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ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM (EC/LSS) FOR THE 1975 SPACE STATION

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16. ABSTRACT

This report contains the results of a preliminary study to define an Environmental Control and Life Support Subsystem (EC/LSS) that is applicable to a long-term earth-orbital space station for the 1975 time period. The Space Station is capable of supporting a 12-man crew continuously over an extended period of time with regular resupply. The EC/LSS must maintain a system life requirement of 10 years through maintenance spares and redundancy. A survey was made to define a group of assemblies that is suitable for fulfilling the requirements of the EC/LSS. The primary assemblies are as follows: atmospheric supply and pressurization; oxygen recovery; atmospheric purification; thermal control; water management; water reclamation; waste management; suit loop/PLSS; crew systems; and expendables. This report contains detailed descriptions of primary assemblies, including design criteria, approaches, advantages, disadvantages, component descriptions, preliminary weight, volume, and power summaries, and other pertinent information.

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TECHNICAL MEMORANDUM X-64508

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM (EC/LSS) FOR THE 1975 SPACE STATION

SUMMARY

This report contains the results of a preliminary study to define an Environmental Control and Life Support Subsystem (EC/LSS) that is applicable to a long-term earth-orbital space station for the 1975 time period. The Space station envelope that was selected for development of the earth-orbital space station is illustrated in Figure 1. The Space Station is capable of supporting a 12-man crew continuously over an extended period of time with regular resupply. The EC/LSS must maintain a system life requirement of 10 years through maintenance spares and redundancy. A survey was made to define a group of assemblies that is suitable for fulfilling the requirements of the EC/LSS. The primary assemblies are as follows: atmospheric supply and pressurization; oxygen recovery; atmospheric purification; thermal control; water management; water reclamation; waste management; suit loop/PLSS; crew systems; and expendables. This report contains detailed descriptions of primary assemblies, including design criteria, approaches, advantages, disadvantages, component descriptions, preliminary weight, volume, and power summaries, and other pertinent information.

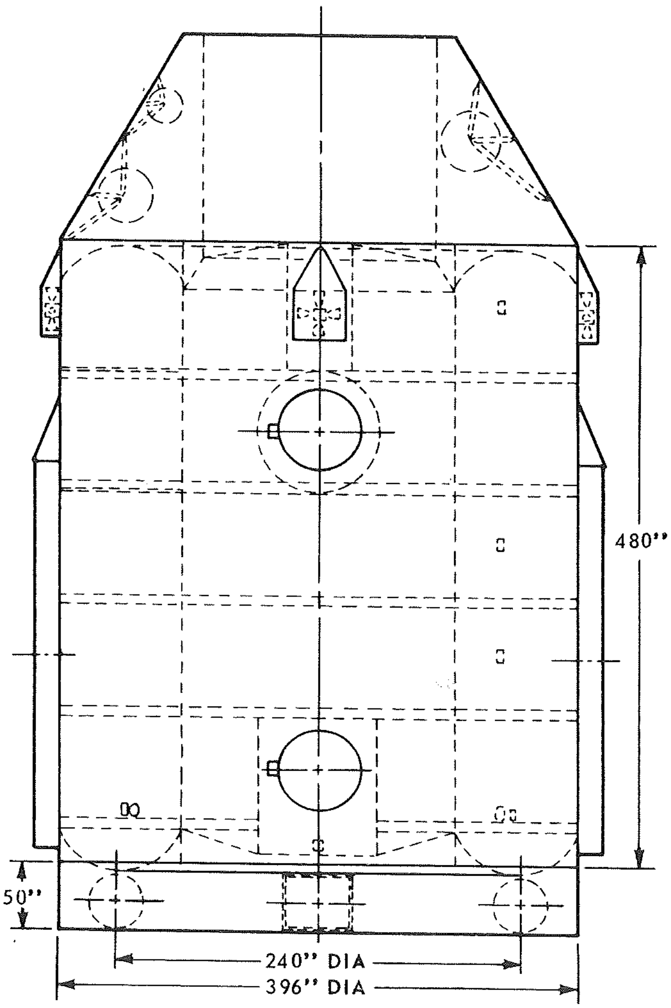


Figure 1. Space station envelope.

SECTION I. INTRODUCTION

The development of EC/LSS for short-duration space flights was based on open-loop, high-performance, aircraft environmental control systems. For longer-duration missions, scientists and engineers have undertaken the development of equipment and techniques aimed at closing the loop of man's metabolic process. Regenerative concepts have been under study, test, and development for some time for application to earth-orbital missions. Several examples are the research model regenerative Integrated Life Support System (ILSS) that is being evaluated at the Langley Research Center of the National Aeronautics and Space Administration, and the 60-day manned test performed at the McDonnell Douglas Astrionics Company, Santa Monica, California. Plans have been made for an extension of this test setup with more advanced EC/LSS assemblies to 90 days during the summer of 1970.

This report presents the results of a preliminary study of the use of existing assemblies, prototype equipment, and more advanced assemblies to fulfill the basic oxygen and nitrogen consumable requirements for leakage, metabolic, repressurization, EVA, etc. These consumables could possibly be stored supercritically and gaseous in AAP O_2, N_2, and Apollo He bottles; new bottles will be used for storing gaseous oxygen. For extreme emergency conditions, oxygen can be obtained from onboard chlorate candles. Metabolic oxygen requirements are satisfied through the use of Sabatier/Methane Dump oxygen recovery units and wick-feed electrolysis assemblies. Steam desorption removes carbon dioxide; catalytic burners, presorbent, post-sorbent, and other sorbent beds control contaminants; condensing heat exchangers are employed for humidity control. Thermal control is achieved with an active system (fluid loops, radiators, heat exchangers, fans, etc.). Vapor diffusion/compression water recovery units satisfy the water reclamation requirements. The waste management system selected is an integrated vacuum decomposition concept that eliminates the human handling of wastes. A suit loop and Portable Life Support System (PLSS) are used during emergency situations. Lists of the necessary crew systems and expendables are included in Sections VIII and X.

SECTION II. OVERALL EC/LSS GUIDELINES, REQUIREMENTS, AND CANDIDATES SUMMARIZATION

The primary objective of the EC/LSS is to maintain continuously habitable conditions on board the Space Station during the entire mission. The secondary objective of the EC/LSS is to maintain suitable environmental conditions for operational and experimental equipment contained within the Space Station.

This section describes briefly the EC/LSS and the functions required considering a 24-man crew (12-man continuous and 24-man during crew rotation), an unmanned launch of the Space Station in 1975, a manned launch approximately 24 hours later, and a 90-day resupply cycle. The EC/LSS must provide all the necessary elements that are listed in Table 1, to maintain the life and well being of the crew (continuous and turn-around) onboard the Space Station. Some of the general types of conceptual candidate equipment approaches that should be available to satisfy the EC/LSS equipment approaches are also listed. The fundamental criteria and requirements are based primarily on Reference 1 and are shown in Table 2.

The approach toward selecting an EC/LSS provided for the selection of a primary and an auxiliary subsystem, both capable of performing the critical functions. The primary subsystem has the capability to support the 12-man continuous crew without support from the auxiliary subsystem. In the event of primary subsystem malfunction, or during periods of repair and maintenance, or ultimate failure of the primary subsystem, the auxiliary subsystem permits continuation of the mission without modification to mission objectives or reduction in EC/LSS performance of vital functions. Sufficient spares and emergency supplies (food, water, oxygen) are on board the Space Station or Shuttle to provide a safe contingency during emergency situations and during high usage periods such as the 5-day turnaround time for the additional 12 men.

The EC/LSS lifetime requirement as stated in the Space Station work statement is 10 years. Flight-qualified assemblies for missions of a 10-year duration certainly do not currently exist and the availability of these systems for use in 1975 will depend heavily upon the advancement of the state-of-the-art and substantial development funding.

TABLE 1. EC/LSS FUNCTIONS AND EQUIPMENT APPROACHES

System	Functions	Candidates
Atmospheric supply and pressurization (*including oxygen recovery*)	• Storage of atmospheric constituents for metabolic, leakage, and repressurization • Metabolic oxygen and nitrogen supply, including oxygen recovery • Monitoring of atmospheric leakage to space • Conservation of atmospheric losses due to decompression/repressurization compartments and airlocks	• Storage of atmospheric constituents Gaseous — Apollo He tanks (Nitrogen)[a] New Tanks (Oxygen)[a] Subcritical cryogenic Supercritical cryogenic — AAP type tanks[a] • Delivery of atmospheric constituents Plumbing (pipes, fittings, valves, etc.) Fans, pumps, or pressure regulators • Oxygen recovery Sabatier with methane dump[a] Sabatier with methane cracking Solid electrolyte Fused salt Bosch Water electrolysis Gas circulation Wick feed[a] *Ion exchange membrane* Circulating electrolyte Rotating unit
Atmospheric purification	• CO_2 removal and control • Trace contaminant and bacteria control • Relative humidity control • Suit-loop interface requirements	• CO_2 removal Molecular sieve Solid amine Steam desorption[a] Electrodialysis Mechanical freezout Carbonation cell H_2 depolarized cell Membrane diffusion Liquid absorption • Trace contaminant and bacteria control Catalytic burner[a] Debris trap[a] Roughing filters[a] Bacteria filters[a] • Humidity control Heat exchangers[a]
Thermal control	• Thermal control of atmosphere and systems • Atmospheric circulation and mixing • Suit-loop interface requirements	• Active and passive systems (including fluid loops, fans, heat exchangers)[a]

a. Selected assembly

TABLE 1. (Concluded)

System	Functions	Candidates

Water management	• Supply and storage of potable water
	• Reclamation and purification of potable water from urine, perspiration, respiration, and wash water
	• Potability testing of reclaimed water
	• Suit-loop interface requirements
		• Required components with any system
		  • Storage tanks[a]
		  • Control panel with dispenser[a]
		  • Potability check equipment
		• Water reclamation
		  • Vapor compression
		  • Air evaporation
		  • Electrodialyses
		  • Membrane diffusion
		  • Waste heat vacuum distillation
		  • Vapor diffusion/compression[a]
		  • Reverse osmosis
		  • Multifiltration (condensate only)[a]

Waste management	• Collection, transfer, processing, storage, and/or disposal of all waste	• Integrated vacuum decomposition[a] • Wet oxidation • Anerobic biodegradation • Aerobic biodegradation • Gamma irradiation • Beta excited X-ray irradiation • Freezing of wet waste • Vacuum drying utilizing separate functions • Liquid germicide addition • Integrated vacuum drying • Flush flow oxygen incineration • Pyrolysis/batch incineration
Suit-loop system/ PLSS	• Ventilating gas supply for pressure suits • Provides heat transport fluid flow to pressure suit connectors • Controls temperature of the heat transport fluid • Removes moisture, carbon dioxide, and contaminants from the oxygen	• Suit loop • PLSS

a. Selected assembly

TABLE 2. SPACE STATION EC/LSS REQUIREMENTS/GUIDELINES

A. Crew Data	
1. Number of crew (continuous)	12 men
2. Intermittent for 120 hours maximum duration	24 men
3. Metabolic heat generation (Btu/man-day)	11 200
4. O_2 consumption (lb/man-day)	1.68
5. CO_2 produced (lb/man-day)	2.06
6. Water consumption rates	
• Food preparation (lb/man-day)	1.143
• Drink preparation (lb/man-day)	0.34
• Drinking (lb/man-day)	5.51
• Water of oxidation (lb/man-day)	0.78
• Clothes washing (lb/man-day)	3.01
• Utensils washing (lb/man-day)	0.89
• Shower (lb/man-day)	5.56
• Local Body (lb/man-day)	1.50
• Housekeeping (lb/man-day)	0.44
7. Water production rates	
• Urine water (lb/man-day)	3.08
including solids (lb/man-day)	3.24
• Urinal rinse water (lb/man-day)	2.00
• Perspiration and respiration (lb/man-day)	4.30
• Fecal water (lb/man-day)	0.25[a]
including solids	0.34
8. Water in food waste (lb/man-day)	0.14[a]
9. Water reclamation rates	
• Urine (lb/man-day)	2.926
• Urinal rinse (lb/man-day)	1.98
• Perspiration and respiration (lb/man-day)	4.257
• Wash water (lb/man-day)	3.861
• Personal hygiene (lb/man-day)	7.413
10. Freeze-dried food (lb/man-day)	1.58
including packaging (lb/man-day)	1.78
11. Frozen food (lb/man-day)	3.00
including packaging (lb/man-day)	3.30

a. Unrecovered

TABLE 2. (Continued)

B. Baseline Mission Data	
1. Resupply interval (days)	90
2. Systems life requirement with maintainability, spares, and redundancy (years)	10
3. Launch vehicle	Saturn V (INT 21)
4. Approximate launch load (g, axial direction)	5.2
(g, transverse direction)	1.2
5. Gravity (g)	0-1
6. Orbit period (min)	94.6
7. Flight operational time frame (year)	1975
8. Altitude (n. mi.)	270
9. Inclination (deg)	55
10. Crew safety: Probability, no critical injury, 3 years	0.99
C. Space Station Data	
1. Atmospheric — Total pressure (psia)	14.7
2. Atmospheric mixture (by volume)	21 percent O_2 79 percent N_2
3. O_2 partial pressure (psia)	3.09
4. N_2 partial pressure (psia)	11.61
5. CO_2 partial pressure, nominal maximum	$\leq$ 7.6 mm Hg $\leq$ 1.00% $\leq$ (0.147 psia)
6. CO_2 emergency, maximum	$\leq$ 15 mm Hg $\leq$ 1.97% $\leq$ (0.290 psia)
7. Leakage (lb/day)	19
8. Vehicle free volume (33 ft dia. by 40 ft)	34 195 ft^3
9. Repressurizations reserve (1 vol.)	34 195 ft^3
10. Cabin temperature (°F)	70 ± 5
11. Relative humidity (%)	40 ± 10
12. Wall inside temperature will be higher than the maximum dew-point temperature	(see C. 11)
13. Maximum cabin contaminants (mm Hg) vapor	0.05
maximum cabin contaminants ($m\ g/m^3$) aerosols	0.100

TABLE 2. (Concluded)

C. Space Station Data (Concluded)

14. Space Station ventilation (fpm)
   - o Maximum velocity in occupied zones — 40
   - o Minimum velocity in occupied zones — 15

15. Acoustical criteria (decibels) [2]

Zone	Speech Interference Level (SIL)[b]	Noise Criteria (NC)
A	45	45
B	55	55
C	75	75

Zone A: Command and control areas.
Laboratory workshop areas during delicate experiments.
Sleeping quarters.

Zone B: Laboratory workshop area during routine activity.
Mess and recreation areas.
Manned auxiliary equipment rooms.

Zone C: Unmanned auxiliary equipment rooms requiring occasional entry for maintenance.

16. Micrometeoroid puncture probability, 10 years — 0.9
17. Radiation environment limit, 6-month exposure

At 0.1 mm skin depth	250 rem
At 5 cm tissure depth	25 rem

b. The speech interference level (SIL) is the average of the octave-band sound pressure levels from 600 to 4800 hertz.

Since the degree of maintainability, repairability, and reliability required of these advanced systems is now unknown, it was necessary to make certain engineering judgments in assembly selection. Redundancy of assemblies, especially in the critical areas, is the preferred mode. The approach also assumes the packaging of assembly components for removal and replacement where repair techniques are found desirable.

An examination was made of the various candidates for the subsystem assemblies, and a selection was made for each assembly. The assemblies are identified to provide information necessary for the conceptual design of the Space Station. Table 3 lists the selected assemblies, their respective manufacturer, weight, volume, approximate power, and certain other pertinent data.

The Space Station atmosphere is composed of 21 percent oxygen and 79 percent nitrogen at a total pressure of 14.7 psia. Oxygen and nitrogen consumables will possibly be stored supercritically and gaseous in AAP O_2, N_2, and Apollo He bottles; new bottles will be used for storing gaseous oxygen. Sabatier/Methane Dump oxygen recovery units are used to satisfy the metabolic requirements. Carbon dioxide removal is achieved through a steam desorption concept. Contamination control is provided by catalytic oxidizers, presorbent, post-sorbent, and other sorbent beds. Humidity control is accomplished through condensing heat exchangers. Thermal control requirements will be satisfied through the use of an active system that will contain heat exchangers for maintaining proper cabin and suit temperatures, cold plates for electrical equipment, fluid loops for heat transport, and a radiator for heat rejection. Water requirements are satisfied through the use of two vapor diffusion/compression water recovery units (one redundant), a multifiltration unit, the initial water supply, and the reclaimed water accumulated during the mission. The waste-management system selected is an integrated vacuum decomposition concept that eliminates the human handling of the wastes. A suit loop that provides emergency oxygen, coolant, and pressurization is included for the crew to use under emergency situations. During an emergency situation, such as depressurization, contamination of spacecraft atmosphere, or fire, the PLSS can be used. A total of 7835 pounds of crew provisions and 22 195 pounds of expendables as listed in Sections X and XI will be required.

Figure 2 is a simplified schematic of the overall integrated EC/LSS and shows major interfaces among the assemblies. Figure 3 illustrates the closed-cycle mass balance for the 12-man crew. A summary description of each EC/LSS assembly is presented in subsequent sections of this report.

TABLE 3. 1975 SPACE STATION EC/LSS ASSEMBLIES (24 MEN)

Assembly	Selected Candidate	Manufacturer	Weight[a] (lb)	Volume (ft^3)	Estimated Peak Power (W)	Remarks
Atmosphere Supp/Press.	Gaseous/Cryogenic	Bendix (Sat. I Cryogenic Tanks)	10 112	396	1080	Emerg Press, EVA (Gas) Leakage, Reserves (Cryo)
CO_2 Removal	Steam Desorption	Mine Safety Appliances	901	54 6(S)	3024[b]	Simplicity, Reliable, Low Maint., Steam Purge, Safe
CO_2 Reduct.	Sabatier/CH_4 Dump	Garrett Corp., Los Angeles	170	25 14(S)	0[c]	Very Safe; Avail. Reactor Dev; 28- and 60-Day Prototype
H_2O Electro.	Wick Feed	Allis-Chalmers	887	10.2 6.3 (S)	3690[c]	Safe, Avail., Growth Good Noise Low; Low O_2 Circ. Rate
Contaminant Control	Catalytic Burner Plus Sorbent Beds	Lockheed and AiResearch	713	13 4(S)	422	Cat. Burner Removes CH_4, H_2, and CO
Thermal Control	Cabin Heat Exch. Cond. Heat Exch. Fans; Radiations Fluid Loops	AiResearch, Etc.	3800	?	2500	Typical System
Water Mgt.	H_2O Tankage Sterilizers Showers, Etc.	?	1127	?	522	Typical System
Urine and Wash Loop	Vapor Diffusion/ Compression	Hamilton Standard	257 (2 units)	28 11(S)	2668[c]	Safe, Flight Prototype, Membrance Major Problem
Condensate Loop	Multifiltration	G. D. and Pall Corp.	303	8 8(S)	24	Perspiration and Respiration
Waste Mgt.	Integrated Vac. Decomposition	Gatco	710	127.1 2.9(S)	1400	Safe; No Manned Transfer of Waste, Noise Low
Suit Loop	?	?	310	?	100	
Steam Gener.	?	?	?	?	840	
Contingency (5%)			965	?	813	
Total Weight			20 255	661.3 52.2(S)	17 083	

a. Includes spares
b. Three units operating (24 men)
c. Two units operating (12 men)
(S) indicates spares volume

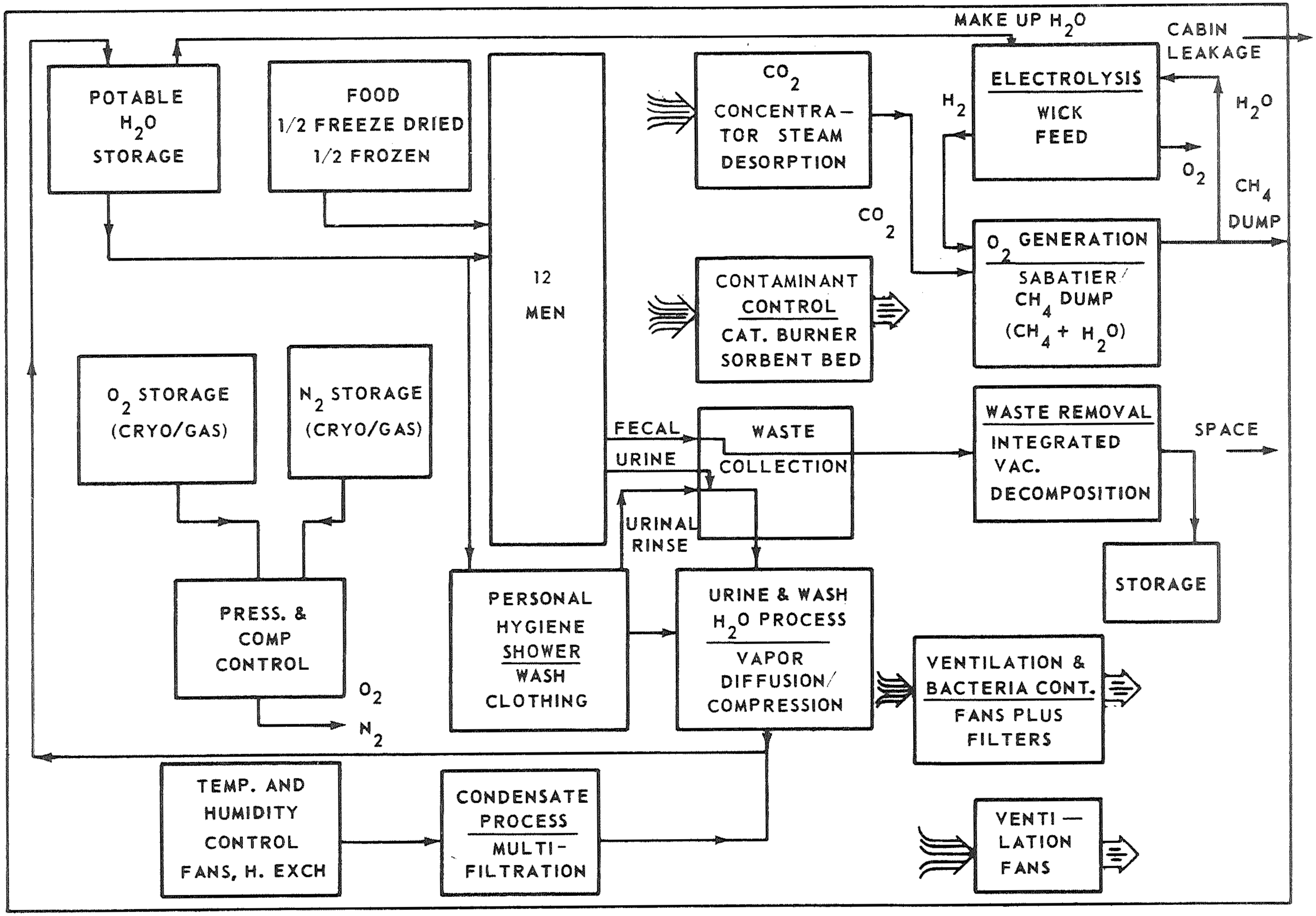


Figure 2. EC/LSS overall schematic.

