STUDY AND ASSESSMENT
OF
ADVANCED ETC/LSS APPLICATION
TO
SPACE SHUTTLE

FINAL REPORT

BY

CHARLES L. BEAL

PREPARED UNDER CONTRACT NAS 9-13964

BY

HAMILTON STANDARD

DIVISION OF UNITED AIRCRAFT CORPORATION

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ABSTRACT

STUDY AND ASSESSMENT OF ADVANCED ETC/LSS APPLICATION TO SPACE SHUTTLE

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This report describes a study that was performed to evaluate a variety of advanced life support components and subsystems that were developed under NASA contract to determine their potential application to the Space Shuttle Orbiter and related vehicles.

FOREWORD

This report was prepared by the Hamilton Standard Division of United Aircraft Corporation for the National Aeronautics and Space Administration's Lyndon B. Johnson Space Center in accordance with the requirements of Contract NAS 9-13964, Study and Assessment of Advanced ETC/LSS Application to Space Shuttle. The period of performance for the program was May 1974 through April 1975. The objective of the program was to determine those technology advancements which merit consideration for incorporation in the Shuttle ETC/LSS baseline or which merit additional development for future mission requirements. For purposes of this study, the Shuttle baseline ETC/LSS configuration was that which existed as of December 31, 1974.

All measurements and calculations contained in this report are expressed in SI (metric) units. Conventional units are given in parentheses.

Personnel responsible for the conduct of this program were Mr. C. L. Beal, Program Manager, Mr. H. F. Brose, Engineering Manager, Mr. C. Flugel, Design Engineer, and Mr. E. Tepper, Analytical Engineer. Appreciation is expressed to Mr. F. Collier, Technical Monitor for NASA-JSC, whose guidance made the successful completion of this program possible.

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INTRODUCTION

Recent ETC/LSS developments, accomplished under contract to NASA, have produced a variety of advanced life support components and subsystems that have potential application in the Space Shuttle Orbiter. These developments were undertaken to satisfy the Shuttle's requirements for low weight, simplicity, high reliability, high rate of reusability, maintainability and quick turnaround capability. The purpose of this study was to evaluate each of the advancements in detail for application to the Space Shuttle and/or associated payloads. The objective was to determine which of the technology advancements should be considered for incorporation in the Shuttle ETC/LSS baseline and/or which areas merit additional development for future mission requirements.

The technology areas considered in this study were specified in contract, NAS 9-13964 as was the general study methodology. For each of the eleven (11) technology areas defined in the contract, a preliminary assessment was performed. These studies included definition of the subsystem requirements, a description of the Shuttle baseline presently performing the function, a description of the advanced concepts and comparison and evaluation of the concepts considering their potential applications. Based on the results of the preliminary assessment task, NASA selected six (6) of the eleven (11) advanced technology concepts for the detailed assessment task.

Using the preliminary assessment as a point of departure, the selected concepts were studied by generating definitive engineering data to determine which concepts can be cost effective and/or will, by their incorporation into the Space Shuttle or Shuttle related vehicle, be beneficial in such areas as weight, volume, crew handling, power and ease of refurbishment. The goal of the detailed assessment was to make a realistic assessment of the actual technical and programmatic impact of incorporating the advanced technology concept.

SUMMARY

A study was performed to evaluate eleven (11) advanced ETC/LSS concepts for application to the Space Shuttle Orbiter or Shuttle Related vehicles. The concepts were screened by means of a preliminary assessment task to select those which appeared most advantageous, on the basis of current mission requirements, considering performance, state of development and programmatic impact. The selected concepts were then studied in depth in the detailed assessment task.

The following concepts were selected for the detailed assessment task:

- Iodine Biocide Generator with Iodine Sensor
- Lightweight Long Life Heat Exchanger
- Regenerable CO_2 and Humidity Control System
- Compression Distillation Water Reclamation System
- Waste Sampling and Measurement System
- Hydrogen Depolarized Concentrator/Water Vapor Electrolysis Unit

Those concepts not selected for the detail assessment task were:

- Flash Evaporator
- Chemical Nitrogen Supply
- Regenerable Filter
- Two Gas Controller Using Mass Spectrometer
- Hydrogen Depolarized Concentrator

CONCLUSIONS AND RECOMMENDATIONS

Advanced Technology Subsystem & Function	NASA-JSC Contract	Contractor	Study Conclusions	Potential Applications	Recommendations
• Iodine Biocide Generator with Iodine Sensor	NAS 9-13931 K. Houck 713-483-5536 NAS 9-14298 R. Sauer 713-483-5191	Life Systems R. Wynveen 216-464-3291 Beckman J. Walsh 714-997-0730	• Provides excellent back-up for Silver Bromide • Competitive on fixed weight and size basis • Power penalty of iodine sensor of 1.4 kg (3.0 lbs) adds to total equivalent weight.	• Shuttle • Future long duration Spacecraft (Silver may not be acceptable for use in Water Reclamation Systems)	• Continue development of generator and sensor as a back-up for Shuttle. • Investigate concepts to reduce power. • Evaluate in a potable water loop (possibly as a future upgrade to RSECS)
• Lightweight Long Life Heat Exchanger	NAS 9-13552 F. Collier 713-483-2171	Hamilton Standard F. Greenwood 203-623-1621 Ext. 2111	• Will be physically and functionally interchangeable with Shuttle ARS condensing heat exchanger • Will save 8.3 kg (19.3 lbs) • Development/retrofit justified based on cost effectiveness.	• Shuttle condensing heat exchanger. • Other Shuttle heat exchangers • Spacelab • Long duration manned Spacecraft • Aircraft heat exchangers	• Design, build, and test a prototype condensing heat exchanger for the Orbiter ARS. • Conduct a materials compatibility program with aluminum and steel in a heat transport loop. • Evaluate in RSECS.
• Compression Distillation Water Reclamation System	NAS 9-9191 W. Revely 713-483-5536	Chemtric R. Bambenek 312-671-2755	• Superior to stored water for long duration missions. • Definition of physical and functional parameters Including: Weight, size, power and packaging.	• Long duration Spacecraft.	• Continue development activity for extended mission use.
• Regenerable CO_2 and Humidity Control System	NAS 9-13624 R. Cusick 713-483-5536	Hamilton Standard F. Greenwood 203-623-1621 Ext. 2111	• Equal to LiOH in total equivalent weight for baseline mission. • Saves cost after 3 years of operational life • Superior to LiOH for larger crew sizes and mission durations.	• Shuttle Orbiter ARS • Spacelab ARS • Spacelab Life Sciences Payload	• Redirect breadboard system program to optimize canister design configuration for Shuttle Orbiter ARS (Single canister). • Evaluate breadboard system in RSECS. • Initiate development of flight prototype system for Shuttle.

Figure 1. Conclusions and Recommendations

FOLDOUT FRAME 1

CONCLUSIONS AND RECOMMENDATIONS (CONTINUED)

Advanced Technology Subsystem & Function	NASA-JSC Contract	Contractor	Study Conclusions	Potential Applications	Recommendations
• Waste Sampling	NAS 1-1143 R. Sauer 713-483-5191	General Electric R. Murray	• Urine system believed feasible • Feasibility of feces sampling not proven	• Shuttle • Spacelab • Space Station • Earth based Environmental Systems	• Continue development of present urine concept. • Evaluate new concepts for feces sampling. • Develop feces sampling concept(s). • Design, build, and test flight prototype unit. • Implement for manned Spacecraft.
• Hydrogen Depolarized Concentrator/Water Vapor Electrolysis	NAS 9-13679 N. Lance 713-483-5536	Hamilton Standard F. Greenwood 203-623-1621 Ext. 2111	• Definition of physical and functional parameters including: weight, size, power, and packaging. • Superior to LiOH for missions with solar cell power supplies.	• Long duration vehicles with solar cell power supplies. • Submarine ECS (HDC)	• Continue research and development effort to gain understanding of cell function and to improve HDC electrode efficiency and endurance life. • Conduct program to investigate utilization of HDC power for the Spacecraft system. • Initiate Shuttle flight experiment program for a small scale (1-man size) HDC/WVE system, to verify system performance in zero-g.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Figure 1. Conclusions and Recommendations (Continued)

IODINE BIOCIDE GENERATOR WITH IODINE SENSOR

Summary

All potable water available on the Space Shuttle Orbiter, except for that initially loaded preflight, will be supplied by fuel cells. The water will be used for consumption, personal hygiene and as an expendable evaporant for system cooling system. NASA specifications for potable water require that the water be sterile throughout the course of the mission necessitating the use of a microbiological elimination technique in the water supply system.

Acceptable biocide levels may be achieved utilizing treatment with chemicals having biocidal properties. The current Shuttle baseline concept employs silver bromide (Ag Br) and requires that the silver ion concentration in the water leaving the bactericide system be maintained between 50 and 100 parts per billion (ppb). An alternate approach utilizes iodine I_2, as the bactericide and requires an iodination level between 1 and 5 parts per million (ppm). For both systems lower concentrations result in questionable biocidal treatment while higher levels impact human factors such as palatability or physiological side effects.

On a total equivalent weight basis, the silver bromide and iodine concepts are essentially equal. The power weight penalty of iodine concept is 1.4 kg (3.0 lbs) which represents 14 percent of the total equivalent weight of the iodine concept and is an area worthy of further investigation. Neither concept offers a refurbishment advantage since both chemical requirements for multiple missions are minor in comparison to total concept weight and volume. The current filter life limitation (30 days) of the Ag Br system is expected to be significantly extended as experience is gained in "real world" fuel cell operation.

Because neither the silver bromide or iodine concepts have proven capability for application to the Shuttle, continued development of iodination technology is warranted as a potential backup. The iodination concept fulfills a need on long duration, manned missions such as a space station. Such missions would utilize solar cells for power, necessitating waste water reclamation so water can be recycled. However, silver bromide may be unsatisfactory for treating water where such ions as chloride and ammonium may be present. Chloride depresses the biocide concentration, and ammonium elevates it. Thus, the biocide could be either ineffective (low concentration) or toxic (high concentration). These conditions could be guarded against by adequate monitoring and control but recent work on silver ion concentration measurement has been discouraging. Furthermore, potential microbial contamination from waste water sources (i.e., urine and wash water) is much greater than from fuel cell produced water. Silver ions are not sufficient to control microbial growth from waste waters. Thus, there is a need for a stronger, more versatile biocide. Iodine has these characteristics.

Development of the iodination concept should continue, primarily as a backup for the Shuttle silver bromide concept and secondly to meet the biocide requirement for a space station mission.

Power consumption of the iodination monitor/controller is the major negative factor in this evaluation. Sources of power consumption are being identified so that power demand may be reduced.

Technical Description

Requirements

The biocide system must process water from the fuel cell with the following constraints:

Water Flow Rate:

Minimum:	22.7 cc/min (3 lbs/hr)
Maximum:	172.5 cc/min (22.8 lbs/hr)
Average:	98 cc/min (13 lbs/hr)
Total:	13.95 liter/mission (1850 lbs/mission)

Water Inlet Temperature:

Maximum: 71°C (160°F)

Pressure Drop:

Maximum: 10.3×10^3 pascal at 172.5 cc/min (1.5 psid at 22.8 lbs/hr)

Trace Contaminants:

1 mgm/Liter

Solids:

Particle Size (microns)	No. Particles/500 ml fluid
0-10	Unlimited
10-25	1000
25-50	200
50-100	100
100-250	10

Subsystem Description

Iodine in the dosages required for biocidal action has most of the characteristics desirable for chemical treatment of water in space. An electrochemical device to inject I_2 into spacecraft water supply and a colorimetric device that detects and measures iodination levels are currently under development. Combining these devices produces an automated water iodinating subsystem (AWIS).

Figure 2 schematically illustrates the functional elements of the I_2 generator subassembly. A slurry of I_2 crystals and water is stored in the accumulator; an electrolytic "valve" controls the flow of I_2 from the storage to the water system; and a compartment is provided for dispensing the I_2 to the water being treated. The "valve" is an ion exchange membrane sandwiched between two platinum electrodes which functionally separates the I_2 slurry from the potable water system while transferring the desired quantity of iodide ion (I^-).

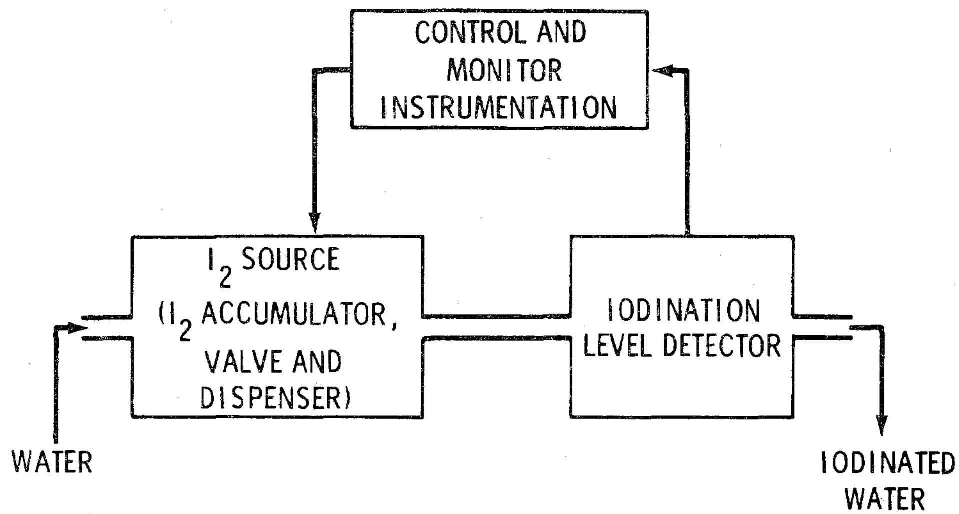
The life limiting item for this concept is the quantity of I_2 slurry contained in the system. Treatment of 839 liters of water (1850 lbs) per 7 day mission to 5 ppm I_2 requires 4.19 gms of I_2 which occupies a volume of 0.85 cu. cm (.052 in^3). These values are sufficiently small so that multimission recharges produce minimal weight/volume impact on the system. The system will contain 91 grams of I_2 per generator, a quantity sufficient for treatment of 18263 liters (40,270 lbs) water or 22 Shuttle missions at a 5 ppm level or 55 missions at a 2 ppm level.

The iodination level monitor subsystem consists of a spectrophotometric cell including its optical system plus electronics necessary to convert the variation in light wave-length intensity (a function of iodination level) into a signal that can be used to regulate the quantity of I_2 flowing through the electrolytic valve. Figure 3 is a schematic of the optical system and photometric cell.

Instrumentation provides hands-off operation while processing the signal from the iodination level monitor thru control logic that regulates the valves power supply. The system provides positive and automatic iodination level control in a fail-safe manner for every identifiable operating mode. A Failure Mode Effect Analysis (FMEA) has been performed on the iodination system.

Design Data

The values presented herein for weight, power, and size are forecasted estimates of what is believed achievable assuming continued development. The generator weight is estimated at 0.9 kg (2.0 lbs) and the I_2 Sensor and Electronics is estimated at 0.9 kg (2.0 lbs).



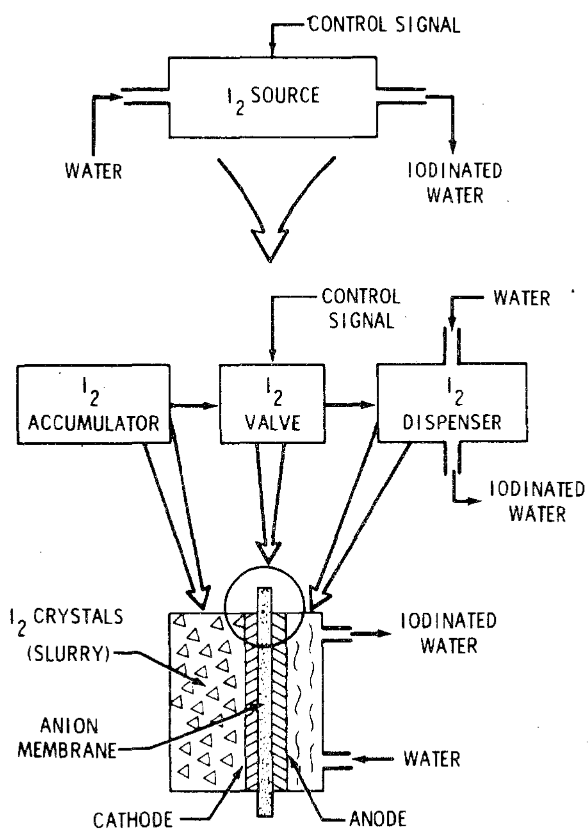


FIGURE 2. IODINE GENERATOR ASSEMBLY

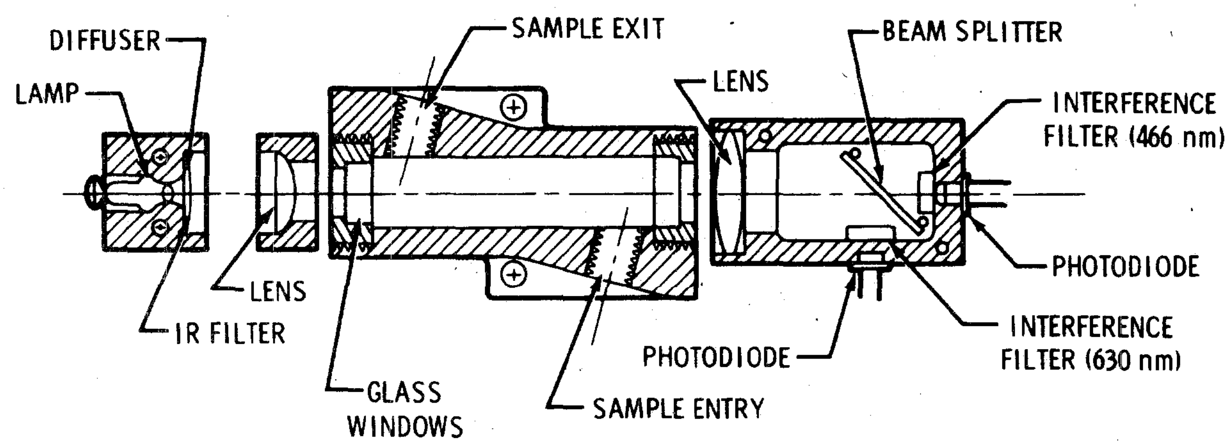


FIGURE 3. IODINE SENSOR OPTICAL SYSTEM AND PHOTOMETRIC CELL

Power to operate the electrolytic I_2 valve in the generator is nominally 30 milliwatts and 112 milliwatts maximum. Power for the sensor is estimated at 6 watts, including power conditioning for both valve and sensor electronics.

The physical size of the integrated generator sensor is shown in figure 4. The unit has a total volume of 1485 cm^3 (86 in^3).

Vehicle Integration

Baseline System

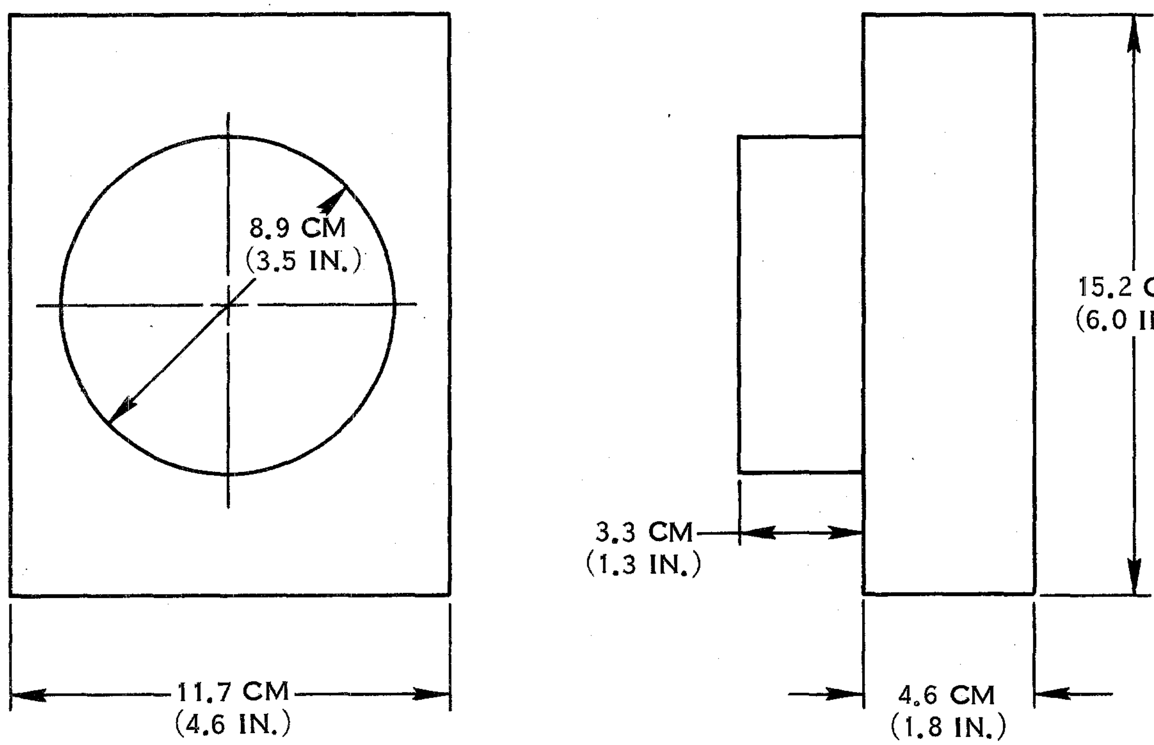
Figure 5 illustrates the design of the baseline silver ion water bactericide canister. It consists of a two-piece 316 stainless steel housing fastened by a v-band clamp, a filter cartridge, and a column of mixed silver bromide and activated charcoal granules. Maintainability for re-use of the system is provided by quick disconnects.

Fuel cell water enters the cartridge via an inlet port and is distributed by a manifold into the housing. The water then flows radially through the filtering element, axially through the silver bromide/activated charcoal column and finally exits through the outlet port. The filter is required to prevent plugging of the central column and is sized for a 10 micron rating since smaller particles will pass through the packing. This feature is not required in the iodine concept since filtration is not required for iodine performance and there is no present requirement to filter the potable water. The activated charcoal particles are required to separate the silver bromide granules to prevent their reaggregation.

Figure 6 shows a schematic of the baseline biocide subsystem as it is integrated into the Shuttle water management subsystem. Fuel cell product water passes first through a water chiller which reduces the temperature to 65-75°F. This results in a passive form of concentration control because the AgBr solubility at this temperature level is between 50 and 100 ppb. Flow next passes through the on-line generator before delivery to the potable water storage tanks.

The standby unit is normally isolated by means of a manual shutoff valve. A delta pressure sensor located from inlet to outlet on the on-line generator provides an indication that the filter is becoming clogged. The standby generator is activated by turning the manual shutoff valve.

Current specifications permit routine canister change-out at the end of each seven day mission but the existing filter design has the capacity for thirty days and will be tested for three seven day missions. The filter is the life limiting component in the system since the chemical quantity is sufficient for up to six months. Reduced particulate levels in the inlet water could significantly extend maintenance change-out.



ADVANCED COMBINED IODINE DISPENSOR/DETECTOR
(1975 DEVELOPMENT)

FIGURE 4. INTEGRATED GENERATOR/SENSOR

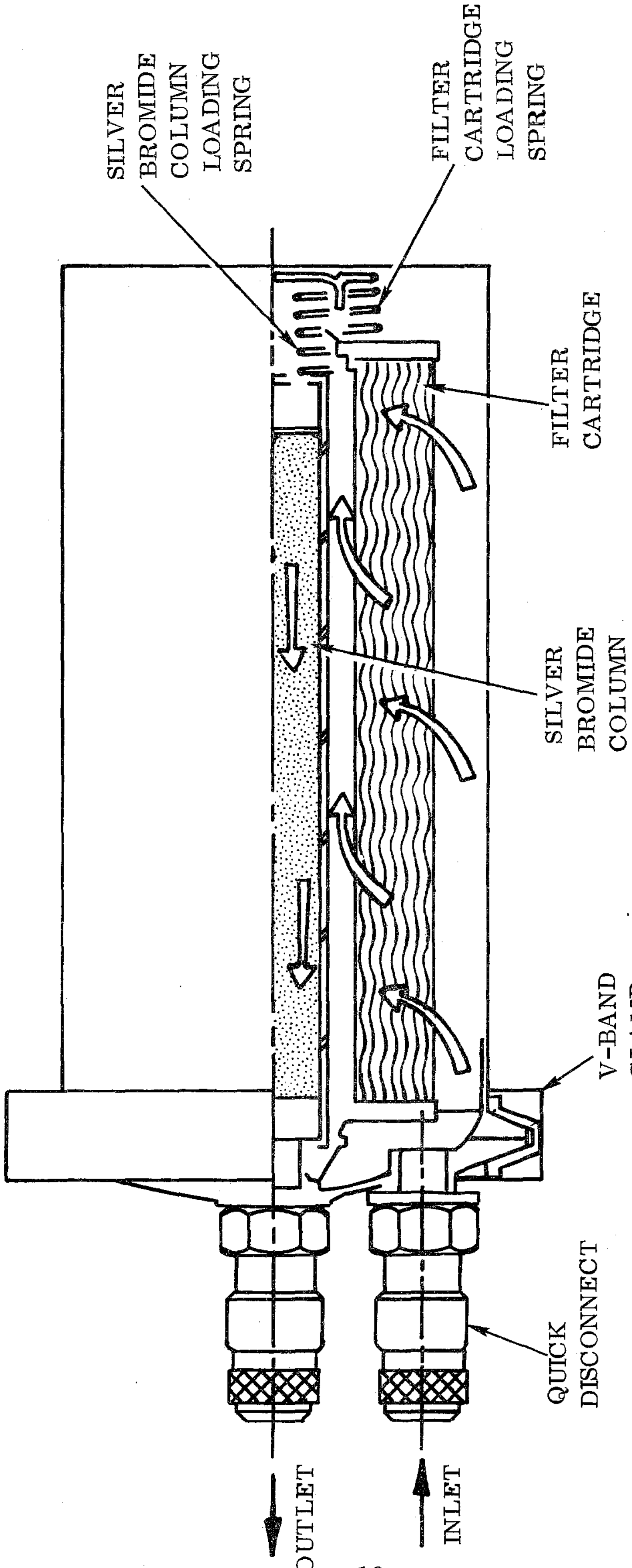


FIGURE 5. SILVER ION BACTERICIDE GENERATOR

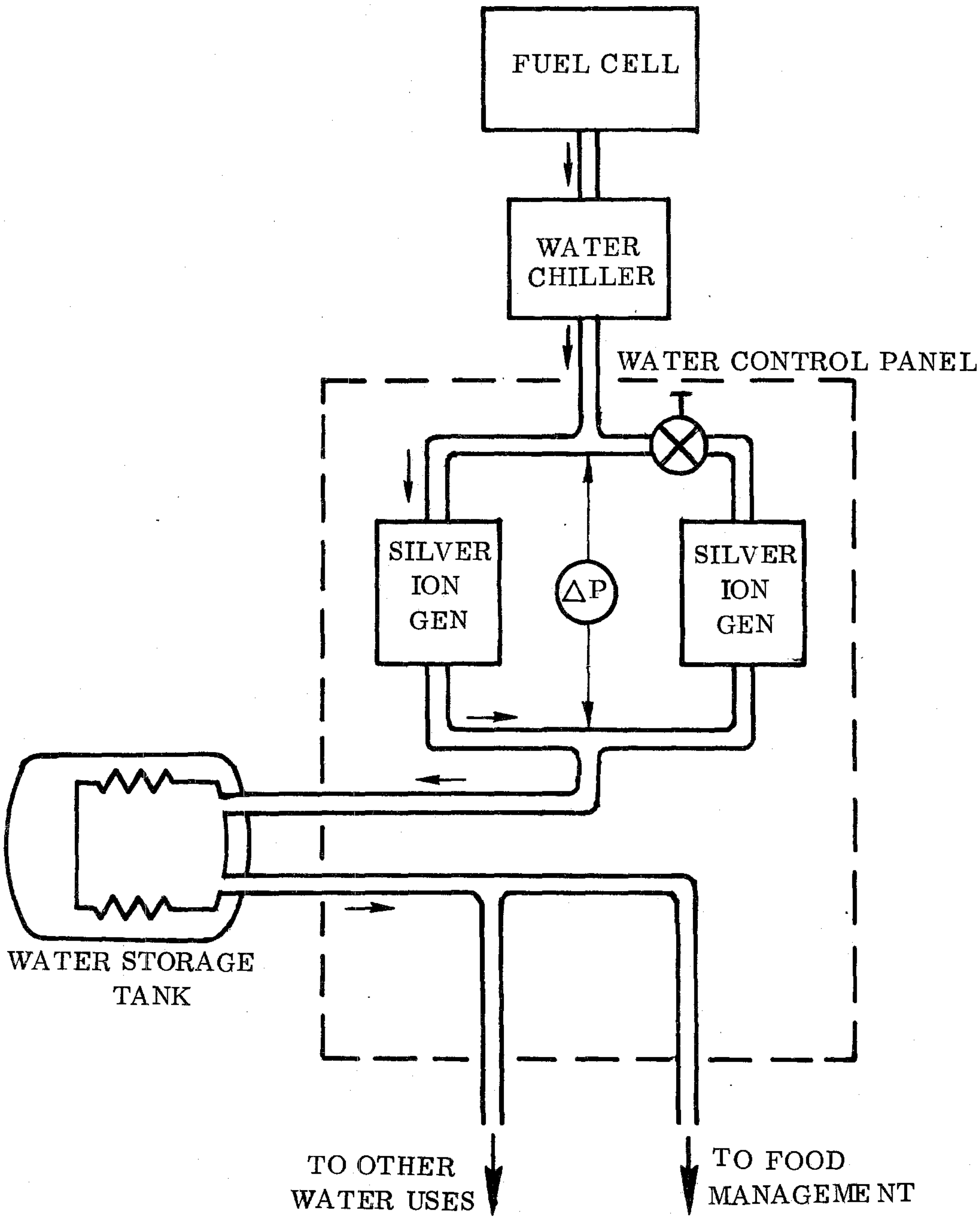


FIGURE 6. BASELINE BIOCIDE SUBSYSTEM SCHEMATIC

The system design does not protect against channeling or internal bypass since no active concentration monitoring is available. Also, the absence of isolation valves prevents the shutoff of a leaking or channeling unit. Incorporation of a concentration monitor (already included in the I_2 design) is currently under development.

Vehicle Considerations

A schematic of the iodine biocide generator with iodine sensor is shown in figure 7. Water flows directly from the fuel cell to the water control panel where is passes through the automated water iodination subsystem. Two I_2 subsystems are positioned in parallel in the fuel cell water discharge line and feed the water storage facility. Two three-way valves are utilized to isolate the standby system and place on-line the activated system. Water then flows to the water tanks. Each generator subsystem has an associated iodine concentration sensor which performs two functions: (1) provide a signal to the generator so as to maintain the proper iodine concentration, (2) provide a signal whereby the crew can monitor the iodine concentration of the water leaving the subsystem. The crew will thereby be alerted to a failed subsystem and be able to manually switch to the standby system.

A third monitor/controller is located downstream of the storage tanks in the potable water line, near the water use ports. This instrumentation is used to confirm I_2 levels in the use water and detect back contamination from the use point. Any corrective action required as a result of a discrepancy noted at the use point will be accomplished by manually resetting the on-line I_2 generator system.

The iodine system can meet the performance requirements over a large inlet temperature range and, as a result, a water chiller is not required. This represents a 2.2 kg (4.9 lb) savings to the iodine system.

Vehicle Packaging

The biocide systems are packaged within the water control panel. The silver and iodine systems are illustrated in figures 8 and 9 respectively, and their overall dimensions are compared below:

	Iodine		Silver Biocide	
	cm	in	cm	in
Length	55.1	21.7	52.6	20.7
Width	43.2	17.0	43.2	17.0
Height	14.0	5.5	14.0	5.5

Although the iodine package is slightly larger, the presently available Orbiter envelope will accommodate either package.

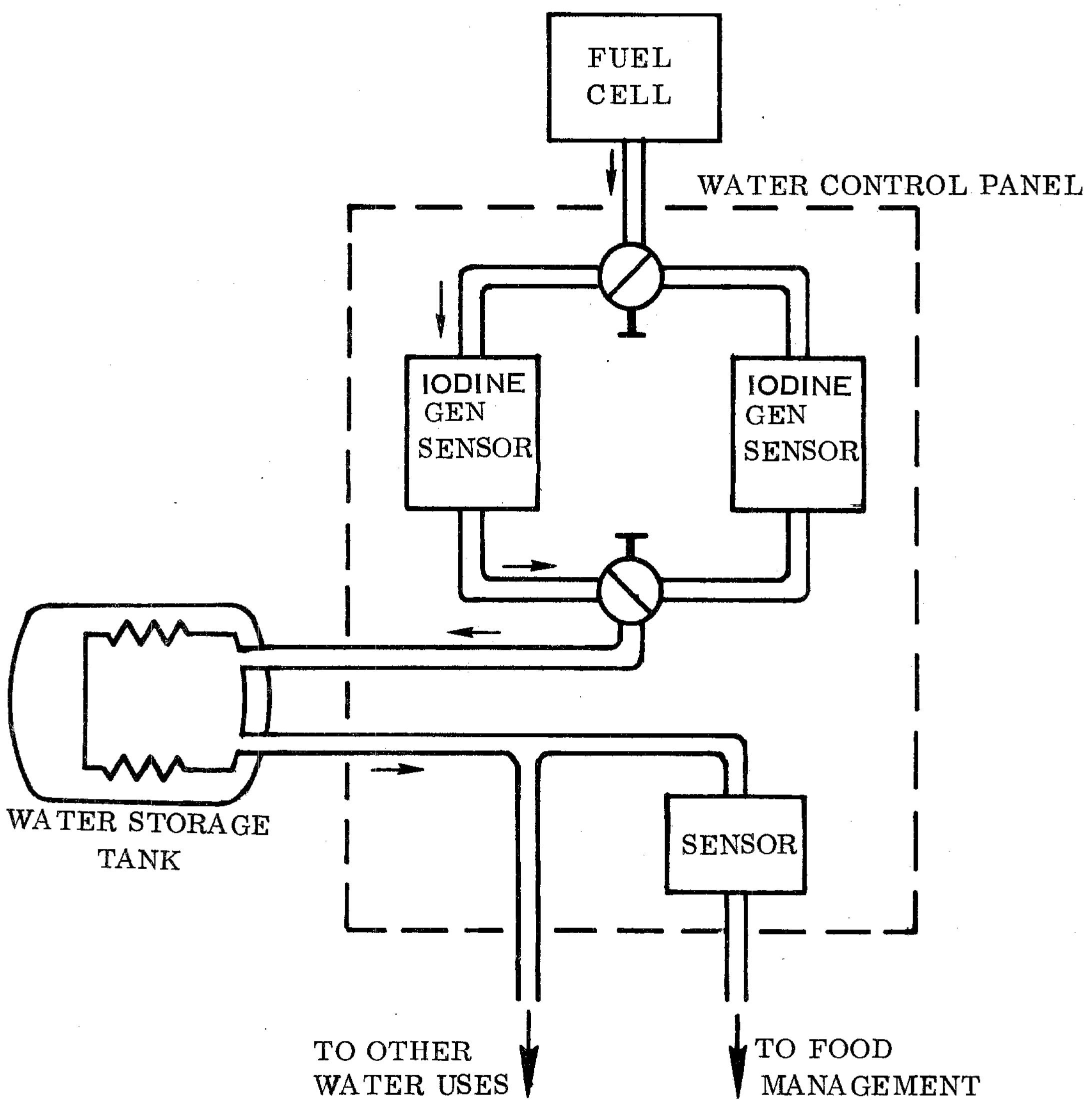


FIGURE 7. IODINE BIOCIDE SUBSYSTEM SCHEMATIC

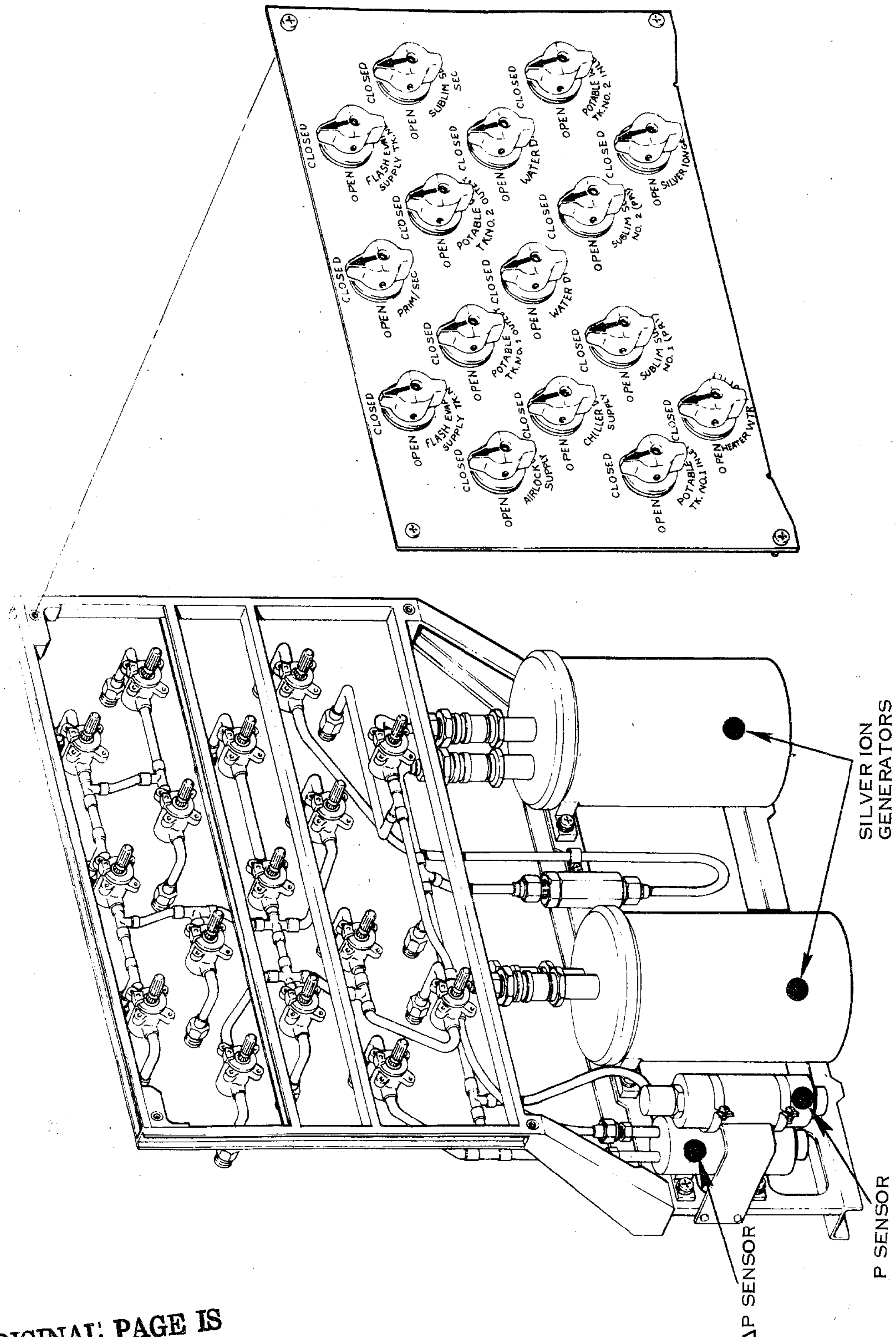


FIGURE 8. SILVER ION GENERATOR CONTROL PANEL

ORIGINAL PAGE IS OF POOR QUALITY

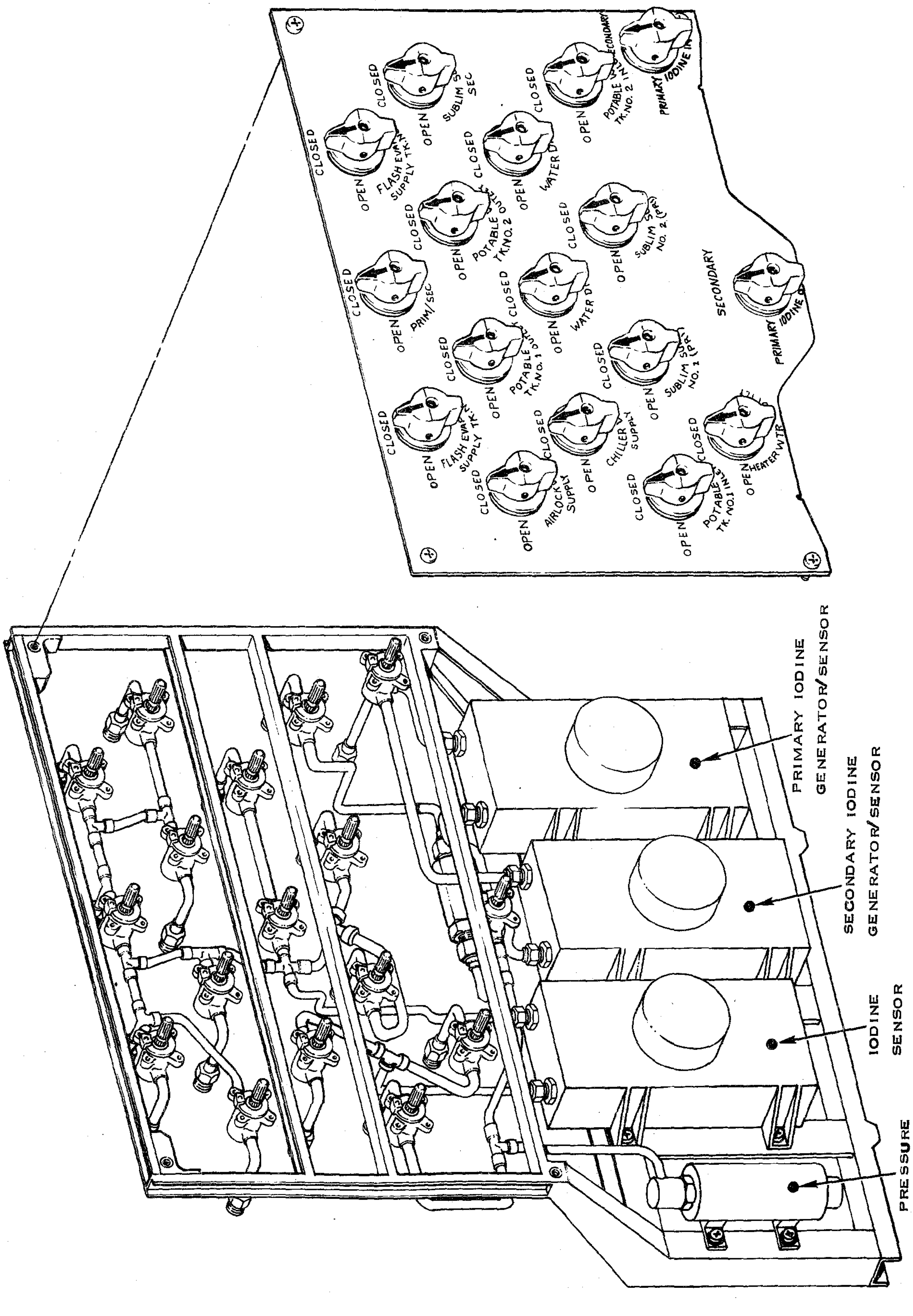


FIGURE 9. REVISED WATER CONTROL PANEL

WEIGHT TRADE-OFF

	Silver Bromide		Iodine	
	kg	(lbs)	kg	(lbs)
Biocide Generator (2)	4.1	(9.0)	1.8	(4.0)
Biocide Sensor (3)	-	-	2.7	(5.9)
Panel, Valves, and Sensor	4.1	(9.0)	3.8	(8.4)
Water Chiller	2.2	(4.9)	-	-
TOTAL	10.4	(22.9)	8.3	(18.3)

The power equivalent weight of iodine system was estimated at 1.4 kg (3.0 lbs) as follows:

2 Sensors x 6 Watts/Sensor = 12 Watts continuous

12 Watts x .114 kg/Watt = 1.4 kg (3.0 lbs)

Programmatic Impact

Shuttle Status

The silver ion generator is presently being developed by Chemtric under Rockwell contract. The generator is a component within the water control panel for which Rockwell is presently in the process of awarding a contract.

State of Development

The iodine biocide generator is presently being developed by Life Systems under contract NAS 9-13931. The current phase of the program is planned for completion in early 1975. The iodine sensor is presently being developed by Beckman under contract NAS 9-14298. The current phase of the program is planned for completion in mid 1975. An advanced combined iodine dispensor/ detector, whose expected physical characteristics have been reported in this section is being identified.

