this water deficit would be to improve the performance of the vapor diffusion unit which appears feasible, or select an alternate urine water reclamation system capable of exceeding a 95 percent recovery.

Selection of one of the air evaporation concepts would provide the necessary water contingency. Assuming a 99 percent water recovery efficiency, an excess of about 1.0 pound of water per day could be reclaimed. This would provide a 500-pound water contingency over the 500-day mission. As discussed in the Water Management section, however, significant improvements in the long-term sterility characteristics of this system would be necessary.

The wet oxidation process considered in the waste control section trade-off could produce the additional water required; but its high weight, about 1000 pounds over the selected waste processing concept, is not competitive with stored contingency methods.

Another possibility exists, ignoring for the moment the potential bacteriological problems, in the recovery of water from food wastes, feces, and urine residuum. A water content of 3.69 to 5.58 pounds per day is available for further processing. A conservative fifty-percent recovery of this water will produce approximately two pounds per day, or 1000 pounds in a 500-day mission.

Dehydration of wet food wastes alone would require a less complex process which could possibly be accomplished in a conventional oven at a much smaller penalty. This approach is not taken because: 1) the nature of the wet wastes (nonfecal containing) are not defined nor is the hardware to accomplish the water recovery available and 2) a nominal water balance exists, so a trade-off must compare assumed hardware weights with a preliminary estimate of required water contingency. Increased leak rates, required water contingencies, and possibly fire fighting water requirements could influence the need for wet food waste water recovery, but it does not appear justifiable under the present AILSS conditions.

Summary. - The present metabolic water and oxygen quantities do balance but the margin is sufficiently low that the situation requires a contingent water inventory. Stored water (300 pounds) is selected to provide this contingency, because it provides a positive source of water, does not require extension of the state-of-the-art, and can be easily provided by filling three of the water tanks prior to launch.

The combination of metabolic and leakage oxygen quantities can be provided by the water and oxygen generation subsystems, provided that repressurization oxygen is supplied by storage. Although the possibility of supplying leakage oxygen by electrolysis of excess water exists, it depends on an accurate evaluation of vehicle leakage.

Energy Balance

Energy is added to the vehicle system in the form of electrical, thermal, and chemical energy, and is rejected in the form of heat (both sensible and latent) and chemical energy. No net work is performed on the environment so that a balance must exist. Designs 1, 2, and 3, using different electrical and thermal power sources, are discussed separately. The electrical and thermal power inputs are summarized below.

Power input (watts)	Design 1	Design 2	Design 3
EC/LS electrical	10 339	6 445	7 822
EC/LS thermal	—	7 638	5 814
Total EC/LS	10 339	14 083	13 636
Vehicle electrical (defined by spec.)	8 050	8 050	8 050
Total electrical	18 389	14 495	15 872

A more detailed breakdown of the EC/LS and vehicle loads is presented in tables 55, 56, and 57 for Designs 1, 2, and 3 respectively.

Design 1. - A total of 18 389 watts are consumed in Design 1. All of the 8050 watts of vehicle load are rejected internally as heat. The EC/LS peak power of 10 339 watts is converted to 7316 watts of thermal energy, an additional 1030 watts into chemical energy (in the form of carbon and oxygen), 915 watts is rejected overboard as a latent load during waste dehydration. The low thermal rejection is the result of peak heating values rejected over longer periods.

The remaining portion of the thermal energy is dissipated over a long period, thus reducing the required heat rejection rates. A similar situation exists with the steam desorbed CO_2 concentrator. Heat is rejected over a long period relative to the input and the heat rejection rate is therefore lowered. The 1030 watts of chemical energy in the carbon and oxygen could in fact be reclaimed by combustion. Actually, the carbon is discarded and the generated oxygen along with the food is metabolized by the crew, producing 1130 watts of energy. An exact balance does not result because the chemical energy content in the food is not the same as in the waste products.

Design 2. -The primary object of using a radioisotope heat source in conjunction with the solar cell electrical power supply in Design 2 is to reduce solar cell area required. By using isotope heating wherever thermal power is required, and by selecting subsystems using thermal power in preference to electrical energy while consistently applying primary selection criteria, a reduction of about four kilowatts was made.

TABLE 55
DESIGN 1 ENERGY BALANCE

Subsystem series	Input Power (watts)	Output Power, (watts)			
		Crew Cabin	Equip Cabin	Liquid Cooled	Total
Gas storage & pressurization	6	0	6	0	6
Trace contaminant control	112	112	0	0	112
Water reclamation & management	1 798	0	1 798	1 000	1 798
Thermal control circuit	400	0	0	400	400
Temperature, humidity & ventilation	2 017	935	1 082	0	2 017
Crew provisions equipment	510	510	0	0	510
Oxygen generation	2 244	0	1 222	0	1 222
Waste management	1 945	400	0	0	400
Carbon dioxide control	1 107	168	161	322	785
EC/LS instrumentation	200	0	200	0	200
EC/LS subtotal	10 339	2 125	3 469	1 722	7 316
Crew total metabolic		500	630	0	1 130
Vehicle loads					
Communications	4 000	1 000	1 700	1 300	4 000
Instrumentation	800	200	400	200	800
Control & guidance	1 000	100	0	900	1 000
Scientific exp.	1 500	0	1 450	50	1 500
Vehicle services	750	300	450	0	750
Vehicle load Subtotal	8 050	1 600	4 000	2 450	8 050
Total - EC/LS, crew, & vehicle	18 389	4 225	8 099	4 172	16 496

TABLE 56
DESIGN 2 ENERGY BALANCE

Subsystem Series	Input Power (watts)		Output Power (watts)			
	Electric	Isotope	Crew Cabin	Equip Cabin	Liquid Cool.	Total
Gas storage & pressurization	6	0	0	6	0	6
Trace contaminant control	80	224	304	0	0	304
Water reclamation & management	179	4 574	0	628	4 175	4 753
Thermal control circuits	500	0	0	100	400	500
Temperature humidity & ventilation	2 017	0	935	1 082	0	2 017
Crew provisions equipment	505	100	605	0	0	605
Oxygen generation	2 244	0	0	1 222	0	1 222
Waste management	435	1 500	435	0	1 500	1 935
Carbon dioxide control	279	1 240	168	161	1 190	1 519
EC/LS instrumentation	200	0	0	200	0	200
EC/LS subtotal	6 445	7 638	2 447	3 399	7 215	13 061
Crew total metabolic	—	—	500	630	0	1 130
Vehicle loads						
Communications	4 000	0	1 000	1 700	1 300	4 000
Instrumentation	800	0	200	400	200	800
Control & guidance	1 000	0	100	0	900	1 000
Scientific exp	1 500	0	0	1 450	50	1 500
Vehicle services	750	0	300	450	0	750
Vehical subtotal	8 050	0	1 600	4 000	2 450	8 050
Total - EC/LS, crew vehicle	14 495	7 638	4 547	8 029	9 665	22 241

TABLE 57
DESIGN 3 ENERGY BALANCE

Subsystem Series	Input Power (watts)		Output Power (watts)			
	Electric	Brayton	Crew Cabin	Equip Cabin	Liquid Cool	Total
Gas storage & pressurization	6	0	0	6	0	6
Trace Contaminant control	112	0	112	0	0	112
Water reclamation & management	179	4 574	0	643	4 110	4 753
Thermal control circuits	500	0	0	100	400	500
Temperature, humidity & ventilation	2 017	0	935	1 082	0	2 017
Crew provisions equipment	510	0	510	0	0	510
Oxygen generation	2 244	0	0	1 222	0	1 222
Waste management	1 945	0	400	0	0	400
Carbon dioxide control	109	1 240	75	84	1 190	1 349
EC/LS instrumentation	200	0	0	200	0	200
EC/LS subtotal	7 822	5 814	2 032	3 337	5 700	11 969
Crew total metabolic	—	—	500	630	0	1 130
Vehicle loads						
Communications	4 000	0	1 000	1 700	1 300	4 000
Instrumentation	800	0	200	400	200	800
Control and guidance	1 000	0	100	0	900	1 000
Scientific exp	1 500	0	0	1 450	50	1 500
Vehicle services	750	0	300	450	0	7 500
Vehicle subtotal	8 030	0	1 600	4 000	2 450	8 050
Total - EC/LS, crew vehicle	15 872	5 814	4 132	7 967	8 150	20 249

Total EC/LS energy requirements, however, increase to 14 083 watts. Factors contributing towards making these loads larger than those of Design 1 include the addition of a high thermal energy vapor diffusion distillation system and the use of radioisotopes which must always run at maximum output and may not be regulated as with electrical heaters. Catalytic oxidizer heater power is supplied continuously for two units, with only one normally operating. The isotope is therefore generating a constant 224 watts when only 112 watts are required. The peak heat power required by the waste control subsystem is 1500 watts, which includes 915 watts for initial waste dehydration. During the remainder of the cycle, only 315 watts are required for heat leak to the ambient, and the 915 watts must be discharged via the isotope loop high temperature radiator.

Design 3. - The maximum Brayton cycle waste heat temperatures of 375°F are insufficient to provide catalytic oxidizer and waste control subsystem temperature requirements. Electrical energy therefore is used for these purposes with an electrical power increase of about 1.4 kilowatts over that of Design 2.

Considering the 7.72 kilowatts of electrical EC/LS power, 8.05 additional kilowatts of assumed vehicle loads, and a Brayton cycle efficiency of about 40%, some 20 kilowatts of waste heat must be rejected by the primary Brayton cycle radiator. The 5.8 kilowatts of waste taken by the EC/LS is well within the available energy.

Subsystem Interactions

Certain operational requirements of functions affect more than one subsystem and must therefore be considered during system integration. The thermal control subsystem design, which involves interfaces with most other subsystems, is an example. This subject is fully discussed in the Thermal Control Subsystem section. Five other areas are mentioned in various subsystem sections but need further consideration from the overall system viewpoint. These areas are the following interfaces:

1. CO_2 concentration/O_2 generation
2. CO_2 removal/trace contaminant control
3. Temperature and humidity control/bacteria control/ventilation
4. Pressure control/O_2 generation
5. Microbiological control/EC/LS system

CO_2 concentration/O_2 generation. - Nitrogen impurity in concentrated CO_2 can cause excessive pressure buildup in the CO_2 reduction/O_2 generation unit. There are two general approaches to solving this problem: 1) design a CO_2 concentrator that supplies extremely pure CO_2 to the O_2 generation unit and 2) bleed off a purge stream from the O_2 generation unit so that nitrogen concentration will reach and maintain some steady state value. The second approach was chosen for the AILSS for reasons of reliability and availability.

Three ways of implementing the purge approach are: 1) purge overboard, 2) purge through the catalytic burner (to oxidize contained carbon monoxide), and 3) purge through a separate oxidizer to the CO_2 concentrator inlet. The third method is chosen for the AILSS to minimize penalty and interface complexity.

The other general approach to the problem is concentration of very pure CO_2. Three ways that this could be accomplished are: 1) use an electrochemical concentrator, 2) use a membrane concentrator, and 3) use a membrane final filter for the selected sorption process. As an alternate, should the purge approach prove impractical, the third method probably has the best chance for success in the AILSS. A small, membrane separator could be placed at the CO_2 accumulator outlet. A controlled purge from the accumulator outlet to the concentrator inlet would remove accumulated nitrogen. The minute quantity of nitrogen which would pass through the membrane filter into the O_2 generation unit would be released during carbon removal maintenance.

<u>CO_2 removal/trace contaminant control.</u> - Both the CO_2 concentrator and the trace contaminant sorbent canister require similar amounts of process air flow with similar pressure drops. They, along with the catalytic oxidizer, handle either all or part of the man-produced contaminants. Several arrangements of separate and combined fans, and series and parallel flow arrangements, may be considered.

The flow requirement for the trace contaminant sorbent is 50 cfm at 3.0 inches of water pressure drop. A 60 cfm flow at 4.0 inches of water pressure drop is required for the CO_2 concentrator. The catalytic oxidizer requires 3 to 6 cfm at a minimum pressure of 4.0 inches of water. Flow requirements of the sorbent canister and the CO_2 concentrator are similar enough to select a common fan in order to reduce the spares requirement. Three spares are required for each different fan, but only a total of four spares are required for two common fans. The catalytic oxidizer, because of its low flow requirements, may be conventiently located in parallel with either unit. Although independent fan units do have the advantage of flexibility, a desirable reduction in fan spares and system weight is obtained by using one fan for all three functions. An arrangement of installing the sorbent canister and the CO_2 concentrator ion exchange resin bed in series, and the catalytic oxidizer in parallel with these units, allows one fan to be used. Several other advantages are produced. First, a reduction in fan flow from 113 cfm (50 + 60 + 3) to 63 cfm allows the process flow to be distributed through the cabins at minimum penalty; and second, the series arrangement allows the catalytic oxidizer to be designed smaller for the high available pressure drop. A third advantage is the capability of operating both catalytic oxidizers on line with a subsequent near doubling of the process flow. A 5 percent flow reduction through the sorbent and concentrator branch, which occurs when this is done, will not affect performance.

<u>Temperature and humidity control/bacteria control/ventilation.</u> - High process flow rates and low-to-medium pressure drops are in common with the cabin heat exchanger, bacteria control, and ventilation fan flows. Shower air flow is a part-time operation

with flow and pressure drop requirements identical to those of the temperature and humidity control system. A common fan therefore is used for this application. A summary of the high flow fan selections is given below:

	No. of Units	Power each/total	cfm each	ΔP (in. H_2O)
Cabin temperature and humidity control (variable speed)	3	325/975 watts	1000	1.20
Bacteria control	3	230/690 watts	750	1.00
Circulation	2	100/200 watts	1500	0.20
Shower (identical to cabin unit)	1	325 watts (intermittent)	1000	1.20

The collective flow of the temperature and humidity control fans, bacteria control fans, and separate circulation fans provides the required cabin ventilation. Cabin configuration considerations affect the flows and locations of the fans used. Actual fan sizes and quantity depend on a detailed cabin layout to determine whether single large units or multiple units are to be used. With a set of specific fan sizes known, it will then be possible to fully investigate fan commonality, thereby reducing the number of spares. Only one such case, the shower fan, is assumed for the present designs.

Although not selected, a possibility of using a common fan for the cabin heat exchanger, bacteria filter, and circulation fan exists if relative flows and pressure drops remain as specified. The variable speed cabin heat exchanger fan motor could operate at three points. At full speed and matched to the cabin heat exchanger, 1000 cfm at 1.2 in. H_2O is produced. At part speed (about 70 percent), 750 cfm at 1.00 in H_2O would be possible when a bacteria filter is located in the duct. With the fan unloaded and used as a circulation fan, about 1500 cfm at a head of about 0.2 in H_2O is produced. This approach would result in a power penalty of about 250 pounds (or a total equivalent weight increase of about 125 pounds, including spares). Such a decision will have to be based on an actual cabin configuration, load definition, and cost study.

An alternate arrangement considered for the bacteria filter is to add it to the inlet of the cabin temperature and humidity packages. This arrangement results in some fan commonality possibilities, and it also provides partial protection of the condensing section of the heat exchanger from bacteria exposure. This is a partial protection because the filter is not absolute, and the presence of a single spore or bacterium can initiate a colony. Required fan pressure rise at the 1000 cfm/fan heat exchanger flow rate would increase power requirements by 750 watts, with a power equivalent weight penalty increase of 438 pounds over the proposed system. The advantages of locating the bacteria fans in the heat exchanger inlets are not considered sufficient to justify the weight increase.

Pressure control/O_2 generation. - Oxygen requirements are provided by both the gas storage subsystem and the oxygen generation subsystem. The storage system provides about 0.5 pounds of oxygen per day which is equal to the oxygen cabin leakage, while the solid electrolyte system provides about 15 pounds of oxygen per day which is equal to that of metabolic consumption. Pressure control then must involve both subsystems, as discussed in detail in the Pressure Control section. The oxygen partial pressure is controlled by varying water flow into the oxygen generation subsystem, CO_2 is fed into the reactor as collected independently of the water flow. This adds a requirement to the solid electrolyte control system, but no significant changes are required of the subsystem hardware. Stored oxygen is added to the cabin along with nitrogen to maintain total pressure only.

Microbiological control/EC/LS system. - Microbiological control for the AILSS employs filters, high temperature water storage, and steam sterilization for miscellaneous pipes and equipment. The first two of these control methods are useful for specific application in the water management system, but they are not techniques to provide an overall sterilization capability. For this, the use of steam is recommended.

Steam sterilization is specifically provided in the water management system, and all parts of that system can be steam-sterilized, including the urinals. Because of this, there is an indirect connection to much of the waste management system as well. In addition, the wet waste and fecal collectors, and most of the other equipment, such as heat exchangers, water separators, etc., interface with steam through several strategically-placed flexible insulated steam hoses.

While no problem of excessive humidity buildup exists from steaming closed loops, some consideration must be given to open loop steaming, in which the steam is exhausted directly to the cabin. Preliminary calculations indicate that for a 65° F cabin, only about 10 minutes of effective steaming (a rate of about 10 lb/hr) could be tolerated. With a 75° F cabin, however, about 30 minutes of steaming could be tolerated, and this should be adequate for most situations. If the steam generator provided for the AILSS does not have sufficient capacity for these situations, a second unit could be added at a reasonably low penalty.

Further consideration must be given to the problem of microbiological control if the use of steam were deemed impossible or impractical. Under these circumstances, a number of alternate approaches are possible and are discussed below.

Hot water: Much of the same control characteristics achievable with steam can be gained with the use of a hot water flush. It is somewhat less efficient because of the slightly lower temperatures involved.

Hot air: The use of forced circulated hot air is also an effective control mechanism, and its action is similar to steam and hot water. Dry heat, as opposed to wet heat, is not as efficient, and it requires a considerably longer time to achieve equivalent kill levels at a given temperature.

Toxic gas: The use of toxic gases, such as ozone or ethylene oxide, is also an effective bacteriological control method, but the gases are very difficult to control, and they are also very toxic to man. This method cannot be recommended for the AILSS.

Biocidal solutions: Various materials such as iodine, chlorine, alcohol, certain quarternary amines, silver ions, and hydrogen peroxide have been used to sterilize water and, in aqueous solutions, to sterilize equipment. Such materials are attractive because of their relatively low penalties and convenience of use. However, problems of toxicity and offgassing from the solutions must be solved. One of the most promising of these materials is silver ions, which can be generated as required.

Other methods: In addition to the methods discussed above, there are several other possibilities. These are irradiation, ultrasonics, electrohydraulics, and bacteriophaze. None of these are sufficiently developed for consideration at this time.

Recommendations: Under a condition where steam sterilization is not possible or is impractical, it is recommended that hot water be the first alternative considered. Following, the use of silver ions appears to be attractive though of perhaps lower overall efficiency. Finally, hot air may be considered.

Configuration Considerations

Essentially all subsystem selections are based on reliability/maintainability and total equivalent weight. Vehicle configuration did not enter into the selection procedure. As the total system is synthesized and the system schematic defined, some vehicle configuration assumptions must be made.

The general situation of more than one compartment presents process air transport problems, because air ducts penetrating pressure bulkheads must have isolation valves in the event of a compartment depressurization. Liquid, high pressure gas, and electrical line wall penetrations are not really affected but should be minimized.

Arrangement and interface process flow lines must be located such that plumbing is minimized. The actual impact of extensive piping is not apparent in studies such as this, but experience with present test beds and flight systems indicates that exceptional care should be exercised in the piping layout. Piping and fluid weight, heat and pressure losses, and potential leaks and hot spot dangers must be minimized or eliminated.

The cabin configuration assumed for the AILSS includes two compartments separated by a pressure bulkhead. They are considered to be the equipment compartment, and the crew and control compartment. Normal occupancy is assumed to be four to five men, with a nine-man capability. Further subdivisions are possible but were not considered, because the use of two compartments illustrates the integration consideration sufficiently. Figure 105 shows a block diagram of equipment location within the assumed vehicle configuration.

Equipment sizing is largely influenced by cabin size and arrangement. The following factors are considered:

Temperature and humidity control. - A sensible load split of about 2:1 exists due to the location of the majority of the heat producing equipment in one compartment. Latent load, however, is split evenly. These load variations are to be processed by three equal sized cabin heat exchanger units; two in the equipment compartment and one in the crew compartment. Use of two different size units, one for each compartment, would present a negligible weight saving.

Carbon dioxide and trace contaminant control. - As discussed previously in Operational Requirements, a combined carbon dioxide and trace contamination control package is selected. With multiple compartments it must be decided whether modular packages are located in each compartment or whether a single central process system is used. Considering both possibilities, the central process system is chosen for the AILSS mission.

Considering the primary selection criteria as applied to a modular configuration with respect to a central process system, it is apparent that:

1. MTBF will double for an arrangement using twice the number of parts
2. Crew time will essentially double for the same reason.
3. Total equivalent weight will increase by about 80 percent.

Secondary characteristics of flexibility and growth are at a stand-off with interfaces, so that a decision to use a central system may be justified on primary criteria.

Bacteria control. - Three 750 cfm units are provided to minimize the subsystem power penalty. The two units in the crew quarters provide the required low-level bacteria counts in the crew compartment with nine-man occupancy. A single unit is provided for the equipment compartment which has a normal occupancy of three to four men. The high flow rates required here make a centralized unit impractical.

Down times. - Cabin configuration also influences depressurization and repressurization time. Assuming 5000 cubic feet for each compartment, ample time is available for cabin isolation in the event of a meteoroid penetration assumed to be 0.5 inches in diameter. The cabin also acts as a large accumulator to allow for repairs during equip-

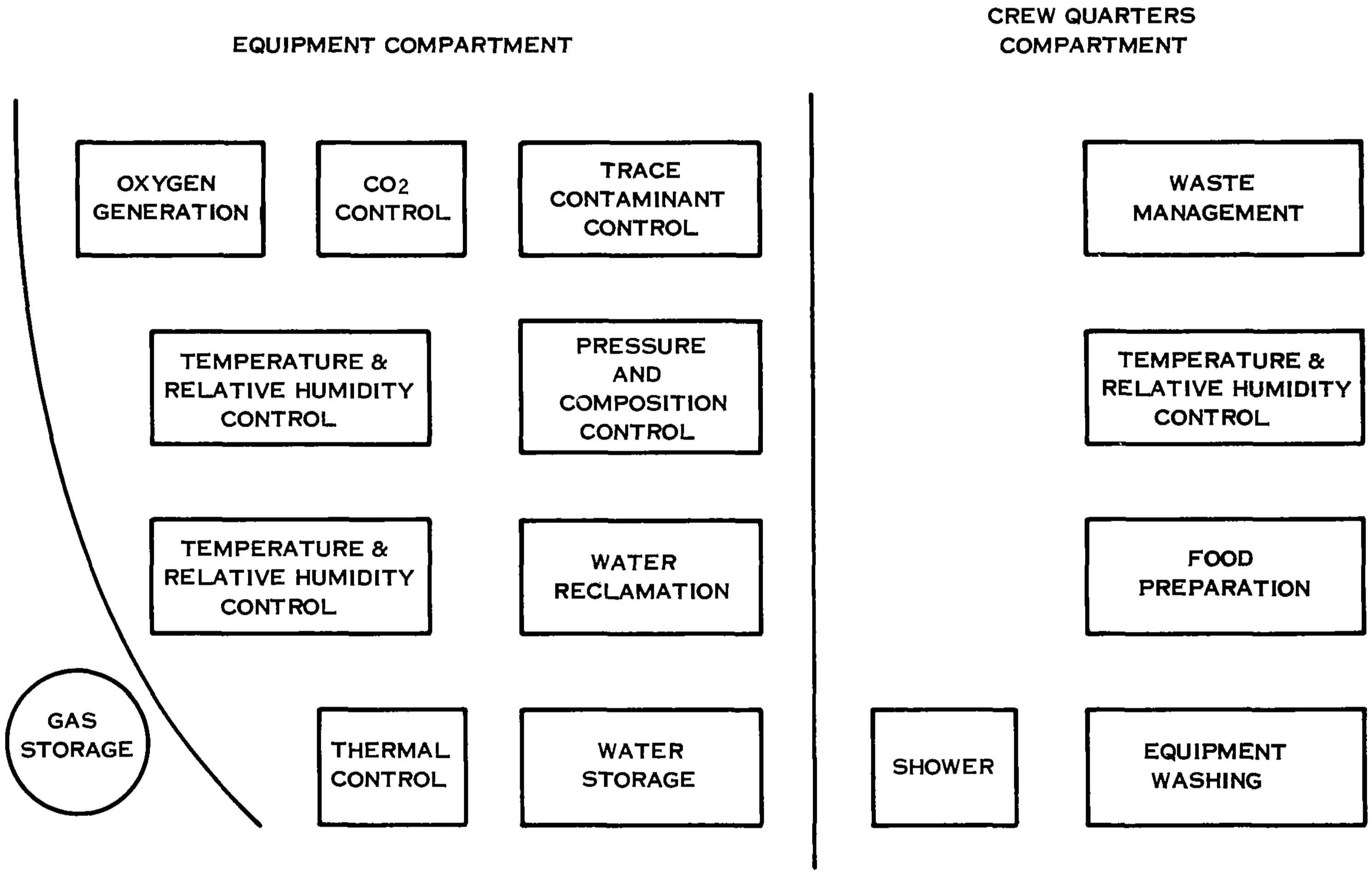


Figure 105. Configuration Schematic

ment downtime. This is true for CO_2 control, humidity control, and trace contaminant control. Temperature control, however, remains critical. It is anticipated that a cabin heat exchanger failure will result in an initial 20°F cabin temperature rise in about 10 minutes as the heat transferred to the lower temperature walls equals the cabin air load. This point is expected to be at a 90°F air temperature. The lower 70° to 75°F wall and equipment temperatures will help the situation due to available radiation cooling. Heat exchanger downtimes, however, should be held to a minimum to return to normal cabin temperature in a reasonable time.

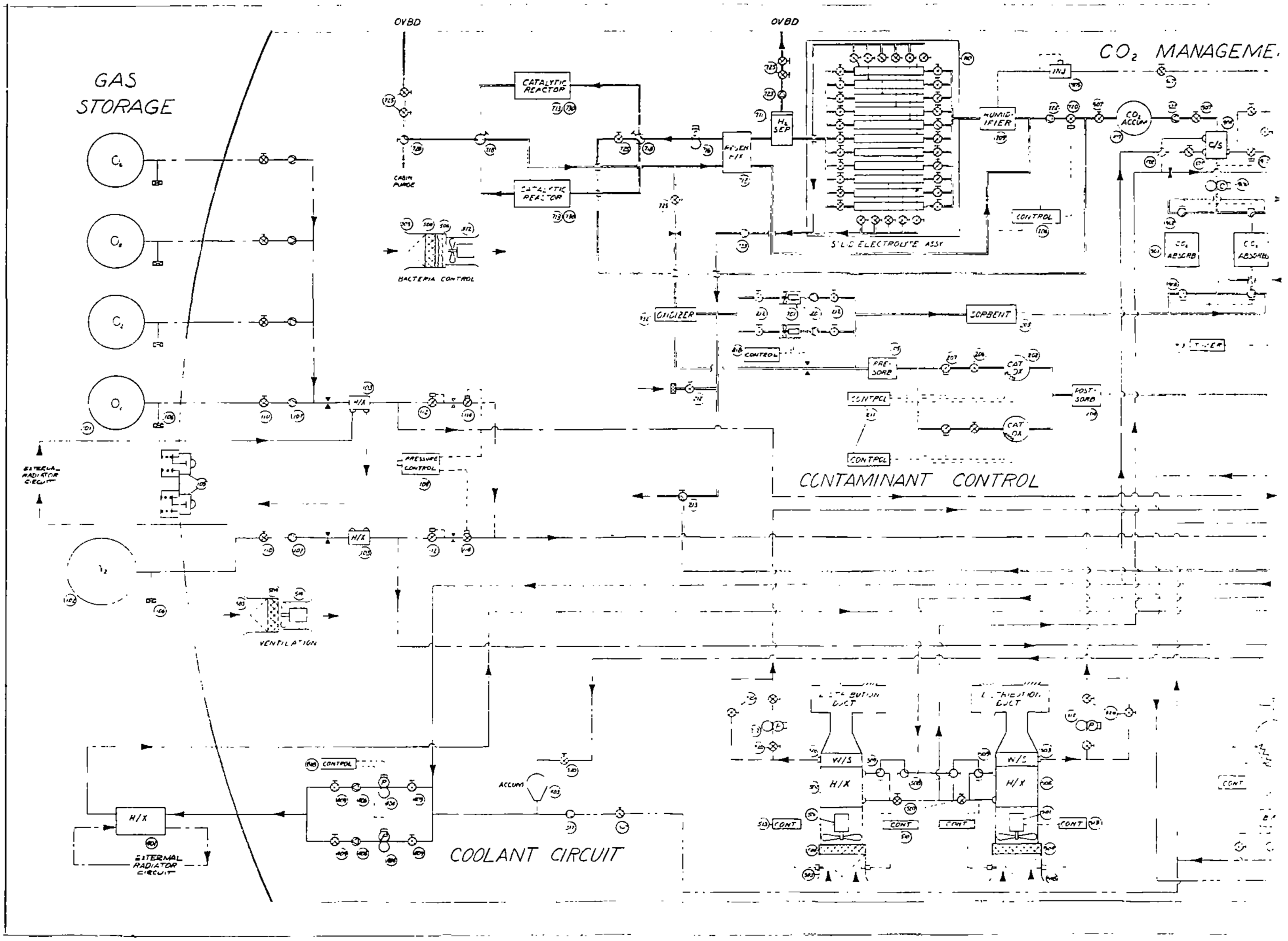
DESIGN 1 - SOLAR CELL

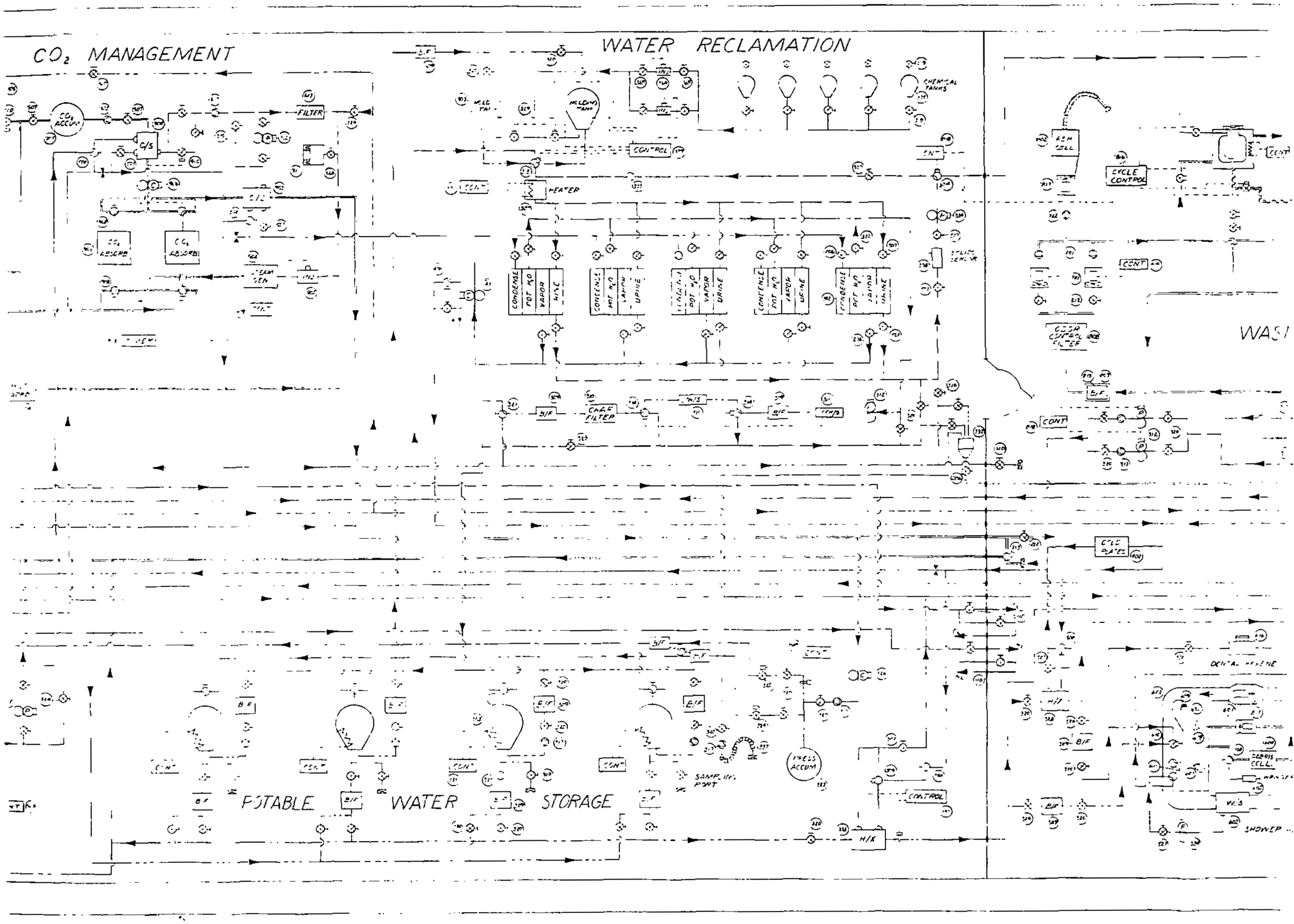
System Description

Design 1 is an integrated EC/LS system selected for compatibility with a solar cell electrical power supply. No high temperature thermal power is available other than that provided by electrical heating, so subsystem selections are biased by a heating power penalty. Specific subsystem selections for Design 1 and the other designs included in this report are given in table 53. The Design EC/LS schematic showing the detailed hardware implementation is presented in figure 106. A component list and reliability analysis is given in table 58. The reliability analysis summary for this system is shown in table 59. A weight, power, and volume summary is given in table 60. Figure 107 presents gas processing flows, and figure 108 presents water system materials balance.