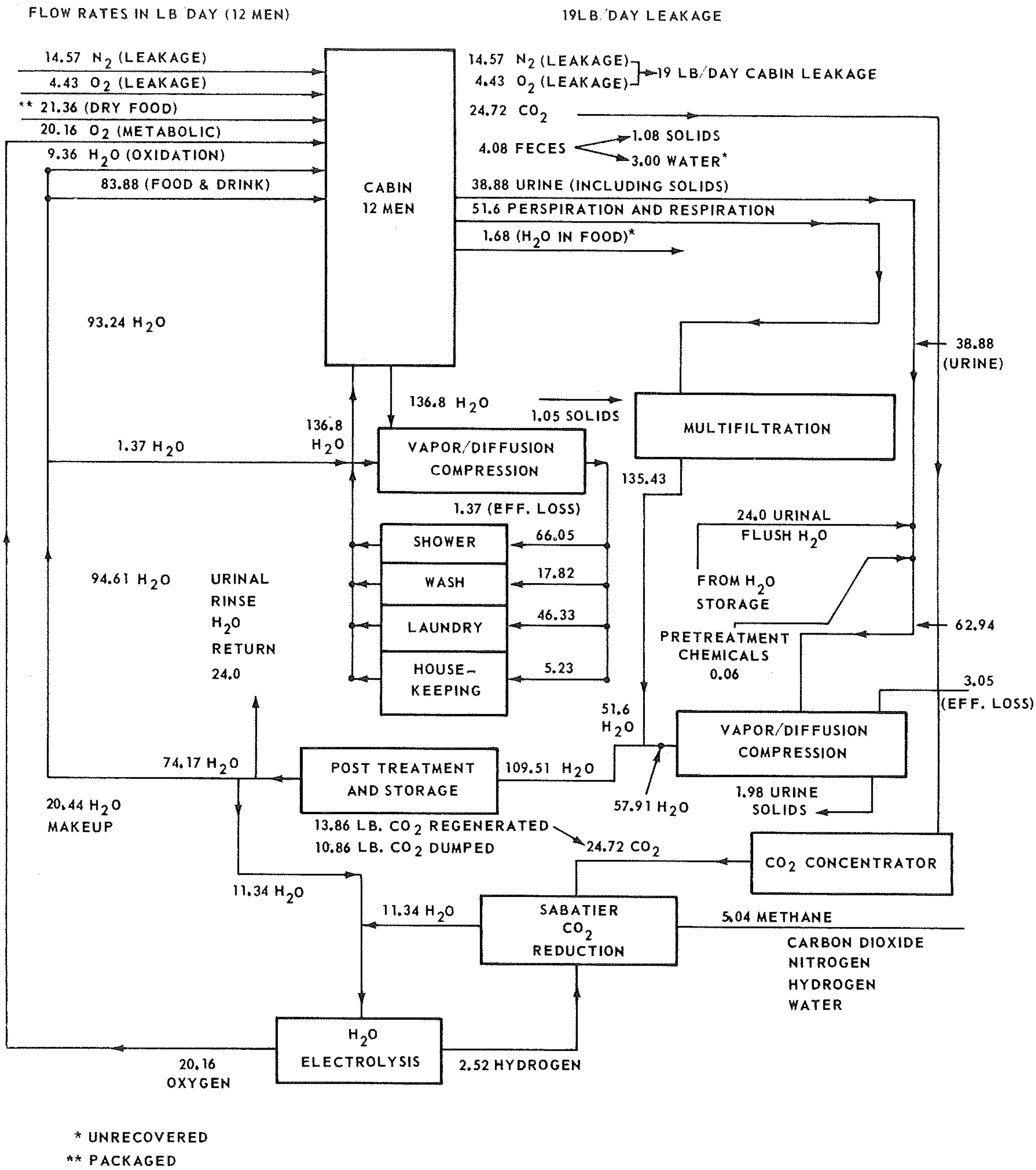


Figure 3. Closed cycle mass balance 12-man crew.

SECTION III. ATMOSPHERIC SUPPLY AND PRESSURIZATION ASSEMBLY

The atmospheric supply and pressurization assembly supplies oxygen to the crew using recovery from man-produced carbon dioxide and water in the oxygen generation assembly. Other functions of the atmospheric supply and pressurization assembly include maintaining carbon dioxide partial pressure at a nontoxic level and suitable partial pressures of oxygen and nitrogen gas in the cabin atmosphere. Control of atmospheric temperature, humidity, and ventilation is maintained by the thermal control assembly rather than the atmospheric supply and pressurization assembly.

An atmospheric mixture of 21-percent oxygen and 79-percent nitrogen (by volume) is maintained at a total pressure of 14.7 psia. Partial pressures are 3.09 psia for oxygen and 11.61 psia for nitrogen. A value of 19 pounds per day was assumed for atmospheric leakage, of which 4.43 pounds per day is oxygen and 14.57 pounds per day is nitrogen. Two types of flow demands are placed on this assembly: (1) A rather high flow rate is required for short periods of time to meet the Space Station compartment and PLSS repressurization requirements, and (2) a relatively low constant flow rate is necessary to meet the metabolic and leakage requirements.

The storage methods considered for atmospheric storage were high-pressure gaseous, supercritical cryogenic, and subcritical cryogenic. Subcritical cryogenic, based on minimum weight and volume requirements, would be a good selection to meet the relative constant flow-rate situation; however, significant development is required to ensure phase orientation under zero-g operation. To satisfy the high gas-flow demand of repressurization, the subcritical storage concept requires an extremely large amount of thermal energy to convert the cryogenic liquid to the gaseous state. If the thermal energy is produced by electrical power, the power demand is extremely high. A high-pressure gas storage, which easily meets the high flow time requirements was selected for repressurization although it means a relatively high tankage weight penalty. Recent advances in cryogenic vessel design make the cryogenic approach preferable to high-pressure gas storage to meet the constant flow requirements.

Oxygen and nitrogen consumables will be stored initially for 90 days above the fifth level of the Space Station in the conical portion attached to the nuclear reactor. An additional 90-day supply will be transported approximately 24 hours later on the initial manned launch. This is to comply with the ground rule that 90 days of expendables must be maintained on board the Space Station in case a resupply mission is delayed. A 10-day metabolic and leakage reserve is included, along with additional supplies for such items as EVA or IVA, maintainability, crew rotation, repressurization, etc.

Oxygen (2274 pounds) and nitrogen (5320 pounds) consumables will possibly be stored supercritically and gaseous. The consumables for the 12-man, 90-day mission would require 3 AAP tanks, 12 Apollo He tanks, and 3 new tanks for gaseous oxygen. Oxygen cannot be stored in Apollo He tanks, because they are fabricated from titanium. The gaseous storage will include one emergency repressurization as well as gaseous oxygen for repressurization of the PLSS units.

A schematic of the high-pressure gaseous concept, which shows an Apollo He tank containing nitrogen, is shown in Figure 4. Supercritical storage, which utilizes the AAP-type tank, is depicted in Figure 5.

The initial 21-percent oxygen and 79-percent nitrogen pressurization gas will be loaded into the Space Station compartments. Thus, there will be no need to contain the initial atmosphere supply in the storage tanks.

The AAP oxygen tank referred to herein is the development tank under study at Bendix. Tests and analysis have indicated potential extension of the tank storage lifetime to the 9- to 12-month range. By varying the number of shields (up to three maximum within existing envelope), adding super insulation externally, or a combination of the two, and adding a refrigeration loop to control the external ambient temperature, a 9- to 12-month duration or greater could potentially be achieved. The proposed AAP tank consists of a 38-inch-diameter inner pressure vessel (Inconel 718) and a 41.5-inch-diameter outer shell (aluminum) with aluminum shield(s) (potentially vapor cooled) installed in the annulus, midway between the inner and outer shell. This tank, which operates under a maximum pressure of 950 psia, has a capacity of containing either 1200 pounds of oxygen, 850 pounds of nitrogen, or 75 pounds of hydrogen. A weight breakdown of this tank, which has been proposed for use on the Dry Workshop, is given in Table 4.

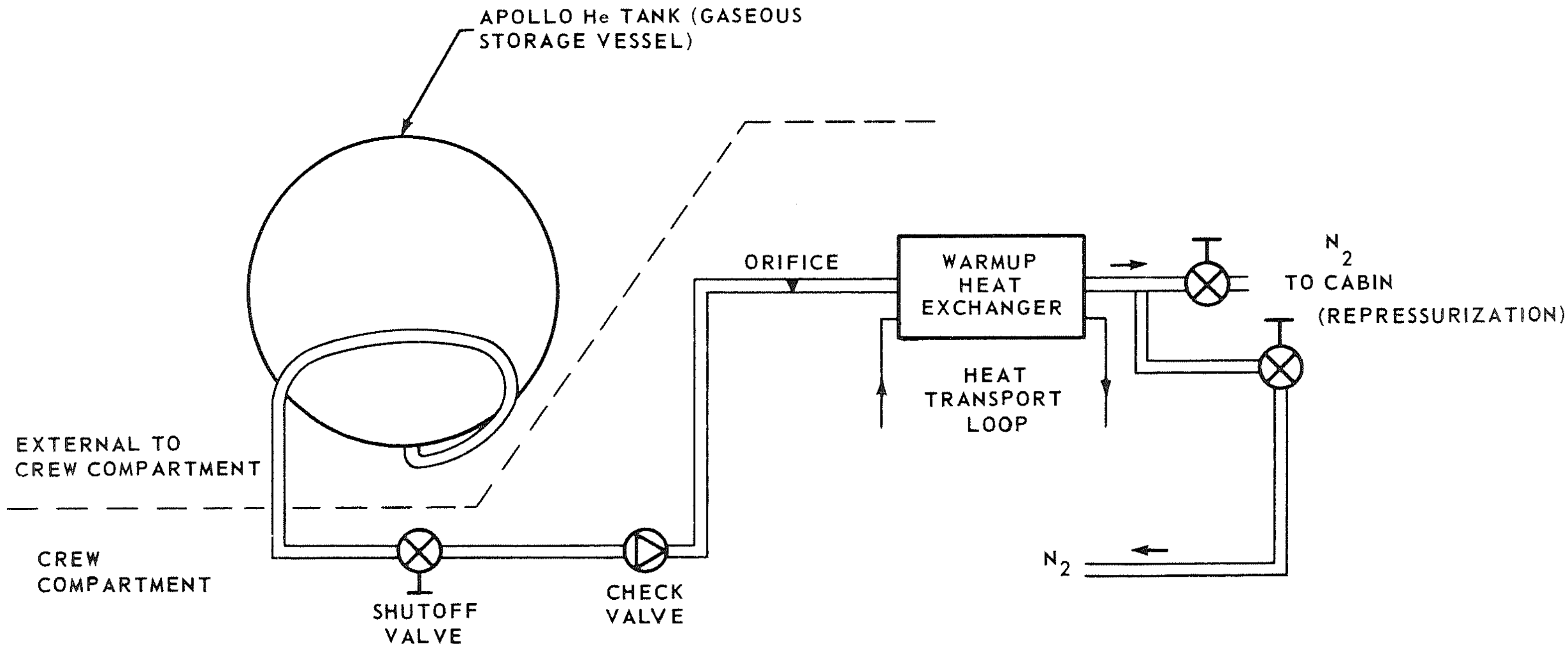


Figure 4. High pressure gaseous storage concept.

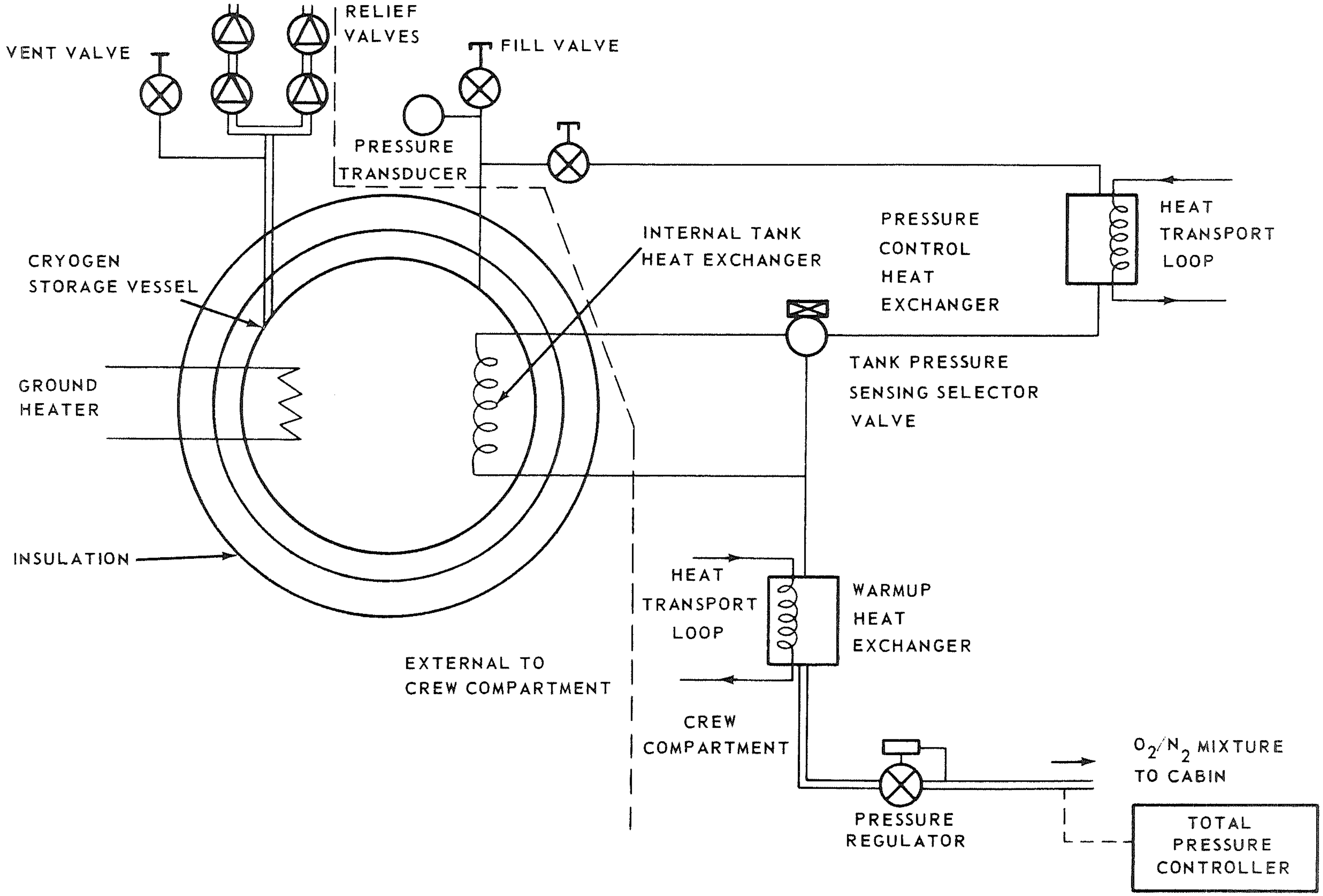


Figure 5. Supercritical storage system (oxygen or nitrogen).

TABLE 4. WEIGHT BREAKDOWN OF BENDIX AAP TANK

Part Description	Quantity	Weight (lb)
Storage Tank Assembly		
Pressure Vessel	1	187.00
Quantity Sensor and Leads	1	2.07
Temperature Sensor and Leads	1	0.08
Heater and Leads	8	1.76
Motor Fan and Leads	2	2.41
Support Tube	2	1.86
Inner Shield	1	14.62
Outer Shield	1	17.34
Vapor Cooling Tube	1	5.03
Fill/Vent Tube	2	0.89
Shield Support	-	0.18
Vessel Support	16	7.69
Outer Shell	1	37.91
Rupture Disc	1	0.24
Ion Pump and Magnet	1	2.89
External Insulation	-	8.25
Total Tank Assembly		290.22
External Components		
Mount Carriage	1	30.00
Electrical Connectors	7	2.74
Quantity Signal Conditioner	1	2.20
Temperature Signal Conditioner	1	0.42
Pressure Transducer and Signal Conditioner	1	0.54
Pressure Switch	2	1.88
Ion Pump Power Supply	1	0.83
Check Valve	1	0.12
Relief Valve L.P.	1	1.06
Relief Valve H.P.	1	1.06
Supply Filter	1	0.45
External Tubing and Fittings	-	2.60
Total System Weight		334.12

The high-pressure Apollo He tank was selected for storage of the gaseous nitrogen. The 41-inch-diameter tank weighs 392 pounds and has an operating pressure of 3300 psi. This tank has a usable capacity of 314 pounds of nitrogen. These tanks should have redundant pressure transducers, which serve as quantity indicators on a gaseous system, and redundant pressure regulators, since here, as in the supercritical storage system, failure of a single regulator would otherwise result in dumping of stored fluid. It has been assumed for this study that the gaseous oxygen tanks will be the same size as the Apollo He tanks. They would be fabricated from Inconel 718 steel and weigh approximately 750 pounds.

A comparison of some potential atmospheric fluid storage methods for the 12-man 90-day mission is compiled in Table 5. The all-gaseous system shows a substantial weight and volume penalty. The all-cryogenic system (spheres or cylinders), even though the weight is favorable, would only satisfy the constant flow requirements; therefore, a hybrid approach (gaseous plus cryogenic) was chosen as the current baseline.

If rapid cabin repressurization is not considered necessary, it would be possible to have an all-cryogenic system, thus saving considerably on both weight and volume. An 0.5-inch-diameter micrometeoroid penetration requires approximately 1 hour to depressurize a 5000-ft^3 compartment to 4.0 psi [1]. Thus, ample time is available for the crew to transfer to another compartment while repairs are being made. If this approach (all-cryogenic system) were taken, a savings of 5700 pounds in weight, 200 ft^3 in volume, and the elimination of the requirement to fabricate new bottles for the gaseous oxygen would result.

There exists the possiblity that certain extreme emergencies will arise within the Space Station; for example, both water electrolysis units for producing oxygen are permanently nonfunctional and the 10-day reserve metabolic oxygen supply is almost depleted. To offset such a situation, an emergency oxygen supply in the form of chlorate candles (Fig. 6) is supplied onboard. These candles are presently used on board submarines, the Lockheed C-5A, and the Douglas DC-10. The chemical solid-state oxygen generator contains a single block of sodium chlorate. When triggered by the activating mechanism on top of the canister, the sodium chlorate undergoes a thermal reaction that releases medically pure breathing oxygen as the end product. Table 6 reflects the weights, size, and number required for the Space Station mission.

A weight breakdown of the atmospheric supply and pressurization constituents, which does not include oxygen recovery equipment, is given in Table 7.

TABLE 5. COMPARISON OF ATMOSPHERE FLUID STORAGE METHODS (12 MEN — 90 DAYS)

Item	High Pressure Gaseous Storage		Hybrid Gaseous and Super-critical Storage		Supercritical Storage			
					AAP Sph. Tank		AAP Cyl. Tank	
	O_2	N_2	O_2	N_2	O_2	N_2	O_2	N_2
Stored Fluid (lb)	2274	5320	2274	5320	2274	5320	2274	5320
Type of Tank	Dry W/S	Apollo He	—[a]	—[b]	AAP	AAP	EOSS[c]	EOSS[c]
No. of Tanks	7	17	4	14	2	7	1	3
Individual Tank Weight (lb)	750	392	—	—	334	334	630	630
Total Tank Weight (lb)	5250	6664	2584	5372	668	2338	630	1890
Individual Tank Size	40.0-in. I.D.	40.9-in. O.D.	—	—	41.5-in. O.D.	41.5-in. O.D.	41.5-in. O.D. by 73-in. long	41.5-in. O.D. by 73-in. long
Approximate Total Tank Volume (ft^3)	145	352	88	291	43	152	46	139

a. Includes 1 AAP O_2 tank; 3 new tanks
b. Includes 2 AAP N_2 tanks; 12 Apollo He tanks
c. Tank characteristics described in DAC 56550, dated November 1967 [3]

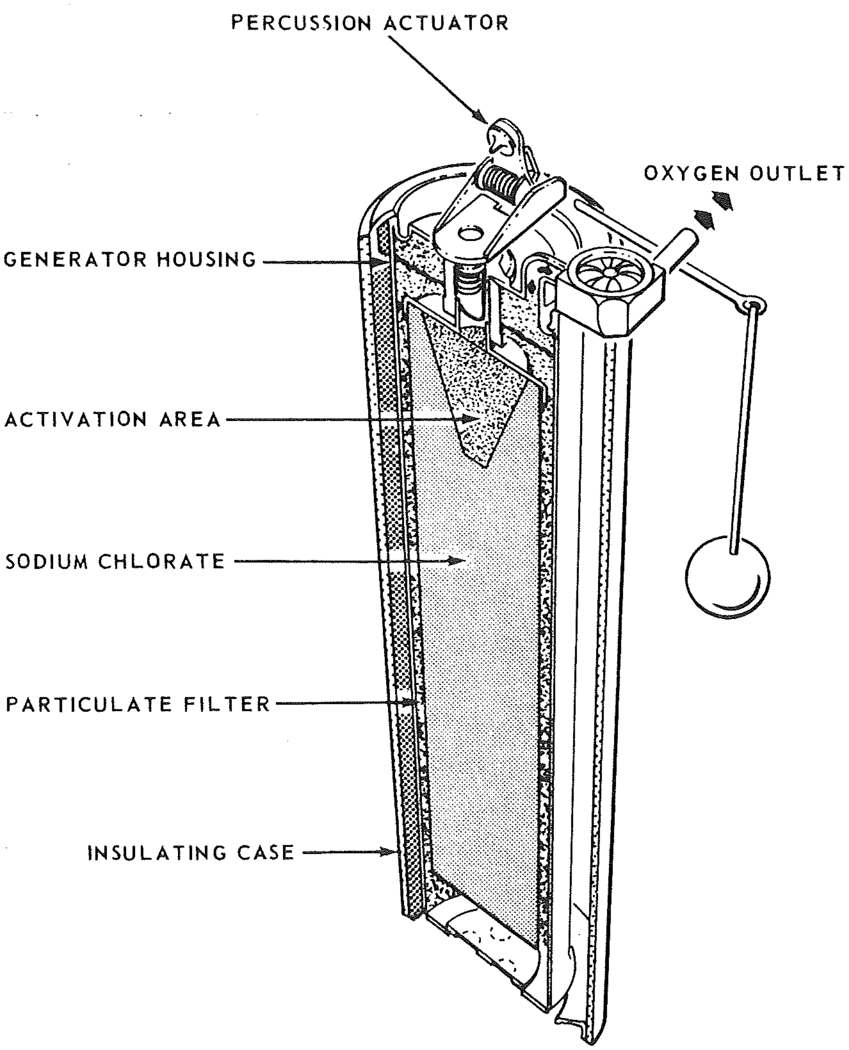


Figure 6. Chlorate candle unit (instant oxygen).