Tests have been made in the presence of I_2 with tubing materials typical of those to be used in the Orbiter Water Management System. The tests indicated that I_2 levels could be maintained above 0.5 ppm(the lower limit used in the Apollo LM) at a 5.0 ppm set point provided the tubing is preflushed with the iodine solution. Thus, recirculation and the attendant tank recirculation pump will not be necessary if prelaunch ground operations include iodine flushing procedures.

Schedule Impact

Implementation of a change to the Shuttle program to incorporate the iodine biocide generator and sensor can be incorporated with relatively minor vehicle impact when the basic generator and sensor technology is fully developed. This can be accomplished by retrofitting the water control panels by replacing the two silver ion generators with two iodine generators, three iodine sensors and the associated valving and plumbing. The modified panel could have the same mounting provision and fluid connections, and nearly the same total volume as the baseline panel with the silver ion generator. Minor changes would be needed to the electrical interface to provide power to the iodine generator and sensor. The above changes could be incorporated by means of a retrofit at any time in the program after the iodine generator and sensor are developed without interference with the mainstream Shuttle development or flight program.

References

1. Brose, H. F.; Greenwood, F. H.; Thompson, C. D.; and Willis, Noel C.; The Representative Shuttle Environmental Control System; ASME 74-ENAS-52; August, 1974.

2. Wynveen, R. A.; Powell, J. D.; and Schubert, F. H.; Development of an Iodine Generator for Reclaimed Water Purification in Manned Spacecraft Applications; LSI ER 171-3-2; August, 1973.

3. Beckman Instruments, Inc., ASMS: Automatic Iodine Monitor/Controller System.

4. Houck, O. K. and Wynveen, Dr. R. A.; An Automated Water Iodinating Subsystem for Manned Space Flight, ASME 74-ENAS-54; August, 1974.

LIGHTWEIGHT LONG LIFE HEAT EXCHANGER

Summary

An aluminum heat exchanger which utilizes aluminum/titanium parting sheets to prevent corrosion has been developed. The unit has been compared in detail with the Shuttle ARS condensing heat exchanger which is stainless steel and nickel. The size and performance of the lightweight heat exchanger allow it to directly replace the stainless steel unit with no vehicle reworking and a resultant weight savings of approximately 46%. Testing of the aluminum unit has demonstrated the durability of the unit and its compatibility in a stainless steel environment. The unit would also be cost effective to incorporate into the Shuttle baseline vehicle.

Technical Description

- The heat exchanger shall operate within the Atmospheric Revitalization Subsystem (ARS) to provide cabin temperature and humidity control.

- The heat exchanger shall satisfy the thermodynamic design requirements specified in figure 10.

- The heat exchanger shall be compatible with applicable Shuttle Orbiter environmental and structural requirements.

- The heat exchanger shall be physically interchangeable with the Orbiter ARS condensing heat exchanger.

Subsystem Description

The cabin condensing heat exchanger operates within the Atmospheric Revitalization Subsystem (ARS) to provide for cabin temperature and humidity control as well as cooling for cabin avionics. A flow schematic of the ARS showing location of the condensing heat exchanger is shown in figure 11.

During operation of the ARS, air flow passes through the condensing heat exchanger and is cooled below the dewpoint to condense excess moisture and remove excessive cabin heat. The condensed moisture is removed from the heat exchanger by means of an integral slurper device. This device is located at the heat exchanger air outlet where a small suction flow drains a mixture of water and air from the heat exchanger. The slurper assembly is shown in figure 12. The two phase mixture is then passed through a motor driven centrifugal separator, and the air is returned to the cabin. The coolant fluid for the heat exchanger is water.

CONDENSING HEAT EXCHANGER

THERMODYNAMIC DESIGN REQUIREMENTS

SHUTTLE MISSION PHASE 17

Air Inlet
T = 26.94°C (80.5°F)
TDP = 11.83°C (53.3°F)
P = 1 atm.
= 634 Kg/hr (1398 lb/hr)

Water Outlet
T = 17.33°C (63.2°F)

Water Inlet
T = 6.28°C (43.3°F)
= 260 Kg/hr (574 lb/hr)
P = 3.3 atm.

Condensing Heat Exchanger

Q_s = 2979 w (10,168 Btu/hr)
Q_l = 372 w (1,268 Btu/hr)
Q_t = 3351 w (11,436 Btu/hr)

Air Outlet
T = 10.28°C (50.5°F)
TDP = 10.28°C (50.5°F)

Condensate
= .54 Kg/hr (1.19 lb/hr

ΔP coolant = 34.6 mbar (.5 psi)
ΔP air = 2 mbar (.8" H_2O)

FIGURE 10. CONDENSING HEAT EXCHANGER THERMODYNAMIC DESIGN REQUIREMENTS

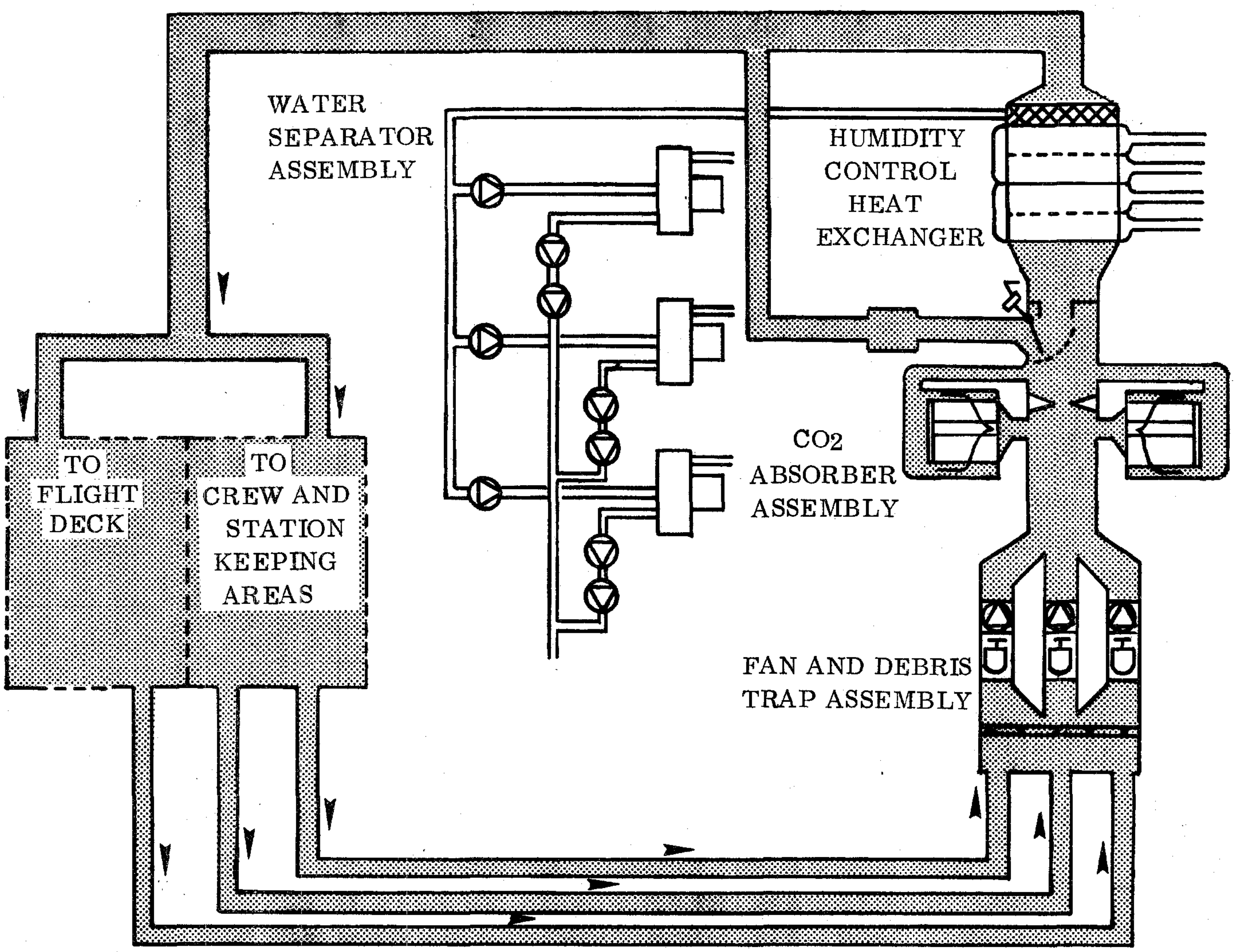


FIGURE 11. ARS FLOW SCHEMATIC

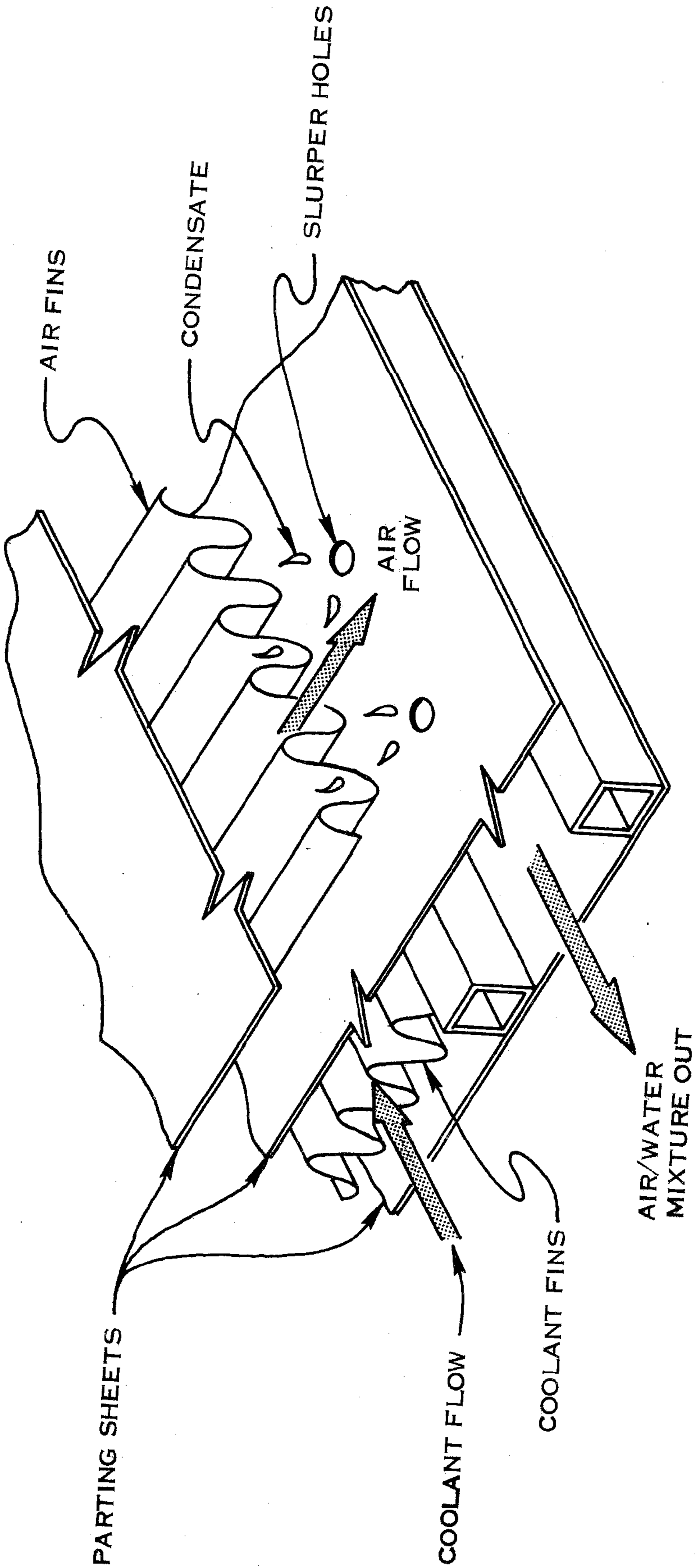


FIGURE 12. SLURPER ASSEMBLY

The unit is a three fluid heat exchanger: one air circuit plus two coolant circuits, one primary and one redundant. Component performance must be met with either or both coolant circuits operational. A non-operational coolant circuit is considered void of fluid.

Life requirements, primarily in the form of corrosion resistance, have necessitated the use of stainless steel construction for the baseline Shuttle condensing heat exchanger. Because of the need for light yet reliable flight hardware, a study was conducted under Contract NAS 9-13552 to develop an advanced, lightweight replacement for the relatively heavy ARS condensing heat exchanger.

The result of this program was the design of an aluminum plate-fin heat exchanger, which uses the corrosion resistance properties of titanium to prolong its effective life. The heat exchanger uses diffusion bonded aluminum/titanium laminated parting sheets to prevent penetration of the parting sheets and thus prevent leakage between the water coolant and cabin air circuits and between the redundant coolant circuits. The thickness and non-criticality of the remainder of the heat exchanger allows the use of lightweight aluminum without danger of failure. A series of section views of the lightweight heat exchanger core is shown in figure 13.

The primary purpose of the parting sheet is to isolate the operating fluids while imposing minimum resistance to the transfer of heat between the fluids. Experience has indicated that corrosion breakdown and leakage through the parting sheets is the most frequent cause of heat exchanger failure. To prevent such failures, the conventional parting sheets are replaced with a laminated layer. The laminate consists of layers of aluminum with a durable titanium centercore. This type of construction, shown in figure 14 is particularly applicable in condensing heat exchangers where concentrations of electrolyte result in accelerated corrosion problems. Three different test programs were conducted to demonstrate the corrosion resistance of this construction. In one test program, uncoated sample strips of the lamination were placed in a salt spray chamber. After five weeks exposure to the accelerated corrosion environment of the salt spray, micro examination of the laminates showed that pitting had progressed through the aluminum layer but was stopped by the more noble center layer. Salt spray testing continued, and while it is difficult to correlate an accelerated test such as salt spray exposure to real time, the exposure duration was in excess of 8,500 hours which should be at least three times more severe that a normal condensing application. It was concluded that the laminates will give protection for at least 25,000 hours.

Because exposure of dissimilar metals is inherent in pitting and corrosion of a laminated parting sheet, a second test series was conducted to determine the rate of corrosion product generation for corroding parting sheets. This test was performed because the galvanic couple developed at the bimetallic interface generally results in accelerated corrosion. By measuring the non-volatile residue in the water in which

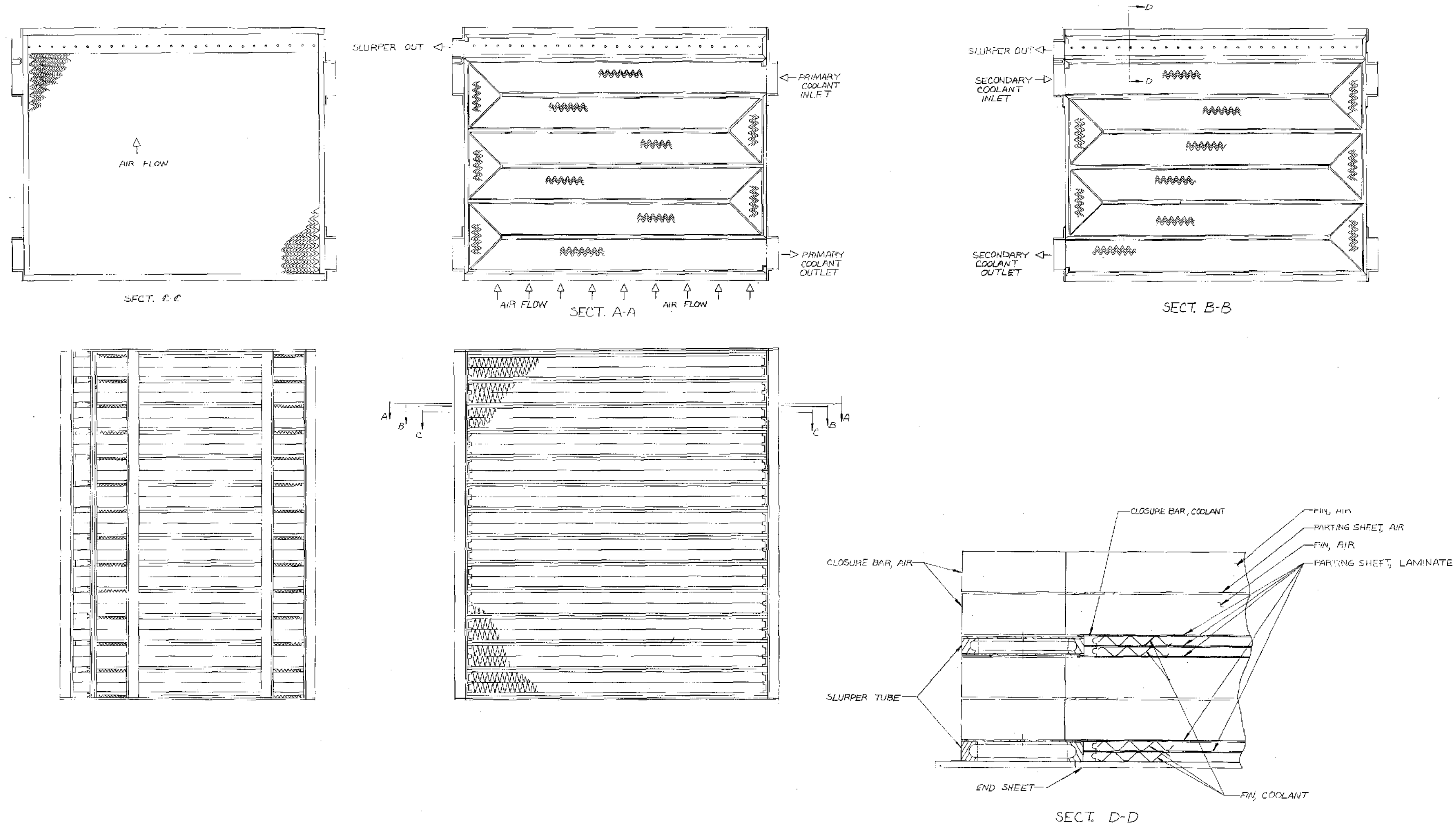


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FIGURE 13. LIGHTWEIGHT HEAT EXCHANGER CORE

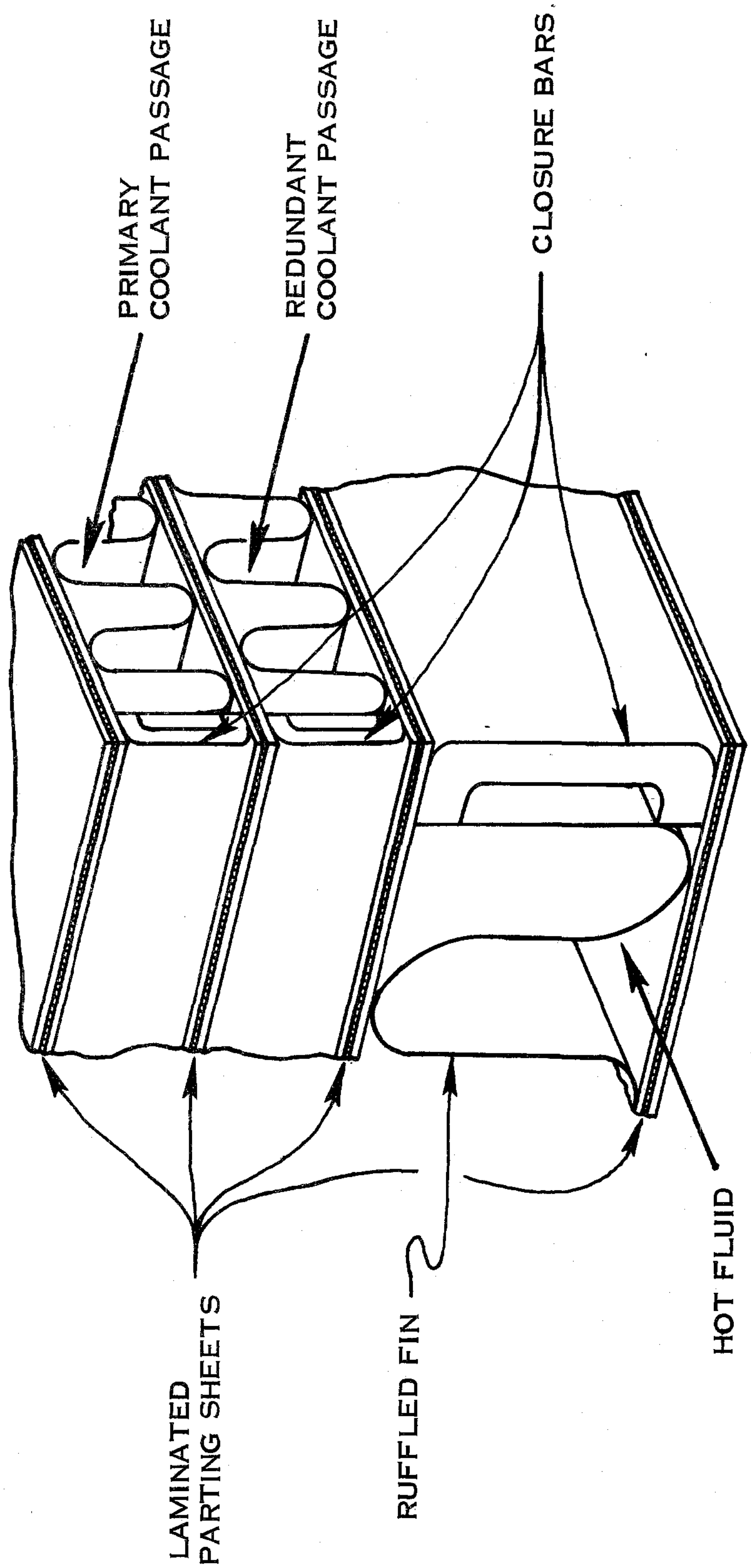


FIGURE 14. LIGHTWEIGHT HEAT EXCHANGER CONSTRUCTION

each sample is immersed, a quantitative determination of the extent of corrosion was made. These tests showed the residue from the laminates was not significantly different from the plain aluminum alloy. Thus, it was concluded that corrosion pitting to the titanium surface will not result in accelerated corrosion and that the titanium is unaffected.

A third accelerated corrosion test was set up to confirm the acceptability of aluminum alloy heat exchangers in an otherwise stainless steel water circuit. The test circuits contained a portion of stainless steel to aluminum alloy surface area similar to that expected in the Shuttle. Mating flanges, ducts and housings were also similar to those anticipated in the Shuttle. Results from these tests demonstrated that relatively little corrosion attack will take place in the lightweight aluminum heat exchanger in a neutral water stainless steel circuit, and a ten year life is likely.

Results from these initial tests confirmed the durability of the unit. As such it is a desirable alternative to the present Shuttle condensing heat exchanger.

Design Data

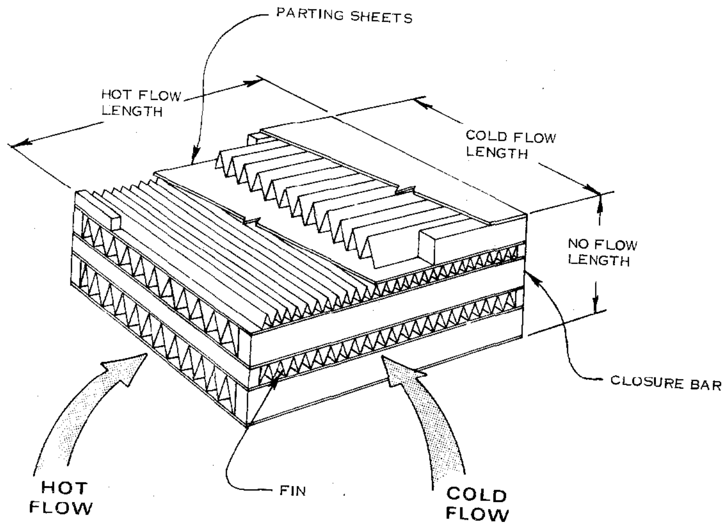
The lightweight, long life heat exchanger has been designed to directly replace (considering both envelope and performance) the present Shuttle condensing heat exchanger. Figure 15 lists the description of both the baseline Shuttle and the lightweight, long life designs including a comparison of unit weight and volume.

Weight and Power

The estimated weight for the lightweight, long life heat exchanger is 10.1 Kg (22.3 lb). Since air and water pressure drop were defined as identical to the baseline, there is no fan or pump power impact. As discussed under "Vehicle Integration", there is a potential power reduction for the water separator fan because the slurper air flow may be reduced.

Packaging

The lightweight, long life heat exchanger was specifically sized to be interchangeable with the present stainless steel heat exchanger. A package drawing of the heat exchanger is shown in figure 16.



	Shuttle Design	LLL Design
Cold Flow Length, m (inch)	0.307 (12.1)	0.241 (9.5)
Number of Cold Passes	4	6
Cold Fin Height, mm (inch)	1.27 (.05)	1.91 (.075)
Cold Fin Thickness, mm (inch)	.046 (.0018)	.127 (.005)
Cold Fin Density, fin/mm (fin/inch)	1.102 (28)	.394 (10)
Number of Cold Layers	35	14
Number of Redundant Cold Layers	35	14
Cold Fin Configuration	Ruffled	Ruffled
Cold Fin Material	Nickel	Aluminum
No Flow Length, m (inch)	0.274 (10.78)	0.2858 (11.25)
Parting Plate Thickness, mm (inch)	.102 (.004)	.254 (.01)
Parting Plate Material	Cres	Aluminum/Titanium
Hot Flow Length, m (inch)	0.170 (6.71)	0.194 (7.625)
Number of Hot Passes	1	1
Hot Fin Height, mm (inch)	5.1 (.2)	16.4 (.645)
Hot Fin Thickness, mm (inch)	.046 (.0018)	.127 (.005)
Hot Fin Density, Fin/mm (fin/inch)	.55 (14)	.55 (14)
Number of Hot Layers	34	13
Hot Fin Configuration	Ruffled	Ruffled
Hot Fin Material	Cres	Aluminum
Core Volume, m^3 (in^3)	.0144 (875.24)	.0134 (814.921)
Core Weight, kg (pounds)	13.53 (29.82)	6.73 (14.83)
Heat Exchanger Weight, kg (pounds)	18.89 (41.64)	10.10 (22.26)

FIGURE 15. COMPARISON OF LIGHTWEIGHT LONG LIFE HEAT EXCHANGER TO THE SHUTTLE BASELINE UNIT

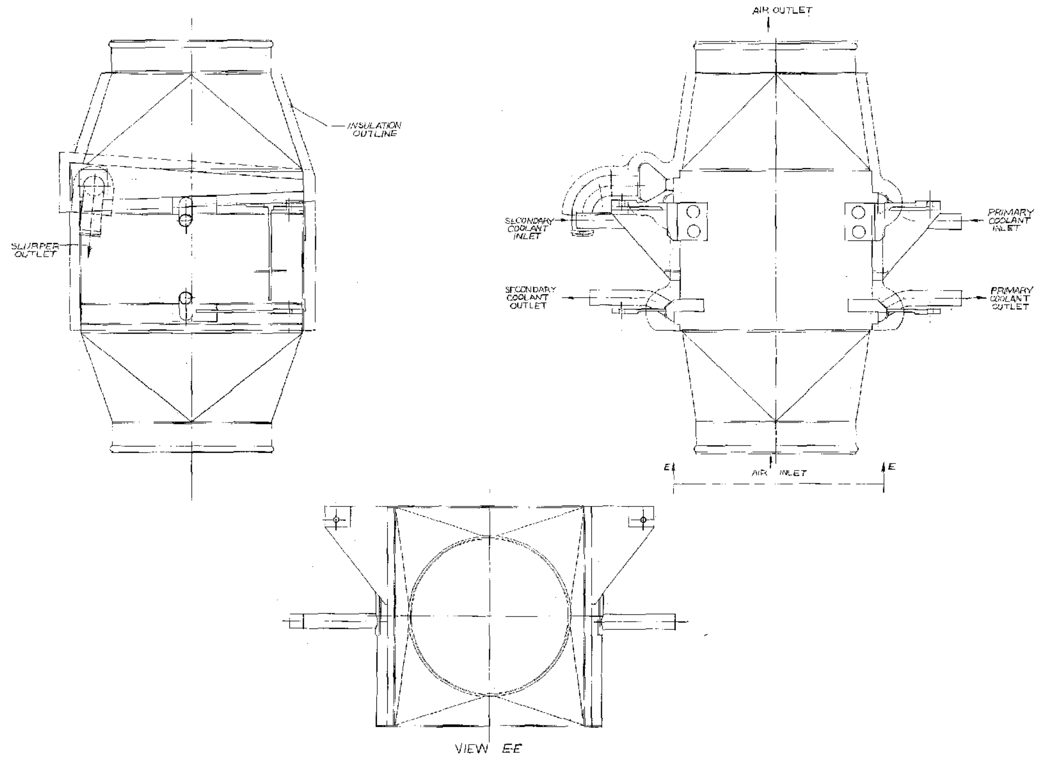


FIGURE 16. HEAT EXCHANGER PACKAGE DRAWINGS

Vehicle Integration

Baseline System

The baseline Orbiter condensing heat exchanger is a stainless steel unit whose characteristics are defined in figure 15. Figure 17 is the installation drawing for this heat exchanger.

Vehicle Considerations

Although the lightweight, long life heat exchanger is physically and functionally interchangeable with the Orbiter unit, the new heat exchanger has sifnificantly fewer air passages, and the slurper air flow may be reduced from 4.5×10^{-3} m^3/s (9.5 cfm) to 2.1×10^{-3} m^3/s (4.4 cfm). If the fan/water separator were redesigned for this reduced flow, the power consumption could be reduced from 13.8 watts to 6.4 watts.

Vehicle Packaging

There will be no impact on vehicle packaging.

Weight Comparison

The lightweight, long life heat exchanger will save 8.8 Kg (19.3 lb) relative to the baseline as indicated below:

Baseline Heat Exchanger	18.9 Kg	(41.6 lb)
Lightweight Heat Exchanger	10.1 Kg	(22.3 lb)
SAVINGS	8.8 Kg	(19.3 lb)
% SAVINGS	46%	

Programmatic Impact

Shuttle Status

The Orbiter condensing heat exchanger is presently under development as part of the Atmospheric Revitalization Subsystem. Development at the component level is scheduled for completion early in 1975 and will be followed by ARS logic group testing to be completed in the third quarter of 1975. Delivery of the ARS to Rockwell for the horizontal flight vehicle (101) is planned for late 1975 and hardware for the verticle (102) is planned for late in 1977.

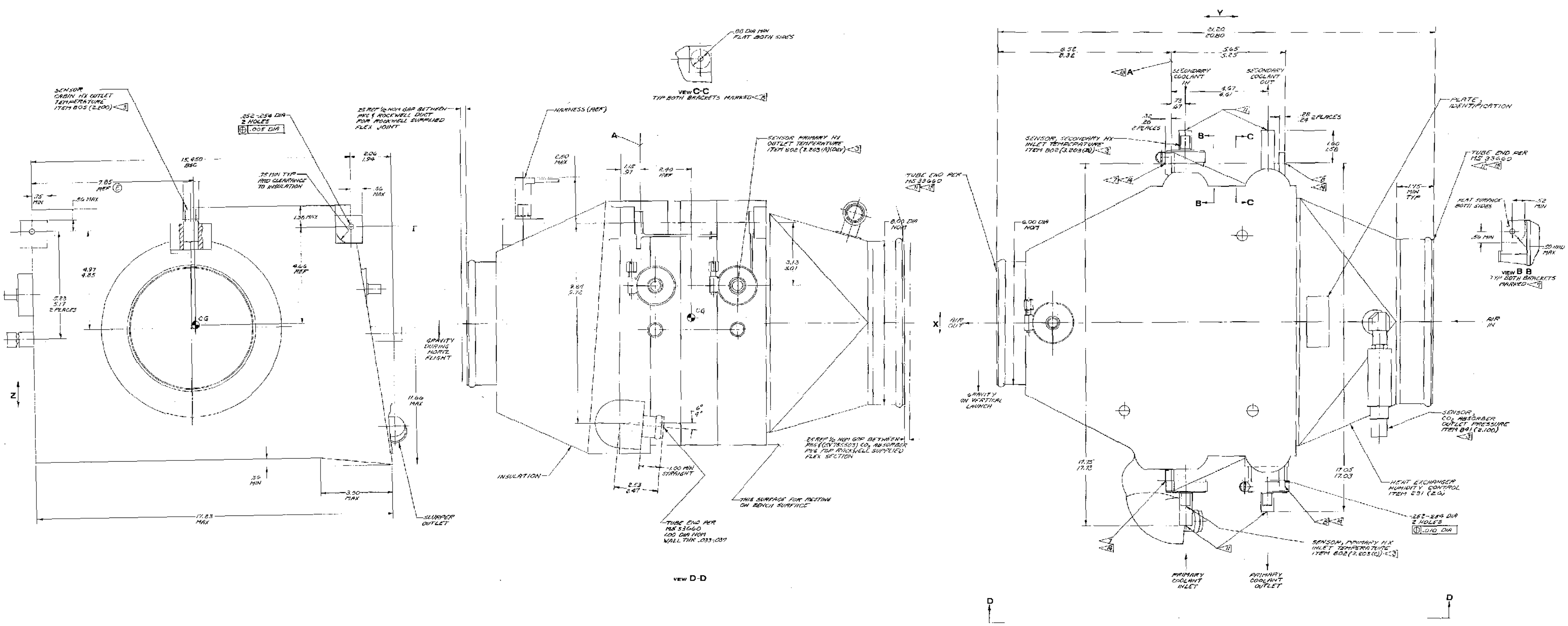


FIGURE 17. INSTALLATION DRAWING FOR SHUTTLE CONDENSING HEAT EXCHANGER

State of Development

The Lightweight Long Life Heat Exchanger Program was awarded by NASA via Contract NAS 9-13552 in January 1973. The program to date has placed emphasis on the laminate plate development, heat exchanger core braze development and verification, and performance determination. Additional effort is underway on an alternate method of producing the laminate plates (roll cladding), and to produce a second full scale heat exchanger core. The second full scale heat exchanger will then experience a comprehensive test program which will include performance tests, vibration tests, thermal shock and cycling tests, and a series of one hundred simulated mission cycle tests. The test program will verify performance, evaluate any potential performance degradation due to the corrosive environment and test the resistance of the laminate construction to corrosion and to stresses caused by thermal cycling. The base program therefore will verify the technical feasibility of producing a lightweight long life heat exchanger.

The next phase of development will be to produce a prototype lightweight long life heat exchanger designed to meet the requirements of the condensing heat exchanger contained in the Space Shuttle ARS. The basic objective is to meet all requirements of the ARS condensing heat exchanger while maintaining a heat exchanger weight of no more than 60 percent of an equivalent stainless steel heat exchanger. The prototype heat exchanger will be manufactured with production type tooling. At the completion of the fabrication phase, tests will be conducted on the prototype unit to determine its performance capability and ability to meet the Shuttle vibration environment. At the completion of the test program the prototype lightweight long life heat exchanger will be delivered to the NASA.

The overall program schedule for the heat exchanger program is presented in figure 18. As indicated, the program is planned for completion in early 1976.

Schedule Impact

Assuming the successful completion of the prototype lightweight long life heat exchanger program, a decision to implement a change for Shuttle could be made in early 1976. It is estimated that 16 months would be required from go-ahead through delivery of the first production heat exchanger to Rockwell. As a result, the new heat exchanger design could be implemented on Shuttle unit 103 and subsequent with no schedule impact. Units 101 and 102 which would have already been delivered to Rockwell in the stainless steel configuration would be replaced with new heat exchangers as part of the ARS retrofit. This plan allows for the orderly incorporation of the new heat exchanger with no impact to the presently planned delivery dates.

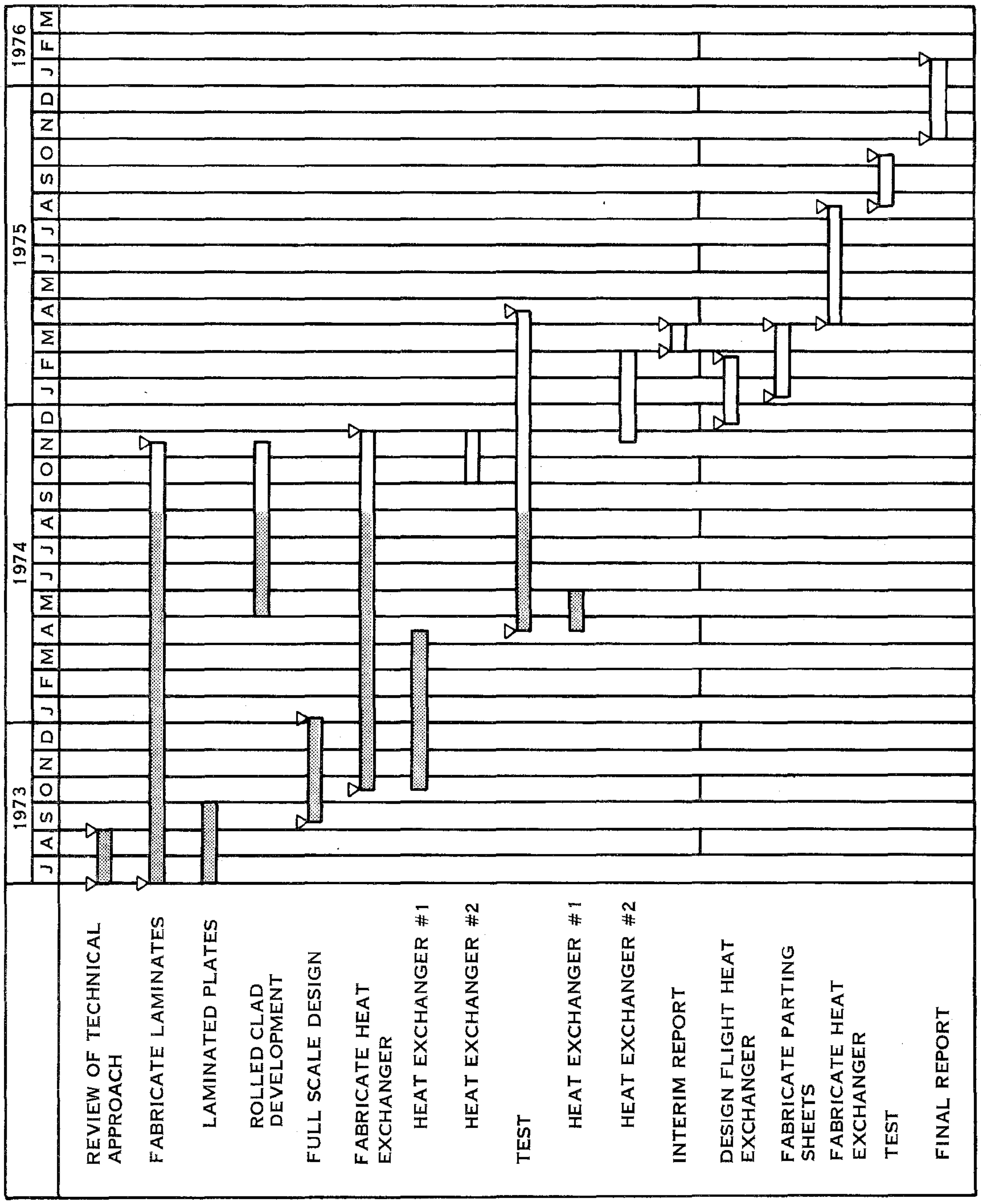


FIGURE 18. MASTER PROGRAM SCHEDULE

Cost Impact

The cost impact to the Shuttle ARS program for implementing this change is estimated at $350,000 on a rough order of magnitude basis. This estimate includes heat exchanger qualification, replacement of units 101 and 102, plus an incremental cost increase for all other units.

• Heat exchanger qualification including two (2) test units	$200,000
• Replacement of Units 101 and 102	$100,000
• Incremental Cost Impact on five (5) heat exchangers (103, 104, 105, spare, and ground test hardware)	$ 50,000
	$350,000

Weight/Cost Effectiveness

The cost benefit of implementing the lightweight long life heat exchanger program for Shuttle was evaluated for a range of cost effectiveness criteria. As indicated in figure 19, a change to the new heat exchanger would be justified for cost effectiveness values greater than $8,230/Kg ($18,100/lb) at which point the cost to implement the change equals the cost saving associated with a reduction in weight. At a cost effectiveness value of $15,873/Kg ($35,000/lb), the lightweight heat exchanger would result in a total program cost savings of $325,000. Since current Shuttle cost effectiveness criteria are equal to or greater than $15,873/Kg ($35,000/lb), implementation of the lightweight long life heat exchanger is justified.

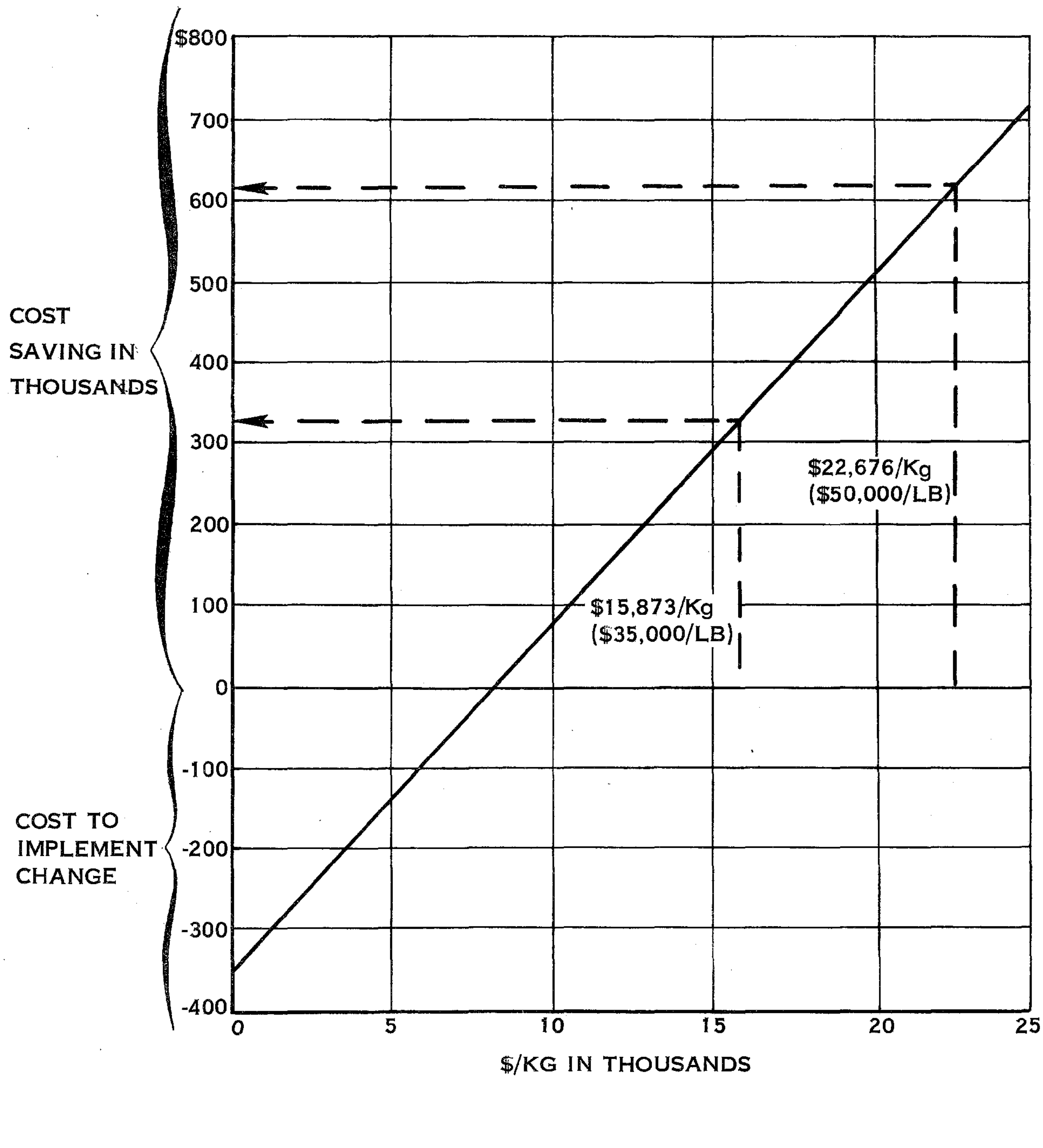


FIGURE 19. LIGHTWEIGHT LONG LIFE HEAT EXCHANGER WEIGHT/COST EFFECTIVENESS

COMPRESSION - DISTILLATION WATER RECLAMATION SYSTEM

Summary

For relatively short duration space missions such as the Shuttle Orbiter, potable water is provided from the fuel cells as a by-product of power generation. For long duration missions, where power supplies other than fuel cells are used, potable water must be provided by other means. Since the weight penalty for stored water is excessive, reclamation of waste water becomes attractive. Vapor compression is a competitive technique for reclaiming waste water on long duration missions either related or unrelated to Shuttle.