A description of the integrated system is presented below, covering the individual subsystems in the following order:

1. Thermal control
2. Temperature and humidity control
3. Ventilation
4. Bacteria control
5. Trace contaminant control
6. CO_2 control and concentration
7. Oxygen generation
8. Oxygen and nitrogen storage and pressurization
9. Water reclamation
10. Potable water management
11. Waste management
12. Crew provisions - Washing, foods, feeding, and clothing
13. Instrumentation


GAS STORAGE
O_2
OVBD
CATALYTIC REACTOR
713 730
CATALYTIC REACTOR
713 730
725
728
718
CABIN PURGE
BACTERIA CONTROL
509
506
512
726
714
716
REGEN H/X
712
711
H₂ SEP
723
725
SOLID ELECTROLYTE ASSY
HUMIDIFIER
709
INJ
CO₂ MANAGEME
CO₂ ACCUM
C/S
CONTROL
CO₂ ABSORB
CO₂ ABSORB
OXIDIZER
732
212
SORBENT
CONTROL
PRE-SORB
207
208
CAT OX
CAT OX
POST-SORB
CONTROL
CONTROL
CONTAMINANT CONTROL
TIMER
H/X
103
110
107
112
114
PRESSURE CONTROL
108
105
H/X
103
EXTERNAL RADIATOR CIRCUIT
106
VENTILATION
503
504
511
213
CONTROL
ACCUM
403
211
H/X
401
EXTERNAL RADIATOR CIRCUIT
COOLANT CIRCUIT
DISTRIBUTION DUCT
DISTRIBUTION DUCT
W/S
W/S
H/X
H/X
CONT
CONT
CONT
CONT
CONT
P
P
F


CO₂ MANAGEMENT
WATER RECLAMATION
CO₂ ACCUM
C/S
FILTER
CO₂ ABSORB
CO₂ ABSORB
STEAM GEN
CHEMICAL TANKS
HOLDING TANK
CONTROL
HEATER
CONDENSE
POT H₂O
VAPOR
URINE
CHAR FILTER
B/F
CONT
CYCLE CONTROL
ODOR CONTROL FILTER
WAS
DENTAL HYGIENE
DEBRIS CELL
W/S
SHOWER
B/F
POTABLE WATER STORAGE
SAMPLING PORT
PRESS ACCUM
CONTROL
H/X

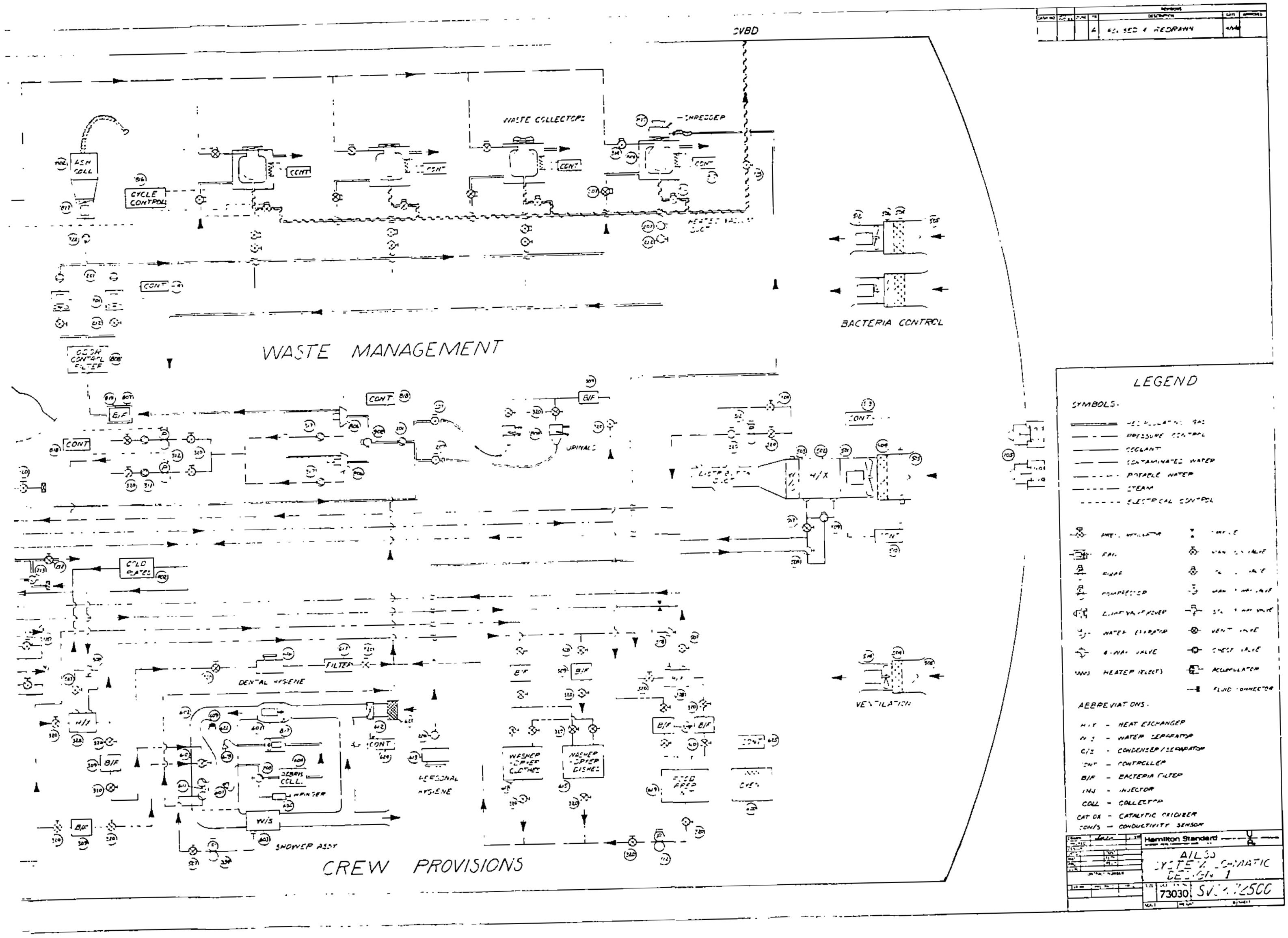
SVBD
WASTE COLLECTORS
SHREDDER
CONT
ASH COLL
CYCLE CONTROL
HEATED BALLAST DUCT
BACTERIA CONTROL
WASTE MANAGEMENT
ODOR CONTROL FILTER
CONT
B/F
URINALS
H/X
VENTILATION
COLD PLATES
FILTER
DENTAL HYGIENE
H/X
B/F
DEBRIS COLL.
WRINGER
W/S
CONT
PERSONAL HYGIENE
SHOWER ASSY
WASHER DRIER CLOTHES
WASHER DRIER DISHES
FOOD PREP
OVEN
CREW PROVISIONS
REVISIONS
A
REVISED & REDRAWN
LEGEND
SYMBOLS-
RECIRCULATING GAS
PRESSURE CONTROL
COOLANT
CONTAMINATED WATER
POTABLE WATER
STEAM
ELECTRICAL CONTROL
FAN
PUMP
COMPRESSOR
WATER SEPARATOR
4-WAY VALVE
HEATER (ELECT)
VENT VALVE
CHECK VALVE
ACCUMULATOR
FLUID CONNECTOR
ABBREVIATIONS.
H/X - HEAT EXCHANGER
W/S - WATER SEPARATOR
C/S - CONDENSER/SEPARATOR
CONT - CONTROLLER
B/F - BACTERIA FILTER
INJ - INJECTOR
COLL - COLLECTOR
CAT OX - CATALYTIC OXIDIZER
CON/S - CONDUCTIVITY SENSOR
Hamilton Standard
AILSS
SYSTEM SCHEMATIC
DESIGN 1
73030
SV

TABLE 58

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
100	$O_2 + N_2$ Storage and Pressure Control						
101	Tank, Storage, O_2	3	0.01	12 000	0.000360	Install 1 Redundant Tank	0.000002
102	Tank, Storage, N_2	1	0.01	12 000	0.000120	-	0.000120
103	Heat Exchanger	2	0.004	12 000	0.000096	-	0.000096
104	Controller, Total Press.						
	1. Amp.	1	1.32	12 000	0.015840	2 Spares	0.000001
	2. Sensor	1	4.17	12 000	0.050040	2 Spares	0.000020
105	Valve, Cabin Dump & Relief						
	1. Launch						
	a. Fail Closed	2	2.54	100	0.000508	Install Redundant Valves	0.000001
	b. Fail Open	4	0.76	100	0.000304	-	0.000304
	2. Orbit (capped)	4	(0.76) (12 000) 0.05	12 000	0.000022	-	0.000022
106	Fill Valve (cap)	5	0.001	12 000	0.000060	-	0.000060
107	Check Valve	5	0.27 (0.000120)	12 000	0.000002	-	0.000002
110	Valve, Shutoff						
	1. Tank Isolation	5	0.42 (0.000120)	12 000	0.000003	-	0.000003
	2. Cabin Refill	4	0.42	12 000	0.020160	2 Spares	0.000001
112	Pressure Regulator, O_2/N_2	2	2.94	12 000	0.070560	2 Spares	0.000001
114	Valve, Solenoid Shutoff	2	0.72	12 000	0.017280	2 Spares	0.000001
	1. Total Expected Failures				0.175355		
	2. Expected Failures Req. Crew Action				0.174848		
	3. Probability of Failure with Spares						0.000634
	4. Total Subsystem Reliability						0.999366

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
200	Trace Contaminant Control						
201	Valve, Gas Check (Fan Isol.)	5	0.27 (0.042)	12 000	0.000680	Spares Supplied with Fans 701	0.000001
202	Oxidizer, Catalytic	1	5.0	12 000	0.060000	Install 1 Redundant Plus 1 Spare	0.000040
203	Canister, Sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
204	Canister, Post-sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
205	Canister, Pre-sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
206	Valve, Manual Shutoff (Isolation)						
	1. Item 202	2	0.02 (0.06)	12 000	0.000029	-	0.000029
	2. Item 332 (Leakage Not. Crit.)	1	-	-	-	-	-
	3. Item 613 (Leakage Not. Crit.)	1	-	-	-	-	-
	4. Item 342	10	0.2 (0.0017)	12 000	0.000041	-	0.000041
207	Valve, Solenoid Shutoff						
	1. Item 202 Emerg. Isolation	2	0.072 (0.03)	12 000	0.000052	-	0.000052
	2. Item 804 Isol.	2	0.72	12 000	0.017280	3 Spares	0.000004
	3. Item 801 Gas Lines	8	0.72	12 000	0.069120		
213	Valve, Manual 3-Way	2	0.5	12 000	0.012000	1 Spare	0.000060
211	Control, Cat. Oxidizer Temp	1	3.5	12 000	0.042000	1 Spare + Installed	0.000015
212	Valve, Manual Shutoff						
	1. Item 701 Isolation	6	0.02 (0.042)	12 000	0.000061	-	0.000081
	2. Cabin Inlet, Outlet	2	0.2	12 000	0.004800	1 Spare	0.000011
	3. Item 207 Isol. Va.	4	0.02 (0.00864)	12 000	0.000008	-	0.000008
	1. Total Expected Failures				0.209671		
	2. Expected Failures Req. Crew Action				0.209671		
	3. Probability of Failure with Spares						0.000325
	4. Total Subsystem Reliability						0.999675

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate $(\lambda \times 10^{-6})$	Oper. time T (hr)	Expected failures $(n\lambda t)$	Spares/redundancy req.	Resulting unreliability
300	Water Management						
303	Tank, Potable Water (Bladderless)	6	1.01	12 000	0.072720	Install 2 Redundant Heaters	0.000726
305	Tank, Chemical Storage	4	0.1	12 000	0.004800	Install Redundant Tanks	0.000010
306	Injector, Chemical	1	1.0	12 000	0.012000	Install Redundant Valves	0.000060
307	Heater	1	1.0	12 000	0.012000	Install 2 Redundant Heaters	0.000001
308	Solids Sensor	1	5.0	12 000	0.060000	2 Spares	0.000040
309	Bacteria Filter	20	0.1	12 000	0.024000	2 Spare Cover Seals	0.000003
310	Charcoal Filter	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
311	Sensor, Conductivity & Control	2	4.0	12 000	0.096000	3 Spares	0.000003
312	Pump	7	6.0	12 000	0.504000	5 Spares	0.000015
313	Valve, 4-Way Solenoid	1	1.67	12 000	0.020040	2 Spares	0.000002
314	Valve, 3-Way Solenoid	7	1.67	12 000	0.140280	3 Spares	0.000012
317	Check Valve	12	0.27	12 000	0.038880	2 Spares	0.000009
318	Valve, Shutoff Chem.						
	1. Tank	5	0.2 (0.00012)	12 000	0.000001	-	0.000001
	2. Injector	4	0.02 (0.012)	12 000	0.000012	-	0.000012
319	Valve, Vent	5	0.2 (0.00012)	12 000	0.000001	-	0.000001

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures (n λ t)	Spares/redundancy req.	Resulting unreliability
320	Valve, Shutoff (Isolation)						
	1. Item 309 (Minor Leak Not Crit)	33	0.001 (0.0012)	12 000	0.000001	-	0.000001
	2. Item 312 (Minor Leak Not Crit)	16	0.001 (0.072)	12 000	0.000014	-	0.000014
	3. Item 324 (Minor Leak Not Crit)	1	0.001 (0.0353)	12 000	0.000001	-	0.000001
	4. Item 325 (Minor Leak Not Crit)	1	0.001 (0.0353)	12 000	0.000001	-	0.000001
	5. Item 326 (Minor Leak Not Crit)	1	0.001 (0.072)	12 000	0.000001	-	0.000001
	6. Item 328 (Minor Leak Not Crit)	2	0.001 (0.0028)	12 000	0.000001	-	0.000001
	7. Item 333 (Minor Leak Not Crit)	1	0.001 (0.0015)	12 000	0.000001	-	0.000001
	8. Item 617 (Minor Leak Not Crit)	7	0.001	12 000	0.000084	-	0.000084
	9. W/Disconn. (Minor Leak Not Crit)	6	0.001 (0.012)	12 000	0.000001	-	0.000001
	10. Item 403 (Minor Leak Not Crit)	2	0.001	12 000	0.000024	-	0.000024
	11. Item 615 (Minor Leak Not Crit)	3	0.001 (0.05)	12 000	0.000002	-	0.000002
	12. Item 618 (Minor Leak Not Crit)	3	0.001 (0.05)	12 000	0.000002	-	0.000002
	13. Item 342	4	0.2 (0.0017)	12 000	0.000016	-	0.000016
	14. Item 905 (Minor Leak Not Crit)	1	0.001 (0.0086)	12 000	0.000001	-	0.000001
	15. 4 Misc. Bypass (Minor Leak Not Crit)	4	0.001	12 000	0.000048	-	0.000048
	16. Item 616	1	0.2	12 000	0.002400	-	
	17. Item 804	2	0.2	12 000	0.004800		
	18. Item 332	2	0.2	12 000	0.004800	2 Spares	0.000001
	19. Shower VA's	2	0.2	12 000	0.004800		
321	Diverter Valve, Manual	5	0.5	12 000	0.030000	2 Spares	0.000005
323	Check Valve	2	0.27	12 000	0.006480	1 Spare	0.000020
324	Regulator, 25 psi	1	2.94	12 000	0.035280	2 Spares	0.000008
325	Regulator, 20 psi	1	2.94	12 000	0.035280	2 Spares	0.000008
326	Compressor	1	7.0	12 000	0.084000	3 Spares	0.000002
327	Accumulator	1	0.01	12 000	0.000120	-	0.000120
328	Chiller	2	0.23	12 000	0.005520	1 Spare	0.000015

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
329	Valve, Solenoid Shutoff, Chem.	2	1.0	12 000	0.024000	2 Spares	0.000003
331	Control, Heater	5	3.5	12 000	0.210000	4 Spares	0.000003
332	Collector, Liquid	1	0.001	12 000	0.000012	- -	0.000012
333	Heat Exchanger	1	0.125	12 000	0.001500	1 Spare	0.000001
334	Pump	2	6.0	12 000	0.144000	3 Spares	0.000012
335	Cartridges, Bacteria Filter	20	0.1	12 000	0.024000	2 Spares	0.000003
336	Cartridges, Charcoal Filter, Sm.	1	0.1	12 000	0.001200	1 Spare	0.000001
337	Hose & Connector	1	1.0	10	0.000010	-	0.000010
339	Control, Tank Level	1	5.2	12 000	0.062400	3 Spares	0.000001
340	Control, Heater	1	3.5	12 000	0.042000	2 Spares	0.000015
343	Compressor, Vapor	1	7.0	12 000	0.084000	3 Spares	0.000001
342	Diffusion Still Assy	3	4.975	4 000	0.059700	2 Standby Stills	0.000040
	1. Total Expected Failures				1.852434		
	2. Expected Failures Req. Crew Action				1.824763		
	3. Probability of Failure with Spares						0.001375
	4. Total Subsystem Reliability						0.998625

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. Time T (hr)	Expected failure ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
400	Thermal Control						
401	Heat Sink Assembly	1	Unknown	-	-	-	-
402	Cold Plate Assembly	1	Unknown	-	-	-	-
403	Accumulator (Bladderless)	1	0.01	12 000	0.000120	-	0.000120
404	Pump	1	6.0	12 000	0.072000	Install Redundant Pump & Carry 1 Spare	0.000055
406	Valve, Check	2	0.27 (0.072)	12 000	0.000467	Spare Supplied with Pump	0.000010
408	Valve, Manual, 3-Way						
	1. Item 343, Sol. (Minor Leak Not Crit)	1	0.001 (0.084)	12 000	0.000001	-	0.000001
	2. Bypass Leakage (Leakage Not Crit)	1	0.001	12 000	0.000012	-	0.000012
409	Valve, Manual, Shutoff						
	1. Item 404 Isolation Va.	4	0.001 (0.072)	12 000	0.000003	-	0.000003
	2. Item 343 Isolation Va.	1	0.001 (0.084)	12 000	0.000001	-	0.000001
	1. Total Expected Failures				0.072604		
	2. Expected Failures Req. Crew Action				0.070133		
	3. Probability of Failure with Spares						0.000202
	4. Total Subsystem Reliability						0.999798

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
500	Cabin Temp + Humidity Control						
501	Fan	3	5.25	12 000	0.189000	3 Spares	0.000040
502	Heat Exchanger/Condenser	3	0.25	12 000	0.009000	1 Spare	0.000040
503	Separator, Water	3	1.2	12 000	0.043200	2 Spares	0.000015
504	Filter	8	0.01	12 000	0.000960	1 Spare	0.000001
505	Silencer/Debris Trap	8	-	-	-	-	-
506	Filter, Bacteria	12	0.1	12 000	0.014400	2 Spares	0.000001
507	Valve, Shutoff, Manual (Isolation)						
	1. Item 308 (Minor Leakage Not Crit)	1	0.001 (0.06)	12 000	0.000001	-	0.000001
	2. Item 342	10	0.2 (0.0017)	12 000	0.000041	-	0.000041
	3. Item 334 (Minor Leak Not Crit)	3	0.001 (0.072)	12 000	0.000003	-	0.000003
	4. Item 328 (Minor Leak Not Crit)	2	0.001 (0.0028)	12 000	0.000001	-	0.000001
	5. Item 509 (Minor Leak Not Crit)	4	0.001 (0.08)	12 000	0.000004	-	0.000004
	6. Item 720 (Minor Leak Not Crit)	1	0.001 (0.035)	12 000	0.000001	-	0.000001
	7. Item 903 (Minor Leak Not Crit)	1	0.001 (0.0144)	12 000	0.000001	-	0.000001
	8. Item 904 (Minor Leak Not Crit)	2	0.001 (0.0144)	12 000	0.000001	-	0.000001
	9. Item 809 (Minor Leak Not Crit)	1	0.001 (0.0015)	12 000	0.000001	-	0.000001
508	Valve, Manual, 3-Way (Isolation)						
	Bypass Port Leakage (Minor Leak Not Crit)	8	0.001	12 000	0.000096	-	0.000096
	Isolation Port Leakage						
	1. Item 509 (Minor Leak Not Crit)	4	0.001 (0.08)	12 000	0.000004	-	0.000004
	2. Item 308 (Minor Leak Not Crit)	2	0.001 (0.06)	12 000	0.000001	-	0.000001
	3. Item 903 (Minor Leak Not Crit)	1	0.001 (0.0144)	12 000	0.000001	-	0.000001
	4. Item 904 (Minor Leak Not Crit)	1	0.001 (0.0144)	12 000	0.000001	-	0.000001
	5. Item 809 (Minor Leak Not Crit)	1	0.001 (0.0015)	12 000	0.000001		0.000001
509	Valve, Modulating	4	1.67	12 000	0.080160	3 Spares	0.000002
510	Control, Humidity	3	10	12 000	0.360000	4 Spares	0.000035

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
512	Fan, Bacteria Control	3	3.5	12 000	0.126000	3 Spares	0.000007
513	Control Motor Speed	3	6.5	12 000	0.234000	4 Spares	0.000004
514	Fan, Vent	2	3.5	12 000	0.084000	3 Spares	0.000001
	1. Total Expected Failures 2. Expected Failures Req. Crew. Action 3. Probability of Failure with Spares 4. Total Subsystem Reliability				1.140878 1.140878		0.000304 0.999696
600	Crew Provisions 1						
601	Fan, Shower	1	35	125	0.004375	1 Spare	0.000009
602	Stall, Shower	1	Unk	-	-	-	-
603	Separator/Filter, Water	1	50	125	0.006250	1 Spare	0.000018
604	Collector, Debris	1	-	-	-	-	-
605	Wringer, Manual	1	0.1	125	0.000013	-	0.000013
607	Vacuum Line & Attachment	1	0.1	125	0.000013	-	0.000013
608	Air Line & Attachment	1	0.1	125	0.000013	-	0.000013
609	Shower Head	1	0.05	125	0.000006	-	0.000006
610	Valve, Water Mixing	1	0.4	125	0.000050	1 Spare	0.000001
611	Valve, Diverter, Multiple	1	0.4	125	0.000050	1 Spare	0.000001

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
612	Valve, Air Inlet						
	1. Valve	1	0.1	125	0.000013	-	0.000013
	2. Actuator	1	6.0	125	0.000750	1 Spare	0.000001
613	Receptacle, Personal Hygiene	1	-	-	-	-	-
614	Battery, Shower Fan	1	40	125	0.005000	1 Spare	0.000012
615	Washer/Dryer, Dishes	1	100	500	0.050000	Carry 2 Spares of Rotating Parts (i.e. Pumps, Brgs, etc.)	0.000020
616	Receptacle, Dental Debris	1	-	-	-	-	-
617	Filter	2	0.1	12 000	0.002400	1 Spare	0.000003
618	Washer/Dryer, Clothes	1	100	500	0.050000	Same as 615	0.000020
619	Unit, Food Preparation	1	Unk	-	-	-	-
620	Oven	1	1.0	500	0.000500	Install 2 Redundant Heaters	0.000001
622	Filter	1	0.1	12 000	0.001200	1 Spare	0.000001
624	Control, Temperature	1	3.5	125	0.000438	1 Spare	0.000001
625	Control, Oven Temp	1	3.5	500	0.001750	1 Spare	0.000002
	1. Total Expected Failures				0.122821		
	2. Expected Failures Req. Crew Action				0.122321		
	3. Probability of Failure with Spares						0.000148
	4. Total Subsystem Reliability						0.999852

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
700	Oxygen Generation						
701	Fan	2	3.5	12 000	0.084000	3 Spares	0.000002
706	Control, Pressure	1	10	12 000	0.120000	3 Spares	0.000008
709	Humidifier	1	1.2	12 000	0.014400	2 Spares	0.000001
710	Reactor, Electrolyte						
	1. Life (Failure Rate Within 250 Day Life Req. Per Stack)	15 Stacks	11.3/Stack	12 000	2.034000	10 Stacks	
	2. Leakage	15 Stacks	1.70/Stack	12 000	0.360000	3 Modules Assembly is Subdivided Into Modules Containing 5 Stacks. Six Modules Req. to Meet 500-Day Life Req. Five Standby Modules Req. for Redundancy	0.000296
	3. Isolation Valve	33	0.2	12 000	0.079200	2 Failures are Required to Affect Subsyst. Perf.	0.000127
711	Separator, H_2	1	0.125	12 000	0.001500	1 Spare	0.000001
712	Heat Exchanger, Regen.	1	0.125	12 000	0.001500	1 Spare	0.000001
713	Reactor, Catalytic	2	0.5	6 000	0.006000	1 Spare	0.000018
716	Compressor	1	14.0	12 000	0.168000	3 Spares	0.000020
718	Valve, Diverter, 4-Way	2	6.24	12 000	0.149760	3 Spares	0.000015
720	Regulator, CO_2	1	2.94	12 000	0.035080	2 Spares	0.000007
722	Valve, Check, Gas	2	0.27	12 000	0.006480	1 Spare	0.000018

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
723	Valve, Check, Hi-Temp	2	0.27	12 000	0.006480	1 Spare	0.000018
725	Valve, Shutoff, Manual						
	1. Item 713 OVBD Dump	1	0.2	12 000	0.002400	Install Redundant Va.	0.000006
	2. Item 711, 723 Isol. Va.	1	0.02 (0.0048)	12 000	0.000001	-	0.000001
	3. Item 812 Isol. Va.	1	0.02 (0.3456)	12 000	0.000083	-	0.000083
728	Valve, Purge, Selector	1	0.4	12 000	0.004800	1 Spare	0.000012
730	Catalyst Cartridge	2	0.1	6 000	0.001200	1 Spare	0.000001
732	Oxidizer	1	0.1	12 000	0.001200	1 Spare	0.000001
	1. Total Expected Failures				3.076084		
	2. Expected Failures Req. Crew Action				2.994484		
	3. Probability of Failure with Spares						0.000636
	4. Total Subsystem Reliability						0.999364
800	Waste Management						
801	Collector, Waste						
	1. Hatch Seal	4	2.0	12 000	0.096000	3 Spares	0.000003
	2. Heater	4	1.0	12 000	0.048000	Install 2 Redundant Heaters	0.000001
	3. HSG.	4	0.01	12 000	0.000480	-	0.000480
802	Collector, Ash	1	0.1	125	0.000013	-	0.000013
804	Urinal	2	0.3	225	0.000135	1 Spare	0.000001
806	Separator, Air/Urine	1	50	450	0.022500	1 Installed + 1 Spare	0.000002

TABLE 58 (Continued)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda x 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
807	Filter, Bacteria	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
808	Filter, Odor Control	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
809	Heat Exchanger	1	0.125	12 000	0.001500	1 Spare	0.000001
810	Control, Heater	4	3.5	6 000	0.084000	3 Spares	0.000002
811	Collection Bags	2	UNK	-	-	-	-
812	Valve, Sol., Shutoff Hi Temp.	4	7.2	12 000	0.345600	4 Spares	0.000030
815	Shredder	1	50	450	0.022500	2 Spares	0.000002
816	Cycle Control	1	13	12 000	0.156000	3 Spares	0.000015
817	Fan	2	35	125	0.008750	2 Spares	0.000001
818	Control	7	2.0 (0.072)	12 000	0.012096	Not Req. For Mission Comp.	-
819	Cartridges, Bacteria Filter	1	0.1	12 000	0.000120	1 Spare	0.000001
820	Cartridges, Charcoal Filter	1	0.1	12 000	0.000120	1 Spare	0.000001
	1. Total Expected Failures				0.800214		
	2. Expected Failures Req. Crew Action				0.800214		
	3. Probability of Failure with Spares						0.000555
	4. Total Subsystem Reliability						0.999445

TABLE 58 (Concluded)

EC/LS COMPONENT LIST AND RELIABILITY DATA - DESIGN 1 SOLAR CELL

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
900	CO_2 Concentration						
901	Bed, Ion Exchange Resin	2	1.2	12 000	0.028800	2 Spares	0.000004
902	Steam/Battery Generator,	1	1.15	12 000	0.013800	Redundant Heaters + 1 Spare	0.000001
903	Condenser/Separator	1	1.2	12 000	0.014400	2 Spares	0.000001
904	Condenser/Separator, CO_2	1	1.2	12 000	0.014400	2 Spares	0.000001
905	Injector, Water	2	0.72	12 000	0.017280	2 Spares	0.000001
906	Compressor, CO_2	1	7.0	12 000	0.084000	3 Spares	0.000002
907	Accumulator, CO_2	1	0.01	12 000	0.000120	-	0.000120
908	Valve, 3-Way Solenoid	5	6.24	12 000	0.374400	4 Spares	0.000040
909	Control, Heater	1	3.5	12 000	0.042000	2 Spares	0.000015
911	Accumulator, Water	1	1.29	12 000	0.015480	2 Spares	0.000001
910	Water Regulator	1	1.46	12 000	0.017520	2 Spares	0.000001
913	Timer	1	13	12 000	0.156000	3 Spares	0.000015
	1. Total Expected Failures				0.778200		
	2. Expected Failures Req. Crew Action				0.778200		
	3. Probability of Failure with Spares						0.000202
	4. Total Subsystem Reliability						0.999798

TABLE 59

DESIGN 1 - RELIABILITY ANALYSES SUMMARY

Subsystem	Total subsystem MTBF (hr)	Total expected failures	Failures with automatic redundancy	Expected failures requiring crew action		Total subsystem reliability
				Manual switching only required	Maintenance req.	
Oxygen & nitrogen storage & pressure control	68 400	0. 1754	0. 0005	0. 0005	0. 1744	0. 999366
Trace contaminant control	57 200	0. 2097	—	0. 0027	0. 2070	0. 999675
Water management	6 500	1. 8524	—	0. 1605	1. 6919	0. 998625
Thermal control	165 300	0. 0726	0. 0025	—	0. 0701	0. 999798
Cabin temperature & humidity control	10 500	1. 1409	—	—	1. 1409	0. 999696
Crew provisions	97 700	0. 1228	—	0. 0005	0. 1223	0. 999852
Oxygen generation	3 900	3. 0761	0. 0816	2. 3937	0. 6008	0. 999634
Waste management	15 000	0. 8002	—	0. 0480	0. 7522	0. 999445
CO_2 concentration	15 500	0. 7782	—	0. 0120	0. 7662	0. 999798
Total	1460	8. 2283	0. 0846	2. 6179	5. 5258	0. 995619

TABLE 60
DESIGN 1 WEIGHT, POWER, AND VOLUME SUMMARY

EC/LS	Weight (lb)			Power (watts)		[b]Volume
	[a]Hardware	Expendables	Total	Electrical	Thermal	(ft^3)
O_2 & N_2 Storage	952.6	1393.0	2 345.6	6	-	103.8
Contaminant Control	376.0	75.0	451.0	112	-	24.4
Water Mgt.	916.0	559.8	1 475.8	1 639	-	116.9
Thermal Control	52.3		52.3	400	-	2.5
Cabin Temp & Humidity Control	699.7	670.0	1 369.7	1 965	-	55.6
Crew Provisions	610.2		610.2	535	-	64.3
O_2 Generation	380.6	614.4	995.0	2 252	-	189.1
Waste Mgt	534.1	887.1	1 421.2	1 835	-	130.0
CO_2 Conc.	510.3		510.3	1 100	-	24.0
Instrumentation	206.0		206.0	200	-	9.9
EC/LS Totals	5237.8	4199.3	9 437.1	10 044	-	720.5
Food			10 630.0	-	-	683.0
Clothing			43.0	-	-	5.0
Total			20 110.1	10 044	-	1408.5

[a] Includes Spares

[b] Includes Spares and Expendables

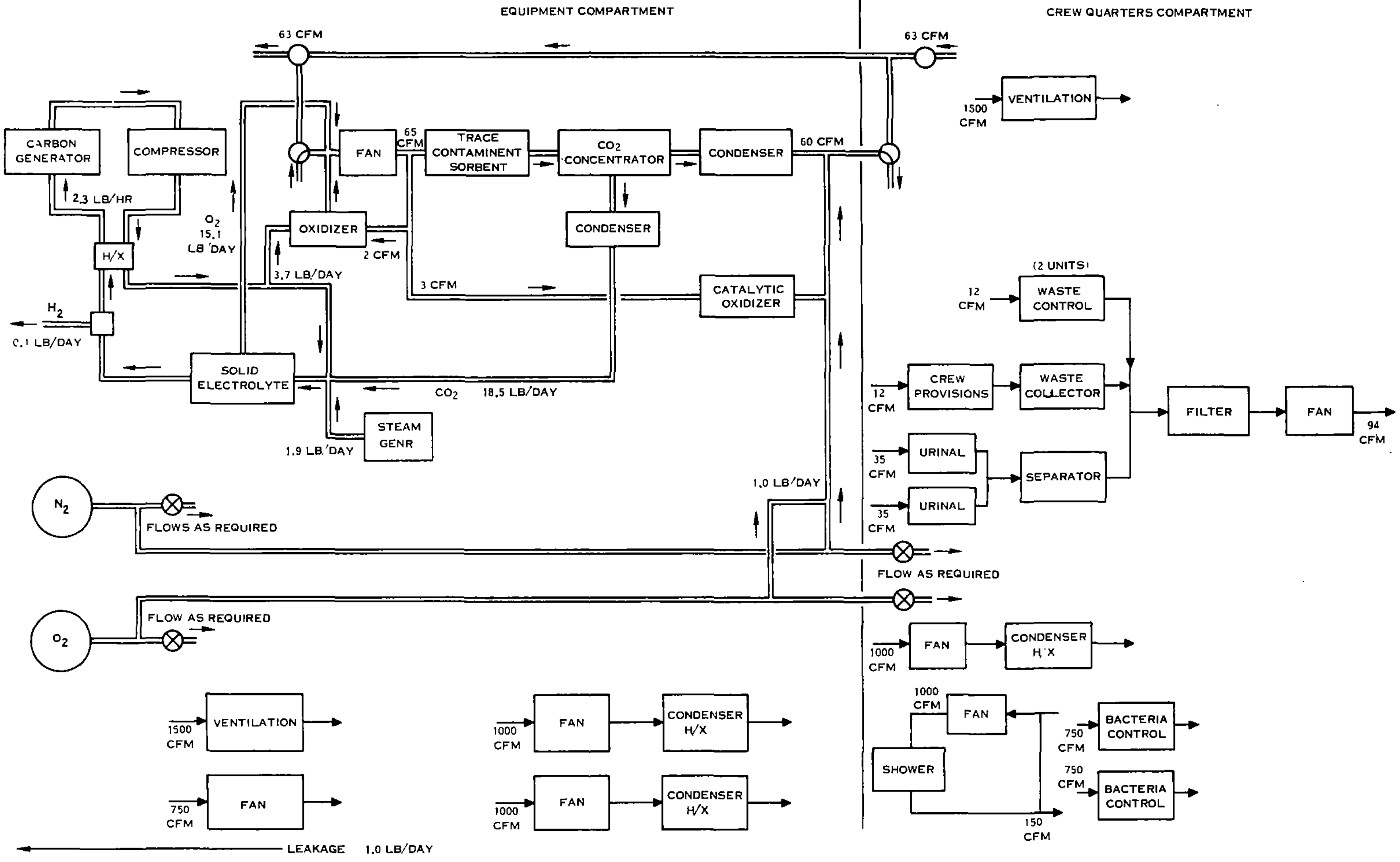


Figure 107. Gas Processing Flows - Design 1.

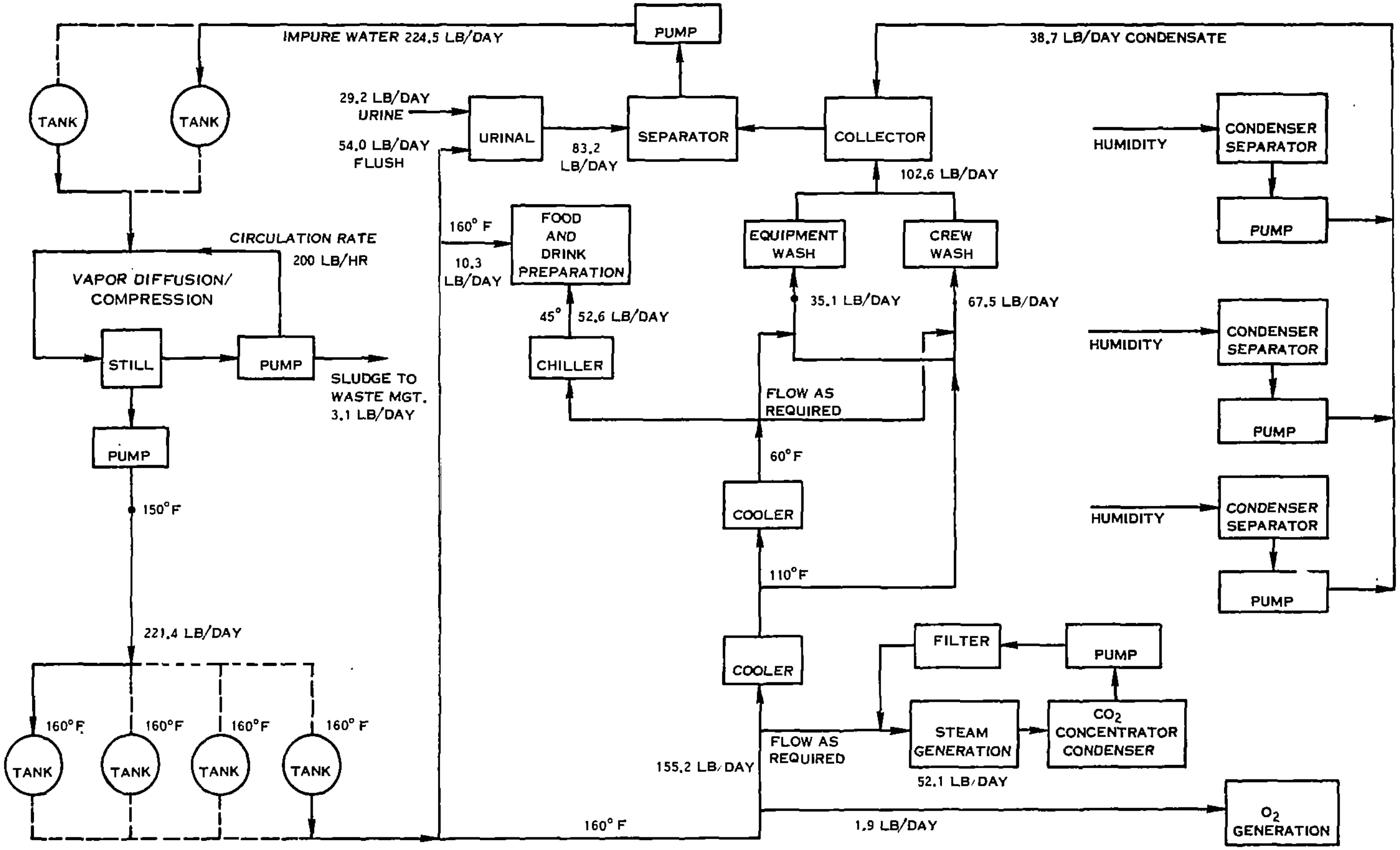


Figure 108. Water System Materials Balance - Design 1

Thermal control. - The Design 1 thermal control subsystem rejects about 50 000 Btu/hr of energy via the liquid transport loop to the space radiator, Items necessary for the thermal control loop to function are identified on the detailed schematic as the 500 series.

Water is used in the thermal control subsystem as the heat transport fluid. A discussion of the selection of water and further thermal load details is given in the Thermal Control section of this report. Cooling of the water loop is accomplished in the radiator loop heat exchanger (item 401). Water temperature is controlled to 38 ±2°F. Actual loop design is based on a 40°F maximum temperature, with lower temperature compensated for by system controls. The 40°F range is maintained by a temperature control in the radiator loop. Water flow from the radiator system enters the drinking water chiller (item 328) and then goes to the condensing cabin heat exchangers and the CO_2 concentrator condensers. The average chiller load on the coolant loop results in approximately a 1/2°F temperature rise. Instantaneous rates of 2°F are possible for periods of up to 15 minutes of cold potable water use. Potable water is delivered on demand at 40° to 45°F.

Coolant flow is divided between the three cabin heat exchangers (item 502) and the CO_2 feed line condenser (item 703). Of the 3600 lb/hr total flow, 1200 lb/hr goes to the crew quarters heat exchanger and the remainder to the two equipment compartment heat exchangers. Liquid flow modulation through the heat exchangers is accomplished by the relative humidity control sensor. Flow out of the two equipment cabin heat exchangers is joined with the CO_2 delivery line condenser, and is used in series in the CO_2 process air condenser and the water reclamation system vapor compressor motor cooling jacket. Water flow out of the compressor motor then enters the crew cabin and is joined with flow out of the crew cabin heat exchanger. Coolant temperature at this point is about 54°F and is split for assorted electronic cold plate cooling shown as a box on the schematic, and for potable water cooling to 60°F for washing and consumption. Item 328 is the water cooler providing 60°F potable water for drinking and wash purposes.

Although the electronic liquid loads may be located in both cabins, they are shown as one box in the crew cabin. Associated liquid-line routing to and from the cold plates and with the water cooler will be highly dependent on the final vehicle configuration. The assumed routing is to be taken as typical to exemplify piping complexity within the AILSS.

The cold plate and the 60°F water cooler flow are combined and then pass through the primary water cooler which conditions 160°F water from the storage tank to 110°F. Large transient coolant loop loads required of this heat exchanger do not influence other coolant loop functions because it is the last load in the loop.

The 3600 lb/hr coolant water circulation flow is provided by a 400-watt pump located at the entrance to the radiator loop heat exchanger. A redundant pump installation is used to avoid maintenance downtime. Pump failures are detected by speed and pressure sensors which automatically switch on the redundant pump. Replacement of the failed pump with another spare unit may then be accomplished.

Temperature and humidity control. - Sensible and latent heat load removal, and regulation of air temperature and relative humidity, are effected by the cabin heat exchanger package. One package is located in the crew compartment, and two are located in the equipment cabin. This packaging arrangement is selected to accommodate a possible 2:1 load split with three common sets of hardware. The primary components in each set include:

Item 501	Fan
Item 502	Condensing heat exchanger
Item 503	Water separator
Item 509	Flow modulation valves
Item 510	RH sensor
Item 513	Temperature sensor

An air flow of 1000 cfm per unit is cooled in the condenser, in which the system latent load is removed. Water is extracted by means of a face-wick water separator. Temperature control is provided by a fan speed control which enables cabin temperatures of 65 to 75°F to be selected. Relative humidity is held at 50 to 60 percent by means of coolant flow modulations.

The sensible heat load is essentially constant, but the system will accommodate sensible load variations of about 2:1.

Crew latent load will vary from zero to a maximum of about 3000 Btu/hr per cabin. At high cabin temperatures (e.g., 75° F), latent loads of up to 10 000 Btu/hr may be accommodated by each heat exchanger.

The face-wick water separator is a replaceable component. Water contained in the separator at 45°to 55° F temperatures can support bacteria buildup. Provisions are provided for removal and disposal of the wicks.

Ventilation. - Total ventilation flow is provided collectively by the circulation fans, 1500 cfm each, the temperature and humidity control fans, 1000 cfm each, and the bacteria control fans, 750 cfm each. The arrangement of one temperature and humidity control fan, two bacteria control fans, one circulation flow fan in the crew compartment, two temperature and humidity control fans, one bacteria control fan, and one circulation fan in the equipment compartment provides local air velocities of 50 cfm within the vehicle. A simple vehicle and circulation model is assumed in arriving at this hardware definition. A different vehicle configuration could result in changes to the assumed arrangement.

Trace contaminant and carbon dioxide control. - A central air process circulation system is used to collect and distribute cabin air for carbon dioxide and trace contaminant removal. A 63 cfm process fan provides a 60 cfm flow to a chemical sorbent bed and the CO_2 concentrator located in series, and 3 cfm to a catalytic oxidizer. A boost mode is possible in which a second catalytic oxidizer may be brought on line in parallel with the first unit to increase oxidization flow to essentially 6 cfm. A slight but tolerable flow reduction will result in the sorbent and concentrator branch.

Process flow is distributed first to the crew quarters, then back through the return ducting or the inter-cabin hatch, if open to the equipment compartment. Air returns to the process units via a return duct in the equipment compartment. A redundant installed process fan is used to eliminate excessive operation time, shut down, and startup if a fan fails and must be replaced. The single, integrated fan considerably reduces the spares requirement.

Trace contaminant control: The atmospheric contamination control maintains acceptable concentrations of trace gases, bacteria, and particulates in the spacecraft cabin. These contaminants are controlled by chemical destruction, absolute filtration, and filtration, respectively.