TABLE 6. CHLORATE CANDLES (EMERGENCY OXYGEN SUPPLY)[a]

Component	No. Required	Weight (lb)	Estimated Volume or Size
Chlorate Candles	12	312	6.25-inch diameter by 11 3/8-inch length
Chlorate Cylinders (0.137 #/# O_2)	12	200	
Fixed Weight		10	
Total		522	
Spares			
Chlorate Candles	12	312	

a. Burning time = 50 + 5 minutes for 121.8 ft^3 of O_2/candle

TABLE 7. ATMOSPHERIC SUPPLY AND PRESSURIZATION DETAILED DRY WEIGHT (12-MAN STATION)

Component	No. Required	Weight (lb)	Estimated Volume (ft^3)	Power (W)
O_2 Tankage (AAP Tanks)	1	334	22	360
N_2 Tankage (AAP Tanks)	2	668	44	720
O_2 Tankage (New Tanks)	3	2250	66	
N_2 Tankage (Apollo He Tanks)	12	4704	269	
Plumbing (25 lb/Tank)		450		
Pump-down System (15 min on any Pressurized Element)		91		
Pump (Fwd)	1	18		
Pump (Aft)	1	56		
Three-way Valve	7	7		
Low-pressure Piping	?	10		
EVA/IVA Gas Distribution System	1	93.0		
O_2 Heat Exchanger	1	5.0		
N_2 Heat Exchanger	1	5.0		
Controller, Total Pressure	1	2.7		
Valve, Cabin Dump and Relief	2	9.0		
Valve, Fill (gas)	20	15.0		
Valve, Check (gas)	20	15.0		
Valve, Shutoff (gas)	20	15.0		
Regulator, Pressure O_2/N_2	2	5.0		
Valve, Solenoid Shutoff	2	1.0		
Umbilicals, EVA and IVA (12, 60 ft)		240		
Pressure Control Heat Exchanger (cryo)	1	11.0		
Delivery Selector Valve (cryo)	2	4.6		
Pressure Transducer (cryo)	3	2.7		
Valve, Shutoff (cryo)	3	1.0		
Chlorate Candles and Canisters	12	522.0		
Contingency (3%)		307.0		
Total		9751		
Spares:				
Pressure Regulator (cryo)	2	5.0		
Pressure Regulator (gas)	2	5.0		
Pressure Control Heat Exchanger (cryo)	1	11.0		
Pressure Transducer	3	2.7		
Delivery Selector Valve	2	4.8		
Warmup Heat Exchangers	4	20.0		
Chlorate Candles	12	312.0		
		360.5		1080

SECTION IV. OXYGEN RECOVERY ASSEMBLY

Large quantities of oxygen will be required for the Space Station mission for crew metabolic requirements, leakage, and repressurization. Oxygen for leakage and repressurization is lost to space and must be included in the launch weight of the Space Station. However, the metabolic oxygen can be recycled for use. In general, the requirements are to generate 20.16 pounds of oxygen per day and to remove and process 24.74 pounds of carbon dioxide per day for the 12-man crew.

There are a number of possible means by which oxygen can be recovered from carbon dioxide and these are discussed in detail below. All of these systems will impose a weight penalty on the Space Station because of assembly hardware, additional electrical power system generating capacity, and increased cooling system capacity. Oxygen recovery systems of interest are in various stages of development and will require considerable time, effort, and cost to develop a flight hardware assembly.

For CO_2 reduction, the four leading candidate concepts are the Sabatier (methane dump or methane cracking), the Bosch, the Solid Electrolyte, and the Fused Salt. All but the Fused Salt require a separate CO_2 removal assembly; in addition, the Sabatier, Bosch, and Fused Salt assemblies require a separate unit for electrolyzing water. These systems are depicted in Figure 7.

The Sabatier-Methane Dump assembly (selected candidate) uses a single reduction reactor operating at about 600° F; it is a hydrogenation process. The system operates in conjunction with the CO_2 concentration and water electrolysis assemblies. During normal operations, carbon dioxide (from the concentrator) and hydrogen (from electrolysis and/or storage) are combined and fed to the hydrogenater (Sabatier) reactor. The carbon dioxide is then hydrogenerated to form water and methane by the following reaction:

$$CO_2 + 4H_2 \rightleftarrows CH_4 + 2H_2O \quad .$$

The water is electrolyzed to form oxygen and a portion of the hydrogen needed to sustain the basic reaction. Since the methane is dumped overboard, its hydrogen is lost, and make-up hydrogen from stored water must supplement the hydrogen recovered by electrolysis.

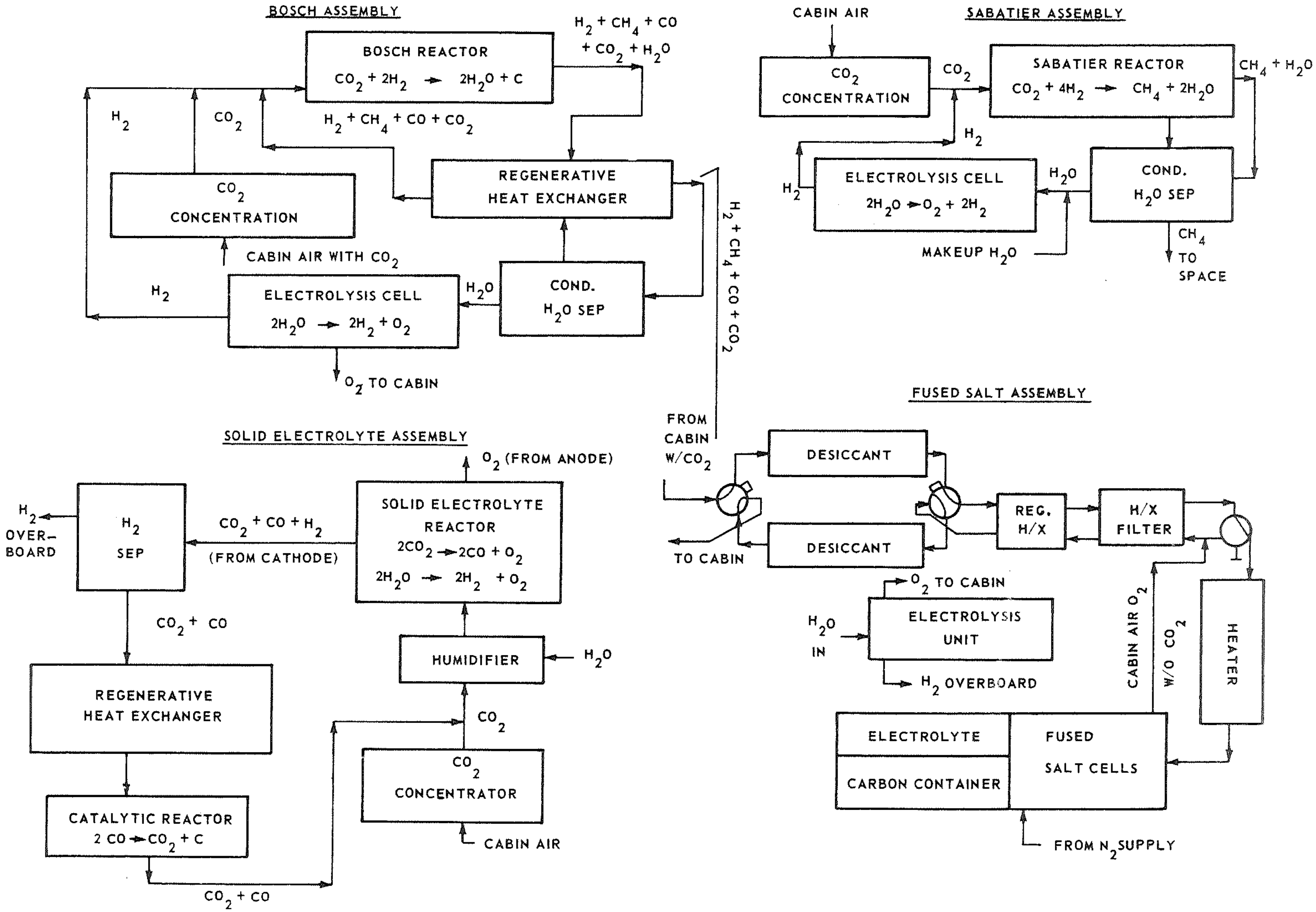


Figure 7. Candidate oxygen recovery assemblies.

The Sabatier-methane cracking process is similar to the Sabatier process described above except that a methane reactor is employed to recover the hydrogen. This reactor has to operate at 1800° F, which means that it is considerably more complex than the basic Sabatier reactor. Other methods include converting the methane to acetylene, or benzene and hydrogen. During normal operations, the methane is decomposed to carbon and hydrogen by the following reaction:

$$CH_4 \rightleftarrows C + 2H_2$$

The Sabatier assembly is the farthest advanced in development status among the oxygen recovery systems. Prototype development is advanced enough to allow immediate start of the flight hardware phase. A prototype unit successfully completed a 60-day manned test as an integrated element of a life-support sytem, and another unit completed a similar 28-day test. It has a comparatively low-reaction temperature (600° F) that minimizes the materials problems. Its principal disadvantage is need for makeup hydrogen. The hydrogen deficiency is made up by recovering, storing, and electrolyzing just enough additional water to produce the required metabolic oxygen. There is insufficient hydrogen to reduce all the carbon dioxide, so the unused carbon dioxide is vented overboard. Figure 8 illustrates the flow diagram of the reclaimed metabolic oxygen. Figure 9 is identical to Figure 8 except that additional water is stored, recovered, and electrolyzed to produce oxygen for leakage makeup. The resulting hydrogen is therefore available to reduce additional carbon dioxide. This would eliminate all oxygen normally carried onboard for leakage makeup (4.43 pounds per day O_2).

Another approach for recovering oxygen would be recovery from electrolysis only, thus eliminating the Sabatier reactor and accessories. This would require the storage of 2041 pounds of H_2O for metabolic O_2 only every 90 days, and dumping of the hydrogen and carbon dioxide overboard.

The Bosch assembly is similar to the Sabatier assembly except that the by-product of the basic reaction is carbon, so the replenishment of hydrogen is not required. As the gas circulates, carbon dioxide (from the concentrator) and hydrogen (from electrolysis) are added and water and carbon are formed in the reactor on a steel-wool catalyst. Carbon is removed from the assembly by periodic replacement of the carbon-loaded catalyst cartridge. The most serious problems are removing carbon from

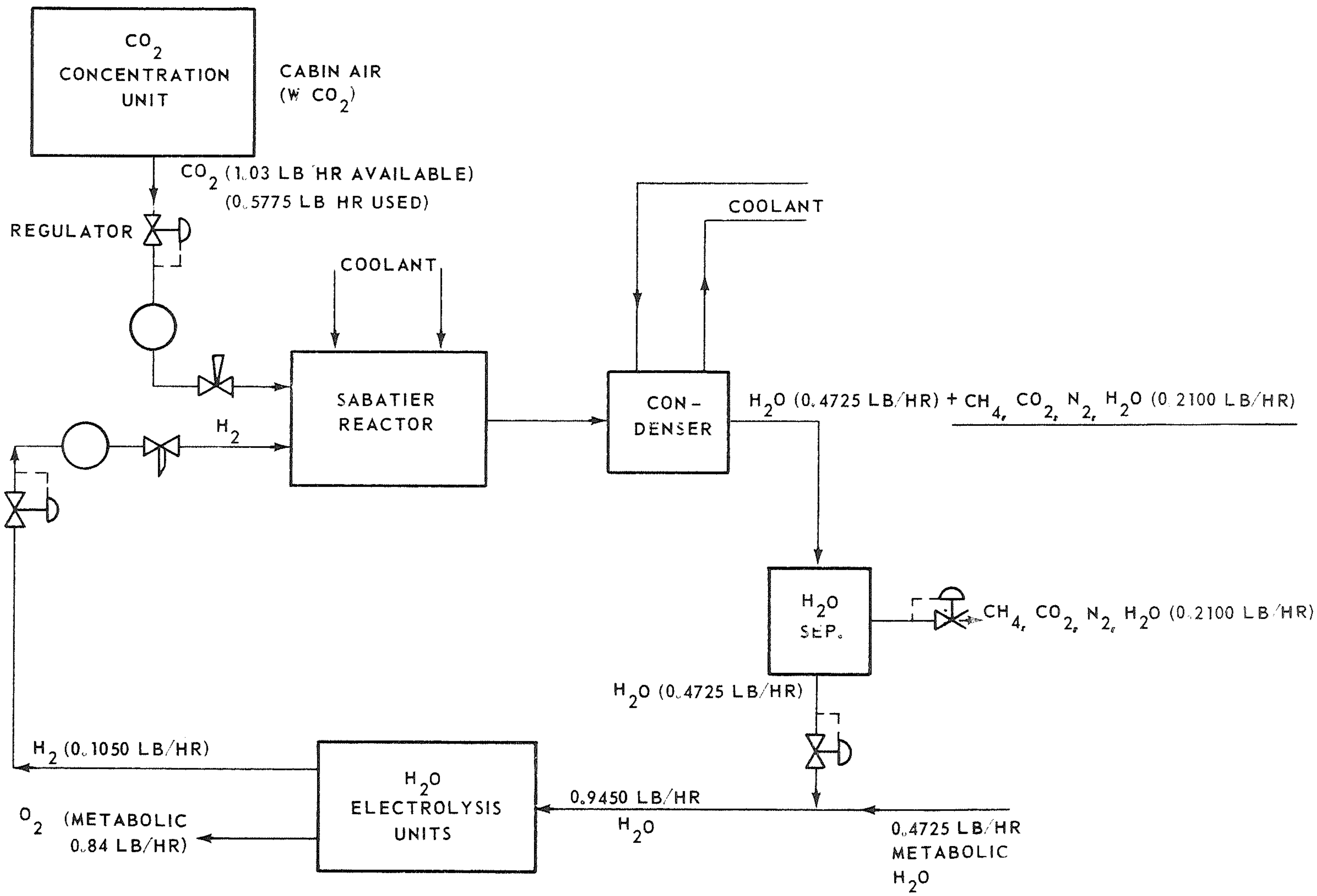


Figure 8. Sabatier reduction system flow schematic (metabolic O_2 recovery).

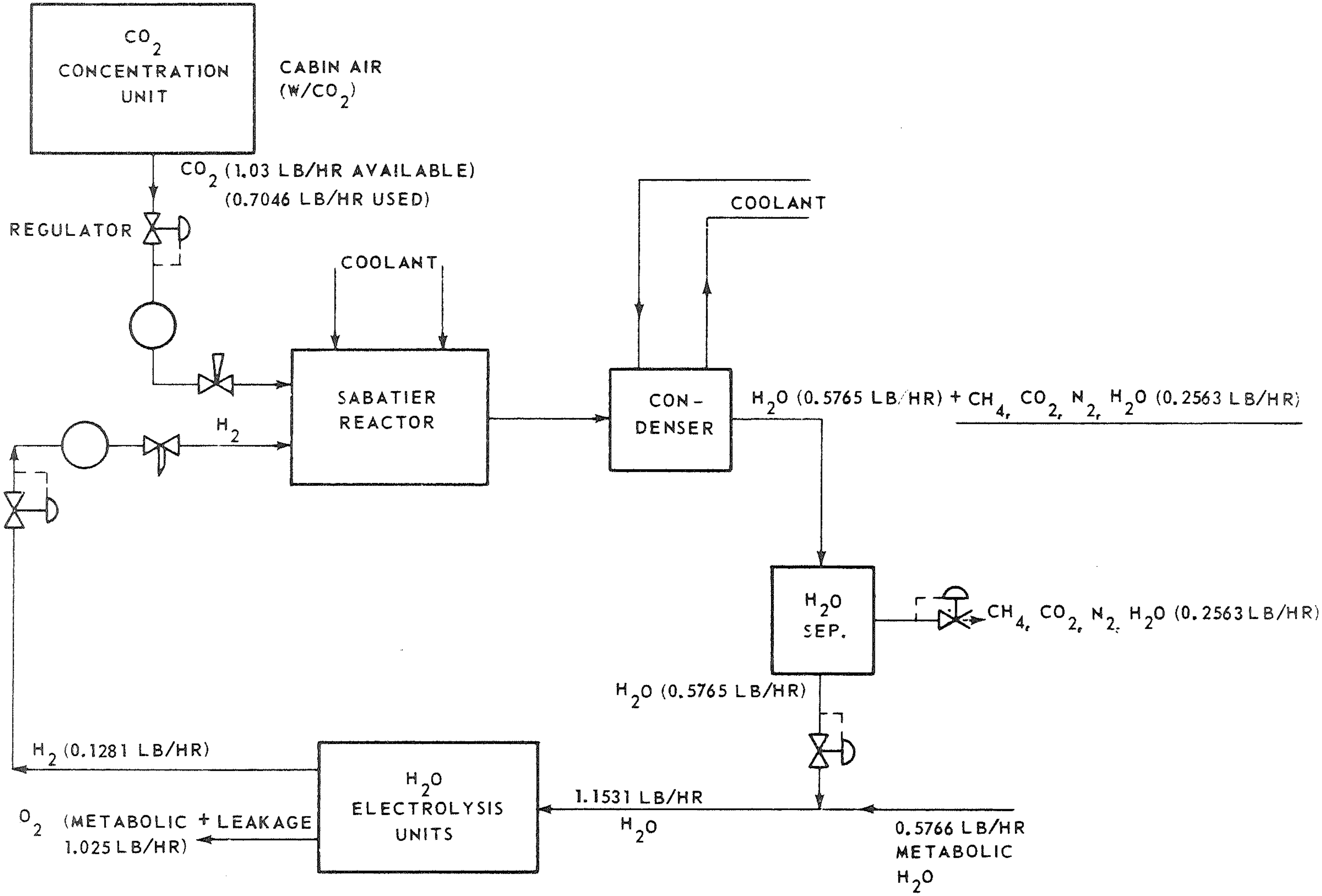


Figure 9. Sabatier reduction system flow schematic (metabolic plus leakage O_2 recovery).

the reactor cartridge and carbon formation outside the cartridge. Confidence that carbon problems can be solved is good. The Bosch assembly is now in the prototype phase of development and can possibly be developed for flight as early as 1977.

The solid electrolyte assembly recovers oxygen from carbon dioxide and water vapor in a single step at 1800° F but it requires a second reaction step at 1000° F for carbon deposition. Oxygen is formed at 1800° F within the reactor, which consists of stacks of ceramic cylinders or discs surrounded by an insulated outer casing by the following simultaneous reactions:

$$2CO_2 \rightleftarrows 2CO + O_2 \qquad \text{and} \qquad 2H_2O \rightleftarrows 2H_2 + O_2$$

These reactions are actually assisted by the electrochemical transfer of oxygen ions from the cathode through the electrolyte to the anode where oxygen is formed. The reactor outflow contains carbon monoxide and some hydrogen, but it must also contain a small percentage of carbon dioxide because the solid electrolyte material would decompose if all the carbon dioxide were reacted. This outflow is cooled to 1000° F and passed through a hydrogen separator. The hydrogen is dumped overboard and the remainder of the gas stream is reacted in the disproportionation reactor where carbon is deposited by the following reaction:

$$2CO \rightarrow C + CO_2$$

Development of the solid electrolyte system is well into the research stage; however, a fully qualified flight assembly could not be finished until 1979. The principal advantage of the solid electrolyte assembly is that it does not involve electrolysis of water, and there are no liquid gas phase separation problems. The high operating temperature (1800° F) of the basic reactor may lead to severe materials problems.

The Fused Salt assembly operates at 1200° F and does not require a CO_2 concentrator, but needs a small electrolysis unit. Cabin air is processed directly through the assembly and is then returned to the cabin atmosphere. As it passes through the assembly, carbon dioxide is removed and oxygen is added to the cabin atmosphere in a single step. Good performance is anticipated; however, a lightweight assembly will probably be unavailable until 1980.

Water Electrolysis

Water electrolysis is required in most of the O_2 reclamation systems. The water electrolysis unit dissociates water into breathing oxygen, which is fed to the cabin, and hydrogen, which is fed to the Sabatier reduction unit. Water electrolysis cells suitable for zero-g operations have been developed and tested by General Electric, Allis Chalmers, TRW, AiResearch, and others. Fuel cell technology has been used extensively in the design of these electrolysis cells, which can be considered within the state-of-the-art.

The electrolysis unit selected for operation with the Sabatier reactor is based on studies conducted by the Research Division of Allis Chalmers. Two water electrolysis assemblies with built-in redundancy are employed to generate a constant flow of oxygen for a crew of 12 men. Each assembly consists of three identical modules, each with enough capacity for 4.5 men. Two modules of each assembly would operate at a slightly reduced rate during 12-man occupancy. The third module in each assembly is an operational spare. Each module contains three operating cell stacks of 1.5-man capacity, a current controller, a condenser, back-pressure regulators for each of the two-gas exit lines, a water supply regulator, and instrumentation. These modules are designed to operate only in the daylight portion of low earth orbit.

This electrolysis assembly is a wick-fed concept and, with an unusually strong effort, can be developed for a flight as early as 1974. Development is well into the prototype phase. A 4-man unit has completed a 360-hour test as part of the NASA Langley Research Center ILSS.

Figure 10 is an overall schematic of the electrolysis unit and Table 8 gives a detailed weight breakdown, including spares, of the Sabatier and electrolysis units.

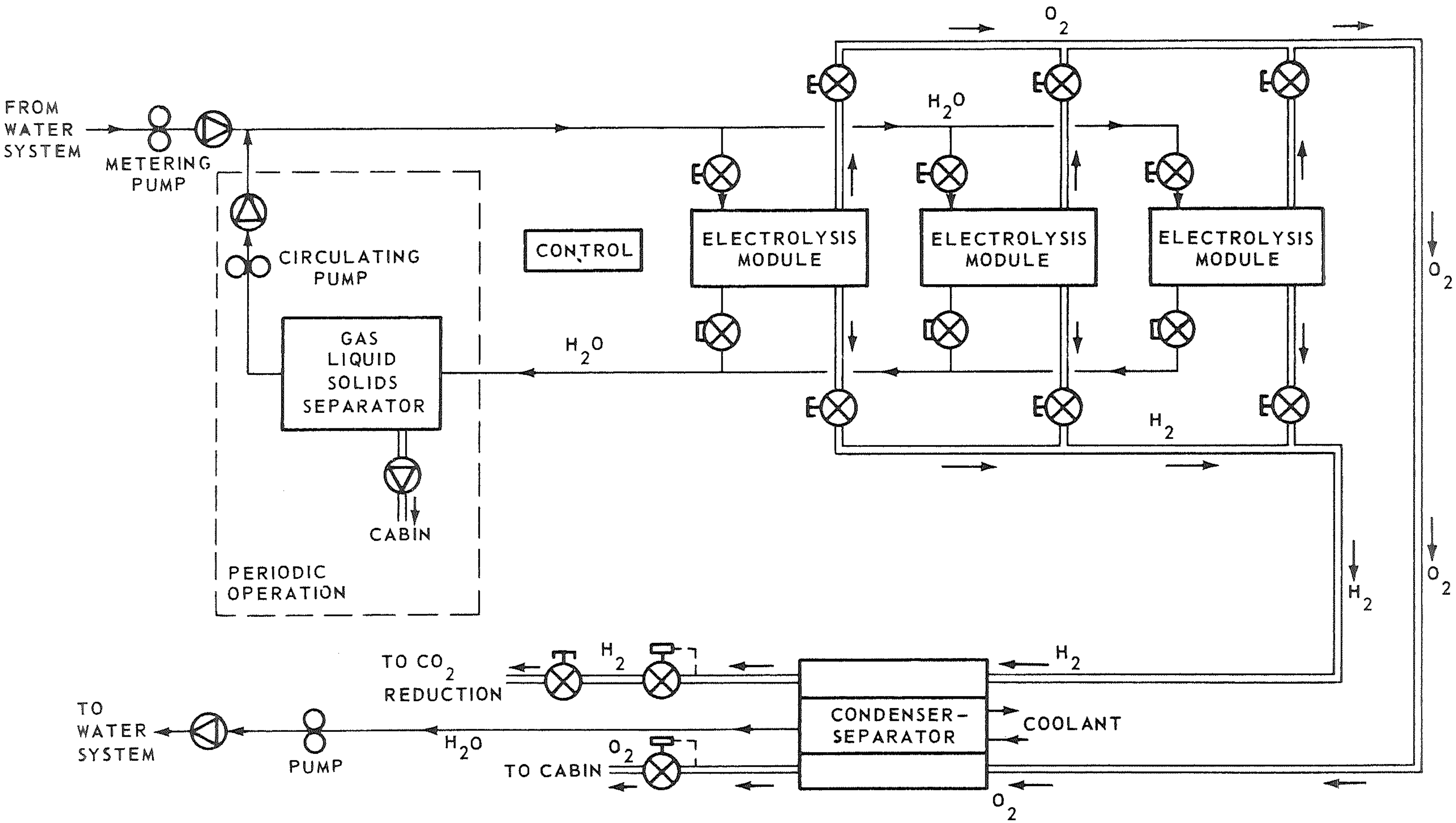


Figure 10. Water electrolysis (wick fed) concept.