Since the vapor compression water reclamation method is only competitive for long duration missions, comparison with the Shuttle baseline, in which water is provided by fuel cells, was considered inappropriate. Accordingly, the baseline for this study was defined as stored potable water and stored urine.

Technical Description

Subsystem Requirements

- The subsystem shall process urine at a rate of 1.56 kg/man-day (3.44 lbs/man-day). Urine composition is 96% water and 4% solids.
- The subsystem shall provide potable water at a rate of 1.50 kg/man-day (3.30 lbs/man-day).
- Potable water shall be in accordance with NASA/JSC specification SE-S-0073A dated 12 September 1974, Space Shuttle Fluid.
- The subsystem shall deliver potable water at a delivery pressure of 137.5 KPa gauge (20 psig) minimum.
- The subsystem shall receive urine at a pressure of 1.33 KPa (0.193 psig) to 34.47 KPa (5.0 psia).
- Cabin pressure shall be 101.4 KPa absolute (14.7 psia) with a tolerance of ± 5%.
- Cabin temperature can vary between 18.3°-26.7°C (65-80°F).
- There shall be no overboard water loss nor any odors or bacteria introduced into the cabin.

- The system shall be designed to fail safe.

- All other environmental, handling and design requirements are per the Shuttle General Design Specification SVHS 6400.

Subsystem Description

Vapor compression distillation is a process which can produce pure liquids from contaminated mixtures of liquids or liquids, gases and solids. The process is good for purifying any type of waste water and is especially well suited to recovering pure water from urine because of the initial low percent (4%) solids concentration.

The purification process takes place in a still (Block C of figure 20) where the pure water is evaporated from the residual and then condensed for use. Figure 20 also shows the other ancillary functions which must accompany the still. The pretreated urine enters the system through a filter tank which removes the suspended solids from the liquid. This prevents blockage and performance degradation of other items in the system. The pump assembly (containing three pump sections) feeds the raw liquid to the still and returns the concentrated waste fluid to the filter and solids storage tank for recycling. The third section of the pump delivers the pure water to the final condensate testing and filtering section. The water conductivity valve is used as a "go - no-go" test. Good water is then delivered to the potable water storage system, bad water is returned to the process recycle loop. The non-condensable gases which are dissolved in the urine supply are purged from the still, filtered and have their odor removed prior to being returned to the cabin.

Because of the zero "g" requirements, the distillation unit is a rotating device which separates the liquids and gases by centrifugal force. Because of the high power penalties associated with space stations the system power requirements must be low. The condensing section of the still is maintained at a higher pressure than the evaporator section, resulting in a condensing temperature higher than that of the evaporator, thus heat flows from condensing surface to the evaporator surface. In this way the latent heat of condensation is used to evaporate more liquid and the power required by the whole process is kept at a minimum.

The overall schematic diagram for the subsystem is shown in figure 21. The waste liquid is fed to the distillation system from the waste tank for processing. The waste liquid enters the system upstream of the recycle/filter tank (Item 4). A constant displacement type pump (Item 3) delivers the filtered liquid at a fixed flow rate to the evaporator section of the vapor compression still (Item 1) through a feed tube at the motor end. The process rate is determined by the crew size and cabin temperature. For 7-men, it is about 2.95 kg/hr (6.5 lbs/hr). The feed pump may be mounted on a common drive shaft with the recycle and condensate pumps in order to provide properly coordinated flows.

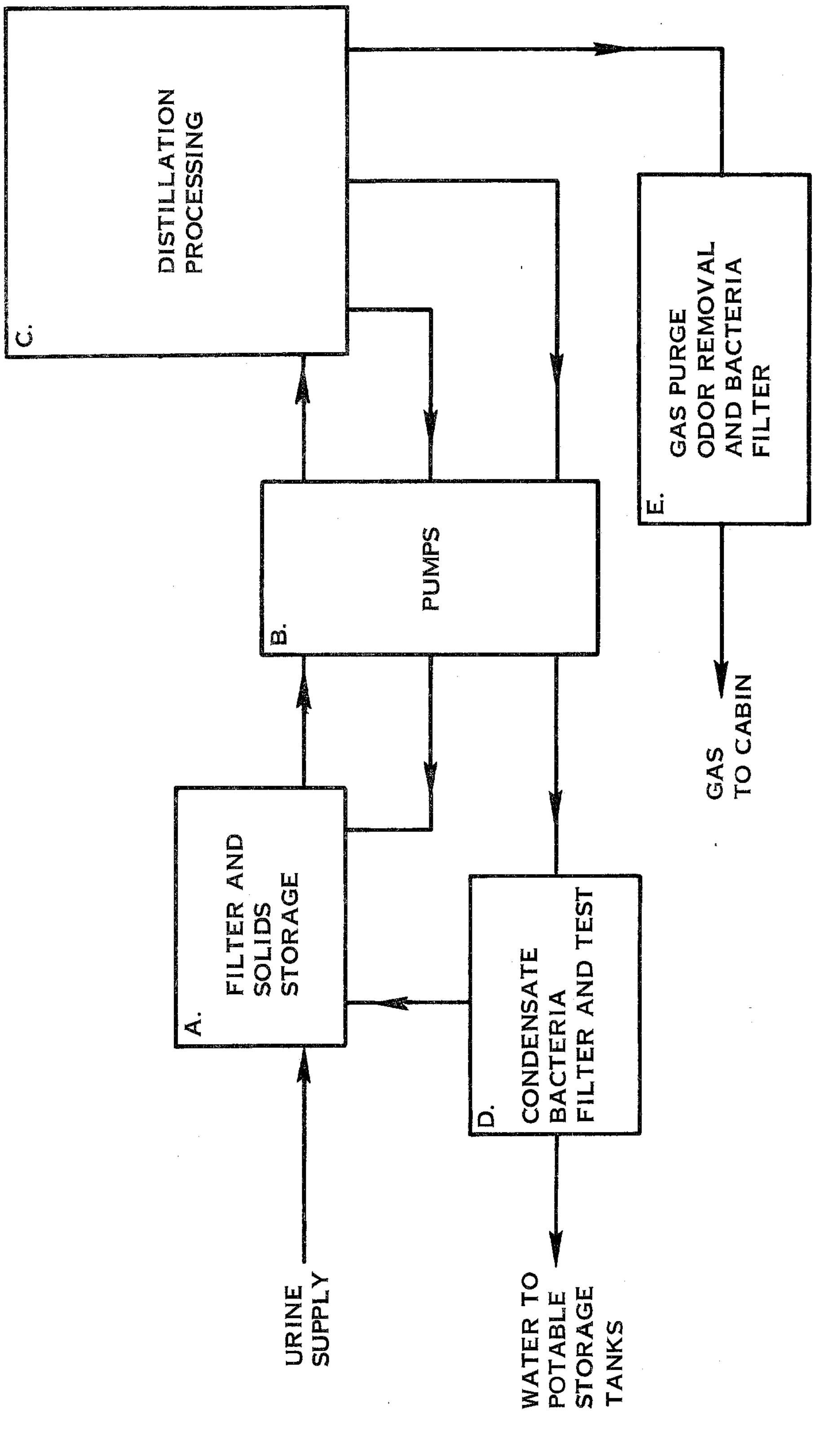


FIGURE 20. VAPOR COMPRESSION DISTILLATION SYSTEM BLOCK DIAGRAM

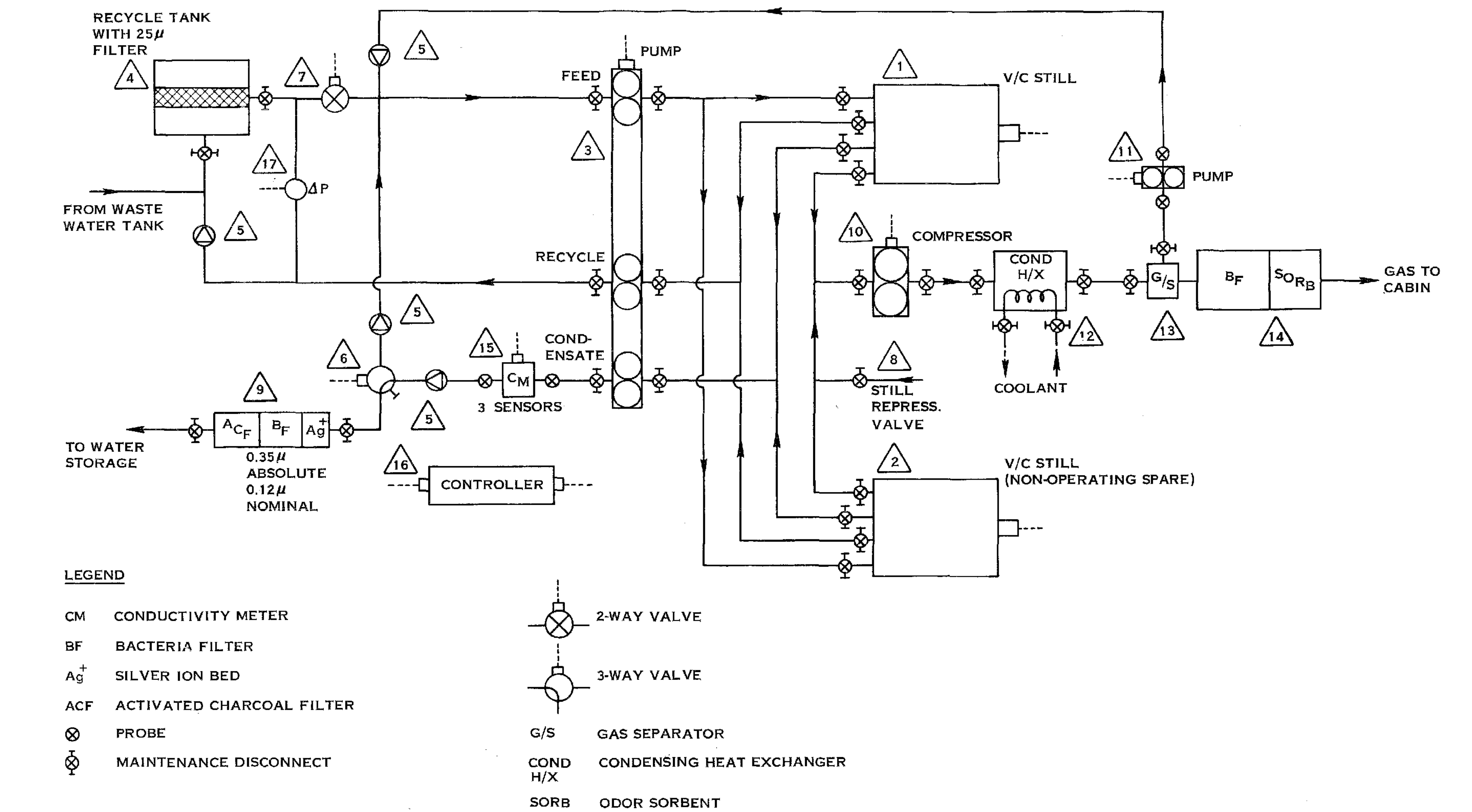


FIGURE 21. VAPOR COMPRESSION DISTILLATION SYSTEM

FOLDOUT FRAME 1

FOLDOUT FRAME 3

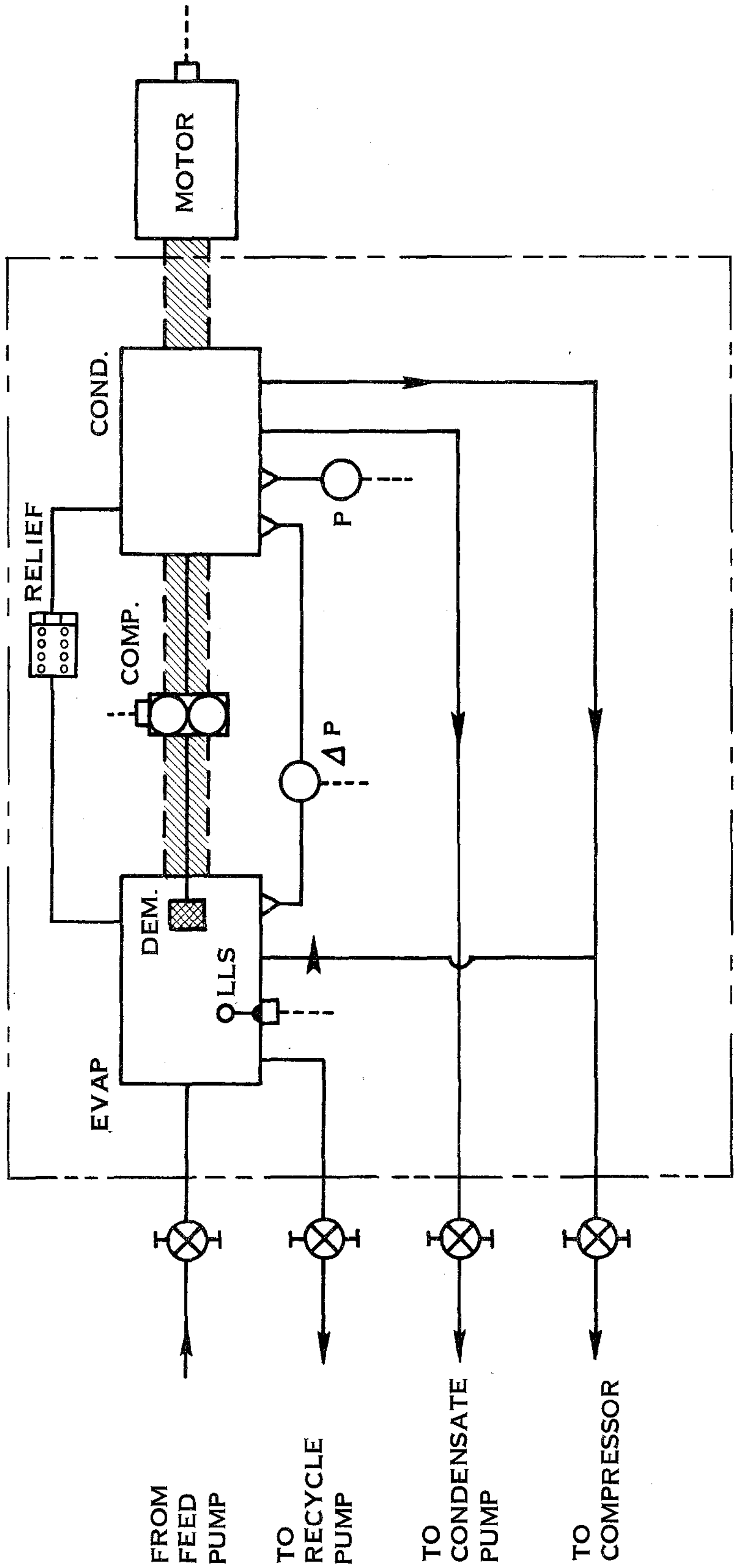
Since the fluid is evaporating as it progresses down the evaporator from the feed tube to the sump, the salt content would increase with a corresponding increase in boiling point temperature. To avoid this situation, the feed rate is established at approximately six times the evaporation rate which reduces the boiling point rise. The penalty for this increased flow rate is minimal, at approximately 1/8 of a watt for each 1/2 Kg/Hr (~ 1 lb/hr) of pumping rate. This penalty is less than other solutions such as using a larger compressor with a greater compression ratio to increase the condenser temperature.

The distillation units (Items 1 and 2) are motor driven, cylindrical devices which separate liquids and gases by centrifugal force. Two concentric cylinders are used to form an inner evaporator and an annular condenser. (See figures 22 and 23). The vapor compressor is statically sealed and is driven by an externally mounted motor at a rotational speed of approximately 3400 rpm. Timing gears step down the speed so that the bowl is driven by the same motor at about 240 rpm. Centrifugal force holds the waste water against the inside of the evaporator cylindrical surface and latent heat, recovered by conduction from the condenser section, evaporates the water thus concentrating the waste in the solution. The concentration of dissolved solids is greatest at the hub end of the evaporator, which contains an annular sump.

A baffle between the evaporator and the evaporator recycle sump contains holes to maintain the waste water depth required to assure wetting of all the evaporator sur face. The baffle holes are traiangular shaped to avoid surging. A liquid level sensor probe, attached to the stationary hub, is provided to sense and indicate a high level condition if the waste water covers the holes in the baffle. Concentrated waste water is forced out of the evaporator sump by a stationary impact tube and fed through the tube to the recycle pump (second section of Item 3 in figure 21).

The solids concentration in this liquid is limited to a maximum of 50% by periodic replacement of the recycle/filter tank (Item 4). It receives concentrated waste from the evaporator and newly supplied waste water from the waste tank, and then delivers that mixture back to the evaporator. The recycle tank contains a built-in filter to prevent the majority of suspended solids from entering the still. The recycle tank will be pressurized and maintained full by the waste tank. Any gas which might enter the waste stream will eventually enter the distillation unit and be purged back to the cabin atmosphere, thus a life limiting, low reliability bladder or other phase separation device is not required in the recycle tank.

Initially, the recycle tank will contain only silver or other biocide dosed fresh water. With use, however, solids will accumulate in the recycle loop, 90% of which will be contained in the recycle tank. Solids disposal is accomplished by periodically replacing the recycle tank with a fresh one containing only clean dosed water. Simultaneously, the recycle circuit filter will be replaced because it is internal to and



LLS LIQUID LEVEL SENSOR

DEM DEMISTER (LIQUID TRAP)

FIGURE 22. VCD STILL SCHEMATIC

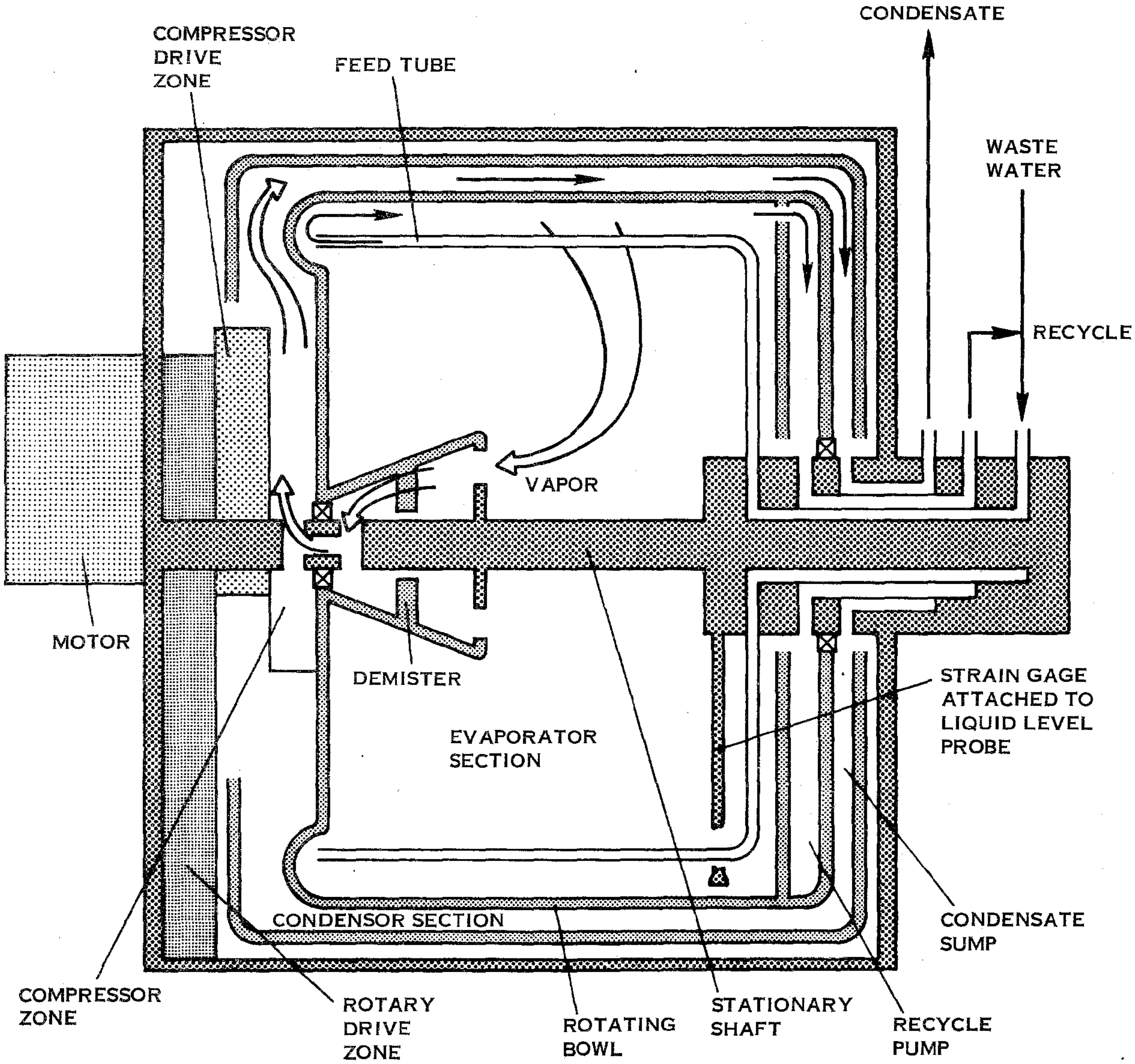


FIGURE 23. ROTATING STILL OPERATION

integral with the tank. The clean water originally contained in the recycle tank is make-up water for any losses or external uses (such as the water lost with the 50% waste concentrate, overboard cabin leakage or dumps, PLSS sublimator cooling, CO_2 reduction water vapor losses to space vacuum, etc.), and is automatically displaced from the constant volume recycle circuit by the solids accumulation. This clean water also will flush any precipitated solids of other components in the recycle loop. This solids disposal/water replacement approach was selected for the above features as well as its high reliability and low total equivalent weight penalty.

Water vapor and gases are drawn from the evaporator section of the still through a spinning demister into the rotary lobe vapor compressor and then forced into the condenser section of the still. A relief valve is located on the compression discharge to avoid any excessive pressure differentials that could cause overly vigorous boiling and to permit rapid start up with cabin gas in the condenser. Water vapor is condensed on the outer surface of the evaporator cylinder and centrifuged as droplets to the inner surface of the outer shell where it flows into an annular condensate sump. The condensate is then transferred out of the condenser by another stationary impact tube and fed through the condensate section of the pump (Item 3), through a conductivity meter (Item 15), a check valve (Item 5), and a motor driven three-way valve (Item 6). The meter, which is tripleredundant for high reliability, signals the valve which is driven to a recycle position, blocking the flow of raw condensate to the post treatment circuit whenever the condensate is bad. In addition, a signal is sent to the on-board checkout system (OCS) alerting the crew. Inlet flow to the stills is then stopped by closing the feed valve (Item 7). The still continues to rotate with the condensate being recycled within the circuit. The processed water is diverted by Item 6 into the waste side of the system until fault isolation detection analysis is completed and corrections are made or until the system has flushed the condensate clean. The condensate valve (Item 6) is then manually rotated to the normal mode and the system operates normally again. The raw condensate, with an acceptable conductivity level is transferred through the bacteria filter/activated charcoal bed (Item 9) to the Storage and Sterilization Subsystem. The filter contains a small quantity of silver ions to retard the bacterial grow-through process thus increasing the filter's life from 7-10 days to 30 days without significantly reducing the charcoal performance. The required start-up time is approximately one hour to reach the normal processing rate for the still. If the feed supply is depleted, the still will continue to rotate to dry out the evaporator and prevent fouling. Normal dry out time is one to two hours.

Should the evaporator section of the still become flooded due to some failure in the evaporator, recycle or feed pump the liquid level sensor will detect this anomaly and will close the feed valve (Item 7).

Non-condensable gases are purged out of the condenser through the hub end of the distillation unit by a compressor (Item 10). It compresses the vapor and sends it to a condensing heat exchanger (Item 12) and on through a gas separator (Item 13) where the water is pumped back to the recycle loop by Item 11. The gas is returned to the cabin through a bacteria/sorbent filter (Item 14). In some vehicles, further system integration may be accomplished by returning the compressor outlet vapors to a continuously running urinal and thus eliminate Items 11 through 14. This integration was not assumed for this study. The check valve (Item 5) downstream of the condensate valve (Item 6) prevents back flow contamination of the condensate. The other three check valves (Item 5) prevent waste contamination of the cabin due to pump failures upstream of these valves if the pump is a peristalltic type, which has been assumed for this study.

Instrumentation is provided to indicate feed, evaporator, and condenser pressures. A signal from the pressure switch on the waste water tank is required to close the feed valve (Item 7) and shut the feed and initiate the shutdown cycle whenever the waste tank is emptied. The distillation unit continues to dry itself until the pressure in the feed line is less than 1.333 kPa (10 torr) and is then shut off by a vacuum pressure switch. The unit cannot be restarted until a latching relay is closed, the feed valve is opened, and waste water has been accumulated in the waste tank. OCS interfaces for this subsystem are from the waste tank quantity gage, distillation module controller (Item 16), conductivity meter (Item 15) and delta P sensor (Item 17).

The ΔP sensor (Item 17) aids in determining if early replacement of the recycle tank (Item 4) is required. High ΔP could be due to either premature filter clogging, due to a large quantity of solids in the input or due to the solids concentration exceeding the 50% value.

The probes and maintenance disconnects shown in Figure 21 allow for performance of maintenance in a minimal time and without system drainage in either zero or one "g" conditions. All expendables (particulate and bacteria filters as well as the recycle tanks) will need to be changed on a scheduled maintenance basis.

Design Data

Vapor Compression Stills (Items 1 and 2) - The water recovery rate attainable with a given compression distillation unit is primarily a function of vapor density, volumetric efficiency of the compressor and the boiling point of the liquor in the evaporator. In addition, the boiling coefficient is a function of the concentration of dissolved solids in the liquor. The water recovery rate decreases and the internal still compressor power increases as the solids accumulate in the recycle loop. (See figures 24 and 25). On the other hand, the water yield (total water recovered) is also increased as the loop recycles up to very high solids concentrations. There is an optimum operating point at which further solids concentration (less water loss) is offset by the additional weight penalties for the increase in electric power and/or still size

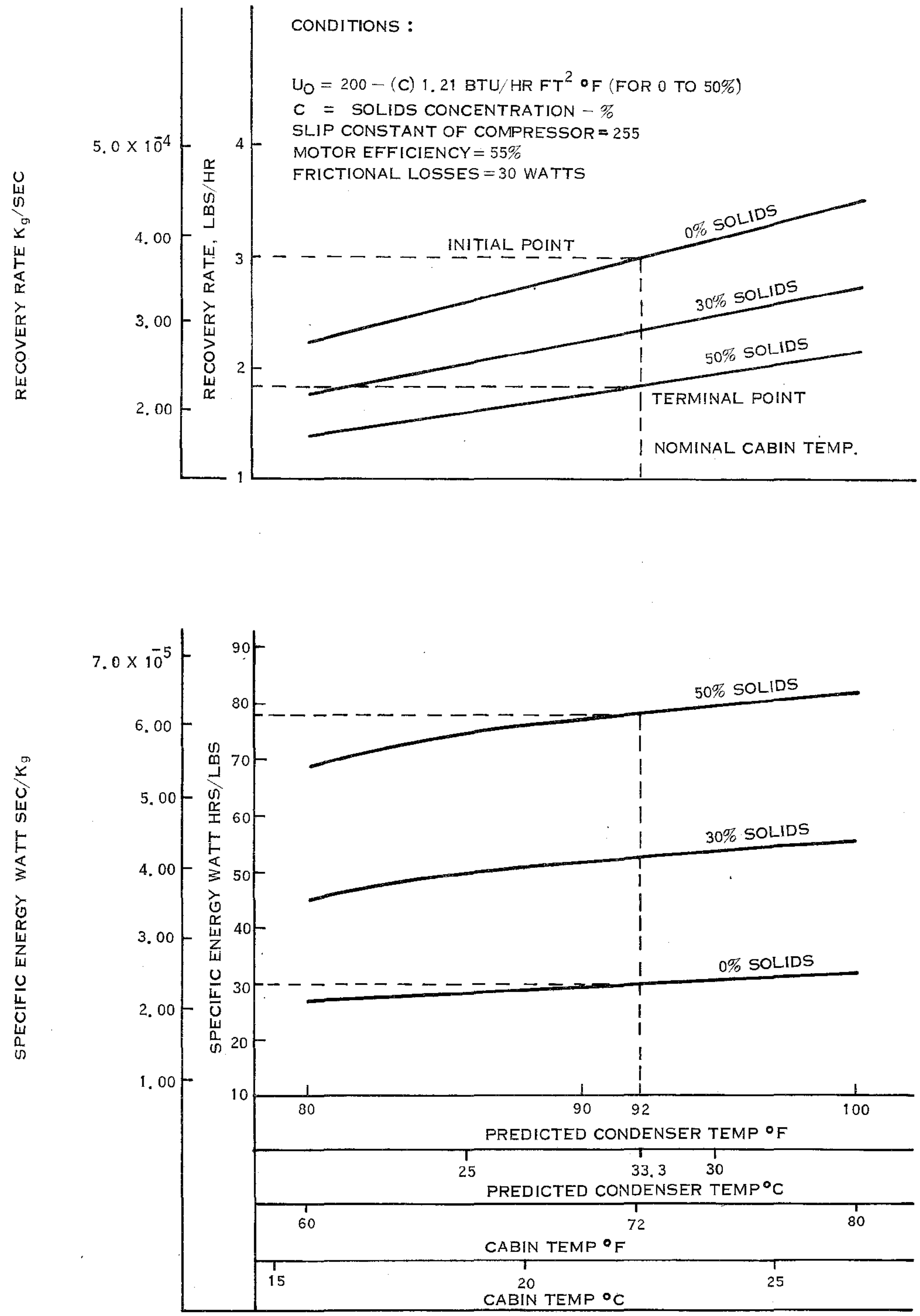


FIGURE 24. EFFECTS OF DISSOLVED SOLIDS ON VARIOUS STILL PERFORMANCE PARAMETERS

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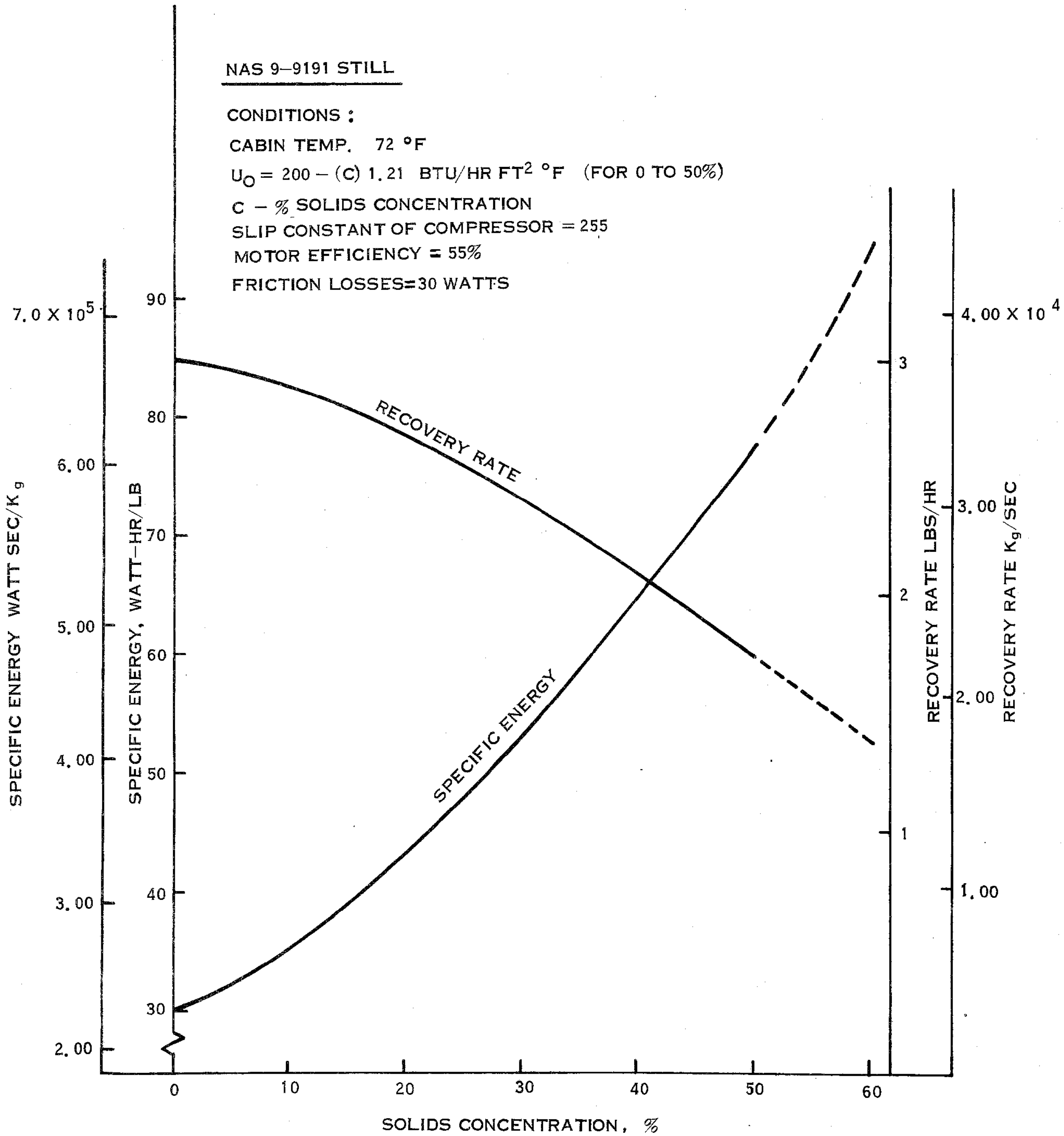


FIGURE 25. EFFECTS OF DISSOLVED SOLIDS ON STILL SPECIFIC ENERGY CONSUMPTION

Using a tank weight penalty of 0.224 kg of tank per kg of water stored (due to water lost during recycle filter changeout) and a power penalty of 0.322 kg/watt (0.71 lbs/watt) and a heat rejection penalty of 0.198 kg/watt (0.437 lbs/watt) one finds that the recycle loop optimum maximum solids concentration at changeout which yields the least total equivalent weight is slightly under 60%.

Experience on the NAS 9-9191 contract has shown that when the solids concentration is over 60%, the liquor is too viscous for reliable pumping. In fact, some precipitation of solids occurs whenever the dissolved solids concentration exceeds 40%. Thus, the still and recycle tanks will be sized for a liquor concentration containing 45% dissolved solids and 5-10% precipitated solids.

The seven man still has an average process rate at 25% solids and 22.2°C (72°F) of 455 gms/hr (1.003 lbs/hr) and weighs 28.12 Kg (62 lbs). It uses 109 watts and its outer drum dimensions are 34.54 cm (13.6 inches) diameter and 36.83 cm (14.5 inches) long.

The four man still processes 259.5 gms/hr (.573 lbs/hr), weighs 26.3 Kg (58 lbs), uses 102 watts and its drum dimensions are 32.51 cm (12.8 inches) diameter and 34.54 cm (13.6 inches) long. Figure 26 compares the still envelopes.

Compressor (Item 10) - This unit evacuates and maintains the vapor compression distillation unit at a low operating pressure by purging the non-condensable vapors from the condenser. It draws 0.5 Kg/day (1.1 lbs/day) of vapors and gas (about 10% is non-condensable gas) from the still in order to maintain a sufficiently low non-condensable gas partial pressure (about 1100 pascals) (.016 psia). The total pressure rise and inlet pressure of this compressor yields a pressure ratio of about 62:1. Thus, it is a two stage unit; each stage has about an 8:1 pressure ratio.

From the Space Station Prototype data, this unit will weigh about 6.72 kg (14.8 lbs) and consumes about 25.4 watts to accomplish an equivalent adiabatic compression work level of 5.54 watts. The large inefficiencies are due to seal friction (2.95 watts), 15% crankcase bearing losses, 63% efficient planetary gear train reducer and a 61% efficient motor.

Recycle and Filter Tank (Item 4) - Two 100% size tanks are required for reliability reasons. The correct number of filters must be designed into each tank in order to provide the proper filter/tank life. An optimum tank shape would be a sphere considering tank weight only. However, cylindrical tanks are necessary to use standard shape filters and to match the total water volume and life to the filter life.

The filter tested in the NAS 9-9191 contract was a 51 cu. in. device that was usable for about 120 man-days. Two such filters are arranged axially in the tank sized here, thus providing a 14% margin of safety on filter life.

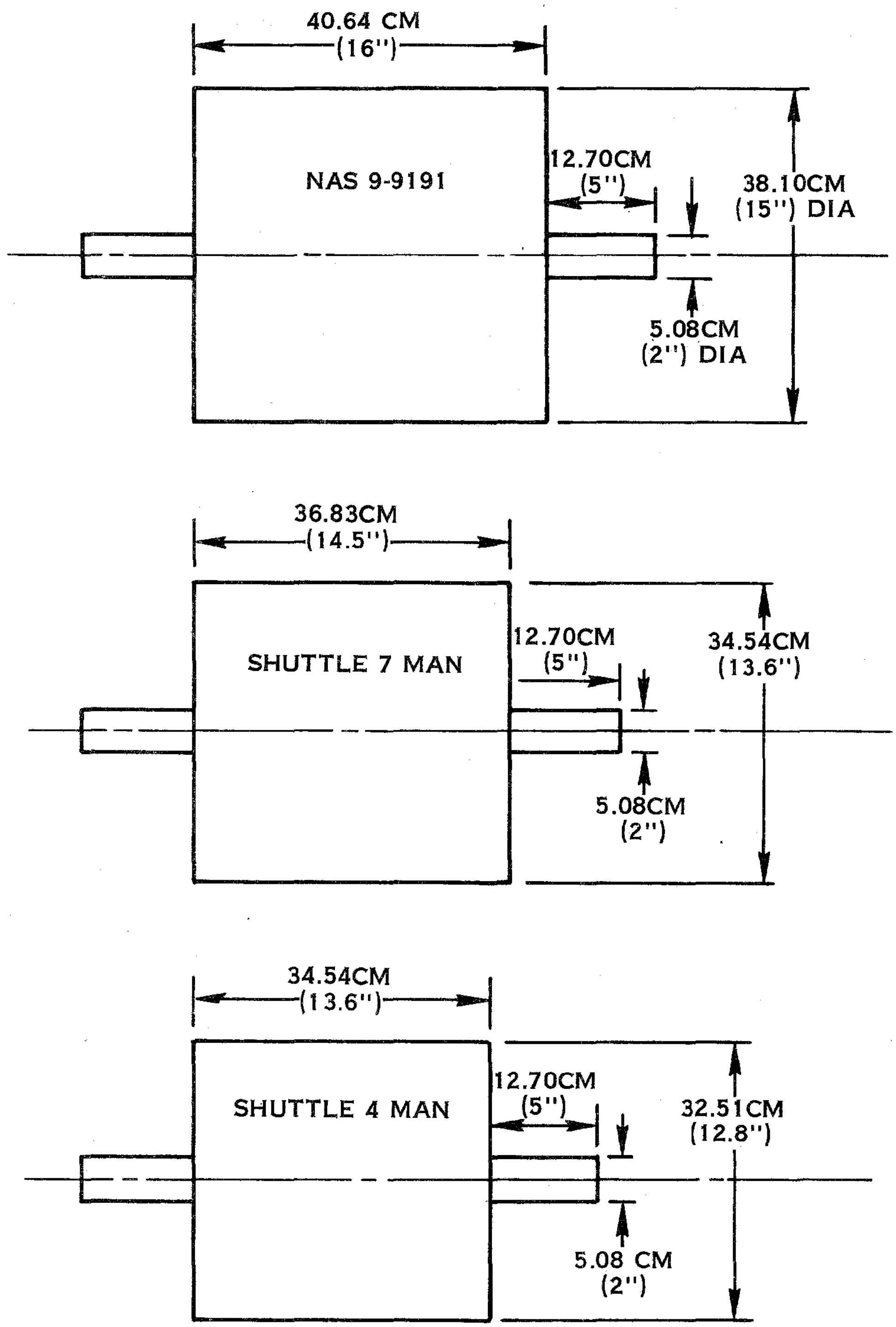


FIGURE 26. STILL ENVELOPES FOR VARIOUS REQUIREMENTS

$$\frac{(2)}{(7\text{ men})}\ \frac{(120\text{ man-days})}{(30\text{ days})} = 1.143\text{ margin}$$

Using three filters instead of two and increasing the tank volume by 50% would have required an increase in the tank length by 50%. Thus, the tank L/D ratio would have increased by 50% driving it further from the optimum sphere design. The whole unit wet weight would also exceed the 75 lbs upper limit imposed by SSP for zero "g" maintenance by one man.

Using one filter would have resulted in an almost spherical vessel, however, it would only have a 15 day life thus causing a maintenance nuisance. Also, spheres are difficult to package and store efficiently.

The selected design, using two filters, yields a tank which is about 22.85 cm (9.0 inches) in diameter and 58.42 cm (23 inches) overall length and weighs 24.4 Kg (53.8 lbs) when filled with fresh water and 30.4 Kg (67.1 lbs) when filled with 50% concentrated brine and filtered solids. It also packages quite well and is easily maintainable on a 30 day basis, so it appears to be an overall optimum configuration. The same size tank was used for the 4 man system. Its life in that system is 52.5 days.

Weight and Power

The weights and powers of the 4 and 7 man systems are shown in Tables I and II. The values for the smaller items were based either on Shuttle Orbiter designs or modified flight type SSP hardware.

The power weight penalties include both the power usage and the heat rejection penalties. The power usage penalty assumed for continuous regulated AC power is 0.322 Kg/watt (0.71 lbs/watt). The heat rejection penalty is made up of two components. The first is the direct rejection of about 13.4 watts (1100 Btu's/day) to the coolant circuit from the condensing heat exchanger. This penalty has been assumed to be .0836 kg/watt (.184 lbs/watt). The second rejection penalty is that of 191 watts heat rejection to the cabin air. This indirect heat rejection has a higher penalty of 0.198 kg/watt (.437 lbs/watt) because it affects the cabin fan and heat exchanger sizes and powers in addition to those of the coolant circuit and radiator.