Ammonia is controlled by processing cabin air through a granular chemisorbent. This chemisorbent bed is designed to remove all ammonia generated during the mission. Most other contaminants are controlled by catalytic oxidation at 700°F, which converts them to carbon dioxide and/or water vapor. A small presorbent bed, similar to the main sorbent, keeps ammonia out of the catalytic oxidizer. A small alkaline post-sorbent bed removes toxic acids that may be generated from certain halogenated hydrocarbons in the oxidizer. Certain other contaminants, such as hydrogen sulfide generated at low rates, will poison a portion of the oxidation catalyst, which is sized to allow for this. The second installed oxidizer is a backup unit as well as providing the previously mentioned boost mode.

Airborne bacteria are controlled by filter-fan units. The single unit in the equipment compartment holds the bacteria level to 20 per cubic foot during normal operation, and the two identical units in the crew compartment hold the level to 20 per cubic foot even during emergency operation with the entire crew in that compartment. These units also provide part of the ventilation cabin air circulation function. Each filter package consists of a debris trap, a prefilter, and an absolute filter which remove nearly all incidental bacteria. Adequate control is maintained with an air flow of 750 cfm in each unit.

Particulate control is achieved by two-stage filtration. A dual filter package is located at the inlet of each temperature and humidity control fan, providing a particulate filtration process rate of 2000 cfm in the equipment compartment and 1000 cfm in the crew compartment. The bacteria filters also remove particulate matter, however, so that the total process rates are 2750 cfm in the equipment cabin and 2500 cfm in the crew cabin. Within each filter package, the first filter is a debris trap consisting of a hydrophobic conical screen that retains liquid water or wet matter. The second filter is a high-efficiency dry particle filter.

Carbon dioxide removal: Carbon dioxide is removed from the cabin atmosphere by the CO_2 concentration system and delivered to the oxygen generation section. It is removed at a rate of 18.5 lb/day, which is the normal metabolic generation rate.

The concentrator actually processes and delivers 20.2 lb/day of carbon dioxide to the accumulator. This difference from the production rate results from a continuous purge of the solid electrolyte oxygen generation subsystem to remove nitrogen impurities contained in the CO_2 feed stream, to the concentrator inlet. A maximum normal carbon dioxide concentration of 5.7 mm Hg is held at the concentrator inlet in the equipment compartment. Concentration in the crew compartment will normally be in the range of 4 to 5 mm Hg. During peak exercise or maintenance periods, the maximum attainable concentration will be 7.6 mm Hg.

The major equipment in the concentrator section consists of a steam generator, two sorbent canisters, a process air flow condenser, a compressor, a condenser/separator, and an accumulator. In operation, this concentrator section cyclically sorbs carbon dioxide from cabin air and desorbs it to the accumulator. A typical cycle starts as flow of cabin air through the sorbent canister and back to the cabin via the condenser. This operation continues for 45 minutes for each of the two canisters. At the end of this period a 15-minute steam desorption begins. The steam generator converts 160° F water to 180° F steam at a rate of 52.1 lb/day. Cycling of the two canisters is phased to minimize peak electrical power. Some of the steam is carried over with CO_2 desorbed from the sorbent canister, and it is pumped with the CO_2 into the condenser/separator. Steam is condensed, removed, and transferred to the water management subsystem. Carbon dioxide, containing a small amount of water, is pumped to the accumulator by the compressor. This cyclic carbon dioxide delivery causes varying accumulator pressure with a maximum design value of 40 psia. As the next cycle begins, adsorbed steam is desorbed into the incoming air, achieving evaporative cooling of the sorbent bed. This desorbed steam goes with the effluent air to the condenser.

Oxygen generation. - Major equipment used in the oxygen generation section is identified as the 700 series, and it consists of the solid electrolyte reactor, the disproportionation reactors, a regenerative heat exchanger, a humidifier, a hydrogen separator, and a recycle pump. In operation, inlet carbon dioxide from the concentrator joins the hot recycle gas stream just ahead of the humidifier. Water metered into the humidifier from the water management subsystem evaporates into the hot gas stream, which then enters the solid electrolyte reactor. This reactor consists of three modules, each containing five solid electrolyte cell stacks. In these stacks, carbon dioxide and water vapor in the gas stream are decomposed at 1800° F to form oxygen, carbon monoxide, and hydrogen. The oxygen is transported through the ceramic cell stack walls by electrochemical action of the applied voltage for release to the cabin atmosphere. The carbon monoxide and hydrogen leave the reactor with the reaction gas stream. This outlet gas stream then passes through a palladium-silver hydrogen separator, where hydrogen permeates the metal tubes and is relased overboard at a rate of 0.2 lb/day. The gas stream next enters the disproportionation reactor, where much of the carbon monoxide is catalytically converted to carbon dioxide and carbon at 1000° F.

The temperature difference between the two reaction steps is maintained by a regenerative heat exchanger. Carbon forms and is retained on the disproportionation catalyst, and it is removed every 10 days when the catalyst cartridge is replaced. Regenerated carbon dioxide recycles with the gas stream to the humidifier inlet at a rate of 2.4 lb/hr. The purge stream comes off just upstream of the disproportionation reactor and goes to a combustor before returning to the cabin atmosphere. The oxygen generation rate is controllable to a nominal value of 15.12 lb/day. The water feed makes up 1.84 lb/day of this total and is modulated to maintain the correct oxygen partial pressure within the cabin.

Oxygen and nitorgen storage and pressurization. - A high pressure gaseous storage system (the 100 series) provides both oxygen and nitrogen for cabin leakage makeup and repressurization. Gas pressure is 3000 psi in the single nitrogen bottle and in four (three required) oxygen bottles. Normal leakage makeup is controlled by a total pressure sensor which opens both oxygen and nitrogen inflow valves. Pressure in both lines is regulated so that the oxygen/nitrogen flow ratio matches that of the leakage outflow. If required, this inflow ratio may be varied by changing the pressure regulator settings.

Compartment repressurization, when required, is manually actuated from the other, still pressurized, compartment. This is a configuration sensitive detail dependent on vehicle design. A gas inflow heat exchanger is provided to maintain acceptable inflow temperatures during rapid repressurizations. This is necessary to prevent regulator valve freezeup.

Redundancy is provided in the oxygen tankage because of the extreme criticality of a single tank loss. Four one-third size tanks are selected, based on a weight optimization study. A single nitrogen tank loss is not critical since the crew could return in a pure oxygen cabin environment under a slightly higher stress mode.

Water reclamation. - The reclamation system interfaces with almost as many parts of the total system as the heat transport loop. Contaminated water is collected for processing in the cabin heat exchangers (item 502) and waste control subsystem as urine, flush water, and used wash water. Atmospheric condensate is pumped by small water pumps (item 312) to the water distillation system holding tanks. Wash water and flushed urine water is passed through a gas liquid separator (item 80) and then pumped via other (item 312) pumps to the water distillation system holding tanks (item 304). Water subsequently passed through the distillation system is then transferred to the potable water tanks.

Water distillation is performed in a modularized vapor diffusion/compression system (item 301). System feed is from the (item 304) holding tanks, into which a pretreat chemical is injected. The contaminated waste water is fed into a circulation loop to one of the five vapor diffusion/compression units, the remaining four being on standby. When the residuum solids concentration reaches 50 percent, a solids sensor triggers the discharge of the residuum to the waste management system.

Evaporation takes place at 150°F across a membrane that performs a dual role of phase control and bacteria filtration. The water vapor thus generated is compressed and then condensed on a porous plate condenser. Heat of condensation is transferred to the waste water and provides the evaporation heat. Product water passes through a conductivity sensor as a final test and is delivered to the potable tanks.

Potable water management. - Potable water is stored in the four (item 303) tanks at 160°F to eliminate a bacteria problem. The tank arrangement allows for usage from one unit while filling another, with a third tank in a holding mode for testing. A fourth tank is supplied to provide capacity for recycled flow and for holding the launch contingency.

Water is drawn from the tanks at a rate of 221.4 pounds per day for use as 1) food and drink input at 62.9 lb/day, 2) wash water at 102.6 lb/day, 3) urinal flush water at 54 lb/day, and 4) water for oxygen generation at 1.9 lb/day. 160°F water is delivered directly to the oxygen generator system evaporator (item 709) and to the urinal (item 804). Ten lb/day of 160°F water is used for food preparation. The remaining water is drawn on demand through a cooler (item 328) for wash water and human consumption. Coolant flow is provided by the heat transport fluid loop. Although the 110°F water delivered is adequate for both crew and equipment washing, item 328 coolers are provided to condition the water to any temperature between 60° and 110°F. Cooling is provided by the liquid transport loop. Drinking water is drawn on demand through another item 328 for water chilling. This heat exchanger uses cold coolant loop flow. The thermal loads imposed upon the liquid transport loop are transient and are located so that no critical functions will be upset. The large thermal mass of the heat transport loop will damp out actual temperature transients.

Demand flow heat exchangers are provided, rather than accumulator-type heat exchangers, to minimize the quantity of water held stagnant at lower than pasteurization temperatures. Bacteria filters are located at water taps to prevent possible bacteria backflows. Autoclaving and/or pasteurizing is used for system sterilization.

Waste management. - The waste control subsystem (800 series) is comprised of four wet waste collector/vacuum decomposition units (one with removable shredder), two urinals, and a common process flow circuit. Of the four wet waste collector/processors, two are always available for collection during any 24-hour period. The second two collectors treat wastes during the first 12 hours of the same period; the remaining 12 hours are used for chamber cooldown. Waste processing is accomplished by sealing the collector and applying heater power to bring the chamber to 300°F for approximately 30 minutes with the vacuum valve closed. The vacuum valve is then opened and the vapor and gases vented to space. This initial sterilization process ensures that only sterile gases and vapor are vented overboard. With the vacuum valve remaining open, electrical heater power is increased to bring the chamber up to 1200°F. The wastes then are decomposed during the remaining 11 1/2 hours of the 12-hour cycle. After process completion, the remaining ash residue is vacuumed into an ash collector. After completing a 12-hour cooldown period, the wet waste collector/incinerator is available for waste collection. Collection is accomplished by placing a plastic bag in the collection vessel once every 24 hours to contain feces, tissue, and urine sludge which is pumped in, and vomitus as required. The wet waste collector is provided with a seat, foot restraints, and a restraining belt to enable zero-gravity operation.

A process flow circuit consisting of a bacteria filter, charcoal and chemical sorption filter, centrifugal fan, and urine/air separator is provided to facilitate contamination control and zero-gravity operation. The process flow fan is actuated during collection of any of the three waste categories: wet waste, dry waste, and urine, as well as the ash residue. A cabin air stream drawn through the collectors provides the zero-gravity transfer mechanism and prevents odors, aerosols, and bacteria from escaping to the cabin. The plastic collection bag contains a hydrophilic patch, which will pass process flow air, and retain solids and liquid. Decomposition of the bags eliminates the need for replaceable filters and their inherent microbiological replacement problems. Provisions are made for steam sterilization of the process flow loop in the event of collection bag rupture.

A urine/air separator, used in conjunction with the process flow fan, and a pump are used for collection and immediate transfer of urine to the water management subsystem. Provisions are made for both a water flush and steam sterilization of the urine circuit. Urine collection is accomplished while seated on the wet waste collector. Each crewman is provided with his own adjustable positive-sealing diaphragm that is inserted in the urinal after removing the sealing cap. Three urinals are included; two in the crew compartment which are the ones normally used, and one in the equipment compartment which is normally used for liquid (nonurine) collection.

Crew provisions. - Crew provisions include the functions of feeding and food preparation, personal hygiene, clothing, and clothes washing. A shower is provided (items 601 to 624) to enable crew members to shower once every three days. The shower concept uses a 1000 cfm recirculation air stream (the fan is common with the cabin heat exchanger fan) and a hand-held shower head. A 60 cfm local air stream blower and vacuum (the fan being common with the trace contaminant flow fan) is available for handling local water accumulations. Main air circulation velocities (about 160 fpm) are too low for effective water removal from surfaces, but they provide necessary free moisture transport to the drain system. Item 603 is a high volumetric flow low pressure drop water separator which must be cleaned after shower use.

Due to the short duty cycle of the unit, three 8-minute showers/day, a battery storage system is provided to avoid a 325 watt power penalty. The battery power storage system may be eliminated if it is found that 8 minute power peaks can be provided by the power supply system at a reasonable penalty.

Item 618 is a washing machine and dryer for clothes washing. Reusable clothing is used by the crew. Wash water at 105°F is provided by the water management system. 320 watts are consumed in the device and provide power for both washing and drying. Drying time is extended to hold down the power requirements.

Freeze-dried foods that can be reconstituted with hot and cold water are provided. Cooked foods use 160°F hot water and are placed in an oven (item 620) until cooked. Food wastes and packaging wastes are transferred to the waste management subsystem.

Instrumentation. - Instrumentation features are not shown on the schematic but the following functions are performed:

1. Process control
2. System monitoring
3. Fault detection and isolation
4. Data management
5. Display processing

To minimize wiring and circuitry, analog data are multiplexed to an analog-to-digital (A/D) converter. The data are then stored in a buffer memory, which provides information for fault isolation after a system failure and makes data available to the processor as required. Three identical computers perform functions of fault detection and isolation, data management and isolation, and data management and display control. Essentially, all process control is performed locally by sensing parameters such as temperature, pressure (total and partial), liquid and gas flow, valve positions, voltage, current, power, and by providing control signals in response to parameter levels. To provide data logging, data are stored on magnetic tape and may be retrieved for transmission or readout on a cathode ray tube display.

Reliability

The reliability of Design 1, excluding display instrumentation, is estimated at 0.9956. The selected goal is 0.995. The reliability analysis for each subsystem is presented in table 58. This table presents the estimated failure rate, operating time, probability of failure, spares, and redundancy requirements for each component in the system. The spares requirement outlined on the reference tables only accounts for random failures and is additional to the expendable spares. For this reliability analysis, it was assumed that all items within the system and subsystems have been completely developed and qualified for flight and manned system tests have disclosed no unsolvable problem areas.

The most likely number of random hardware and instrumentation failures occurring during the 500-day mission is estimated to be 13. Of the eight hardware failures, it is estimated that three failures will require only a switching operation, and five will require component replacement. This results in a mean time between component replacement of 1460 hours.

Although the probability of failure of the oxygen storage tank is low, redundant tanks are included, because failure would be critical. Only one nitrogen tank is installed, because it is assumed that the system can degrade to a one-gas atmosphere at a lower pressure and still permit mission completion. The following assumptions are made in determining equipment reliability:

1. All plumbing is of welded construction.

2. Fittings have replaceable seals.

3. Normally open isolation valves have a failure rate of 10 percent of their operating (normally closed) failure rate.

4. Redundant sealing for external leakage is provided for isolation valves.

5. Estimated failure rates reflect the potential or maximum attainable regardless of current development status.

System Maintenance Considerations

In general, maintenance of the equipment in this system is on a component replacement basis. Because all heating functions are supplied by electric power, maintenance of these devices consists of either replacing units designed for simple plug-in exchange, or switching to alternate or redundant sensors and heating elements where replacement is impractical. Where electrical heaters and sensors are installed in liquid lines or tanks, the use of well-type units would allow replacement without breaking any seals.

The coolant circuit containing water operates at relatively low temperatures, and it requires a minimum of insulation on the lines to prevent condensation. This allows low maintenance times and ease of leakage isolation. The circuit operates with most equipment in parallel, minimizing the effects of subsystem interaction. By providing constant impedance bypasses around each load, maintenance may be performed on a particular subsystem, including complete shutdown, with little or no effect on other subsystems in the coolant circuit. Pumps are provided with standby redundancy because of the small allowable downtime of this circuit. Provisions are included, however, to replace a failed pump while the circuit is operating. Standby redundancy is also provided in the contaminated water recycle circuit; in this case, with automatic switchover provisions for the water separator, fan, and water pump. These units must operate whenever urinals are in use or risk spillage into the cabin.

Standby redundancy is also provided in the main intercabin air process fan serving both the CO_2 concentrator and contaminant control subsystems. A fan failure would therefore involve shutdown of these subsystems, if redundancy were not installed. These standby devices are replaceable on failure.

Crew time. - The actual crew time required to operate and maintain the system can be divided into three major areas:

1. Scheduled maintenance - those maintenance functions which are predictable, such as replacement of expendables and limited-life items

2. Unscheduled maintenance - those maintenance functions brought on by random failures of EC/LS equipment

3. Operating time - the time required of the crew for manual operation of certain system functions.

A summary of crew times is included in table 61 for each of the alternate designs. A breakdown of the major contributing factors follows.

Scheduled maintenance. - Scheduled maintenance for all designs is 524 hours per mission, or approximately one man-hour per day. Major contributors to this total are shower and washer/drier cleanup and maintenance, ash collector and waste receptacle bag replacements, air and water bacteria filter changes, scheduled replacement of porous place water separators, and carbon removal (cartridge replacement).

Unscheduled maintenance. - The estimated time required for unscheduled maintenance is 11.9 man-hours per mission. It is based on eight likely hardware failures (not including instrumentation) of the least reliable equipment.

Operational time. - Operating time is chiefly influenced by the large number of manual operations required in the operation of the waste management and crew provisions subsystems. These two systems account for about 90 percent of the total system operating time (not including actual time consumed in elimination of body wastes) and include such functions as urinal flushing, operation of the garbage/waste shredder, ash collection, and manual cycle control in the waste management system, estimated at 1425 hours per mission. The crew provisions section includes time for housekeeping, food preparation and cleanup for 18 000 meals and snacks, manual control of the shower and local body wash items, and clothing upkeep, but it does not include an estimated 5325 hours of actual eating and personal washing time.

TABLE 61

OPERATIONAL AND MAINTENANCE TIME, HOURS

	Design 1	Design 2	Design 3
I SCHEDULED MAINTENANCE			
Gas storage and pressurization	0	0	0
Trace contaminant control	3	3	3
Water reclamation	56	56	56
Water management	0	0	0
Coolant Circuit	0	0	0
Temperature, Humidity and Ventilation	75	75	75
Crew provisions	158	158	158
CO_2 removal	16	16	16
O_2 generation	111	111	111
Waste management	105	105	105
Sub Total	524	524	524
II UNSCHEDULED MAINTENANCE			
Gas Storage and pressurization	0	0	0
Trace contaminant control	0	0.1	0
Water reclamation	1.1	1.0	1.0
Water management	2.0	2.2	2.2
Coolant circuit	2.0	2.5	2.4
Temperature, humidity and ventilation	2.3	2.3	2.3
Crew provisions	0.5	0.5	0.5
CO_2 removal	1.5	1.6	1.6
O_2 generation	0.5	0.5	0.5
Waste management	2.0	2.1	2.0
Sub Total	11.9	12.8	12.5
III OPERATIONAL TIME			
Gas storage and pressurization	0	0	0
Trace contaminant control	0	0	0
Water reclamation	0	0	0
Water management	375	375	375
Coolant circuit	0	0	0
Temperature, humidity and ventilation	0	0	0
Crew provisions	2500	2500	2500
CO_2 removal	0	0	0
O_2 generation	0	0	0
Waste management	2945	2945	2945
Sub Total	5820	5820	5820

Under normal conditions, the water reclamation system will operate continuously and require a startup/shutdown cycle only for maintenance. All water processing equipment is sized for 18 hours/day operation to allow for maintenance time. Potable water tanks will require manual switching three times per day. The time required to make a water purity check is not included in this total.

DESIGN 2 - SOLAR CELL/ISOTOPE

System Description

EC/LS Design 2 provides the environmental control life support functions with a solar cell battery electrical power supply and an isotope thermal energy power supply. Thermal power is available for subsystem heat power requirements. A 1600°F heat source capability exists, but this system design uses heat at a temperature of 200°F obtained from a central heat process loop, a 700°F local isotope heater, and a second 1200°F local isotope heater. An intermediate heat transport loop is provided such that the EC/LS heat transport loop is isolated from the isotope power supply to eliminate a high temperature liquid transfer loop in the cabin. The power penalty charged for the radioisotope heat required is 50 lb/kW. A power penalty of 135 lb/kW is charged for all heat rejected to the EC/LS.

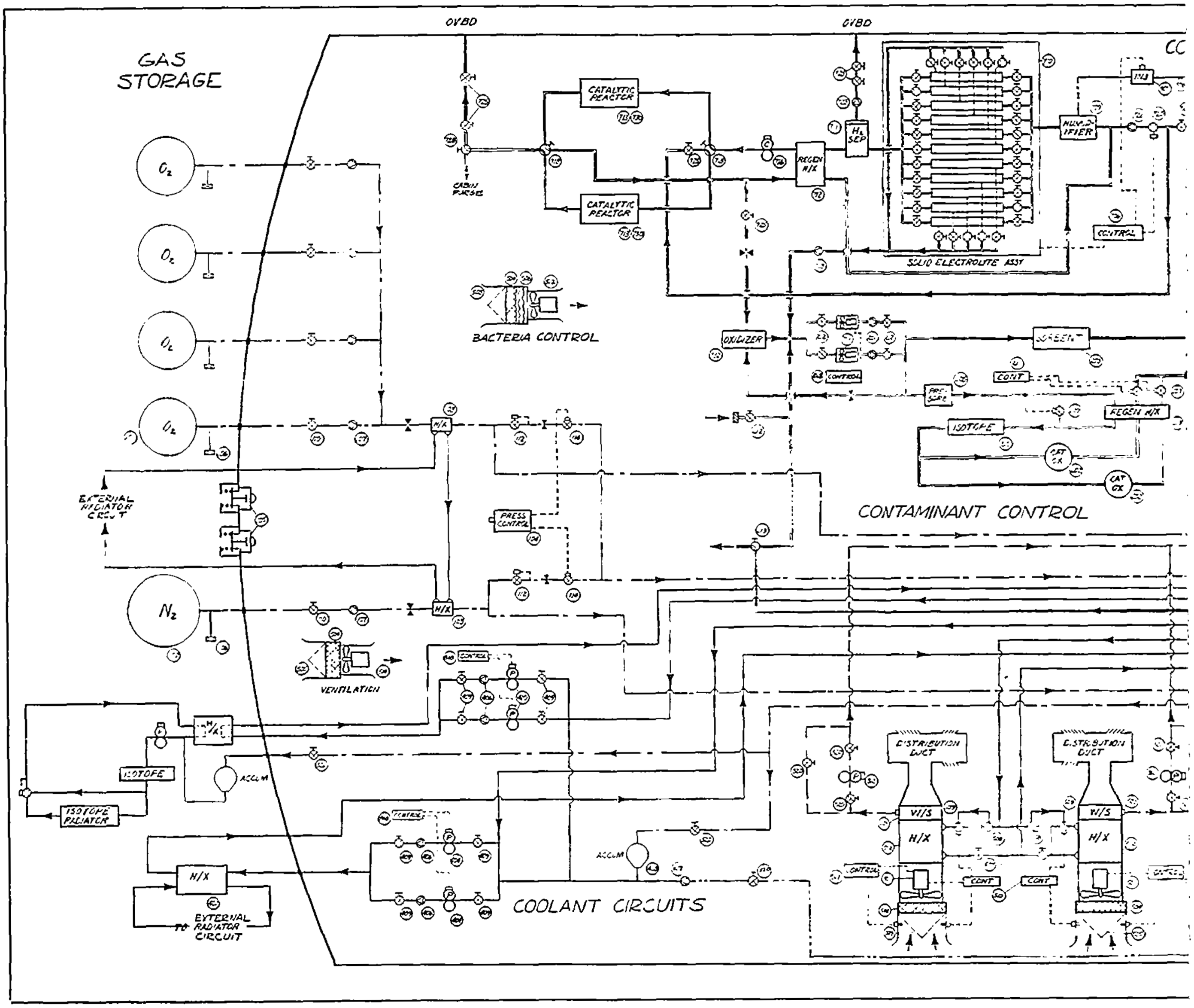
Specific subsystem selections for Design 2 are given in table 53, and discussed below in the same order as presented on the table. The Design 2 EC/LS schematic showing the detailed hardware implementation is presented in figure 109. The component list and reliability analysis list for this design is shown on table 62. A reliability summary is given in table 63. Figures 110 and 111 give air flow and water balance schematics.

As identified in table 53, differences from Design 1 are in the areas of:

1. Thermal control
2. Trace contaminant control
3. CO_2 control and concentration
4. Water reclamation
5. Potable water management
6. Waste management
7. Crew provisions

Other functions of cabin temperature and humidity control, ventilation, bacteria control, oxygen generation, O_2 and N_2 storage, pressure control, and instrumentation are identical to those discussed under Design 1.

<u>Thermal control.</u> - The thermal control function includes a coolant loop, as in Design 1, but also includes three separate radioisotope process heat sources. An iso-


GAS STORAGE
OVBD
OVBD
CC
CATALYTIC REACTOR
CATALYTIC REACTOR
CABIN PURGE
REGEN H/X
H_2 SEP
SOLID ELECTROLITE ASSY
HUMIDIFIER
CONTROL
O_2
O_2
O_2
O_2
N_2
BACTERIA CONTROL
OXIDIZER
CONTROL
SORBENT
CONT
PRESSURE
REGEN H/X
ISOTOPE
CAT OX
CAT OX
H/X
H/X
EXTERNAL RADIATOR CIRCUIT
PRESS CONTROL
CONTAMINANT CONTROL
VENTILATION
CONTROL
H/X
ISOTOPE
ACCUM
ISOTOPE RADIATOR
CONTROL
ACCUM
H/X
EXTERNAL RADIATOR CIRCUIT
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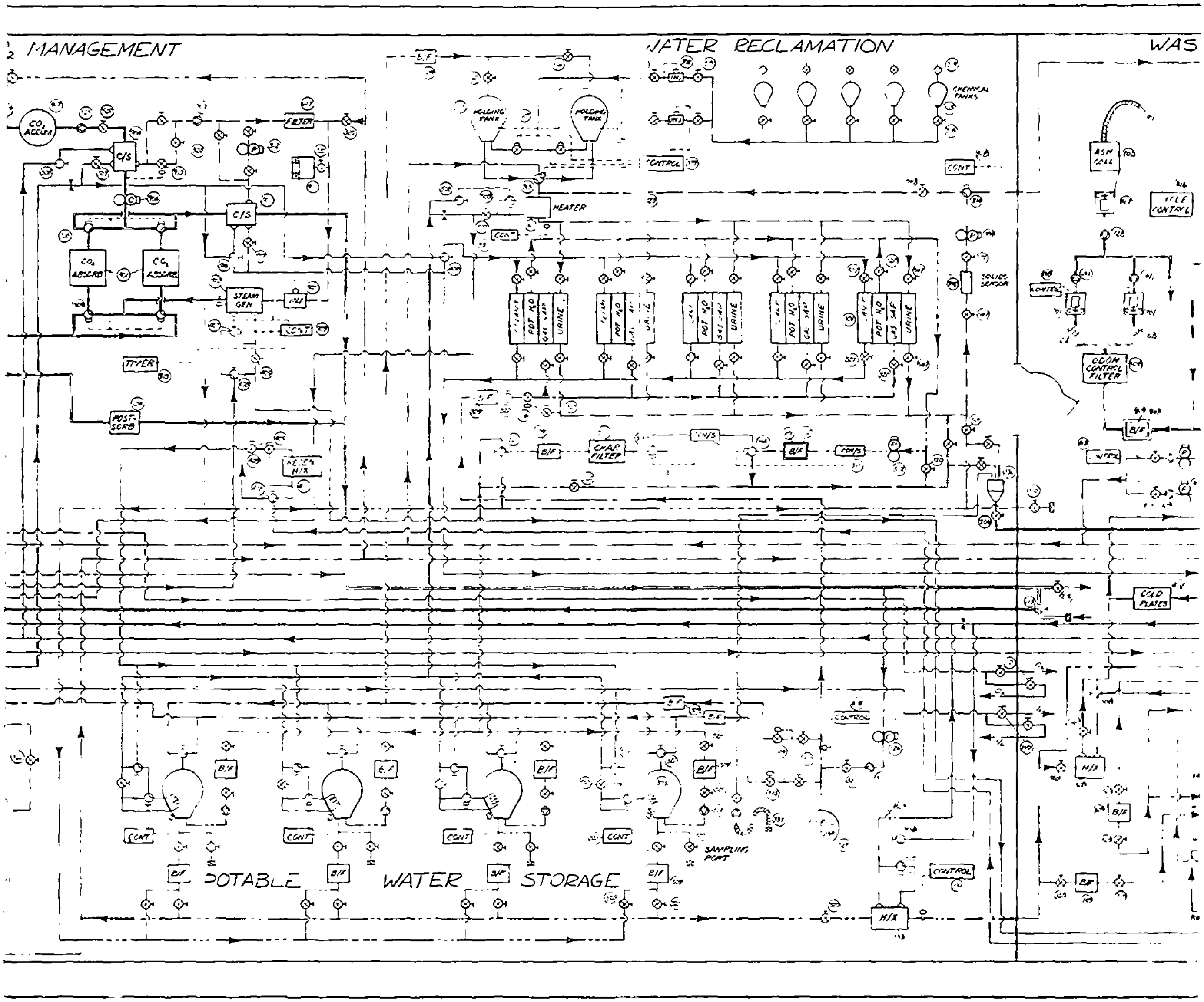
MANAGEMENT
WATER RECLAMATION
WAS
CO₂ ACCUM
C/S
FILTER
C/S
CO₂ ABSORB
CO₂ ABSORB
STEAM GEN
CONT
TIMER
POST-SCRB
HOLDING TANK
HOLDING TANK
HEATER
CONT
CONTROL
CHEMICAL TANKS
CONT
POT H₂O
GAS SAP
URINE
SOLIDS SENSOR
ASH CELL
CONTROL
ODOR CONTROL FILTER
B/F
CHAR FILTER
B/F
COLD PLATES
CONTROL
H/X
B/F
CONT
SAMPLING PORT
POTABLE WATER STORAGE

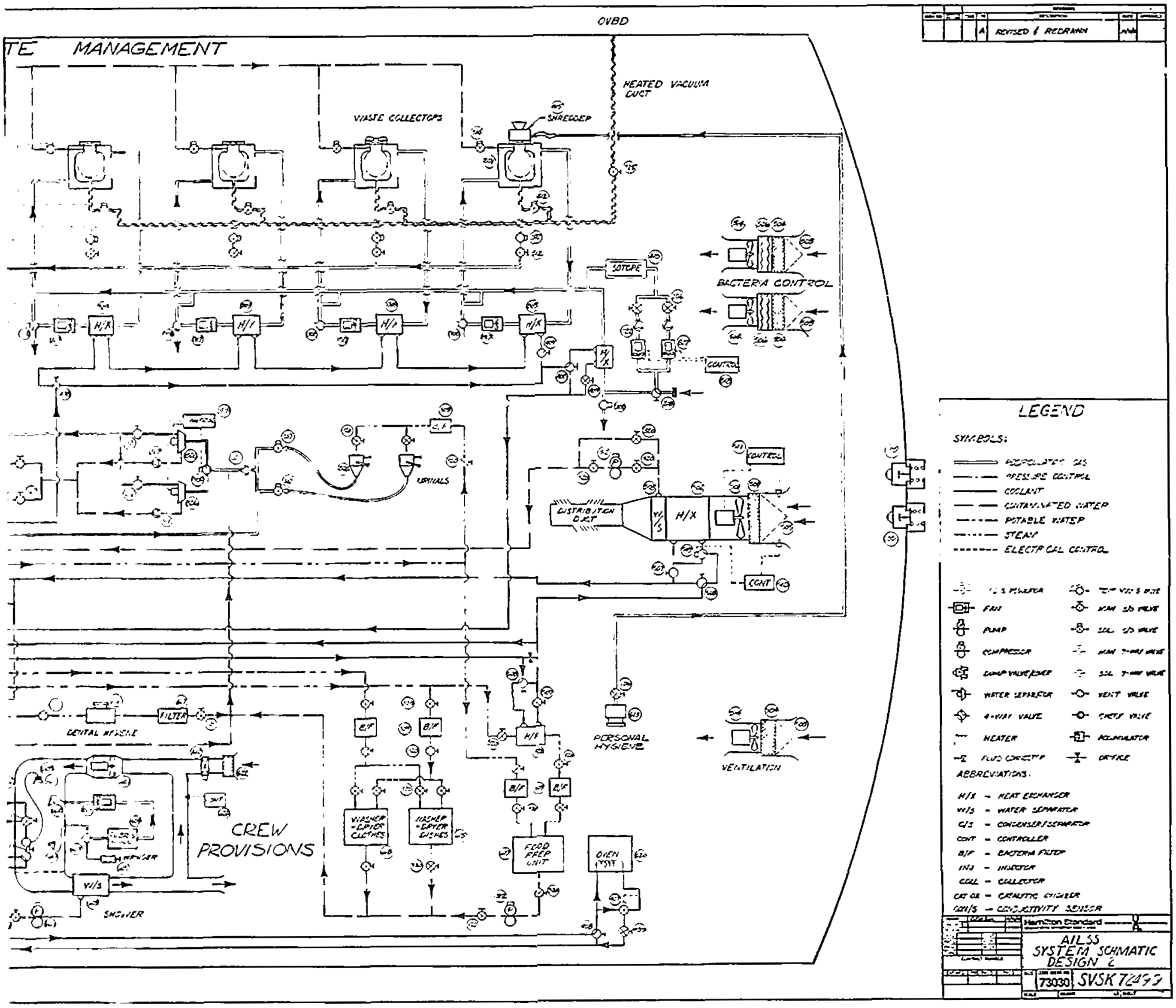
A REVISED & REDRAWN
OVBD
TE MANAGEMENT
HEATED VACUUM DUCT
WASTE COLLECTORS
SHREDDER
SORTER
BACTERIA CONTROL
H/X
CONTROL
URINALS
DISTRIBUTION DUCT
W/S
CONT
PERSONAL HYGIENE
VENTILATION
DENTAL HYGIENE
FILTER
CREW PROVISIONS
WASHER-DRYER CLOTHES
WASHER-DRYER DISHES
B/F
FOOD PREP UNIT
OVEN
SHOWER
W/S
WRINGER
LEGEND
SYMBOLS:
RECIRCULATED GAS
PRESSURE CONTROL
COOLANT
CONTAMINATED WATER
POTABLE WATER
STEAM
ELECTRICAL CONTROL
FAN
PUMP
COMPRESSOR
WATER SEPARATOR
4-WAY VALVE
HEATER
VENT VALVE
CHECK VALVE
ACCUMULATOR
ORIFICE
ABBREVIATIONS.
H/X - HEAT EXCHANGER
W/S - WATER SEPARATOR
C/S - CONDENSER/SEPARATOR
CONT - CONTROLLER
B/F - BACTERIA FILTER
INJ - INJECTOR
COLL - COLLECTOR
CAT OX - CATALYTIC OXIDIZER
CON/S - CONDUCTIVITY SENSOR
Hamilton Standard
AILSS SYSTEM SCHMATIC DESIGN 2
73030
SVSK 72493

TABLE 62

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item No.	Description	No.	Failure Rate ($\lambda \times 10^{-6}$)	Oper. Time T (hr)	Expected failures ($n\lambda t$)	Spares/reduandancy req.	Resulting unreliability
100	O_2 & N_2 Storage and Pressure Control						
101	Tank, Storage, O_2	3	0.01	12 000	0.000360	Install 1 Redundant Tank	0.000002
102	Tank, Storage, N_2	1	0.01	12 000	0.000120	-	0.000120
103	Heat Exchanger	2	0.004	12 000	0.000096	-	0.000096
104	Controller, Total Press.						
	1. Amp.	1	1.32	12 000	0.015840	2 Spares	0.000001
	2. Sensor	1	4.17	12 000	0.050040	2 Spares	0.000020
105	Valve, Cabin Dump & Relief						
	1. Launch						
	a. Fail Closed	2	2.54	100	0.000508	Install Redundant Valves	0.000001
	b. Fail Open	4	0.76	100	0.000304	-	0.000304
	2. Orbit (capped)	4	(0.76)(12 000)0.05	12 000	0.000022	-	0.000022
106	Fill Valve (cap)	5	0.001	12 000	0.000060	-	0.000060
107	Check Valve	5	0.27 (0.000120)	12 000	0.000002	-	0.000002
110	Valve, Shutoff						
	1. Tank Isolation	5	0.42 (0.000120)	12 000	0.000003	-	0.000003
	2. Cabin Refill	4	0.42	12 000	0.020160	2 Spares	0.000001
112	Pressure Regulator, O_2/N_2	2	2.94	12 000	0.070560	2 Spares	0.000001
114	Valve, Solenoid Shutoff	2	0.72	12 000	0.017280	2 Spares	0.000001
	1. Total Expected Failures				0.175355		
	2. Expected Failures Req. Crew Action				0.174848		
	3. Probability of Failure with Spares						0.000634
	4. Total Subsystem Reliability						0.999366

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures (n λ t)	Spares/redundancy req.	Resulting unreliability
200	TRACE CONTAMINANT CONTROL						
201	Valve, Gas Check (Fan Isol.)	5	0.27 (0.042)	12 000	0.000680	Spares Supplied with Fans 701	0.000001
202	Oxidizer, Catalytic	1	5.0	12 000	0.060000	Install 1 Redundant Plus 1 Spare	0.000040
203	Canister, Sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
204	Canister, Post-sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
205	Canister, Pre-sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
206	Valve, Manual Shutoff (Isolation						
	1. Item 332 (Leakage Not. Crit.)	1	-	-	-	-	-
	2. Item 613 (Leakage Not. Crit.)	1	-	-	-	-	-
	3. Item 817 Isolation	2	0.02(0.042)	12 000	0.000020	-	0.000020
207	Valve, Solenoid Shutoff						
	1. Item 202 Emerg. Isolation	2	0.072(0.03)	12 000	0.000052	-	0.000052
	2. Item 804 Isol.	2	0.72	12 000	0.017280	2 Spares	0.000003
	3. Item 801 Gas Lines	4	0.72	12 000	0.034560		
	4. Item 202	1	0.02(0.06)	12 000	0.000015	-	0.000015
209	Heat Exchanger, Regenerative	1	0.125	12 000	0.001500	1 Spare	0.000001
210	Isotope	1	Unknown	-	-	-	-
211	Control. Cat. Oxidizer Temp	1	3.5	12 000	0.042000	1 Spare + Installed	0.000015

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures (n λ t)	Spares/redundancy req.	Resulting unreliability
212	Valve, Manual Shutoff						
	1. Item 701 Isolation	6	0.02(0.042)	12 000	0.000061	-	0.000081
	2. Cabin Inlet, Outlet	2	0.2	12 000	0.004800	1 Spare	0.000011
	3. Item 207 Isol. Va.	4	0.02(0.00864)	12 000	0.000008	-	0.000008
	4. Item 806 Isol.	2	0.02(0.0225)	12 000	0.000011		0.000011
213	Valve Manual 3-Way	2	0.5	12 000	0.012000	1 Spare	0.000060
	1. Total Expected Failures				0.176587		
	2. Expected Failures Req. Crew Action				0.176587		
	3. Probability of Failure with Spares						0.000299
	4. Total Subsystem Reliability						0.999701
300	WATER MANAGEMENT						
303	Tank, Potable Water (Bladderless)	6	0.012	12 000	0.000864		0.000864
305	Tank, Chemical Storage	4	0.1	12 000	0.004800	Install 1 Redundant Tank	0.000010
306	Injector, Chemical	1	1.0	12 000	0.012000	Install Redundant Valves	0.000060
307	Heater	1	0.125	12 000	0.001500	1 Spare	0.000001
308	Solids Sensor	1	5.0	12 000	0.060000	2 Spares	0.000040
309	Bacteria Filter	21	0.1	12 000	0.025200	2 Spare Cover Seals	0.000004
310	Charcoal Filter	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
311	Sensor, Conductivity & Control	2	4.0	12 000	0.096000	3 Spares	0.000003
312	Pump	8	6.0	12 000	0.576000	5 Spares	0.000025
313	Valve, 4-Way Solenoid	1	1.67	12 000	0.020040	2 Spares	0.000002
314	Valve, 3-Way Solenoid	7	1.67	12 000	0.140280	3 Spares	0.000012
316	Regulator	1	2.94	12 000	0.035280	2 Spares	0.000008