TABLE 8. OXYGEN RECLAMATION ASSEMBLY DETAILED WEIGHT BREAKDOWN

Component	Number Required	Weight (lb)	Power (W)
Sabatier/Methane Dump			
Sabatier Reactor	3	15.0	
Pressure Transducer	3	1.5	
CO_2 Orifice	1	0.05	
Pressure Ratio Regulator	1	1.25	
H_2 Orifice	1	0.05	
Flow Transducer	2	2.0	
CH_4 Orifice	1	0.05	
Shutoff Valve	6	1.8	
Cycle Accumulator	6	18.0	
O_2 Warning Sensor	1	0.1	
Signal Conditioner	1	0.5	
Temperature Transducer	2	0.4	
Signal Conditioner	2	0.6	
Solenoid Valve	2	0.5	
Timer, Electrical	1	0.2	
Condenser/Water Separator	3	18.0	
Temperature Control Valve	1	1.0	
Temperature Controller	1	1.0	
Installation Provisions		33.0	
		95.0	?
Electrolysis Unit (Six 3-Man Modules)			
Cell Stack	18	432.0	
Condenser	6	72.0	
Current Regulator	18	90.0	
Cold Plate	6	24.0	
Back Pressure Regulator	12	12.0	
Instrumentation		60.0	
Plumbing and Wiring		54.0	
Mounting		18.0	
Insulation		18.0	
Electrolysis unit volume = 15.3 ft^3		780.0	3690[a]

a. Two assemblies operating (12 men)

TABLE 8. (Concluded)

Component	Number Required	Weight (lb)	Power (W)
Spares (Sabatier Reactor)			
Sabatier Reactor	2	10.0	
Pressure Transducer	5	2.5	
Pressure Ratio Regulator	3	3.7	
Shutoff Valve	2	0.6	
Cycle Accumulator	5	15.0	
O_2 Warning Sensor	1	0.1	
Solenoid Valve	2	1.0	
Timer, Electrical	2	0.4	
Condenser/Water Separator	6	36.0	
Temperature Control Valve	3	3.0	
Temperature Controller	3	2.7	
		75.0	
Spares (Electrolysis Unit) (6.3 ft^3)			
Cell Stack (One 3-Man Module)	3	72.0	
Condenser	1	12.0	
Current Regulator	3	15.0	
Cold Plate	1	4.0	
Back Pressure Regulator	2	2.0	
Instrumentation		2.0	
		107.0	
TOTAL (OVERALL)		1057.0	

SECTION V. ATMOSPHERIC PURIFICATION ASSEMBLY

The main purpose of the atmospheric purification assembly is to maintain the carbon dioxide, trace contaminants, and bacterial count within acceptable limits. To assure continuous, long-duration control of these items, redundancy will have to be provided through interconnected dual components, maintainability, repair, replacement, safety equipment, and spares.

Carbon dioxide (CO_2) concentration in the cabin atmosphere must be controlled to an acceptable level. When all 12 men are in the same compartment, CO_2 partial pressure (nominal maximum) must not exceed 7.6 mm Hg; when the crew is fairly evenly distributed throughout the space station, CO_2 partial pressure 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.

Nine candidate concepts for CO_2 removal are listed in Table 1. All concepts can remove and concentrate CO_2 at an adequate rate. Concepts with acceptable, but limited, purity are molecular sieve, solid amine, steam desorbed resin, liquid absorption, and mechanical freezeout. Purity of the membrane diffusion, carbonation cell, electrodialysis, and H_2 depolarized cell concepts are potentially unlimited; however, some inherent problems exist that prevent their acceptance. The electrodialysis, carbonation cell, and mechanical freezeout concepts are very heavy in weight. Membrane diffusion is limited for use because of fire hazard and toxicity problems. The presence of hydrogen and oxygen in the electrodialysis and hydrogen-depolarized cell concepts presents a potential fire or explosion hazard. Liquid absorption has more definite problems with potential for carryover or leakage of corrosive liquid, which makes maintenance dangerous. The solid amine concept requires more development, and the nature of the sorbent (a mixture of chemicals deposited on a solid carrier) raises doubt about bed life. The only candidates remaining for Space Station selection are the steam desorption and molecular sieve concepts.

The steam desorption concept is selected for the Space Station because of its all around superiority. It is relatively safe except for the possibility of some amine carryover, which is considered unlikely. Materials are not flammable, and gas leakage cannot result in a toxic or explosive condition. Periodic processing of steam, which is safe at ambient pressure, should help prevent bacteria growth in the condenser-separators. The molecular sieve concept is relatively well developed, but its potential for further technological growth is limited; however, it can serve as a backup candidate in case development problems occur on the steam desorption concept.

The steam desorption concept is now in the early prototype phase and can be developed for flight as early as 1975 or 1976. The pacing item may be the zero-g steam generator or a compressor that handles CO_2 efficiently. The molecular sieve has the most successful operating history of all the candidates.

The steam desorption concept is described quantitatively and schematically in Figure 11. In normal operation, both ion exchange resin 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 until a 40- to 50-percent CO_2 concentration is attained. When one bed reaches this condition, it begins the desorption phase (while the other bed continues absorption) with air bypassing this bed. During desorption, steam at ambient pressure is generated directly into the desorbing bed.

A schematic of the molecular sieve concept is shown in Figure 12. 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 sieve) is used. Two canisters function alternately in absorbing 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 absorb the moisture from the process steam before it enters the CO_2 removal beds.

A detailed weight breakdown of the atmospheric purification and control assembly is given in Table 9.

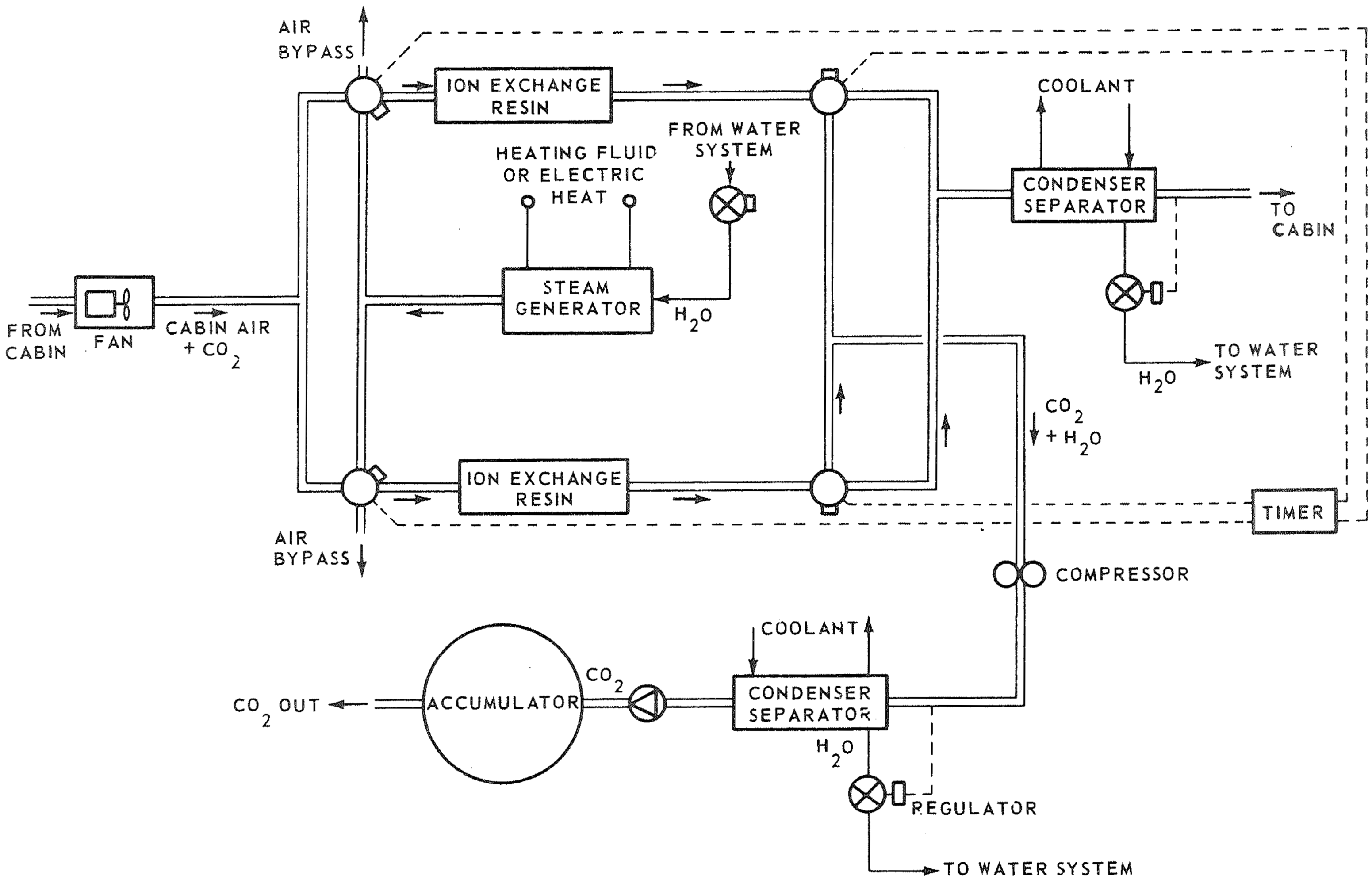


Figure 11. Steam desorbed resin CO_2 concentrator concept.

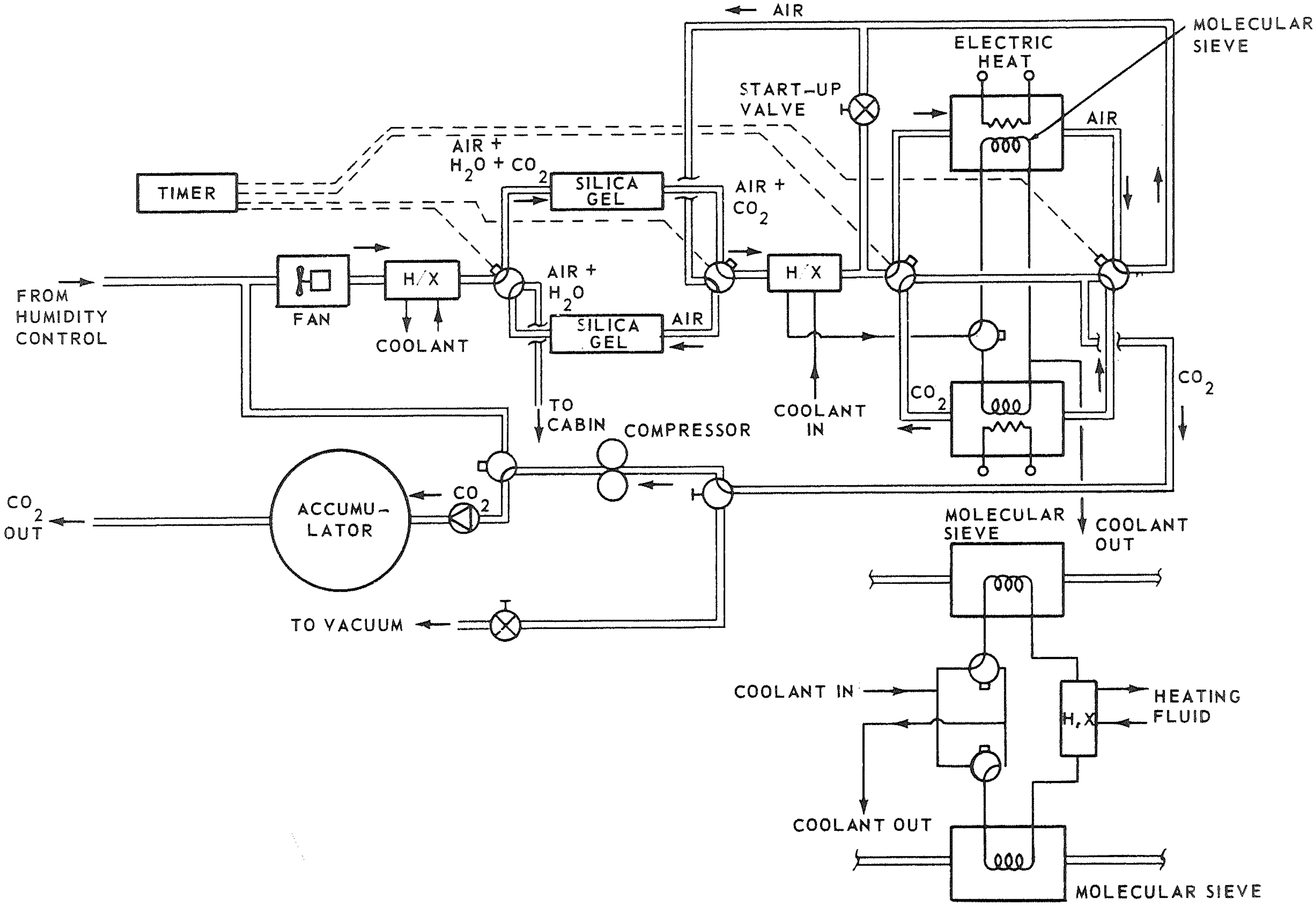


Figure 12. Molecular sieve CO_2 concentrator concept.

TABLE 9. ATMOSPHERIC PURIFICATION AND CONTROL ASSEMBLY DETAILED WEIGHT BREAKDOWN

Component	Number Required	Weight (lb)	Power (W)
CO_2 CONCENTRATOR ASSEMBLY			
Fan	3	7.5	
Ion Exchange Resin Bed (enlarged)	6	420.0	
Steam Generator	3	25.5	
Condenser/Separator	2	12.0	
Condenser/Separator CO_2	2	19.0	
Compressor	2	20.2	
Accumulator (11 ft^3)	2	10.0	
Water Injector	2	7.2	
Water Regulator	4	6.0	
Diverter Valve, Solenoid	4	9.6	
Timer	2	13.0	
Solenoid Valve, Shutoff	4	9.6	
Check Valve	2	1.4	
Control Panel		4.0	
Instrumentation		15.0	
Ducting and Wiring		20.0	
Insulation		30.0	
Structural Support		40.0	
Total		670.0	3024[a]
CO_2 Assembly Volume = 54 ft^3 (estimated)			
CONTAMINANT CONTROL			
Trace Gas Assembly			
Fan	2	15.0	
Heater Control	3	9.0	
Sorbent Canister	2	75.0	
Presorb Canister	4	48.0	
Catalytic Burner	4	48.0	
Post-sorb Canister	4	48.0	
Valve, Solenoid Shutoff	13	23.4	

a. Three assemblies operating

TABLE 9. (continued)

Component	Number Required	Weight (lb)	Power (W)
CONTAMINANT CONTROL (Concluded)			
Trace Gas Assembly (Concluded)			
Valve, Manual Shutoff	30	24.0	
Valve, Manual 3-Way	4	9.6	
H/X, Regenerative	2	5.0	
Total		305.0	422[a]
Trace Gas Assembly Volume = 13 ft^3 (estimated)			
Bacteria Contaminant Assembly			
Bacteria Filter (Estimated life of 50 days)	6	30.0	
Storage bags and processing	6	5.0	
Total		35.0	
Particulate Contamination Assembly			
Roughing Filter	18	45.0	
Debris Trap	18	58.5	
Total		103.5	
SPARES			
CO_2 Concentrator (6 ft^3)			
Ion Exchange Resin Bed	1	70.0	
Fans	2	5.0	
Diverter Valve, Solenoid	4	4.4	
Steam Generator	1	8.5	
Condenser/Separator	10	95.0	
Timers	3	19.5	
Solenoid Valve, Shutoff	2	4.8	

a. Three assemblies operating

TABLE 9. (Concluded)

Component	Number Required	Weight (lb)	Power (W)
SPARES (Concluded)			
CO_2 Concentrator (6 ft^3) (Concluded)			
Compressor	2	20.2	
Water Regulator	2	3.0	
Check Valve	1	0.6	
Total		231.0	
Trace Gas Assembly (4 ft^3)			
Fan	2	15.0	
Sorbent Canister	1	38.0	
Catalytic Burner	1	12.0	
Presorb Canister	1	12.0	
Post-sorb Canister	1	12.0	
Heater Control	1	3.0	
Total		92.0	
Bacteria Control Assembly			
Bacteria Filter	12	60.0	
Storage bags and processing	12	9.0	
Total		69.0	
Particulate Control Assembly			
Roughing Filter	12	30.0	
Debris Trap	12	78.0	
Total		108.0	

SECTION VI. THERMAL CONTROL ASSEMBLY

The primary function of the thermal control system is to maintain a shirtsleeve environment at a temperature of 70 ± 5° F and a relative humidity of 40 ± 10 percent. An active double-loop thermal control system was selected for analysis, with FC-75 fluid in the radiator loop and water in the cabin loop. The cabin loop absorbs heat from the components inside the Space Station and transfers this heat to the radiator loop by means of an intermediate (liquid/liquid) heat exchanger. This heat is then radiated to space through the Space Station radiator. The double-loop thermal control system has been designed to reject 40 kilowatts of thermal energy (136 520 Btu/hr).

A. Cabin Loop

The cabin-loop schematic is shown in Figure 13. Two gas/liquid heat exchangers are used, only one of which condenses the moisture from the cabin air, and the other is a noncondensing heat exchanger. Through the use of two gas/liquid heat exchangers, it seems possible to achieve a higher inlet temperature of the water to the liquid/liquid heat exchanger and, thus, a higher radiator-inlet temperature than if only one gas/liquid heat exchanger were used (with only one gas/liquid heat exchanger, a larger percentage of the cabin air would have to be brought to a temperature sufficiently low to condense the moisture). This seems possible theoretically; however, in actual practice it may be difficult to construct a gas/liquid heat exchanger capable of condensing enough moisture with a minimum cooling of the cabin air. Such a heat exchanger would have to incorporate a low air-bypass factor as well as a high water-condensing efficiency.

The gas/liquid heat exchanger consists of a number of tubes through which coolant water flows (Fig. 14). A fan moves the cabin atmosphere across these tubes. The cabin air passes through the noncondensing heat exchanger first and then a portion of this air passes into the condensing heat exchanger. This allows the air entering the condensing heat exchanger to be at a lower temperature than if warm air were routed through both exchangers. Thus, theoretically, the condensing heat exchanger will operate more efficiently.

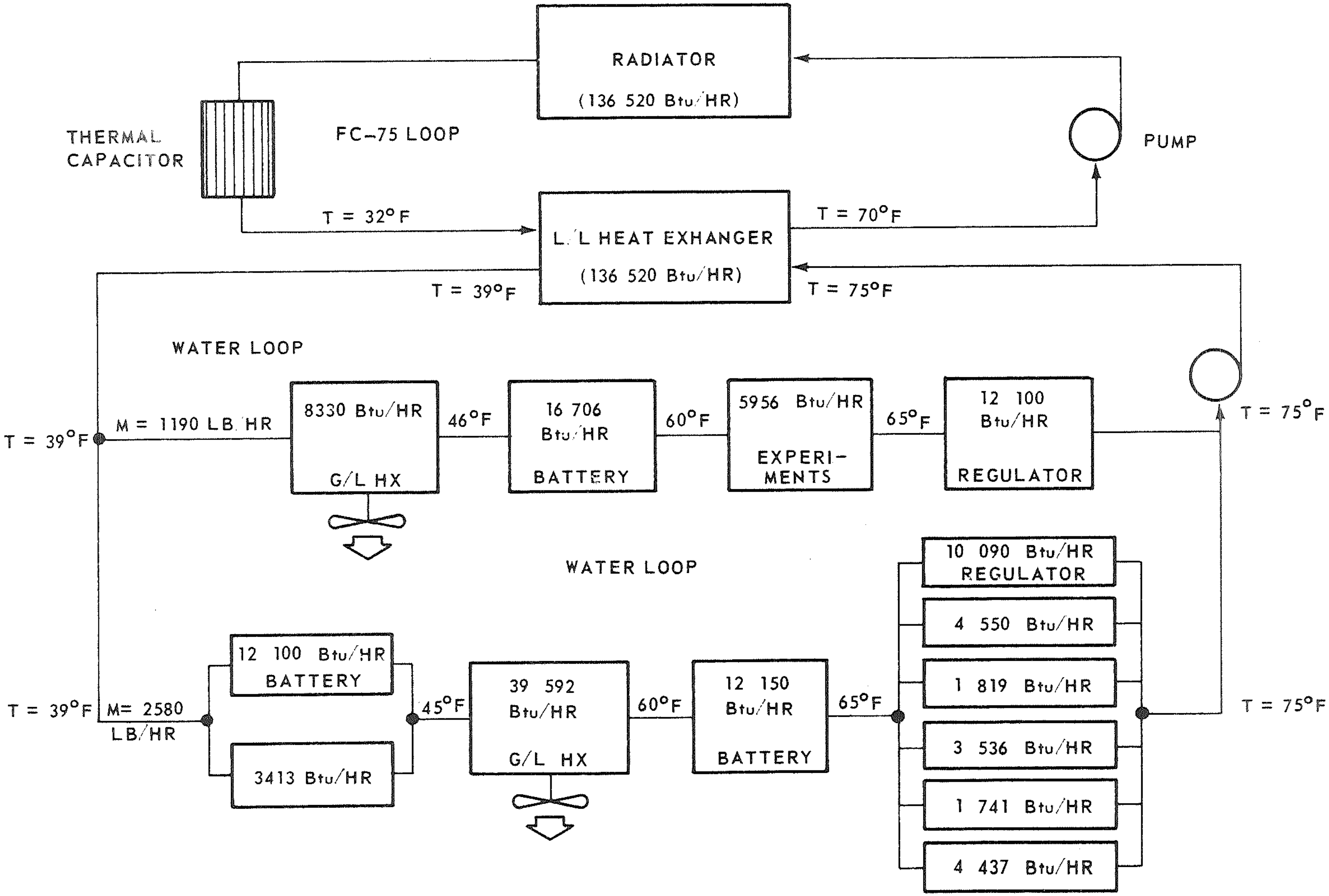


Figure 13. Thermal control system schematic.