Figures 27 and 28 show the 4 and 7 man systems' total equivalent weight versus mission length. These weights vary with mission length because of the three expendable items (recycle tanks, condensate filters and air outlet filters). The spares quantities were held constant over the 180 day time period. It should be noted here that commonality in a space station design would reduce the spares weight penalty for this vapor compression distillation system. Common valves, etc., would use common spares, and would reduce the weight by about 9.5 Kg (20.9 lbs). Elimination of Items 11 through

TABLE 1
FOUR MAN VCD SYSTEM

Item No.	Name	Installed Qty	Expendable Qty*	Spare Qty*	Total Qty	Unit Weight (lbs)	Unit Weight Kg	Total Weight (lbs)	Total Weight Kg	Total Power (Watts)	Remarks
1 & 2	Still, Vapor Compression	2	-	-	2	(58.0)	26.31	(116.0)	52.62	102.0	Only one operates at a time, other is installed redundancy
3	Pump, Feed and Recycle	1	-	2	3	(6.2)	2.81	(18.6)	8.43	9.0	
4	Tank, Recycle/Filter	1	3	1	5	(53.8)	24.40	(269.0)	122.00	-	Weight includes 20.2 Kg (44.5 lbs) of water per tank
5	Valve, Check	4	-	2	6	(0.25)	0.113	(1.5)	0.678	-	
6	Valve, 3-Way Diverter	1	-	1	2	(1.5)	0.68	(3.0)	1.36	-	Average power is 0, peak is 30 watts
7	Valve, Waste Feed	1	-	1	2	(1.4)	0.64	(2.8)	1.28	-	Average power is 0, peak is 30 watts
8	Valve, Still Repress.	1	-	1	2	(0.2)	0.090	(0.4)	0.18	-	
9	Filter, Condensate	1	5	2	8	(15.2)	6.89	(121.6)	55.12	-	Expendables are based on 30 day life
10	Compressor	1	-	1	2	(14.8)	6.71	(29.6)	13.4	25.4	
11	Pump, Water Return	1	-	1	2	(0.8)	0.36	(1.6)	.72	5.0	
12	Heat Exchanger, Condensing	1	-	1	2	(1.5)	0.68	(3.0)	1.36	-	
13	Separator, Gas	1	-	1	2	(3.0)	1.36	(6.0)	2.72	-	
14	Filter, Gas Outlet	1	1	1	3	(4.5)	2.04	(13.5)	6.12	-	
15	Conductivity Meter	1	-	-	1	(0.7)	0.32	(0.7)	0.32	0.3	Has three redundant sensors in one unit
16	Controller	1	-	-	1	(12.0)	5.44	(12.0)	5.44	9.0	Has built-in redundancy and meets Shuttle EMC
17	Sensor, ΔP	1	-	1	2	(0.7)	0.32	(1.4)	0.64	0.1	
	Total Component Weight							(600.7)	272.39		Weight of installed items per Figure 21 is 105.8 Kg (233.3 lbs).
	Packaging							(233.7)	106.01		Based on typical packaging factors from HS experience
	System Water							(6.0)	2.72		Based on plumbing estimate and component volumes
	Total Hardware Weight							(840.4)	381.12	150.8	
	Power Weight Penalty							(175.5)	79.60		48.6 Kg (107.1 lbs) is power usage, 29.9 Kg (65.9 lbs) is cabin air heat rejection and 1.1 Kg (2.5 lbs) is coolant loop heat rejection.
	Total Equivalent Weight							(1015.9)	460.72		

*Based on 180 Day Mission

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 2
SEVEN MAN VCD SYSTEM

Item No.	Name	Installed Qty	Expendable Qty*	Spare Qty*	Total Qty	Unit Weight (lbs)	Unit Weight Kg	Total Weight (lbs)	Total Weight Kg	Total Power (Watts)	Remarks
1 & 2	Still, Vapor Compression	2	-	-	2	(62.0)	28.12	(124.0)	56.24	109.0	Only one operates at a time, other is installed redundancy
3	Pump, Feed and Recycle	1	-	2	3	(6.9)	3.13	(20.7)	9.39	15.0	
4	Tank, Recycle/Filter	1	5	1	7	(53.8)	24.40	(376.6)	170.8	-	Weight includes 20.2 Kg (44.5 lbs) of water per tank
5	Valve, Check	4	-	2	6	(0.25)	0.113	(1.5)	0.68	-	
6	Valve, 3-Way Diverter	1	-	1	2	(1.5)	0.68	(3.0)	1.36	-	Average power is 0, Peak is 30 watts
7	Valve, Waste Feed	1	-	1	2	(1.4)	0.64	(2.8)	1.28	-	Average power is 0, Peak is 30 watts
8	Valve, Still Repress.	1	-	1	2	(0.2)	0.09	(0.4)	0.18	-	
9	Filter, Condensate	1	5	2	8	(15.2)	6.89	(121.6)	55.15	-	Expendables are based on 30 day life
10	Compressor	1	-	1	2	(14.8)	6.71	(29.6)	13.42	25.4	
11	Pump, Water Return	1	-	1	2	(0.8)	0.36	(1.6)	0.72	5.0	
12	Heat Exchanger, Condensing	1	-	1	2	(1.5)	0.68	(3.0)	1.36	-	
13	Separator, Gas	1	-	1	2	(3.0)	1.36	(6.0)	2.72	-	
14	Filter, Gas Outlet	1	2	1	4	(4.5)	2.04	(18.0)	8.16	-	
15	Conductivity Meter	1	-	-	1	(0.7)	0.32	(0.7)	0.32	0.3	Has three redundant sensors in one unit
16	Controller	1	-	-	1	(12.0)	5.44	(12.0)	5.44	9.0	Has built-in redundancy and meets Shuttle EMC
17	Sensor, ΔP	1	-	1	2	(0.7)	0.32	(1.4)	0.64	0.1	
	Total Component Weight							(722.9)	327.85		Weight of Installed Items per Figure 21 is 109.8 Kg (242.0 lbs)
	Packaging							(271.8)	123.26		Based on typical packaging factors from HS experience
	System Water							(6.3)	2.86		Based on plumbing estimate and component volumes
	Total Hardware Weight							(1001.0)	453.97	163.8	
	Power Weight Penalty							(190.4)	86.35		52.7 Kg (116.3 lbs) is power usage, 33.5 Kg (71.6 lbs) is cabin air heat rejection and 1.1 Kg (2.5 lbs) is coolant loop heat rejection.
	Total Equivalent Weight							(1191.4)	540.32		

*Based on 180 Day Mission

FOLDOUT FRAME 1

FOLDOUT FRAME 2

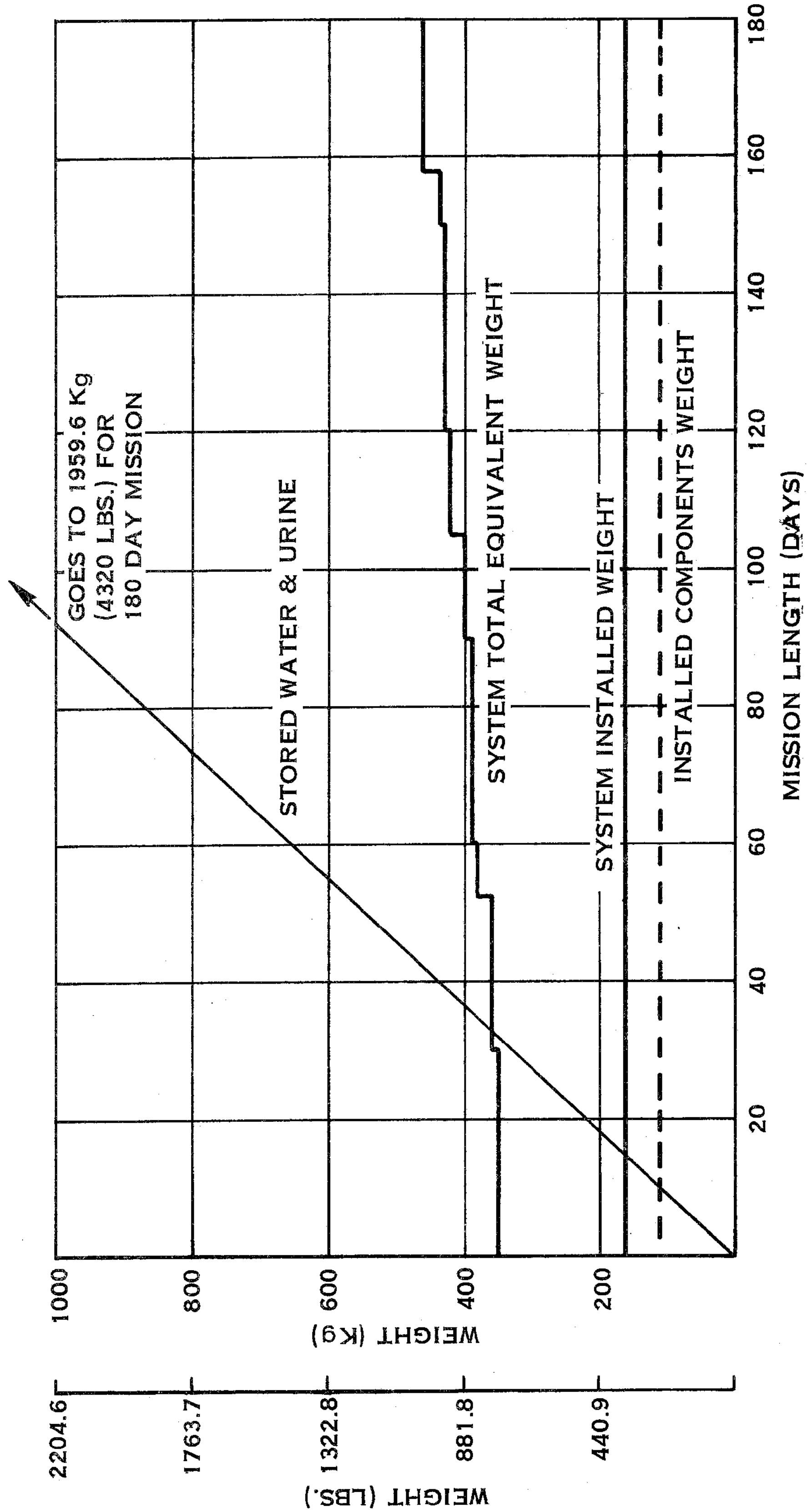


FIGURE 27. VCD WEIGHT VS MISSION LENGTH (4 MAN SYSTEM)

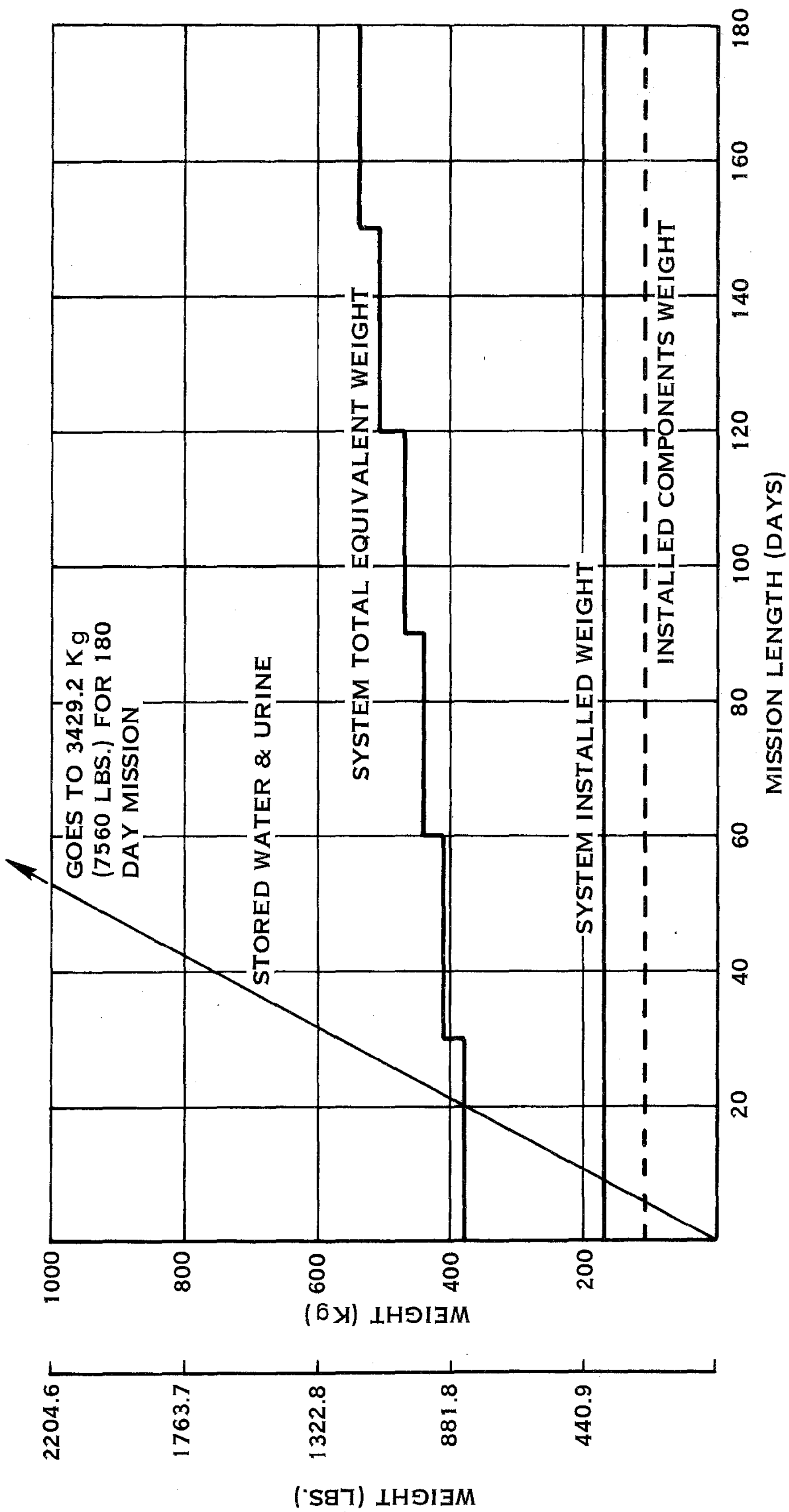


FIGURE 28. VCD WEIGHT VS MISSION LENGTH (7 MAN SYSTEM)

14 and returning the compressor outlet vapors to a continuously running urinal system could save about 11 Kg (24.25 lbs). Systems integrations of these types were not considered as part of this study.

Figures 27 and 28 also include curves of a stored water and urine approach. These curves include power penalties for quantity sensors, pressure gauges, heaters, etc., but they do include a 25% redundancy penalty in order to meet the reliability requirements of long missions. A 25% reliability penalty is quite optimistic as it assumes five 25% capacity tanks. Usually, because of excessive valving, plumbing and other packaging and structural penalties associated with five tanks, systems with a 50% penalty (three 50% capacity tanks) are selected.

Packaging

The VCD package can fit in a space of about 142.2 cm long by 86.4 cm wide by 50.8 cm deep (56 x 34 x 20 inches). The total volume is thus about 0.624 cubic meters (22.04 cu.ft.). The package envelope is shown in figure 29.

All of the components can be removed from either the front or back face of the package. The controller must be removed first in order to provide access to some of the small valves and meters, but because this item is totally electrical no maintenance groundrules are violated. The two stills or just their motors can be removed to reduce the 142.2 cm (56 inch) dimension to 127 cm (50 inches) in order to meet the Orbiter and space station standard hatchway requirements of 127 x 101.6 cm (50 x 40 x 40 inches).

Programmatic Impact

As a result of the work conducted on the Vapor Compression Distillation (VCD) Concept during the Space Station Prototype contract, NAS 9-10273, and the Integrated Water Waste Management Program contract NAS 9-9191 the concept has reached the advanced prototype stage. More development work should still be conducted, however, it would be reasonable to consider the concept ready for a flight development program. The areas of most concern are the life, maintenance of the peristaltic metering pumps, purge pump development and automatic operation of the subsystem. Particularly the automatic shutdown and dryout modes of operation must be demonstrated. Precipitation may pose a very significant problem in these modes.

Since the VCD is not appropriate for a spacecraft which uses fuel cells for power supply, and therefore has an adequate water supply, it follows that the VCD is not an appropriate concept for the baseline Space Shuttle. However, for any extended mission using solar cells, the weight savings can be significant as is seen from figures 27 and 28. Assuming the Shuttle cost per kg of $77,000 ($35,000/lb) a 4 man 90-day mission could justify about $46 million to develop and qualify the VCD. This cost is approximately an order of magnitude more than would be required. It is therefore recommended that the development activities continue on the VCD for eventual extended mission use.

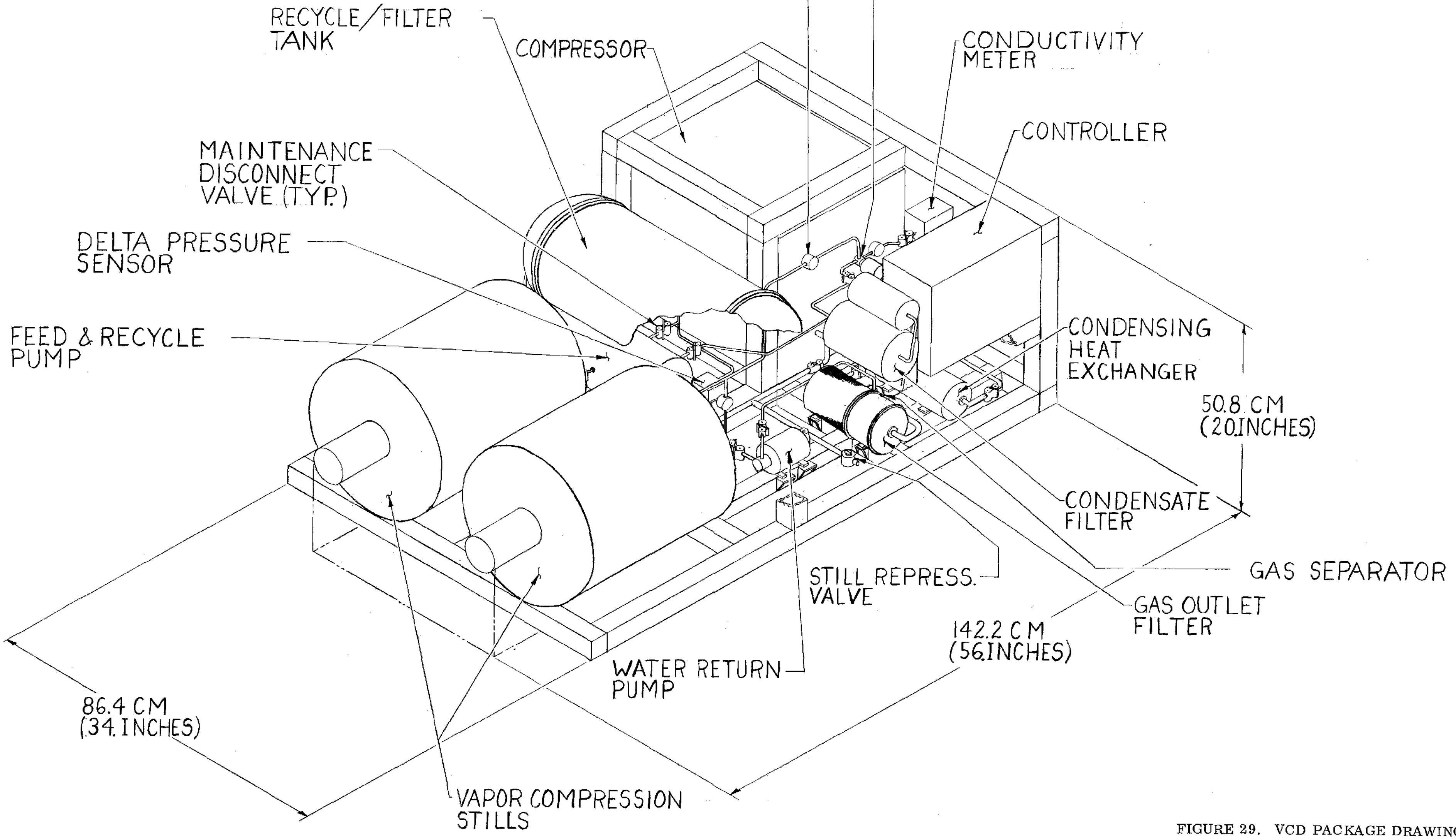


FIGURE 29. VCD PACKAGE DRAWING

FOLDOUT FRAME 1

FOLDOUT FRAME 2

REGENERABLE CO_2 AND HUMIDITY CONTROL SYSTEM

Summary

A regenerable CO_2 and humidity control system has been studied for possible application to the Shuttle Orbiter ARS. The system makes use of beds of absorbent material, called HS-C, which alternately adsorb CO_2 and water vapor from a process air stream and desorb CO_2 and water vapor to space vacuum. Incorporation of a system of this type in Shuttle would replace the expendable LiOH cartridges as the primary method of CO_2 removal and the condensing heat exchanger as the primary method of humidity control.

The results of this study indicate that the regenerable system is competitive with LiOH for the basic Shuttle mission (4 men for 7 days) and is superior for larger crew sizes and/or longer mission durations. On a cost basis the regenerable system would trade off in about 3 years of operational life at which point the cost saving in LiOH cartridges equals the development and procurement cost of the regenerable system.

In performing this study, an effort was made to present a complete and realistic assessment of the impact of incorporating the regenerable system into the Shuttle program. For example, a basic groundrule was established that the regenerable system would be studied as an add-on to the current ARS with essentially no modifications to hardware already under development for Shuttle. With this approach, the regenerable system could be implemented for Shuttle at any point in time prior to the operational phase without unreasonable impact. Although this groundrule does not allow full technical optimization of the regenerable system within the ARS it does provide the technical benefits as described herein and is practical from a programmatic point of view.

The regenerable system described in this study is based on the work currently being performed by Hamilton Standard under NASA JSC Contract NAS 9-13624 for development of a breadboard regenerable CO_2 and humidity control system. The relationship between the study and the development program is presented in figure 30.

RELATIONSHIP BETWEEN THIS STUDY AND HS-C DEVELOPMENT PROGRAM NAS 9-13624

Requirement/Configuration	Study	Development Program	Comments
Crew Size/Cycle Time			
Maximum	7/30 minutes	10/15 minutes	
Normal	4/52 minutes	4/52 minutes	
Reliability	Fail Safe	Fail Operational/ Fail Safe	Both approaches use LiOH for fail-safe backup.
Canisters			
Number	One full size	Three half size	Configuration for the study based on most recent Orbiter ARS reliability criteria
Total Adsorbent	19.0 kg (42 lbs)	28.6 kg (63 lbs)	
Configuration	Single canister consists of 2 beds* each containing 9.5 kg (21 lbs) of adsorbant	Each canister contains 9.5 kg (21 lbs) of adsorbent	Study based on bed identical to that currently being developed. Bed is slightly oversized (maximum crew of 7 versus 10).
Ullage	Ullage reduced by compressor **	Present weight trades based on ullage dump with equalization.	Ullage save compressor reduces total equivalent weight.

* Each bed consists of an adsorbing and desorbing section.

** Equalization not required - affects desorption time by less than 1%

FIGURE 30.

Technical Description

Requirements

The subsystem shall control the CO_2 level of the cabin atmosphere within .67 kPa (5 mm Hg) nominal and 1.01 kPa (7.6 mm Hg) maximum.

The subsystem shall control cabin humidity between the dewpoint temperature of 3.9°C to 16.1°C (39°-61°F).

The subsystem shall control the contaminant level of the cabin atmosphere. Contaminants requiring active sorbent control are given in figure 31.

The system shall be sized for a four-man crew at maximum metabolic rates and for a seven-man crew at nominal metabolic rates. Crew metabolic rates are defined by figure 32.

In the event of vehicle failure (something other than ARS or HS-C), expendables shall be sized for a contingency of 4 men for 4 days.

The Shuttle cabin temperature can vary between 18.3° - 26.7°C(65°-80°F)

The Shuttle cabin pressure is 101.4 kPa (14.7 psia) ± 5%.

All other environmental, handling, and design requirements shall be in accordance with the Shuttle ARS general design specification, SVHS 6400.

The system shall be designed to fail safe.

a. No single failure shall result in a loss of cabin atmosphere

b. The system shall be capable of operation in a fail-safe mode for 20 hours with a 7 man crew. (This sizes fail safe expendables such as LiOH). i.e., 3 LiOH cartridges, (6.3 lbs/cartridge).

c. During emergency conditions the partial pressure of CO_2 may rise to a maximum level of 2.0 kPa (15mm HG); the PCO_2 shall not be above 1.01 kPa (7.6 mmHG) for longer than 2 hours.

Subsystem Description

<u>HS-C Description</u> - HS-C is an imine developed at Hamilton Standard to perform the functions of humidity control and CO_2 removal for a Space Shuttle type vehicle. A system using this compound has the unique ability to adsorb both CO_2 and metabolic water vapor independent of each other from a cabin air stream and desorb both to space vacuum simultaneously.

CONTAMINANT	PRODUCT RATE GM/DAY (LBS/DAY)	MAX. CONC MG/L
AMMONIA	1.50 (.0033)	0.0170
CARBON MONOXIDE	0.20 (0.0004)	0.0170
INDOLE	0.15 (0.0003)	0.0024
PHENOL	0.57 (0.0013)	0.0019
PYRUVIC ACID	1.26 (0.0028)	0.0009
SKATOLE	0.15 (0.0003)	0.0025

FIGURE 31. ACTIVE TRACE CONTAMINANT CONTROL USE OF A SORBENT

Cabin Temperature °C (°F)	Heat Output kJ/Man-Day (BTU/Man-Day)			
	Nominal		Maximum	
	Latent	Sensible	Latent	Sensible
18.3 (65)	2962 (2805)	8371 (7928)	5174 (4900)	8341 (7900)
21.1 (70)	3838 (3636)	7495 (7098)	6040 (5720)	7476 (7080)
23.9 (75)	4986 (4722)	6347 (6011)	7155 (6776)	6361 (6024)
26.7 (80)	6198 (5870)	5135 (4863)	8350 (7908)	5165 (4892)

CO_2 PRODUCTION

kg/Man-Day (lb/Man-Day)	
Nominal	Maximum
.96 (2.11)	1.14 (2.51)

FIGURE 32. CREW METABOLIC RATES

(Continued)

HS-C is made from a spherical porous substrate (diameter about 0.5 mm) which is coated with a thick non-volatile liquid imine. The substrate is a polymeric acrylic ester similar to plexiglas while the coating is a polyethylenimine (PEI) with a molecular weight of 1800.

Under operation, cabin air flows through the HS-C bed for the selected adsorption time while heat is removed from the chemically reacting sorbent bed. At the end of the adsorb cycle, desorption begins automatically with the isolation of the bed from the cabin air loop and the application of a hard vacuum to the HS-C bed in its canister. At this time heat must be applied to the sorbent to maintain an isothermal condition in the bed. The entire cycle is repeated for the required mission duration. The adsorbing HS-C transfers heat directly to the desorbing HS-C. This design reduces system volume and power requirements.

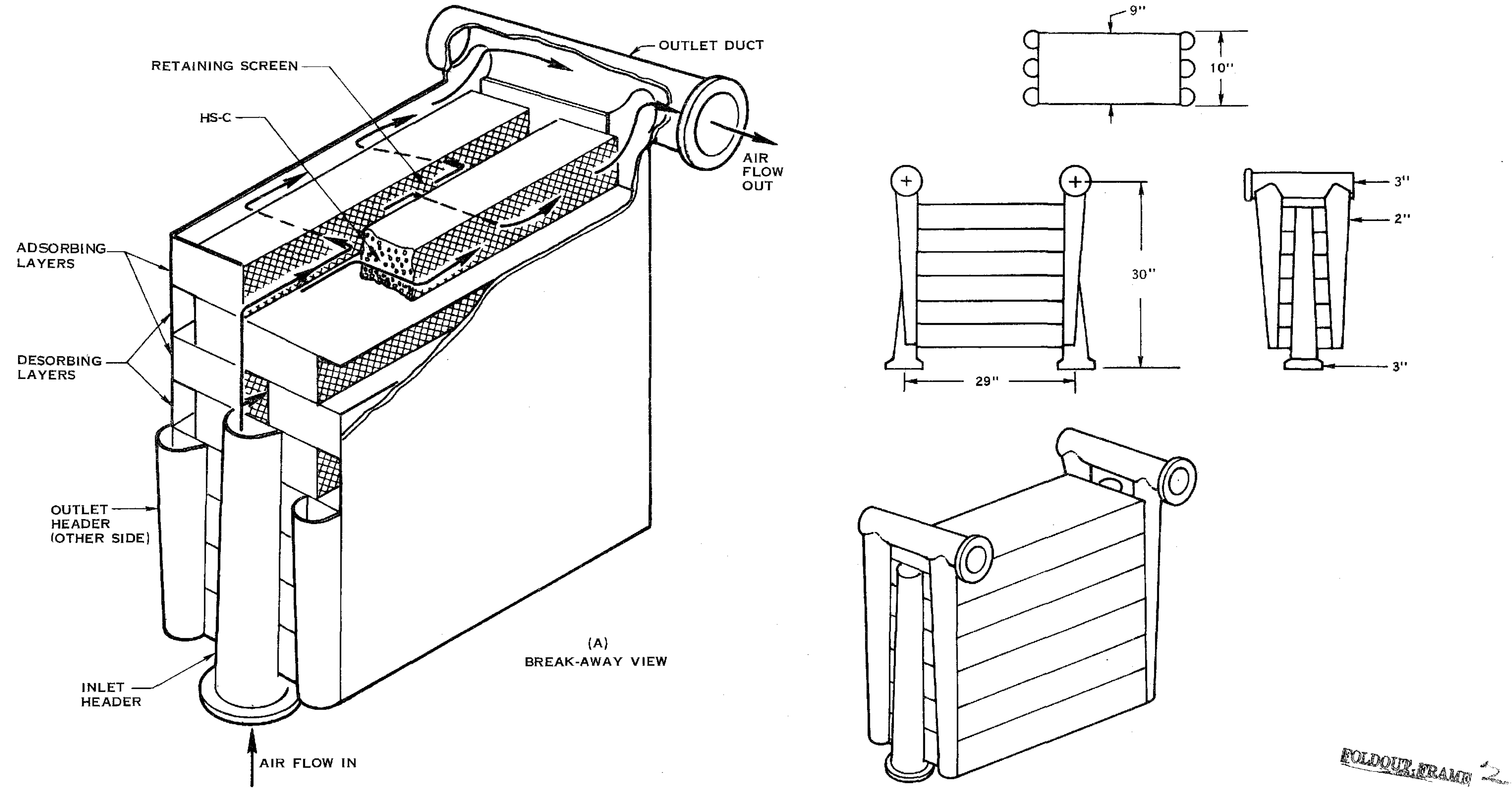
Figure 33 illustrates how the concept would be incorporated into a canister. The HS-C canister core consists of alternating layer separated by parting sheets. One layer of HS-C is adsorbing while the two adjacent layers are desorbing. External headers connect the alternate layers to a common duct so that there will be four air passage flanges.

Subsystem Operation - The HS-C subsystem performs both the CO_2 removal and humidity control functions for the Orbiter vehicle. The HS-C subsystem is shown schematically in figure 34. The subsystem plumbs into the ARS supply ducting that connects the cabin to the cabin fan package.

The subsystem draws air from the supply duct. This air first passes through a debris filter which takes out airborne particulate matter. The air then passes through one of the canister cycle valves, through the HS-C adsorbing bed and out through another cycle valve. Four cycle valves are required to control the operation of the two HS-C beds. While one bed is adsorbing the second bed is desorbing to space vacuum.

The air flow then mixes with humidity control bypass flow, travels through the subsystem fan and is exited back into the ARS supply duct downstream of the HS-C inlet tee but still upstream of the cabin fan package. The flow is essentially taken from and returned to the same point in the ARS.

The humidity control bypass valve is a modulating valve that varies the flow through the HS-C canister from .0165 to .0236 m^3/sec (35 to 50 cfm). This prevents cabin humidity from dropping below 3.9°C (39°F) while still maintaining the cabin CO_2 level at a nominal .66 kPa (5 mmHg).



FOLDOUT FRAME 1

FOLDOUT FRAME 2

FIGURE 33. HSC HEAT EXCHANGER

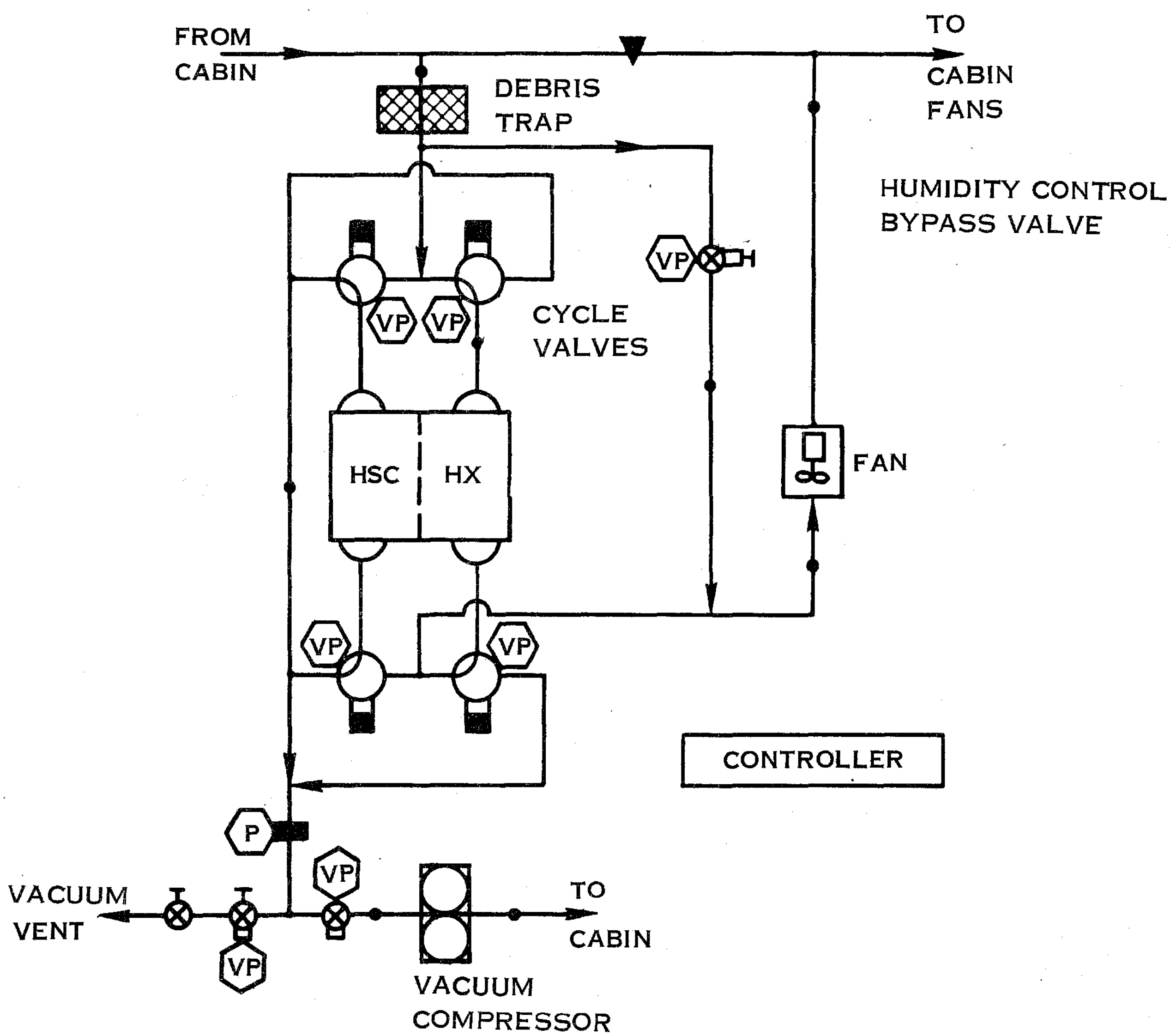


FIGURE 34. HSC SUBSYSTEM SCHEMATIC ULLAGE SAVE CONFIGURATION

The desorption cycle is controlled by a series of valves and a compressor. The desorption cycle starts with the two cycle valves shutting off the adsorbing air flow thus isolating the canister from the cabin. The cycle valves then open the canister to the vacuum duct. This duct is isolated from the space vacuum until the compressor pumps the canister down to 6.9 kPa (1.0 psia). The compressor cycle saves 87% of the cabin gas that would otherwise be dumped overboard with each cycle. The ullage save cycle takes 2 minutes, at which time the two vacuum valves switch over, isolating the compressor and exposing the HS-C canister to hard, space vacuum.

A manual isolation valve is provided in the vacuum line for fail safe isolation of the vacuum source should excessive leakage occur. Excessive leakage is detected by monitoring the final desorption pressure at the end of each cycle by a pressure transducer provided in the vacuum line.

The subsystem is monitored, controlled and cycled by an electronic controller with built-in logic for detecting malfunctions and degraded performance.

Fail Safe Operation - The HS-C subsystem is designed to be fail safe and as such, only one HS-C canister is required with redundancy provided only on the vacuum plumbing. Here an isolation valve is provided should a vacuum valve leak, thus satisfying the requirement that no single failure should result in a loss of cabin atmosphere.

Should a failure occur resulting in the shutting down of the HS-C subsystem, the 20 hour contingency operation is provided by the present Shuttle baseline systems of LiOH for CO_2 removal and the cabin heat exchanger for humidity control.

Flow Diagram - A flow diagram is shown in figure 35. This flow chart is the same for both a 4 man crew and a 7 man crew. The only variable dependent on metabolic loading is cycle time. For a 7 man crew at nominal metabolic conditions, the beds will cycle every 30 minutes; and for a 4 man crew at maximum metabolic conditions, the beds will cycle every 52 minutes.

Design Data

Design Point - The critical design point for the HS-C subsystem is based on the 7 man crew size. This case sizes the air flow rates and bed chemical quantity.

The 4-man crew size is easily handled by the subsystem with no modifications. To avoid excessively low dewpoints in the cabin and to minimize ullage dump, the cycle time is increased for the 4-man crew.

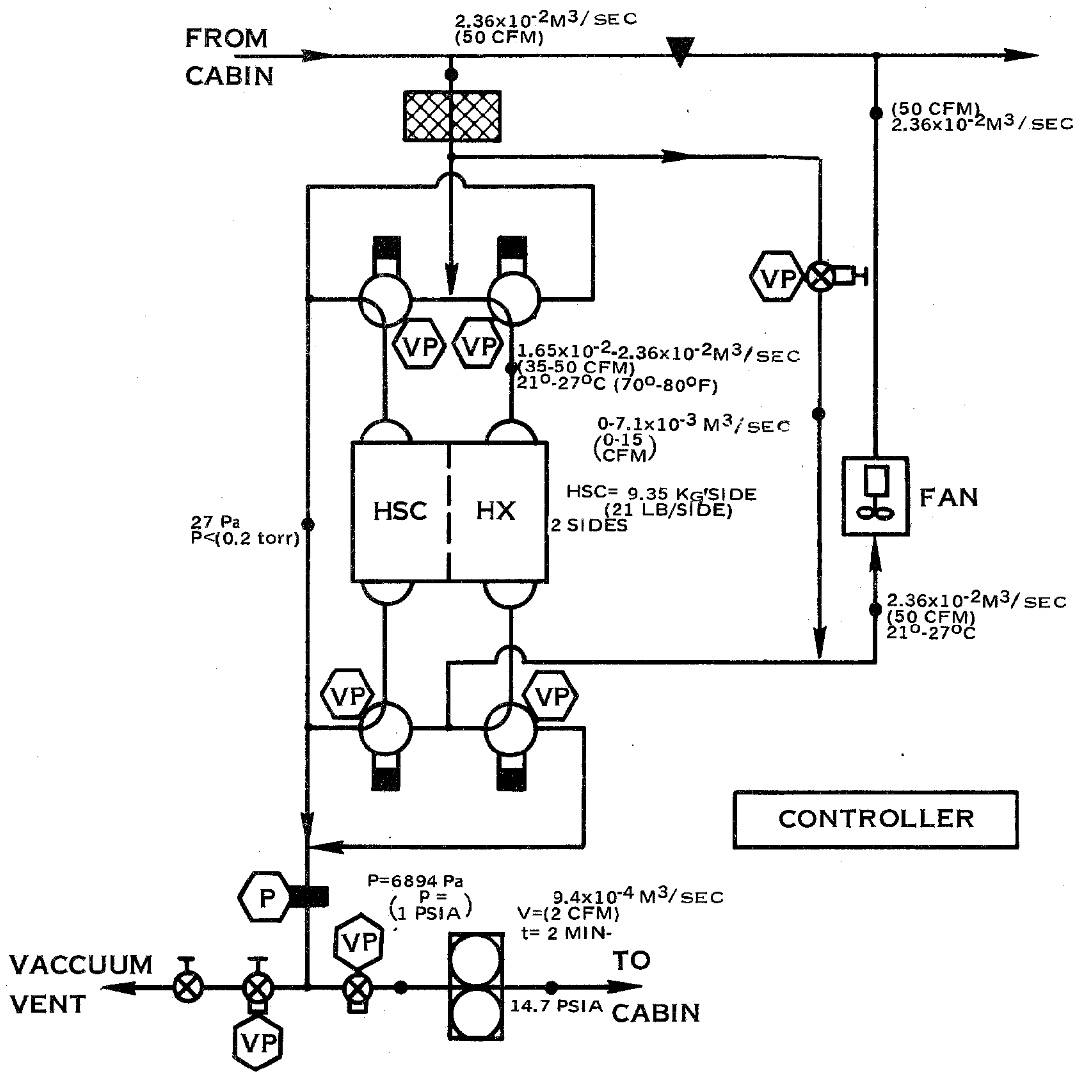


FIGURE 35. HSC SUBSYSTEM FLOW DIAGRAM ULLAGE SAVE CONFIGURATION

Mission duration has very little impact on subsystem sizing. The bed quantity is not affected. The only time dependent expendables needed for long duration missions are the odor filters (replaced every 22 days for a 4 man crew), the fuel-cell power penalty and a gas make-up penalty. Expendables for the baseline 7 day mission are minimal and can be accommodated in existing vehicle storage systems.

Bed Sizing - The HS-C bed sizing is based on an interplay between man-loading cycle time and mission length. For long duration missions, a large bed with long cycle times will result in a lower total equivalent weight than a small bed with short cycle times. This lower total equivalent weight is a result of the reduced ullage and the compressor power and gas storage penalties associated with the longer cycle times.

This study is based on the 19.05 kg (42 lb) bed being developed under contract NAS 9-13624. Because this bed is sized for a 10 man loading with a 15 minute cycle it is oversized for the range of crew sizes considered in the study (4 to 7 men). If a new bed were designed specifically for these requirements, the HS-C subsystem would be superior to LiOH for the baseline Shuttle missions.

Ullage and Ullage-Save Compressor - The most important sub-trade affecting the HS-C subsystem design is the ullage penalty associated with dumping cabin gas overboard with every cycle switchover. The extra gas that must be carried together with its tankage penalty quickly add up for long mission durations as shown in figure 36. This graph shows both the 4 men and 7 men ullage loss and the make-up penalty based on using Shuttle baseline O_2 and N_2 gaseous storage tanks. It should be noted that these curves are based on equalizing both sides of the canister and dumping the ullage at 51.8 kPa (7.5 psia) and not dumping the full 101.4 kPa (14.7 psia) canister.

Superimposed on this graph is a curve of the total equivalent weight of the ullage-save compressor approach. This curve includes the fixed weight of the compressor, extra valves and plumbing, extra controller capacity and supporting structure. The curve also includes the expendable weights of compressor power penalty and ullage make-up penalty for dumping gas at 6.0 kPa (1.0 psia) overboard.

Figure 37 shows a more detailed breakdown of the ullage-save compressor approach. This curve shows both the 4 men and 7 men cases.