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures (n λ t)	Spares/redundancy req.	Resulting unreliability
317	Check Valve	12	0.27	12 000	0.038880	2 Spares	0.000009
318	Valve, Shutoff Chem.						
	1. Tank	5	0.2(0.00012)	12 000	0.000001	-	0.000001
	2. Injector	4	0.02(0.012)	12 000	0.000012	-	0.000012
319	Valve, Vent	5	0.2(0.00012)	12 000	0.000001	-	0.000001
320	Valve, Shutoff (Isolation)						
	1. Item 309 (Minor Leak Not Crit)	33	0.001(0.0012)	12 000	0.000001	-	0.000001
	2. Item 312 (Minor Leak Not Crit)	16	0.001(0.072)	12 000	0.000014	-	0.000014
	3. Item 324 (Minor Leak Not Crit)	1	0.001(0.0353)	12 000	0.000001	-	0.000001
	4. Item 325 (Minor Leak Not Crit)	1	0.001(0.0353)	12 000	0.000001	-	0.000001
	5. Item 326 (Minor Leak Not Crit)	1	0.001(0.072)	12 000	0.000001	-	0.000001
	6. Item 328 (Minor Leak Not Crit)	2	0.001(0.0028)	12 000	0.000001	-	0.000001
	7. Item 333 (Minor Leak Not Crit)	1	0.001(0.0015)	12 000	0.000001	-	0.000001
	8. Item 617 (Minor Leak Not Crit)	7	0.001	12 000	0.000084	-	0.000084
	9. W/Disconn. (Minor Leak Not Crit)	6	0.001(0.012)	12 000	0.000001	-	0.000001
	10. Item 403 (Minor Leak Not Crit)	2	0.001	12 000	0.000024	-	0.000024
	11. Item 615 (Minor Leak Not Crit)	3	0.001(0.05)	12 000	0.000002	-	0.000002
	12. Item 618 (Minor Leak Not Crit)	3	0.001(0.05)	12 000	0.000002	-	0.000002
	13. Item 342	4	0.2(0.0017)	12 000	0.000016	-	0.000016
	14. Item 905 (Minor Leak Not Crit)	1	0.001(0.0086)	12 000	0.000001	-	0.000001
	15. 4 Misc. Bypass (Minor Leak Not Crit)	4	0.001	12 000	0.000048	-	0.000048
	16. Item 616	1	0.2	12 000	0.002400	-	
	17. Item 804	2	0.2	12 000	0.004800	2 Spares	0.000001
	18. Item 332	2	0.2	12 000	0.004800		
	19. Shower VA's	2	0.2	12 000	0.004800		
	20. Item 316	2	0.02(0.0175)	12 000	0.000008	-	0.000008
	21. Item 301	5	0.2(0.0017)	12 000	0.000020	-	0.000020

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item No.	Description	No.	Failure Rate (λ x 10^{-6})	Oper. Time T (hr)	Expected failures ($n\lambda t$)	Spares/redundancy req.	Resulting unreliability
321	Diverter Valve, Manual	5	0.5	12 000	0.030000	2 Spares	0.000005
323	Check Valve	2	0.27	12 000	0.006480	1 Spare	0.000020
324	Regulator, 25 psi	1	2.94	12 000	0.035280	2 Spares	0.000008
325	Regulator, 20 psi	1	2.94	12 000	0.035280	2 Spares	0.000008
326	Compressor	1	7.0	12 000	0.084000	3 Spares	0.000002
327	Accumulator	1	0.01	12 000	0.000120	-	0.000120
328	Chiller	2	0.23	12 000	0.005520	1 Spare	0.000015
329	Valve, Solenoid Shutoff, Chem.	2	1.0	12 000	0.024000	2 Spares	0.000003
331	Control, Heater	6	3.5	12 000	0.252000	4 Spares	0.000006
332	Collector, Liquid	1	0.001	12 000	0.000012	-	0.000012
333	Heat Exchanger	1	0.125	12 000	0.001500	1 Spare	0.000001
334	Pump	2	6.0	12 000	0.144000	3 Spares	0.000012
335	Cartridges Bacteria Filter	20	0.1	12 000	0.024000	2 Spares	0.000003
336	Cartridges, Charcoal Filter, Sm	1	0.1	12 000	0.001200	1 Spare	0.000001
337	Hose & Connector	1	1.0	10	0.000010		0.000010
339	Control, Tank Level	1	5.2	12 000	0.062400	3 Spares	0.000001
342	Diffusion Still Assy	3	4.975	4 000	0.059700	2 Standby Stills	0.000040
	1. Total Expected Failures				1.794586		
	2. Expected Failures Req. Crew Action				1.794586		
	3. Probability of Failure with Spares						0.001546
	4. Total Subsystem Reliability						0.998454

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item No.	Description	No.	Failure Rate ($\lambda \times 10^{-6}$)	Oper. Time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
400	THERMAL CONTROL						
401	Heat Sink Assembly	1	Unknown	-	-	-	-
402	Cold Plate Assembly	1	Unknown	-	-	-	-
403	Accumulator (Bladderless)	1	0.01	12 000	0.000120	-	0.000120
404	Pump	1	6.0	12 000	0.072000	Install Redundant Pump & Carry 1 Spare	0.000055
405	Valve, Modulating	2	1.215	12 000	0.029160	2 Spares	0.000004
406	Valve, Check	4	0.27(0.072)	12 000	0.000934	Spare Supplied with Pump	0.000020
407	Valve, Modulating	1	1.67	12 000	0.020040	2 Spares	0.000002
408	Manual 3-Way Valve						
	3. Item 405 Isol. (Minor Leak not Crit)	2	0.001(0.029)	12 000	0.000001	-	0.000001
	a. Bypass Leakage Not Crit.	2	0.001	12 000	0.000024	-	0.000024
	2. Item 407 Isol. (Minor Leak not Crit)	1	0.001(0.020)	12 000	0.000001	-	0.000001
	a. Bypass Leakage not Crit.	1	0.001	12 000	0.000012	-	0.000012
	3. Item 809 Isol. (Minor Leak not Crit)	2	0.001(0.0075)	12 000	0.000002	-	0.000002
	a. Bypass Leakage not Crit.	2	0.001	12 000	0.000024	-	0.000024
	4. Bypass Valve	1	0.001	12 000	0.000012	-	0.000012
409	Valve, Manual, Shutoff						
	1. Item 404 Isolation Va.	4	0.001(0.072)	12 000	0.000003	-	0.000003
	3. Item 405 Isol. (Minor Leak not Crit)	2	0.001(0.029)	12 000	0.000001	-	0.000001
	4. Item 407 Isol. (Minor Leak not Crit)	1	0.001(0.02)	12 000	0.000001	-	0.000001
	5. Item 410 Isol. (Minor Leak not Crit)	4	0.001(0.042)	12 000	0.000003	-	0.000003
	6. Item 809 Isol. (Minor Leak not Crit)	1	0.001(0.0075)	12 000	0.000001	-	0.000001

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
410	Coolant Pump	1	6.0	12 000	0.072000	1 Installed Pump + 1 Spare	0.000055
411	Heat Exchanger	1	0.125	12 000	0.001500	1 Spare	0.000001
	1. Total Expected Failures				0.195853		
	2. Expected Failures Req. Crew Action				0.193382		
	3. Proabability of Failure with Spares						0.000356
	4. Total Subsystem Reliability						0.999644
500	CABIN TEMPERATURE AND HUMIDITY CONTROL						
501	Fan	3	5.25	12 000	0.189000	3 Spares	0.000040
502	Heat Exchanger/Condenser	3	0.25	12 000	0.009000	1 Spare	0.000040
503	Separator, Water	3	1.2	12 000	0.043200	2 Spares	0.000015
504	Filter	8	0.01	12 000	0.000960	1 Spare	0.000001
505	Silencer/Debris Trap	8	-	-	-	-	-
506	Filter, Bacteria	12	0.1	12 000	0.014400	2 Spares	0.000001
507	Valve, Shutoff, Manual (Isolation)						
	1. Item 308 (Minor Leakage not Crit)	1	0.001(0.06)	12 000	0.000001	-	0.000001
	2. Item 342	10	0.2(0.0017)	12 000	0.000041	-	0.000041
	3. Item 334 (Minor Leak not Crit)	3	0.001(0.072)	12 000	0.000003	-	0.000003
	4. Item 328 (Minor Leak not Crit)	2	0.001(0.0028)	12 000	0.000001	-	0.000001
	5. Item 509 (Minor Leak not Crit)	4	0.001(0.08)	12 000	0.000004	-	0.000004
	6. Item 720 (Minor Leak not Crit)	1	0.001(0.035)	12 000	0.000001	-	0.000001
	7. Item 903 (Minor Leak not Crit)	1	0.001(0.0144)	12 000	0.000001	-	0.000001
	8. Item 904 (Minor Leak not Crit)	2	0.001(0.0144)	12 000	0.000001	-	0.000001
	9. Item 301 Isol.	10	0.2(0.0017)	12 000	0.000041	-	0.000041
	10. Item 509 Isol (Minor Leak not Crit)	5	0.001(0.1)	12 000	0.000006	-	0.000006

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item No.	Description	No.	Failure Rate (λx 10^{-6})	Oper. Time T (hr)	Expected failures ($n\lambda t$)	Spares/redundancy req.	Resulting unreliability
508	Valve, Manual, 3-Way (Isolation)						
	Bypass Leakage (Minor Leak not Crit)	13	0.001	12 000	0.000156	-	0.000156
	1. Item 509 (Minor Leak not Crit)	4	0.001(0.08)	12 000	0.000004	-	0.000004
	2. Item 308 (Minor Leak not Crit)	2	0.001(0.06)	12 000	0.000001	-	0.000001
	3. Item 903 (Minor Leak not Crit)	1	0.001(0.0144)	12 000	0.000001	-	0.000001
	4. Item 904 (Minor Leak not Crit)	1	0.001(0.0144)	12 000	0.000001	-	0.000001
	5. Item 509 (Minor Leak not Crit)	5	0.001(0.1)	12 000	0.000006	-	0.000006
509	Valve, Modulating	9	1.67	12 000	0.180360	3 Spares	0.000037
510	Control, Humidity	3	10	12 000	0.360000	4 Spares	0.000035
512	Fan, Bacteria Control	3	3.5	12 000	0.126000	3 Spares	0.000007
513	Control Motor Speed	3	6.5	12 000	0.234000	4 Spares	0.000004
514	Fan, Vent	2	3.5	12 000	0.084000	3 Spares	0.000001
	1. Total Expected Failures				1.241189		
	2. Expected Failures Req. Crew.				1.241189		
	3. Probability of Failure with Spares						0.000450
	4. Total Subsystem Reliability						0.999550
600	CREW PROVISIONS						
601	Fan, Shower	1	35	125	0.004375	1 Spare	0.000009
602	Stall, Shower	1	Unknown	-		-	-
603	Separator Filter, Water	1	50	125	0.006250	1 Spare	0.000018
604	Collector, Debris	1	-	-	-	-	-
605	Wringer, Manual	1	0.1	125	0.000013	-	0.000013
607	Vacuum Line & Attachment	1	0.1	125	0.000013	-	0.000013

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
608	Air Line & Attachment	1	0.1	125	0.000013	-	0.000013
609	Shower Head	1	0.05	125	0.000006	-	0.000006
610	Valve, Water Mixing	1	0.4	125	0.000050	1 Spare	0.000001
611	Valve, Diverter, Multiple	1	0.4	125	0.000050	1 Spare	0.000001
612	Valve, Air Inlet						
	1. Valve	1	0.1	125	0.000013	-	0.000013
	2. Actuator	1	6.0	125	0.000750	1 Spare	0.000001
613	Receptacle, Personal Hygiene	1	-	-	-	-	-
614	Battery, Shower Fan	1	40	125	0.005000	1 Spare	0.000012
615	Washer/Dryer, Dishes	1	100	500	0.050000	Carry 2 Spares of Rotating Parts (i.e. Pumps, Brgs, etc.)	0.000020
616	Receptacle, Dental Debris	1	-	-	-	-	-
617	Filter	2	0.1	12 000	0.002400	1 Spare	0.000003
618	Washer/Dryer, Clothes	1	100	500	0.050000	Same as 615	0.000020
619	Unit, Food Preparation	1	Unknown		-	-	-
620	Oven	1	0.01	12 000	0.000120	-	0.000120
622	Filter	1	0.1	12 000	0.001200	1 Spare	0.000001
624	Control, Temperature	1	3.5	125	0.000438	1 Spare	0.000001
	1. Total Expected Failures				0.120691		
	2. Expected Failures Req. Crew Action				0.120691		
	3. Probability of Failure with Spares						0.000265
	4. Total Subsystem Reliability						0.999735

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item No.	Description	No.	Failure Rate ($\lambda \times 10^{-6}$)	Oper. Time T (hr)	Expected failures ($n\lambda t$)	Spares/redundancy req.	Resulting unreliability
700	OXYGEN GENERATION						
701	Fan	2	3.5	12 000	0.084000	3 Spares	0.000002
706	Control, Pressure	1	10	12 000	0.120000	3 Spares	0.000008
709	Humidifier	1	1.2	12 000	0.014400	2 Spares	0.000001
710	Reactor, Electrolyte						
	1. Life (Failure Rate Within 250 Day Life Req. Per Stack)	15 Stacks	11.3/Stack	12 000	2.034000	10 Stacks	
	2. Leakage	15 Stacks	1.70/Stack	12 000	0.360000	3 Modules Assembly is Subdivided Into Modules Containing 5 Stacks. Six Modules Req. to Meet 500-Day Life Req. Five Standby Modules Req. for Redundancy.	0.000296
	3. Isolation Valve	33	0.2	12 000	0.079200	2 Failures are Required to Affect Subsyst. Perf.	0.000127
711	Separator, H_2	1	0.125	12 000	0.001500	1 Spare	0.000001
712	Heat Exchanger, Regen.	1	0.125	12 000	0.001500	1 Spare	0.000001
713	Reactor, Catalytic	2	0.5	6 000	0.006000	1 Spare	0.000018
716	Compressor	1	14.0	12 000	0.168000	3 Spares	0.000020
718	Valve, Diverter, 4-Way	2	6.24	12 000	0.149760	3 Spares	0.000015
720	Regulator, CO_2	1	2.94	12 000	0.035080	2 Spares	0.000007

TABLE 62 (Continued)

DESIGN 2 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
722	Valve, Check, Gas	2	0.27	12 000	0.006480	1 Spare	0.000018
723	Valve, Check, Hi-Temp	2	0.27	12 000	0.006480	1 Spare	0.000018
725	Valve, Shutoff, Manual						
	1. Item 713 OVBD Dump	1	0.2	12 000	0.002400	Install Redundant Va.	0.000006
	2. Item 711, 723 Isol. Va.	1	0.02 (0.0048)	12 000	0.000001	-	0.000001
	3. Item 812 Isol. Va.	1	0.02 (0.3456)	12 000	0.000083	-	0.000083
728	Valve, Purge, Selector	1	0.4	12 000	0.004800	1 Spare	0.000012
730	Catalyst Cartridge	2	0.1	6 000	0.001200	1 Spare	0.000001
732	Oxidizer	1	0.1	12 000	0.001200	1 Spare	0.000001
	1. Total Expected Failures				3.076084		
	2. Expected Failures Req. Crew Action				2.994484		
	3. Probability of Failure with Spares						0.000636
	4. Total Subsystem Reliability						0.999364
800	WASTE MANAGEMENT						
801	Collector, Waste						
	1. Hatch Seal	4	2.0	12 000	0.096000	3 Spares	0.000003
	2. HSG.	4	0.01	12 000	0.000480	-	0.000480
802	Collector, Ash	1	0.1	125	0.000013	-	0.000013
804	Urinal	2	0.3	225	0.000135	1 Spare	0.000001
806	Separator, Air/Urine	1	50	450	0.022500	1 Installed + 1 Spare	0.000002
807	Filter, Bacteria	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
808	Filter, Odor Control	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
809	Heat Exchanger	5	0.125	12 000	0.007500	1 Spare	0.000030

TABLE 63

DESIGN 2 - RELIABILITY ANALYSES SUMMARY

Subsystem	Total subsystem MTBF (hr)	Total expected failures	Failures with automatic redundancy	Expected failures requiring crew action		Total subsystem reliability
				Manual switching only required	Maintenance req'd.	
Oxygen & nitrogen storage & pressure control	68 400	0.1754	0.0005	0.0005	0.1744	0.999366
Trace contaminant control	68 000	0.1766	—	0.0027	0.1739	0.999701
Water management	6 800	1.7946	-	0.0765	1.7181	0.998454
Thermal control	61 300	0.1959	0.0038	—	0.1921	0.999644
Cabin temperature & humidity control	9 700	1.2412	—	—	1.2412	0.999550
Crew provisions	99 400	0.1207	—	—	0.1207	0.999735
Oxygen generation	3 900	3.0761	0.0816	2.3937	0.6008	0.999634
Waste management	15 000	0.8012	0.0190	—	0.7822	0.999402
CO_2 concentration	13 900	0.8658	—	-	0.8658	0.999797
Total	1420	8.4474	0.1049	2.4734	5.8692	0.995013

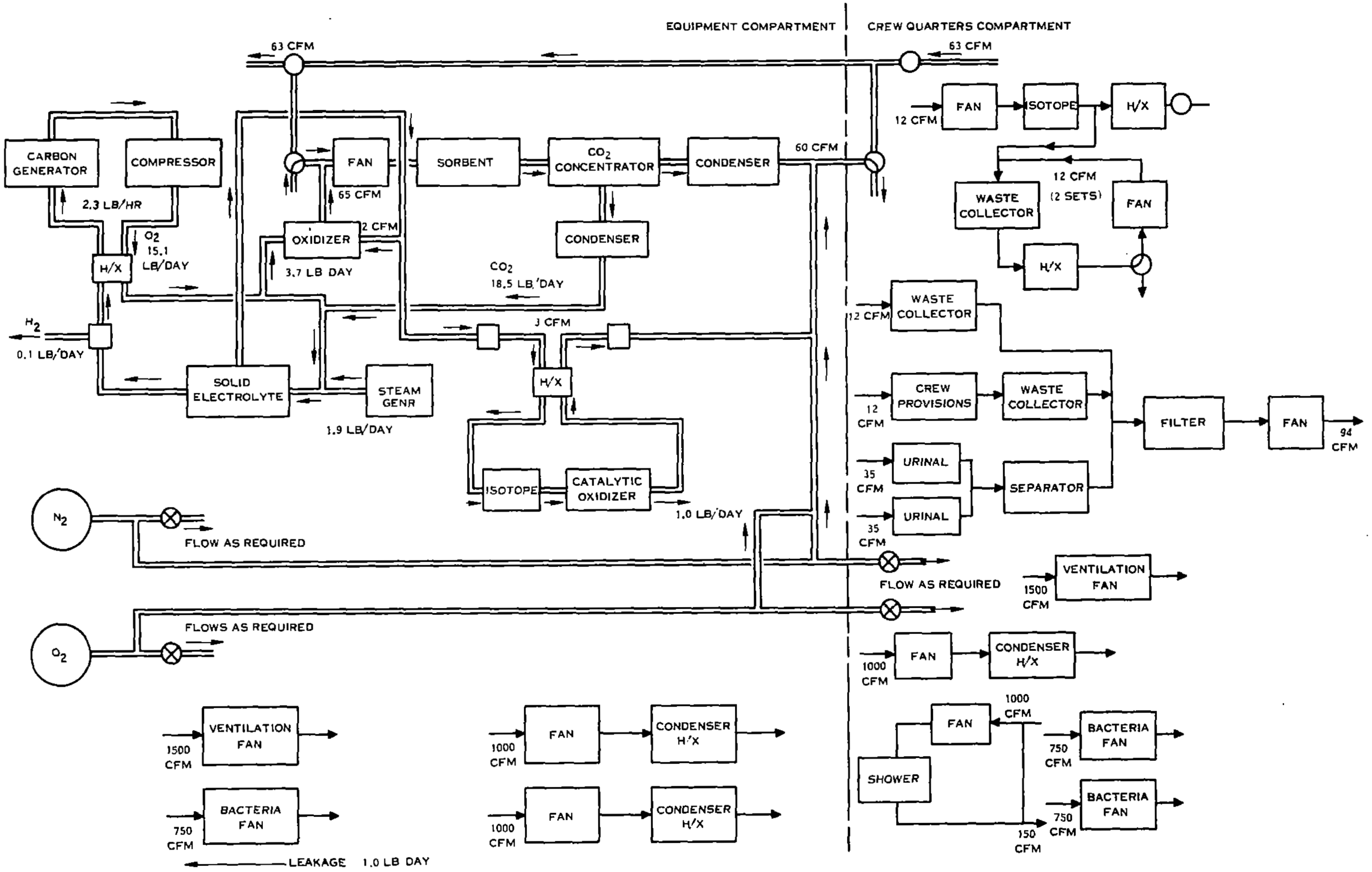

Figure 110. Gas Processing Flows - Design 2.

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tope heated, low temperature (200°F), source liquid heat transport loop is used to provide 6.8 kW of thermal power for CO_2 concentrator steam generation, oven heating, tank heating, and the heat of evaporation for the water reclamation system. Local isotopes are used in the catalytic oxidizer at 700°F and in the waste management subsystem at 1200°F. The 700°F catalytic oxidizer source is a 224 watt unit which ultimately rejects its heat to the cabin atmosphere. In the event of an equipment compartment depressurization, heat dissapation of the catalytic oxidizer isotope will be via conduction and radiation to the environment at a somewhat higher than normal operating temperature.

Heat dissipation of the waste control subsystem isotope heater, under cabin depressurization conditions, is directly to the liquid coolant loop. This heat source (1.5 kw thermal) is too large to rely upon passive heat rejection.

Temperature control of the 200°F isotope loop is effected by a separate high temperature radiator and radiator bypass control. This radiator also provides a heat sink for the isotope during periods of low or zero process heat demand. A silicone base heat transport fluid is recommended for the external isotope - radiator loop to accommodate both high isotope surface temperatures and low radiator freezing temperatures. The total equivalent weight penalty table 64 includes a weight penalty for the isotope radiator.

Water is circulated through the heat process loop to internal cabin components. The recirculation rate is 900 lb/hr with the loop pressure set at 20 psia. Components processed by the loop are in order of flow, the CO_2 concentrator steam generator, the food preparation oven, the potable water tanks, and the vapor diffusion water reclamation system evaporator heater.

In order to conserve isotope energy, and to minimize subsystem interactions, a regenerative heat exchanger (item 411) and temperature controls is used to step down the heat transfer fluid temperature at the outlet of the steam generator to 165°F for potable water tank heating. The water reclamation system heat exchanger (item 307) is also located within the regenerative loop. This unit provides heat of evaporation to the contaminated water recirculated through the membrane evaporator section of the distillation unit. Heat transport fluid flow out of the heater passes back through the regenerative heat exchanger, through the hot water circulation pumps (items 410), and back to the heat source heat exchanger.

The Design 2 coolant loop flow is similar to that of Design 1 with the following exceptions. Coolant flow out of the radiator loop heat exchanger (item 401) passes through the water chiller (item 328), divides, with a branch returning to the equipment compartment passing through the two equipment cabin temperature and humidity control heat exchangers (item 502) and the CO_2 feed line condenser-separator (item 904). In the equipment compartment, flow out of items 502 and 904 units are rejoined for temperature mixing purposes and divided again for the CO_2 process air condenser (item 903) and for the active vapor diffusion still condenser located within the (item 301) modules. Flow

TABLE 64
DESIGN 2 WEIGHT, POWER, AND VOLUME SUMMARY

	Weight (lb)			Power (watts)		^{b}Volume
EC/LS	^{a}Hardware	Expendables	Total	Electrical	Thermal	(ft^3)
O_2 & N_2 Storage	950.6	1393.0	2 343.6	6.0	0	103.8
Contaminant Control	395.2	75.0	470.2	0	224.0	24.4
Water Mgt	763.4	559.8	1 323.2	194.0	4574.0	114.9
Thermal Control	113.1		113.1	500.0	0	3.5
Cabin Temp & Humidity Control	735.1	670.0	1 405.1	1965.0	0	55.6
Crew Provisions	607.4		607.4	425.0	100.0	64.3
O_2 Generation	384.4	614.4	998.8	2252.0	0	191.1
Waste Mgt.	651.1	887.1	1 538.2	315.0	1500.0	133.0
CO_2 Con.	453.7		453.7	272.0	1240.0	24.0
Instrumentation	206.0		206.0	200.0	0	9.9
Subtotals	5260.0	4199.3	9 459.3	6129.0	7638.0	724.5
Food			10 630.0	-	-	683.0
Clothing			43.0	-	-	5.0
Total			20 132.3	6129.0	7638.0	1412.5

[a] Includes Spares

[b] Includes Spares and Expendables

out of these units rejoins, passes through the pressure bulkhead wall to the crew compartment, joins with the coolant flow out of the (item 502) crew cabin heat exchanger, and enters, in parallel with the electronic cold plates (item 402) and the potable water cooler (item 328). Coolant lines rejoin at this point, and, still in the crew compartment, is used in five parallel (item 809) waste management system air cooling heat exchangers. Flow out of these heat exchangers, as in Design 1, is through the hot potable water cooler (item 333), through the coolant loop circulation pumps, (item 404), and back into the radiator loop heat exchanger.

Trace contaminant control. - The chemical sorbent bed (item 203) used primarily for ammonia control is identical to that of Design 1. Application of a radioisotope heater for catalytic oxidizer heating requires some hardware changes. A 224 watt isotope heating unit (item 210) is separate from the two catalytic oxidizer units (items 202) and all three are located within a temperature controlled regenerative air loop. The (item 209) regenerative heat exchanger is a three pass design, allowing the (item 207) flow valves to be located in a cool section of the system. Pre-sorbers and post-sorbers are located before and after the regenerative loop.

CO_2 control and concentration. - Operation and major components of the ion exchange CO_2 concentrator are identical to those described in Design 1. The only difference is in the steam generation device (Item 902). Electrical heaters are replaced by a liquid heater located in the 200°F isotope heating circuit. Steam flow is regulated by a metered injection of water into the generator for fifteen minute periods every half hour.

Water reclamation. - A vapor diffusion, thermal distillation unit in Design 2 replaces the vapor diffusion/compression system selected for Design 1. This is a distillation process using isotope loop heat at 160°F for evaporation, and 55°F to 60°F coolant loop flow in its integral porous plate condenser.

The heat of evaporation is applied to recirculating contaminated water in the (Item 307) heater, but the actual evaporation process occurs across a membrane in the (item 301) still module. Design process rates are the same as in Design 1.

Potable water management. - Potable water leaving the system is at 55 to 60°F, the condenser operating temperature, and must therefore be heated to 160°F in the (item 303) storage tanks. In this design,the heat,in addition to the ambient tank heat loss,is provided by the isotope heat transport loop by means of internal tank heating coils. These coils replace the controlled electrical heaters of Design 1. All other functions and operations of the potable water management system are the same as described in the Design 1 description.

Waste management. - Process heat for the four vacuum decomposition waste process units (items 801) is supplied by a single, isolated, radioisotope heat source (item 810). Heat transport to and temperature control of the decomposition chambers is provided by a cabin air heat transport circuit. Cabin air is heated by the isotope and is directed through an insulated ducting system to one of two units in the decomposition mode. Individual cooling blowers (items 809) and flow control valves (items 908) are located in cool or cooled parts of the air heat transport circuit.

The collection, process cycle,and cooldown functions are identical to those described under Design 1.

Crew provisions. - The only change in the crew provisions equipment is the use of an isotope loop heated food preparation oven (Item 620) in the crew cabin. Electrical heat is used in Design 1 but was replaced by hot liquid heating in Design 2 to minimize electrical energy requirements.

Reliability

Reliability of Design 2, excluding display instrumentation, is estimated at 0.9950. The reliability analysis for each subsystem is presented in table 62.

The most likely number of failures, assuming a completely flight qualified system, occurring during the 500 day mission has been estimated to be 8. Of the total it is estimated that two failures will require only a switching operation and six will require component replacement. This results in a mean-time-between-failures of 1420 hours. The reliability of the isotope was not included in this analysis because of insufficient isotope failure rate data available. It is felt that isotope reliability will not significantly affect the system estimates quoted.

System Maintenance Considerations

Since major subsystems are similar but not identical in all system designs, maintenance concepts remain relatively similar. Since expendables and wearout items remain unchanged from Design 1, and since system operation is virtually identical among all 3 power system designs, scheduled maintenance times and system operational times remain nearly constant throughout. Significant changes, however, are reflected in increased unscheduled maintenance, brought about by the use of an isotope-heated liquid coolant circuit, with additional pumps, valves, and leakage paths, and by the use of isotope-heated hot gas circulating loops in the waste management and contaminant control systems, with additional redundant circulating fans. Because of these additional items, the anticipated number of failures is slightly greater than 8, yielding an estimated 12.8 hours of unscheduled maintenance time.

DESIGN 3 - BRAYTON CYCLE

System Description

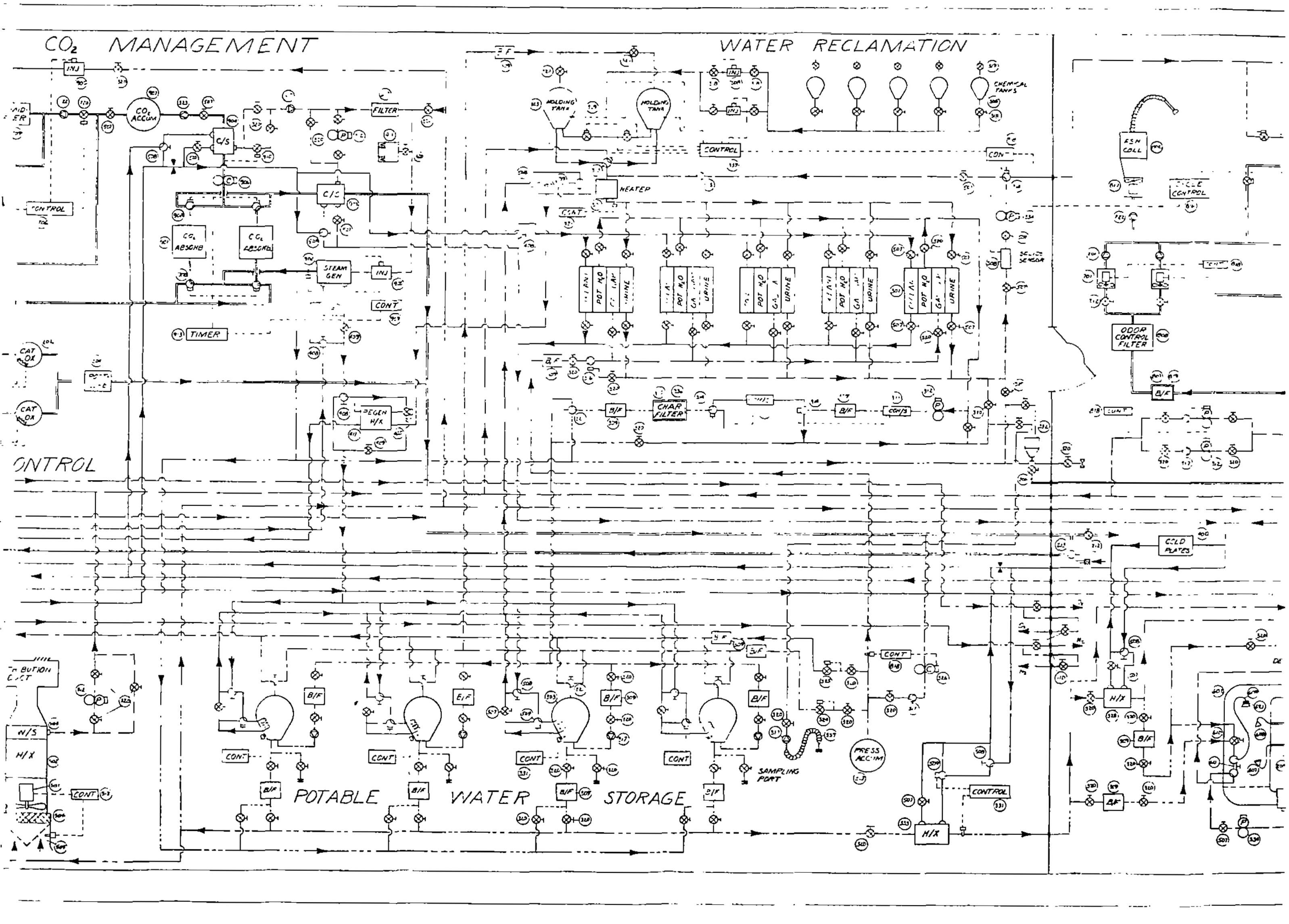
EC/LS Design 3 is intended for use in a vehicle using a Brayton cycle electrical power system. Waste heat generated by the Brayton cycle is made available to the EC/LS at 375° F. Thermal power is used in Design 3, as is radioisotope energy in Design 2, to reduce electrical power consumption and total equivalent weight. Electrical power penalty is 450 lb/kW, and thermal power is available at essentially zero penalty. Thermal power is obtained at the Brayton cycle radiator via an intermediate heat transport loop and is delivered to the EC/LS at 200°F.

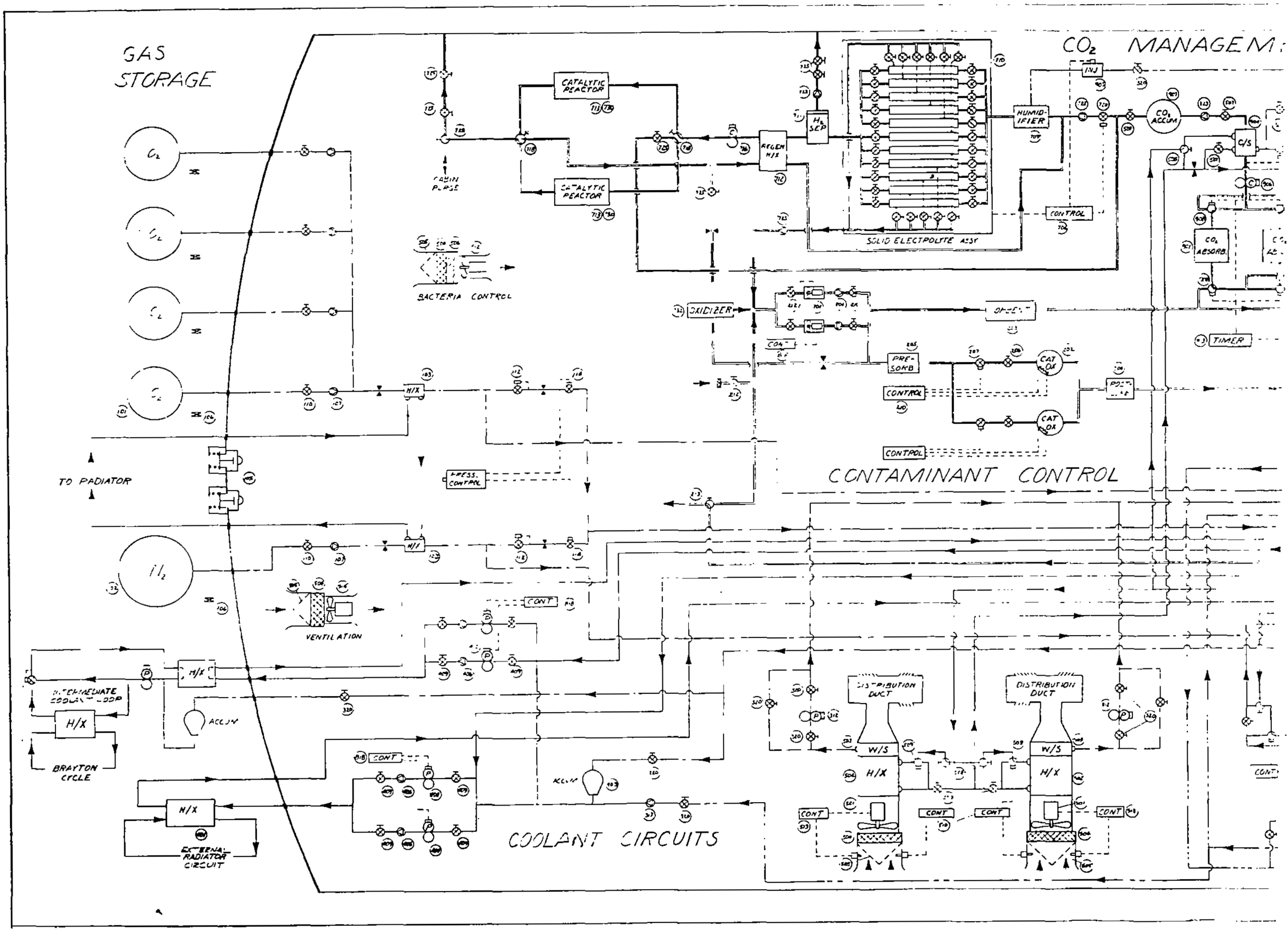
Figure 112 presents a detailed schematic of EC/LS Design 3. The corresponding parts list is shown on table 65. Basic hardware selections are similar to those of Designs 1 and 2, as can be seen in table 53. Whereas isotope heating is used in Design 2 to provide 700°F heating in the catalytic oxidizer and 1200°F heating in the waste management system, Design 3 relies upon electrical resistance heating, as does Design 1. With the exception of an electrically heated oven, the remaining subsystems are identical to those of Design 2. Specific Design 3 differences are discussed below. A weight, power, and volume summary is given in table 66. Figures 113 and 114 give gas processing flows and water balance schematics.

Thermal control. - Brayton cycle waste heat is rejected by the gaseous power cycle fluid to a liquid circuit which passes through a separate space radiator. Contiguous to the gas to liquid intermediate heat exchanger in the Brayton cycle is the heat pickup for the EC/LS. Temperature control of the hot water loop is effected within the intermediate loop, by bypassing of the Brayton cycle heat exchanger. A temperature control holds the intermediate fluid to 210° F, resulting in a 200° F hot water temperature for EC/LS use.

At reduced EC/LS heat power requirements the Brayton cycle heat exchanger is bypassed, with heat being accepted only as needed. At zero load requirements all flow is bypassed to maintain the desired 210° F inlet temperature. The Brayton cycle must then reject all of its waste heat in the Brayton cycle radiator.

The remainder of the hot water process heat circuit services the CO_2 concentrator steam generator, and within the regenerative temperature control loop, the hot potable water tanks and the vapor diffusion contaminated water heater. Design 3 has an electrically heated food preparation oven rather than the hot water heated oven in Design 2. This change was made for Design 3 to eliminate the routing of 200°F hot water lines through the pressure bulkhead separating the two compartments.