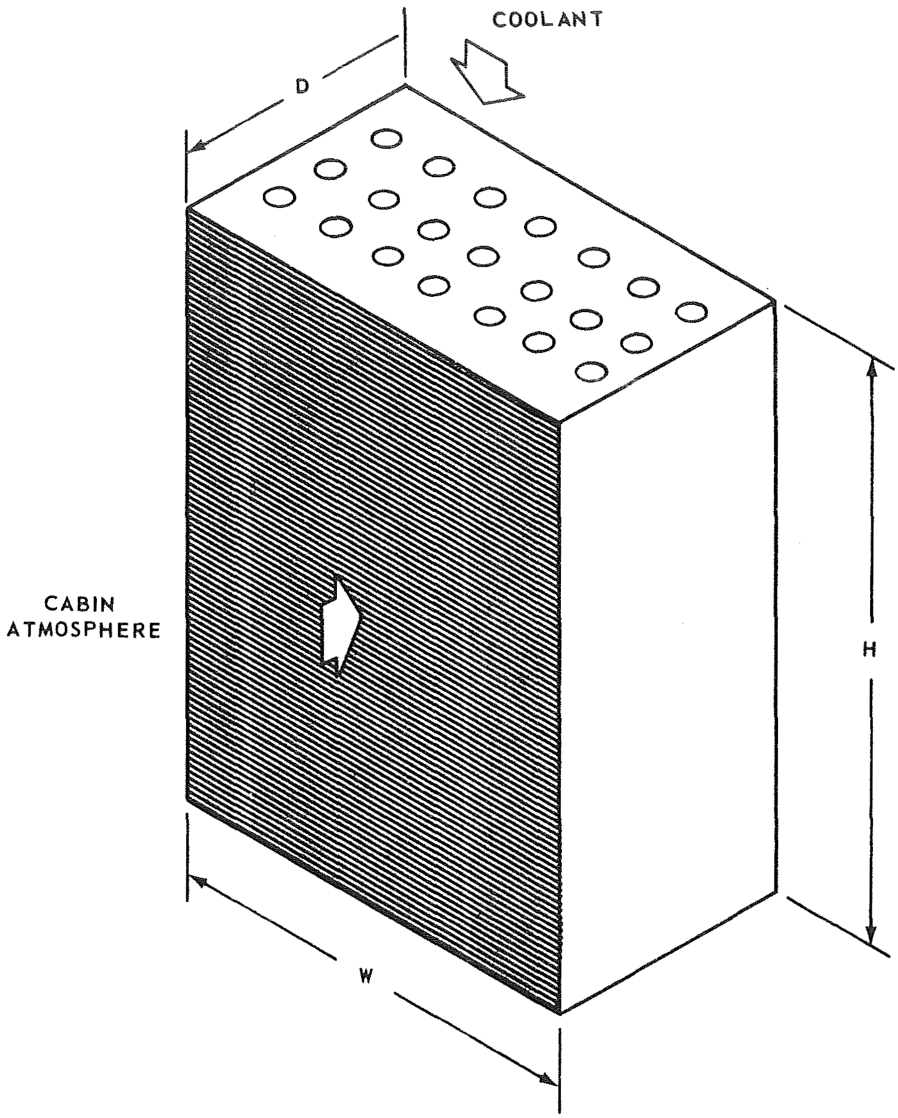


Figure 14. Cabin heat exchanger configuration.

Water is the coolant fluid recommended for the secondary (cabin) loop since it provides for maximum safety from fire and toxicity during the long-duration mission and a practical maintenance capability. Its disadvantages are a high vapor pressure and its restriction to operation above 32° F.

The heat generated by the fans in the gas/liquid heat exchangers is dissipated to the air, whereas the heat generated by the pump is either transferred to the air or to a cold plate.

Cold plates are used to cool various items of equipment in the cabin (Figs. 13 and 15 and Table 10). A cold-plate configuration is shown in Figure 15. It consists of a plate-fin arrangement through which the water passes. Table 10 and Figure 13 give the characteristics of the gas/liquid heat exchangers and cold plates for a total heat load of 136 520 Btu/hr and for the configurations shown in Figure 13.

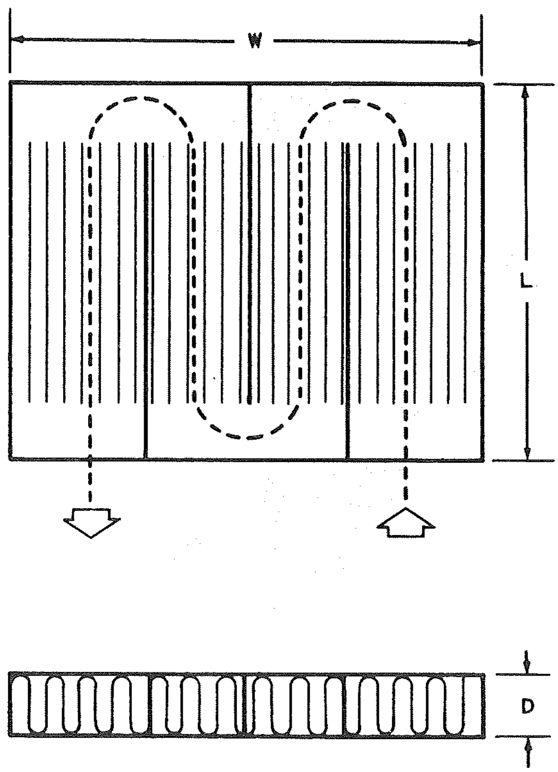


Figure 15. Cold plate configuration.

The liquid/liquid heat exchanger is used to transfer heat from the secondary (cabin) loop to the primary (radiator) loop. Figure 16 shows the flow arrangement for the liquid/liquid heat exchanger that consists of a compact plate-fin arrangement in cross flow and has a 0.85 effectiveness.

TABLE 10. CHARACTERISTICS OF CABIN LOOP THERMAL CONTROL SYSTEM COMPONENTS

Cold Plate Number	Cold-Plate Characteristics					System
	Heat Load (Btu/hr)	Volume (ft^3)	Weight (lb)	Length (ft)	Width (ft)	
1	16 706	0.063	12.3	2.5	3.9	Battery
2	5 956	0.022	4.3	1.5	2.3	Experiments
3	12 100	0.046	9.0	2.1	2.6	Regulator
4	12 100	0.046	9.0	2.1	2.6	Battery
5	3 413	0.0127	2.5	1.0	2.0	Operations center
6	12 150	0.046	9.0	2.1	2.6	Battery
7	10 090	0.037	7.2	2.0	3.0	Regulator
8	4 550	0.017	3.3	1.3	2.0	Water reclamation and management
9	1 819	0.0068	1.3	1.0	1.0	Thermal control circuit
10	3 536	0.0128	2.6	1.0	2.1	Carbon dioxide control
11	1 741	0.0065	1.3	0.9	1.0	Attitude control
12	4 437	0.016	3.2	1.2	2.0	Instrumentation and communication
Totals		0.332	65.0			

Gas/Liquid Heat Exchanger Characteristics

	Condensing Heat Exchanger	Noncondensing Heat Exchanger
Heat load (Btu/hr)	8330	39 592
Weight (lb)	16	38
Height (ft)	1.67	2.45
Width (ft)	1.67	2.45
Depth (ft)	0.25	0.25
Volume (ft^3)	0.70	1.50

Fan Characteristics

	Condensing Heat Exchanger	Noncondensing Heat Exchanger
Input Power (W)	200	1290
Weight (lb)	5.0	15.0

Liquid/Liquid Heat Exchanger Characteristics

Weight	100 lb
Length (L)	5.5 ft
Width (W)	0.15 ft
Depth (D)	5.5 ft
Volume	4.5 ft^3

Notes:

1. Cabin air flow rate = 14 000 ft^3/min
2. Cabin air velocity = 15 ft/min
3. Supplemental fans are used for stagnation areas (weight = 20 lb, input power = 780 W)

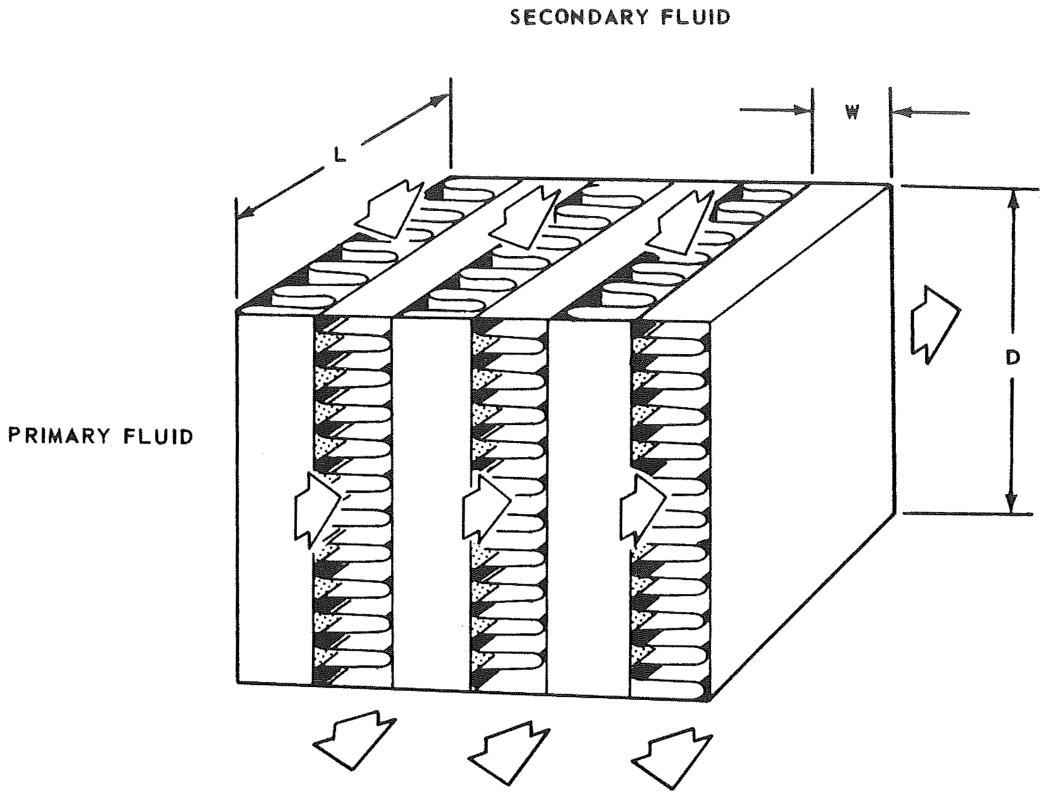
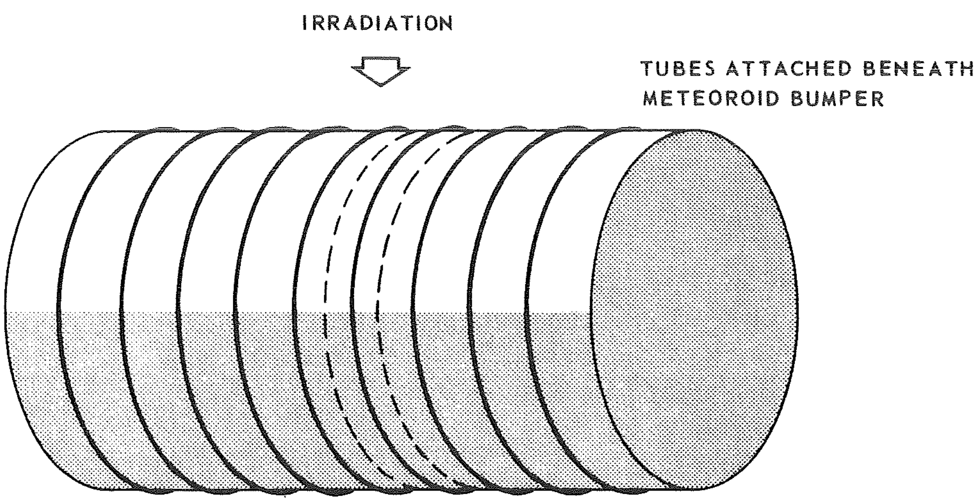


Figure 16. Flow arrangement of intermediate heat exchanger.

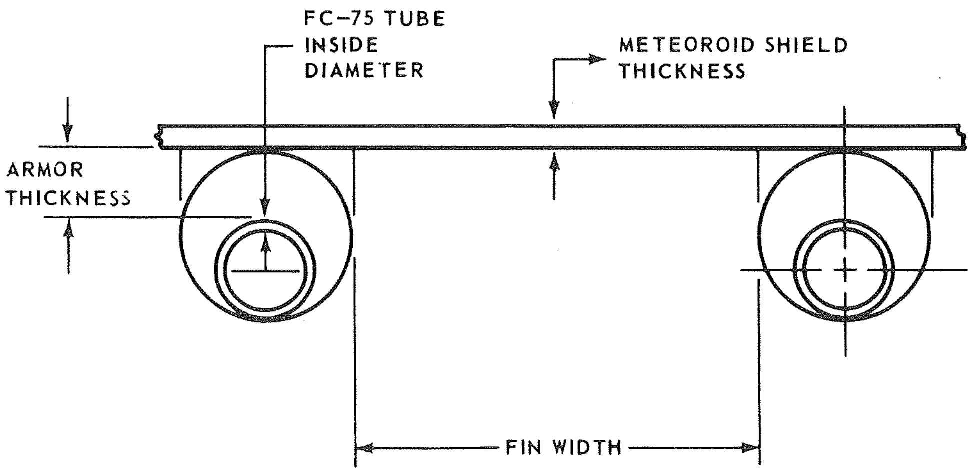
Table 10 shows the characteristics of the liquid/liquid heat exchanger for a total heat transfer rate of 136 520 Btu/hr. The arrangement shown in Figure 13 gives an inlet temperature to the liquid/liquid heat exchanger of 75° F and an outlet temperature of 39° F.

B. Radiator Loop

Radiator design is an important item in the overall thermal control system because of the large surface area required for heat rejection. An integral-type radiator (fabricated as part of the spacecraft skin structure) was selected for the Space Station because of its simplicity and weight saving. The integral-type radiator has its tubes attached underneath the spacecraft skin (meteoroid shield) and utilizes the skin between tubes as the radiating fins (Fig. 17). A radiator having circumferential cooling tubes was selected to minimize control problems. This selection allows the heat



a. POSITION OF RADIATOR ON SPACE STATION



b. DETAILED DESCRIPTION OF TUBE-FIN DESIGN ANALYZED

Figure 17. Tube and fin configuration for integral radiator.

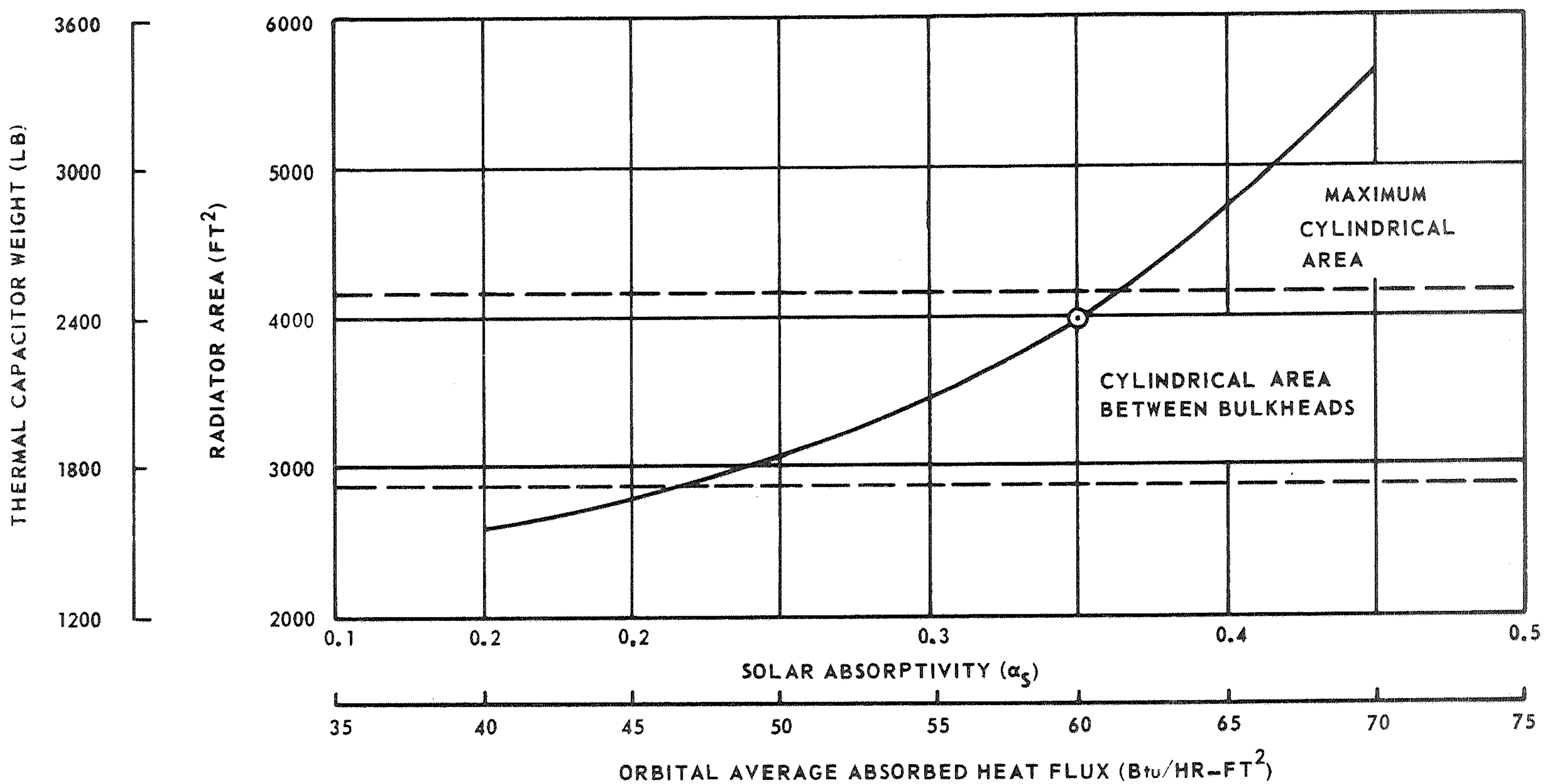
absorbed (irradiation) to be averaged over the circumference. This gives a tube length of approximately 104 feet. FC-75 is the coolant fluid recommended for the radiator loop. This fluid is produced by the Minnesota Mining and Manufacturing Company, is an inert fluorochemical that has low power requirements, and is nonflammable and mildly toxic. A disadvantage, however, is its high density.

Figure 18 presents the effects of solar absorptivity on radiator design. The application of Z-93 paint and its optical properties will have to be controlled. High values of solar absorptance necessitate large radiator areas. Other Space Station orientations such as broadside-to-sun could require even larger radiator areas.

The radiator was designed using an orbital-averaged heat flux of 60 Btu/hr-ft^2 and a heat rejection of 40 kilowatts. Table 11 presents the characteristics of the radiator loop. The required surface area is 3962 ft^2, whereas the maximum cylindrical area is only 4160 ft^2. If docking ports, windows, antennae, etc., require much cylindrical area, other sources for radiator area will have to be obtained (e.g., deployable radiators). Since the outer meteoroid shield is only 0.03-inch thick, additional armor has to be supplied for the radiator tubes. The total radiator loop weight is 2932 pounds which does not include the weight of the meteoroid shield.

Since the bulkheads will be insulated and used for mounting equipment, only the cylindrical section of the Space Station has been considered in determining the absorbed irradiation and heat rejection capability. For additional thermal control of the radiator, a system with a constant-flow pump and a modulating valve to bypass a portion of the total flow around the radiator may be utilized. This provides a means of controlling the proper heat rejection rates. Figure 19 illustrates the modulating valve bypass system.

Using the maximum orbital-averaged absorbed heat flux necessitates the utilization of a thermal capacitor to absorb the excess heat during times of maximum heating (when vehicle is in sunlight) and to reject heat when in the earth's shadow. This capacitor probably can best be placed just before the inlet to the liquid/liquid heat exchanger in the radiation loop (Fig. 13). Operating in this manner it will keep the temperature at the inlet to the liquid/liquid heat exchanger at the melting point of the phase-change substance employed in the capacitor.



NOTES:

FIN EFFICIENCY (η) = 0.973

RADIATOR INLET TEMPERATURE = 70°F

RADIATOR OUTLET TEMPERATURE = 32°F

⊙ = DESIGN POINT

Figure 18. Radiator area and thermal capacitor weight versus solar absorptivity and orbital average absorbed heat flux.

TABLE 11. INTEGRAL RADIATOR DESIGN

Item	Data
Total spacecraft heat load	136 520 Btu/hr
Absorbed radiation heat flux	60.0 Btu/hr-ft^2
Flow rate through radiator	16 070 lbm/hr
Tube diameter	0.25 in.
Radiator fluid	FC-75
Radiator length	104 ft
Radiator width	38.1 ft
Radiator area	3962 ft^2
Inlet temperature	70° F
Outlet temperature	32° F
Number of tubes	53
Armor thickness	0.17 in.
Pump power requirements	160 W
Fin width	0.68 ft
Fin efficiency	0.973
	Weight (lb)
Tubes and armor	1200
Surface coating	172
Thermal capacitor (3 ft by 3 ft by 3 ft)	750[a]
FC-75	770
Pump	40
Total Radiator Loop (excluding fin)	2932

a. Includes only the structural members of the capacitor which requires 1190 pounds of reserve water to be used as the phase-change medium.