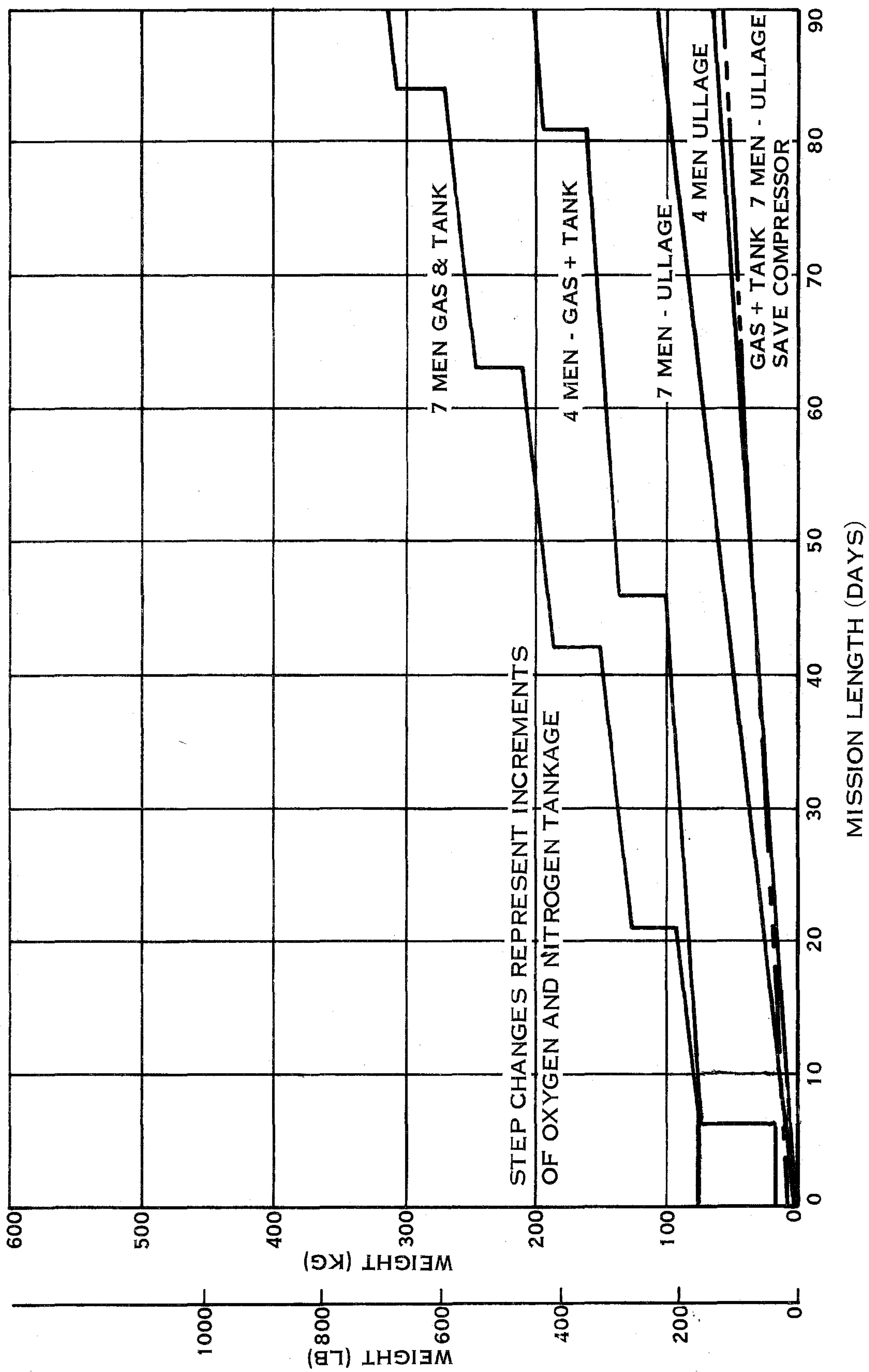


FIGURE 36. ULLAGE PENALTY MAKE-UP GAS STORAGE

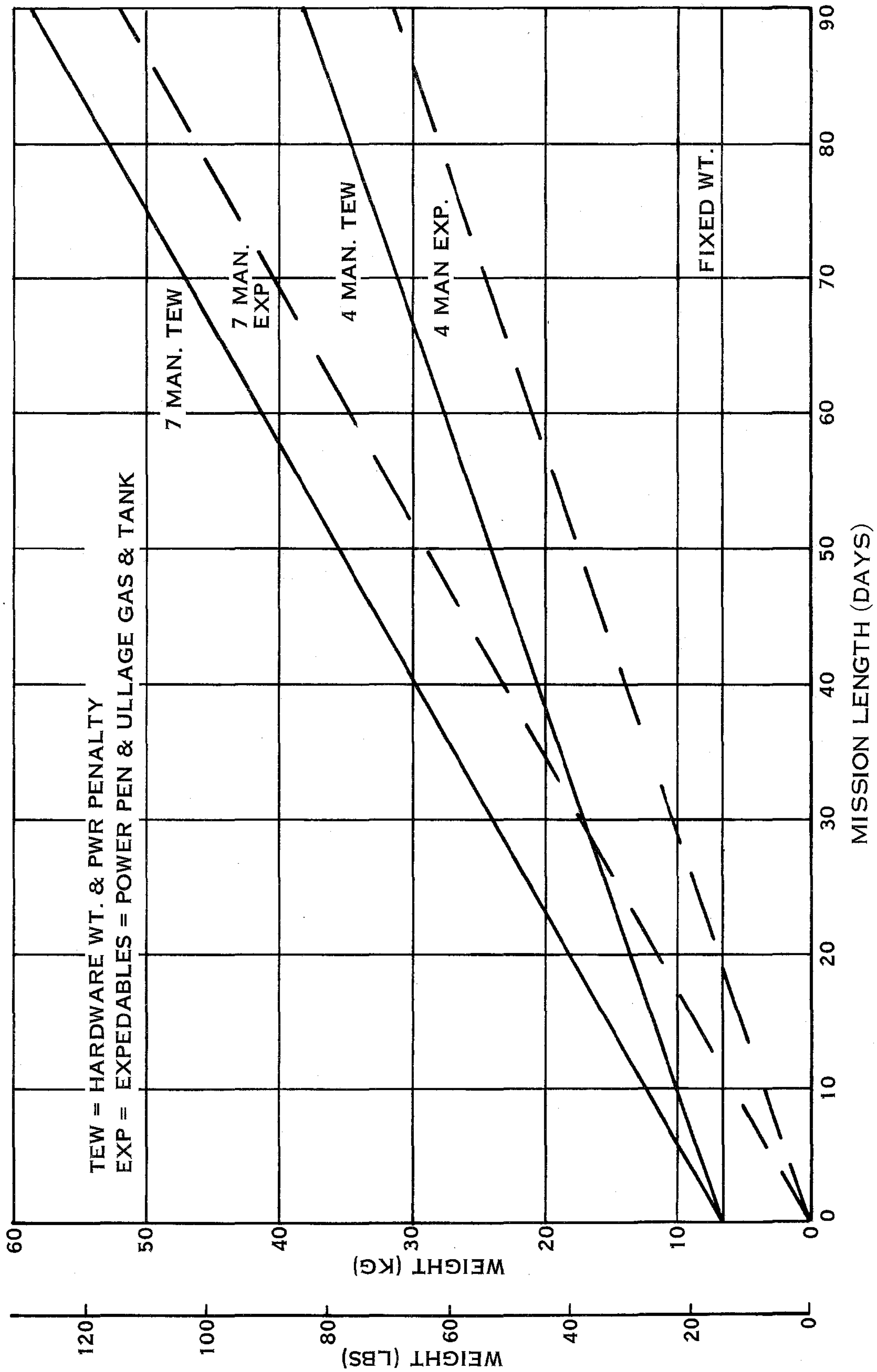


FIGURE 37. ULLAGE - SAVE COMPRESSOR

Weight and Power

Weight and power estimates are given in figure 38. The HS-C canister is based on the HS-C development program design. The other major weight item is packaging. This includes structure, plumbing, wiring harnesses, electrical connectors and component brackets. The weight was derived from factors associated with packaging ECS hardware which depend on the size and make-up of major components and the total weight of all components.

The power is divided into two columns; total power in watts and cumulative power in watts-hours per day for a 7 man crew. From these data the expendable fuel-cell power penalty is derived for both 4 men and 7 men. For the 4 man case, the total power is the same, but the different cycle time affects the watt-hours/day.

Packaging

A packaging concept for the HS-C subsystem is shown in figure 39. The overall package envelope is defined by a section of the Shuttle orbiter presently occupied by LiOH storage and a waste water tank. This envelope is outlined as "Available Vehicle Envelope" on the packaging drawing. It can be seen that the package, which is 1.00 m (39.5 in) wide x .95 m (37.5 in) long x .70 m (27 in) deep, easily fits into the available vehicle space.

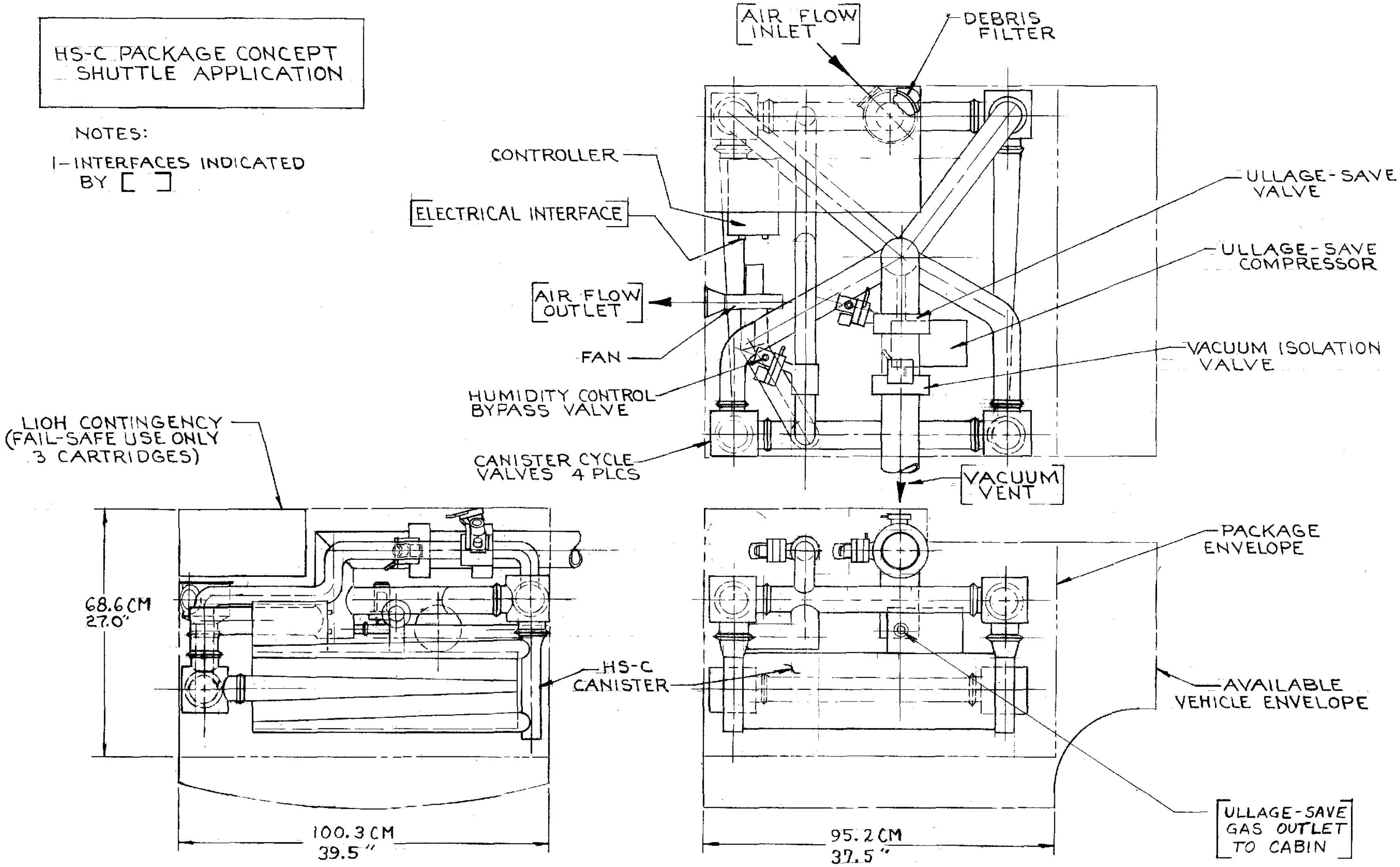
The package is designed to fit under and mount to the vehicle floor structure. All components requiring access are located on top of the package under the floor panel previously used for LiOH cartridge access. These components include:

- LiOH Fail-Safe Contingency
- Debris Filter
- Vacuum Valve Handles
- Humidity Bypass Valve Handle
- Plumbing Interfaces
- Electrical Interfaces

The HS-C canister is located at the bottom of the package because it does not require access. All the other components and plumbing are mounted on top of the canister. The vacuum plumbing extends from the four cycle valves at each corner of the canister to a common vacuum duct in the top middle of the package. All other components are located in between and under this plumbing. The debris filter, which is only cleaned between missions, is located under the removable LiOH contingency shelf.

Component	Qty	WT (Kg)	WT (lb)	PWR (watts)	Op. Time HR/Day	WT-HR per Day
HSC Hx	1	40.6	89.5			
Cycle Valves	4	6.9	15.2	50	.32	16
Debris Trap	1	0.5	1.1			
Bypass Valve	1	1.0	2.2			
Fan	1	1.3	2.9	65	24	1560
Controller	1	3.4	7.5	10	24	240
Vac. Valve	1	1.3	2.9	50	.11	5.5
Isolation Va.	1	0.9	2.0			
Compr. Valve	1	0.7	1.5	50	.11	5.5
Compressor	1	2.2	4.9	160	1.62	259
Subtotal		58.8	129.7			
Packaging		23.0	50.7			
Totals		81.8	180.4	385		2086

FIGURE 38. HSC WEIGHT AND POWER SUMMARY



FOLDOUT FRAME

FIGURE 39. PACKAGING CONCEPT FOR HS-C SUBSYSTEM

FOLDOUT FRAME

The package interfaces are identified in figure 39 by square brackets. The flow inlet interface is the inlet to the debris filter. The flow outlet interface is the fan outlet. The vacuum interface is located at the outlet of the vacuum isolation valve. The ullage-save compressor flow is dumped directly from the compressor outlet with no plumbing connection due to the minimum amount of gas discharged (.04 m^3/cycle (1.5 ft^3/cycle)). The electrical interface is located directly on the controller.

The LiOH contingency storage shelf is considered to be similar to Rockwell's baseline design as identified on drawing VL70-003348.

Vehicle Integration

Baseline System

The HS-C subsystem is designed to handle the following ARS functions:

- CO_2 Removal
- Odor and Trace Contaminant Control
- Humidity Control

The Shuttle baseline system controls CO_2 removal, odors, and trace contaminants with LiOH/charcoal cartridges. The cartridge is shown in figure 40.

Each cylindrical radial flow cartridge contains 2.27 kg (5 lb) of LiOH, 0.045 kg (0.1 lb) of activated charcoal, 0.068 kg (0.15 lb) of Purafil and teflon filters. The charged cartridge is sized for a 2 man-day capacity and weighs 2.86 kg (6.3 lb).

In addition to removing CO_2, the LiOH system will control CO, NH_3, phenol, H_2S, etc. The chemical beds are preloaded and contain teflon filters at the exit to prevent LiOH dust from entering the cabin air stream. The radial flow beds maximize flow outlet area resulting in a 249 Pa (1.0 inch) pressure drop at $1.56 \times 10^{-2} m^3/s$ (33 cfm for each cartridge).

Two beds are installed in the ARS at all times. With a four man crew, both beds are replaced once a day. With a seven man crew, the two beds must be replaced every 11.0 hours. Because the LiOH undergoes an irreversible chemical reaction in removing CO_2, the beds can not be regenerated. This requires storage of fresh and spent cartridges which can accumulate quickly for a long duration flight. The storage space for the baseline orbiter mission is located in the orbiter floor directly adjacent to the on line ARS LiOH canisters.

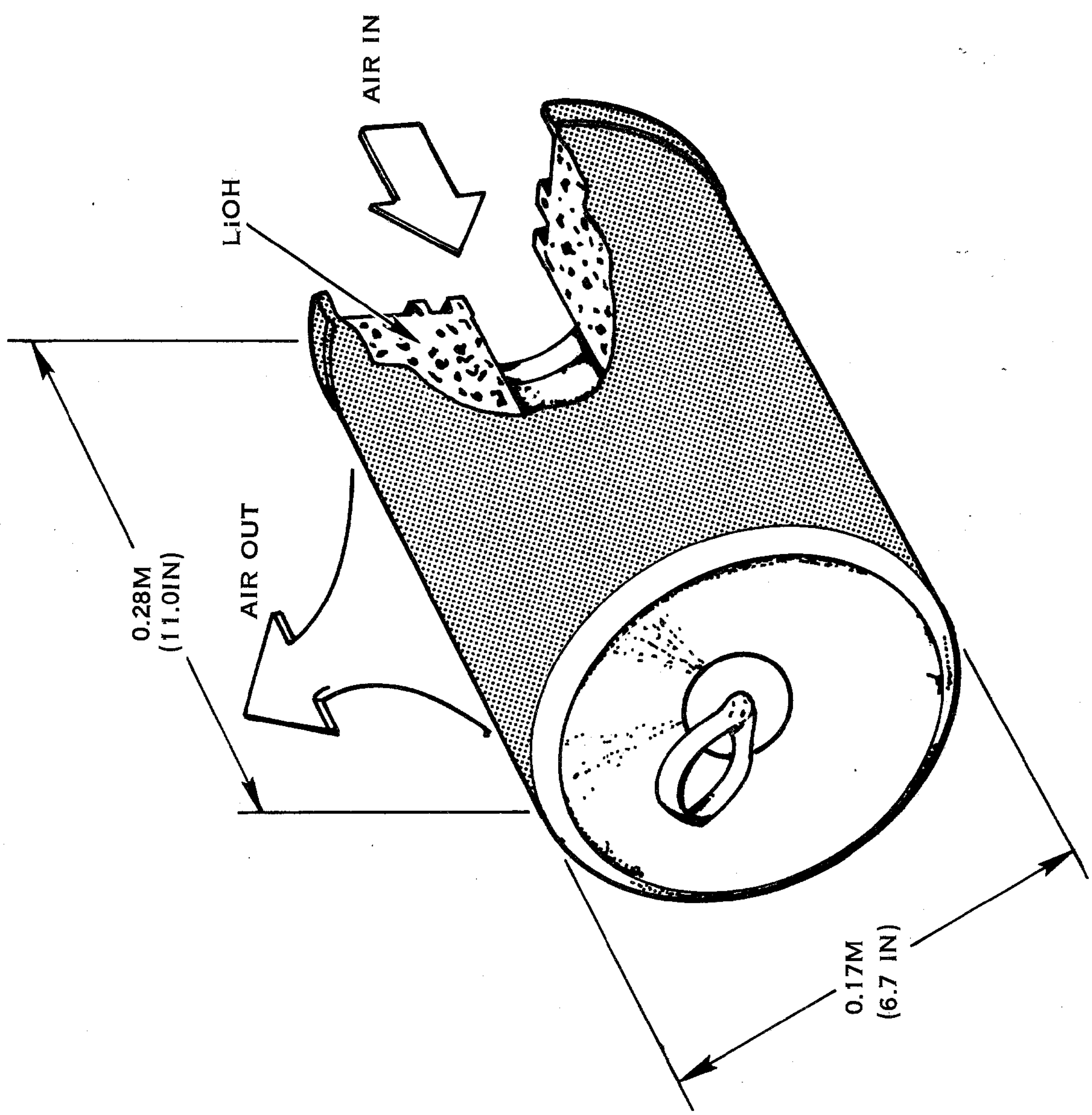


FIGURE 40. LITHIUM HYDROXIDE CARTRIDGE

Humidity control is accomplished on the ARS baseline by the use of a condensing cabin heat exchanger. The free moisture that has condensed on the walls (fins and parting sheets) of the heat exchanger is picked up by slurper tubes located at the outlet of the air side. The slurper tubes are manifolded together and plumbed to a fan/separator package.

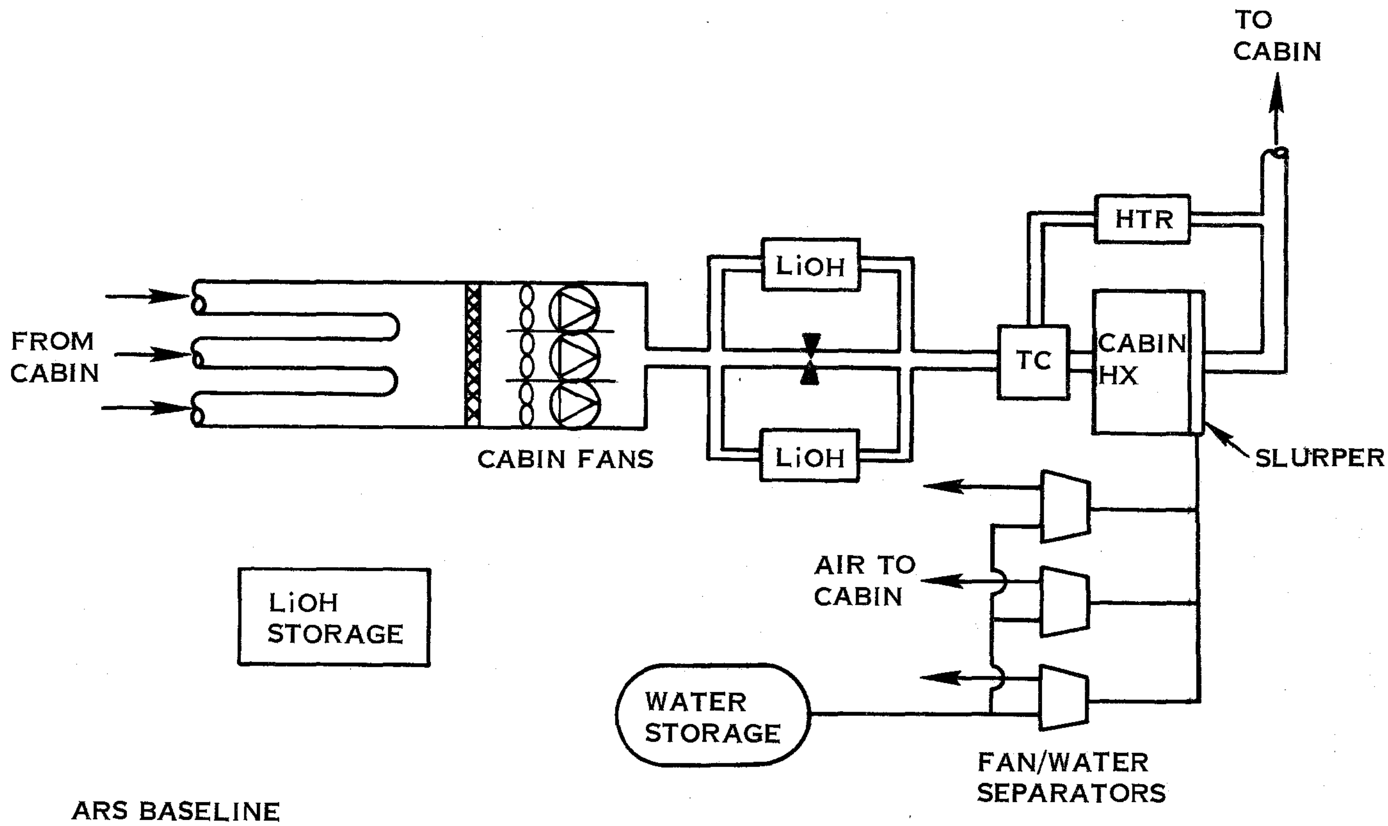
The fan/separator provides the driving force that sucks airflow and condensates into the slurper tubes. It then separates the condensate liquid from the air stream and pumps it into the waste water storage subsystem. The air flow is returned directly to the cabin. Three fan/separators are required to meet the reliability requirements of the humidity control function.

The condensate is stored in the waste water storage subsystem. This subsystem is comprised of three 71.2 kg (157 lb) capacity tanks and associated valving. Two tanks are used on-line and have sufficient capacity to store all the water produced in a baseline mission. This subsystem stores water from only two sources; condensate and urine.

Vehicle Consideration

The baseline Shuttle system affected by HS-C integration is shown in a simplified schematic in figure 43. Vehicle ducting leads from the cabin to the cabin fan package. The LiOH canisters are located in parallel with the mainstream flow downstream of the fans. A temperature control valve (part of the LiOH canister package) regulates the airflow through the cabin condensing heat exchanger. The fan/separators pull the condensate from the slurper section of the heat exchanger and deliver the condensate to a waste water tank. LiOH storage represents the final package affected by the HS-C integration.

Figure 41 shows schematically how the HS-C would integrate into the ARS baseline. The HS-C subsystem would take off and return its air flow to the ARS inlet plumbing. The rest of the ARS would remain the same. The LiOH storage area would be greatly reduced, needing only two cartridges for 4 men for HS-C fail safe operation. The capability for 7 man fail safe operation requires an additional two cartridges to be stored in the payload area. A total of four cartridges are required because utilization with the 7 man crew is less than that for a 4 man crew. Odor filters would be installed in place of the LiOH canisters and would handle the baseline mission without replacement. Replacement would be required for a 22-day four man mission, however. The slurper and fan/separators would be retained in a non-operating mode to handle the fail safe humidity control function of the HS-C. The condensate outlet of the fan/separator could be vented directly overboard or into the waste storage subsystem. In either case, one tank would be eliminated because condensate storate is no longer needed.


TO
CABIN
HTR
LiOH
FROM
CABIN
TC
CABIN
HX
LiOH
CABIN FANS
SLURPER
AIR TO
CABIN
LiOH
STORAGE
WATER
STORAGE
FAN/WATER
SEPARATORS
ARS BASELINE

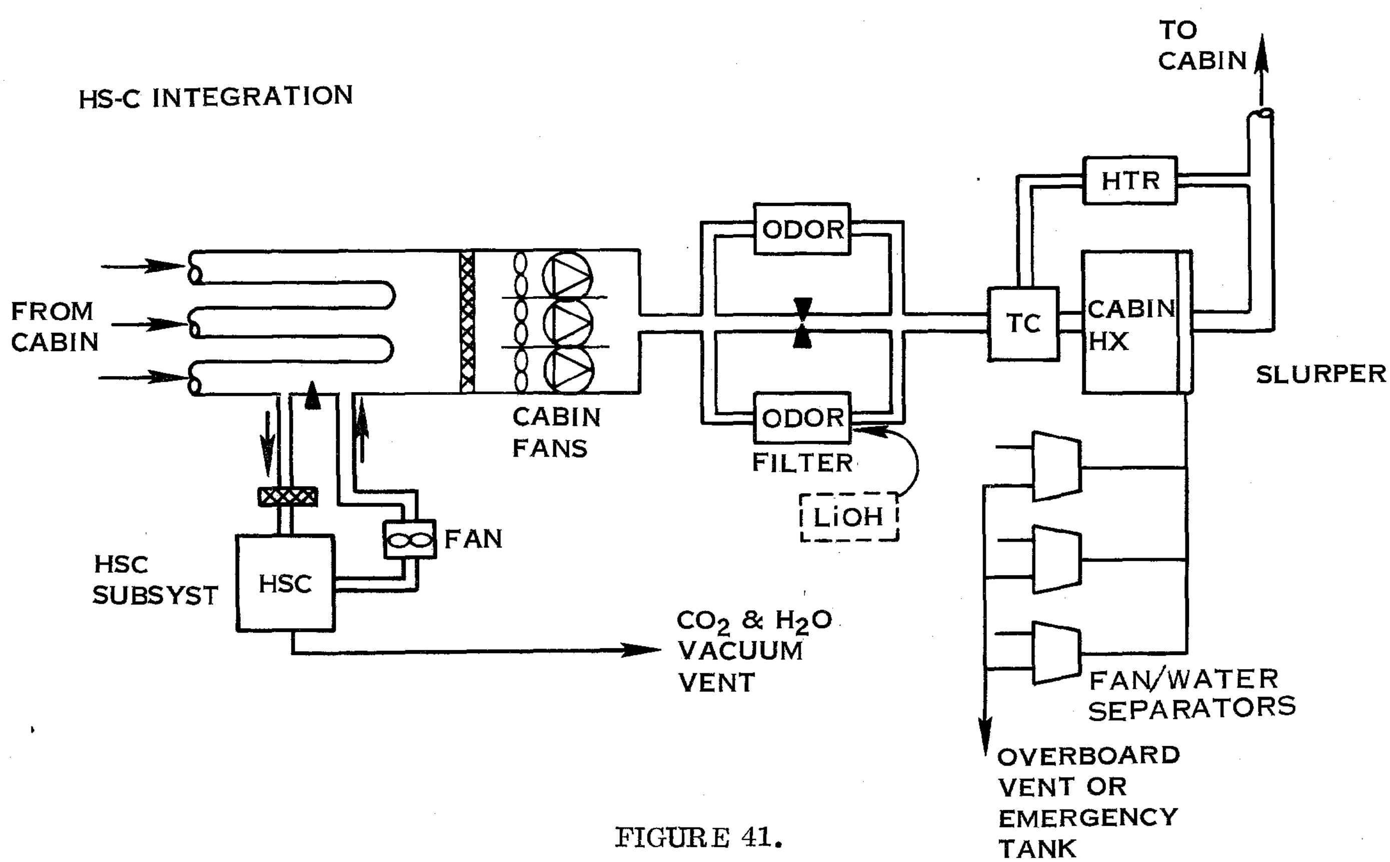

HS-C INTEGRATION
TO
CABIN
HTR
ODOR
FROM
CABIN
TC
CABIN
HX
SLURPER
CABIN
FANS
ODOR
FILTER
LiOH
FAN
HSC
SUBSYST
HSC
CO_2 & H_2O
VACUUM
VENT
FAN/WATER
SEPARATORS
OVERBOARD
VENT OR
EMERGENCY
TANK

FIGURE 41.

The most important groundrule in the vehicle integration study was that the HS-C integration should have a minimum impact on other subsystems and components. As such, the following ARS components were not considered for redesign although all could be modified for optimum HS-C integration:

- Cabin Fans
- LiOH Canisters, Plumbing and Location
- Fan/Water Separators and Package
- Waste Water Storage Tanks

This groundrule is reflected in the HS-C integration schematic previously discussed The vehicle packaging study, therefore, also treated these components and the ARS in total as fixed and not alterable from a hardware standpoint.

Vehicle Packaging

The first task of vehicle packaging is to locate a place in the vehicle where the HS-C package could fit. As a primary objective, as has just been discussed, the package should have a minimum impact on other subsystems and components. As such, the objective is to place the package in areas where existing ARS components are no longer needed because the HS-C subsystem makes them obsolete. Only two components are thus affected. These are the LiOH storage area, which has been reduced from a storage capacity of 27 cartridges to 2 cartridges for 4 man crew, and a waste water tank which has been eliminated because condensate storage is not needed with HS-C. These components are located adjacent to each other in the vehicle, yielding a volume sufficient for the HS-C package. This volume was reflected in the packaging concept previously discussed. A vehicle concept drawing is shown in figure 42. This drawing shows the HS-C package location within the vehicle and its relationship to other ARS hardware.

The package fits into the area between the ARS and the water storage tanks. The HS-C is plumbed into the ARS by a supply duct and return duct that run adjacent to the ARS and tee into one of the vehicle supply ducts as shown. The only other additional plumbing is the vacuum vent line that connects the HS-C package to the unpressurized cargo area of the vehicle. The additional plumbing is located so as not to interfere with any subsystems or stowage areas of the vehicle.

The only adverse effect of this package location might be the blocking of access to and the removal of the waste water tanks. It is understood that these tanks are mounted on rails and are removed through the LiOH storage floor panel. If access should be a problem the following approaches are considered viable: first, the packaging arrangement can be altered to achieve a removable package; or second,

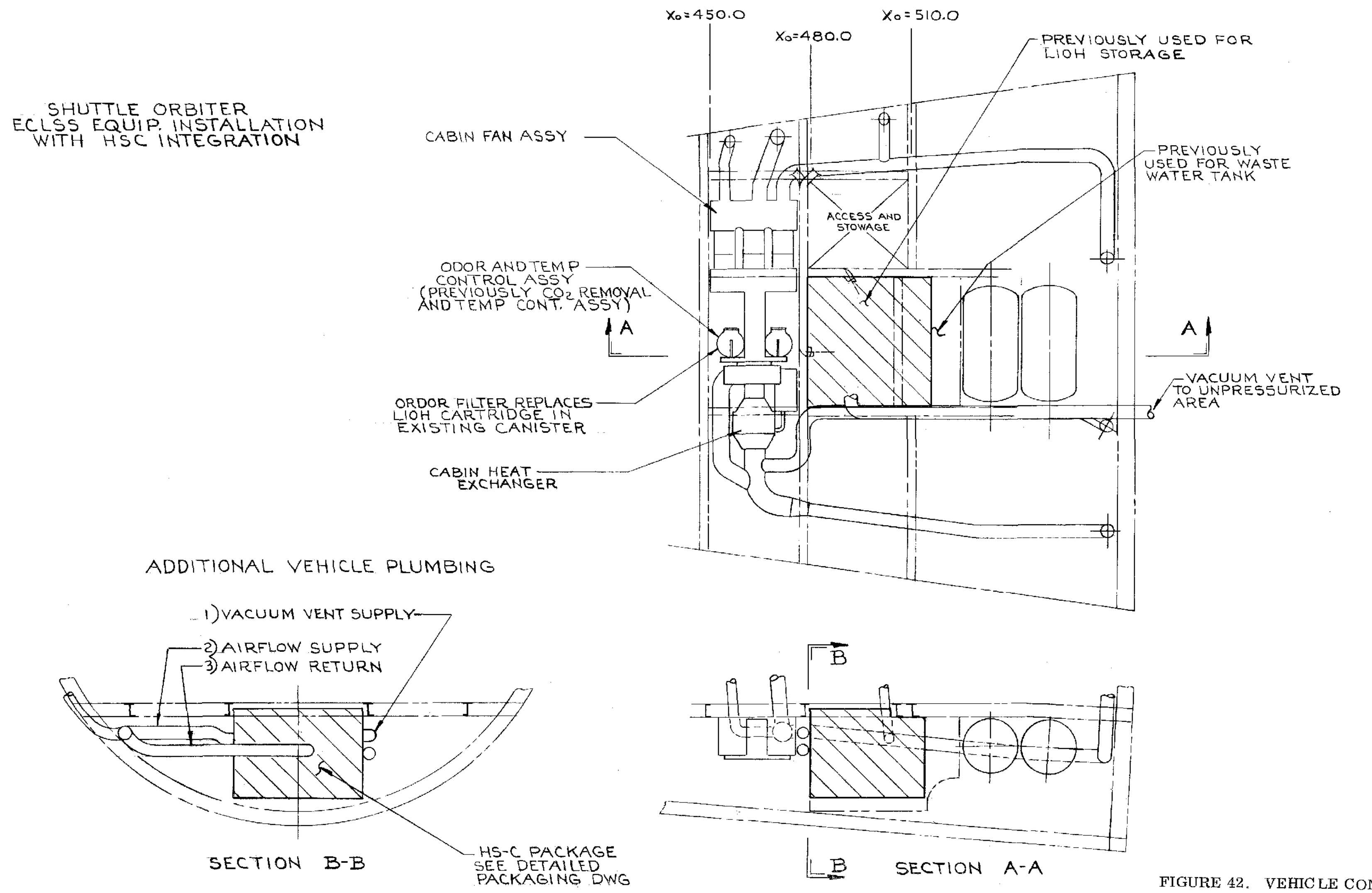


FIGURE 42. VEHICLE CONCEPT DRAWING SHOWING INSTALLATION OF HS-C SUBSYSTEM

ORIGINAL PAGE IS OF POOR QUALITY

FOLDOUT FRAME 1

FOLDOUT FRAME 2

a new access panel can be designed allowing removal of the waste water tanks through the unused portion of the HS-C available envelope.

Weight Trade-off

The weight trade-off is a comparison of the weight of hardware and vehicle penalties that must be added to the vehicle to totally integrate the HS-C subsystem, versus the weight of hardware and penalties that are replaced by the HS-C subsystem. Figure 43 defines the impact of integrating the HS-C concept into the vehicle. This figure is divided into two categories; fixed weight which is not time dependent and expendable weight which is time dependent. The figure is also divided into two columns, one for a four man crew and the other for a seven man crew.

In integrating the HS-C into the vehicle, the following baseline components and penalties are no longer needed; LiOH cartridges and storage facilities, one waste water tank and structure, and the power penalty associated with running the humidity control fan/separators. These items represent the trade-off comparison and are summarized in figure 44.

Figures 43 and 44 can be plotted with respect to time to give a total equivalent weight for any length mission. This graph is shown in figure 45 and shows the following:

- The HS-C subsystem competitive with LiOH for the baseline mission (4 men for 7 days).
- The HS-C subsystem is lightest for 7 man missions greater than 7 days.
- The HS-C subsystem weight advantage becomes significant for increased length missions.

As can be seen, when totaling all parameters affecting vehicle impact, the HS-C subsystem is competitive with, or superior to, LiOH for all possible missions. This equivalent weight includes both hardware weight and power penalties. The only other major parameter affecting vehicle impact is volume. The vehicle packaging drawing, figure 42, shows that the HS-C subsystem fits into less volume than previously occupied by the LiOH storage and waste water tank, for the baseline mission. Expendables for missions other than baseline are stored in the payload section. The HS-C subsystem requires less volume because it stores only one odor filter for every 22 LiOH cartridges needed by the baseline system.

	4 Men		7 Men	
	KG	lb	KG	lb
Fixed Weight				
HS-C Package (a)	81.6	180	81.6	180
LiOH Back-up (b)	10.4	23	17.7	39
Vacuum Plumbing (c)	16.3	36	16.3	36
Vehicle Plumbing (d)	4.1	9	4.1	9
Expendable Contingency (e) (16 man days)	9.1	20	9.1	20
Total Fixed Weight	121.5	268	128.8	284
	KG/day	lb/day	KG/day	lb/day
Expendable Weight				
Power Penalty (f)	1.78	3.93	1.89	4.17
Ullage Penalty (Gas and Tank)(g)	.20	.45	.34	.76
Odor Filters and Storage (h)	.33	.73	.58	1.28
Total Expendable Weight	2.31	5.1	2.81	6.2

Footnotes

(a) HS-C Package-Based on figure 40.

(b) LiOH back-up for HSC - Based on 20 hr. contingency; 2 cartridges for 4 men and 4 cartridges for 7 men. They are stored in one section of the baseline Orbiter LiOH Storage Container. Storage penalty based on a Rockwell estimate.

(c) Vacuum Vent Line - Based on a Rockwell estimate

(d) Vehicle Plumbing (Supply and Return Line) - Based on two four foot lengths of 3 inch aluminum ducting with a 100% structural support penalty.

(e) Contingency - 16 man-days worth of expendables are required for all missions as a contingency. This is added to Fixed Weight. This requirement is based on 4 men from the "Expendable Weight" section of the table x 4 days- but also applies to 7 man crew. Also based on good ECS and bad vehicle.

FIGURE 43. WEIGHT SUMMARY: HS-C INTEGRATION

(Continued)

(f) Power Penalty

1. Based on fuel cell penalties which are 0.91 kg/kw-hr (2.0 lb/kw-hr)

2. Good for missions up to 30 days.

3. For missions over 30 days solar cells should be added for further weight savings.

4. Power penalty would change slope at 30 days if solar cells used because penalty would be less.

(g) Ullage Penalty - Based on dumping canister at 1.0 psia - Penalty is for make-up gas plus tankage.

(h) Odor Filters - Based on Shuttle man-day loading. Conservative based on efficiencies of packing and contact time.

Storage penalty based on conservative estimate of LiOH storage (45%).

FIGURE 43. WEIGHT SUMMARY: HS-C INTEGRATION (CONTINUED)

	4 Men		7 Men	
	KG	lb	KG	lb
Fixed Weight				
Water Tank and Structure (a)	47.6	105	47.6	105
Expendable Contingency (b)	33.1	73	33.1	73
Total Fixed Weight	80.7	178	80.7	178
	KG/day	lb/day	KG/day	lb/day
Expendable Weight				
LiOH Cartridges (c)	5.72	12.6	12.47	27.5
LiOH Storage (d)	1.72	3.8	3.77	8.3
Power Penalty (Fan/Sep.) (e)	.86	1.9	.86	1.9
Total Expendable Weight	8.30	18.3	17.10	37.7

Footnotes

(a) Water Tank and Structure - Based on Rockwell input for one tank.

(b) Expendable Contingency - 16 man-day supply of expendagles. Based on 4 men from the "Expendable Weight" section of the table x 4 days.

(c) LiOH - Based on Shuttle ARS test data. Cartridge weight is 6.3 lbs.

(d) LiOH Storage - Estimated at 30% of cartridge weight.

(e) Power Penalty - Based on full time operation of the 40 watt fan/separator. The HS-C subsystem only has to store 20 hours of power penalty for this component as it used only in the fail safe mode.

FIGURE 44. WEIGHT SUMMARY: SHUTTLE BASELINE

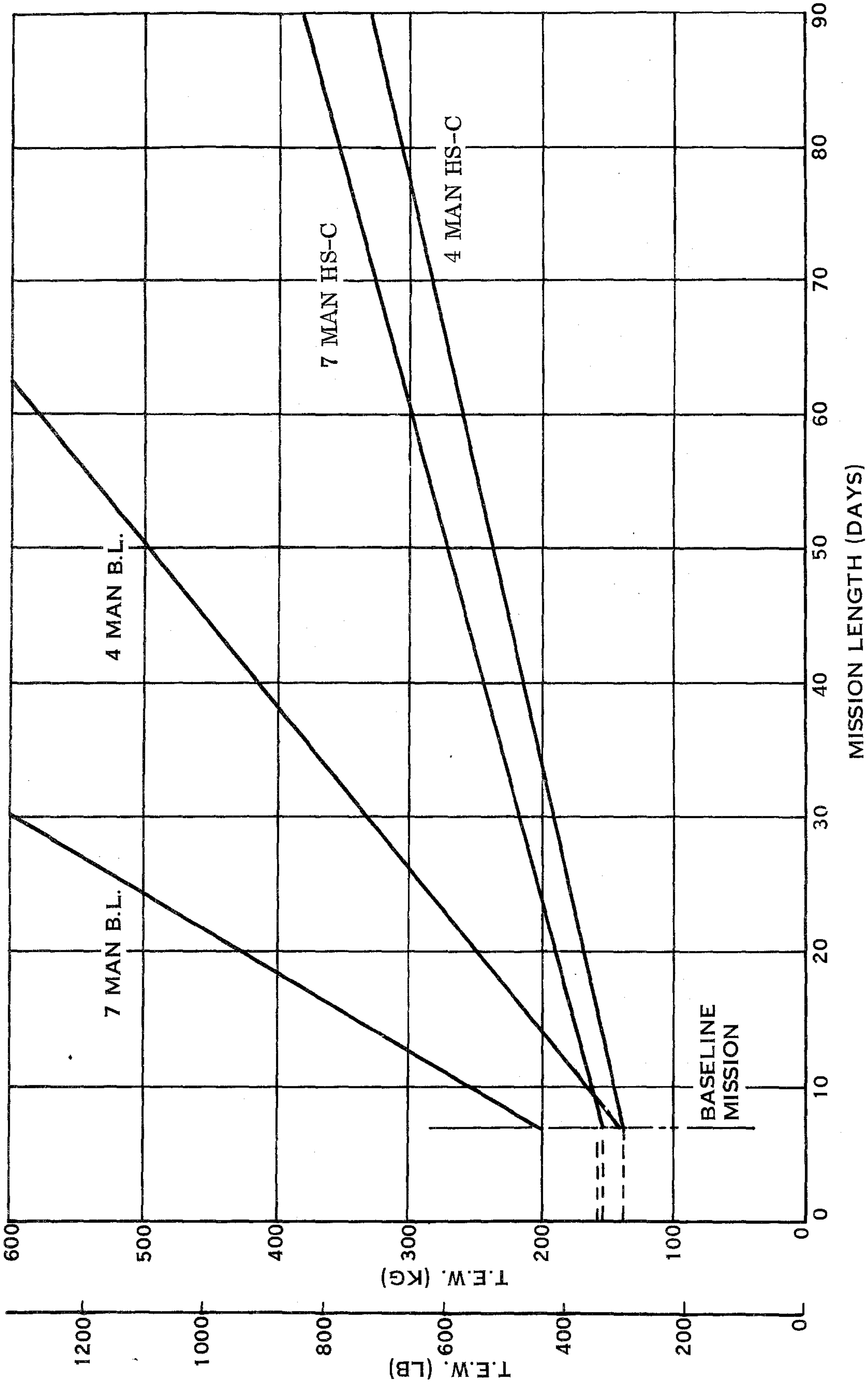


FIGURE 45. HS-C VS. SHUTTLE BASELINE

Other Vehicle Considerations

Fail Safe Operation - The fail safe operations must be good for 20 hours. This sizes fail safe expendables such as LiOH back-up for HS-C.

Fail Safe CO_2 Control - Should the HS-C subsystem fail, a LiOH contingency has been included and these cartridges replace the odor filters in the ARS.

Fail Safe Humidity Control - Should the HS-C subsystem fail, the cabin heat exchanger would be reactivated as a condensing heat exchanger. The slurper and fan/separator, which have been passive, would be activated and humidity control would be achieved as presently designed.

Cabin Heat Exchanger - Although a critical item in both candidate subsystems, its size remains the same for both approaches.

Waste Water Storage Subsystem - The waste water storage subsystem is comprised of three tanks and associated valving. One tank is on line at all times and, when full, is isolated with manual valves. A second tank is then brought on-line until full and finally the third tank. All three tanks provide capacity for greater than 42 man-days of urine and humidity condensate. The nominal urine production rate is 2 kg/man-day (4.41 lb/man-day) and the nominal condensate rate is 2.04 kg/man-day (2.50 lb/man-day) for a 75°cabin temperature.

With the HS-C subsystem, condensate is vented directly overboard and storage is not needed. Therefore, the waste water storage subsystem need only store urine which at 2 kg/man-day, is less than half the previous storage rate of 4.04 kg/man-day. As such, one of the three tanks can be eliminated and the remaining two tanks will have a 35% capacity margin (i.e., two tanks have 35% more capacity storing urine than 3 tanks had storing urine plus condensate). This extra capacity can be used to store condensate for the 20 hour fail-safe contingency period.

Refurbishment - Due to the potential gradual degradation of the HS-C material with time (via cross-linking), the canisters may require periodic repacking. HS-C life expectancy is now greater than two years.

Potential Refinements

Fan/Separators - To qualify as a non-operating back-up, only two fan/separators are needed. Since three fan/separators are presently included in the ARS baseline and this study it would be possible to further reduce the HS-C impact by eliminating one fan/separator. The estimated weight saving would be 1.5 kg (3.4 lb).

Cabin Fans - The cabin fans could be further optimized by relocating the odor filters. This could reduce the fan power by 60 watts. This would be equivalent to a weight saving of 9.2 kg (20.2 lb) for a seven day mission or 39.2 kg (86.4 lb) for a 30 day mission.

Programmatic Impact

Shuttle Status

Development of the Orbiter Atmospheric Revitalization Subsystem (ARS) is presently scheduled for completion in early 1976 and will be followed by ARS logic group testing to be completed in the third quarter of 1976. These milestones are consistent with the Orbiter horizontal flight test program in 1977 and the first verticle flight test in 1979.

State of Development

The HS-C Regenerable CO_2 and Humidity Control System is presently being developed under NASA-JSC Contract NAS 9-13624. This program is the third in a series of related NASA programs which began in mid-1971 (figure 46). The first program, NAS 9-11571, consisted of the following four main activities: material evaluation and preparation, a small and large scale test program, development of a computer program, and generation of a system design concept. The second program in the series, NAS 9-12957, began in mid-1972, and had as its purpose the evaluation of off-gassing and life characteristics of HS-C. The conclusions from this phase were that the off-gassing is not a problem for Shuttle, that HS-C will not support micro-biological life forms and that HS-C shows negligible degradation for nominal Shuttle conditions.