CO₂ MANAGEMENT
WATER RECLAMATION
ONTROL
POTABLE WATER STORAGE
INJ
CO₂ ACCUM
C/S
FILTER
CONTROL
C/C
CO₂ ABSORB
CO₂ ABSORB
STEAM GEN
INJ
CONT
TIMER
CAT OX
CAT OX
REGEN H/X
HOLDING TANK
HOLDING TANK
CHEMICAL TANKS
CONTROL
CONT
HEATER
POT H₂O
URINE
B/F
CHAR FILTER
CONT
FSH COLL
ODOR CONTROL FILTER
B/F
COLD PLATES
H/X
B/F
CONT
PRESS ACCUM
SAMPLING PORT
CONTROL
H/X
W/S
H/X
CONT
B/F


GAS STORAGE
O_2
O_2
O_2
O_2
H_2
CO2 MANAGEM
CATALYTIC REACTOR
CATALYTIC REACTOR
CABIN PURGE
REGEN H/X
H_2 SEP
SOLID ELECTROLYTE ASSY
HUMIDIFIER
INJ
CO_2 ACCUM
C/S
CONTROL
CO_2 ABSORB.
BACTERIA CONTROL
OXIDIZER
CONT
PRE-SORB
CAT OX
CAT OX
CONTROL
CONTROL
POST-SORB
TIMER
CONTAMINANT CONTROL
TO RADIATOR
H/X
H/X
PRESS. CONTROL
VENTILATION
CONT
INTERMEDIATE COOLANT LOOP
H/X
BRAYTON CYCLE
ACCUM
H/X
EXTERNAL RADIATOR CIRCUIT
CONT
PUMP
COOLANT CIRCUITS
DISTRIBUTION DUCT
DISTRIBUTION DUCT
W/S
W/S
H/X
H/X
CONT
CONT
CONT
CONT
CONT

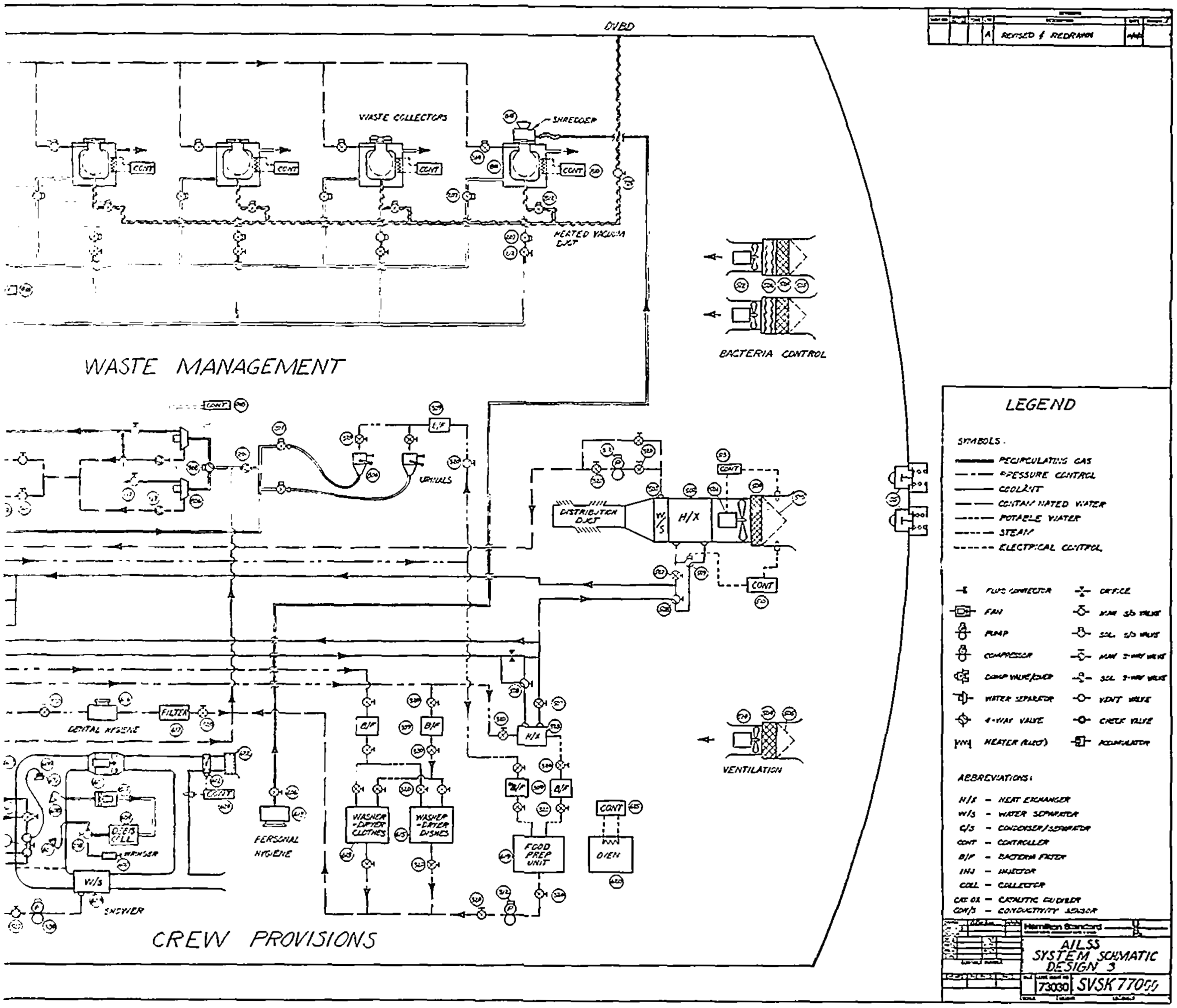

OVBD
A REVISED & REDRAWN
WASTE COLLECTORS
SHREDDER
CONT
CONT
CONT
CONT
HEATED VACUUM DUCT
WASTE MANAGEMENT
BACTERIA CONTROL
CONT
E/F
URINALS
DISTRIBUTION DUCT
W/S
H/X
CONT
CONT
FILTER
DENTAL HYGIENE
CONT
OVER CELL
WASHER
W/S
SHOWER
PERSONAL HYGIENE
B/F
B/F
WASHER -DRYER CLOTHES
WASHER -DRYER DISHES
H/X
B/F
B/F
FOOD PREP UNIT
CONT
OVEN
VENTILATION
CREW PROVISIONS
LEGEND
SYMBOLS.
RECIRCULATING GAS
PRESSURE CONTROL
COOLANT
CONTAMINATED WATER
POTABLE WATER
STEAM
ELECTRICAL CONTROL
FLUID CONNECTOR
FAN
PUMP
COMPRESSOR
COMP VALVE/DVER
WATER SEPARATOR
4-WAY VALVE
HEATER (ELECT)
ORIFICE
MAN S/O VALVE
SOL. S/O VALVE
MAN 3-WAY VALVE
SOL 3-WAY VALVE
VENT VALVE
CHECK VALVE
ACCUMULATOR
ABBREVIATIONS:
H/X - HEAT EXCHANGER
W/S - WATER SEPARATOR
C/S - CONDENSER/SEPARATOR
CONT - CONTROLLER
B/F - BACTERIA FILTER
INJ - INJECTOR
COLL - COLLECTOR
CAT OX - CATALYTIC OXIDIZER
CON/S - CONDUCTIVITY SENSOR
Hamilton Standard
AILSS
SYSTEM SCHMATIC
DESIGN 3
73030
SVSK 77099

TABLE 65

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
100	O_2 & N_2 Storage and Pressure Control						
101	Tank, Storage, O_2	3	0.01	12 000	0.000360	Install 1 Redundant Tank	0.000002
102	Tank, Storage, N_2	1	0.01	12 000	0.000120	-	0.000120
103	Heat Exchanger	2	0.004	12 000	0.000096	-	0.000096
104	Controller, Total Press.						
	1. Amp.	1	1.32	12 000	0.015840	2 Spares	0.000001
	2. Sensor	1	4.17	12 000	0.050040	2 Spares	0.000020
105	Valve, Cabin Dump & Relief						
	1. Launch						
	a. Fail Closed	2	2.54	100	0.000508	Install Redundant Valves	0.000001
	b. Fail Open	4	0.76	100	0.000304	-	0.000304
	2. Orbit (capped)	4	(0.76 (12 000) 0.05	12 000	0.000022	-	0.000022
106	Fill Valve (cap)	5	0.001	12 000	0.000060	-	0.000060
107	Check Valve	5	0.27 (0.000120)	12 000	0.000002	-	0.000002
110	Valve, Shutoff						
	1. Tank Isolation	5	0.42 (0.000120)	12 000	0.000003		0.000003
	2. Cabin Refill	4	0.42	12 000	0.020160	2 Spares	0.000001
112	Pressure Regulator, O_2/N_2	2	2.94	12 000	0.070580	2 Spares	0.000001
114	Valve, Solenoid Shutoff	2	0.72	12 000	0.017280	2 Spares	0.000001
	1. Total Expected Failures				0.175355		
	2. Expected Failures Req. Crew Action				0.174848		
	3. Probability of Failure with Spares						0.000634
	4. Total Subsystem Reliability						0.999366

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures (n λ t)	Spares/redundancy req.	Resulting unreliability
200	Trace Contaminant Control						
201	Valve, Gas Check (Fan Isol.)	5	0.27 (0.042)	12 000	0.000680	Spares Supplied with Fans 701	0.000001
202	Oxidizer, Catalytic	1	5.0	12 000	0.060000	Install 1 Redundant Plus 1 Spare	0.000040
203	Canister, Sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
204	Canister, Post-sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
205	Canister, Pre-sorbent	1	0.1	12 000	0.001200	1 Spare	0.000001
206	Valve, Manual Shutoff (Isolation)						
	1. Item 202	2	0.02 (0.06)	12 000	0.000029	-	0.000029
	2. Item 332 (Leakage Not. Crit.)	1	-	-	-	-	-
	3. Item 613 (Leakage Not. Crit.)	1	-	-	-	-	-
207	Valve, Solenoid Shutoff						
	1. Item 202 Emerg. Isolation	2	0.072 (0.03)	12 000	0.000052		0.000052
	2. Item 804 Isol.	2	0.72	12 000	0.017280	3 Spares	
	3. Item 801 Gas Lines	8	0.72	12 000	0.069120		0.000004
213	Valve, Manual 3-Way	2	0.5	12 000	0.012000	1 Spare	0.000060
211	Control, Cat. Oxidizer Temp	1	3.5	12 000	0.042000	1 Spare + Installed	0.000015

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
212	Valve, Manual Shutoff						
	1. Item 701 Isolation	6	0.02 (0.042)	12 000	0.000061	-	0.000061
	2. Cabin Inlet, Outlet	2	0.2	12 000	0.004800	1 Spare	0.000011
	3. Item 207 Isol. Va.	4	0.02 (0.00864)	12 000	0.000008	-	0.000008
	4. Item 806 Isolation	2	0.02 (0.0225)	12 000	0.000011	-	0.000011
	1. Total Expected Failures				0.209653		
	2. Expected Failures Req. Crew Action				0.209653		
	3. Probability of Failure with Spares						0.000307
	4. Total Subsystem Reliability						0.999693
300	Water Management						
303	Tank, Potable Water (Bladderless)	6	0.012	12 000	0.000864		0.000864
305	Tank, Chemical Storage	4	0.1	12 000	0.004800	Install 1 Redundant Tank	0.000010
306	Injector, Chemical	1	1.0	12 000	0.012000	Install 1 Redundant Valve	0.000060
307	Heater	1	0.125	12 000	0.001500	1 Spare	0.000001
308	Solids Sensor	1	5.0	12 000	0.060000	2 Spares	0.000040
309	Bacteria Filter	21	0.1	12 000	0.025200	2 Spare Cover Seals	0.000004
310	Charcoal Filter	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
311	Sensor, Conductivity & Control	2	4.0	12 000	0.096000	3 Spares	0.000003
312	Pump	8	6.0	12 000	0.576000	5 Spares	0.000025
313	Valve, 4-Way Solenoid	1	1.67	12 000	0.020040	2 Spares	0.000002

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures (n λ t)	Spares/redundancy req.	**Resulting unreliability**
314	Valve, 3-Way Solenoid	7	1.67	12 000	0.140280	3 Spares	0.000012
316	Regulator	1	2.94	12 000	0.035280	2 Spares	0.000008
317	Check Valve	12	0.27	12 000	0.038880	2 Spares	0.000009
318	Valve, Shutoff Chem.						
	1. Tank	5	0.2 (0.00012)	12 000	0.000001	-	0.000001
	2. Injector	4	0.02 (0.012)	12 000	0.000012	-	0.000012
319	Valve, Vent	5	0.2 (0.00012)	12 000	0.000001	-	0.000001
320	Valve, Shutoff (Isolation)						
	1. Item 309 (Minor Leak Not Crit)	33	0.001 (0.0012)	12 000	0.000001	-	0.000001
	2. Item 312 (Minor Leak Not Crit)	16	0.001 (0.072)	12 000	0.000014	-	0.000014
	3. Item 324 (Minor Leak Not Crit)	1	0.001 (0.0353)	12 000	0.000001	-	0.000001
	4. Item 325 (Minor Leak Not Crit)	1	0.001 (0.0353)	12 000	0.000001	-	0.000001
	5. Item 326 (Minor Leak Not Crit)	1	0.001 (0.072)	12 000	0.000001	-	0.000001
	6. Item 328 (Minor Leak Not Crit)	2	0.001 (0.0028)	12 000	0.000001	-	0.000001
	7. Item 333 (Minor Leak Not Crit)	1	0.001 (0.0015)	12 000	0.000001	-	0.000001
	8. Item 617 (Minor Leak Not Crit)	7	0.001	12 000	0.000084	-	0.000084
	9. W/Disconn. (Minor Leak Not Crit)	6	0.001 (0.012)	12 000	0.000001	-	0.000001
	10. Item 403 (Minor Leak Not Crit)	2	0.001	12 000	0.000024	-	0.000024
	11. Item 615 (Minor Leak Not Crit)	3	0.001 (0.05)	12 000	0.000002	-	0.000002
	12. Item 618 (Minor Leak Not Crit)	3	0.001 (0.05)	12 000	0.000002	-	0.000002
	13. Item 342	4	0.2 (0.0017)	12 000	0.000016	-	0.000016
	14. Item 905 (Minor Leak Not Crit)	1	0.001 (0.0086)	12 000	0.000001	-	0.000001
	15. 4 Misc. Byps. (Minor Leak Not Cr.)	4	0.001	12 000	0.000048	-	0.000048
	16. Item 616	1	0.2	12 000	0.002400	-	
	17. Item 804	2	0.2	12 000	0.004800	-	
	18. Item 332	2	0.2	12 000	0.004800	2 Spares	0.000001
	19. Shower VA's	2	0.2	12 000	0.004800	-	
	20. Item 316	2	0.02 (0.0175)	12 000	0.000008	-	0.000008
	21. Item 301	5	0.2 (0.0017)	12 000	0.000020	-	0.000020
321	Diverter Valve, Manual	5	0.5	12 000	0.030000	2 Spares	0.000005

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
323	Check Valve	2	0.27	12 000	0.006480	1 Spare	0.000020
324	Regulator, 25 psi	1	2.94	12 000	0.035280	2 Spares	0.000008
325	Regulator, 20 psi	1	2.94	12 000	0.035280	2 Spares	0.000008
326	Compressor	1	7.0	12 000	0.084000	3 Spares	0.000002
327	Accumulator	1	0.01	12 000	0.000120	-	0.000120
328	Chiller	2	0.23	12 000	0.005520	1 Spare	0.000015
329	Valve, Solenoid Shutoff, Chem.	2	1.0	12 000	0.024000	2 Spares	0.000003
331	Control, Heater	6	3.5	12 000	0.252000	4 Spares	0.000006
332	Collector, Liquid	1	0.001	12 000	0.000012	-	0.000012
333	Heat Exchanger	1	0.125	12 000	0.001500	1 Spare	0.000001
334	Pump	2	6.0	12 000	0.144000	3 Spares	0.000012
335	Cartridges, Bacteria Filter	20	0.1	12 000	0.02400	2 Spares	0.000003
336	Cartridges, Charcoal Filter, SM	1	0.1	12 000	0.001200	1 Spare	0.000001
337	Hose & Connector	1	1.0	10	0.000010		0.000010
339	Control, Tank Level	1	5.2	12 000	0.062400	3 Spares	0.000001
342	Diffusion Still Assy.	3	4.975	4 000	0.059700	2 Standby Stills	0.000040
	1. Total Expected Failures 2. Expected Failures Req. Crew Action 3. Probability of Failure with Spares 4. *Total Subsystem Reliability*				1.794286 1.794286		0.001546 0.998454

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
400	Thermal Control						
401	Heat Sink Assembly	1	Unknown	-	-	-	-
402	Cold Plate Assembly	1	Unknown	-	-	-	-
403	Accumulator (Bladderless)	1	0.01	12 000	0.000120	-	0.000120
404	Pump	1	6.0	12 000	0.072000	Install 1 Redundant Pump & Carry 1 Spare	0.000055
405	Valve Modulating	1	1.215	12 000	0.014580	2 Spares	0.000001
406	Valve, Check	4	0.27 (0.072)	12 000	0.000934	Spare Supplied with Pump	0.000020
407	Valve, Modulating	1	1.67	12 000	0.020040	2 Spares	0.000002
408	Valve, Manual, 3-Way						
	1. Item 405 Isol (Minor Leak Not Crit)	1	0.001 (0.014)	12 000	0.000001	-	0.000001
	a. Bypass Leak not crit	1	0.001	12 000	0.000012	-	0.000012
	2. Item 407 Isol (Minor Leak Not Crit)	1	0.001 (0.02)	12 000	0.000001	-	0.000001
	a. Bypass Leak not crit	1	0.001	12 000	0.000012	-	0.000012
	3. Bypass Valve	1	0.001	12 000	0.000012	-	0.000012
409	Valve, Manual, Shutoff						
	1. Item 404 Isolation Va.	4	0.001 (0.072)	12 000	0.000003	-	0.000003
	2. Item 405 Isol (Minor Leak Not Crit)	1	0.001 (0.029)	12 000	0.000001	-	0.000001
	3. Item 407 Isol (Minor Leak Not Crit)	1	0.001 (0.02)	12 000	0.000001	-	0.000001
	4. Item 410 Isol (Minor Leak Not Crit)	4	0.001 (0.042)	12 000	0.000003	-	0.000003
410	Coolant Pump	1	6.0	12 000	0.072000	1 Install Pump + 1 Spare	0.000055

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
411	Heat Exchanger	1	0.125	12 000	0.001500	1 Spare	0.000001
	1. Total Expected Failures				0.181234		
	2. Expected Failures Req. Crew Action				0.178763		
	3. Probability of Failure with Spares						0.000314
	4. Total Subsystem Reliability						0.999686
500	Cabin Temp. & Humidity Control						
501	Fan	3	5.25	12 000	0.189000	3 Spares	0.000040
502	Heat Exchanger/Condenser	3	0.25	12 000	0.009000	1 Spare	0.000040
503	Separator, Water	3	1.2	12 000	0.043200	2 Spares	0.000015
504	Filter	8	0.01	12 000	0.000960	1 Spare	0.000001
505	Silencer/Debris Trap	8	-	-	-	-	-
506	Filter, Bacteria	12	0.1	12 000	0.014400	2 Spares	0.000001
507	Valve, Shutoff, Manual (Isolation)						
	1. Item 308 (Minor Leak Not Crit)	1	0.001 (0.06)	12 000	0.000001	-	0.000001
	2. Item 342	10	0.2 (0.0017)	12 000	0.000041	-	0.000041
	3. Item 334 (Minor Leak Not Crit)	3	0.001 (0.072)	12 000	0.000003	-	0.000003
	4. Item 328 (Minor Leak Not Crit)	2	0.001 (0.0028)	12 000	0.000001	-	0.000001
	5. Item 509 (Minor Leak Not Crit)	4	0.001 (0.08)	12 000	0.000004	-	0.000004
	6. Item 720 (Minor Leak Not Crit)	1	0.001 (0.035)	12 000	0.000001	-	0.000001
	7. Item 903 (Minor Leak Not Crit)	1	0.001 (0.0144)	12 000	0.000001	-	0.000001
	8. Item 904 (Minor Leak Not Crit)	2	0.001 (0.0144)	12 000	0.000001	-	0.000001
	9. Item 301	10	0.2 (0.0017)	12 000	0.000041	-	0.000041
	10. Item 509 (Minor Leak Not Crit)	5	0.001 (0.1)	12 000	0.000006	-	0.000006
	11. Item 809 (Minor Leak Not Crit)	1	0.001 (0.0015)	12 000	0.000001	-	0.000001

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures $(n \lambda t)$	Spares/redundancy req.	Resulting unreliability
508	Valve, Manual, 3-Way (Isolation)						
	Bypass Port Leakage (Minor Leak Not Crit)	14	0.001	12 000	0.000156	-	0.000156
	Isolation Port Leakage						
	1. Item 509 (Minor Leak Not Crit)	4	0.001 (0.08)	12 000	0.000004	-	0.000004
	2. Item 308 (Minor Leak Not Crit)	2	0.001 (0.06)	12 000	0.000001	-	0.000001
	3. Item 903 (Minor Leak Not Crit)	1	0.001 (0.0144)	12 000	0.000001	-	0.000001
	4. Item 904 (Minor Leak Not Crit)	1	0.001 (0.0144)	12 000	0.000001	-	0.000001
	5. Item 509 (Minor Leak Not Crit)	5	0.001 (0.1)	12 000	0.000006	-	0.000006
	6. Item 809 (Minor Leak Not Crit)	1	0.001 (0.0015)	12 000	0.000001	-	0.000001
509	Valve, Modulating	9	1.67	12 000	0.180360	3 Spares	0.000037
510	Control, Humidity	3	10	12 000	0.360000	4 Spares	0.000035
512	Fan, Bacteria Control	3	3.5	12 000	0.126000	3 Spares	0.000007
513	Control Motor Speed	3	6.5	12 000	0.234000	4 Spares	0.000004
514	Fan, Vent	2	3.5	12 000	0.084000	3 Spares	0.000001
	1. Total Expected Failures				1.241191		
	2. Expected Failure Req. Crew. Action				1.241191		
	3. Probability of Failure with Spares						0.000452
	4. Total Subsystem Reliability						0.999548

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
600	Crew Provisions 1						
601	Fan, Shower	1	35	125	0.004375	1 Spare	0.000009
602	Stall, Shower	1	Unk	-		-	-
603	Separator/Filter, Water	1	50	125	0.006250	1 Spare	0.000018
604	Collector, Debris	1	-	-	-	-	-
605	Wringer, Manual	1	0.1	125	0.000013	-	0.000013
607	Vacuum Line & Attachment	1	0.1	125	0.000013	-	0.000013
608	Air Line & Attachment	1	0.1	125	0.000013	-	0.000013
609	Shower Head	1	0.05	125	0.000006	-	0.000006
610	Valve, Water Mixing	1	0.4	125	0.000050	1 Spare	0.000001
611	Valve, Diverter, Multiple	1	0.4	125	0.000050	1 Spare	0.000001
612	Valve, Air Inlet						
	1. Valve	1	0.1	125	0.000013	-	0.000013
	2. Actuator	1	6.0	125	0.000750	1 Spare	0.000001
613	Receptacle, Personal Hygiene	1	-	-	-	-	-
614	Battery, Shower Fan	1	40	125	0.005000	1 Spare	0.000012
615	Washer/Dryer, Dishes	1	100	500	0.050000	Carry 2 Spares of Rotating Parts (i.e. Pumps, Brgs, etc.)	0.000020

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
616	Receptacle, Dental Debris	1	-	-	-	-	-
617	Filter	2	0.1	12 000	0.002400	1 Spare	0.000003
618	Washer/Dryer, Clothes	1	100	500	0.050000	Same as 615	0.000020
619	Unit, Food Preparation	1	Unk	-	-	-	-
620	Oven	1	1.0	500	0.000500	Install 2 Redundant Headers	0.000001
622	Filter	1	0.1	12 000	0.001200	1 Spare	0.000001
624	Control, Temperature	1	3.5	125	0.000439	1 Spare	0.000001
625	Control, Oven Temp	1	3.5	500	0.001750	1 Spare	0.000002
	1. Total Expected Failures 2. Expected Failures Req. Crew Action 3. Probability of Failure with Spares 4. Total Subsystem Reliability				0.122821 0.122321		0.000148 0.999852
700	Oxygen Generation						
701	Fan	2	3.5	12 000	0.084000	3 Spares	0.000002
706	Control, Pressure	1	10	12 000	0.120000	3 Spares	0.000008
709	Humidifier	1	1.2	12 000	0.014000	2 Spares	0.000001

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate (λ x 10^{-6})	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
710	Reactor, Electrolyte						
	1. Life (Failure Rate Within 250 Day Life Req. Per Stack)	15 Stacks	11.3/Stack	12 000	2.034000	10 Stacks	
	2. Leakage	15 Stacks	1.70/Stack	12 000	0.360000	3 Modules Assembly is Subdivided Into Modules Containing 5 Stacks, Sic Modules Req. to Meet 500-Day Life Req. Five Standby Modules Req. for Redundancy	0.000296
	3. Isolation Valve	33	0.2	12 000	0.079200	2 Failures are Required to Affect Subsyst. Perf.	0.000127
611	Separator H_2	1	0.125	12 000	0.001500	1 Spare	0.000001
712	Heat Exchanger, Regen.	1	0.125	12 000	0.001500	1 Spare	0.000001
713	Reactor, Catalytic	2	0.5	6 000	0.006000	1 Spare	0.000018
716	Compressor	1	14.0	12 000	0.168000	3 Spares	0.000020
718	Valve, Diverter, 4-Way	2	6.24	12 000	0.149760	3 Spares	0.000015
720	Regulator, CO_2	1	2.94	12 000	0.035080	2 Spares	0.000007
722	Valve, Check, Gas	2	0.27	12 000	0.006480	1 Spare	0.000018
723	Valve, Check, Hi-Temp	2	0.27	12 000	0.006480	1 Spare	0.000018
725	Valve, Shutoff, Manual						
	1. Item 713 OVBD Dump	1	0.2	12 000	0.002400	Install Redundant Va.	0.000006
	2. Item 711, 723 Isol. Va.	1	0.02 (0.0048)	12 000	0.000001	-	0.000001
	3. Item 812 Isol. Va.	1	0.02 (0.3456)	12 000	0.000083	-	0.000083

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda x 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	**Resulting unreliability**
728	Valve, Purge, Selector	1	0.4	12 000	0.004800	1 Spare	0.000012
730	Catalyst Cartridge	2	0.1	6 000	0.001200	1 Spare	0.000001
732	Oxidizer	1	0.1	12 000	0.001200	1 Spare	0.000001
	1. Total Expected Failures				3.076084		
	2. Expected Failures Req. Crew Action				2.994484		
	3. Probability of Failure with Spares						0.000636
	4. Total Subsystem Reliability						0.999364
800	Waste Management						
801	Collector, Waste	4	-	-	-	-	-
	1. Hatch Seal	4	2.0	12 000	0.096000	3 Spares	0.000003
	2. Heater	4	1.0	12 000	0.048000	Install 2 Redundant Heaters	0.000001
	3. HSG.	4	0.01	12 000	0.000480	-	0.000480
802	Collector, Ash	1	0.1	125	0.000013	-	0.000013
804	Urinal	2	0.3	225	0.000135	1 Spare	0.000001
806	Separator, Air/Urine	1	50	450	0.022500	1 Installed + 1 Spare	0.000002
807	Filter, Bacteria	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
808	Filter, Odor Control	1	0.1	12 000	0.001200	1 Spare Cover Seal	0.000001
809	Heat Exchanger	1	0.125	12 000	0.001500	1 Spare	0.000001
810	Control, Heater	1	3.5	6 000	0.084000	3 Spares	0.000002
811	Collection Bags	2	Unknown	-	-	-	-

TABLE 65 (Continued)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
812	Valve, Sol., Shutoff Hi Temp.	4	7.2	12 000	0.345600	4 Spares	0.000030
815	Shredder	1	50	450	0.022500	2 Spares	0.000002
816	Cycle Control	1	13	12 000	0.156000	3 Spares	0.000015
817	Fan	2	35	125	0.008750	2 Spares	0.000001
818	Control	7	2.0 (0.072)	12 000	0.012096	Not Req. For Mission Comp.	-
819	Cartridges, Bacteria Filter	1	0.1	12 000	0.000120	1 Spare	0.000001
820	Cartridges, Charcoal Filter	1	0.1	12 000	0.000120	1 Spare	0.000001
	1. Total Expected Failures				0.800214		
	2. Expected Failures Req. Crew Action				0.800214		
	3. Probability of Failure with Spares						0.000555
	4. Total Subsystem Reliability						0.999445
900	CO_2 Concentration						
901	Bed, Ion Exchange Resin	2	1.2	12 000	0.028800	2 Spares	0.000004
902	Generator, Steam	1	0.15	12 000	0.001800	1 Spare	0.000001

TABLE 65 (Concluded)

DESIGN 3 COMPONENT LIST AND RELIABILITY DATA

Item no.	Description	No.	Failure rate ($\lambda \times 10^{-6}$)	Oper. time T (hr)	Expected failures ($n \lambda t$)	Spares/redundancy req.	Resulting unreliability
903	Condenser/Separator	1	1.2	12 000	0.014400	2 Spares	0.000001
904	Condenser/Separator, CO_2	1	1.2	12 000	0.014400	2 Spares	0.000001
905	Injector, Water	2	0.72	12 000	0.017280	2 Spares	0.000001
906	Compressor, CO_2	1	7.0	12 000	0.084000	3 Spares	0.000002
907	Accumulator, CO_2	1	0.01	12 000	0.000120		0.000120
908	Valve, 3-Way Solenoid	5	6.24	12 000	0.374400	4 Spares	0.000040
909	Control, Heater	1	3.5	12 000	0.042000	2 Spares	0.000015
910	Accumulator, Water	1	1.29	12 000	0.015480	2 Spares	0.000001
911	Water Regulator	1	1.46	12 000	0.017520	2 Spares	0.000001
913	Timer	1	13	12 000	0.156000	3 Spares	0.000015
	1. Total Expected Failures				0.765600		
	2. Expected Failures Req. Crew Action				0.765600		
	3. Probability of Failure with Spares						0.000202
	4. Total Subsystem Reliability						0.999798

TABLE 66
DESIGN 3 WEIGHT, POWER, AND VOLUME SUMMARY

EC/LS	Weight (lb)			Power (watts)		[b]Volume
	[a]Hardware	Expendables	Total	Electrical	Thermal	(ft^3)
O_2 & N_2 Storage	957.1	1393.0	2 350.1	6.0	0	103.8
Contaminant Control	371.4	75.0	446.4	112.0	0	24.4
Water Mgt.	787.6	559.8	1 347.4	194.0	4574.0	114.9
Thermal Control	104.1		104.1	500.0	0	3.5
Cabin Temp & Humidity Control	732.2	670.0	1 402.2	1965.0	0	55.6
Crew Provisions	612.9		612.9	535.0	0	64.3
O_2 Generation	382.4	614.4	996.8	2252.0	0	191.1
Waste Mgt.	534.1	887.1	1 421.2	1835.0	0	130.0
CO_2 Conc.	441.3		441.3	272.0	1240.0	24.0
Instrumentation	206.0		206.0	200.0	0	9.9
Subtotals	5129.1	4199.3	9 328.4	7871.0	5814.0	721.5
Food			10 630.0	-	-	683.0
Clothing			43.0	-	-	5.0
Total			20 001.4	7871.0	5814.0	1409.5

[a] Includes Spares
[b] Includes Spares and Expendables

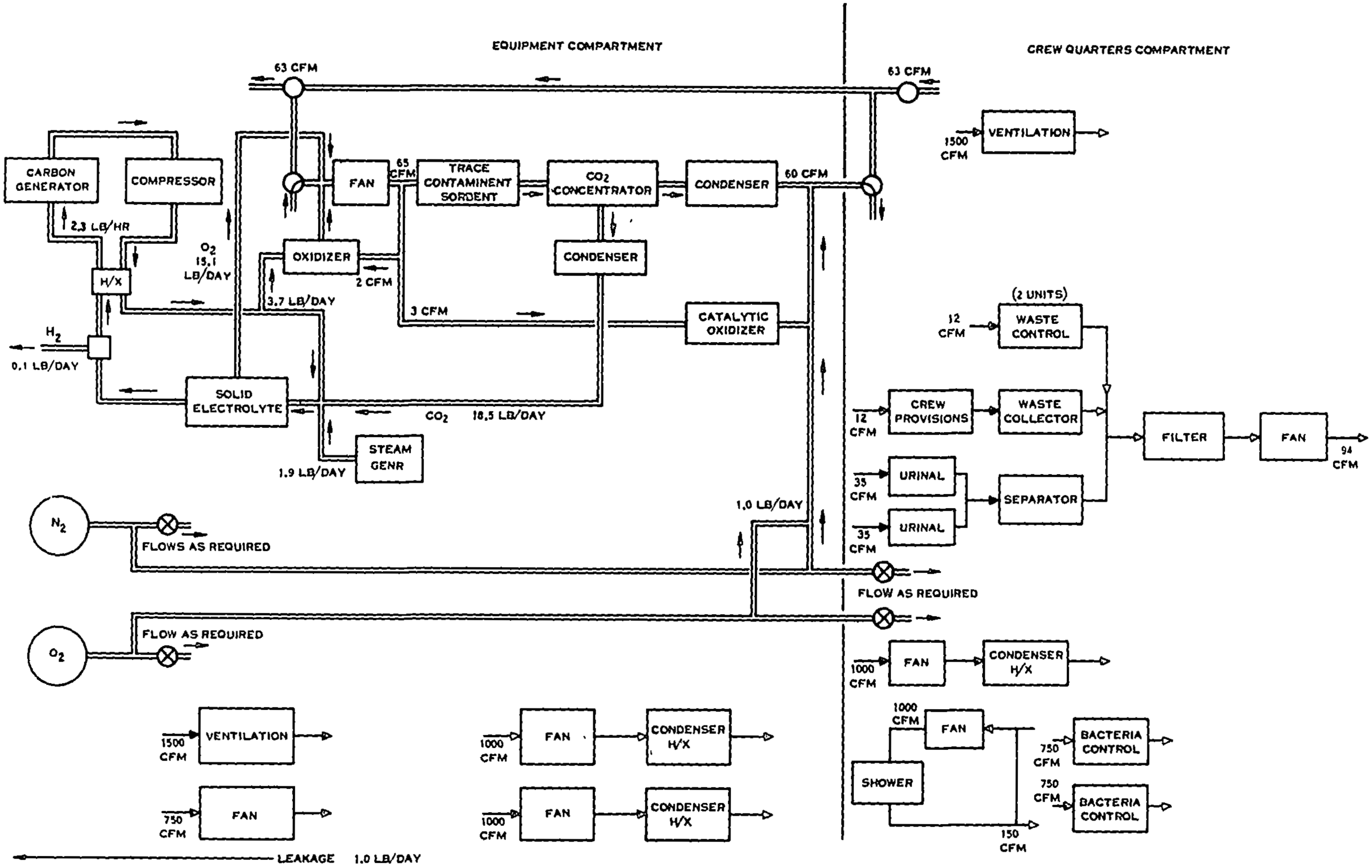


Figure 113. Gas Processing Flows - Design 3.

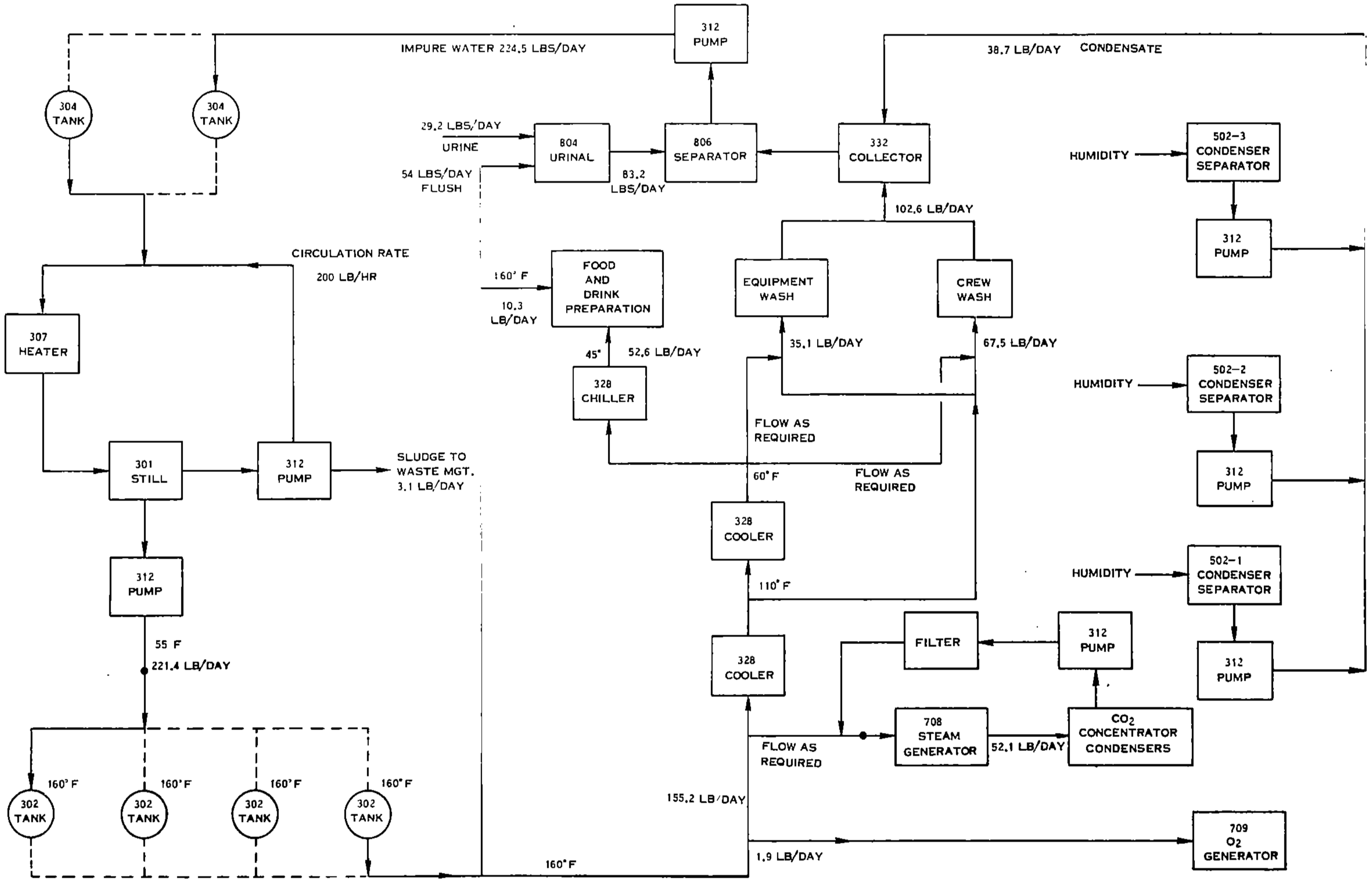


Figure 114. Water System Material Balance – Design 3.