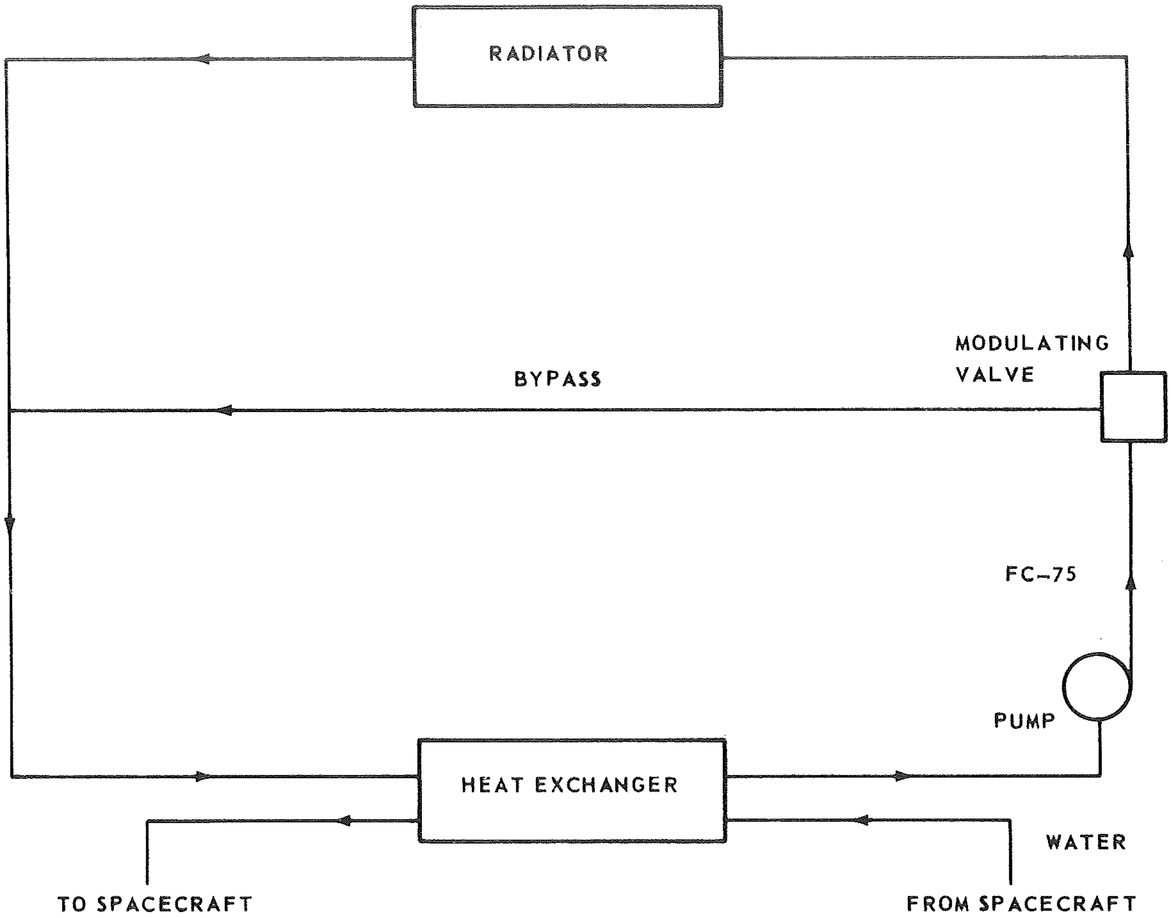


Figure 19. Primary system modulating bypass schematic.

In this analysis, reserve water was considered as the phase-change medium in the capacitor. Thus, the outlet temperature of the radiator will be kept near 32° F where it enters the liquid/liquid heat exchanger. When in sunlight, the radiator outlet temperature will be higher because of the incident solar radiation than when in the shadow; but, the water (ice) will absorb the excess heat from the FC-75 and melt, thus collecting heat for rejection on the cold side of the orbit. When in the earth's shadow, the cold FC-75 fluid will absorb heat from the water in the capacitor and reject it to space by means of the radiator, while the water will tend to freeze. Thus, the FC-75 entering the liquid/liquid heat exchanger will be kept at approximately 32° F. Water is recommended for use in the thermal capacitor since it has a relatively high heat of fusion and since the reserve water on board may be used for this purpose. Figure 18 shows the weights of the thermal capacitor for varying values of time-averaged irradiation.

In this analysis, the sizes and weights of the main thermal control system components have been estimated for preliminary design purposes. This includes the radiator, thermal capacitor, liquid/liquid heat exchanger, cabin heat exchangers, cold plates, pumps, coolant fluids, and structural members. Table 12 gives the weight breakdown for the entire thermal control system.

TABLE 12. WEIGHTS FOR ACTIVE DOUBLE-LOOP THERMAL CONTROL SYSTEM

Item	Weight (lb)
Radiator	
Tubes and armor	1200
Surface coating	172
Thermal capacitor	750[a]
FC-75	770
Pump	40
L/L heat exchanger	100
Cold plates	65
G/L heat exchanger (condensing)	21
G/L heat exchanger (noncondensing)	53
Pump (cabin loop)	20
Tubing (cabin loop)	50
Water (cabin loop)	220
Supplemental fans	20
Mounting brackets and misc.	319
Total	3800
Pumps and fans required power (peak)	2500 W

a. Includes only the structural members of the capacitor which requires 1190 pounds of reserve water to be used as the phase-change medium.

C. Conclusions

Conclusions drawn from the thermal-control investigation are as follows:

1. Radiator design is a critical item. The radiator area required (based upon $\alpha_s = 0.35$, $\epsilon = 0.85$ - Z-93 surface coating) to reject 40 kilowatts of waste heat when exposed to the maximum orbital-averaged absorbed irradiation (a thermal capacitor being used) is approximately 3962 ft^2. The maximum cylindrical area of the vehicle is 4160 ft^2. The area between the bulkheads is 2872 ft^2. Some of the surface will be unavailable for radiator area because of space for windows, antennae, solar panel attachments, docking ports, etc., and thus it is unlikely that sufficient radiator area can be found on the vehicle surface.

2. It appears that with the vehicle oriented in the X-POP mode or broadside-to-the-sun, deployable radiators will have to be used. There are several recourses that may prove workable and enable rejection of the heat without deployable radiators. These are as follows:

a. Maintaining an approximate vehicle nose-to-sun orientation. The nose-to-sun orientation would require a heavier attitude and control system than the X-POP orientation but may prove feasible.

b. Vehicle power programming. Vehicle power programming (lowering power requirements when the vehicle is in sunlight) certainly is not desirable as it would interfere with experiments and other spacecraft functions.

3. An active-loop thermal-control system is recommended because of the low component temperatures and the range of temperatures of the various components. Little, if any, advantage can be obtained by use of a heat-pipe system.

4. The phase-change material in the thermal capacitor should be water. Water is recommended since it has a rather high heat of fusion and because the reserve water already on board the Space Station may be used in the capacitor for weight savings.

5. The requirements of a low relative humidity necessitates relatively low water temperatures in the cabin loop and limits the radiator-inlet temperature. A condensing and noncondensing heat exchanger combination may not have a great advantage over a single-cabin heat exchanger, depending on whether a very efficient condensing heat exchanger can be constructed. This condensing heat exchanger would have to require only limited overall cooling of the cabin air while removing a sufficient amount of moisture. This problem should be further investigated.

SECTION VII. WATER MANAGEMENT/WATER RECLAMATION ASSEMBLY

The primary function of the water management/water reclamation assembly is to maintain a potable water supply in the closed environment of the Space Station. The water must always be sterile and free of organic and inorganic toxic material. Man needs approximately 7 pounds of water per day for drinking and food preparation, and, in addition, about 13 pounds per day for washing and personal hygiene. The delivery of potable water for use on demand implies supplying specific quantities for specified uses at the proper temperature. It is possible to obtain potable water reclaimed from wash water, urine, and humidity condensate. The most difficult is the reclamation of water from urine. The fecal water and the water used in the food are unrecovered.

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 Manned Space Missions. SSB defines microbiological potable water as that containing no more than 10 viable organisms per milliliter. Urine requires a pretreatment agent to prevent bacterial growth and to chemically fix the volatile ammonia. This agent also neutralizes the many minor contaminants found in urine and keeps them from being carried along with the reclamation process and ending up in the potable water. The most effective agents available are a mixture of chromium trioxide and sulfuric acid added to the waste water in the holding tanks.

Table 13 summarizes the Space Station water balance for the 12-man crew. The values shown in this table require that the overall water recovery efficiency be 99 percent for the wash-water loop, 95 percent for the urine loop, and 100 percent for the condensate.

The state-of-the-art processes of meeting the requirements for water reclamation fall into two broad categories: distillation and filtration. The practical distillation assemblies include various forms of evaporators and condensers. The filtration assemblies include such methods as reverse osmosis, electrodialysis, and multifiltration.

TABLE 13. SPACE STATION WATER BALANCE (12 MEN)

Water Sources	Quantity (lb/day)
Water Requirements	
Food and drink (6.99 lb/man-day)	83.88
Water of oxidation (0.78 lb/man-day)	9.36
Wash water (3.90 lb/man-day)	46.80
Personal hygiene (7.50 lb/man-day)	90.00
Urinal rinse water (2 lb/man-day)	24.00
Electrolysis (makeup H_2O)	11.34
Total required	265.38
Human	
Urine (95% efficiency)	35.11
Perspiration and respiration	51.60
Water in food waste	1.68[a]
Water in feces	3.00[a]
Equipment and Processes	
Wash water (99% efficiency)	135.43
Urinal flush water (95% efficiency)	22.80
Reclamation inefficiencies (stored)	4.42
Stored makeup H_2O	16.02
Total	270.06
Total unrecovered	-4.68
Total available	265.38

a. Unrecovered

The best possible choices of candidates for water recovery are air evaporation, vacuum distillation/ compression, vapor diffusion/compression, vapor diffusion, multifiltration, and reverse osmosis. These assemblies are shown in Figures 20 through 26.

In the air-evaporation assembly (Fig. 20), waste water is collected in the pretreatment tanks and fed to the evaporator wicks through a metering pump. The water then evaporates into a carrier gas (circulated past the wicks), which 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, the gas is drawn back to the evaporator, after just passing through a heater. The condensed water is continuously removed and pumped through a series of charcoal and bacteria filters.

One of the main advantages of the air-evaporation technique is that it is capable of recovering nearly 100 percent of the water from urine. It also produces water of excellent potability. Prototype air-evaporation systems have been put through extensive tests. One assembly has completed a successful 28-day test in the NASA ILSS. The air-evaporation concept can reasonably be developed for flight as early as 1974. This concept has two major safety hazards: (1) during operations, conditions in the wick are ideal for bacterial growth and the wicks are flammable, and (2) their storage on board the Space Station poses a fire hazard.

The vacuum distillation/compression assembly refers to a vacuum distillation assembly with some type of artificial gravity and intermediate vapor compression. The assembly (Fig. 21) employes a rotary drum vacuum distillation unit with an integral vapor compressor. Waste water is fed 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. When condensation occurs, the heat of condensation is transferred by conduction to the evaporator.

Vapor diffusion (Fig. 22) and vapor diffusion/compression (Fig. 23) are similar enough to warrant discussing them together. The only difference is that a compressor is added to permit recovery of the heat of condensation. Vapor diffusion is an ambient pressure distillation process in which water

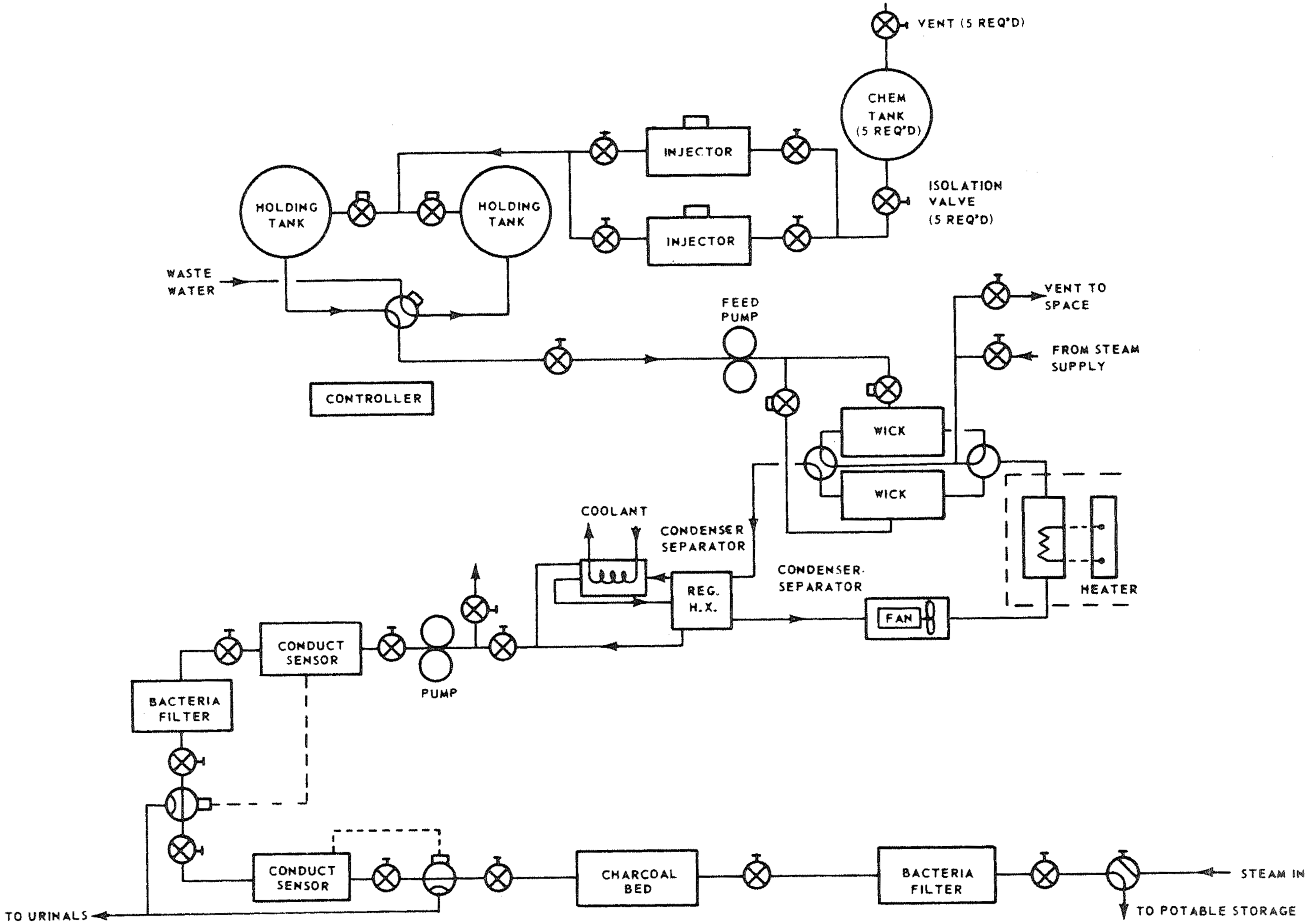


Figure 20. Closed cycle air evaporation concept.

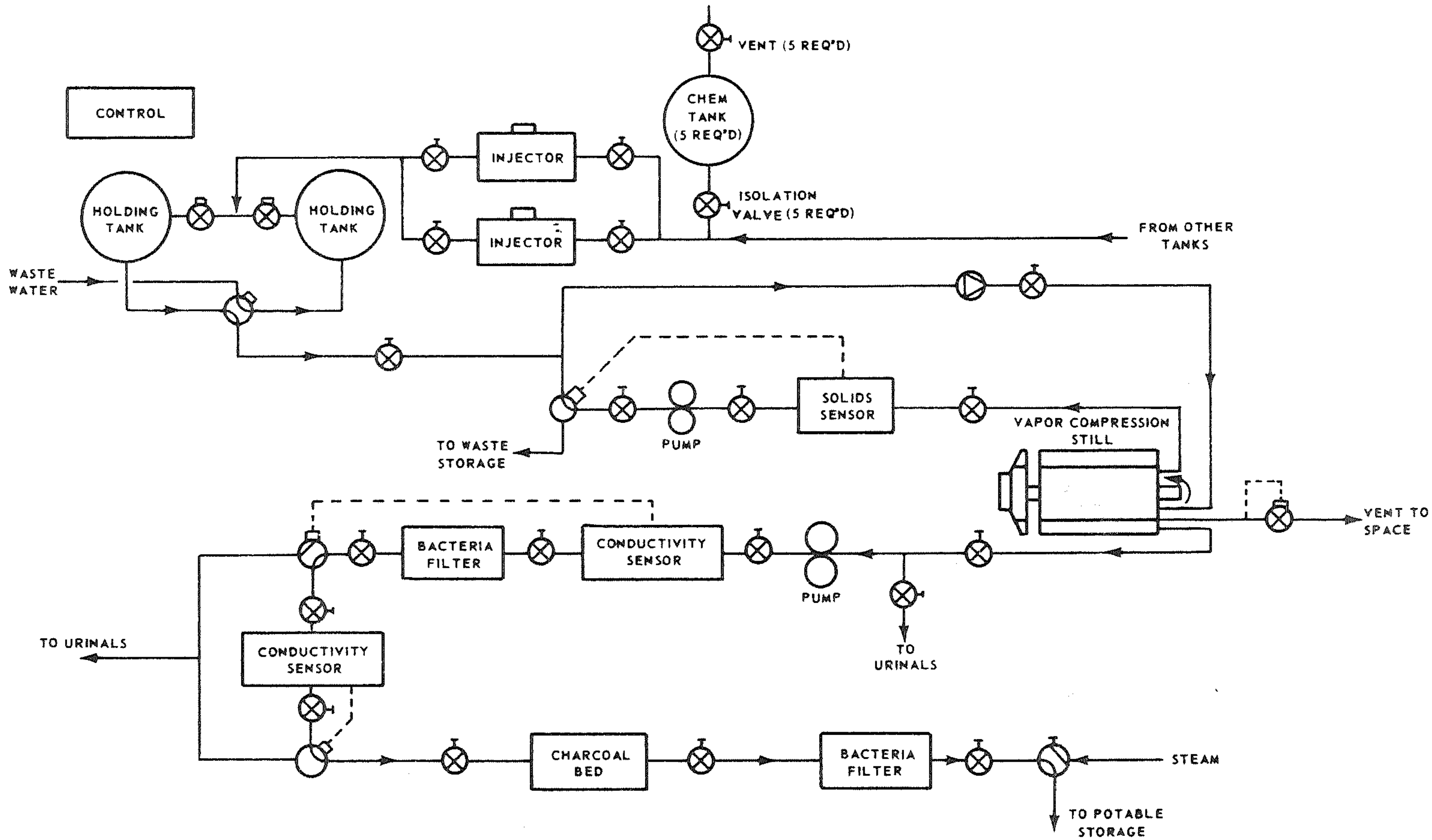


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Figure 21. Vacuum distillation/compression concept.

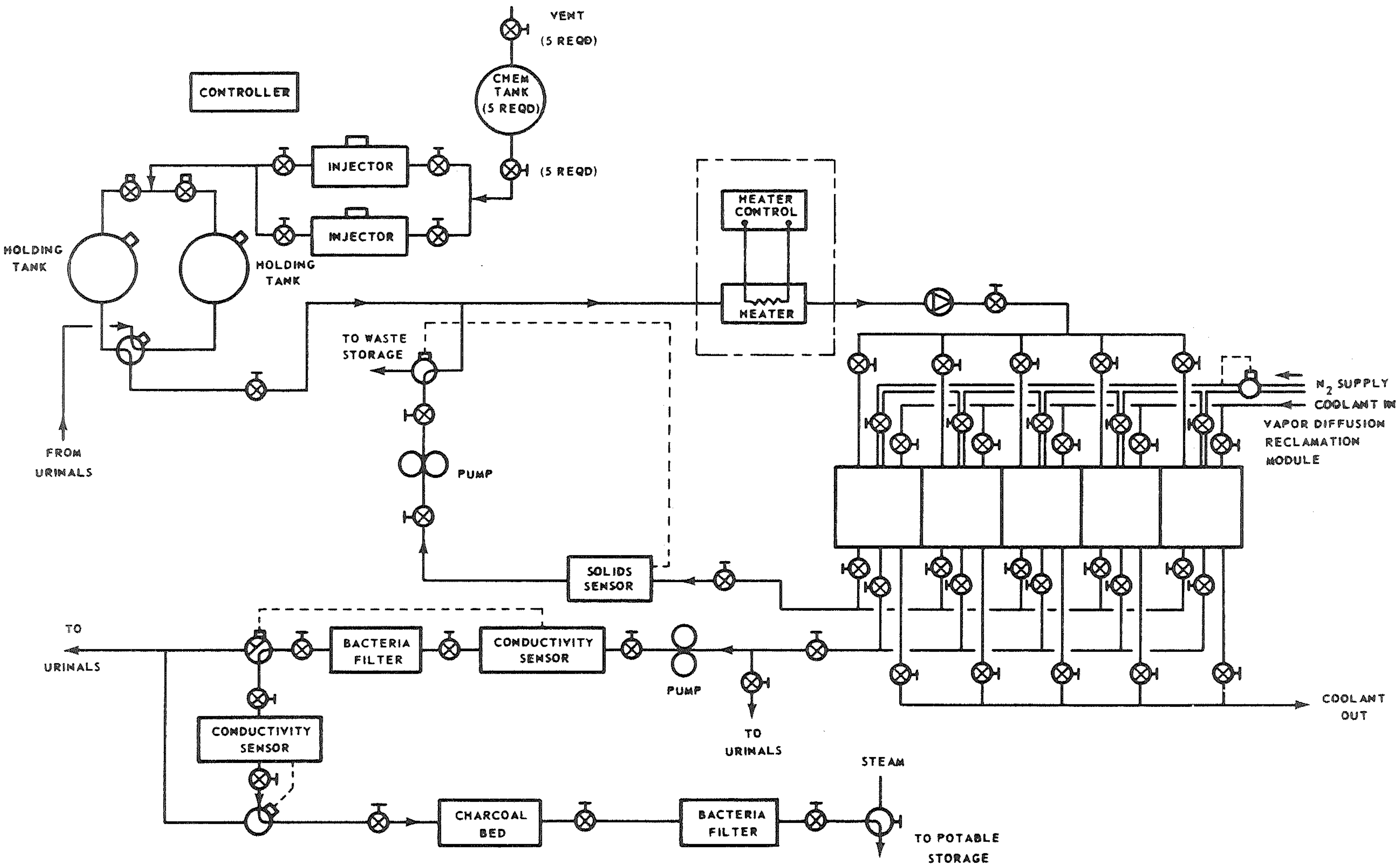

Figure 22. Vapor diffusion concept.