The current program, NAS 9-13624, was started in late 1973 and involves building and evaluating a full scale system designed to handle either a ten-man crew at nominal metabolic loads or a four-man crew at maximum metabolic loads. Following a closed loop test including a simulation of cabin volume, the unit will be delivered to NASA-JSC where it will be integrated into the RSECS ARS for evaluation in the chamber.

For the current program, the HS-C canister design is being executed in a flight weight configuration. Ancillary hardware such as valves, plumbing, and structure will be the best commercially available items that can be located.

Accordingly, the system to be delivered to NASA will be well suited for functional evaluation in RSECS but will require additional design and development prior to being implemented for the Shuttle program. It is planned that this additional effort will be accomplished in a subsequent program phase to be started in mid-1975 and completed in early 1977.

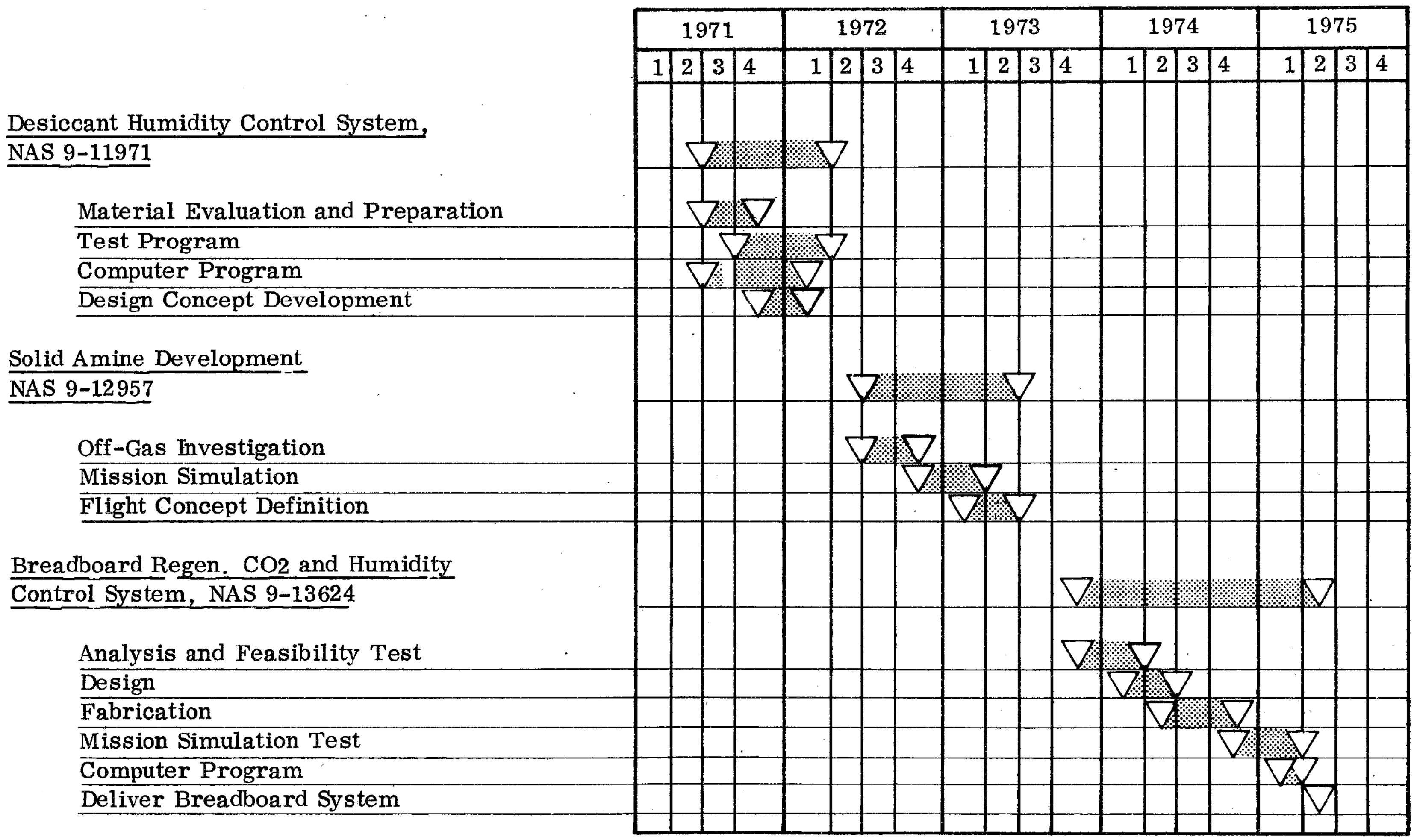


FIGURE 46. HS-C DEVELOPMENT SCHEDULE

Shuttle Impact

If the planned development effort described above is completed successfully, a decision to implement a change for Shuttle could be made early in 1977. It is estimated that 18 months would be required from go-ahead through delivery of the first production unit to Rockwell.

This study is based on the ground rule that the HS-C will integrate with the Orbiter with minor modifications to the ARS and vehicle. The concept studied diverts a portion of the ARS flow to the HS-C for processing and then returns the flow to essentially the same point. Accordingly, the flows, pressure drops, heat balance, etc., within the ARS will be essentially unchanged. Conceptually, the HS-C can be integrated by making the following ARS changes:

- Modification of the cabin fan assembly inlet duct to accommodate the HS-C subsystem inlet and outlet ducts.
- Installation of odor control cartridges in place of the LiOH cartridges.

Changes related to other vehicle subsystems include:

- Deletion of one water storage tank.
- Modification of the LiOH storage area to accommodate the HS-C subsystem.
- Installation of a vacuum manifold and other mechanical and electrical interfaces.

In view of the type of modification required the HS-C subsystem lends itself to incorporation into the Shuttle Orbiter at any point in time at which it is fully developed. As a result, it appears advantageous to continue development of HS-C in an orderly manner and to periodically review its status and that of the Orbiter program to determine when the HS-C should be implemented.

Cost Impact

The cost impact to the Shuttle ARS program for incorporating the HS-C subsystem is estimated at $2,500,000 on a rough order of magnitude basis. This estimate is derived as follows:

HS-C Qualification (Including 2 Engineering Units)	$1,000,000
Delivery Units (7)	$1,400,000
Subtotal	$2,400,000
ARS Modification (Inlet Duct and Charcoal Cartridge)	100,000
TOTAL	$2,500,000

The HS-C would also require a periodic servicing which is estimated at $100,000 per year.

In addition to the above cost, the expendable cost for providing LiOH cartridges must be considered. In the case of the current ARS a total of 27 cartridges are required per flight. Since only 2 cartridges are required per flight for HS-C backup, there is a net saving of 25 cartridges per flight. Assuming a cost of $1,000 per cartridge, there is a cost saving associated with the HS-C of $25,000 per flight. With a traffic model of 40 flights/year, the HS-C subsystem would generate savings of $900,000/year ($1,000,000 for LiOH less $100,000 for HS-C servicing) and within 3 years the cost saved would equal the initial HS-C development and procurement cost. The estimate for servicing is intended to cover replacement of fans, compressors, and bed material. Theoretically, the savings over a 10-year period with 40 flights/year would be $6,500,000.

The above rough cost study does not take into consideration any cost impacts to the Shuttle vehicle such as reconfiguration of the LiOH storage area to accomodate the HS-C subsystem, addition of a vacuum manifold, and deletion of one waste water storage tank.

Estimates for these areas are variable depending on the point in time at which the change is implemented and it would be more appropriate for the vehicle prime contractor to assess these cost impacts.

It should be recognized that for larger crew sizes or longer duration missions the HS-C subsystem would provide additional saving in LiOH cartridge cost. For example, a seven-man, seven day mission would require 60 LiOH cartridges versus 4 as backup for the HS-C subsystem. Incorporation of the HS-C would save approximately $56,000/flight.

For a four-man, 30 day mission, 86 LiOH cartridges would be needed in the current Shuttle ARS versus two for HS-C backup. In this case the HS-C subsystem would provide a savings of $84,000 per flight.

In addition to the cost savings in LiOH cartridges generated by the HS-C for larger crew sizes or longer duration missions, the HS-C also provides substantial benefits in terms of additional payload weight that can be carried. For a 7-man, 7-day mission, the HS-C saves 40 kg (88 lb) and for a 4-man, 30 day mission a weight saving of 139 kg (306 lb) can be realized. These weight savings can be applied to added payload which in turn can be expressed in a cost benefit. The actual value of these savings is dependent on the frequency and type of mission that are ultimately planned and performed.

WASTE SAMPLING AND MEASUREMENT SYSTEM

Summary

The function of waste sampling is to provide biomedical data for crew members during space missions. These data may be used to evaluate the adaptation of each crew member to the space environment and to serve as a diagnostic tool should illness set in during flight. The present Shuttle requirements do not include the capability for waste sampling. This study assesses the impact of adding waste sampling to the Shuttle waste collection system.

Technical Description

Requirements

The Waste Sampling Subsystem shall be capable of taking the following samples:

a. Urine
b. Feces
c. Vomitus

The subsystem shall be capable of measuring the mass of each void/emesis within the following accuracy.

a. Urine within $\pm$ 2%
b. Feces, within $\pm$ 2%
c. Vomitus within $\pm$ 2%

There shall be positive identification of each sample as to:

a. Type
b. Crewmember Identification
c. Date
d. Time
e. Quantity

There shall be no cross-contamination between sample types.

Cross-contamination within any sample type shall be less than 0.5 ml.

The subsystem shall be designed so that the crew member shall have the option of bypassing the sampling hardware and using the baseline collection and processing mode of operation.

The feces and vomitus sample shall include the entire void.

The urine sampling hardware shall be capable of collecting three independent samples:

a. Microbiological sample (2 ml)
b. Chemical sample (5 ml)
c. 24-hour pool sample (110 ml)

The urine microbiological sample and chemical sample shall be representative of an individual void.

The urine 24-hour pool sample shall be representative of one crewmembers accumulated voids over a 24 hour period. This sample shall represent 10% of the total voids.

The subsystem shall be capable of on-board analysis or preservation of samples.

Sample preservation at both -18°C (-0.4°F) and -70°C (-94°F) shall be considered as to vehicle impact.

The urine sampling interfaces are as follows:

Urine Quantity:	35-1000 ml/micturation
Urine Flow Rate:	25 ml/sec/maximum
Uses:	5-10 uses/man-day
Total Urine Quantity Input:	600-4000 ml/man-day
Urine Output to Waste Water Storage	540-3900 ml/man-day (2000 ml/man-day average)

The feces and vomitus sampling interfaces are as follows:

Max. Defecation:	500 grams/day
Av. Defecation:	110 grams/day
Av. Uses:	1 use/man-day
Diarrhetic Collection:	500 grams/discharge 1200 grams/man-day
Vomitus Collection:	500 grams/discharge 1000 grams/man-day

Subsystem Description

The Waste Sampling Subsystem, shown schematically in figure 47, is divided into three distinct packages; the urine sampling assembly, the feces sampling assembly and the sample freezer/storage unit. The urine and feces packages are self contained, completely independent systems that can be operated either separately or together to provide the urine or simultaneous urine/feces collection capability for the vehicle. Independent packages are provided rather than combining similar functions because minimum power and maximum convenience are obtained based on the operating cycles and constraints of each package. However, for operator convenience, the manual controls and buttons of both packages are located together on the urine sampling assembly.

Urine Sampling - The urine sampling assembly is designed to take three types of samples.

- 24-hour pool sample (110 ml)
- Chemical (real time) sample (5 ml)
- Microbiological sample (2 ml)

The 24-hour pool sample is taken on a daily basis and is an accurate sample of a complete days urination for each crewmember. The hardware is designed to mix and store 10% of each urination in an 24-hour pool container. A separate container is provided for each astronaut. The sampling hardware automatically selects the proper container by crewmember identification and built-in electronic logic.

At the end of each daily period, the 24-hour pool sample is reduced to 110 ml and frozen for later analysis. This sample has the greatest hardware impact because it requires complex and intricate mechanisms to select and plumb up to each crewmember's individual container. The hardware must also accurately measure each micturation's volume and record that data for each crewmember.

The real time (chemical) sample is used to determine the chemical composition of any urination. This sample is important for on-board analysis of ill crewmembers and for determining patterns of circadian rhythm. The chemical sampler must be installed into the pool sampler rig before micturation and removed after each micturation.

The microbiological sampler is used independent of other sampling hardware. It is a small cylindrical shaped device that fits into the urinal outlet. The sample wick is adequately protected from contamination and splashing and only collects direct impingement urine, thus assuring an accurate and valid sample.

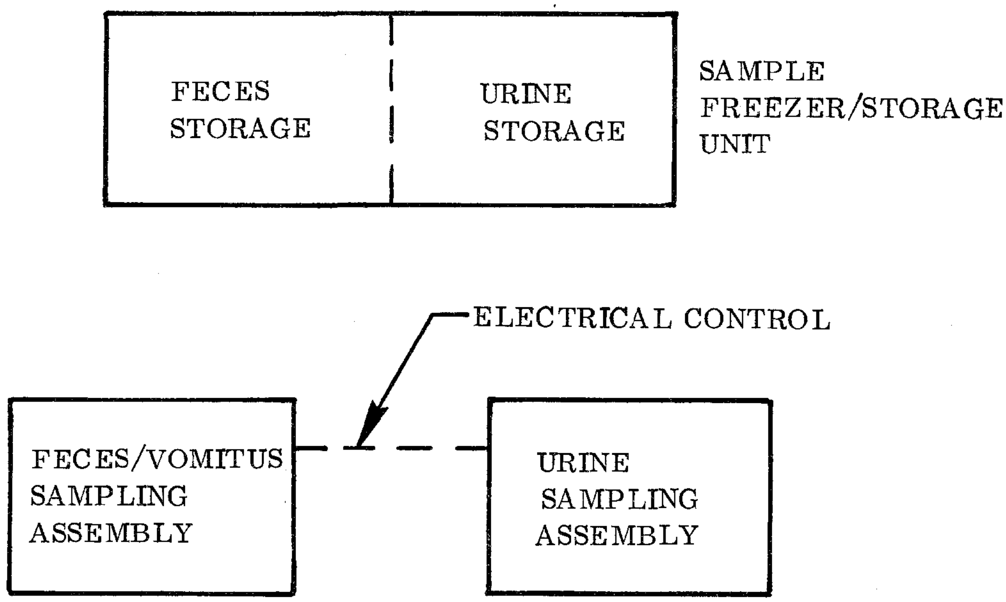


FIGURE 47. WASTE SAMPLING SUBSYSTEM BLOCK SCHEMATIC

The sampler is removed without touching by replacing the cover assembly and pulling the sample out of the urinal where it is capped. It can then either be cultured or preserved.

Figure 48 is a photograph of the urine sampling assembly; figure 49 illustrates the subsystem block diagram. The urine, phase separator, blower and filter provide the urine collection capability. The urinal, a hand held funnel shaped receptacle connected by a flexible hose to the phase separator, also encloses the microbiological sample container. The blower provides a source of transport air for conveying the urine into the phase separator. The filter prevents odor and bacteria from being exhausted to the ambient environment via the transport air stream. The centrifugal phase separator both stores the incoming urine, provides a mixing action so that the urine is homogenous and separates the transport air from the liquid urine. The peristaltic pump and accumulator provide both volume measurement and sample isolation functions. The accumulator has two chambers on a common shaft. The larger chamber has a nominal volume of 25 ml, the smaller, 2.5 ml. The output of the smaller chamber may be directed to the 24-hour sample container to provide a representative 10% sample of the total 24-hour voiding and/or directed to a chemical sample container. The dual tube peristaltic pump is used to fill the accumulator. The pump also prevents flow back to the phase separator when the accumulator discharges. The 24-hour pool sample containers, flexible evacuated plastic bags, are located in a refrigerated pool compartment (the side access door in figure 48). The chemical sample container is located on top of this compartment. The pressure sensor is used to acquire control data for the programmer to terminate volume measurement and sampling and start or by-pass (for micturition volumes less than 50 ml) the volume measurement and sampling portion of the cycle. The total volume for each micturition, which exceeded the minimum size of 50 ml, is recorded on an external printer along with biowaste event data. The programmer includes the pressure sensor signal conditioner, phase separator motor servo speed control, and control logic for controlling the system operating sequence.

The subsystem is designed to be operated with or independently of the Solids Subsystem. However, the operator controls for both subsystems are combined into one panel arrangement located on the top surface of the Urine Subsystem structure. Some electronic components are also shared between the two subsystems.

Feces Sampling - The feces sampling assembly is similar in size, shape and collection technique to the proposed Orbiter waste collection. However, the sampling concept has been designed to utilize air drying rather than vacuum drying for non-sample preservation. This difference eliminates the vacuum connection, but adds a relative humidity sensor, large odor filter, and a two speed fan. The second fan speed is needed to provide the drying airflow which is on continuously when the system is not used for collection.

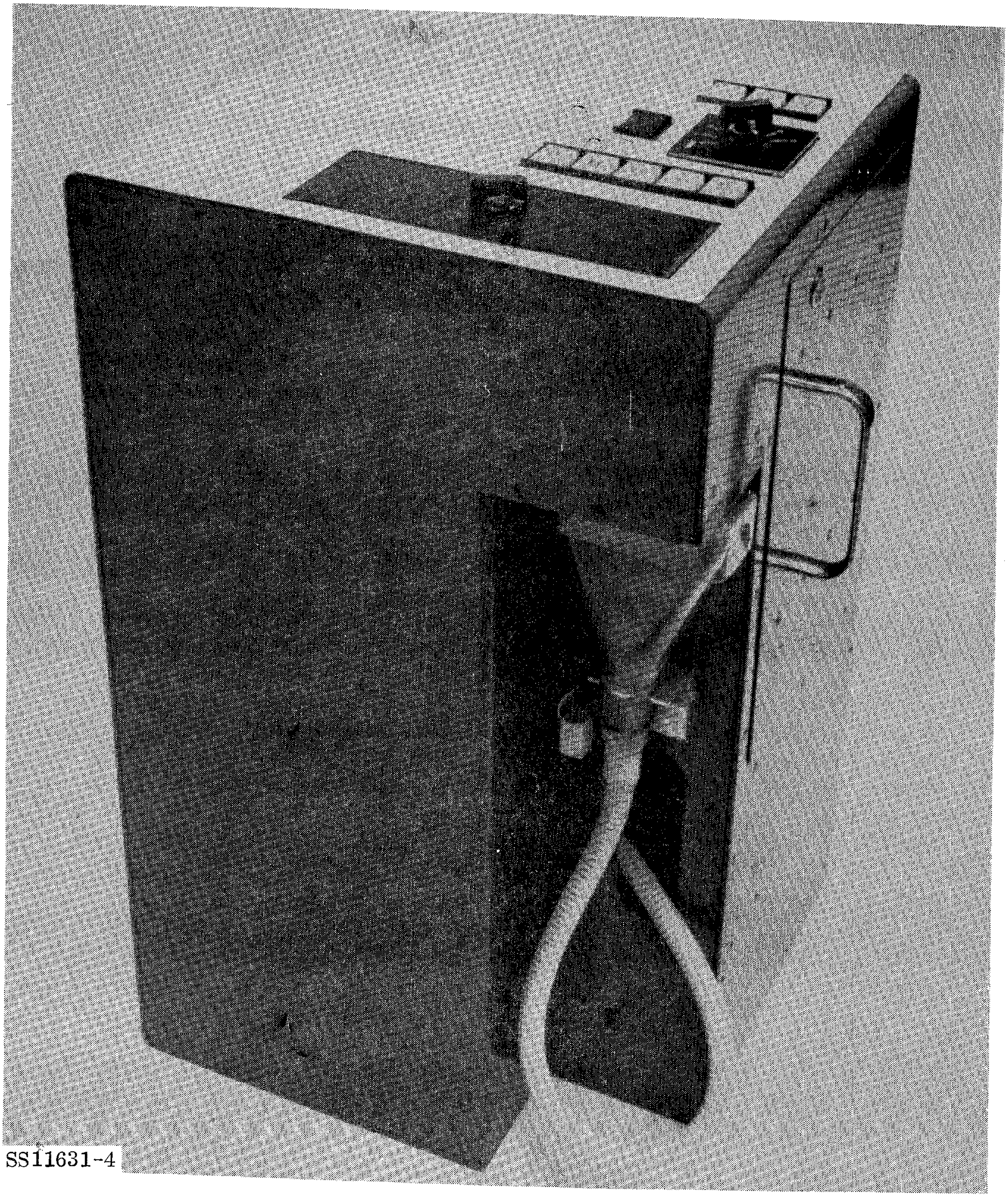


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FIGURE 48. URINE SUBSYSTEM OPERATING MODEL

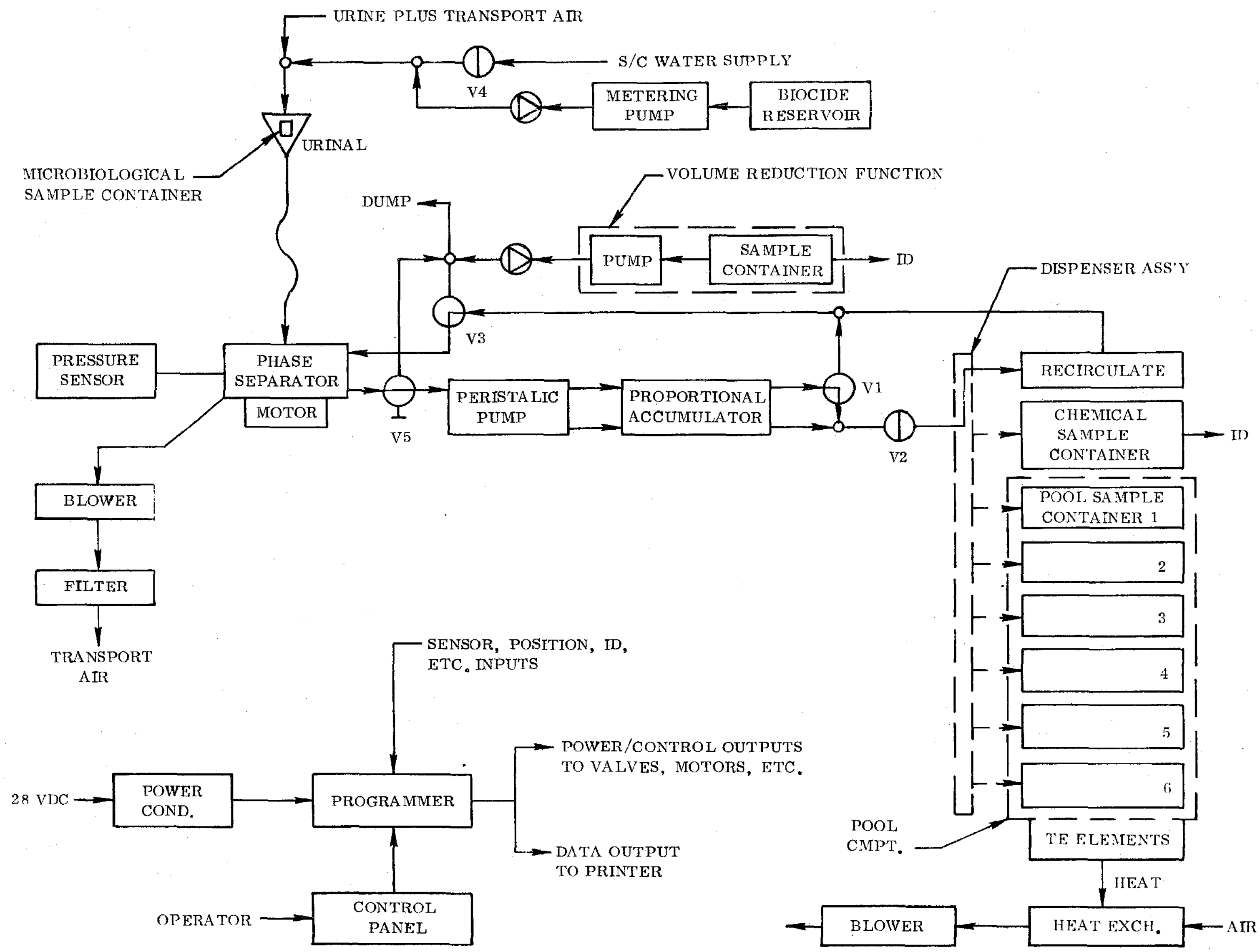

FIGURE 49. ABSS URINE SUBSYSTEM OPERATING MODEL BLOCK DIAGRAM

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Figure 50 is a photograph of the feces sampling assembly, figure 51 illustrates the subsystem block diagram. The seat, slide value, slinger and associated debris filter and phase separator, blower and filter combine to provide the collection capability. The seat serves to position the user coaxially with the slide valve assembly. The slide valve assembly isolates the storage chamber contents from ambient when the subsystem is not in use. The blower provides a source of transport air for conveying feces (or vomitus) into contact with the slinger assembly. The rotating slinger assembly in turn distributes the biowaste material in a thin relatively uniform layer, about the inner periphery of the storage container. The resulting large exposed area promotes rapid air drying (for microorganism deactivation) using ambient air circulated by the blower. A debris filter and phase separator capability are combined into the slinger assembly to prevent solid/liquid particles from leaving the storage container. Since wiping tissue will not reliably pass through the slinger, a tissue bypass mechanism is provided. On command, the tissue bypass blocks tissue from the slinger.

If desired, the total mass of feces (or vomitus) may be collected as a sample. This is accomplished automatically by use of a sampling element which is inserted into the storage container, closely encircling the slinger. Feces or vomitus passing through the slinger is thus "trapped" on the sampling element. The sampling element is then withdrawn into an exterior mounted sampling container, which can be removed and placed in refrigerated storage. At each use, the user identification mission time and sample container number (if used) are recorded on an external printer.

The subsystem is designed to be operated with or independently of the Urine Subsystem structure. Some electronic components are shared between the two subsystems.

Design Data

Design Point - The design point for evaluating the waste sampling concept is seven (7) men for thirty (30) days. This is the baseline mission for the orbiter Waste Collection Subsystem design and represents the longest probable payload missions which are orbiter dependent.

Mission size and length have a great impact on the waste sampling subsystem because of the freezer space needed for sample preservation and storage.

Urine Sample Storage - The urine sampling freezer must have storage capacity for all three types of samplers; the microbiological, the chemical and the 24-hour pool. If all the crew takes samples at each micturation for 30 days, the following number of samplers must be stored:

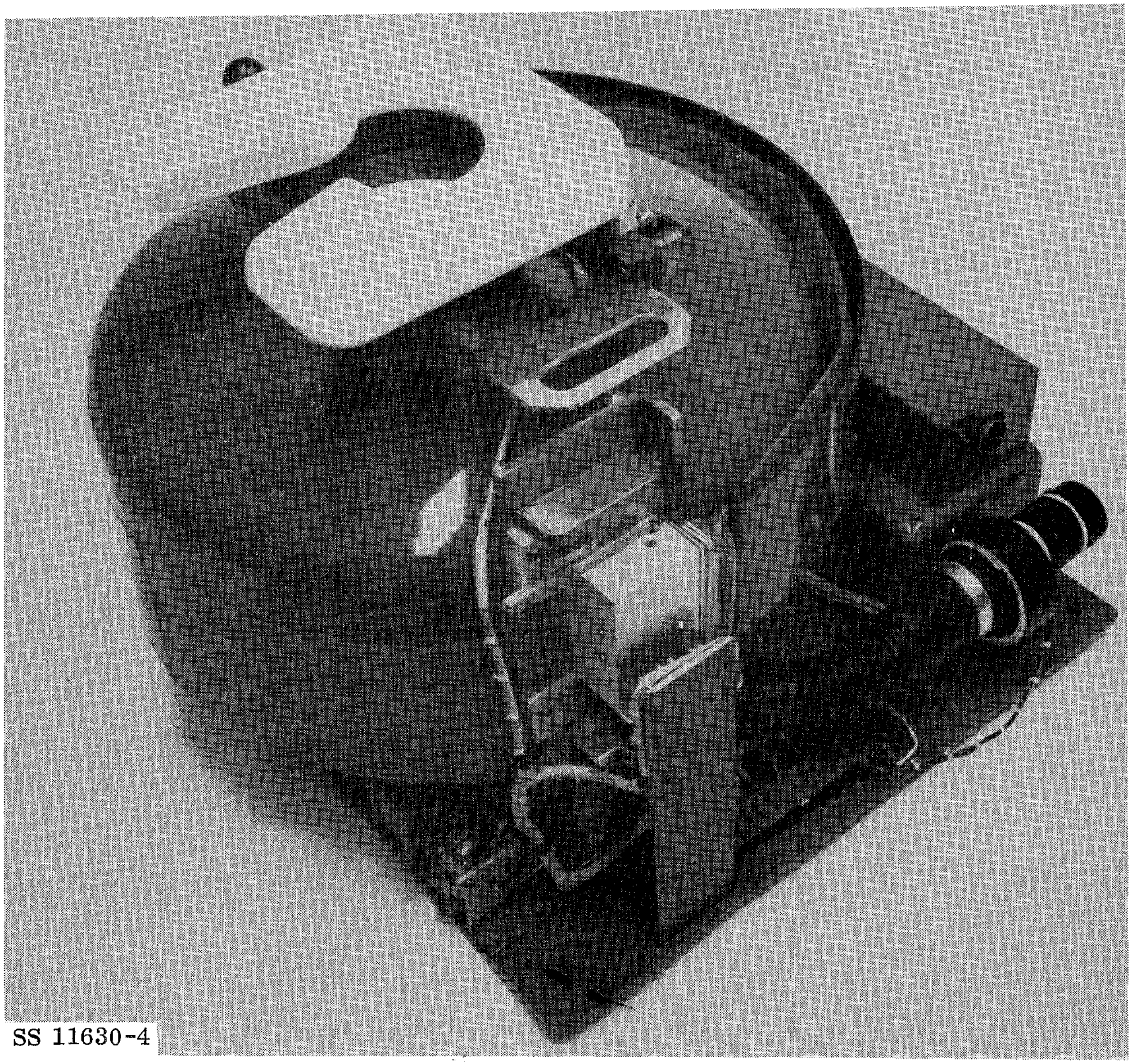

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FIGURE 50. SOLIDS SUBSYSTEM OPERATING MODEL

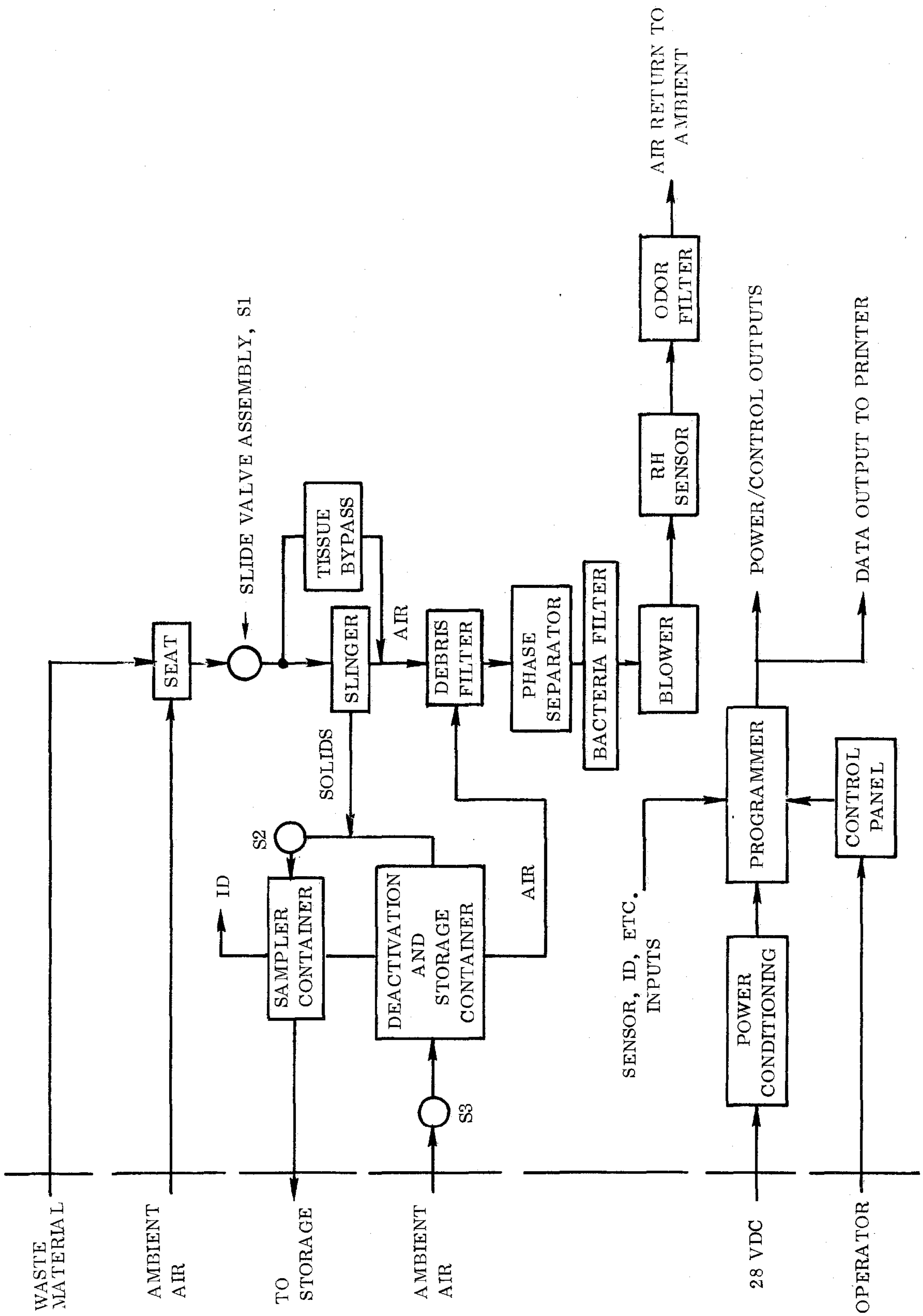

FIGURE 51. SOLIDS SUBSYSTEM BLOCK DIAGRAM

a. Microbiological:

210 man-days x 7 uses/man-day = 1470 samplers

b. Chemical:

210 man-days x 7 uses/man-day = 1470 samplers

c. 24-hour pool

210 man-days x 1 container/man-day = 210 samplers

Assuming the freezer unit has sample trays .433 m. wide x .305 m. deep (17 x 12 in) the number of trays needed to store the samplers is given in the following table.

STORAGE REQUIREMENTS

Sample	Sampler Quantity	Height of Tray	No. of Trays	Storage Volume m^3 (ft^3)
Microbiological	1470	1.25	7	.093 (3.28)
Chemical	1470	1.25	15	.093 (3.28)
24-hour	210	2.25	9	.043 (1.53)
TOTALS	3150		31	.229 (8.09)

The storage section of the freezer would occupy an envelope of .915 m. wide x .712 m. high x .356 m. deep (36 in. W x 28 in. H x 14 in. D) without insulation. To maintain a freezing temperature of -18°C (-0.4°F), two (2) inches of insulation are needed to minimize the heat leak and freezer power. This insulation would increase the envelope to 1.015 m. wide x .814 m. high x .457 m. deep (40 in. W x 32 in. H x 18 in. D) and the freezer would occupy .377 m^3 (13.3 ft^3) of cabin volume. This volume is for sampler storage only and does not include the actual mechanical freezing hardware.

Feces Storage - The feces storage container must have capacity for 210 samplers. The samplers are .79 m. wide x .305 m. deep x .108 m. high (35 in. W x 12 in. D x 4.25 in. H) and holds 24 samplers. Nine (9) trays are needed for total storage requiring an overall storage envelope of .915m. wide x 1.03 m. high x .356 m. deep (36 in. W x 41 in. H x 14 in. D) without insulation. A thickness of 5.1 cm (2.0 inch) of insulation is needed to maintain a -18°C (-0.4°F) freezer. This increased the storage envelope to 1.015 m. wide x 1.14 m. high x .457 m. deep (40 in. W x 45 in. H x 18 in. D) or .53 m^3 (18.7 ft^3) of cabin volume.

TABLE 3
WASTE SAMPLING

Package	Weight Kg	(Lb.)	Power (WATTS)	Op. Time Hr/Day	Wt-Hr/Day	Volume m^3	(ft^3)
Urine Sampling	19.5	(43)	175	1.7	298	.071	(2.5)
Urine Storage	50.3	(111)	0			.377	(13.3)
Feces Sampling	12.3	(27)	50 60	23 1.0	1150 160	.17	(6.0)
Feces Storage	50	(109)	0	0	0	.53	(18.7)
Refrig. Unit	4.5	(10)	26	24	624		
Heat Rejection Penalty	26.3	(58)	0	0	0		
Total	162.8	(358)	251		2232	1.15	(40.5)

Expendables	kg/day	lb/Day)
Urine Samplers	3.85	(8.5)
Feces Samplers	1.59	(3.5)
Subtotal	5.44	(12.0)
Sampler Storage	1.81	(4.0)
Power Penalty	2.20	(4.46)
Total Expendables	9.27	(20.46)

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Feces Collector - The feces collector is designed to independently store and process solid wastes if samples are not desired. The development collector was designed with adequate storage capacity for 168 man-days of feces, toilet tissue and a nominal amount of trash. This size is not adequate for a 210 man-day mission since, even with sampling, all the toilet tissue is deposited in the collector. The tissue normally occupies 90% of the storage volume and requires the impact momentum of the feces to compact it. With sampling, the feces is collected immediately and is not available for compaction of tissues. Therefore, the volume required for tissue storage will be greater than that normally associated with the dry-john approach. As such, the diameter of the collector will have to be increased from .508 m (20 in.) to approximately .61 m (24 in.). This size is the same as the Shuttle Orbiter baseline waste collector and weight estimates are therefore, based on the baseline collector.

Weight, Power, Volume

The weight, power and volume required to incorporate waste sampling on a Shuttle payload is given in Table 3. The table gives both fixed and expendable weight. The sampler storage units are sized for a 30 day mission. It is assumed that only one size freezer will be developed and that it will be sized for the maximum mission. The samplers, however, are easily supplied and stored for a specific mission profile. As such, the samplers are treated as expendables. The urine sampler weight of 3.85 kg/day (8.5 lb/day) is based on:

7	24-hr. samplers x .136 kg	=	0.952
49	Chem. samplers x .0454 kg	=	2.225
49	Micro. samplers x .0137 kg	=	0.671
	TOTAL	=	3.848

The feces sampler weight is based on seven (7) samplers times .227 kg/sampler which equals 1.59 kg/day (3.5 lb/day). The sampler storage penalty is based on a 33% storage factor for the containers and structure. This factor is consistent with other storage facilities in the Shuttle.

The power penalty is based on fuel cell expendables and is limited to 30 day missions. The expendable rates are based on the daily operating time of each electrical component. In the case of feces sampling, there are two operating modes. The collection mode operates for one hour per day at full power and the air drying mode operates at full fan power for 23 hours per day. This second mode is used to dry the contents of the collector. An analysis of the vendor drying data indicates that 25 cfm is needed continuously to handle a seven (7) man crew, and therefore, the high power penalty.

The heat rejection penalty is made up of two components. The first is the direct rejection of 320 Btu/hr to the coolant circuit from the refrigerator condenser. A radiator penalty of .0245 kg/Btu/Hr (.054 lb/Btu/Hr) is applied to this heat source and yields a total penalty of 7.85 kg (17.31 lb). The second component is the indirect rejection of heat from all the electrical components to the cabin air. This indirect heat rejection has a penalty of .058 kg/Btu/Hr (.128 lb/Btu/Hr) which is higher than the direct heat rejection penalty because of the fan and heat exchanger needed in addition to the radiator. The sampling hardware uses an average of 93.2 watts which yields 318 Btu/Hr of heat. The penalty for this component is 18.45 kg (40.7 lb) for a combined penalty of 26.3 kg (58 lb).

The fixed weight and expendable weight can be combined to produce the mission profile curve of figure 52. This curve shows that the design point mission (7 men for 30 days) will cost 441 kg (972 lb) in weight and penalties.

Waste Sampling Packages

A package concept showing how the sampling packages could be located with respect to each other is shown in figures 53 and 54. In this arrangement, the feces sampling assembly is centrally located against the wall with the urine sampling assembly oriented beside it for maximum user convenience. In this location, the urinal can be used either in the seated position in conjunction with feces collection or it can be used by a standing male for urine collection only.

The sample freezer/storage unit forms a partition on one side of the collection hardware. Both the urine and feces sample storage are combined into one integrated unit with urine storage access on one side of the package and feces storage access on the other side. The refrigeration unit is located in the bottom of the package next to the feces collector.

This package arrangement is not intended for any vehicle in particular. It is presented to show a typical vehicle arrangement, showing a logical relationship between the packages. This arrangement could apply to the life sciences payload or any other long duration payload vehicle.