Except for the deletion of the waste management air to liquid heat exchangers, the Design 3 coolant circuit is identical to the one discussed in Design 2.

Trace contaminant control. - The required catalytic oxidizer temperatures of 700°F are considerably higher than the available Brayton cycle waste heat temperatures. Electrical heating, as in Design 1, is therefore necessary. The chemical sorbent, ammonia control canister, and the two catalytic oxidizers are identical to those of Design 1.

CO_2 control and concentration. - The basic hardware and functional operation of the ion exchange CO_2 concentrator is the same in all three EC/LS designs. Brayton cycle waste heat, via the 200°F water heat process loop, provides the thermal energy required to generate the purge steam in the (item 902) steam generator. Design 1 uses electrical heating.

Water reclamation. - A vapor diffusion water reclamation system is used in Design 3. Operation and integration are as in Design 2. Brayton cycle waste heat, at no penalty, is used to provide the heat of evaporation for the process. This energy is ultimately rejected to the water coolant loop via the condenser in the (item 301) vapor diffusion-reclamation module.

Potable water management. - Potable water delivered by the water reclamation system must be heated to 160°F, and held at that temperature until used. The heating function for Design 3 is identical to that discussed in Design 2. The heat process loop heating the four tanks derives its thermal energy from the Brayton cycle.

Waste management. - The four waste processing units are electrically heated as in Design 1. Interfaces with the liquid coolant loop are not required, with cooling provided by blowing cabin air through cooling jackets in each unit.

Crew provisions. - As discussed in the thermal control section, Design 3 uses an electrically heated food preparation oven. This was selected for Design 3 primarily to minimize hot water plumbing through the vehicle.

Reliability

The reliability of Design 3 assuming a completely flight qualified system, excluding instrumentation, is estimated at 0.9952. The subsystem reliability analysis is presented in table 65. The summary is presented in table 67. Mean-time-between-failure for this system has been estimated to be 1440 hours. Thirteen failures are expected for this design, the same as for Designs 1 and 2.

TABLE 67

DESIGN 3 - RELIABILITY ANALYSES SUMMARY

Subsystem	Total subsystem MTBF (hr)	Total expected failures	Failures with automatic redundancy	Expected failures requiring crew action		Total subsystem reliability
				Manual switching only required	Maintenance req'd	
Oxygen & nitrogen storage & pressure control	68 400	0.1754	0.0005	0.0005	0.1744	0.999366
Trace contaminant control	57 200	0.2097	—	0.0027	0.2070	0.999693
Water management	6 700	1.7943	-	0.0765	1.7178	0.998454
Thermal control	66 200	0.1812	0.0038	--	0.1774	0.999686
Cabin temperature & humidity control	9 700	1.2412	—	—	1.2412	0.999548
Crew provisions	97 700	0.1228	—	0.0005	0.1223	0.999852
Oxygen generation	3 900	3.0761	0.0816	2.3937	0.6008	0.999634
Waste Management	15 000	0.8002	—	0.0480	0.7522	0.999445
CO_2 concentration	15 700	0.7656	—	0.0138	0.7518	0.999798
Total	1 440	8.3665	0.0859	2.5357	5.7449	0.995208

System Maintenance Considerations

Design 3 retains all the maintenance concepts described in the all electric heat system (Design 1), but incorporates a waste-heat coolant circuit at a moderate temperatures (200° F) to heat the water reclamation system, the steam generation in the CO_2 concentrator, and the potable water storage tanks, replacing electric heaters in these areas.

Scheduled maintenance for this design remains similar to other concepts, approximately 1 hour per day. Operating time remains substantially constant regardless of power or heat source, as reflected in table 61.

Unscheduled maintenance time is somewhat longer than design 1 due to exchanging certain electrical controllers and heaters with coolant modulating valves, requiring basically longer replacement times. Anticipated number of hardware failures remains at 8, with a resulting total unscheduled maintenance time of 12.5 hours per mission.

DESIGN 4 - FLEXIBLE SYSTEM

System Selection

Although very similar in most respects, EC/LS Designs 1, 2, and 3 have some significant differences in the implementation of process heat addition. In the three EC/LS designs, definition of a power plant type has influenced the designs of single components within a subsystem, many components, and possibly the operating concept of a subsystem or major portions of an integrated system. Present differences in these three designs may be expected to increase if three EC/LS systems, each mated with a different power supply, are individually optimized and developed.

All three power supply systems specified for this study have at present equal chances of being selected for the AILSS mission, but it is anticipated that several years will elapse before a power supply selection and a design freeze is made. The interim period must also be dedicated to the development of advanced EC/LS systems in parallel with the development of power generation systems. It is impractical that three EC/LS development programs be initiated prior to definition of a power supply. Some flexibility is necessary.

A fourth EC/LS design is, however, presented which retains the salient characteristics of the three basic designs, but which is flexible enough to adapt to any of the specified power supply systems. Considering the basic similarities of the three designs, this flexible system is practical within reasonable total equivalent weight penalties. Development of an AILSS based on this approach could therefore start immediately.

In defining the fourth system, or Design 4 as it is called, it must be realized that it is not a single system but a baseline adaptable to different power supplies. Table 53 outlines such a baseline as Design 4. The baseline subsystem descriptions are discussed below along with the particulars of how the thermal interfaces are varied to adapt to the solar cell, the solar cell with isotope, or the Brayton cycle electrical power systems. Figure 115 presents a schematic of the baseline system, with flexible interfaces shown. The corresponding parts list is shown in table 68.

System Description

Thermal control. - The coolant loop is essentially similar to that of Design 1, with the potable water coolers, the cabin heat exchangers, the CO_2 concentrator condensers, the cold plates, and the water reclamation system compressor motor cooling jacket. Hot air coolers for waste management system cooling are located in the circuit just upstream of the hot potable water cooler. These five heat exchangers are the same as those defined in Design 2, but will be used here with all of the three power plants.

When mated with a solar cell system, the CO_2 concentrator steam generator and the hot water tanks will be electrically heated. If isotopes are available, or if the baseline is mated with a Brayton cycle, a 200°F heat process loop may be added, as in Design 2 and 3. Figure 116 is a sketch of the optional high temperature heat transport loop.

Temperature and humidity control. - Hardware to perform this function is the same for Designs 1, 2, and 3. There will be some slight variations in cabin sensible loads between Designs 1, 2, 3, and 4, but the differences are provided for in the design contingencies. An increased load condition can be handled by setting a 70°F minimum cabin temperature rather than 65°F. This will allow a 25 percent increase in cabin heat load.

Ventilation. - This function is provided by one 1500 cfm circulation fan located in each of the two compartments. This is the same as in Designs 1, 2, and 3.

Bacteria control. - Bacteria control is provided by three 750 cfm fans flowing cabin air through 0.3 micron depth filters. As in Designs 1, 2,and 3, there are two units located in the crew quarters cabin and one in the equipment cabin.

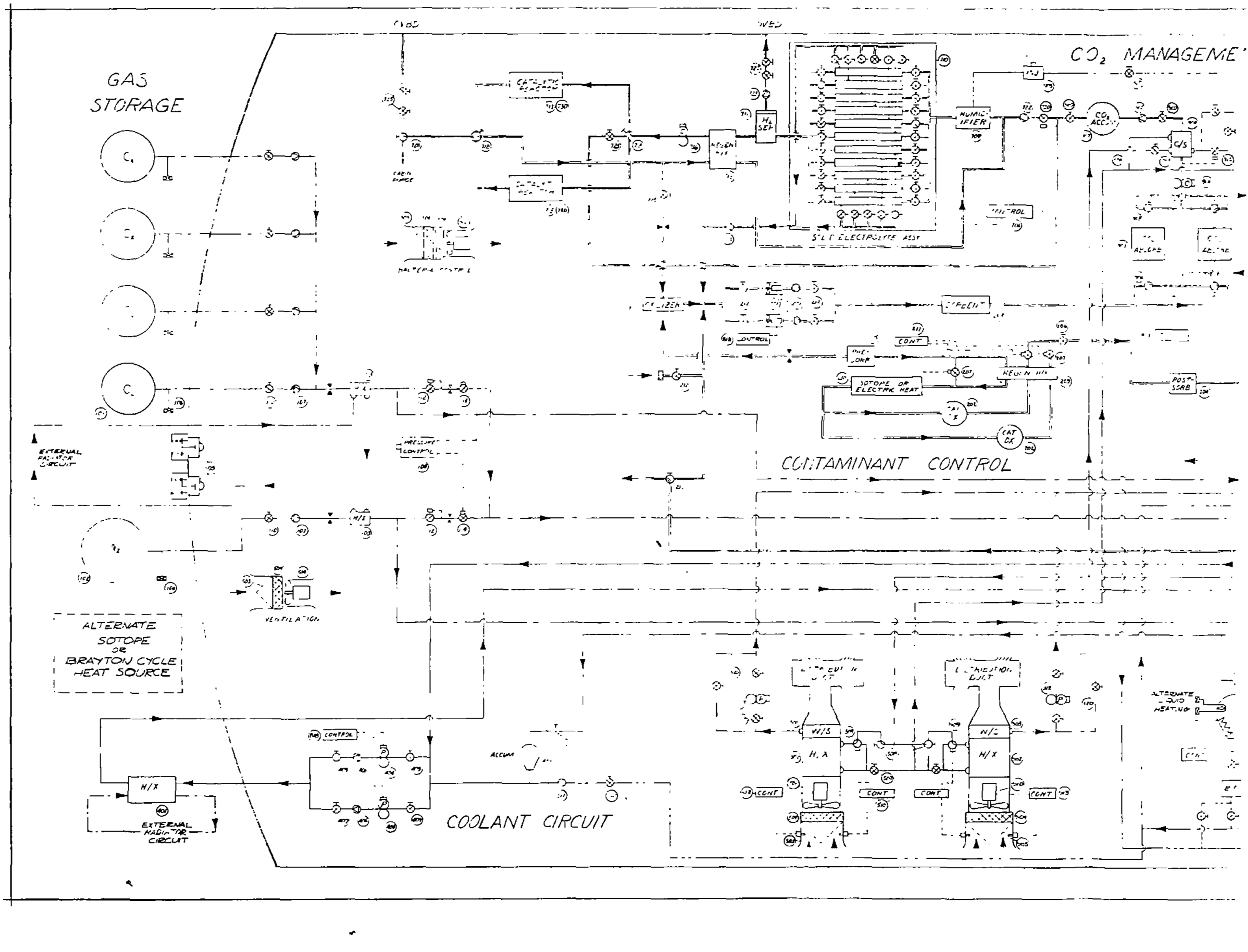
Trace contaminant control. - The items concerned here are the chemical sorbent bed for ammonia control, and the two catalytic oxidizers; one used for a boost mode and

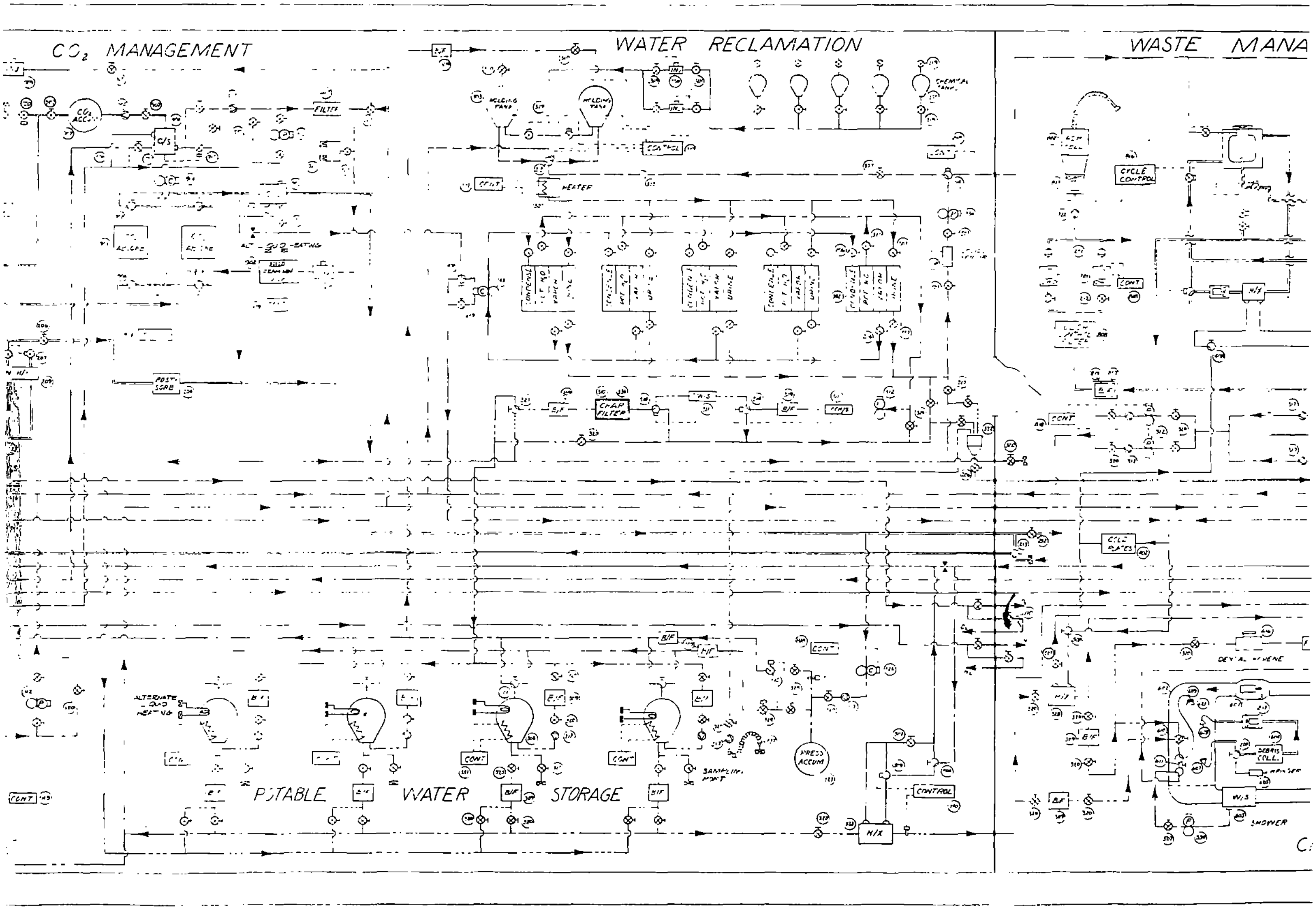
TABLE 68
EC/LS PARTS LIST - DESIGN 4, FLEXIBLE BASELINE

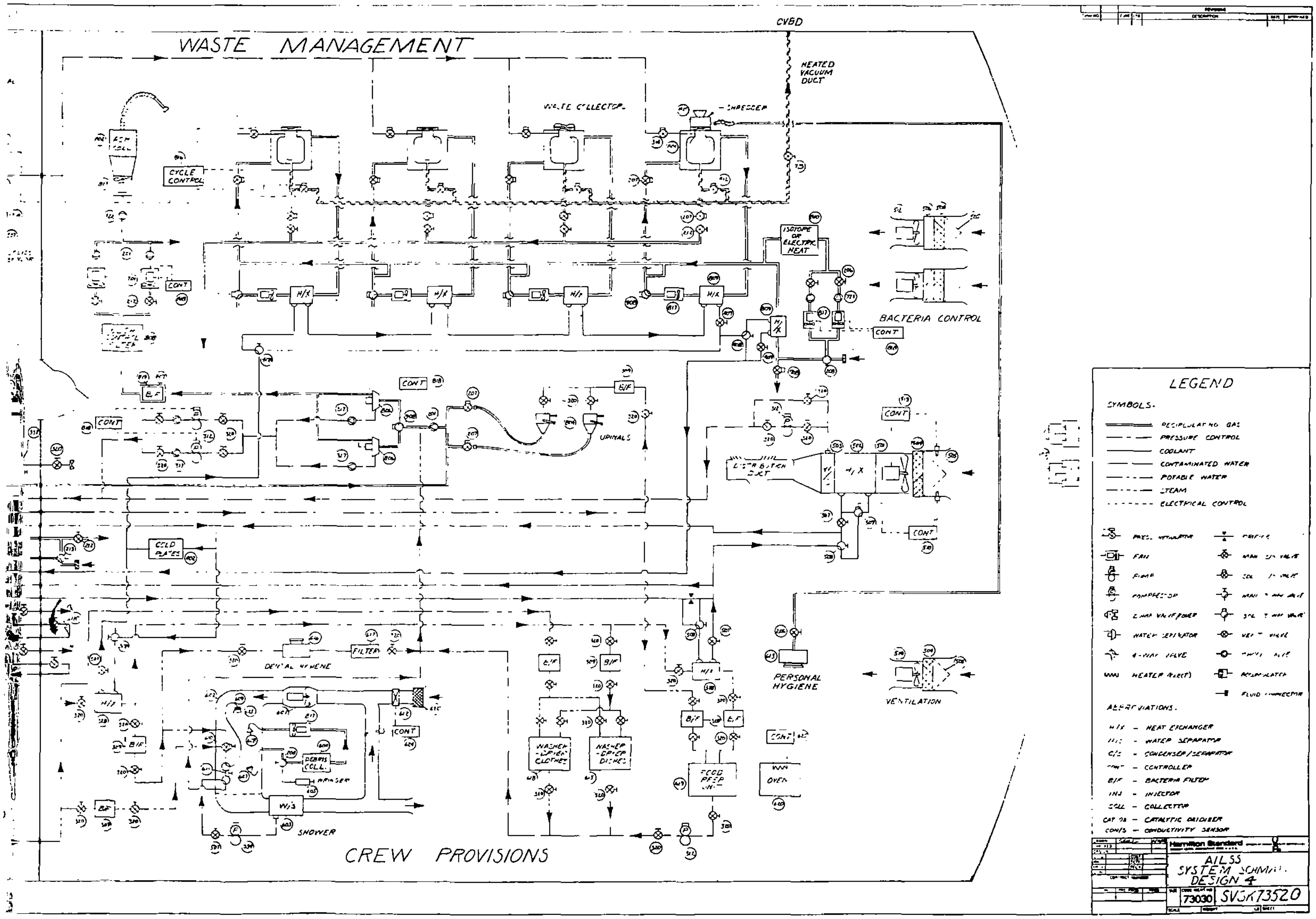
Item	Name	Qty	Item	Name	Qty
101	Tank, Storage, O_2	3	319	Valve, Vent	4
102	Tank, Storage, N_2	1	320	Valve, Shutoff, Manual	90
103	HX	2	321	Valve, Diverter, Manual	5
104	Controller, Total Pressure	1	323	Valve, Check	2
105	Valve, Cabin Dump & Relief	2	324	Regulator, 25 psi	1
106	Valve Fill	4	325	Regulator, 20 psi	1
107	Valve, Check	4	326	Compressor	1
110	Valve, Shutoff	8	327	Accumulator	1
112	Regulator, Pressure O_2/N_2	2	328	Chiller	2
114	Valve, Solenoid Shutoff	2	329	Valve Solenoid Shutoff Chemical	2
201	Valve, Gas Check	5	331	Control, Heater	5
202	Oxidizer, Catalytic	2	332	Collector, Liquid	1
203	Canister, Sorbent	2	333	HX	1
204	Canister, Post-sorbent	1	334	Pump	2
205	Canister, Presorbent	1	335	Cartridges, Bacteria Filter	20
206	Valve, Manual Shutoff	15	336	Cartridges, Charcoal Filter, Sm.	1
207	Valve, Solenoid Shutoff	13			
208	Valve, Manual 3-Way	2	337	Hose & Connector	1
209	H/X, Regenerative	1	339	Control, Tank Level	1
211	Control, Catalytic Oxidizer Temperature	1	340	Control, Heater	1
			343	Compressor, Vapor	1
212	Valve, Manual Shutoff	12			
213	Valve, Solenoid Shutoff	2	401	Heat Sink Assembly	1
			402	Cold Plate Assembly	1
342	Diffusion Still Assembly	3	403	Accumulator	1
303	Tank, Potable Water	6	404	Pump	1
305	Tank, Chemical Storage	4	406	Valve, Check	2
306	Injector, Chemical	1	408	Valve, Manual 3-Way	3
307	Heater	1	409	Valve, Manual Shutoff	7
308	Sensor, Solids	1			
309	Filter, Bacteria	20	501	Fan	3
310	Filter, Charcoal	1	502	HX Condenser	3
311	Sensor, Conductivity & Control	2	503	Separator, Water	3
			504	Filter, Roughing	8
312	Pump	7	505	Silencer/Debris Trap	8
313	Valve, 4-Way Solenoid	1	506	Filter, Bacteria	12
314	Valve, 3-Way Solenoid	7	507	Valve, Shutoff, Manual	24
317	Valve, Check	12	508	Valve, 3-Way, Manual	8
318	Valve, Shutoff Chemical	8	509	Valve, Modulating	4

TABLE 68 (Concluded)
EC/LS PARTS LIST - DESIGN 4, FLEXIBLE BASELINE

Item	Name	Qty
510	Control, Humidity	3
512	Fan, Bacteria Control	3
513	Control, Motor Speed	3
514	Fan, Vent	2
601	Fan, Shower	1
602	Stall, Shower	1
603	Separator/Filter, Water	1
604	Collector, Debris	1
605	Wringer, Manual	1
607	Vacuum Line & Attachment	1
608	Air Line & Attachment	1
609	Shower Head	1
610	Valve, Water Mixing	1
611	Valve, Diverter, Multiple	1
612	Valve, Air Inlet	1
613	Receptacle, Personal Hygiene	1
614	Battery, Shower Pan	1
615	Washer/Dryer, Dishes	1
616	Receptacle, Dental Debris	1
617	Filter	1
618	Washer/Dryer, Clothes	1
619	Unit, Food Preparation	1
620	Oven	1
622	Filter	1
624	Control, Temperature	1
625	Control, Oven Temperature	1
701	Fan	2
706	Control, Pressure	1
709	Humidifier	1
710	Reactor, Solid Electrolyte	6
711	Separator, H_2	1
712	HX, Regenerative	1
713	Reactor, Catalytic	2
716	Compressor	1
718	Valve, Diverter, 4-Way	2
720	Regulator, CO_2	1
722	Valve, Check, Gas	4
723	Valve, Check, High Temperature	5
725	Valve, Shutoff Manual	5
728	Valve, Purge Selector	1
730	Catalyst Cartridge	2
732	Oxidizer Chamber	1
801	Collector, Waste	4
802	Collector, Ash	1
804	Urinal	2
806	Separator, Air/Urine	1
807	Filter, Bacteria	1
808	Filter, Odor Control	1
809	H/X	5
811	Collection Bags	2
812	Valve, Solenoid Shutoff, High Temperature	4
815	Shredder	1
816	Cycle Control	1
817	Fan	7
818	Control	7
819	Cartridges, Bacterial Filter	50
820	Cartridges, Charcoal Filter	20
901	Bed, Ion Exchange Resin	2
902	Generator, Steam	1
903	Condenser Separator	1
904	Condenser Separator CO_2	1
905	Injector, Water	2
906	Compressor, CO_2	1
907	Accumulator, CO_2	1
908	Valve, 3-Way Solenoid, Latching	10
909	Control, Heater	
910	Regulator, Water	1
911	Accumulator, Water	1
913	Timer	1


GAS STORAGE
CO₂ MANAGEME
CONTAMINANT CONTROL
COOLANT CIRCUIT
ALTERNATE SOTOPE OR BRAYTON CYCLE HEAT SOURCE
EXTERNAL RADIATOR CIRCUIT
H₂ SEP
REGEN H/X
HUMIDIFIER
CO₂ ACCUM
C/S
SOLID ELECTROLYTE ASSY
CATALYTIC REACTOR
CONTROL
CONT
SOTOPE OR ELECTRIC HEAT
CAT OX
REGEN H/X
POST-SORB
PRESSURE CONTROL
VENTILATION
H/X
H/S
ACCUM
ALTERNATE LIQUID HEATING
CABIN PURGE


CO2 MANAGEMENT
WATER RECLAMATION
WASTE MANA
CO2 ACCUM
C/S
FILTER
POST-SORB
HOLDING TANK
HOLDING TANK
CHEMICAL TANK
CONTROL
CONT
HEATER
CHAR FILTER
W/S
B/F
PRESS ACCUM
SAMPLING POINT
ALTERNATE LOAD HEATING
POTABLE WATER STORAGE
H/X
CYCLE CONTROL
COLD PLATES
DENTAL HYGIENE
DEBRIS COLL.
WRINGER
SHOWER


WASTE MANAGEMENT
CVBD
HEATED VACUUM DUCT
WASTE COLLECTOR
INSPECTOR
CYCLE CONTROL
CONT
H/X
ISOTOPE OR ELECTRIC HEAT
BACTERIA CONTROL
B/F
URINALS
COLD PLATES
DISTRIBUTION DUCT
DENTAL HYGIENE
FILTER
PERSONAL HYGIENE
VENTILATION
DEBRIS COLL.
RINSER
W/S
SHOWER
WASHER DRYER CLOTHES
WASHER DRYER DISHES
FOOD PREP UNIT
OVEN
CREW PROVISIONS
LEGEND
SYMBOLS.
RECIRCULATING GAS
PRESSURE CONTROL
COOLANT
CONTAMINATED WATER
POTABLE WATER
STEAM
ELECTRICAL CONTROL
PRESS. REGULATOR
FAN
PUMP
COMPRESSOR
2 WAY VALVE/POWER
WATER SEPARATOR
4-WAY VALVE
HEATER (ELECT)
ORIFICE
MAN. 2 WAY VALVE
SOL. 2 WAY VALVE
MAN. 3 WAY VALVE
SOL. 3 WAY VALVE
VENT VALVE
CHECK VALVE
ACCUMULATOR
FLUID CONNECTOR
ABBREVIATIONS.
H/X - HEAT EXCHANGER
W/S - WATER SEPARATOR
C/S - CONDENSER/SEPARATOR
CONT - CONTROLLER
B/F - BACTERIA FILTER
INJ - INJECTOR
COLL - COLLECTOR
CAT OX - CATALYTIC OXIDIZER
CON/S - CONDUCTIVITY SENSOR
Hamilton Standard
AILSS
SYSTEM SCHMATIC
DESIGN 4
73030
SVSK73520

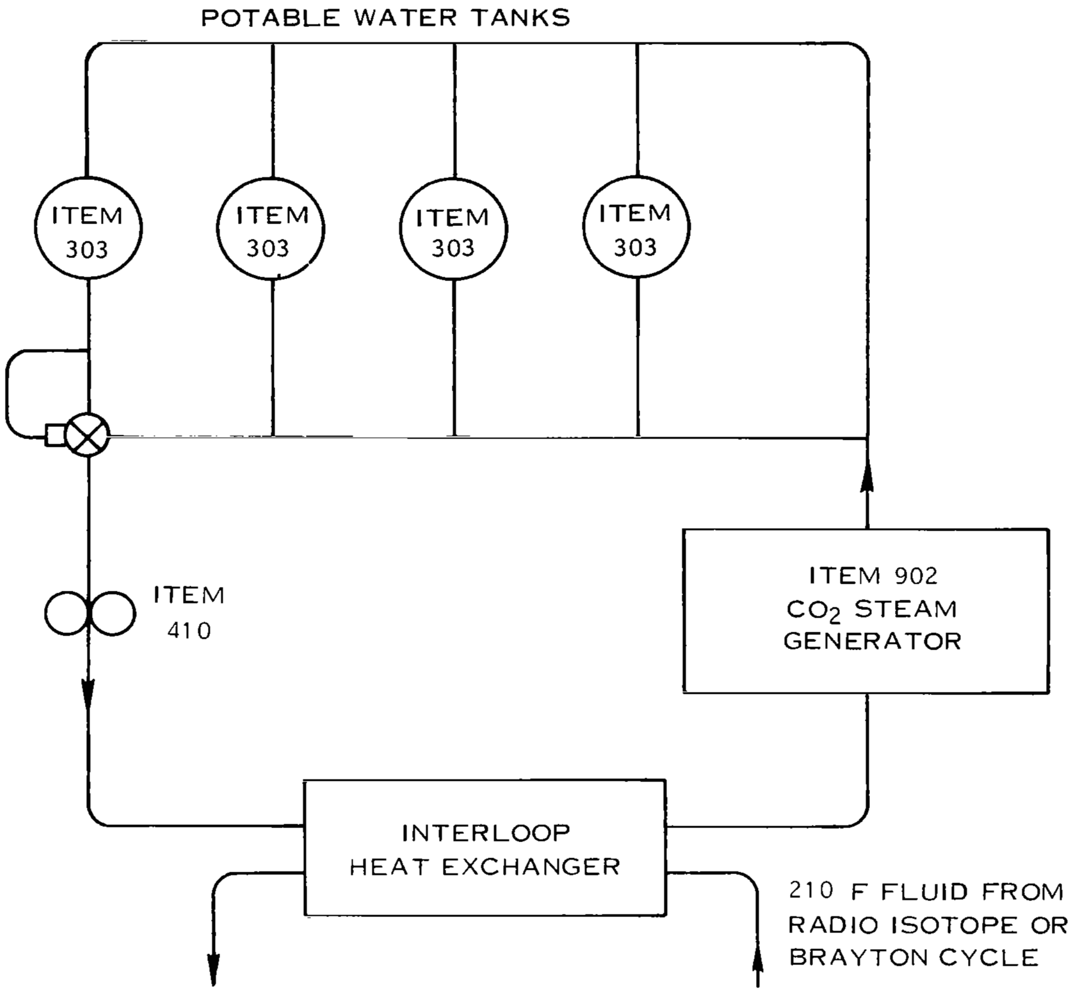


Figure 116. Process Circuit for Design 4

also for redundancy. The sorbent bed and its integration into the trace contaminant and CO_2 control process flow circuit is identical to Design 1, 2 and 3.

In order to maintain compatibility with a power system utilizing local isotopes, the catalytic oxidizer arrangement of Design 2 has been selected for inclusion in the Design 4 baseline. For straight solar cell use, or with a Brayton cycle, the heat source is an electrical resistance heater which may operate at 112 watts for normal operation or at 224 watts for the boost mode. A solar cell-isotope power system would use a 224 watt local isotope as in Design 2.

CO_2 control and concentration. - Except for the steam generator, all components and operating functions of the ion exchange CO_2 concentrator are identical with those of Designs 1, 2,and 3. Two separate steam generators will probably be necessary for use with electrical heating and for liquid heat transport heating. This is a relatively small component although not defined in detail at this point, it is anticipated that design of a dual purpose unit will present no development cost advantages over the design and development of two units.

Oxygen Generation. - This subsystem does not require thermal power and is therefore the same for EC/LS Designs 1, 2, and 3.

Oxygen and nitrogen storage and pressurization. - As in the previous case, this function is independent of the power supply system and is the same for Designs 1, 2, and 3.

Water reclamation. - A vapor diffusion/compression system was selected for Design 4 for all three power supplies, a compromise made in favor of the solar cell application. Heat power availability resulted in the selection of a vapor diffusion thermal distillation system for Designs 2 and 3. No Design 4 total equivalent weight increase resulted over using the vapor diffusion/compression system when used with solar cell power. A vapor diffusion thermal distillation system using solar cell electrical energy for heat of evaporation would result in a 1200 pound penalty over the selected concept.

Potable water management. - With the vapor diffusion/compression system delivering 160°F potable water, the storage tank heaters must supply only heat leak make up of about 25 watts per storage tank. This must be supplied by electrical heaters for a solar cell application. With a 200°F heating fluid availability, it is desirable to eliminate the four electrical heaters and controllers and use the thermal power provided by an isotope or the Brayton cycle. A dual purpose tank is selected for water storage purposes. This tank is designed to contain either electrical or liquid line heaters. Although separate steam generators were selected for the CO_2 concentrator, there was some degree of sophistication which justified the choice. A water tank heater, however, is a rather straight forward design situation such that no dual purpose tank thermal design problems are anticipated.

Waste management. - The design approach selected for the Design 4 waste management system is the same as that used with the catalytic oxidizer. That is, the Design 2 system is selected in which the thermal heat source may be either an isotope or electrical resistance heaters. The resistance heaters would be used in the solar cell or the Brayton cycle applications. Operation with an isotope system is identical to resistance heating, the fifth air-to liquid heat exchanger may be deleted. The purpose of this unit is to allow the isotope to be cooled in an unpressurized cabin. This is a problem electrical heaters do not have since they are simply switched off when not in use.

Crew provisions. - The only difference previously noted in Designs 1, 2, and 3 in the crew provisions area is in the use of liquid thermal power in the food preparation oven in Design 2 rather than an electrical heater in Designs 1 and 3. An electrically heated oven is selected for all power plant applications for Design 4. The primary reason for this choice is to minimize the optional hardware additions (e. g., hot transport fluid piping through the compartments.)

Instrumentation. - No concept changes result in Design 4 as it interfaces with the different power systems. Specific instrumentatin changes will result but these are not anticipated to present any development problems.

Reliability

A reliability estimate of this system has not been determined, since the reliability is influenced by the power supply selected. The system reliability of this design should approximate Design 2. The extra standby equipment included to permit operational flexibility will not significantly affect the quoted estimate.

System Maintainability Considerations

This hybrid system (Design 4) employs some of the features of the other designs to make it adaptable to any anticipated combination of power supply and vehicle heat source. None of these features has any effect on the scheduled maintenance required.

The major differences will appear in the unscheduled maintenance portions of the crew time summary. The unscheduled maintenance is anticipated to be approximately equal to the isotope heated Design 2 concept with only a slight reduction when used with electric heating. Due to the variability of the power supply/heat source combinations, the largest influence is expected to occur with the inclusion or omission of a hot fluid circuit. An average of 8 random failures will yield a total unscheduled maintenance time of 16.1 hours maximum.

CONCLUSIONS

The primary criteria against which Designs 1, 2, and 3 are to be compared are: (1) reliability, (2) crew time, and (3) total equivalent weight (TEW). Table 69 tabulates these values. Designs 1, 2, and 3 are respectively characterized by the following energy sources solar cells, solar cell/radioisotope, and Brayton cycle/waste heat sources. A summary of the primary criteria characteristics of the three designs is given in Table 54. Equivalent power and heat rejection weights for non EC/LS equipment is not included, nor is the equivalent weight for metabolic heat rejection. For all system designs studied the TEW is within 2 percent of 25 000 pounds.

In general, the EC/LS total equivalent weight may be broken down as follows:

1. 20 percent for power and heat rejection
2. 20 percent for fixed and spares weight
3. 40 percent for food and packaging
4. 20 percent for all other expendables

Including food, expendables, and spares, 67 percent of the TEW is mission length dependent.

TABLE 69

PRIMARY CRITERIA SUMMARY

		Design 1	Design 2	Design 3
RELIABILITY				
Total EC/LS system reliability		0.995619	0.995013	0.995208
Total EC/LS system MTBF (hr)		1460	1420	1440
CREW TIME				
Unscheduled Maintenance	(hr/mission)	11.9	12.8	12.5
Scheduled Maintenance and Operating Time	(hr/mission)	6344	6344	6344
TOTAL EQUIVALENT WEIGHT				
Total EC/LS Equivalent Weight, pounds		25 627	25 120	24 946

Design 1

The Design 1 EC/LS equipment requires some 10 339 watts of electrical energy from the solar cell source. It is heavier than Designs 2 and 3. Although scheduled maintenance and operational time are essentially identical for Designs 1, 2, and 3, Design 1 requires the least unscheduled maintenance. The total system reliability for all Designs is 0.995 +, but Design 1 has the longest MTBF.

Design 2

In Design 2, the use of radioisotope thermal energy where applicable reduces the solar cell consumption of the EC/LS by 4 kilowatts as compared to Design 1. However, if non EC/LS consumption (8 kW of vehicle power) is included a net savings of 20 percent in electrical power system size is indicated. This does not appear to be a major savings for the AILSS design, but it could produce major savings in orbital situations where large solar cell panel arrays require considerable orbit keeping penalties. Design 2 has a lower equivalent weight than Design 1. This is primarily due to the fact that the isotope energy source reduces the electrical power requirement, with its inherently high weight penalty to a lower value. However, Design 2 requires the greatest amount of unscheduled maintenance and has the shortest mean time between failure (MTBF) of Designs 1, 2, and 3.

Design 3

Design 3, which employs a Brayton cycle system as a heat and electrical power source, has a TEW four percent less than the heaviest design, Design 1. Again, the factor most effecting the TEW comparison is the electrical power requirement, which is 2.6 kW greater than Design 1 the all electrical power design. The electrical power increase over 2 is due to the need to supply heat to high temperature processes (such as waste management) electrically, since Brayton cycle waste heat is available at only 375°F. The amount of crew stress; i.e., unschedules maintenance, involved with Design 3 is less than Design 2, but more than Design 1. Similarly the MTBF is between the extremes of Designs 1 and 2.

Design 4

Design 4 is not a single system but a baseline adaptable to different power supplies, as indicated in Table 54. Various applications of flexible Design 4 can be discussed.

As expected, the solar cell application of Design 4 is the heaviest of all the designs. Power consumption increases over Design 1 due to the higher fan power requirements of the waste management subsystem using a central electrical heating system.

The TEW of Design 4 using solar cells and radioisotope power is almost the same as in Design 2, a factor influenced mainly by the reduced heat rejection compensating for an increase in electrical requirements.

Design 4, using a Brayton cycle, is 1000 pounds heavier than Design 3. In this case, it is the change from no penalty thermal energy to high cost electrical energy use in the water reclamation system that is the critical factor.

SUMMARY

Based on the results of the AILSS study, as summarized in Table 54, total equivalent weight (TEW), although extremely critical during any actual flight hardware design, is not significantly affected by the type of power/heat source. The other primary criteria, crew time and reliability, are also not strongly effected by power/heat source selection at the EC/LS system level. In summary, although the subsystems designs selected for the general system and each of the three specific systems have significantly different weight and power requirements, the basic concepts do not vary greatly. This is because of the AILSS selection criteria emphasis on maintenance and reliability and because of the assignment of similar weight penalties to the power sources. This leads to the selection of baseline concepts which, with minor modifications, are essentially independent of the power supply/heat source.

As a result of this study, it is evident that a practical regenerative AILSS, suitable for the support of nine men for a 500-day non-resupply mission, is within the state-of-the-art projected for the 1976 to 1980 period, provided the concepts selected for the AILSS undergo extensive and concentrated development effort starting early 1970. This must be followed by comprehensive manned system testing.

IMPACT OF MISSION PARAMETERS

Factors of mission length, crew size, power penalty, resupply capability and flight date are analyzed from the total system level standpoint. The evaluation is a summation of the subsystem conclusions of design point sensitivity. Table 70 presents summaries of the individual subsystem conclusions from which the system level impact may be seen.