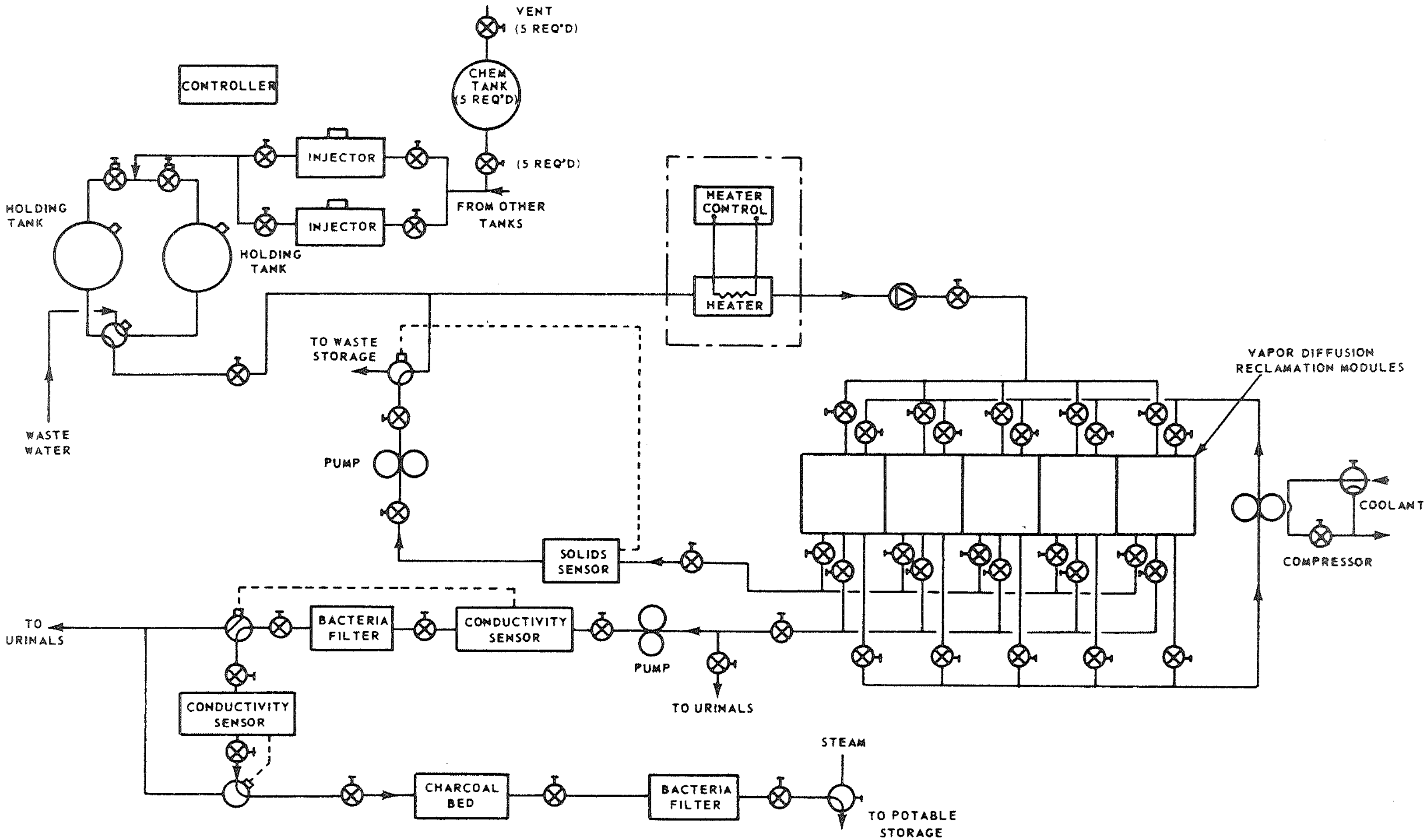

Figure 23. Vapor diffusion/compression concept.

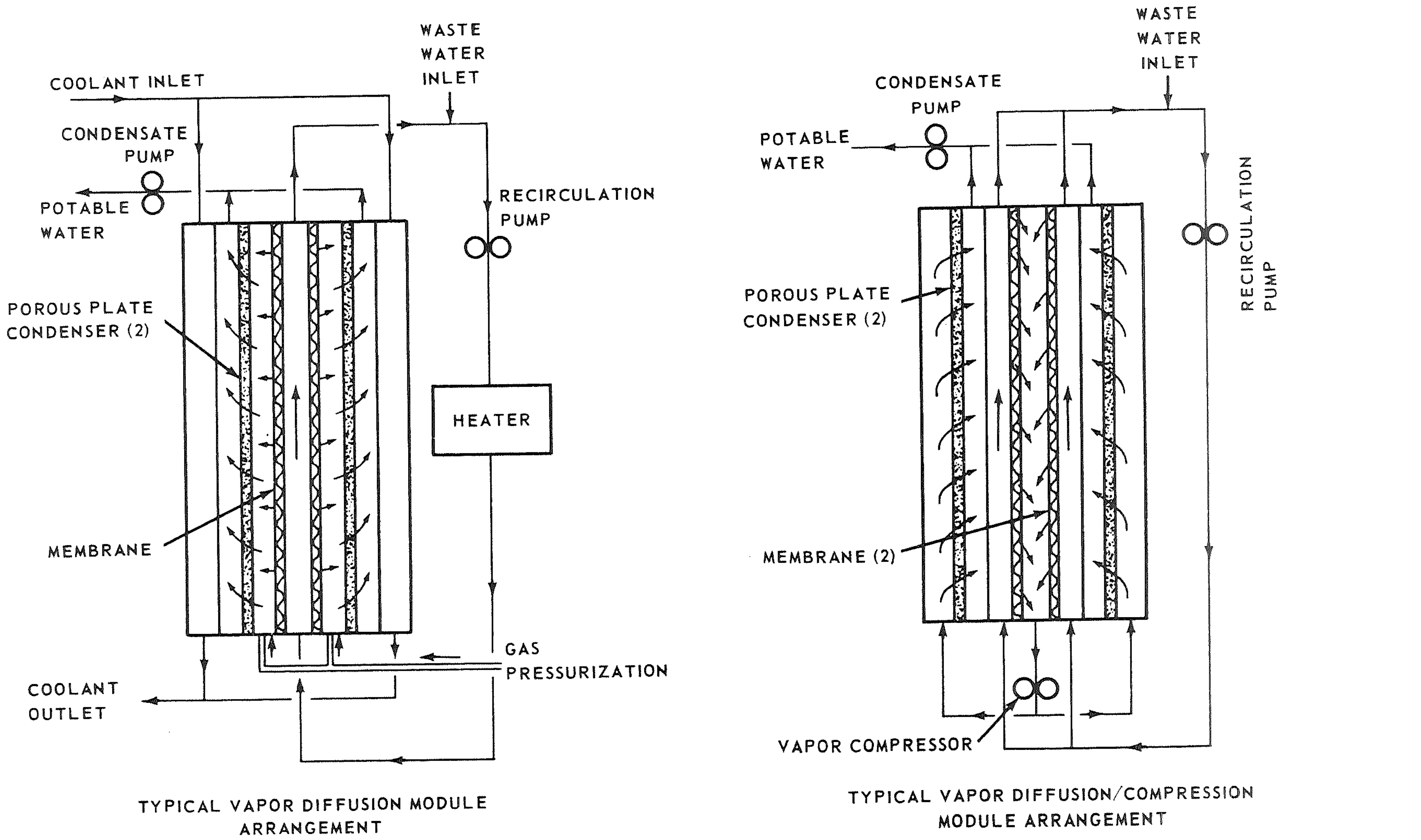

Figure 24. Comparison of vapor diffusion arrangements.

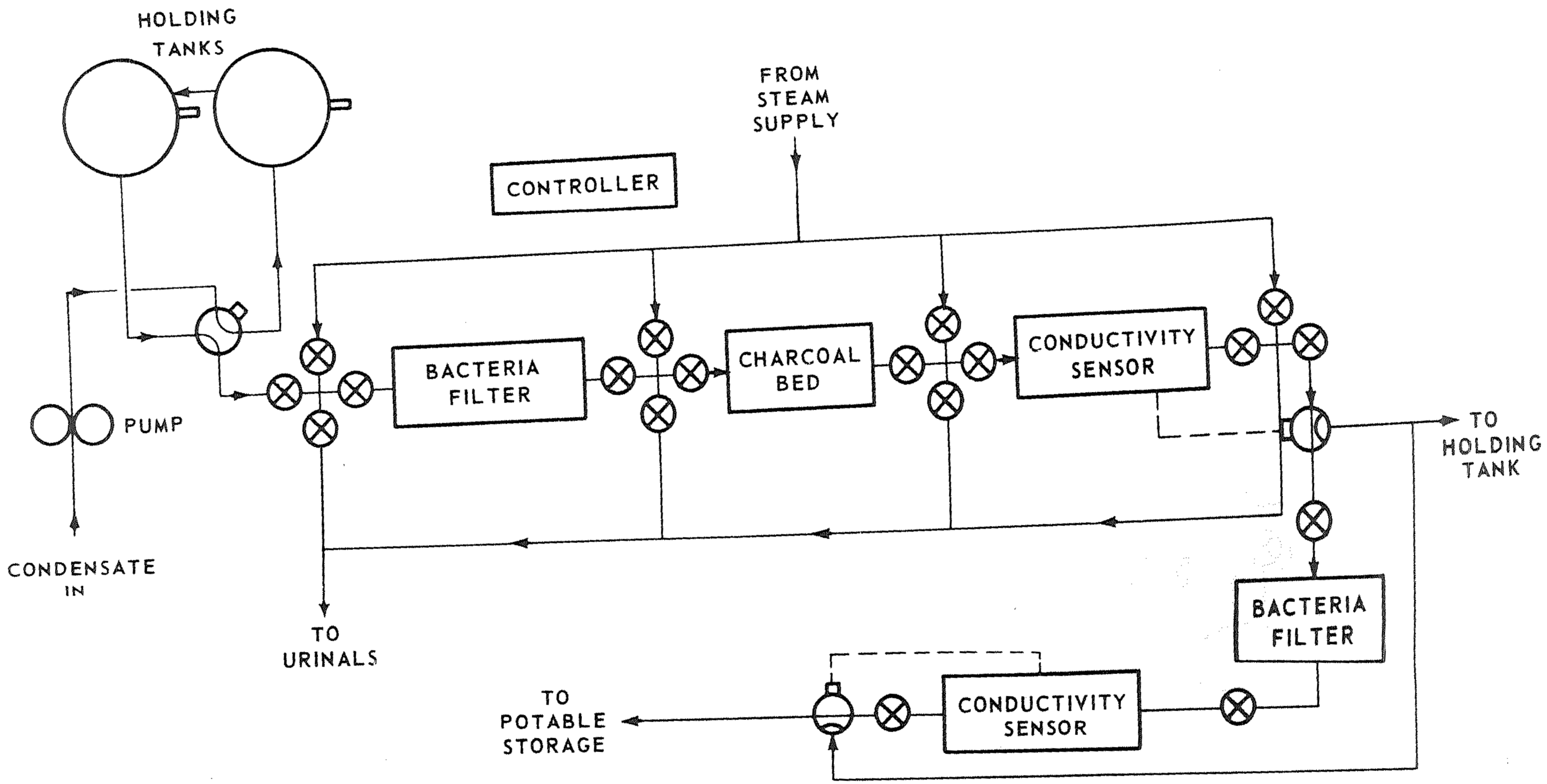

Figure 25. Multifiltration concept.

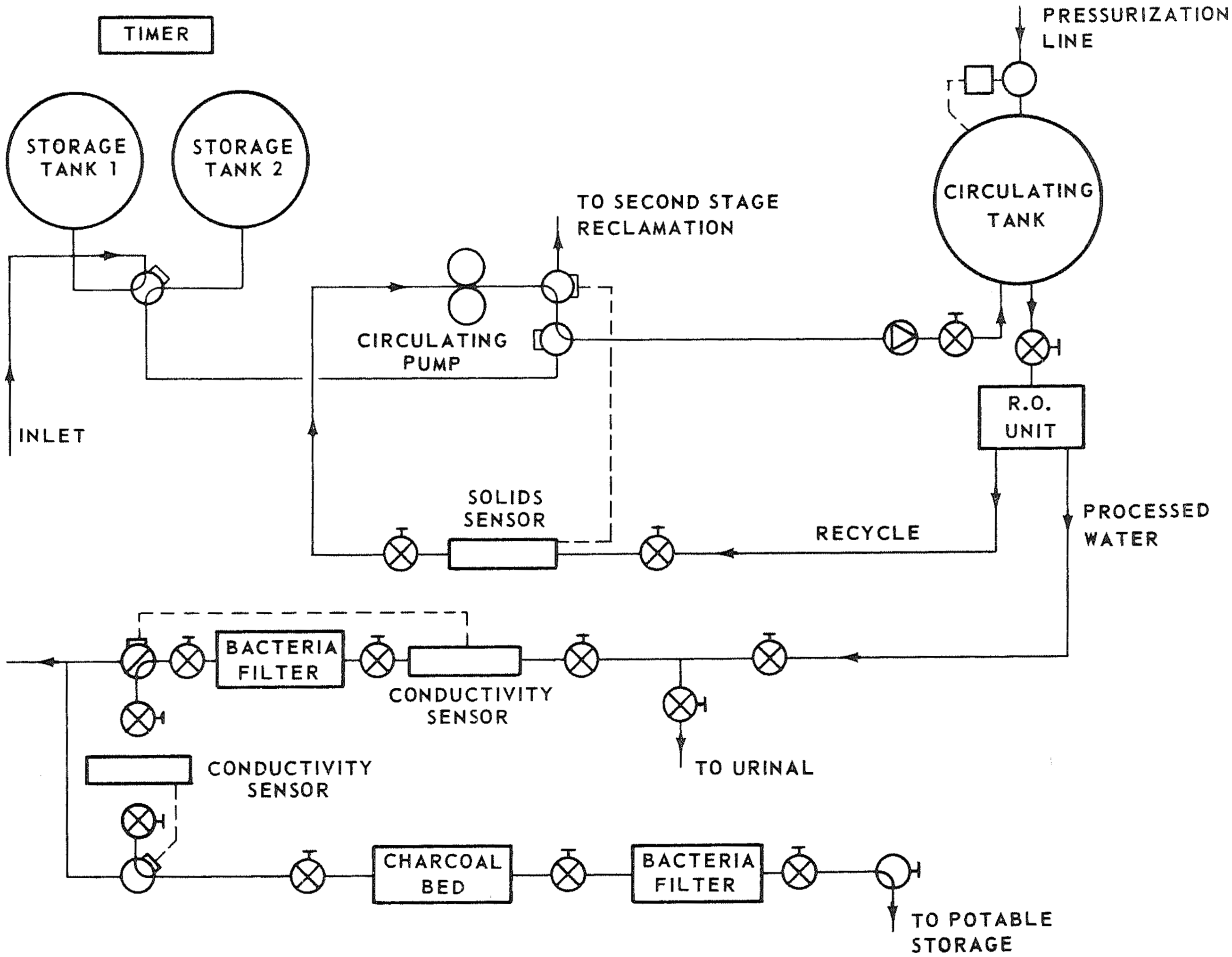

Figure 26. Reverse osmosis concept.

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 into the condenser. In the noncompression version, the 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 (Fig. 24). There it condenses, giving up the heat of condensation to the evaporating fluid.

The membranes in these assemblies are limited life items; therefore, all membranes, including spares, are installed in a modularized unit. Five modules are provided in each vapor diffusion/compression assembly, which has a 9-man capability. Three of the modules per assembly are operating; whereas, two are for redundancy. When a membrane failure occurs, a new module can be activated. Two vapor diffusion/compression assemblies are provided in the Space Station for a 12-man capability.

Multifiltration (Fig. 25) is a method in which waste water is filtered through various materials to remove contaminants. Preliminary analysis indicates that the total equivalent weight required for filtering urine or wash water in this manner is much greater than for any other assembly; thus, multifiltration was considered for condensate reclamation only. Only charcoal and bacterial filters are used for this purpose.

Multifiltration is a relatively simple assembly and the components and materials are available. Recovery efficiency in excess of 99 percent is possible with this assembly. One of the advantages of the system is that the power requirement is negligible.

Reverse osmosis (Fig. 26) is a process that uses high pressure to force water from a solution through a semipermeable membrane into a less concentrated solution. The natural osmotic force tends to cause spontaneous movement of the water from the less to the more-concentrated solution by pressurization of the less-concentrated solution and reversing the flow. This is why it is called reverse osmosis.

The major water-reclamation equipment selected for the Space Station is vapor diffusion/compression for the wash and urine water loops and multi-filtration for humidity condensate. The major factors influencing the selection of the two vapor diffusion concepts were relatively low weight, low maintenance time, and best inherent sterility. Multifiltration can readily be integrated with the vapor diffusion/compression concept with very good performance. Reverse osmosis also is an excellent candidate for condensate recovery.

Three potable water tanks (1205 pounds capacity each) are provided for storing the initial and reclaimed water. Thus, the total capacity of the tanks is 3615 pounds of water, of which 2425 pounds are for reserves and general uses and 1190 pounds for the thermal capacitor in the thermal-control assembly. These tanks can be equipped either with or without bladders. Bladderless tanks are preferred because of their increased reliability and greatly reduced maintenance problems. Their prime drawback, however, is that a true zero-g capability has yet to be demonstrated. The collection tanks, which serve to collect all the waste water for delivery to a single distillation processing assembly, would be the same type bladderless tank as the potable storage water tank. Heaters and insulation are necessary for the tanks to maintain the stored water at 160 degrees to ensure potability.

A detailed weight breakdown of the water management/water reclamation assembly is given in Table 14.

TABLE 14. WATER MANAGEMENT/WATER RECLAMATION ASSEMBLY WEIGHT BREAKDOWN

Component	Number Required	Weight (lb)	Power (W)
Reserve Water Tanks (40-in. I. D.)	3	285.0	300
Diffusion Still Assembly (5 modules)	2	100.0[a]	2668[b]
Multifiltration Assembly	2	274.0[c]	24[b]
Potable Water Tank	12	264.0	
Chemical Storage Tank	10	43.0	
Chemical Injector	4	14.4	20[b]
Heater	2	5.6	
Heater Control	2	1.4	
Solids Sensor	1	1.3	4[b]
Bacteria Filter	40	48.0	
Charcoal Filter	2	3.6	
Conductivity and Control Sensor	2	5.6	4[b]
Pump	14	28.0	20[b]
4-Way Solenoid Valve	2	5.0	40[b]
3-Way Solenoid Valve	14	25.2	6[b]
Check Valve	24	7.2	
Chemical Shutoff Valve	16	5.6	
Vent Valve	8	1.6	
Manual Shutoff Valve	60	24.0	
Manual Diverter Valve	10	8.0	
Check Valve	4	1.2	
Regulator, 25 psi	2	3.0	
Regulator, 20 psi	2	3.0	
Compressor	2	8.0	
Accumulator	2	3.0	
Chiller	4	10.0	
Chemical Solenoid Shutoff Valve	4	6.0	
Heater Control	10	7.0	10[b]
Liquid Collector	2	9.0	
Heat Exchanger	2	14.0	
Pump	4	16.0	30[b]
Bacteria Filter Cartridges	40	72.0	
Charcoal Filter Cartridges	2	9.0	
Hose and Connector	2	4.6	
Tank Level Control	2	1.0	8[b]
Heater Control	2	3.0	
Vapor Compressor	2	64.0	80[b]
Installation		116.7	
Total (Overall)		1501.0	3214

a. Assemblies occupy 28 ft^3.
b. 2 assemblies operating.
c. Assembly occupies 8 ft^3.

TABLE 14. (Concluded)

Component	Number Required	Weight (lb)	Power (W)
Spares			
Vapor Diffusion/Compression (11 ft^3)			
Chemical Tank	1	4.3	
Chemical Injector	1	1.8	
Heater Control	2	1.4	
Pump	3	6.0	
Conductivity Sensor	3	4.2	
Charcoal Canister	1	1.8	
4-Way Solenoid Valve	2	5.0	
Compressor	3	102.0	
Solenoid Diverter Valve	2	3.6	
Heater	1	2.8	
Check Valve	1	0.3	
Pressure Regulator	2	3.0	
Bacterial Filter Canister	1	1.2	
Controller	2	3.0	
Solids Sensor	2	2.6	
Solenoid Shutoff Valve	2	1.6	
Manual 3-Way Valve	1	0.4	
Pump	3	12.0	
Total (Overall)		157.0	
Multifiltration (8 ft^3)			
Charcoal Canister	1	1.8	
Bacteria Filter	1	1.2	
Pump	3	12	
Solenoid Valve	2	3.6	
Conductivity Sensor	3	3.6	
Diverter Valve	2	3.6	
Controller	2	3.0	
Total		28.8	

SECTION VIII. WASTE-MANAGEMENT ASSEMBLY

The waste-management assembly must be equipped to handle both liquid and solid waste materials. This requires the collecting, treating, and storing and/or disposing of these wastes, and independently collecting and transferring raw urine to the water-management assembly. The assembly must be capable of eliminating odors, aerosols, and existing gases. Waste matter should be sterilized to inhibit or eliminate micro-organism production, prevent production of gases (CO_2, CH_4, H_2, H_2S) in the wastes, and prevent crew contamination if stored wastes escape into living areas. The waste materials should be reduced as much as possible in mass and volume for storage purposes.

The variety of wastes encountered presents significant problems in the selection of a waste-control assembly. Such problems as different levels of micro-organism activity and the differences in their physical characteristics (volume, density, composition, etc.) must be considered.

The waste-management system must be capable of handling all types of wastes (liquids and solids). Some of the type wastes that will be encountered are unused food, food containers, urine sludge, urine, feces, hair, vomitus, and fingernail clippings. Appropriate steps must be taken to reduce the volume, to store, or to destroy these materials, because the accumulation of garbage on extended flights will be overwhelming. Micro-organisms contaminate and colonize in food debris, thus causing gases, odors, and health hazards in the cabin atmosphere. Micro-organisms also colonize urine to degrade urea and uric-acid components to toxi-ammonia gas. These factors make it mandatory to eliminate the manual transfer of feces.

Urine collection and transfer must be accomplished under zero-g conditions, while positively preventing the escape of urine to the cabin. The urine collection and transfer assembly 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: the collector/bladder with manual transfer; the liquid/gas flow with sponge/bladder pressurized transfer; and the liquid/gas flow with centrifugal phase separation/transfer.

The liquid/gas flow with centrifugal phase separation/transfer is selected for integration with the integrated vacuum decomposition concept, which is described below. It is the most accepted, psychologically, of the three and requires the minimum of effort on the part of the crew. The collector/ bladder with manual transfer is psychologically unacceptable and is time-consuming for long missions. The liquid/gas flow with sponge/ bladder pressurized transfer is more feasible where urine is dumped to space vacuum.

The liquid/gas flow with centrifugal phase separation/transfer concept employes a centrifugal fan to draw air from the cabin through the urinal during urination. Each crewman is provided with his own diaphragm, which is inserted in the urinal after removing the sealing cap. Positive transfer during zero-g operation is accomplished by activation of the fan during urination. A motor-driven centrifugal separator separates the urine from the air flow, which passes through the bacteria and odor removal filters before returning to the cabin. The raw urine is pumped to the water-management system.

Twelve waste-control concepts are listed in Table 1. The integrated vacuum decomposition concept is the selected candidate for the Space Station because of its light weight, safe characteristics, and low volume.

The integrated vacuum decomposition concept utilizes vacuum and high temperature to decompose waste materials into gaseous products that can be exhausted to vacuum. When the chamber cools down after heating, the residue is vacuumed out of the chamber. This amounts to about 12 percent of the total wastes processed. Four waste collector/incinerators are provided with the concept, of which two are alternately available for collection during any 24-hour period.

The integrated vacuum decomposition concept is schematically illustrated in Figure 27, and a detailed weight breakdown is shown in Table 15.