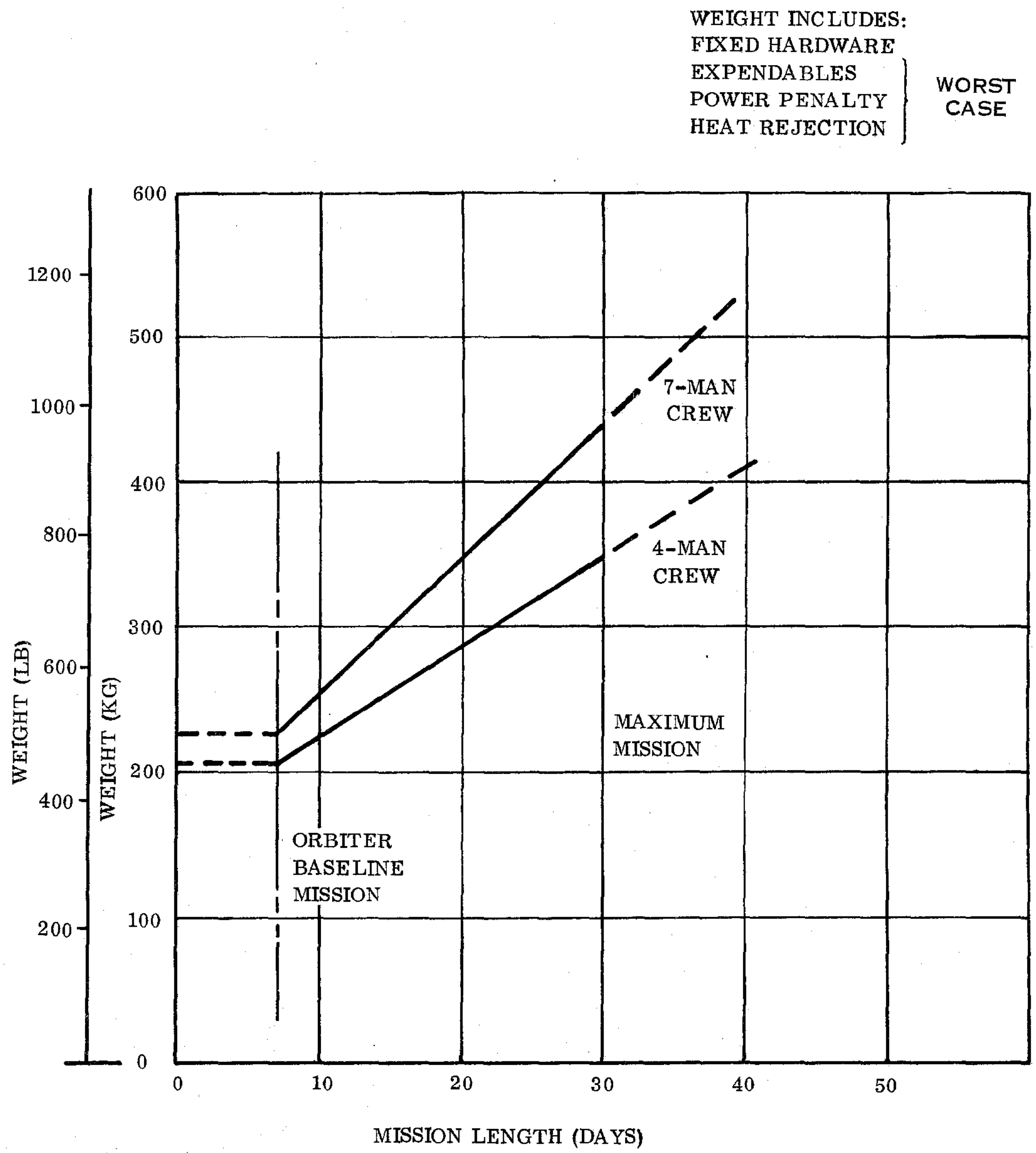


FIGURE 52. WASTE SAMPLING TOTAL EQUIVALENT WEIGHT

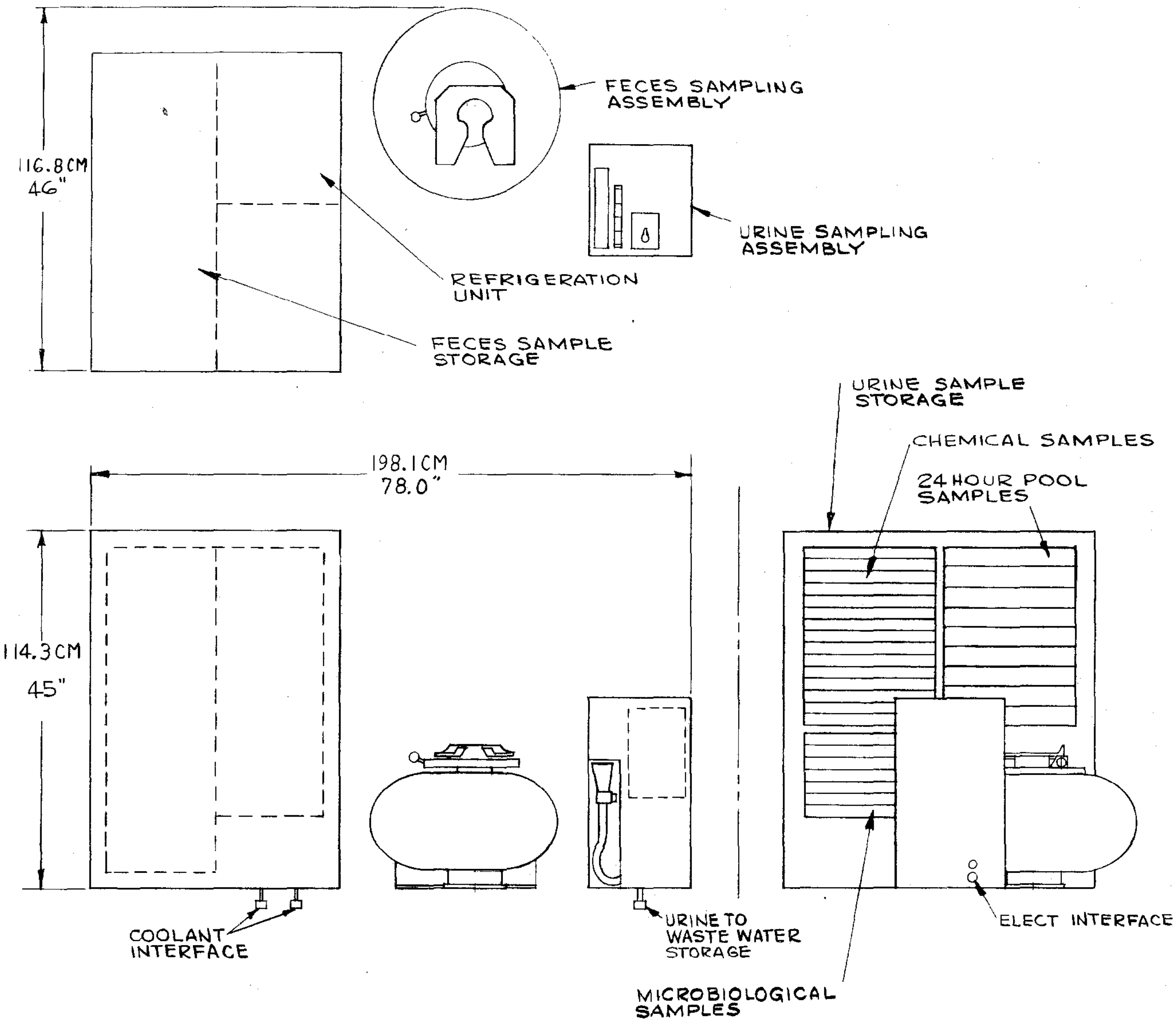


FIGURE 53. WASTE SAMPLE PACKAGE CONCEPT

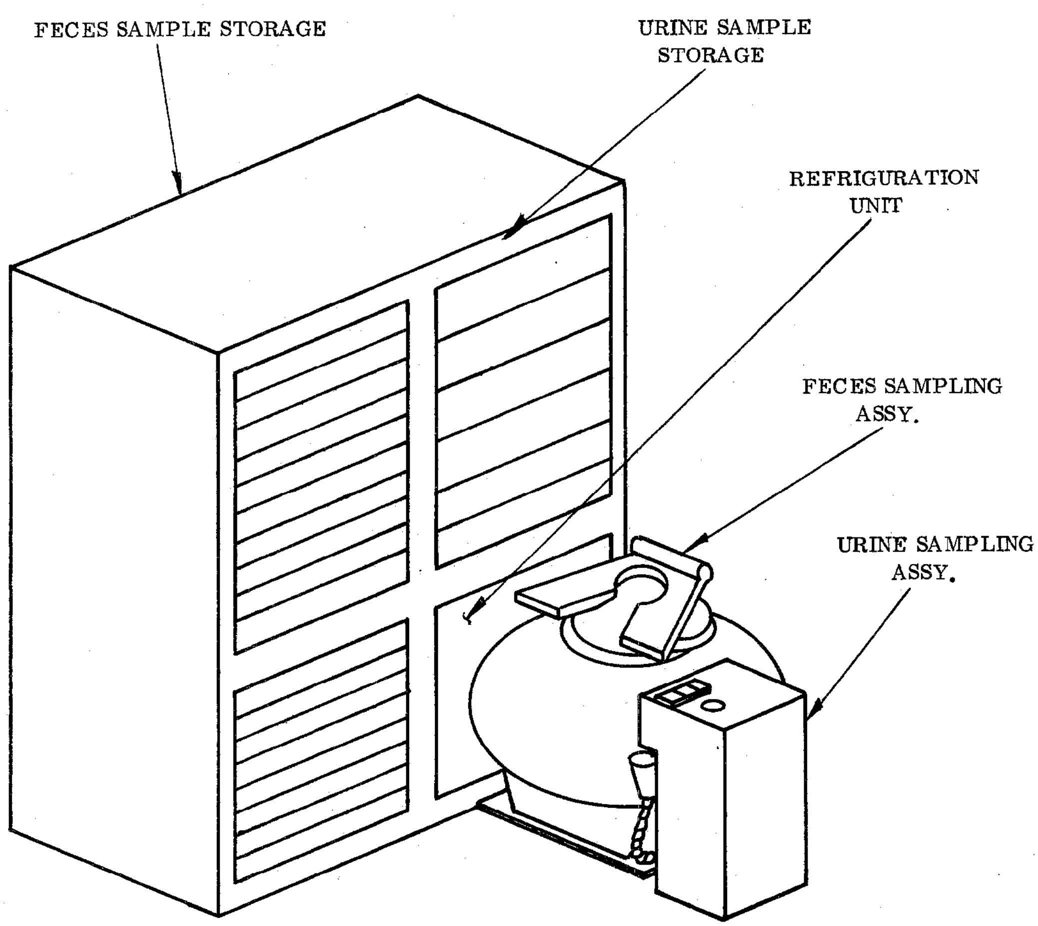


FIGURE 54. WASTE SAMPLING PACKAGE

Other Considerations

The urine sampling concept is somewhat complex because of the flushing and purging cycle needed to minimize cross-contamination of samples. However, the plumbing is arranged so that the sampling hardware can be easily bypassed should a failure occur. In this way, the urine sampling concept, as developed, has the same reliability as the orbiter baseline WCS in performing the function of urine collection and storage.

The feces sampling hardware, as developed has some inherent technical obstacles that must be solved before it can be considered a viable flight candidate. These technical obstacles are:

1. Air drying as an acceptable processing means for a seven (7) man crew.

2. The ability of the sampling strip to penetrate and retrieve a sample when the collector is partially full.

3. The volume needed to store the toilet tissues without the compaction effect of the feces.

Continued development effort is recommended to avoid problems in these areas.

References

1. Fogel, G. L.,; Mangialardi, J.K.; Rosen, F.; Automated Biowaste Sampling System, Urine Subsystem Operating Model; Final Report, Part I, November, 1973; General Electric Space Division.

2. Fogel, G. L.; Mangialardi, J. K.; Stauffer, R. E.; Automated Biowaste Sampling System, Solids Subsystem Operating Model; Final Report, Part II, November, 1973; General Electric Space Division.

HYDROGEN DEPOLARIZED CONCENTRATOR/WATER VAPOR ELECTROLYSIS UNIT

Summary

The functions of the Hydrogen Depolarized Concentrator/Water Vapor Electrolysis Unit are oxygen generation and carbon dioxide removal from the cabin atmosphere. The Shuttle baseline concepts are cryogenic oxygen storage and lithium hydroxide CO_2 removal. The electrochemical approach was studied as a potential improvement to the baseline concepts.

The electrochemical air revitalization concept does not apply to the baseline Shuttle. It would represent weight, volume, and power penalties, with additional cost for the 7 day mission. An apparent weight saving for the 30 day mission is offset by the power penalty, so that there is no net advantage for the electrochemical concept.

The baseline Shuttle concepts of lithium hydroxide for CO_2 removal and supercritical storage for oxygen are proven beyond any doubt. Consequently, the advanced technology concept cannot be regarded as a technological back-up.

The concept fulfills a need on long duration, manned missions such as space stations and interplanetary spacecraft. These applications would reclaim potable water from waste water and oxygen from carbon dioxide. Energy would be provided by radioisotopes or solar cells rather than fuel cells. The Electrochemical Air Revitalization System would integrate very well with a life support system of this type. Excessive weight and volume would make the baseline Shuttle concept, using expendable lithium hydroxide and stored oxygen, impractical for such applications.

TECHNICAL DESCRIPTION

Subsystem Requirements

The Subsystem shall control the CO_2 level of the laboratory module cabin atmosphere to 400 Pa (3 mm Hg) maximum.

The subsystem shall generate oxygen to supply the following requirements:

a. Metabolic consumption: $.98 \times 10^{-5}$ kg/s per man (1.84 lb/man-day).

b. Vehicle leakage: 2.19×10^{-5} kg/s (4.11 lb/day).

c. HDC consumption: $.84 \times 10^{-7}$ kg/s (.0157 lb/day) for each ampere of HDC current.

The subsystem shall be sized for a four-man crew and for a seven-man crew at an average CO_2 production rate of 1.17×10^{-5} kg/s per man (2.2 lb/man-day).

The lab cabin temperature can vary between 18.3°C and 26.7°C (65° to 80°F).

The lab cabin pressure is 101.4 kPa absolute (14.7 psia) ± 5%.

The lab cabin dewpoint can vary between 3.9°C and 16.1°C (39°F to 61°F).

All other environmental, handling, and design requirements per SVHS 6400.

The subsystem shall be designed to fail safe.

a. No single failure shall result in a loss of cabin atmosphere.

b. The fail safe mode of 20 hours with a seven man crew shall be accomplished by the crew returning to the Shuttle Orbiter cabin.

c. During emergency conditions the partial pressure of CO_2 may rise to a maximum level of 2.0 kPa (15mm Hg) and shall not be above 1.01 kPa (7.6 mm Hg) for longer than 2 hours.

Subsystem Description

Since previous studies have indicated that the HDC/WVE CO_2 removal and O_2 generation concept does not integrate well with a system such as the Shuttle Orbiter that uses a fuel cell to generate electricity, it is assumed for the purposes of this study that the vehicle under consideration is a Shuttle launched laboratory module that is solar cell, or nuclear powered. It is also assumed that the laboratory module will be attached to the Shuttle vehicle any time the laboratory is occupied and that the crew can return to the Shuttle Orbiter in the event of laboratory module ARS failure. If the laboratory is not returned to Earth with the Shuttle but is left in orbit for revisitation by subsequent orbiter flights, it is assumed that the cabin environment will be controlled to the extent that temperature, pressure and humidity do not exceed the tolerance of the electrochemical cells so that no pressure tight temperature controlled cell stack enclosure is required.

The HDC/WVE by its very nature is most suitable for long duration space flight by integration with other long duration systems similar to those used on the Space Station Prototype (SSP). It is assumed that odor removal, air filtration, CO_2 reduction and cabin humidity are provided by these other subsystems. In addition, fault isolation, to detect a low voltage cell for instance, is to be performed by an information management computer (IMC) on board the laboratory. Safety parameters are monitored locally by the subsystem controller to provide local emergency shutdown.

HDC/WVE Description - The hydrogen depolarized CO_2 concentrator (HDC) and Water Vapor Electrolysis (WVE) are two separate electrochemical cells that perform major functions in an atmosphere revitalization system (ARS). The function of the HDC is to remove CO_2 from cabin air stream. During the process, the cells consume H_2 and cabin O_2, and liberate water vapor to the cabin. They also generate low voltage electrical power. The function of the WVE is to electrolize water vapor from the cabin generating O_2 to make up for metabolic and HDC consumption and to make up for cabin leakage, and H_2 to supply the HDC.

The electrochemical cell for HDC and WVE consists of a liquid electrolyte trapped in a porous matrix material between two catalyst coated expanded metal electrodes. In the Hamilton Standard configuration these cells are arranged in pairs where the center housing contains the hydrogen passages and the two outer housings contain the air passages (see figure 55). Each cell pair has a matrix filled electrolyte reservoir attached to its air inlet side to accommodate humidity extremes. The reservoir provides an expansion volume for the electrolyte as its specific volume changes to achieve equilibrium with the environment, thereby preventing flooding or dryout with its resulting electrolyte loss or hydrogen leakage. Cell pair construction was selected over an integral cell stack module since each cell pair forms a structurally sound replaceable unit allowing easy inflight replacement of inoperative cell pairs on return visits to the laboratory. Extra cell pairs are included in the subsystem to preclude carrying non-installed spares.

The major difference between the HDC and the WVE cell pairs is the electrolyte which is tetramethylammonium carbonate (TMAC) for HDC and sulfuric acid for the WVE. The matrix material and the electrodes are also different.

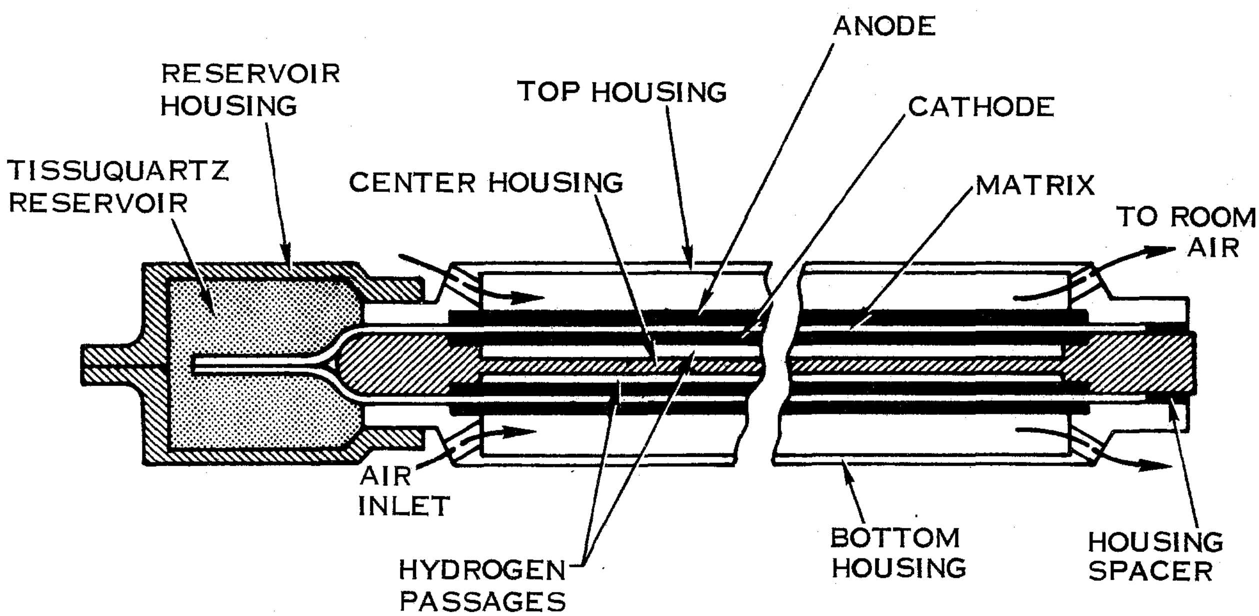


FIGURE 55. HDC CELL PAIR

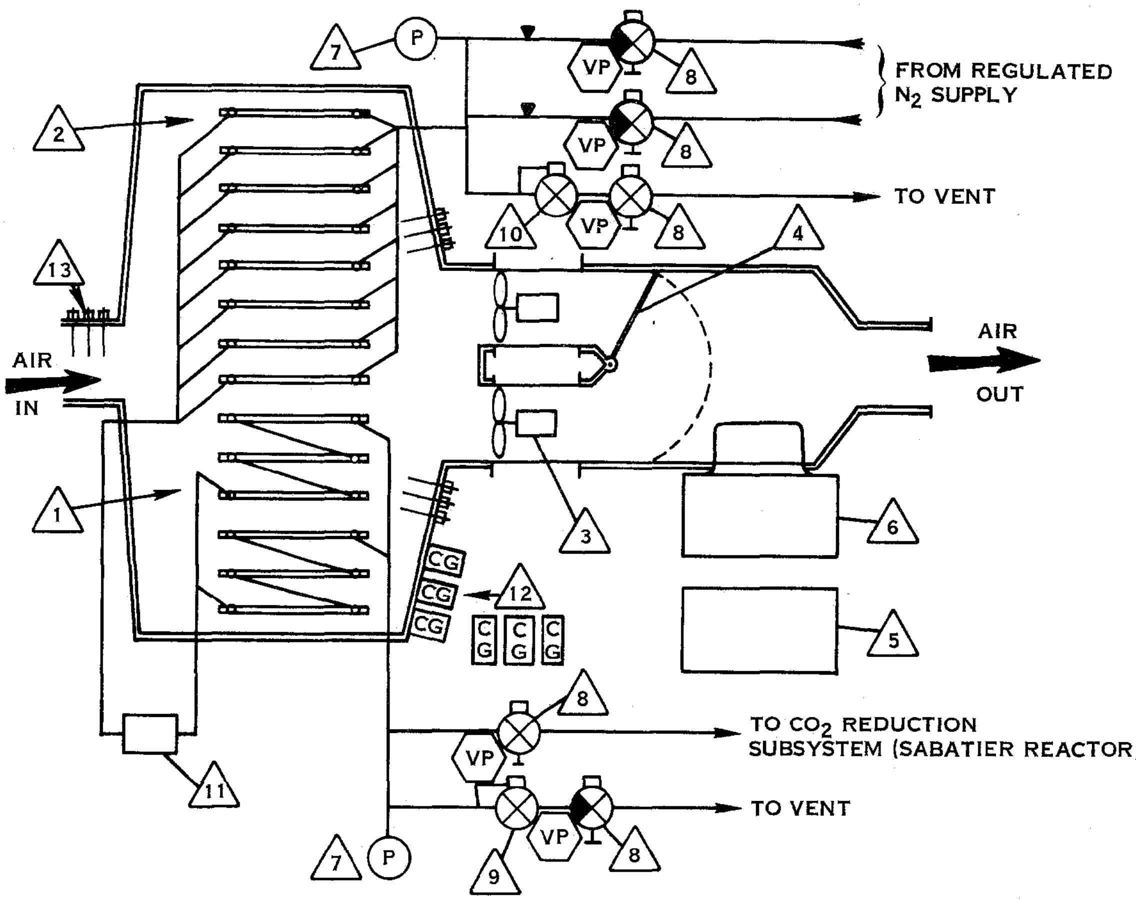
In the WVE/HDC subsystem, cell pairs are mounted in a rack that provides mechanical support, H_2 interface, electrical interface, and airflow. Air is directly drawn from the cabin through this cell stack by a fan. The exhaust from the fan provides cooling for an electronic controller that conditions the power to the WVE, controls the current in the HDC, and dissipates the HDC generated power. A second controller provides normal and emergency automatic shutdown, and system monitoring functions.

In addition to the cell stack, and controller, the subsystem includes valving and plumbing to properly route the H_2 from the WVE to the HDC, and the H_2 and CO_2 from the HDC to the CO_2 reduction subsystem. The valving also provides a nitrogen purge to be used when shutting down the system.

System Operation - There are two separate paths in this subsystem (see figure 56), the air path and the hydrogen path. The air path carries oxygen and CO_2 into the HDC cells where a fuel cell reaction takes place combining H_2 and O_2 to generate water vapor (H_2O) which is released to the air stream. Low voltage electrical power is also generated. The primary function of the HDC cell occurs in conjunction with the fuel cell reaction resulting in the absorption of CO_2 into the electrolyte on the air side, and the liberation of CO_2 on the H_2 side at a much higher partial pressure (see figure 57). The cell in effect acts as an electrochemical CO_2 pump. The air path also carries water vapor into the WVE cells located in parallel with the HDC cells where it is electrolized generating O_2 which is returned to the air stream, and H_2 which is fed to the HDC cells.

The air enters the subsystem through a duct from the cabin air distribution system and has already been filtered by that system. The air flows over inlet temperature sensors, through the cell stack, over outlet temperature sensors and combustible gas detectors and into the operating fan. Two fans are provided to improve system reliability since the fan rotor is the only moving part in the subsystem under normal operation. A manual selector valve and manual switches on the signal controller are provided to switch fans should that be necessary. The selector valve approach is used instead of dual check valves for its reduced weight and pressure drop. The air from the operating fan continues over heat sink fins on the back of the power controller to remove WVE power conditioning heat and HDC current control power dissipation heat, and exits from the subsystem to a duct that interfaces with the cabin air distribution system immediately downstream of the subsystem inlet duct.

The hydrogen path starts in the WVE cells and flows from each cell pair to a collection manifold which then directs the generated hydrogen through a filter and then into the HDC cell pair manifold. A quantity of 16 HDC and 21 WVE cell pairs are required for the four man system, and 28 HDC with 33 WVE are required for the seven man system. In each case, 5 of the WVE cell pairs are required to meet cabin leakage.



ITEM NO.	NAME
1	HDC CELL PAIR
2	WVE CELL PAIR
3	FAN
4	FAN SELECTOR VALVE (MANUAL)
5	CONTROLLER, SIGNAL
6	CONTROLLER, POWER
7	PRESSURE SENSOR (GAGE)
8	ELECTRIC VALVE (WITH POSITION INDICATION & MANUAL OVERRIDE)
9	BACK PRESSURE REGULATOR
10	PRESSURE RELIEF VALVE
11	FILTER
12	COMBUSTIBLE GAS DETECTOR
13	TEMPERATURE SENSOR

FIGURE 56. HDC/WVE SCHEMATIC

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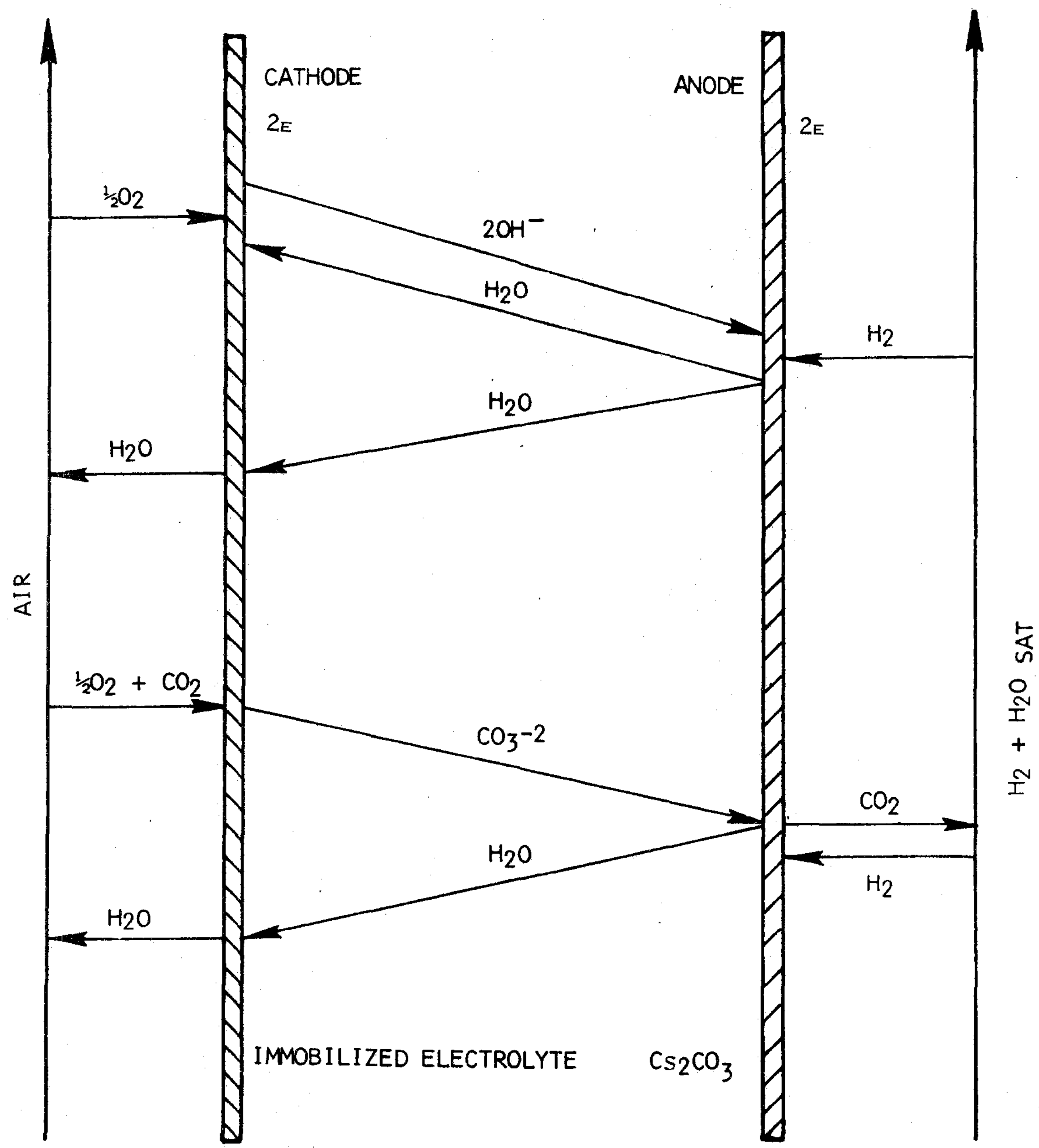


$\frac{1}{2}O_2 + CO_2 + 2E \rightarrow CO_3^{-2}$ $\qquad$ $H_2 + CO_3^{-2} \rightarrow H_2O + CO_2 + 2E$

$2OH^- + CO_2 \rightarrow CO_3^{-2} + H_2O$ $\qquad$ $H_2O + CO_3^{-2} \rightarrow 2OH^- + CO_2$

FIGURE 57. HDC REACTIONS AND MASS TRANSPORT PROCESSES

To improve the reilability of the subsystem two additional HDC and WVE cell pairs have been included for a total of 18 HDC and 23 WVE for 4 men, and 30 HDC and 35 WVE for seven men.

This HDC manifold splits the H_2 flow into six or ten parallel paths of three series cell pairs each for the four or seven man system, respectively. This series/parallel flow path assures even distribution of H_2 flow to all cell pairs without causing excessive pressure drop, or starving cells of H_2.

The resulting H_2 and CO_2 mixture is collected into a common line and diverted to the CO_2 reduction subsystem. The back pressure is controlled by that subsystem to a level that is always greater than ambient cabin pressure assuring that any leakage that occurs will be from the very small volume hydrogen lines into the much larger cabin volume where it is quickly dissipated. Combustible gas detectors are located within the cell stack enclosure and elsewhere in the cabin to feed shutdown signals to the subsystem controller when trace H_2 is detected in quantities well below the lower explosive limit.

When a shutdown signal is received, electrically operated valves admit nitrogen purge gas from a regulated system supply flushing all H_2 from the system. Additional subsystem protection is provided in the form of redundant N_2 purge gas valves, a redundant H_2 and CO_2 backpressure regulator venting to space, and an overpressure relief valve also venting to space. This purge system and the availability of the Shuttle Orbiter ARS satisfies the requirement that the system be fail safe.

Cell parameters such as cell stack temperature rise, cell voltage, and cell current are monitored by the controller to provide performance information, operating and shutdown control, and maintenance decision information.

Flow Diagram - The flow diagram shown in figure 56 is the same for the four-man or the seven-man configuration the only differences being the number of WVE or HDC cell pairs used, the size of the fan and associated ducting, and a slight increase in controller size to monitor the extra cell pairs.

Design Data

The selection of the number of cell pairs, air flow and overall system integration, was based on test data and experience of previous WVE/HDC programs (NAS 9-11830 and NAS 9-12920). The following is a detail analysis of the component sizing.

WVE - The design requirement is to provide sufficient oxygen to maintain an oxygen partial pressure of 22.1 kPa (3.2 psia) in the cabin under varying ambient air humidities and a nominal oxygen consumption which is determined as follows:

Nominal metabolic consumption (4 men)	3.34 kg/day	(7.36 lb/day)
HDC oxygen consumption *	2.05 kg/day	(4.52 lb/day)
Vehicle leakage	1.87 kg/day	(4.11 lb/day)
TOTAL	7.26 kg/day	(15.99 lb/day)

* 16 cell pairs (18 ASF) = 16 cell pairs x 18 amps/cell pairs x .0071 kg O_2/day/amp

In order to maintain this oxygen production level, the WVE will be operated at constant current as follows:

$$\text{Current} = \frac{7.26 \text{ kg/day}}{0.0071 \text{ kg } O_2\text{/day/amp}} = 1019 \text{ amps}$$

The dryest inlet air conditions are 35% relative humidity at 18.3°C (65°F). At this condition the WVE will operate at 43.8 ma/cm^2 (50 ASF) at 1.9 vdc. Since 1.9 vdc is the maximum continuous duty operating voltage for the WVE it follows that the total WVE cell pairs for the system (based on 50 ASF) would be 21.

$$\frac{1054 \text{ amps}}{50 \text{ ASF/cell pair}} = 20.4 \text{ WVE cell pairs}$$

Under inlet air conditions of 90% RH, the WVE cell pair voltage will be 1.66 vdc at a current density of 53.8 ma/cm^2 (50 ASF).

For the 7-man system, oxygen consumption is 11.6 kg/day (25.5 lb/day) and the required current of 1622 amps will be processed by 33 WVE cell pairs.

In order to support the 53.8 ma/cm^2 (50 ASF) operation of the cell pairs at the dryest inlet air conditions a minimum of 0.0033 m^3/sec (7 cfm) air flow through each cell pair is required.

HDC - Parametric testing on a small cell (1/24 std. cell pair) with TMAC electrolyte over an air inlet relative humidity range of 33% to 89% at 21.1°C (70°F) showed no significant effect of relative humidity on CO_2 transfer efficiency. Air volume flow rate, equivalent to .0047 m^3/sec (10 cfm) or greater on the full size cell, had no effect on the CO_2 transfer efficiency at P_{CO_2} above 133 Pa (1 mm Hg). Figure 58 shows the effect of current density on the CO_2 transfer efficiency at three different P_{CO_2} levels. There is a rapid dropoff in efficiency with increasing current density but the absolute amount of CO_2 processed increases slightly (Figure 59). At P_{CO_2} of 400 Pa (3 mm Hg), experience has shown that there is a more rapid decrease in the amount of CO_2 processed when the current is reduced below 19.4 ma/cm^2 (18 ASF). For this reason 19.4 ma/m^2 (18 ASF) was chosen as the nominal current density for the cell pair.

The CO_2 removal efficiency of the HDC cell pair using TMAC is 75% to 80% at P_{CO_2} of 400 Pa (3.0 mm Hg) and is anticipated to be at least 72% at P_{CO_2} of 333 Pa (2.5 mm Hg), thereby sizing the system as follows:

- Nominal CO_2 Production (4 men) — 4.0 kg/day (8.8 lb/day)
- CO_2 Removal Rate — .0196 kg/day/amp (0.0433 lb/day/amp)
- Current Required

$$\frac{4.0\ \text{kg/day}}{.0196\ \text{kg/day/amp}} = 204\ \text{amp}$$

- Number of Cell Pairs (19.4 ma/cm^2 (18 ASF) and 72% efficiency)

$$\frac{204\ \text{amps}}{18\ \text{amps/cell pair} \times .72} = 15.7\ \text{cell pairs}$$

The required hydrogen flow to support the HDC would theoretically be:

$$16\ \text{cell pairs} \times 18\ \text{amps/cell pair} \times .00089\ \text{kg}\ H_2 = 0.25\ \text{kg}\ H_2\text{/day}$$
$$(0.56\ \text{lb}\ H_2\text{/day}$$

Tests show that for the maximum HDC power, 2.5 times stoichiometric flow or .63 kg H_2/day (1.4 lb H_2/day) is required, which is provided by the WVE. Similarly, for the seven-man system, the requirement is 28 cell pairs and 1.11 kg H_2/day (2.45 lb H_2/day).

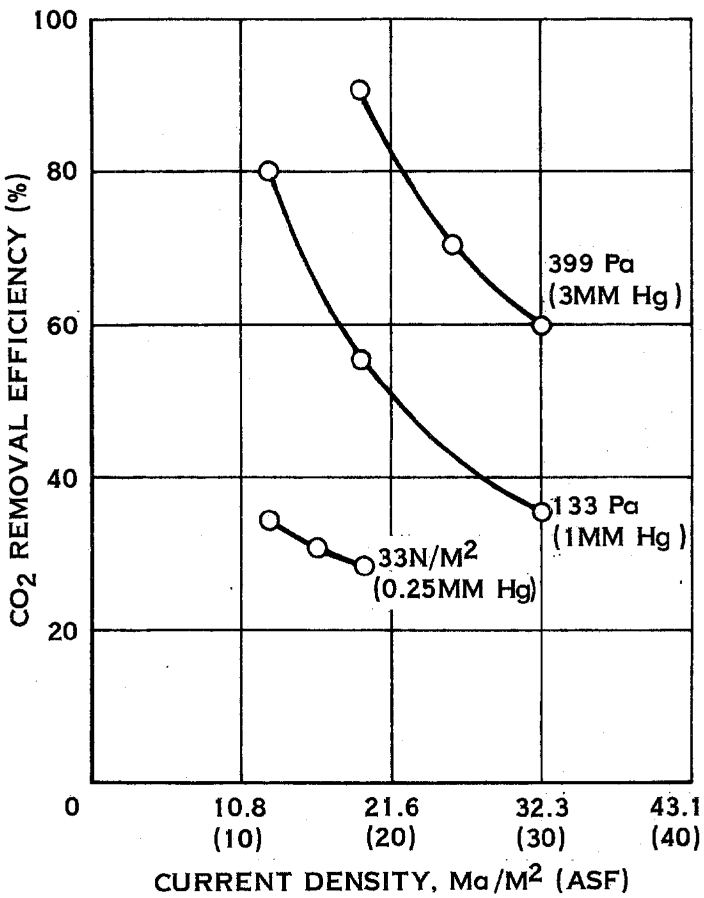


FIGURE 58. HDC CURRENT DENSITY VS CO_2 TRANSFER EFFICIENCY

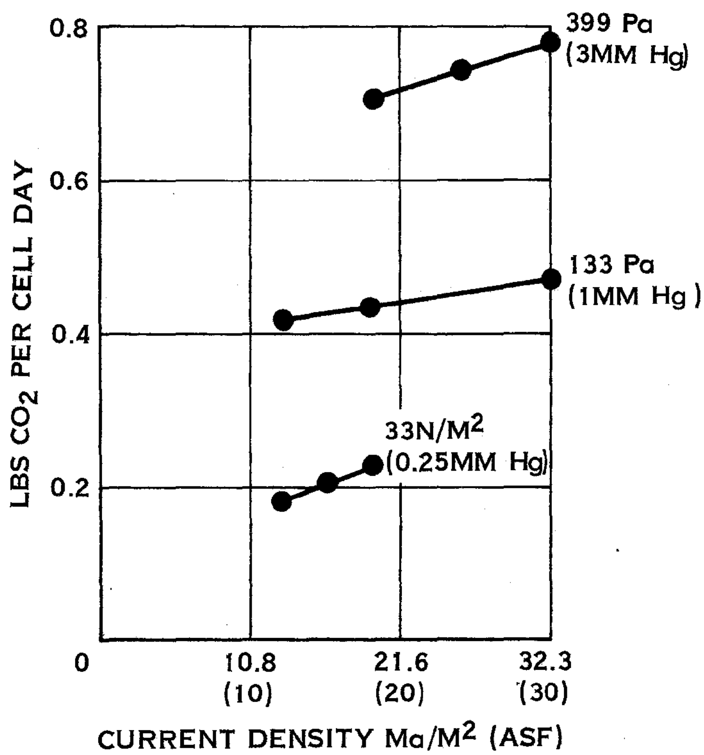


FIGURE 59. HDC CURRENT DENSITY VS CO_2 REMOVAL RATE

Component Weight and Power Table

Figure 60 presents a list of all the components in the four-man and 7-man subsystem, the quantity used, the individual and total weight, the type and amount of power consumed (or generated), and the amount of heat returned to the cabin air. The HDC cell pairs generate power and heat. The direct heat is dissipated in the air stream as shown (282 W and 494W). The electrical power (65W and 114W) is dissipated as heat in the power controller (Item 6) and is included in the controller heat column (247W and 396W). The WVE cell pairs consume large amounts of DC power but dissipate only a small portion of that power as heat; the majority going into the electrolysis of water vapor. Only one of the two fans is operating at any one time, and the total fan power eventually dissipates itself as heat in the cabin air stream. The seven-man fan is the same diameter but slightly longer than the four-man fan and consumes more power.

The fan selector valve is manually operated and consumes no electrical power.

The signal controller contains all of the subsystem control logic. This includes valve actuation components; temperature, pressure, and combustible gas sensor signal conditioning and safety logic. The controller also contains individual cell voltage taps and provides failure detection system access to these taps and other parameters. The four-man and seven-man controllers are identical except for the increase in voltage taps in the seven-man system. The low power level of this controller is dissipated directly to the cabin and structure.

The power controller contains the WVE power conditioning circuits operating on DC power and the HDC current control electronics operating on AC power while dissipating the low voltage DC HDC power. The heat generated in this unit is dissipated through a finned heat sink to the air stream.

Two pressure sensors are used in the system. One monitors the purge gas inlet to detect low purge pressure and signal the opening of the second purge valve. The other monitors the outlet pressure to the CO_2 reduction subsystem and signals the switch to the overboard dump backpressure regulator when the pressure goes out of specification, or signals for a purge sequence if the H_2 pressure to cabin pressure differential drops to zero or goes negative. The pressure sensor power is included in the signal controller.

The electric valves are motor operated ball valves with manual override and valve position indicator switches. They consume AC power and are used only intermittently during normal or emergency shutdown.

The backpressure regulator controls the H_2 and CO_2 pressure above the cabin pressure in the event of a CO_2 reduction subsystem shutdown. The pressure relief valve is identical to the backpressure regulator except in pressure setting and is used to

HDC/WVE COMPONENT WEIGHT/POWER TABLE

Item No.	Name	4 Man System: Quantity	Weight Kg(lbs)	Total Kg(lbs)	AC Power watts	DC Power watts	Heat watts	7 Man System: Quantity	Weight Kg(lbs)	Total Kg (lbs)	AC Power watts	DC Power watts	Heat watts
1	HDC Cell Pair	18	2.95 (6.5)	53.1 (117.0)		* 65	282	30	2.95 (6.5)	88.5 (195.1)		*110	494
2	WVE Cell Pair	23	2.95 (6.5)	67.85 (149.6)		1773	521	35	2.95 (6.5)	103.25 (227.7)		2760	811
3	Fan	2	2.63 (5.8)	5.26 (11.6)	70		70	2	2.95 (6.5)	5.90 (13.0)	110		110
4	Fan Selector Valve	1	.45 (1.0)	.45 (1.0)				1	.45 (1.0)	.45 (1.0)			
5	Controller, Signal	1	5.22 (11.5)	5.22 (11.5)	20		20	1	5.22 (11.5)	5.22 (11.5)	20		20
6	Controller, Power	1	3.63 (8.0)	3.63 (8.0)	5	177	247	1	4.54 (10.0)	4.54 (10.0)	6	276	396
7	Pressure Sensor (Gage)	2	.18 (.4)	.36 (.8)	**			2	.18 (.4)	.36 (.8)	**		
8	Electric Valve (With Position Indication & Manual Override)	5	.82 (1.8)	4.1 (9.0)	***50			5	.82 (1.8)	4.1 (9.0)	***50		
9	Back Pressure Regulator	1	.59 (1.3)	.59 (1.3)					.59 (1.3)	.59 (1.3)			
10	Pressure Relief Valve	1	.59 (1.3)	.59 (1.3)				1	.59 (1.3)	.59 (1.3)			
11	Filter	1	.54 (1.2)	.54 (1.2)				1	.54 (1.2)	.54 (1.2)			
12	Combustible Gas Detector	6	.14 (.3)	.84 (1.8)	**			6	.14 (.3)	.84 (1.8)	**		
13	Temperature Sensor	9	.05 (.1)	.45 (1.0)	**			9	.05 (.1)	.45 (1.0)	**		
	Components Sub Total Kg (lbs)		142.98	(315.1)	95	1950	1140		215.33	(474.7)	136	3036	1831
	Packaging Kg (lbs)		41.96	(92.5)					55.11	(121.5)			
	Hardware Total Kg (lbs)		184.94	(407.6)					270.44	(596.2)			
	Penalties AC Power @ .322 Kg/w	(.710 lbs/w)	30.59	(67.4)					43.79	(96.5)			
	DC Power @ .268 Kg/w	(.59 lbs/w)	522.60	(1152.3)					813.65	(1794.1)			
	Heat @ .198 Kg/watt	(.436 lbs/w)	225.72	(497.7)					362.54	(799.2)			
	Grand Total		963.85	(2125.0)					1490.42	(3286.4)			
	Volume M^3 (ft^3)	.637	(22.5)					.850	(30)				

*Power Generated **Power Included in 5 Controller ***Intermittent Power Only One Fan is Powered At Any One Time

FIGURE 60

FOLDOUT FRAME 1 FOLDOUT FRAME 2

relieve overpressure and prevent cell pair damage in the event of a N_2 purge valve failure. Neither valve consumes electrical power.

The filter is a cartridge of "Purafil" type absorbent material to absorb and trap any impurities in the H_2 stream from the WVE cells such as H_2S or H_2SO_4 that could possibly degrade the HDC cell stack performance.

The combustible gas detectors are located strategically within the system to detect dangerous levels of hydrogen and shutdown the system. The weights shown are only those of the sensing head. The signal conditioning is performed in the controller and the sensors' power is charged to the controller.

The temperature sensors provide temperature related shutdown information to the controller where signal conditioning is performed and power is charged.

Packaging weights including air ducting structural supports, plumbing, brackets, and wiring harness based on estimates from the subsystem package drawing (figure 61). This weight combines with the component total to define the total installed hardware weight. (Not including vehicle plumbing ducting or wiring).

To this installed weight must be added the electrical power penalties and heat dissipation penalties. The AC and DC power penalties are obtained from the SSP requirements and constraints document, SVHS 4655, and are based on continuous regulated AC and DC power from solar cells. The heat rejection penalty is from SSP studies based on cabin heat exchanger and space radiator factors.