TABLE 70 (Page 1 of 3)
IMPACT OF MISSION PARAMETERS

Mission Length

Short	Subsystem	Long
No Change	Thermal Control	No Change
No Change	Temp & Humidity	No Change
No Change	Contaminant Control	Regenerable Charcoal 1000 days
No Change	CO_2 Control	Membrane Concentrator 5 years
Sabatier @ 200 days	O_2 Generation	No Change
No Change	O_2/N_2 Storage	No Change
No Change	Water Management	Wet Waste H_2O Recovery
Vacuum Drying @ 200 days	Waste Management	No Change
Disposable Clothing No Shower	Crew Provisions	No Change

Crew Size

Small Crews	Subsystem	Large Crews
No Change	Thermal Control	No Change
No Change	Temp. & Humidity	No Change
No Change	Contaminant Control	Regenerable Charcoal
No Change	CO_2 Control	No Change
Sabatier	O_2 Generation	No Change
No Change	O_2/N_2 Storage	No Change
No Change	Water Management	Reverse Osmosis Wet Waste H_2O Recovery
Vacuum Drying @ 200 days	Waste Management	No Change
Disposable Clothing No Shower	Crew Provisions	No Change

TABLE 70 (Continued)
IMPACT OF MISSION PARAMETERS

Power Penalty

Low	Subsystem	High & Power Limited
No Change	Thermal Control	No Change
No Change	Temp & Humidity	Low ΔP Integral Wick HX's Decreased Sensible Load
Regenerable Charcoal	Contaminant Control	No Change
No Change	CO_2 Control	Membrane Concentrator
No Change	O_2 Generation	No Change
No Change	O_2/N_2 Storage	No Change
No Change	Water Management	Reverse Osmosis and Vapor Diffusion/Compression
No Change	Waste Management	Vacuum Drying
No Change	Crew Provisions	No Change

Resupply

Subsystem	Effect
Thermal Control	No effect
Temp & Humidity Control	No effect other than spares
Contaminant Control	No effect other than spares
CO_2 Control	No effect other than spares
O_2 Generation	May resupply catalyst cartridges
O_2/N_2 Storage	May resupply leakage make-up
Water Management	May resupply chemicals and bacteria filters
Waste Management	No effect on vacuum decomposition. Vacuum drying may be used to reduce launch weight if resupplied.
Crew Provisions	Food is largest resuppliable item - (40% of EC/LS total equivalent weight)

TABLE 70 (Concluded)
IMPACT OF MISSION PARAMETERS

Flight Date Pre-AILSS	Subsystem	Post-AILSS
No Change	Thermal Control	No Change
No Change	Temp & Humidity	No Change
Non-Regenerable Charcoal - pre 75	Contaminant Control	No Change
Molecular Sieve - pre 75	CO_2 Control	Membrane Diffusion Electro-chemical when high MTBF attained
Sabatier - Pre 76 Bosch - Pre 77	O_2 Generation	No change for AILSS Sabatier with Acetelyne Dump for increased cabin leakage requirement Fused salt
Cryogenics for Early, Short Flights	O_2/N_2 Storage	No Change
Closed Air Evaporation - Pre 76	Water Management	No Change
Vacuum Drying - Pre 76	Waste Management	Wet waste recovery
No shower - Pre 75	Crew Provisions	No Change

The investigation of mission parameter impact on the AILSS system showed that for a mission duration of approximately 200 to 900 days, crew size of 6 to 18 men, power penalty of 0 to 600 lb/kW, resupply, and flight dates well into the 1980's, no significant changes to the basic AILSS will occur. For periods less than 200 days, high power penalty or extremely power limited mission, and pre-AILSS time periods, the AILSS system will be affected to some extent. Detailed discussions concerning mission impact are included at the end of each subsystem section, as applicable, and the selected system section of this report.

Mission Length

Shorter missions. - For missions shorter than 200 days, only the areas of O_2 generation, waste management, and crew provisions may change. A Sabatier reaction using methane dump would be selected for a six month mission. A vacuum drying waste control system could replace the vacuum decomposition selection since storage container weight decreases rapidly.

In the area of crew provisions, several changes are possible. Missions shorter than 200 days can use disposable clothing for about the same weight as reusable clothing. This would be desirable to eliminate washing requirements and equipment. Shorter mission lengths could allow compromises in psychological factors concerning foods and washing. The liquid and chemical diets can give a weight advantage if crew acceptability is not a factor. A more normal diet is, however, desirable for longer missions. Some weight advantage is possible if the shower is eliminated. This decision again is dependent upon crew acceptability.

Longer missions. - As missions longer than about 1000 days are defined, changes may occur in the trace contaminant control area, the CO_2 concentration area, and added functions are required in the Waste control and Water Management area.

Regenerable charcoal becomes desirable for very long mission lengths. Non-regenerable sorbent weights increase with length but a fixed amount of charcoal is required in the regenerable system. Odor control in the waste control subsystem would also use regenerable charcoal.

No change in the CO_2 control subsystem selection is indicated until missions exceeding 5 year durations are flown. At that point the reduced spares requirements of the membrane diffusion concentrator makes it a desirable selection.

No other subsystem changes are anticipated, but the addition of a waste water recovery device recovering waste water from urine sludge and from food wastes, can eliminate the need for an oxygen leakage supply makeup. At 500 days the weight saved for such a device does not justify the increased hardware requirements, and complexity. For missions exceeding 500 days, about one pound per day of stored oxygen, oxygen tankage, and contingency water may be eliminated if waste water recovery is provided.

Crew Size

Small crews. - Smaller crew sizes in the 3 to 6 man range could result in changes in the oxygen generation system, the waste management system, and possibly in the crew provisions area. A Sabatier CO_2 reduction process would considerably reduce crew time requirements at a small increase in total equivalent weight. Hydrogen storage requirements would be considerably reduced over a 9 man system.

In the waste management area the use of a vacuum drying system appears desirable for 3 to 6 man crews. For these conditions storage and weight requirements of vacuum drying units are reduced while the vacuum drying system weights stay about constant. In the 6 to 9 man range the selection would remain vacuum decomposition.

Larger crews. - For larger crews, the waste management selection would remain vacuum decomposition. However, for much larger crews, incineration processes would reduce waste residue storage to 2 percent, a significant reduction from the 12 percent value of the decomposition system. The large oxygen requirement for incineration would have to be made up by electrolysis of reclaimed waste waters such as in urine sludge and in food wastes. This could be accomplished by collecting wet food wastes and urine sludge in a separate waste collector which may be heated to drive off the contained water.

Power Penalty

Considering power penalty variations, it is necessary to consider both low and high equivalent weight penalties, and cases in which power is extremely limited. In the latter case, power may be reduced by the selection of low power subsystems at the expense of fixed weight, reliability, and crew time. Power must therefore be considered the leading primary criteria factor rather than a secondary criteria factor.

Low penalty. - The only system change resulting from a decreased power penalty (to about 200 lb/kW) would be the selection of regenerable charcoal in the trace contaminant control subsystem.

High penalty. - At electrical power penalties of 900 pounds/kW (twice the AILSS value), changes in the waste control, water management and CO_2 control subsystems are indicated. A vacuum drying waste control system would be selected mainly for its low power giving a low total equivalent weight. At 900 pounds/kW it would be about 500 pounds lighter than the vacuum decomposition system.

Reverse osmosis used to process humidity condensate and wash water would result in a 600 pound reduction in total equivalent weight over the vapor diffusion/compression selection for Design 1. No change would result for Designs 2 and 3 which use low cost thermal power to operate the vapor diffusion system.

At 900 pounds/kW penalty the diffusion membrane CO_2 concentrator trades off evenly with the selected steam desorption concentrator. The high MTBF and low crew time of the membrane concentrator would result in its selection.

Power limited. - In a solar cell power limited vehicle application, the subsystem candidate requiring minimum power would be favored. In this case, power would be considered a primary selection criteria along with reliability, crew time, and total equivalent weight. Selections for this situation would be similar to those stated above for high power penalties. A vacuum drying waste control system would be used, along with a combined reverse osmosis and vapor diffusion/compression water reclamation subsystem. Selection of these two subsystems alone would result in a 2.0 kW power reduction. The low power consuming membrane diffusion CO_2 concentrator would save another 600 watts.

In the area of temperature and humidity control, the selection of a low pressure drop heat exchanger system requiring the least power would be desirable. An air-bypass integral wick heat exchanger concept would provide another 200 watt savings. Increased direct liquid cooling of heat loads would further reduce fan power.

The above options would reduce EC/LS power requirements from 10 kW to about 7.0 kW at with increase in the EC/LS total equivalent weight but with less desirable reliability, crew time characteristics, and in some cases, with less favorable secondary characteristics. Actually, other low power options exist but are not recommended because one or more of the selection criteria are unacceptable. Such is the case of nonregenerable charcoal for contaminant control. A 46 watt power reduction is available at a 1600 pound increase in total equivalent weight. This represents a weight increase to power reduction ratio of about 40 to 1. At this point other more effective means to reduce power should be investigated.

Resupply

Resupply capability is of interest when:

a. Launch weight must be decreased at the expense of resupply flights at periodic intervals.

b. Mission extensions are planned in excess of the 500 day design point.

In the first case, subsystem candidates with a large portion of their weight consisting of spares and expendables offer the largest decrease in launch weight. This is true provided the total pounds in orbit for the total mission length (not just for the resupply period) is not excessive.

Although spares and expendables (e.g., food, O_2, and N_2) may be resupplied for almost all AILSS selections, the only subsystems grossly affected are the crew provisions and the waste control subsystems. Food composes the largest expendable item; 10 000 pounds required for nine men for 500 days. Based on a 100 day resupply period, vehicle launch weight may be reduced 8000 pounds, approximately 25% of the 500 day EC/LS total equivalent weight.

In the area of waste control, selection of the vacuum drying concept allows a launch weight reduction of 600 pounds (assuming a 100 day resupply period) over the vacuum decomposition system. This weight savings is possible at no increase in total weight into orbit at 500 days, the AILSS mission design point. Again, compromises in system performance characteristics must be made if the Vacuum Drying concept is used. Also, the inconvenience of resupplying and returning full collection units adds considerable to crew time.

In considering resupply missions, the cumulative pounds into orbit over the total mission is of interest. Rather than launch many resupply vehicles over an entire mission, it might be possible to launch only a few vehicles, along with the initial launch, which contains a system which requires no subsequent resupply. As an example of this, consider a 1000 day waste management system which may be resupplied every 100 days. In comparing a vacuum drying system with a vacuum decomposition system, it is noted that at 1000 days, the vacuum decomposition system requires 600 less pounds launched into orbit.

The optimum combination of initial launch weight and resupplied weight must be determined by a complete, total system cost effectiveness study.

Flight Date

Depending on actual flight date, several changes in the AILSS due to system changes are possible. The specific changes depend on the launch date being earlier or later than the AILSS date. For earlier missions, the selections become highly dependent upon availability. Table 70 presents a summary of subsystem selections as a function of flight date. The most sensitive selection is that of the solid electrolyte system which will not be qualified for flight use until 1979. It is possible that a solid electrolyte system will fly prior to that as a flight experiment.

For post 1980 flights, the situation is less clear. Many unpredicted breakthroughs could occur which may obsolete the list of AILSS subsystem candidates or the specific evaluation results. One area suspect of change in the 1980 to 1985 period is that of oxygen generation, including CO_2 collection and transfer.

Membrane diffusion CO_2 concentrators appear particularly attractive due to their inherent simplicity. With additional materials optimization and proven life characteristics the concept will be highly competitive.

Electrochemical CO_2 concentrators appear to have desirable total equivalent weight characteristics. However, reliabilities of the electrochemical cells estimated to be considerably less than those of solid sorption systems such as the selected steam desorbed resin concept. Future development is anticipated to result in much improved reliabilities of the electrochemical concepts, making them desirable selections. This required improvement, however, will probably not be made prior to 1980.

In the area of CO_2 reduction, it is desirable to eliminate carbon handling. A fully automatic carbon handling device is possible, and a practical design could be made available around 1985. An alternate approach would be to discard the carbon in gaseous form as acetylene (C_2H_2) and completely eliminate the carbon problem. Some research is currently in progress but due to operating difficulties lags the carbon production system technologies. Availability of the gaseous dump system is predicted to be in the 1983 to 1985 time period.

Another concept, the fused salt oxygen generation concept offers a potential one-step CO_2 control and oxygen generation process. Future developments of this concept are expected to offer significant improvements which would make this concept extremely competitive.

PACING TECHNOLOGY

CONTENTS

PACING TECHNOLOGY

The selection of the EC/LS subsystems for the AILSS is, at least in part, a technology forecast in that the research and development effort must be accomplished during the period before the projected 1976 to 1980 flight period. Due to the length of the AILSS mission it is imperative that full size subsystem and system reliability testing be demonstrated rather than relying on feasibility test demonstrations of small, fractional sized equipment. The advances assumed in technology development throughout this report are in fact the overall pacing items and, as a result, the reliability analysis, predicted failure rates, etc. are not valid unless the advances occur. Validation of the selection, therefore, is dependent on vigorous pursuit of the research and development effort that is required for the selected subsystems. In addition, continuation of work is required on alternative concepts which would provide a ready backup if a selected concept should develop unforeseen problems and/or which offer potential advantages over the selected concepts.

The following pacing technology discussion presents a summation of the research and development which is anticipated throughout the study. The primary attention of this section is focused on critical areas of the selected AILSS systems that require concentrated research and development effort. The second part of this section identifies promising alternative subsystem concepts. For each selected concept with some dependency on technology advances, the potential problem areas are identified, an approach to solving these problems is outlined, and approximate planning schedules and funds required to accomplish the tasks are indicated. For promising alternative concepts requiring further development, the attractive features and the problems that prevented selection are noted.

SELECTED SYSTEM CONCEPTS

Pacing areas of the selected AILSS subsystems which require research and/or development effort are listed in the headings to follow. The effort outlined is generally the minimum required to bring the concept to the point where operation is proved and sufficient parametric data is obtained for initiation of a flight unit design with a high level of confidence.

Oxygen and Nitrogen Storage

Potential problem areas. - Filament-wound storage tankage is selected for use in the AILSS. In order to obtain the projected ultimate material strengths for filament-wound tankage for the 1976 to 1980 flight period, early development effort must be expended on materials and fabrication techniques.

Task outline. - The task of attaining filament-wound tankage at the projected strength-to-weight ratios is an evolutionary development process which requires a concentrated effort in two specific areas. Selection and optimization of materials includes the investigation of filament fibers, fiber matrix bonding resins, and metallic liners. A second area of development is the tankage fabrication process, with effort concentrated on improving quality control as well as on reduction of process complexity and cost. Also included is structural testing of full size prototype tanks to verify mounting and structural integrity under anticipated launch and flight conditions, including failure mode analysis.

Task schedule and cost. -

Task	Schedule, years from start 0	1	2	3	4	Preliminary estimate (millions of dollars)
Material selection	▬	▬				0.2
Fabrication techniques and testing		▬	▬	▬		0.7
Total						0.9

Water Reclamation

Potential problem areas. - A dependable water reclamation subsystem is absolutely necessary for the success of an AILSS-type mission. The selected vapor diffusion subsystems require further development of evaporator membranes with high flow rate and long life characteristics. Development of detergent-compatible membranes and other components in the water system is also required.

Membrane development: Membranes commercially available for use in the vapor diffusion system are capable of passing a total of 200 pounds of urine water per square foot of membrane area. The AILSS projection calls for a cumulative throughput of about 1000 pounds of a less contaminated mixture of wash, flush, and urine water per square foot of membrane area. Although the total quantity of contaminants in the water to be processed is roughly the same, it is suspected that the presence of cleansing agents in the wash water can affect performance adversely. Additional development work and perhaps basic research is required to make available membranes with all of the desired characteristics.

The two vapor-diffusion versions selected for the AILSS may require different membranes. In the compression version, the membrane must support a positive pressure difference of several psi in the direction of the process flow, which may accentuate any tendency of the membrane to plug. Membranes optimized for this specific application have not been tested. In the noncompression versions, the pressure difference is opposite to the flow and is less than one psi. This version has been tested extensively.

Detergent compatibility: As yet, a completely acceptable detergent for use in the AILSS has not been completely developed. Part of the reason for this is that any detergent selected must be physically and chemically compatible with the water recovery process. The detergent must not form residues that plug or chemically attach to the membrane, and it must also be non-corrosive, a good cleansing agent, and a low foamer. Because there will probable be less latitude in membrane selection than in detergent selection, this is viewed as primarily a detergent development problem. Nevertheless, there will be considerable interaction between the two areas.

Task outline. - The first task to be performed is continued development of a correlation of the parameters that effect membrane performance, particularly plugging. Basically, this will require an examination of the mechanism of mass transfer through the membrane, identification of the material or materials in the waste water residuum that actually plug the membrane, and determination of any basic chemical changes that may affect performance. Such research will have to be done with candidate detergents that are potentially useful. Included in this task will be laboratory synthesis of membranes that possess the desired characteristics as determined from testing. This step will also require considerable testing to provide parametric data for future designs and to assure successful and repeatable performance. It must also include development of manufacturing processes needed to produce membranes of sufficient size and quality.

The next task involves design and manufacture of prototype units to enable extensive evaluation testing to establish structural limitations, performance life, and operating parameters over a wide range of anticipated operating conditions.

Concurrent with these efforts, detergent development will be required if compatibility problems arise. In any case, detergent compatibility must be considered early in the membrane development program, and the two must interact as required. The detergent development program must include evaluation of cleaning ability, bacteriological control ability, and foaming characteristics.

Task schedule and cost. -

Task	Schedule, years from start 0 1 2 3 4	Preliminary estimate (millions of dollars)
Membrane development		0.2
Detergent development		0.2
Prototype development		0.7
Total		1.1

Water Storage Tanks

Potential problem areas. - Bladderless tanks selected for use in the AILSS depend on surface tension to assure a continuous water supply at the outlet. These tanks contain a capillary flow medium for water retention and require a gas pressurization system to force water out of the tanks. Design for a static zero-gravity condition is relatively easy. Design for gravity loads in any direction, however, requires a careful force balance and small capillaries. Dynamic shifts in gravity force is a complex transient problem and may require use of baffles inside the tank to reduce the influence of sudden accelerations.

Task outline. - The problems just described establish the need for a development program based on the simultaneous use of a computerized mathematical model and full-size prototype hardware. A capillary matrix material, a baffle technique, and a gas pressurization control technique must be developed. Performance and structural testing of full-size prototype tanks is also required, followed by flight testing. Final flight testing would be accomplished after thorough testing involving 180 degree reorientation ground tests.

Task schedule and cost. -

Task	Schedule, years from start 0 1 2 3 4	Preliminary estimate (millions of dollars)
Dynamic analysis		0.1
Capillary matrix studies		0.2
Gas pressurization studies		0.1
Prototype development		0.6
Flight prototype evaluation		0.4
Total cost		1.4

Waste Control

Potential problem areas. - The entire area of waste management has received little development effort relative to other areas of EC/LS. Zero-gravity performance, elimination of manual handling of feces, fecal collection aids, odor and contaminant control, and psychological and physiological considerations all require considerable attention. While feasibility of the selected vacuum decomposition process has been demonstrated, the limited effort expended points out the need for additional information in the following areas:

1. Use of air flow for zero-gravity waste transfer

2. Selection and sizing of sorbent beds for odor removal

3. Accurate determination of residue

4. Long-term operation of the vacuum decomposition process without outlet line clogging from condensable solids

5. High temperature (1200°F) sealing of the incineration chambers and valve operation

6. Reduction of operation and maintenance time

7. Microbiological control

8. Integration and long-term performance with a human interface

Since the waste control system requires a urine/air separator, a better solution of the zero-gravity phase separation problem is an additional concern in the development of a complete waste control system.

Task outline . - The first step in development of any integrated vacuum decomposition waste control subsystem is further feasibility testing. This involves utilizing representative waste quantities of appropriate composition for determination of parametric data to define: heating requirements, process exhaust characteristics, residue quantities, and process time. Evaluation of collection methods will be required. A laboratory prototype unit will be necessary to provide data for process optimization.

The second phase in the evaluation of an integrated vacuum decomposition system would concentrate on design, fabrication, and testing of a development system. Data from the first phase will be utilized to provide design optimization. Emphasis will be on human interface operation, reduction of operational time, odor control, and zero-gravity phase separation feasibility testing where practical.

The last stage of the program will consist of the design, manufacture, and testing of a preflight prototype to determine system performance and overall operating characteristics, including the adequacy of microbiological control.

Task schedule and cost. -

Task	Schedule, years from start					Preliminary estimate (millions of dollars)
	0	1	2	3	4	
Feasibility testing	━	━				0.3
Development testing		━	━			0.5
Prototype testing			━	━	━	0.6
Total cost						1.4

Oxygen Generation

Potential problem areas. - The solid electrolyte concept selected for the AILSS has several areas where assumed operating capability must be confirmed. The following areas require attention:

Material life: The structural integrity of the solid electrolyte cell stacks after extended operation is a major concern. Sudden rupture of a single cell stack could result in an explosion which, although contained, would be serious. Breakdown of the ceramic electrolyte occurs if the voltage becomes excessive or if the carbon dioxide concentration becomes too low. Failure of seals within the cell stack has also been a problem. Endurance testing exceeding 100 days has been favorable, although not completely successful with respect to materials life. This testing should be extended to prove the projected life of these and associated components.

Carbon control: Carbon, whether in this oxygen generation process or in some other, must be generated and contained within the catalyst cartridge. Otherwise, carbon formation in other areas will effect performance and make maintenance of the process equipment impractical. Dust-free carbon formation is required , or else absolute filtration will be essential.

System performance: System testing involves no special problems; it is simply an essential development step that must be accomplished to determine control techniques and to show that dynamic equilibrium conditions are satisfactory, that is, that conversion and hydrogen separation rates are sufficient over an extended time period and that undesirable side reactions do not interfere with the chemical processes.

Task outline. - The first two areas may be attacked simultaneously. System integration should follow completion of the major part of the work in these areas.

Solid electrolyte materials development covering electrolyte breakdown, cell stack sealing, and electrode separation has alredy received considerable attention but must be continued. Electrolyte breakdown depends on both the chemical equilibrium within the cell stack and on impressed voltage characteristics. This aspect of the materials investigation is relatively complex and will require considerable effort to correlate operating parameters. Very little work has been done on high temperature and non-catalytic accessory components such as high temperature valves, heat exchangers, and compressors, and this area requires attention.

Another task is the development of a carbon-retaining catalyst cartridge, which involves development of an effective high temperature low-pressure-drop carbon dust filter at the cartridge outlet.

Integrated system testing of a full-size representative unit must be accomplished to verify system performance and operating life. Also involved are sufficient structural tests to demonstrate the adequacy of the design concept.

Task schedule and cost. -

Task	Schedule, years from start 0 1 2 3 4	Preliminary estimate (millions of dollars)
Material life		0.2
Carbon control		0.4
System testing		0.8
Total		1.4

CO_2 Removal and Concentration

Potential problem areas. - A steam desorbed ion-exchange resin CO_2 concentrator is selected for the AILSS. Since the long-range life of this sorbent material has not been completely demonstrated, life tests must be conducted to determine if performance degradation occurs.

Task outline. - The required tasks involve additional materials tests and design of a prototype sorbent canister to determine proper bed preload, steam injection technique, and optimum sorption and desorption times. Once this is accomplished, long-range endurance life tests can be conducted to determine if dusting, amine carryover, and/or bed design change. Sufficient parametric data must be obtained to permit optimum design of the flight hardware.

Task schedule and cost. -

Task	Schedule, years from start 0	1	2	3	4	Preliminary estimate (millions of dollars)
Materials evaluation and parametric data	▬	▬				0.2
Prototype design and manufacture	▬	▬	▬			0.3
Life tests		▬	▬	▬		0.4
Total						0.9

Nutrition

Potential problem areas. - Any acceptable selection of a food storage technique results in a heavy weight penalty. Food and packaging weight is almost equivalent to the weight of all of the EC/LS equipment in the AILSS. With emphasis on a minimum weight system, the nutrition area stands out as a prime candidate for weight reduction.

Task outline. - This problem can be approached in two ways. One approach is to maintain the selected diet and concentrate on developing new light-weight ways of packaging, storing, and preparing the food for consumption. The other method is to formulate and test a new diet for the crew which is psychologically and nutritionally acceptable. The former approach is recommended because the development of a completely acceptable synthetic diet has been sought for some time, and projections of a satisfactory solution are still not compatible with the AILSS time schedule.

Task schedule and cost. -

Task	Schedule, years from start 0	1	2	3	4	Preliminary estimate (millions of dollars)
Packaging	▬	▬				0.2
Evaluation		▬	▬			0.6
Total						0.8

Phase Separation

Potential problem areas. - Liquid-gas separation problems appear to grow with the size and complexity of EC/LS systems. Several applications, covering variable quantities of water relative to air, contamination levels, and rates, have interrelated problems of separation performance, life, and maintainability characteristics.

Performance: High gas/liquid flow ratio separators as used on condensing cabin heat exchangers are currently under development, but more parametric performance data is necessary to determine zero-gravity efficiency, wicking performance, dry-out characteristics, etc. Low gas/liquid ratio separators have not been developed but are required for liquid line maintenance and liquid flow rate measuring devices. Gas entrainment can produce serious detrimental effects on heat exchangers and other capillary-type process equipment. No concepts are available which are satisfactory in all respects.

Life: Performance degradation due to materials contamination is a constant problem, even with supposedly clean water. Highly contaminated fluids such as urine degrade concepts using capillary or porous media materials in a matter of days.

Maintainability: Replacement due to microbiological contamination or materials degradation must be anticipated. In condenser or liquid line applications, hardware must be capable of being maintained without breaking coolant lines or contaminating or introducing air into a system. Present aerospace concepts are not designed for maintenance, so considerable development effort is required.

A somewhat related area of phase separation is the deaeration of feed waters to almost any of the process functions. Gas in solution will ultimately cause the same problems as entrained gas carryover from water separators. Development of a good deaerator could relieve gas buildup problems.

Task outline. - The phase separation problem is actually a collection of sub-problems. Although some problem areas may be approached independently, emphasis must be placed on coordination to avoid duplication and data gaps. Excluding routine design and development, the overall task may be divided into five parts: 1) design data for high gas: liquid ratio separators, 2) development of low gas: liquid ratio separators, 3) reduction of the clogging problem, 4) development and implementation of maintainability concepts, and 5) development of a deaeration device.

Design data testing for high gas:liquid ratio separators is needed to form the basis for a conventional development program. Current designs must be evaluated in a consistent manner to determine such information as separation efficiency, wick performance data, and dry-out rate data.

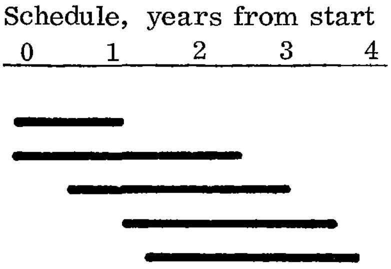
Low gas:liquid ratio separation requires a complete development program. This program must include concepting, analysis, feasibility testing, and prototype design and testing. Flight prototype testing should include zero-gravity flight testing.

Life extension by reduction of the clogging and contamination problem will include investigation of a new transfer element configuration, new materials, decontamination techniques and supplementary equipment. The program requires a systematic approach starting with identification of candidate concepts followed by selection and development of the best concept(s) by means of analysis and feasibility testing.

The development and implementation of maintainability concepts for separation devices is an unexplored area. The problems that must be solved are difficult, and exceptionally creative design work is needed. In addition, the human engineering constraints are formidable, and much of the program should focus on this area.

The development of a deaeration device is a program that will involve two stages: 1) development of a regenerative device to force gas out of solution and 2) the combination of this device with a low gas:liquid ratio separator. Thus, this program must be phased to mesh with the separator program.

Task schedule and cost. -



Task	Preliminary estimate (millions of dollars)
High ratio design data	0.2
Low ratio development	0.3
Life extension	0.3
Maintainability designs	0.3
Deaeration concept	0.2
Total	1.3

Instrumentation

Potential problem areas. - Two areas in the AILSS instrumentation selections which require concentrated development attention are the individual partial pressure sensors and the bioluminescent technique for determining the presence of viable organisms in air and water.

Gas partial pressure sensors: An instrumentation system capable of monitoring the performance of the oxygen generation and carbon dioxide concentrator subsystems is required to assure that they are working properly. This requires individual partial pressure sensors that are capable of being installed directly in the equipment to monitor critical parameters within the process loops. To date, partial pressure sensor for monitoring CO, O_2, and CO_2 have a life of approximately 60 days, which is unacceptable for an AILSS-type mission. The problem is to extend the life of these sensors so they will be useable for the AILSS mission.

Bioluminescent microbiological measurement: The bioluminescent technique is the method selected for demonstrating the presence of viable organisms in the atmosphere and in the potable water supply. The main drawback of the method, however, is the six-month life expectancy of enzyme luciferase, which is the active material used in the instrument. Methods must be found to extend the life expectancy of this enzyme, or some other suitable material must be found. Another area that requires attention is the development of methods to reduce the sample handling and reagent transfer times.

Task *outline*. -

Gas partial pressure sensors: This task requires extensive study of available instrumentation techniques, development and fabrication of selected instrumentation techniques, and endurance testing.

The first phase of this task will be a further study of the most advanced instrumental techniques for gas partial-pressure measurement, and selection of an instrument system capable of meeting the performance requirements of the 500-day AILSS mission.

The second phase will be the development and fabrication of a prototype instrument package which can be used in a zero-gravity environment and miniaturized for spacecraft use.

The final phase will be to conduct system testing to evaluate the validity of the design concept, and to investigate the maintainability, calibration, and service life of the sensors.

Bioluminescent microbiological measurement: The initial phase will concentrate on a study of techniques for stabilizing biological materials, especially enzymes, for periods of two or more years, and the development of an instrument system adaptable to spacecraft use.

The second phase will include the design and development of a prototype instrument system which can be implemented in the spacecraft zero-gravity environment.

The final phase of this task will be system testing to evaluate the validity of the design concept and to determine the maintainability and service life of the system.

Task schedule and cost. -

Task	Schedule, years from start 0 1 2 3 4	Preliminary estimate (millions of dollars)
Partial pressure sensors	━━━━	1.0
Microbiological	━━━━━━━━━━	1.5
Total		2.5

SYSTEM EVALUATION

Potential problem areas. - The true evaluation for an EC/LS system is to assemble and man test it as a closed system. Only in this way can all the various subsystem interfaces and their effects on other subsystems be determined. In fact, this is the only way the effectiveness of the atmosphere contamination control system can be evaluated. Water management, microbiological control, water inventory processes, and decontamination procedures are other items that require integrated system evaluation. Most important is the demonstration of the maintainability of any part of the system without disrupting system operation. This should be demonstrated to prove procedures are adequate and that shut-down or start-up can be accomplished with low crew stress and with safety. In summary, the areas which involve subsystem interfaces and man-machine interactions must be investigated to a much greater extent before long-duration AILSS-type missions can be undertaken with confidence and safety.

In addition to these problems of system integration, major areas of concern are:

1. Definition and resolution of microbiological problems and surface decontamination.
2. Determination of the acceptability of long-term consumption of reclaimed water.
3. Validation of the long-term endurance and performance of a closed flight system.
4. Definition and test of trace contaminant control materials for extended time periods.
5. Demonstration and optimization of instrumentation integration with the EC/LS system.

Task outline. - In order to resolve the problem areas listed, a complete AILSS should be assembled as a flexible test bed for extended equipment, system, and manned testing evaluation.

Task schedule and cost. - Since this task represents a logical second phase in the overall AILSS program, it is considered beyond the scope of this study to provide definite task schedule and cost information.

ALTERNATIVE CONCEPTS

In conducting the subsystem trades, many of the candidates appeared very competitive or had significant potential advantages over the candidate that was selected. Those concepts, which might serve as backups to the selected subsystems or might require a reevaluation of the subsystem selections if particular problems are resolved, are discussed here. It is recommended that development effort on these concepts be continued or initiated for the reasons noted. This effort must be initiated by early 1970 in order for these concepts to be available in time for the AILSS mission.

Oxygen and Nitrogen Storage

High-pressure gas storage is selected for the AILSS. No other concept is as reliable or potentially attractive. However, for shorter missions with large crews and higher leakage rates, cryogenic storage might be preferred because it could have a significant equivalent weight advantage. For this reason, it is recommended that the development of subcritical cryogenic storage be continued with emphasis on improving the insulation, reducing the leakage rate, and extending the mission life capability.

Water Electrolysis

Although a water electrolysis unit is not required for the AILSS, the gas circulation concept is selected for integration with some CO_2 reduction candidates because of its oxygen side vapor feed system and low weight. The wick feed concept, if the problem of gas entrapment is resolved, would become very competitive or at least a good backup candidate because of its high state of development at this time. Continued development of this unit is recommended.

Another candidate, the cabin air concept, is unique in that it is the only candidate with no oxygen or water connections. It is easily modularized and small units can be placed at several locations in the cabin. However, because of its direct interface with the cabin atmosphere, it has problems involving cabin depressurization, atmospheric contamination, and hydrogen transfer. The resolution of these problems would result in an extremely versatile unit.

CO_2 Removal and Concentration

The concept selected for CO_2 removal and concentration in the AILSS is a steam desorbed resin bed, which has high reliability and low weight. An alternate method, the four-bed molecular sieve concept operating at 200°F, is recommended for further development as a backup to the selected system because of its high state of development and generally acceptable characteristics.

Another candidate, the membrane diffusion concept, has a unique combination of advantages that could give it exceptionally high reliability and CO_2 purity if adequately developed. These advantages include a basically static and noncyclic operation. The problems preventing the selection of this concept are unproven membrane chemical stability and life, and the heavy support structure required. It is recommended that effort be expended to resolve these problems. This candidate, if developed sufficiently, would make an ideal concentrator or a final filter for a cyclic sorptive concentrator, making it possible to obtain a CO_2 yield of 99.99 percent purity.

O_2 Generation/CO_2 Control

The solid electrolyte process is selected for the AILSS because of its light weight and fewer interfaces. However, since the Bosch concept is reasonably well developed, it is recommended that this concept be further developed as a backup for the solid electrolyte process.

Another concept having a great potential in the post AILSS period is the fused salt concept, because it combines the CO_2 concentration and reduction functions in a single process, eliminating the CO_2 purity problem and many internal and external interfaces. The problem with this concept is the rather complex electrochemical reactor and its early zero-gravity development status. It is recommended that this concept be developed further to determine whether its potential significant advantages can be achieved in a practical zero-gravity configuration. Another concept, for the post AILSS period, which has good potential is the Sabatier with acetylene dump concept. This concept, once developed should have light weight and no carbon problems.

Atmospheric Contamination Control

The sorbent-protected catalytic burner concept is selected for AILSS trace contaminant control. The alternative regenerable charcoal concept has the potential advantages of low sensitivity to poisoning and indefinite life (it would not be used up as the protective sorbents for the catalytic burner are). The problems that prevented the selection of this concept are high crew time (for regeneration) and bacteria growth potential. It is recommended that further effort be directed toward this approach.

Water Management

The vapor diffusion and vapor compression-diffusion concepts are selected for the AILSS because of low weight and positive control of bacteria. Another concept, the closed air evaporation concept, has achieved very high water recovery efficiencies and is in a high state of development, but has a high equivalent weight. However, considering the state of its development and its high recovery efficiencies, it is recommended that effort be continued on this concept as a backup for the concept selected.

Waste Control

Vacuum decomposition is selected for the AILSS because of its low weight and safe, positive control of bacteria. An alternative concept that has an attractive growth potential is wet oxidation, which recovers water from wet wastes (food, disposable towels, used filters, etc.) and, if necessary, from fecal waste. This concept is not selected because of its high equivalent weight and because the recovery of water wastes is unnecessary for the AILSS materials balance. However, in view of the possible growth potential of this concept, it is recommended that effort be expanded to develop it further, either as a backup for the selected concept or for other longer-duration missions.

Crew Provisions

Crew provisions selections for the AILSS are reuseable clothing, freeze-dried food, and a spray shower for body washing. As alternatives, disposable clothing would save much crew (washing) time, a chemical diet would greatly reduce system equivalent weight, and an automatic sponge body wash would result in a lighter, quieter system that would have far less effect (heat and humidity) on the cabin atmosphere. The problems that prevent the selection of these alternatives are the high weight of disposable clothes; the variety, texture, flavor, and general acceptability problems of a chemical diet; and the lack of emotional satisfaction with the automatic sponge bath. In view of the potential weight savings that these alternatives provide, it is recommended that further effort be expended in these areas.

Microbiological Monitors

The bioluminescent technique is selected to determine the microbiological quality of the AILSS atmosphere. An alternate concept which does not have the serious problem of limited enzyme (luciferase) life is the chemiluminescent concept. However, much effort is required to develop this concept to distinguish between live and dead bacteria. It is recommended that effort be expended on this concept so as to have a potential backup for the selected concept.

DILUENT STUDY

CONTENTS

DILUENT STUDY

Although nitrogen is the diluent gas specified for use in the AILSS, neon and helium may be considered as possible alternates from a physiological point of view. The other noble gases increase the hazard of decompression sickness above the level of the nitrogen hazard and therefore are eliminated from consideration. It is the purpose of this section, then, to examine the AILSS EC/LS equipment to determine the changes that might occur if a diluent other than nitrogen is selected.

There are at least two approaches to this type of study. One approach is to assume that the equipment remains the same both in type and size, and that changes in the gas will cause changes in performance. A second approach, the one taken in this study, is to assume that the performance remains essentially the same and that changes are made in weight, power, or elsewhere.

Thus, this study considers the changes in system weight and power that would result if the diluent were changed from nitrogen to either helium or neon, assuming unchanged functional performance. To make the study more useful, this was done for both relative (normalized) power and specific AILSS total equivalent weights. In general, this discussion follows the same subsystem breakdown used throughout the report.

A list of gas mixtures, pressures, and pertinent properties is shown in table 71.

OXYGEN AND DILUENT STORAGE

Leakage

High pressure storage is the selected method of storing the atmospheric gases for the AILSS. The major factors, then, that determine the capacity and weight of the subsystems (other than metabolic use) stem from the cabin leakage rate and the repressurization requirements.

Leakage to space can occur through equipment such as pressure relief valves in a manner characterized by capillary-free molecular flow or from larger openings in a manner characterized by bulk flow. Because it is impossible to determine which leakage mode may actually be encountered and because the relative quantities of oxygen and diluent lost differ between the two, it is necessary to supply sufficient stored gas to accommodate either extreme.

TABLE 71
PROPERTIES OF GASES AND GAS MIXTURES

Gases		M	k (Btu/ft-hr-°F)	ρ^b (lb/ft^3)	Cp (Btu/lb-°F)	μ (lb/ft-hr)	$N_{PR} = \frac{C_p \mu}{k}$	$\gamma = C_p/C_v$	t_{cr} (°F)	p_{cr} (psia)
Oxygen		32	0.0153	0.0827	0.210	0.0495	0.680	1.40	-182	736
Nitrogen		28	0.0150	0.0725	0.247	0.0425	0.700	1.40	-233	492
Neon		20	0.0026	0.0517	0.248	0.0750	7.15	1.64	-380	395
Helium		4	0.0860	0.0102	1.240	0.0485	0.699	1.63	-451	40.6
Mixtures										
7.0 psia[a]	$O_2 - N_2$	30	0.0151	0.0366	0.227	0.0460	0.690	1.40	—	—
	$O_2 - Ne$	26	0.0102	0.0318	0.225	0.0591	1.299	1.49	—	—
	$O_2 - He$	18	0.0352	0.0219	0.324	0.0524	0.483	1.48	—	—
14.7 psia[a]	$O_2 - N_2$	29.0	0.0151	0.0742	0.237	0.0442	0.695	1.40	—	—
	$O_2 - Ne$	22.8	0.0067	0.0589	0.235	0.0663	2.337	1.56	—	—
	$O_2 - He$	10.7	0.0547	0.0273	0.504	0.0531	0.489	1.55	—	—

[a] P_{O_2} = 3.5 psia in both cases

[b] At 14.7 psia and 530°R

To determine the relative leakage of oxygen and diluent for the capillary-free molecular flow case, use was made of the Knudsen equation as modified by Mason:

$$Q = \frac{5.22\ D^4\ (P_{cb})^2}{10^6\ \mu\ L} + \frac{7.42\ D^3\ P_{cb}}{10^6\ L}\sqrt{\frac{t}{M}} + \left[\frac{7.44\ D^2 \mu t}{10^8\ ML}\right]\left[\ln\left(1+\frac{23.9\ D\ P_{cb}}{\mu}\sqrt{\frac{M}{t}}\right)\right]$$

(Note: A list of symbols appears at the end of this section.)