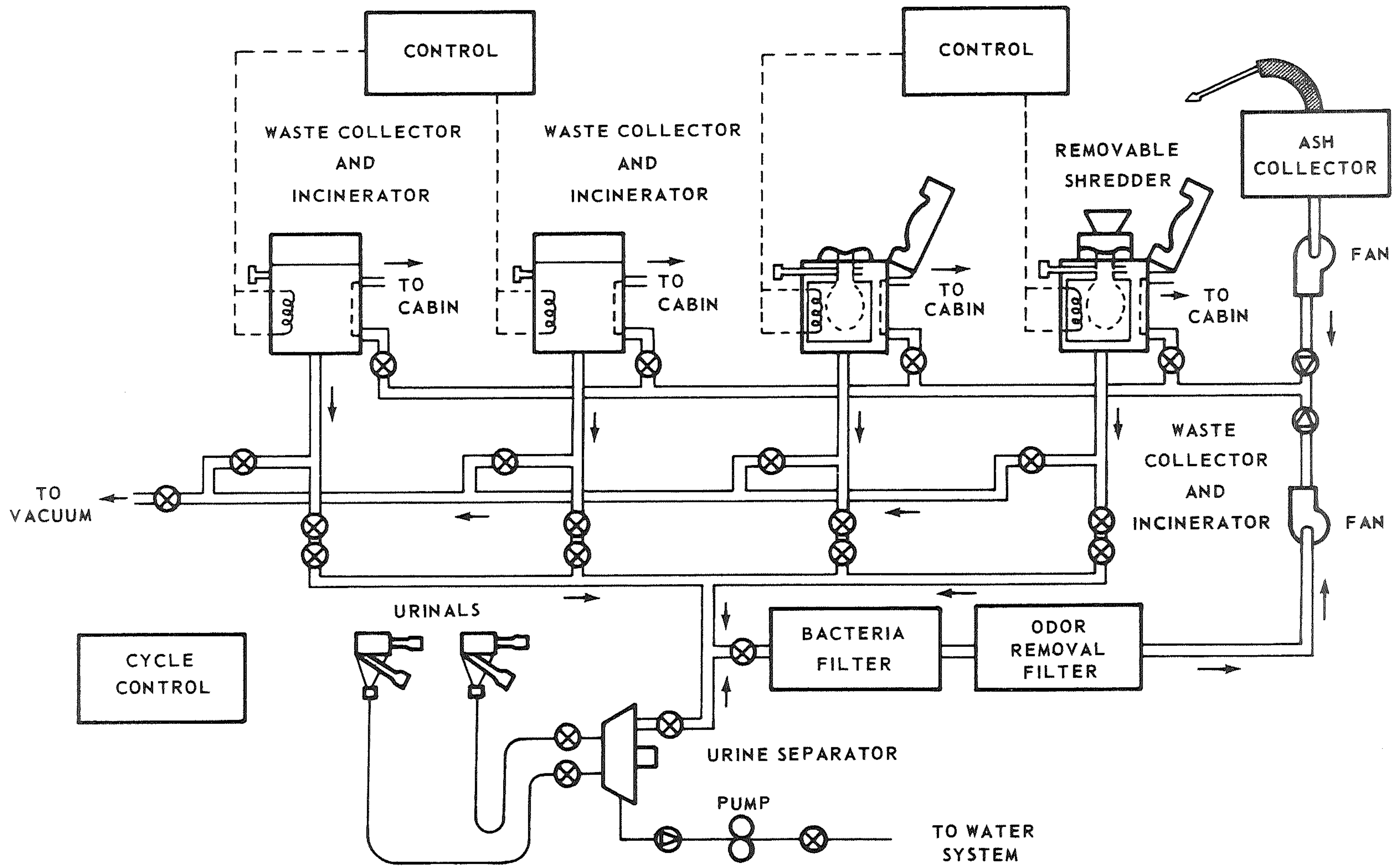

Figure 27. Integrated vacuum decomposition concept.

TABLE 15. WASTE MANAGEMENT ASSEMBLY DETAILED WEIGHT BREAKDOWN

Component	Number Required	Weight (lb)	Power (W)
Waste Collector	4	44.0	
Shredder	1	20.0	
Heater Control	2	1.4	
Ash Collector	1	7.6	
Process Flow Fan	1	2.9	
Urinal	2	6.0	
Cycle Control	1	5.0	
Urine/Air Separator	2	10.0	
Urine Pump	1	1.0	
Bacteria Filter	1	2.0	
Odor Removal Filter	1	7.5	
Ash Collector Fan	1	2.9	
Solenoid Shutoff Valve	12	33.6	
Check Valve	3	1.5	
Manual Shutoff Valve	7	6.3	
Heat Exchangers	5	25.0	
Structures and Installation		155.3	
Miscellaneous		22.0	
Total		354.0	1400
Assembly volume = 127.1 ft^3			
Spares (2.9 ft^3)			
Shredder	2	40.0	
Bacteria Filter	1	2.0	
Bacteria Filter — Expendable	50	100.0	
Urinal	1	3.0	
Urine/Air Separator	2	10.0	
Urine Pump	2	3.0	
Process Flow Fan	2	5.8	
Cycle Control	3	1.5	
Solenoid Shutoff Valve	3	8.4	
Check Valve	1	0.5	
Ash Collector Fan	1	2.8	
High Temperature Shutoff Valve (R)	1	2.8	
High Temperature Shutoff Valve	4	11.2	
Odor Removal Filter — Expendable	20	150.0	
Urine Check Valve	1	1.5	
Incinerator Heater (R)	1	1.5	
Heater Control	2	6.0	
Miscellaneous		6.0	
Total		356.0	

SECTION IX. CREW SYSTEMS ASSEMBLY

Crew systems consist of the equipment necessary to support the personal well-being of the flight crew. Included are food preparation and storage, living accommodations, personal grooming and hygiene, clothing, medical needs, and recreation facilities. A detailed weight breakdown of the crew systems is presented in Table 16. Table 17 reflects the weight and volume of a soft EVA suit that the crew would don during emergencies.

A. Cleaning Facilities

Laundry facilities will be provided for cleaning clothes and bedding. Washable clothing shows a considerable weight savings of about 46 pounds per man when compared with disposable goods, and it also decreases the amount of waste material to be processed by the waste-management system. Table 18 lists the volume and weight of the clothing required.

B. Personal Hygiene

One 3-foot-diameter shower stall is provided for body cleaning. The water is sprayed over the body by a hand-held shower head. A water collector/ blower circuit is used to remove local water accumulation and to assist in drying. Water flow, air flow, and temperature are controlled by the crewman from within the shower. Sponges and body wipes are also provided for local body cleaning. Weight and volume statements for personal-hygiene provisions are listed in Table 19. These items are used for body cleaning, general grooming, and dental hygiene.

C. Food Preparation

The diet plan being considered for the crew is to alternate between frozen and freeze-dried foods. This combination allows a better crew acceptability rating than the use of freeze-dried food alone; however, the frozen foods present somewhat of a greater weight penalty than the freeze-dried foods because a freezer is required and some moisture is still in the food after freezing. Some disadvantages of frozen food are the following: possibility of spoilage if the freezer fails; contamination of the cabin atmosphere by bacteria from spoiled frozen food; and maintenance requirements of the freezer. The freeze-dried food does not require a freezer and would not present any of these problems. Freeze-dried foods have a shelf life of several years without deterioration. Small portions of freeze-dried food are reconstituted in hot water and probably will stay warm long enough to eat. An oven is furnished for preparing the food and a washer/dryer is allocated for cleaning the food utensils. Weight and volume statements for the food preparation equipment and utensils are listed in Tables 16 and 20, respectively. The food preparation utensils are used by a maximum of 8 crewmen because it is anticipated that all 12 men in the station will not eat at the same time.

D. Detergent

A cleaning agent is required for use in the water for body washing, clothes washing, and dish washing. The cleaning agent should meet such requirements as low foaming, nonflammability, nonclogging, nonprecipitating, nonallergenic, nontoxic, not gas producing, not odor producing, and 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 they foam to a degree that would cause trouble in use. Some detergents (soap in particular) are precipitating and would clog membranes.

Cationics are good bactericides, but are not good detergents. They produce foaming and can be allergenic and irritating to the eyes.

Nonionics detergents generally meet the system handling requirements. They are low foaming, effective in low concentrations, will not clog membranes, are nonprecipitating, and not bactericidal. The toxicity, allergenic properties, irritability, flammability characteristics in use concentrations are not known. Because of their desirable properties, the nonionics are recommended as the basic detergent with the additional recommendation that long-term toxicity, allergenic properties, flammability, etc. , be investigated thoroughly.

TABLE 16. SPACE STATION CREW SYSTEMS WEIGHTS (12 MEN ~ 90 DAYS)

Item	Quantity	Unit Size (in.)	Weight (lb) Subtotal		Volume (ft^3)	Power (W)
Food Preparation				1015.0		
Food Preparation Unit	2		90.0		6.0	200
Food Prep. H_2O Tank	4	18 by 13 Dia.	36.0			
Oven	2		30.0		6.0	200
Control, Oven Temp.	2		3.0			10
Washer/Dryer, Dishes	1		30.0		6.0	90
Utensils	(Table 20)		26.0		1.88	
Counters			34.0		19.0	
Food Storage Racks	1		172.0			
Food Freezer			594.0		103.0	
Internal Furnishings				1147.0		
Bunks and Bedding	(24 Men)		467.0			
Seats and Restraints	(12 Men)		270.0			
Living Compartment Furnishings	(12 Men)		400.0			
Stools	4		10.0			
Recreation and Exercise	(12 Men)			400.0		
Medical				164.0		
Medical Kit	2		60.0			
Emergency Medical Kit	2		4.0			
X-ray Machine	1		100			
Personal Effects				235.0		
Personal Hygiene	(Table 19)			335.0	31.0	
Clothing (Reusable)	(Table 18)			118.0	16.5	
Washer/Dryer with Clothes and Fan Ducts				110.0	10.00	
Bedding (4 lb/man-mo)				144.0		
Biovest Assembly	12			36.0		
Emergency O_2 Mask Assy	12			32.0		
Handtool Kits, Handtools, and Tethers	12			216.0		

TABLE 16. (Concluded)

Item	Quantity	Unit Size (in.)	Weight (lb)	Subtotal	Volume (ft^3)	Power (W)
Repair Kit				43.0		
Patches			5.0			
Sealant			5.0			
Connectors			12.0			
Wire			12.0			
Tools			2.0			
Miscellaneous			2.0			
Container			5.0			
Trash Containers				68.0		
Work and Sleep Areas	12	11 by 11 by 30	24.0			
Food and Waste Areas	2	11 by 11 by 33	38.0			
Main Containers	3	11 by 11 by 33	6.0			
Fire Extinguisher	12	8 by 8 by 24		76.0		
Entertainment Equip.				60.0		
Suit Donning/Drying/ Storage Rack	12			180.0		
Pressure Garment Assy (EVA Soft Suits)	24			1527.0	129.0	
Portable Life Support System	12	10.5 by 17.8 by 27		822.0	2.92	
EVA and IVA Supporting Equip				614.0		
Maneuvering Unit	12		72.0			
Umbilicals, EVA and IVA	18	720	360.0			
Umbilicals, Electrical and Communication	12	180	60.0			
Umbilicals, Intercom	18	36	18.0			
Illumination Equip	12		28.0			
Restraint Equip	12		76.0			
Crew Survival Kit				238.0		
Miscellaneous				350.0		500
Total				7929.0	340.2	1000

TABLE 17. PRESSURE GARMENT ASSEMBLY (SOFT SUIT) WEIGHTS

Item	Storage Dimensions (ft)	Storage Volume (ft^3)	Weight (lb)
Pressure Garment with Boots	1.0 by 1.5 by 1.5	2.25	24.70
Helmet with Communications	1.0 by 1.0 by 1.0	1.0	3.80
Fecal Contaminant System			7.50
IV Gloves			1.30
Relief and Purge Valve			0.25
EV Visors			3.50
EV Gloves			2.14
Thermal/Meteoroid Garment	1.0 by 1.0 by 1.0	1.0	8.92
Liquid Cooled Garment	1.0 by 1.0 by 0.5	0.5	4.2
Constant Wear Garment	1.0 by 1.0 by 0.5	0.5	3.56
Suit Maintenance Gear		0.13	3.75
Total		5.38	63.62

TABLE 18. REUSABLE CLOTHING WEIGHTS

Item	Quantity	Weight (lb)	L (in.)	W (in.)	H (in.)	Diameter (in.)	Volume (in.^{3})
Two-Piece Suit	24	36.0	12.0	8.0	4.0		9 216
Undershirts	36	7.92	7.75	6.0	1.625		2 720
Undershorts	36	7.92					
Socks	72	12.24	3.0			2.0	679
Shoes	24	54.0	12.5	8.75	6.00		15 750
Hankerchiefs	48	0.14	4.0			1.0	151
Total		118.22					28 516 or 16.50 ft^3

TABLE 19. PERSONAL HYGIENE WEIGHTS

Item	Quantity	Weight (lb)	L (in.)	W (in.)	H (in.)	Diameter (in.)	Volume (in.^{3})
Body Wipes (Reusable)	24	0.96	10.0	10.0	0.226		647.0
Toothbrushes	72	18.0	6.5	1.0	0.75	0.50	351.0
Dentrifice					2.50		
Hair Preparation	72	9.0	2.0	0.75	0.75		81.0
Antiseptic Cream	24	9.0	7.0	1.0	1.0		168.0
Skin Lubricant	144 (2 ea.)	54.0	7.0	1.0	1.0		1008.0
Body Deodorant	72	27.0	7.0	1.0	1.0		504.0
Dental Floss	12	1.50	2.0	1.0	1.0		24.0
Nail Clippers	12	1.50	2.0	0.75	0.75		14.0
Shaver	12	12.0	4.0	3.0	1.25		180.0
Hairbrush	12		3.0	2.0	0.75		54.0
Comb	12	1.50	6.0	1.0	0.125		9.0
Germicidal Powder	24	9.0	6.5	1.25	1.25		244.0
Beard Preparation	24	9.0	4.0	0.75	0.75		54.0
Cleaning Sponges	432	26.78	3.0	1.0	3.0		3888.0
Bags	26	5.98	9.0	4.0	0.75		27.0
Bath Towels	24	18.0	30.0	18.0	0.266		3449.0
Hair Clippers	2	3.98	9.0	3.0	4.0		216.0
Sewing Kit	6	1.128	4.0	3.0	0.25		18.0
Toilet Tissue	107	27.0			4.5	4.5	30 618
Shower	1	100.0					12 096
Total		335.33					53 650 or 31.0 ft^3

TABLE 20. FOOD PREPARATION UTENSILS

Item	Quantity	Weight (lb)	L (in.)	W (in.)	H (in.)	Diameter (in.)	Volume (in.^{3})
Tray	8	13.28	15.5	11.5	0.625		891.25
Knife, fork, spoon	8	1.52	6.63	1.13	1		59.94
Cup	8	1.60			2.25	4.5	286.28
Can Opener, Hand	1	0.08	5.75	1.25	0.75		5.39
Cooking Fork	1	0.25	13.0	0.75	0.63		6.09
Ladle (4 oz)	1	0.313	15.0	0.75	2		22.5
Butcher Knife	1	0.313	13.0	1.5	0.75		14.63
Pitcher (2.75 qt)	2	1.562			8.32	5.88	451.86
Salt & Pepper Shakers	2	0.22	5.5	2.75	3.75		113.44
Sharpening Stone	1	0.82	6.0	2.0	1.0		12.0
Turner	1	0.44	14.25	3.0	2.75		1.756
Pan and Cover (8 qt)	1	2.189			7.88	10.63	698.23
Tablespoon	2	0.18	7.25	1.56	1.0		22.66
Skillet and Cover	1	1.72			4.5	9.75	427.78
Brush, Scrubbing	3	1.032	9.0	2.5	1.75		118.14
Total		25.52					3131.95 or 1.81 ft^3

SECTION X. SUIT LOOP/PORTABLE LIFE SUPPORT SYSTEM (PLSS)

The suit loop/PLSS provides the crew with a capability of operations either within the Space Station or outside the Space Station; however, the suit loop is provided primarily for the crew to use while in their space suits inside the Space Station. The freedom of movement required inside the Space Station while correcting an emergency condition must be met by providing long umbilicals and numerous pressure suit connectors throughout the Space Station. The umbilicals are interconnected directly to the pressure suit by quick-connect couplings. The system also provides emergency oxygen, coolant, and pressurization for the suits, and operates nominally at a suit pressure of 3.5 psi above ambient. Atmospheric contaminants, such as carbon dioxide, odors, etc., are removed within the loop. Twenty-four EVA suits are provided for the 12-man regular crew and 12-man turnaround crew. A preliminary weight breakdown of the suit loop is shown in Table 21.

The PLSS could be used during emergency situations, such as fire, contamination of the space station atmosphere, or depressurization. However, because of its limitations, the PLSS should be used essentially as a backup system and used primarily internally or externally to the station in selected emergency conditions. Twelve PLSS units provide redundancy for the 12-man regular crew. Table 22 lists the PLSS weights.

TABLE 21. SUIT-LOOP WEIGHT BREAKDOWN

Component	Number Required	Weight (lb)	Power (W)
Debris Trap	3	5.4	
Shutoff Valve	6	7.5	
Compressor	6	15.9	
CO_2 Absorber Filter	6	28.2	
CO_2 Absorber Canister	3	53.1	
Bypass Valve	3	0.15	
Fan	3	3.75	
O_2 Demand Pressure Regulator	3	8.4	
Suit Hose Connector Assy	27	35.1	
Flow Limiter	27	5.4	
Temperature Sensor	3	0.15	
Signal Conditioner	3	0.9	
Dew Point Sensor	3	34.2	
PCO_2 Sensor	3	7.8	
Pressure Transducer	3	0.15	
O_2 Purge Valve	3	0.9	
Contingency		103.0	—
Total (Overall)		310.0	100

TABLE 22. PLSS WEIGHTS

Item	Weight(lb)
PLSS Basic (Incl. Antenna)	49.51
Battery — Prime	5.09
LiOH Cartridge	4.38
Oxygen	1.06
Water	8.43
Total	68.47

SECTION XI. EXPENDABLE REQUIREMENTS

Expendable philosophy has been established to store at least a 180-day supply on board the Space Station for reserves. This would be accomplished by launching 90 days of expendables on both the initial Space Station launch and the first manned launch, which occurs approximately 24 hours later. The amount of expendables is based on the needs of the 12-man crew and would be resupplied to the Space Station every 90 days.

All expendables on the initial and logistics flights are described in terms of fluid requirements and composite expendable/container weights. Gaseous consumables (O_2 and N_2) for such activities as EVA, initial and emergency pressurizations, and pump-down gas losses are depicted on Table 23. Table 24 reflects the consumables (O_2 and N_2) stored cryogenically for metabolic and leakage purposes.

A summary of Space Station expendables plus containers (22 193 pounds) is given in Table 25. Included are food, water, oxygen, nitrogen, and packages or containers for a 90-day space operation. Three AAP tanks are provided to contain the cryogenic oxygen (1200 pounds) and nitrogen (1552 pounds) consumables. The gaseous consumables will require three new tanks for oxygen (1074 pounds) and 12 Apollo He tanks for nitrogen (3678 pounds). An additional 148 pounds of nitrogen can be added in the present tankage.

The expendable usage rates are given in Table 25.

TABLE 23. ATMOSPHERIC STORAGE SYSTEM TOTAL GASEOUS FLUID REQUIREMENTS (90 DAYS — 12 MEN)

Requirement	Fluid Weight (lb)	
	O_2	N_2
EVA (80 manhours @ 0.25 lb/hr)	20	
Initial Space Station Pressurization (34 195 ft^3)	594	1958
Emergency Space Station Pressurization (1)	594	1958
Pump-down Gas Losses	90	79
Gas Losses for Maintainability (23 percent more)	299	919
Experiment Chamber Pressurization	74	245
Contingency	150	516
Overall Requirements	1821	5675
Less Initial Pressurization Gases	-594	-1958
Gaseous Storage	1227	3717

TABLE 24. ATMOSPHERIC STORAGE SYSTEM TOTAL CRYOGENIC FLUID REQUIREMENTS (90 DAYS — 12 MEN)[a]

Requirement	Fluid Weight (lb)	
	O_2	N_2
Space Station Leakage	399	1311
Initial Start-up (1-Day Metabolic for 12 Men)[a]	20	
10-Day Reserve (Metabolic for 24 Men)[a]	403	
10-Day Reserve (Leakage)	44	146
Crew Rotation	101	
Contingency	80	146
Overall Requirements (Cryogenic Storage)	1047	1603

a. Except as noted

TABLE 25. SPACE STATION EXPENDABLE SUMMARY (90 DAYS — 12 MEN)

Expendable	Weight (lb)		Cryogenics (lb)	Gaseous (lb)
Freeze-Dried Food (1.58 lb/man-day)[a]	853			
Frozen Food (3.0 lb/man-day)[a]	1620			
H_2O (Initially stored)	3615			
O_2 (Metabolic)	423	2274	1200[c]	1074
O_2 Leak, Pressurization Reserve, Etc.[b]	1851			
N_2 Leakage[b]	1311	5320	1552[c]	3768
N_2 Pressure, Reserve, Etc.	4009			
Total	13 682		2752	4842

Containers for	Type and Size	No.	Weight/ Container (lb)	Total Container Weight (lb)	Total Weight, Container and Expendables (lb)
Freeze-Dried Food		?	?	108	961
Frozen Food		?	?	162	1782
H_2O	New Tanks (40.0-in. I.D.)	3	95	285	3900
O_2 Cryo. (90 Days)	AAP Tank (41.5-in. Dia)	1	334	334	1534
O_2 Gaseous	New Tanks (40.9-in. Dia)	3	750	2250	3324
N_2 Cryo (90 Days)	AAP Tank (41.5-in. Dia)	2	334	668	2220
N_2 Gaseous	Apollo He Tank (40.9-in. Dia)	12	392	4704	8472
Total				8511	22 193

a. 45 days of food

b. Leakage rate (total configuration) assumed = 19.0 lb/day

c. 0 lb of O_2 and 148 lb of N_2 can be added

REFERENCES

1. Hamilton Standard: Tradeoff Study and Conceptual Designs of Regenerative Advanced Integrated Life Support Systems (AILSS), Contract NAS 1-7905, July 1969.

2. Farrow, J. H.: Orbiting Space Station Acoustic Criteria. MSFC Memorandum S&E-ASTN-ADV-69-14, June 20, 1969.

3. Douglas Aircraft Corporation: Early Orbital Space Station (EOSS). Contract NAS 8-21064, November 1967.

BIBLIOGRAPHY

A Common Mission Module for Both Orbital and Planetary Applications. MSFC IN-P&VE-A-68-1, January 15, 1968.

Wells, Hubert B.: Preliminary Subsystems Design Study of the S-IVB Advanced Workshop and Early Orbital Space Station. MSFC IN-P&VE-A-67-7, October 31, 1967.

North American Aviation, Inc.: Manned Planetary Flyby Missions Based on Saturn/Apollo Systems. Final Report, Volume 6, Subsystems Analysis, Contract NAS8-18025, Report SID-67-549-6-1.

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ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM (EC/LSS) FOR THE 1975 SPACE STATION

By Hubert B. Wells

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This document has also been reviewed and approved for technical accuracy.

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