This type of leak is thus a function of the gas mixture, total pressure, capillary diameter, and capillary length. The first two are predictable, but because the last two are not, an assessment of the effect of gas diluents and pressures must necessarily be a relative one.

Figure 117 presents typical relative leak rates for this type of leak for various gas mixtures. The data is from Mason and others. As expected, the figure indicates that the total gas loss increases as pressure is raised from 7.0 psia to 14.7 psia regardless of the diluent used.

The other leakage extreme, bulk flow, occurs when the holes or openings are large enough to permit the gases to leak out in the same proportion as they exist in the cabin. Thus, it is dependent on the molecular weights of the gases, the total pressure, and the partial pressures of each constituent. For this purpose, it was assumed that oxygen partial pressure was 3.4 psia at a cabin pressure of 7.0 psia and 3.1 psia at a cabin pressure of 14.7 psia. Because such leakage is characterized by isentopic choked flow, the normal gas relationships apply:

$$\dot{m} \sim p\sqrt{M}$$

On this basis, figure 118 was constructed to show the relative effects of pressure and composition on this type of leakage.

The AILSS repressurization requirements include enough gas for two complete repressurizations of the cabin. It is assumed, as in the main study, that four one-third capacity tanks are used for oxygen and one large tank for the diluent.

The following table shows the weight penalties in pounds for each gas and tankage (high pressure) for each gas mixture considered.

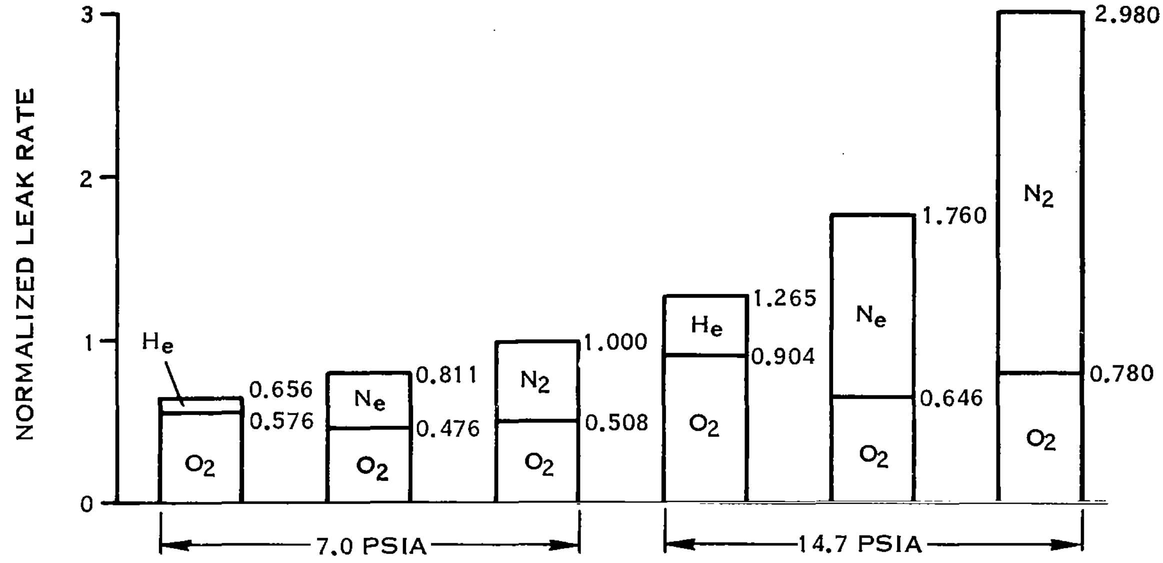


Figure 117. Leak Rate Ratios For Various Atmospheres
Elastomer - Metal Seal (Capillary - Free Molecular) Flow

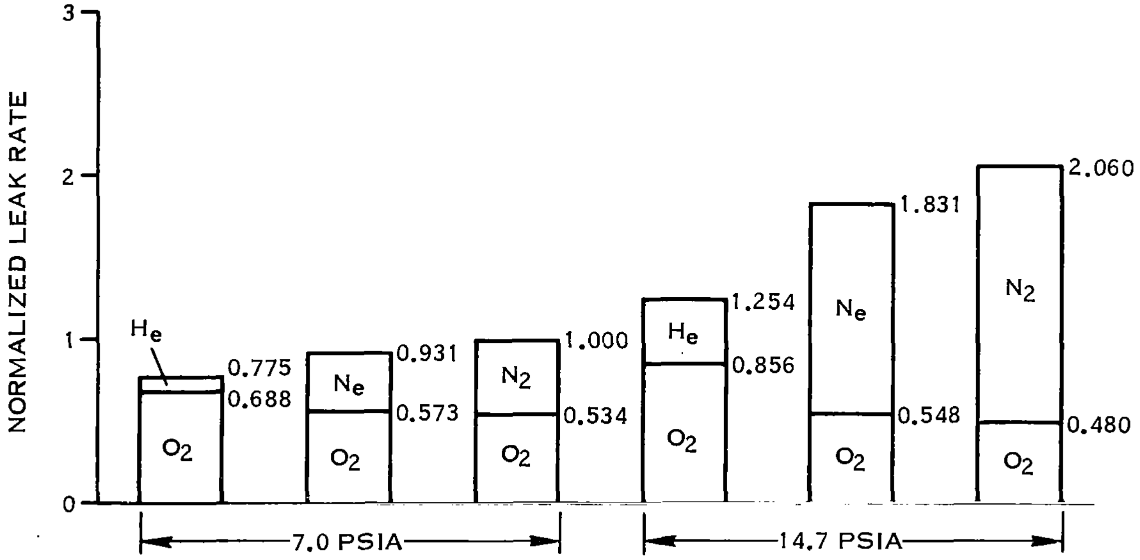


Figure 118. Leak Rate Ratios For Various Atmospheres
Bulk (Orifice) Flow

	7.0 psia			14.7 psia		
	O_2-He	O_2-Ne	O_2-N_2	O_2-He	O_2-Ne	O_2-N2
Oxygen:						
Gas weight	839	702	661	761	726	562
Tank weight	407	342	319	371	352	274
Subtotal	1246	1044	980	1132	1078	836
Diluent:						
Gas weight	110	453	592	300	972	1473
Tank weight	391	343	437	1086	790	846
Subtotal	501	796	939	1386	1762	2319
Total	1747	1840	1919	2518	2840	3155

It should be pointed out that the volume required for high pressure helium storage is quite large; about 56 ft^3 for the 7.0 psia case and about 168 ft^3 for 14.7 psia case.

Decompression

If a pressure relief valve opens, whether intentionally or through failure, or if a failure of the cabin wall occurs due to, say, a meteoroid penetration, the time required to reach a critical pressure level is important. In a situation like this, the worst case is reversible adiabatic choked flow (isentropic flow).

By applying the basic equation of gas dynamics, it can be shown that

$$\frac{p_f}{p_i} = \left[1 + \frac{\delta - 1}{2} \alpha \theta\right]^{\frac{2\delta}{1-\delta}}$$

where $$\alpha = 223 \left(\frac{C_d A}{V_{cb}}\right) \sqrt{\frac{t_i}{M}} \sqrt{\delta \left(\frac{2}{\delta + 1}\right)^{\frac{\delta + 1}{\delta - 1}}}$$

Figure 119 presents a plot of pressure ratio as a function $\frac{\theta C_d A}{V_{cb}}$ for various gas mixtures. The minimum tolerable total pressure for a 7 psia 50 percent O_2-50 percent diluent is 4.2 psia, and the critical pressure ratio for that condition is 0.86. For a mixture initially at 14.7 psia, the minimum tolerable total pressure is 5.1 psia and the critical pressure ratio is 0.346. The time to reach this critical pressure condition can thus be determined for each gas mixture from figure 119.

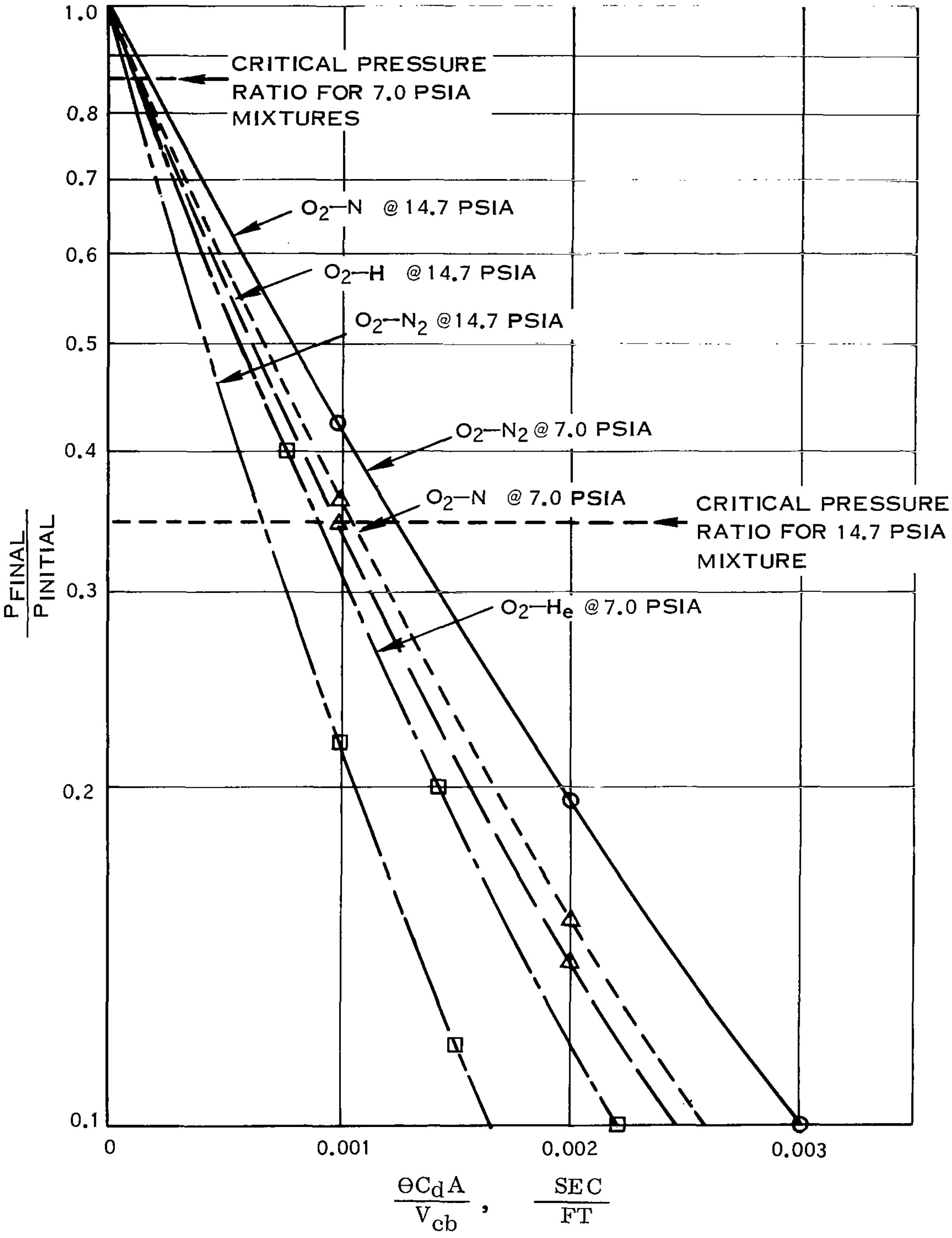


Figure 119. Decompression Pressure Ratio vs. Isentropic Flow

CO_2 REMOVAL AND CONCENTRATION, AND ATMOSPHERIC CONTAMINATION CONTROL

For the purposes of this discussion, the CO_2 removal and concentration and the atmospheric contamination control subsystems are grouped together because they share a common fan, and it is the fan power rather than hardware weight that is the most sensitive to the gas composition.

The steam desorbed resin CO_2 removal and concentration subsystem is composed of several items including a steam generator, CO_2 sorbent beds, compressor, accumulator, condensers, and process flow fan. The atmospheric contamination control subsystem includes several sorbent beds, a catalytic oxidizer, and shares with the CO_2 removal subsystem the same process flow fan. In addition, the atmospheric control subsystem includes several separate bacteria control filters that have their own fans.

The effects that a diluent change would have on these subsystems are:

1. Altered heat loss rates from the equipment to the cabin
2. Altered diluent carryover from the CO_2 concentrator
3. Altered process fan power
4. Altered catalytic oxidizer heater power
5. Altered bacteria control fan power

These effects are discussed in the following paragraphs.

Heat Loss

The heat loss from each item is considered constant for each gas mixture. Since this heat loss is partly a function of the convective heat transfer coefficient, it is assumed that, with different gas mixtures, different ventilating fan flows are required to maintain a constant convective coefficient. Because this requirement is to be met in general by the ventilating fans, the changes necessitated by different diluents are treated subsequently under Thermal Control Subsystem where these fans are discussed.

Diluent Carryover

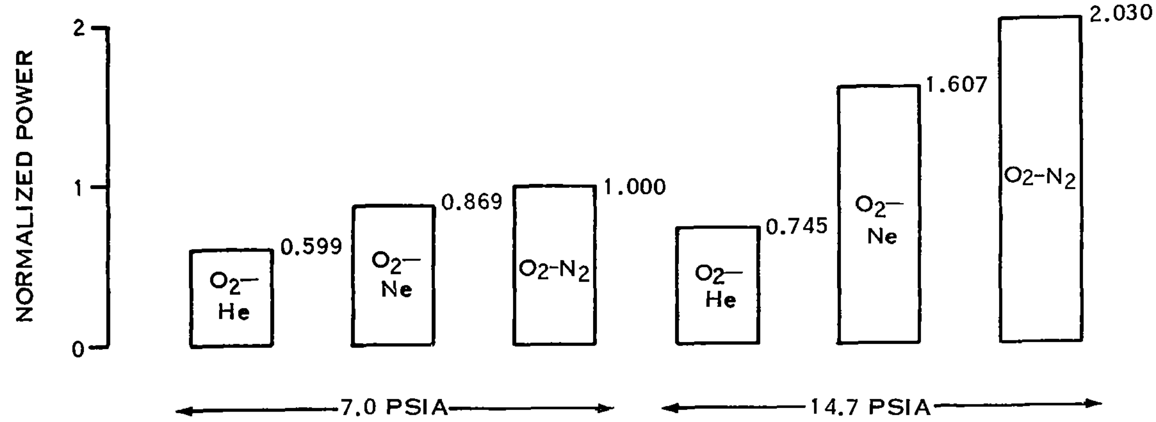
Diluent carryover with concentrated CO_2 is the result of both gas ullage and diluent adsorption on the sorbent. As diluent concentration increases, the diluent impurity in the concentrated CO_2 increases resulting in an increased CO_2 reduction system purge rate. This increased purge rate is returned as recycled CO_2 to the inlet of the CO_2 concentrator with a net increase in CO_2 concentration as well as process rate. It turns out, however, that the amount of penalty increase due to the concentrator is negligible; amounting at most to only 0.1 percent required increase in process flow rate for each 1 percent degradation in purity.

Process Fan Power

The control of CO_2 and trace contaminants in the cabin demands a constant volumetric processing rate. Thus, the power varies as the density as follows:

$$P_2 = P_1 \frac{\rho_2}{\rho_1}$$

The following illustration shows the normalized fan power requirements for the gaseous contamination process flow fan.



The following table shows the various process flow fan power requirements attributable to the gas mixtures studied.

	Mixture	Power (watts)	Weight penalty (lb)
7.0 psia	O_2-He	101	59
	O_2-Ne	146	85
	O_2-N_2	168	99
14.7 psia	O_2-He	125	73
	O_2-Ne	270	153
	O_2-N_2	341	200

Catalytic Oxidizer Heater Power

Thermal performance demands constant heat transfer in the catalytic burner heat exchanger, which in turn requires that the flow vary as the reciprocal of ρC_p. Therefore, a constant flow rate and constant heat transfer cannot be maintained simultaneously. Because a constant volumetric flow rate is fundamental to the contaminant control function, it is maintained with a consequent change in heater power.

Thermally, the catalytic oxidizer is a regenerative heat exchanger and a heater. Therefore,

$$q_{Heater} = \dot{m}\, C_p \left(t_{h_o} - t_{c_i}\right) = \dot{m}\, C_p \left(t_{h_i} - t_{c_i}\right) (1 - \epsilon)$$

because

$$1 - \epsilon = \frac{1}{1 + \dfrac{UA}{\dot{m}\, Cp}},$$

These two expressions can be proportionally combined as follows:

$$\frac{q_2}{q_1} = \frac{\rho_2}{\rho_1} \frac{C_{p_2}}{C_{p_1}} \left[\frac{1 + \dfrac{h_1}{\rho_1 C_{p_1}}}{1 + \dfrac{h_2}{\rho_2 C_{p_2}}} \right]$$

but

$$1 + \frac{h}{\rho C_p} \sim \frac{h}{\rho C_p}$$

for the gases and equipment under discussion. Therefore,

$$\frac{q_2}{q_1} \propto \left(\frac{\rho_2}{\rho_1} \frac{C_{p_2}}{C_{p_1}} \right) \frac{h_1}{h_2}$$

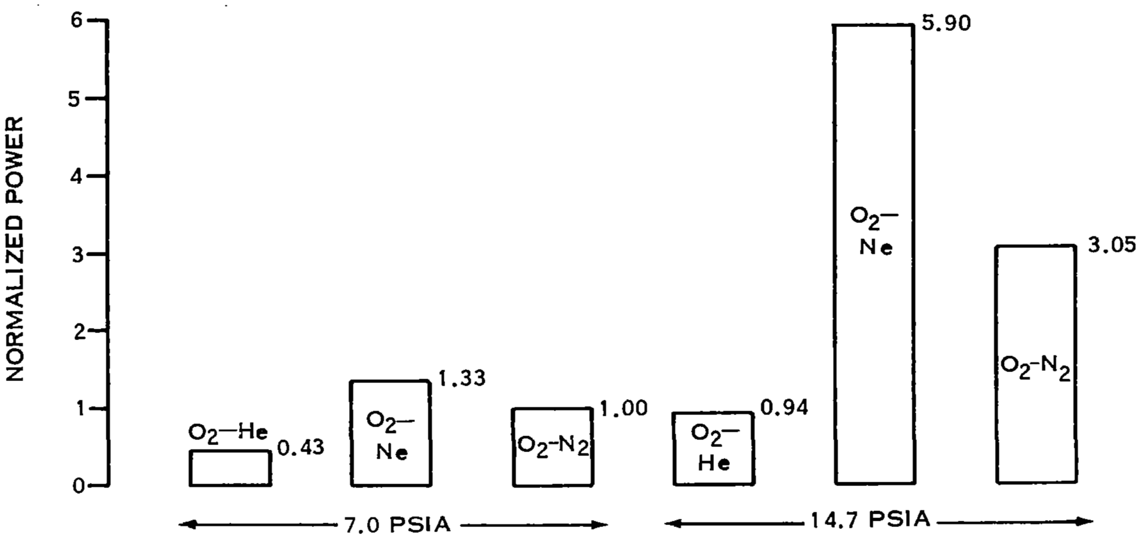
Furthermore, it can be shown that

$$\frac{h_1}{h_2} \propto \frac{k_1}{k_2} \left[\frac{p_1 \mu_2}{p_2 \mu_1} \right]^{1/2}$$

so that

$$\frac{q_2}{q_1} \propto \left(\frac{C_{p_2}}{C_{p_1}} \right)^2 \left(\frac{\mu_2}{\mu_1} \right)^{0.5} \left(\frac{k_1}{k_2} \right) \left(\frac{p_2}{p_1} \right)^{1.5}$$

The following illustration shows the changes in catalytic oxidizer heater power to be expected with the various gas mixtures studied.



The following table shows the corresponding values of catalytic oxidizer heater power for the AILSS.

	Mixture	Power (watts)	Equivalent Wt. (lb)	
			Designs 1 & 3	Design 2
7.0 psia	O_2-He	48	28	9
	O_2-Ne	149	87	28
	O_2-N_2	112	66	21
14.7 psia	O_2-He	105	61	20
	O_2-Ne	660	386	123
	O_2-N_2	342	200	64

Bacteria Control Fan Power

The bacteria control fans (three in each design) draw cabin gas through 0.3 micron absolute filters. Proper control demands a constant volumetric processing rate just as for other contamination control. The normalized power relationships shown in the illustration for the gaseous contamination process fan power apply. The following table shows the actual power values for the three bacteria control fans.

	Mixture	Power (watts)	Equivalent wt. (lb)
7.0 psia	O_2 -He	336	197
	O_2 -Ne	487	286
	O_2 -N_2	561	328
14.7 psia	O_2 -He	418	245
	O_2 -Ne	900	527
	O_2 -N_2	1140	669

O_2 GENERATION/CO_2 REDUCTION

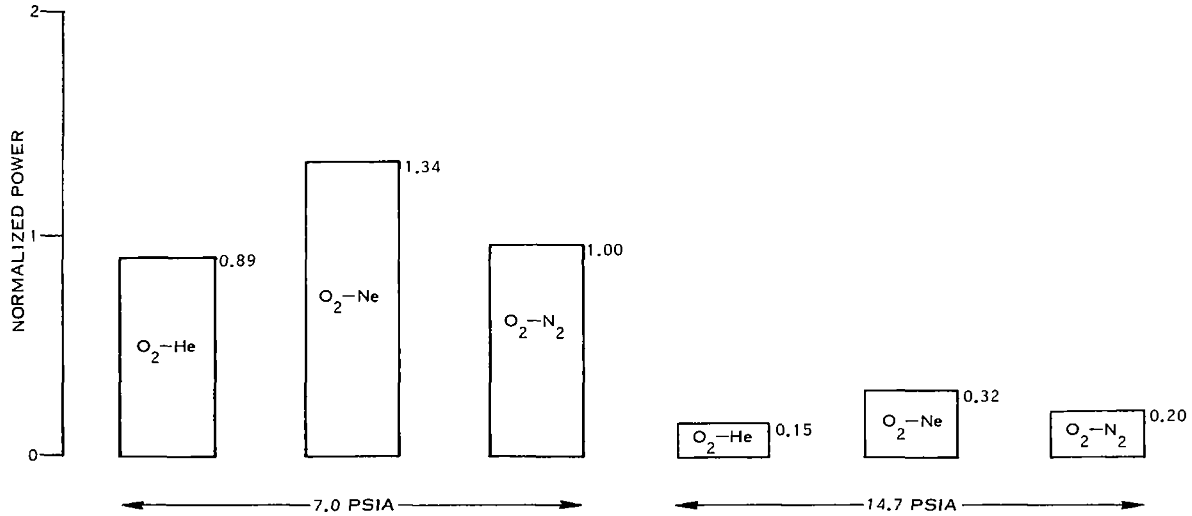
This subsystem has several pieces of equipment that interact with the cabin atmosphere: solid electrolyte cell modules, disproportionator, oxidizer, compressor, and heat exchanger. All of these units exchange heat by convective heat transfer with the cabin gas. In order to maintain the same performance, then, the heat loss from each item is considered to be constant for each gas mixture. For this to be true, the ventilating fans in the cabin have to pump greater or lesser quantities of cabin gas which effect both fan power and weight. Because this is a general requirement to be met by the ventilating fans, the changes necessitated by the different diluents is treated in the Thermal Control Subsystem discussion which follows.

Temperature and Humidity Control

The cabin temperature and humidity control function maintains both a constant cabin temperature and a constant cabin humidity. Thus, it must remove a certain amount of sensible heat and latent heat (humidity). Both of these functions are accomplished in a condensing heat exchanger, but because sensible load removal determines mass flow rate, only changes that occur as a result of the thermal control functions are considered. For this, then, analysis indicates that

$$P \propto \frac{1}{\rho^2 \, C_p^3}$$

The following illustration shows the relative changes in the temperature and humidity control fan power based on O_2 -N_2 at 7.0 psia.



The following table shows the actual AILSS values for the three fans involved.

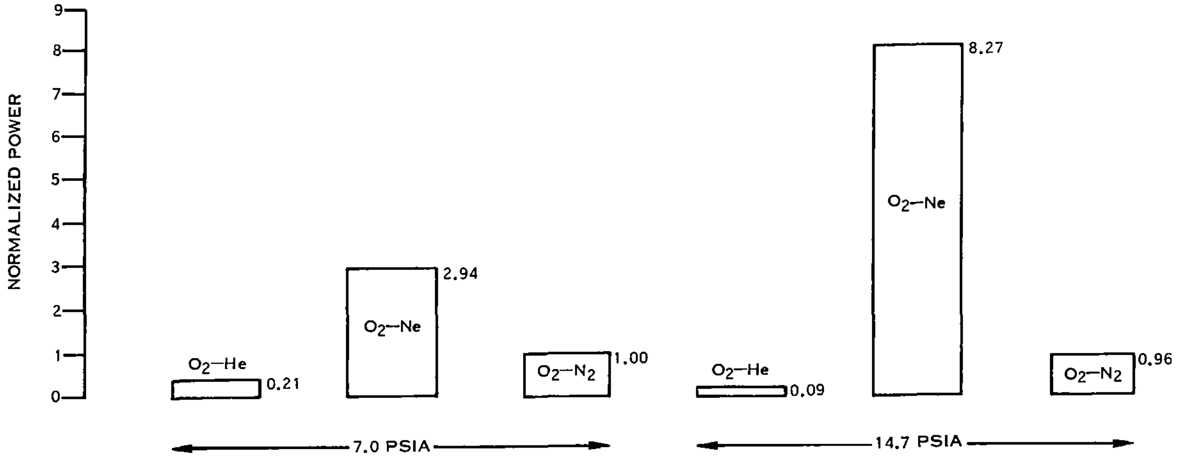
	Mixture	Power (watts)	Equivalent weight (lb)
7.0 psia	O_2-He	868	509
	O_2-Ne	1310	768
	O_2-N_2	975	571
14.7 psia	O_2-He	195	114
	O_2-Ne	312	183
	O_2-N_2	146	86

Ventilation Fans

The function of the ventilation fans is to provide a sufficient velocity, in the face of varying temperature and humidity control fan flow, to maintain a satisfactory heat transfer coefficient. Thus, with the various gas mixtures, the fan flow and power must change so as to maintain the same coefficient. For this to be true, it follows that

$$P \propto \frac{\mu}{k^2}$$

The following illustration shows the relative changes in the ventilating fan power based on O_2-N_2 at 7.0 psia.



The following table shows the actual AILSS values for the two fans involved.

	Mixture	Power (watts)	Equivalent weight (lb)
7.0 psia	O_2-He	40	23
	O_2-Ne	553	324
	O_2-N_2	188	110
14.7 psia	O_2-He	17	10
	O_2-Ne	1555	912
	O_2-N_2	180	105

WATER MANAGEMENT SUBSYSTEM

The water management subsystem interacts with the cabin atmosphere in two significant ways: atmospheric gas can be dissolved in the water and subsequently outgassed, and various pieces of equipment depend on atmospheric cooling. These two subjects are discussed below.

Gas Solubility

As the water in the spacecraft undergoes use and processing, it is heated and cooled through a temperature range of roughly 70° to 150°F. Oxygen and the various diluents dissolve in the water to varying degrees depending on the temperature. Because the solubility of a gas in water is usually decreased with temperature, definite problems can arise in heat exchangers and vapor diffusion stills. Actually, it is the change of solubility with temperature that is of greatest importance. The following table shows the difference in gas solubility with temperature change.

Gas	Solubility (cm^3/liter)		
	70°F	150°F	Δ Sol.
O_2	31.0	18.0	13.0
N_2	16.2	10.0	6.2
Ne	10.5	10.0	0.5
He	8.9	9.9	-1.0

As can be seen, nitrogen displays the greatest outgassing characteristics of all the diluents considered. Any change of diluent, then, relieves the problem rather than accentuates it.

Heat Loss

The heat loss from each item, such as the stills, heater (Designs 2 and 3) or compressor (Design 1), and storage tanks, is considered to be constant. As before, this demands equivalent convective heat transfer coefficients for all gas mixtures. Therefore, the changes in ventilating fan power already discussed should apply.

WASTE MANAGEMENT SUBSYSTEM

The Waste management subsystem interacts with the cabin atmosphere in three ways: cabin gas is pumped by one fan through the system to assist in zero-gravity control of the waste products, another fan is used to vacuum the waste residue from the processor after processing, and various items require convective cooling.

Fan Power

The large waste management fan is used to induce flow through the system to control the flow of the urine, feces, and other waste materials collected in the system. Additionally, this fan is used to direct the gas flow from the processor through odor control beds to remove toxic and odoriferous gases. The smaller fan is used to remove the residue from the processor. All these functions, in zero gravity, can be met by supplying a constant volumetric flow rate. On this basis, the following table shows the fan powers and equivalent weights for both fans for all the diluents considered.

	Mixture	Power (watts)	Equivalent weight (lb)
7.0 psia	O_2-He	132	77
	O_2-Ne	191	112
	O_2-N_2	220	129
14.7 psia	O_2-He	164	96
	O_2-Ne	354	208
	O_2-N_2	447	262

Heat Loss

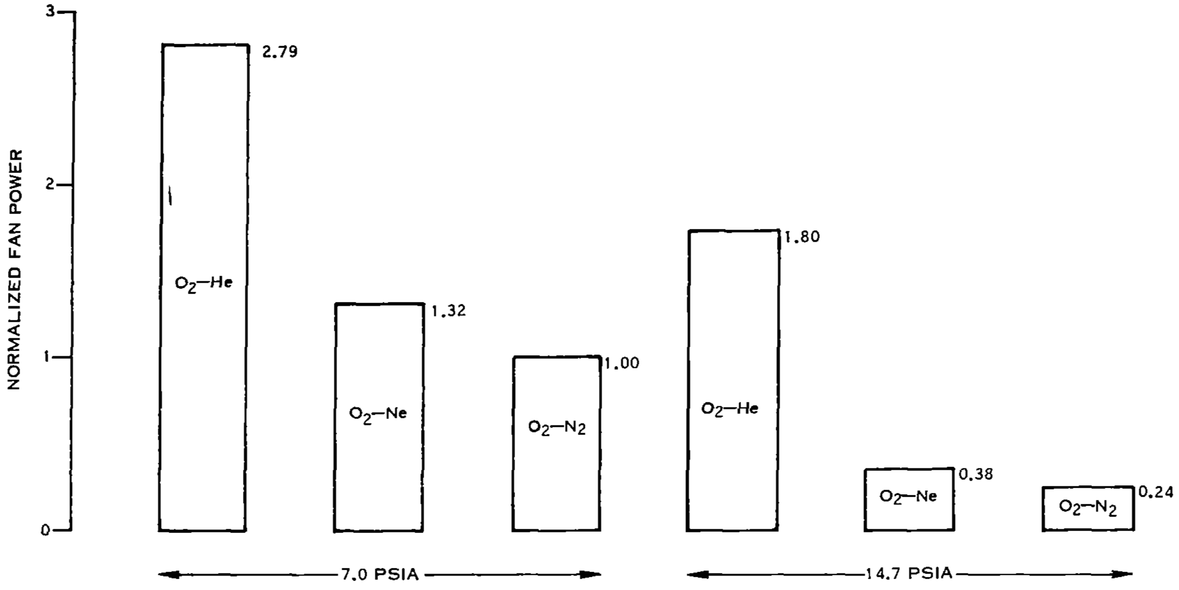
The heat loss from this system is considered constant. As before, this demands equivalent convective heat transfer coefficients for all gas mixtures. Therefore, the changes in ventilating fan power already discussed should apply.

CREW PROVISIONS SUBSYSTEM

The only portion of the crew provisions subsystem that interacts with the cabin atmosphere is the crew shower. In this device, a gas stream is used to control the liquid-gas interfaces and overall liquid flow. This implies a constant gas momentum ($m\overline{V}$) which, in turn, implies a constant mass flow rate ($\dot{m}$). It can be shown that for this to be achieved,

$$P_2 = P_1 \left(\frac{\rho_1}{\rho_2} \right)^2$$

The following illustration shows the normalized shower fan power requirements associated with the different gas mixtures compared to O_2-N_2 at 7. 0 psia.



The following table shows the actual AILSS values for the shower fan.

	Mixture	Power (watts)	Equivalent weight (lb)[a]
7.0 psia	O_2-He	84	212
	O_2-Ne	40	100
	O_2-N_2	30	76
14.7 psia	O_2-He	54	137
	O_2-Ne	11	28
	O_2-N_2	7	18

[a] includes battery weight

INSTRUMENTATION AND CONTROL SUBSYSTEM

There are no significant interactions between this subsystem and the cabin atmosphere that are affected by the diluent.

SUMMARY

In summary, there are four major areas of weight change due to difference in the diluent gas:

1. Fan power penalty
2. Fan weight
3. Catalytic oxidizer heater power penalty
4. Gas storage weight (including gas)

Fan Power Penalty

The fan power penalties discussed throughout the previous sections include:

1. Gaseous contamination control (1 unit)
2. Bacterial control (3 units)
3. Thermal and humidity control (3 units)
4. Ventilation (2 units)
5. Waste management (1 unit)
6. Shower (1 unit)

The following table shows a summary of the total fan power and equivalent weight change for the various gas mixtures involved.

	Mixture	Power (watts)	Equivalent wt. (lb)
7.0 psia	O_2-He	1561	915
	O_2-Ne	2727	1600
	O_2-N_2	2142	1258
14.7 psia	O_2-He	973	570
	O_2-Ne	3402	1999
	O_2-N_2	2261	1328

Fan Weight Penalty

The direct fan weight penalties were held for this summary because certain fans serve more than one subsystem and fan weight varies with total load rather than incremental loads. The values presented here are based on correlations of actual fan weight as a function of power requirements. Obviously, such a scaling procedure is not entirely accurate, but because the absolute values are relatively small, a more thorough analysis is not warranted. The following table shows the total estimated fan weights for each gas mixture.

	Mixture	Weight (lb)
7.0 psia	O_2-He	68
	O_2-Ne	81
	O_2-N_2	73
14.7 psia	O_2-He	58
	O_2-Ne	79
	O_2-N_2	64

Catalytic Oxidizer Heater Power Penalty

This data is the same as presented earlier in the CO_2 Removal and Concentration and Atmospheric Control sections.

Gas Storage Weight

This data is the same as presented earlier in the Oxygen and Diluent Storage sections.

Total Equivalent Weight

The total equivalent weight for each gas mixture associated with the four areas mentioned earlier are shown below.

	7.0 psia			14.7 psia		
Gas sensitive area	O_2-He	O_2-Ne	O_2-N_2	O_2-He	O_2-Ne	O_2-N_2
Fan power	915	1600	1258	570	1999	1328
Fan weight	68	81	73	58	79	64
Catalytic oxidizer Heater						
Designs 1 & 3	28	87	66	61	386	200
Design 2	9	28	21	20	123	64
Gas storage	1747	1840	1919	2518	2840	3155
Total:						
Design 1 & 3	2758	3608	3316	3207	5304	4747
Design 2	2739	3549	3271	3166	5041	4611

The results of this study indicate that the major differences in equivalent weight between the diluents studied occur in fan power and gas storage weight. While other areas show a significant percentage change, the absolute values are small.

A 7.0 psia O_2-He gas mixture offers the lowest total equivalent weight; the heaviest, a 14.7 psia O_2-Ne system would be nearly 2600 pounds heavier for Designs 1 and 3 and 2300 pounds heavier for Design 2. For any of the designs, however, the 7.0 psia O_2-N_2 system is only about 550 pounds heavier than the O_2-He system at the same pressure. In view of the EC/LS approximate total equivalent system weight of 20,000 pounds, the differences in diluent at the normal cabin pressure of 7 psia do not appear significant from an equipment weight point of view. The choice of diluent would appear to be more a function of physiological considerations than of equipment characteristics. Considering the vastly greater amount of test data available for nitrogen and more familiar and predictable physiological reaction to it, nitrogen is the most justifiable choice for an overall suitable diluent.

If a cabin pressure of 14.7 psia is desired, then it might be advantageous to consider a diluent change to helium in view of the nearly 1500 pound differential between nitrogen and helium at that pressure.

SYMBOLS

A - area, ft^2
C_d - coefficient of discharge
C_p - constant pressure specific heat, Btu/lbm-°F
C - constant volume specific heat, Btu/lbm-°F
D - capillary diameter, microns
h - film heat transfer coefficient, Btu/hr-ft^2-°F
k - thermal conductivity, Btu/hr-ft-°F
L - capillary length, cm
$\dot{m}$ - mass flow rate, lbm/hr
M - molecular weight, lbm/mol
N_{PR} - Prandtl number
p - pressure, psia
P - power, watts
q - heat transfer rate, Btu/hr
Q - pressure x volumetric leak rate, micron-liters/sec
t - temperature, °R
U - overall heat transfer coefficient Btu/hr-ft^2-°F
V - volume, ft^3
δ - specific heat ration, Cp/Cv
ϵ - heat exchanger effectiveness
Θ - time, sec
μ - viscosity, lb/ft-hr
ρ - density, lbm/ft^3

Subscripts:

c - cold
cb - cabin
cr - critical
f - final
h - hot
i - inlet or initial
o - outlet

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ABSTRACT

TRADE-OFF STUDY AND CONCEPTUAL DESIGNS OF REGENERATIVE ADVANCED INTEGRATED LIFE SUPPORT SYSTEMS (AILSS)

Prepared by Hamilton Standard for the NASA
Langley Research Center under Contract No. NAS 1-7905

This study analyzes and recommends life support systems for a 500-day, 1976-1980 space flight with a nine man crew and no resupply. In addition, specific research and development programs are recommended for special emphasis, and the engineering impact on the life support system of changing mission duration, crew size, power penalty, resupply approach, flight date, and atmospheric diluent is discussed. Four life support systems are recommended, each for a different power and heat supply situation. Thus, one design interfaces with a solar cell, all-electric power-heat source; another interfaces with a solar cell power source and a multiple isotope heat source; a third interfaces with a Brayton cycle power and waste heat source; and the last design stresses flexibility to interface with any of these power supply systems with a minimum amount of modification. Potable water and oxygen are regenerated, with no stored supplies needed for normal crew consumption. Food is stored, and waste is processed for disposal. For subsystem selection, the candidate concepts are traded off using nonnumerical, sequentially applied criteria. This method uses performance, safety, and availability/confidence as absolute criteria; reliability, crew time, and equivalent weight as primary criteria; and contamination, interfaces, flexibility, growth, noise, volume, and power as secondary criteria. The integration of the life support subsystem concepts selected for each power and heat source is discussed.