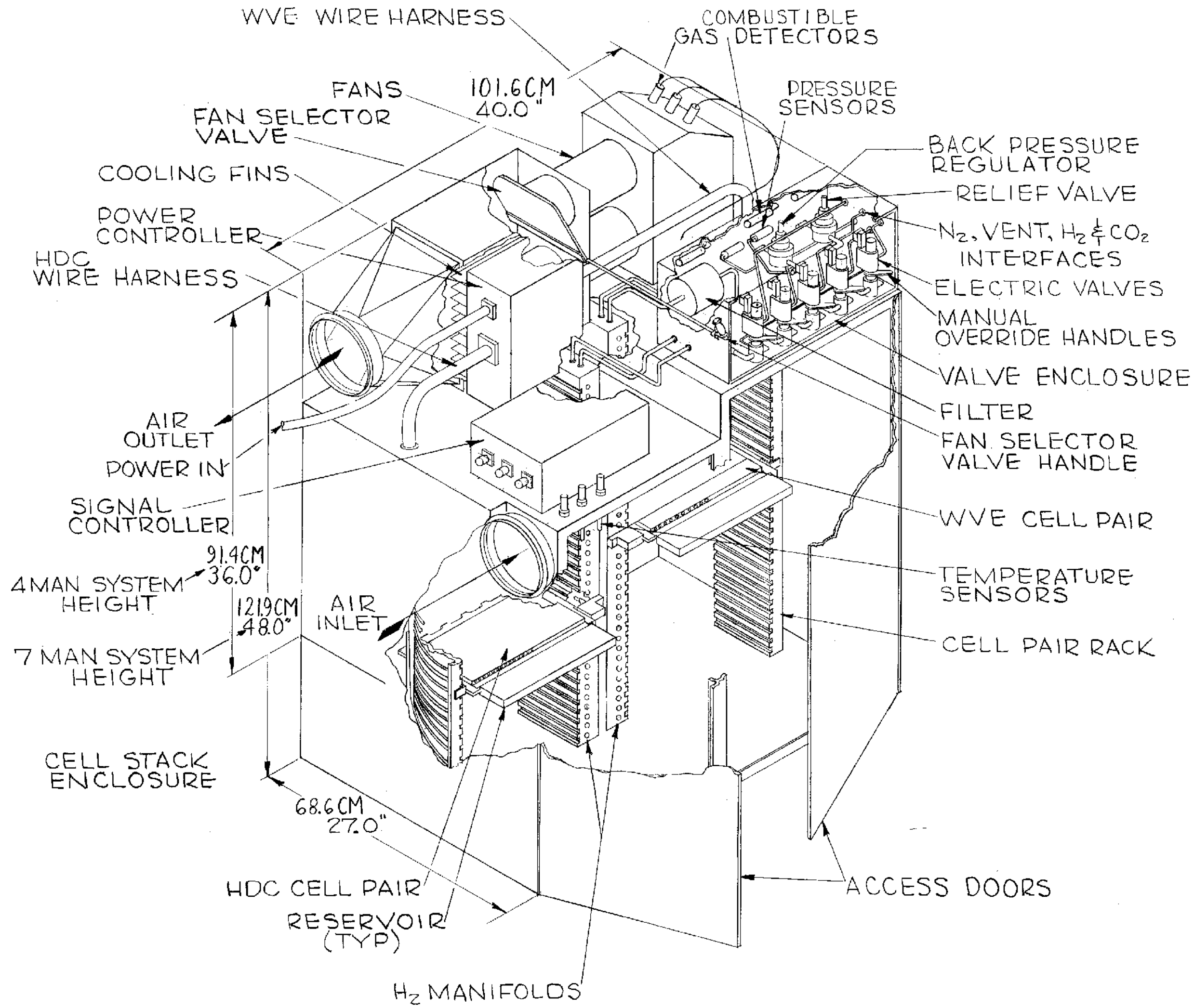
The AC power and heat total do not include the intermittently actuated valve power. The DC power total does not include the power generated by the HDC since it is dissipated as heat and not utilized due to its low voltage.

The total equivalent weight represented by the grand total is a constant independent of mission duration since all penalties are based on fixed installed equipment, and not consumables.

The subsystem volume based on the subsystem package drawing is included on this chart.

Package Drawing

Figure 61 shows the HDC/WVE subsystem as it would exist in a flight configuration. The package draws air in through a duct into a plenum in front of the cell stacks. Air then passes through the cells in parallel, HDC on the left, WVE on the right,



FOLDOUT FRAME

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FIGURE 61. HDC/WVE PACKAGE DRAWING

FOLDOUT FRAME 2

and collects in a second plenum behind the cell stacks and is drawn off through the fan at the top of the package and delivered to the outlet duct. The H_2 manifolds are located between the cell stacks and the electrical harnesses are routed to the outer edge of the stacks. Access doors on the package front allow access for cell removal. Valves and controllers are located on top of the package.

PRELIMINARY ASSESSMENT AND SELECTION

The section presents studies for the five (5) advanced concepts not selected for the detailed assessment task which are:

Chemical Nitrogen Supply

Regenerable Filter

Two-Gas Control Using Mass Spectrometer

Hydrogen Depolarized Concentrator

Flash Evaporator

CHEMICAL N_2 SUPPLY (N_2H_4)

Summary

The function of the nitrogen supply for the Shuttle Orbiter is to provide for leakage make-up, water tank pressurization and cabin airlock repressurization and cabin pressure maintenance following a 1.25 cm (0.5 inch) diameter wall puncture. The Shuttle baseline concept for achieving this function is high pressure nitrogen storage tanks. Chemical nitrogen supply (electrolytic dissociation of N_2H_4) is evaluated herein as a potential improvement to this baseline. Since a chemical system has low nitrogen production rates relative to repressurization requirements which are 1.89×10^{-2} kg/sec (150 lbs/hr) maximum, it is only considered for leakage make-up and water tank pressurization.

At the present time, there appears to be no merit in replacing the Shuttle high pressure storage tanks with the chemical N_2 supply. Although both concepts provide adequate performance for Shuttle Applications, high pressure storage is superior in weight, complexity, ease of refurbishment, handling and cost.

Requirements

The N_2 supply system requirements are:

- Provide 81.65 kg (180 lbs) of usable N_2 for a 0.6×10^6 sec (7 day) mission.
- Deliver nitrogen at a maximum flow rate of 1.89×10^{-2} kg/sec (150 lbs/hr) for repressurization.
- Deliver nitrogen at a flow rate of less than 5.25×10^{-5} kg/sec (10 lbs/day) for leakage make-up and water tank pressurization.

Baseline Concept - Gaseous Nitrogen Storage

The current Shuttle baseline employs four high pressure, 2068×10^4 n/m^2 (3000 psig), tanks each containing 20 kg (45 lbs) of usable nitrogen. Each tank allows delivery at a minimum flow rate of 1.89×10^{-2} kg/sec (150 lbs/hr).

Alternate Concept - Chemical Nitrogen Generation

The chemical nitrogen generation system studied is an electrolytic device for converting hydrazine to nitrogen using potassium hydroxide (KOH) as the electrolyte. Since cabin and airlock repressurization require high flow rates (1.89×10^{-2} kg/sec), these nitrogen supply requirements cannot be handled by chemical nitrogen generation (0.1 g/sec generation range). Thus, the chemical system studied incorporated high pressure nitrogen tankage for repressurization requirements and electrolytic nitrogen generation for only cabin leakage and tank pressurization.

The electrolytic nitrogen generation system is shown schematically in figure 64. The electrolytic and hydrazine and H_2O are continuously circulated between the electrodes of each cell in the electrolytic stack. An electrolyte reservoir controls the system pressure via the external nitrogen pressure reference. A heat exchanger in the liquid circulation circuit provides cooling for the cell stack electrolytic heat generation.

Upon receiving a signal from the cabin pressure controller, nitrogen and oxygen are produced at the electrolysis cell anode while hydrogen from both water and hydrazine is available at the cathode. Figure 65 shows the half-cell reactions that occur at the anode and cathode. The nitrogen and oxygen are fed directly to the cabin while the hydrogen could be supplied to fuel cells; however, since this hydrogen could contain trace amounts of ammonia (about 20 ppm), it will probably not be useful for fuel cells and thus must be dumped.

The main element in this electrolysis nitrogen supply system is the cell stack. Each cell in the stack contains a liquid electrolyte (30% KOH) with hydrazine hydrate center which is continuously circulated between the opposing anode and cathode electrodes as shown in figure 66.

Concept Comparison

Figure 68 presents an evaluation summary for the two concepts. For the baseline tankage concept, data is based on the NASA supplied tankage penalty, 1.64 kg tank and ullage/kg usable N_2. Data for the chemical supply system are estimates assuming design execution of current technology.

- Weight - The weight of each system is roughly the same with the gaseous supply system weighing less for shorter missions and the chemical system being lighter for longer missions.

- Volume - For 0.6×10^6 sec (7 day) missions, the high pressure gas storage concept requires less volume, and thereafter the chemical N_2 supply system is the smaller of the two.

- Cost - Development of the chemical N_2 supply system is estimated at TBD.

- Power/Heat - The power required to operate the electrolytic N_2 generation concept and the heat produced by this system are significant and outweigh any weight and volume advantages it has for longer mission durations.

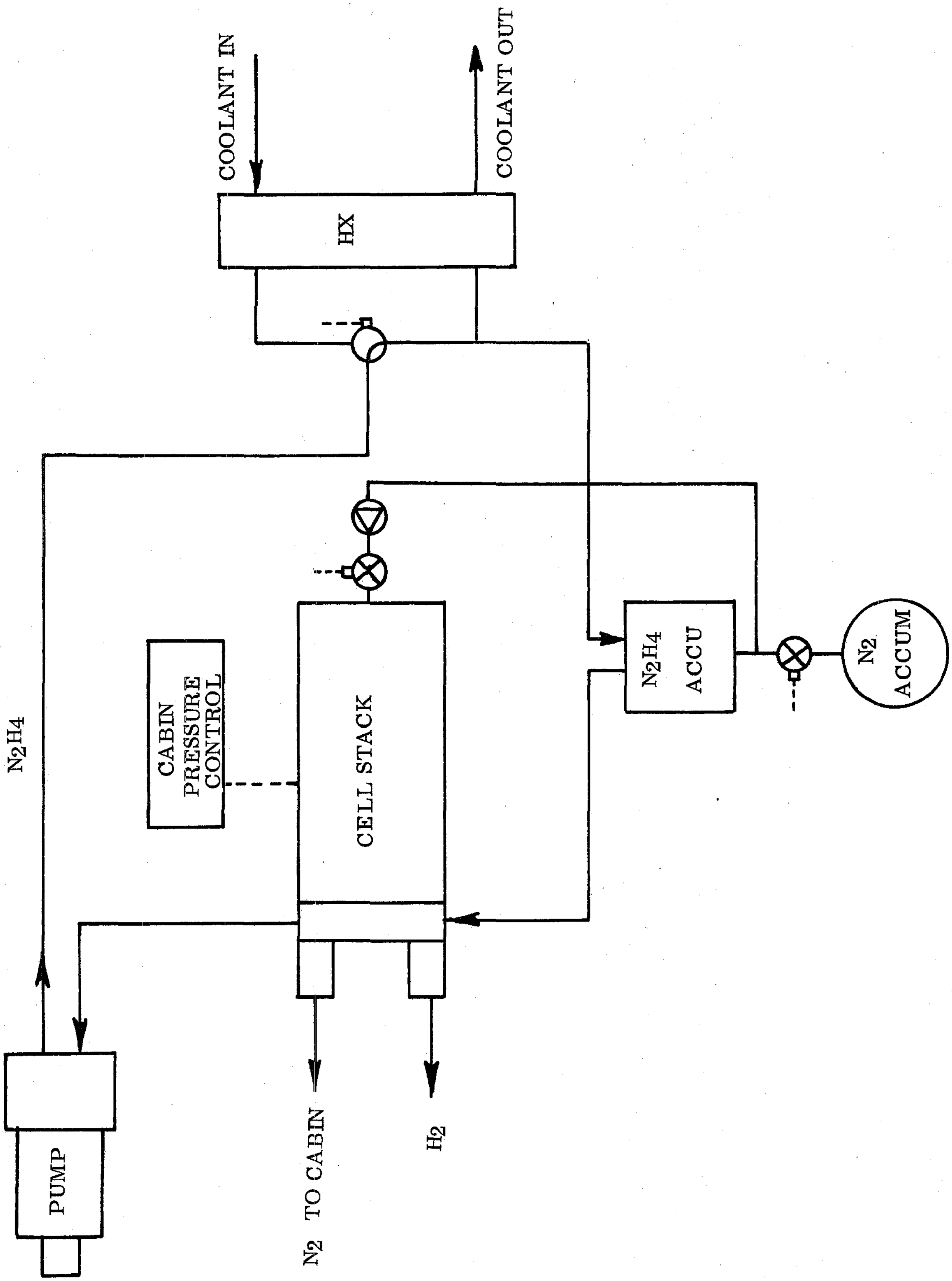

FIGURE 62. CHEMICAL N_2 SUPPLY SCHEMATIC

N_2H_4 - ELECTROLYTIC DISSOCIATION

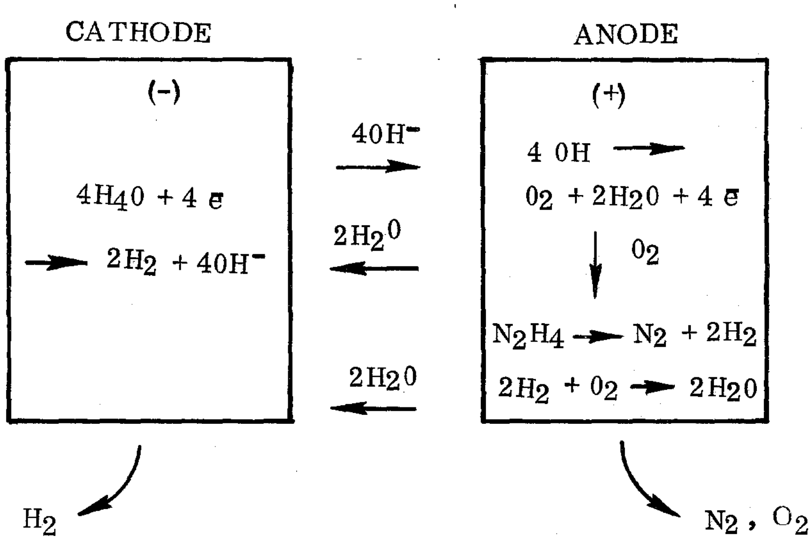

FIGURE 63. N_2H_4 - ELECTROLYTIC DISSOCIATION

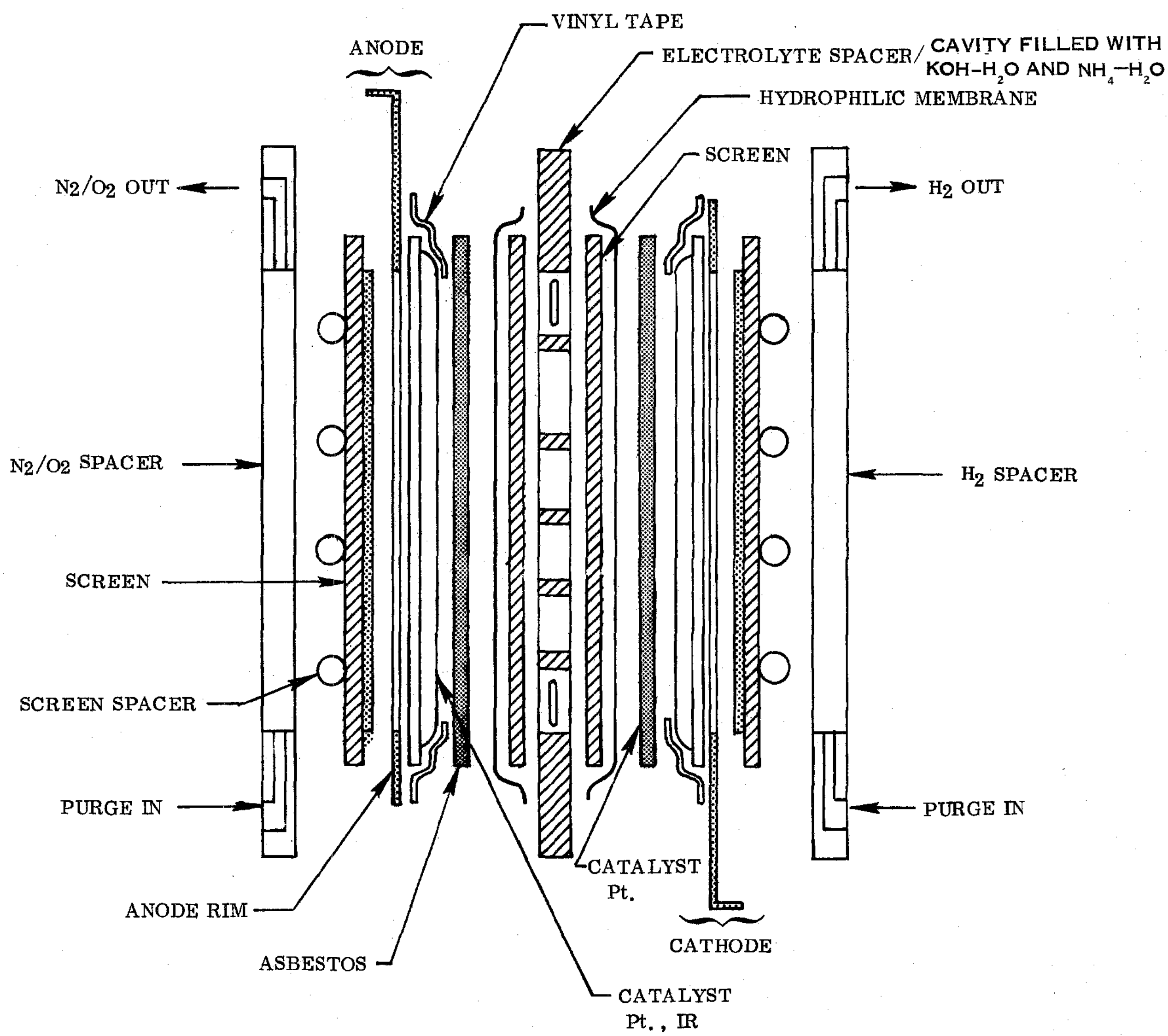

FIGURE 64. ELECTROLYTIC CELL

Crew/Passengers, Mission Length Sec (Days), Parameter	4 and 7 Men			Comments
	0.6×10^6 (7)	2.6×10^6 (30)	7.8×10^6 (90)	
Weight Chemical N_2 Gas N_2	288 (635) 247 (545)	475 (1047) 500 (1110)	930 (2046) 1180 (2600)	Kg's (lbs)
Volume Chemical N_2 Gas N_2	.77 (27.5) .70 (25.0)	1.32 (47) 2.10 (75)	2.63 (94) 3.36 (120)	M^3 (Ft^3)
Cost	-	-	-	TBD
Power/Heat (Watts)	54/18	244/81	666/222	Chemical N_2 Penalty not associated with Gas N_2 System
Performance	Adequate	Adequate	Adequate	Will require significant development
Refurbishment				Chemical N_2 will be more difficult than Gas N_2
Handling				Chemical N_2 will be more difficult than Gas N_2
Vehicle Impact				Incorporation of Chemical N_2 System will require modification to current Shuttle 2-Gas Control scheme

FIGURE 65. ASSESSMENT DATA SHEET

- Performance - Performance for both concepts is deemed adequate, however, significant development effort will be required on the chemical system relative to the high pressure gas storage system.

- Handling - Handling of the chemical N_2 supply system will be more difficult since it involves both tanks and electrolysis cells.

- Vehicle Impact - Incorporation of the chemical N_2 system requires modification to the current Shuttle two-gas control scheme since high pressure N_2 will not be available for cabin leakage make-up.

Item Ranking

Criteria	*Baseline Shuttle Mission Duration*	
	7 Days	30 Days
Weight Saving for Baseline Shuttle	No	No
Backup for Shuttle Baseline Concept	No	No
Cost Effective for Future Application	Yes	

The chemical N_2 supply concept studied does not offer a weight savings over gaseous storage supply for missions of 0.6×10^6 seconds (7 days) and 2.6×10^6 seconds (30 days) when the power and heat penalties are considered.

Since the effectiveness of high pressure N_2 storage was thoroughly proven on all past space programs, chemical N_2 supply cannot be considered a backup.

Chemical N_2 supply is potentially suited to future applications, ie, long duration missions (greater than 90 days). However, it should be noted that while it trades off favorably against high pressure storage for these long missions, it does not compare well with chemical N_2 storage using catalytic dissociation or cryogenic N_2 storage. The catalytic dissociation concept was studied on the Space Station Prototype program and offered a weight savings over cryogenic and high pressure N_2 storage for missions of 30 days or longer (Reference SSP Document A 218).

REFERENCE

1. Greenough, B. M.; and Mahan, R.E.; Development of a Prototype Module for a Non-Cryogenic N_2/O_2 Supply System.

2. Greenough, B. M.; Final Report, The Development and Preliminary Design of An Oxygen-Nitrogen Generation System; NASA CR 66940; June 1970.

3. Hamilton Standard; Chemical Nitrogen Generation Subsystem Preliminary Design Package and Trade Study Report; SSD Document A 218; November 1971.

REGENERABLE FILTERS

Summary

The Shuttle Orbiter requirement for quick turn around makes it desirable to service liquid loop filters without the need to remove the filter and drain the liquid loop. Accordingly, a program was performed to design and develop a regenerable filter system which would allow a fast, convenient method for upgrading liquid systems without replacing filters during the turnaround process. This study evaluates the possible application of the regenerable filter to replace the existing Orbiter liquid filters and for future program applications.

In summary, the regenerable concept, as presently envisioned, does not appear to be cost effective for Shuttle but could apply to future programs.

Requirements

The Shuttle ECS incorporates filtration in the water and freon coolant loops and in the potable water circuit. Filtration must be adequate to protect dynamic equipment so that the required operating life is not jeopardized.

Requirements are:

• Flow	1.45×10^{-4} to 3.64×10^{-4} m^3/sec (2 to 5 gpm)
• Pressure Drop	
Clean	1.38×10^4 Pa (2 psi)
Dirty	3.45×10^4 Pa (5 psi)
• Filtration Size	
Nominal	1.0×10^{-5}m (10 microns)
Absolute	2.5×10^{-5}m (25 microns)
• Filtration Capacity	7 Grams

Baseline Concept - Shop Replaceable Filter Elements

The present Shuttle baseline coolant loops are protected by shop replaceable filter elements. Since the elements are sized for a 100 mission, 10 year life, no routine filter servicing is required. In the event filter elements must be cleaned or replaced, the pump package must be removed from the vehicle.

Alternate Concept - Regenerable Filter

The regenerable filter system consists of a filter housing with an integral, cleanable filter element and two quick disconnect fittings that tee into the filter inlet and outlet plumbing as shown schematically in figure 66. A portable GSE cleaning rig is used to backflush the filter and collect the contaminants as shown in figure 67. The cleaning task can be accomplished in flight but the added weight penalty of the rig moves the trade point out beyond a 10 year mission life. Also, in-flight refurbishment of filters would violate existing Shuttle maintenance groundrules. Therefore, only ground maintenance was considered for this study. The cleaning can be accomplished either on a scheduled or unscheduled basis and either approach does not affect the trade study conclusions.

The filter regenerable unit, figure 67, is a self-contained, compact, portable device that connects to the filter to be regenerated by a set of self-sealing quick disconnect couplings, thereby forming a closed loop system which flows in the reverse direction to the normal operation flow through the filter. The regeneration unit contains an AC motor driven pump, a vortex particle separator, secondary filter, fluid accumulator, and a cooling fan. All of the system components are passive with the exception of the motor/pump and the fan, thus enhancing the overall system reliability.

The high speed AC motor driven pump provides a backflush rate of approximately 7.44×10^{-4} m^3/sec (11.8 GPM), and flow from the pump is directed through the filter being regenerated in the reverse direction to that of normal flow.

The regenerable filter is located in the respective fluid system with external quick disconnects for connection to the regeneration unit. The internal parts of the regenerable filter consist of a filter element and an impingement jet. The impingement jet, located within the filter element, is used to dislodge the particulate from the outer surfaces of the filter element by directing small, high velocity jets of fluid onto the inner surface of the filter element. This jet is the basis of the regeneration process and enables efficient cleaning with a greatly reduced flow rate from that required when not using the jet impingement techniques. Previous regeneration systems using the same filter element size and area required three times the flow rate when not using the impingement jet. This special backflush impingement jet adds approximetely a 13.79×10^3 N/m^2 (2 psid) pressure drop to the filter in the normal system fluid flow direction if an internal bypassing system is not incorporated.

The filter element is specially designed for backflushing and continuous reuse. The development work was performed basically on an element rated at 20 microns nominal and 40 microns absolute. Filter elements having a rating of 10 microns nominal and 25 microns absolute were also successfully tested. The filter element is constructed

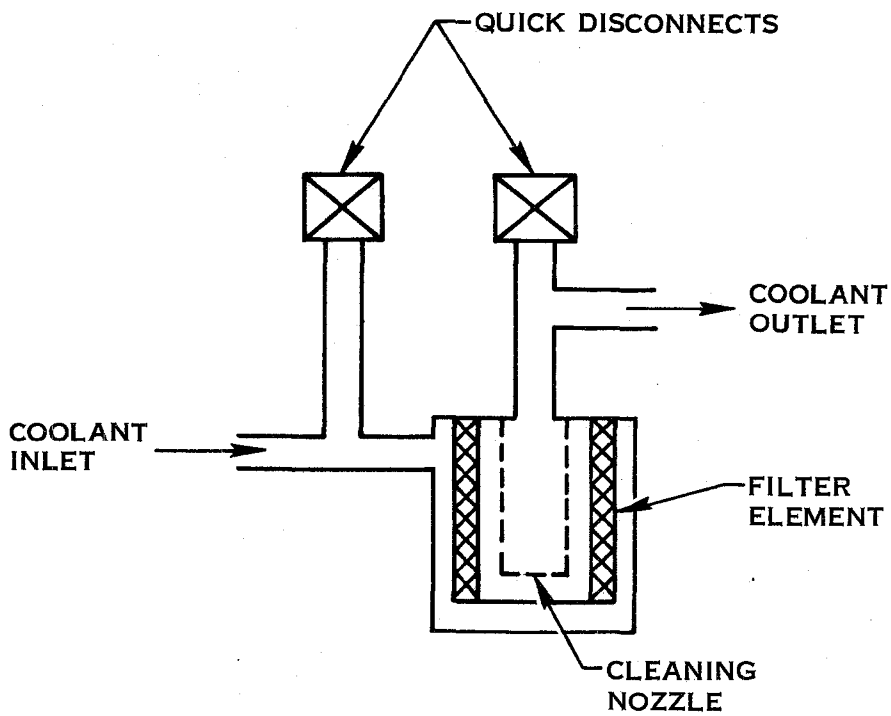

FIGURE 66. REGENERABLE FILTER SCHEMATIC

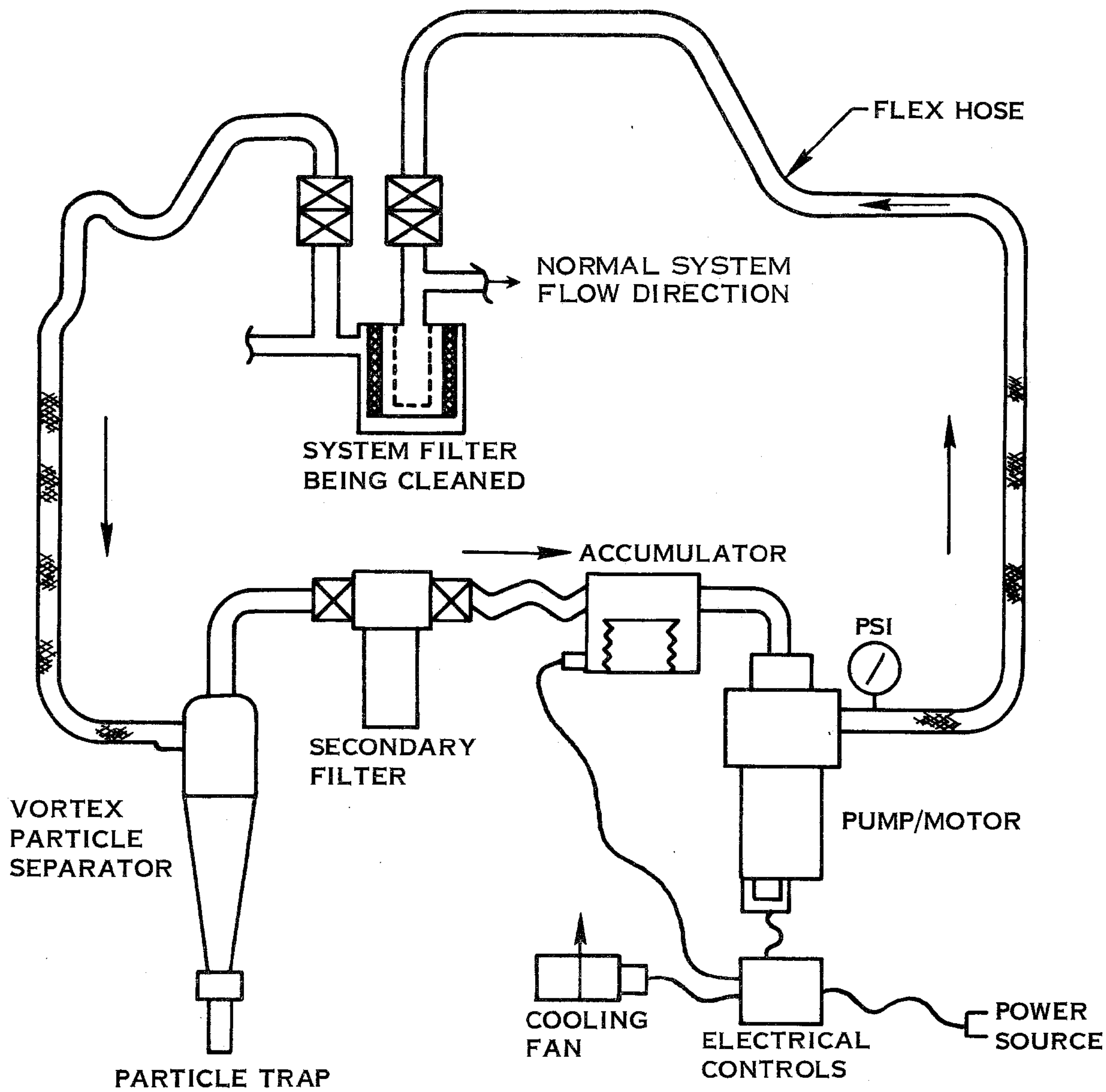

FIGURE 67. REGENERATION UNIT SCHEMATIC

of stainless steel for extended life and ease of cleaning. A differential pressure indicator on the filter housing provides a visible indication when the pressure drop across the element reaches a loaded condition, indicating that the filter should be cleaned.

During the two-minute regeneration cycle, the backflush flow through the regenerable filter removes the particles from the filter element and carries them into the vortex particle separator where the particles are removed from the fluid by centrifugal action. The particle separator is a key element in the regeneration unit and is used as a means of removing and collecting large amounts of contaminant.

The vortex particle separator is a passive component with no moving parts. The separator employs a vortex action where the particles are thrown to the outer surface of the separator and eventually are forced down into a zero-g trap where they are accumulated and prevented from re-entering the normal flow. The particle trap is sized so that little or no change-out is required during a normal mission. The trap can be removed with no loss of fluid and can be either replaced or simply rinsed.

Any remaining particles that were not removed by the vortex action flow out of the separator and into the secondary filter where all 10 micron or larger particles are filtered out of the fluid. The secondary filter insures that no fine particles are transmitted to the inside surface of the regenerable filter that could possibly contaminate the spacecraft fluid system. The secondary filter periodically requires maintenance and since it is identical to the regenerable filter, it can also be regenerated with the regeneration unit. Thus, the regeneration unit is self-sufficient and does not require any additional servicing equipment for particle removal.

Fluid flow from the secondary filter enters the accumulator prior to passing through the motor pump. The accumulator provides makeup fluid to the system that may be lost when the quick disconnects are disconnected and connected. The accumulator houses a small bellows which, when pressurized, provides a positive pressure on the pump inlet preventing cavitation during the regeneration cycle. The storage volume of the fluid contained by the accumulator is also used as a heat sink for the regeneration unit. The cooling fan mounted on the unit is used to remove heat during and after the regeneration cycles.

Concept Comparison

The Data Assessment Sheet (figure 68) compares the regenerable filter with the existing Shuttle concept. Both concepts were evaluated for the water coolant loop filter function. These results can be scaled for other Shuttle applications. At this time there appears to be no merit in replacing the existing filter approach with regenerable filters.

- Weight - The regenerable filter approach is heavier due to the quick disconnects and larger filter housing needed to contain the cleaning nozzle configuration.

- Volume - The alternate concept also requires more volume, mostly due to the quick disconnects.

- Cost - The regenerable approach has inherently more cost for the cleaning nozzle and quick disconnects.

- Power - Both concepts require pumping power to overcome their inherent pressure drop. The regenerable system required more pumping power to overcome the relatively high pressure drop of the cleaning nozzl e.

- Total Equivalent Weight - The installed weight plus power penalty for the regenerable filter exceeds that of the baseline by 1.77 kg (3.7 lb).

- Performance - Both concepts perform the basic cleaning function. However, filter manufacturers' data referenced in this study seriously questions whether the filtration level specified for the Shuttle is optimum in light of existing trends in the aircraft and submarine industries. Both industries have found correlation between cleanliness levels and component failure rates and, as a result, have specified filtration levels of 5 microns absolute or less for all liquid systems. These levels are quite a bit less than the 25 micron absolute level presently specified for Shuttle systems. A filter regeneration system for finer filters will require further development and probably will use more power than the unit presently being developed.

- Refurbishment and Handling - The regenerable approach ranks best with respect to refurbishment and handling. This is because it is refurbished quickly in the vehicle with a minimum of handling. However, the Shuttle baseline is sized for the full 100 mission life of the vehicle and any maintenance will be of the unscheduled failure type only. It is, therefore, difficult to downgrade the baseline concept in this area.

PARAMETER	UNITS	REGENERABLE FILTER	BASELINE	COMMENTS - REGENERABLE FILTER COMPARED TO BASELINE
Weight	Kg (Lb)	1.95 (4.3)	.91 (2)	Twice as heavy
Volume	m3 (in^3)	.0006 (36)	.0004 (25)	Quick disconnects add more volume
Cost	-	More	-	Nozzle and quick disconnects increase equipment cost.
Power	Watts	3.6	.72	Pressure drop of cleaning nozzle adds power.
Total Equivalent Weight	Kg (Lb)	2.78 (6.1)	1.07 (2.4)	Based on a penalty of .23 kg/watt (.51 lb/watt) for a 7-day mission.
Performance	-	Same	Same	Equal
Refurbishment	-	Easier	-	May be performed in vehicle. Baseline is a shop repairable unit.
Handling	-	Easier	-	Baseline must be removed from vehicle for maintenance.
Vehicle Impact	-	Yes	No	Requires Access and Power for cleaning.

The values reflected above are independent of crew size and total mission time in the ranges studied (4 and 7 men, 700 days).

FIGURE 68. DATA ASSESSMENT SHEET - REGENERABLE FILTER

- Vehicle Impact - The regenerable approach would impact the vehicle in that access is required to the filter disconnects. In addition, a power supply should be located nearby to operate the GSE cleaning rig.

Item Ranking

CRITERIA	BASELINE SHUTTLE MISSION DURATION SECONDS (DAYS)	
	$.6 \times 10^6$ (7)	2.6×10^6 (30)
Weight Savings for Baseline Shuttle	No	No
Backup for Shuttle Baseline Concept	No	No
Cost Effective For Future Application	Yes	

The regenerable filter does not offer a weight savings over the present baseline concept. In addition, regenerable filters cannot be considered a viable backup for Shuttle since they use the same filtration principles and configurations and would, therefore, encounter the same development problems.

Regenerable filters have a questionable benefit on long duration non-Shuttle missions. This is due to the inherent weight of the cleaning rig; a separate one being required for each non-compatible fluid on board the vehicle. As a miminum, three rigs would be required for: 1) Potable Water, 2) Coolant Water, and 3) Freon Coolant. This would result in a base weight of 11 kg (72 pounds) for the rigs (3.7 kg each). Replaceable filters trade very favorable at 0.9 to 1.36 kg (2 to 3 lbs) each, especially when a minimum of 10^8 seconds (1000 days) life is expected from each filter. Filter life is guaranteed by initial cleanliness of the systems at launch. Degradation of rotating pump seals are the major cause of contamination during system operation. This contamination may be contained by placing the major filter at the pump outlet. Since this filter is sized to contain seal failures, it is considered a coupled design with the pump. As such, both items can be replaced simultaneous as one unit, dictated by pump performance or failure, not filter degradation. In this way, no maintenance is required specifically for filters thus eliminating the need for a regenerable capability.

Another consideration in evaluating the regenerative process is that the need for filter replacement is not eliminated, it is simply transferred to the cleaning rig. The filters on the cleaning rig are sized with greater capacity than the system filters but periodic replacement is required and spare filters are needed. Replacement of rig filters also have all the inherent problems of maintenance in any liquid loop (zero spillage, air inclusion, etc.) More specifically, a ten year mission would require only three (3) filter changes per loop of a 10^8 second (1000 day) filter whereas 8 to 12 filter changes are required before the 3.7 kg (24 pound) fixed weight of a single cleaning rig will trade off even. Therefore, the regenerable filter does not have a viable potential for use on long duration non-Shuttle missions. If there were many such filters in the system, then the rig weight per filter would be less and the trade point might fall below the 10 year level. However, if there are many filters there is also a stronger possibility of several different fluids existing and as mentioned earlier, this would require a rig for each fluid type, thus tending to move the trade point back out beyond 10 year mission lifes.

However, on a ground system which is prone to contaminant generation, the regenerable filter offers an attractive alternative to present fluid filters with their inherent maintenance problems. As such, this concept is considered cost effective for future applications.

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1. Green, D. C.; Garber, P. J.; Flight Prototype Regenerative Particulate Filter System Development, Final Report, May 1974, NASA Contract NAS 9-12685 by Martin Marietta Corporation CR 134269.

2. Wheeler, H. L. Jr.; Filtration in Modern Fluid Systems, September 1964, Bendix Filter Division of the Bendix Corporation.

3. Farris, J. A.; The Meaning of Fluid Filter Ratings; Field Service Report No. 25, April, 1965. Aircraft Porous Media, Inc.

TWO GAS CONTROLLER USING MASS SPECTROMETER

Summary

The Shuttle Two Gas Control System maintains the Orbiter crew compartment and habitable payload atmospheric composition to an oxygen partial pressure of $2.21 \pm 0.17 \times 10^4$ Pa (3.2 ± 0.25 psia) and a total pressure of $10.14 \pm 0.14 \times 10^4$ P_a (14.7 ± 0.2 psia). The Shuttle baseline concept achieves this balance by employing O_2 partial pressure sensors. A potential improvement to this concept would be the substitution of mass spectrometers for the oxygen partial pressure sensors. Such a device can sense not only oxygen and nitrogen partial pressures for two-gas control, but can also detect the concentration of CO_2, humidity, and total hydrocarbons and can provide signals to the caution and warning system. Thus, it can replace several existing Shuttle sensors.

At the present time, there appears to be no merit in replacing the Shuttle baseline O_2 partial pressure sensors with a mass spectrometer. This is due primarily to the fact that a mass spectrometer weighs more and is more costly and complex than an O_2 partial pressure sensor. However, if a mass spectrometer is included in the Shuttle, it can best be used as a backup to the oxygen partial pressure sensors (replace one of the three), as well as to replace other specific sensors (carbon dioxide sensor, humidity sensor, and total pressure sensor).

Requirements

The two-gas control function is located in the Atmospheric Revitalization Pressure Control Subsystem. Requirements are:

• Cabin Atmosphere:	Oxygen/Nitrogen			
• Cabin Pressure	$10.14 \pm 0.14 \times 10^4$ P_a	(14.7 ± 0.2 psia)	(total)
	$2.21 \pm 0.17 \times 14$ P_a	(3.2 ± 0.25 psia)	(O_2)

Baseline Concepts

The Orbiter baseline employs three oxygen partial pressure sensors and two controllers as shown in figure 69. One of the controllers is in the Primary N_2/O_2 Control section and one is in the Auxiliary N_2/O_2 Control section. Each controller operates the nitrogen supply solenoid valve. Since the nitrogen supply pressure is higher than the oxygen supply pressure, when the N_2 solenoid is open, only nitrogen will flow (cabin O_2 partial pressure being satisfactory). When the cabin O_2 partial pressure is low, the N_2 solenoid valve is closed and oxygen only is delivered to the cabin.

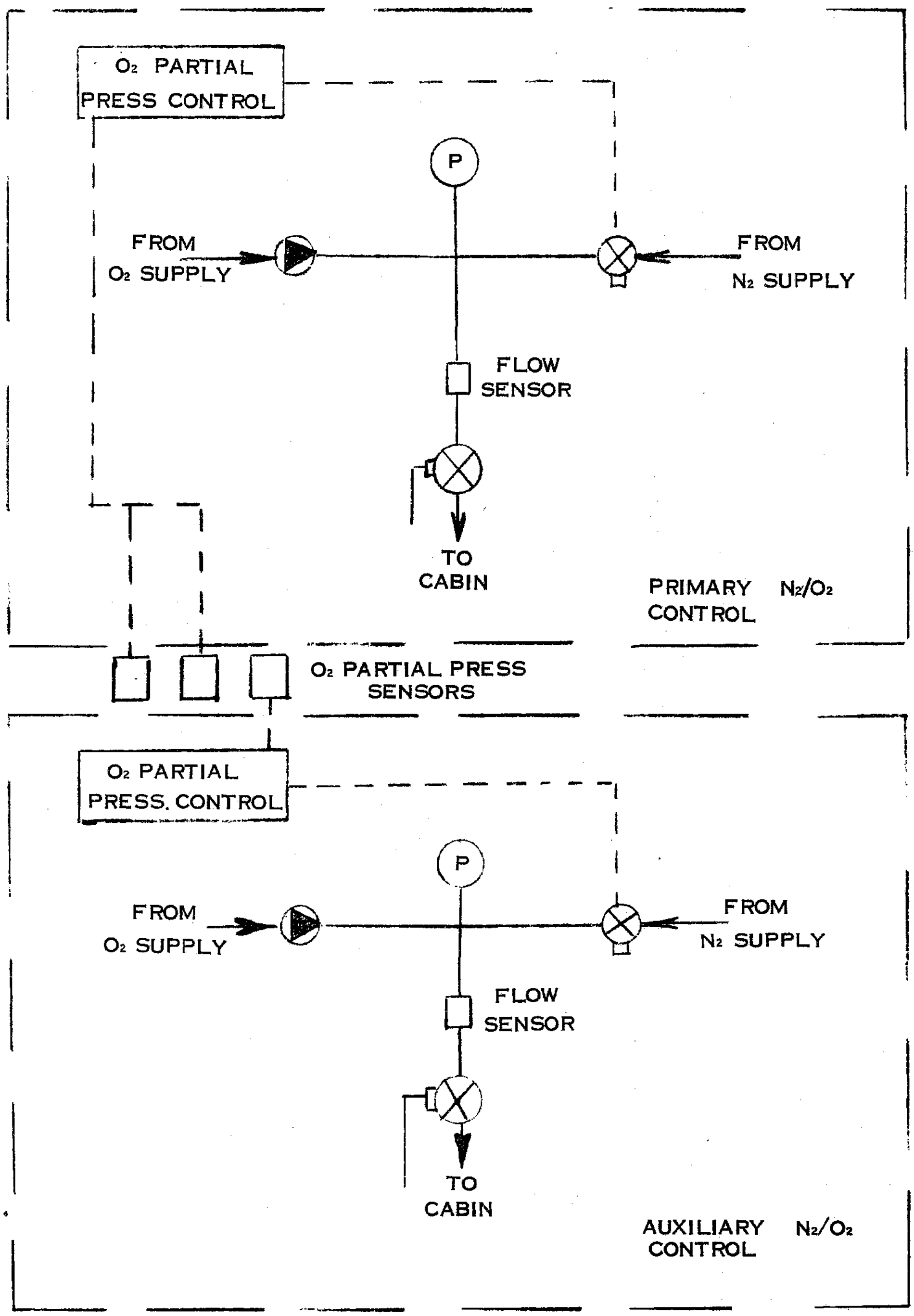

FIGURE 69. BASELINE TWO-GAS CONTROL SCHEME

Alternate Concept - Mass Spectrometer

The mass spectrometer converts partial pressures to electrical signals by ionization of gas molecules and the separation of the resulting molecular ions by the ratio of their molecular weights (figure 70). Figure 71 presents a schematic of the mass spectrometer.

Three approaches to integrating the mass spectrometer into the Shuttle two-gas control scheme were considered:

1. Replace two of the three oxygen partial pressure sensors with mass spectrometers. (Reference figure 72 schematic).

2. Replace two of the three oxygen partial pressure sensors with mass spectrometers that feed oxygen and total pressure signals to an electronic controller programmed to operate separate oxygen and nitrogen solenoid shutoff valves to maintain the specified pressure and composition. (Reference figure 73 schematic). Such a controller could be either on-off or incorporate the Pulse Modulated System studied by MDAC (Ref. 3).

3. Substitute a mass spectrometer for the backup oxygen partial pressure sensor to provide a caution and warning display and fail-safe provisions. (Reference figure 74 schematic).

An assessment of these three systems based on weight, power and performance considerations result in the selection of System 3 for a Shuttle mass spectrometer scheme. As can be seen in the table below, this system has the lowest total equivalent weight penalty.

Configuration	Δ Weight kg (lbs)	Δ Power (Watts)	Total Equivalent Weight Penalty kg (lbs)
System 1	11.5 (25.3)	24.0	17.2 (38.0)
System 2	10.2 (22.4)	26.7	16.6 (36.6)
System 3	5.5 (12.2)	11.5	8.3 (18.3)

Table 4 Mass Spectrometer System Impacts

This selection is further substantiated by the fact that the mass spectrometer is not as accurate for two-gas control as an O_2 partial pressure sensor. Thus, to use it in the primary system would not enhance performance. It is more feasible to use it as in System 3 for display, caution and warning and as a backup for the two primary

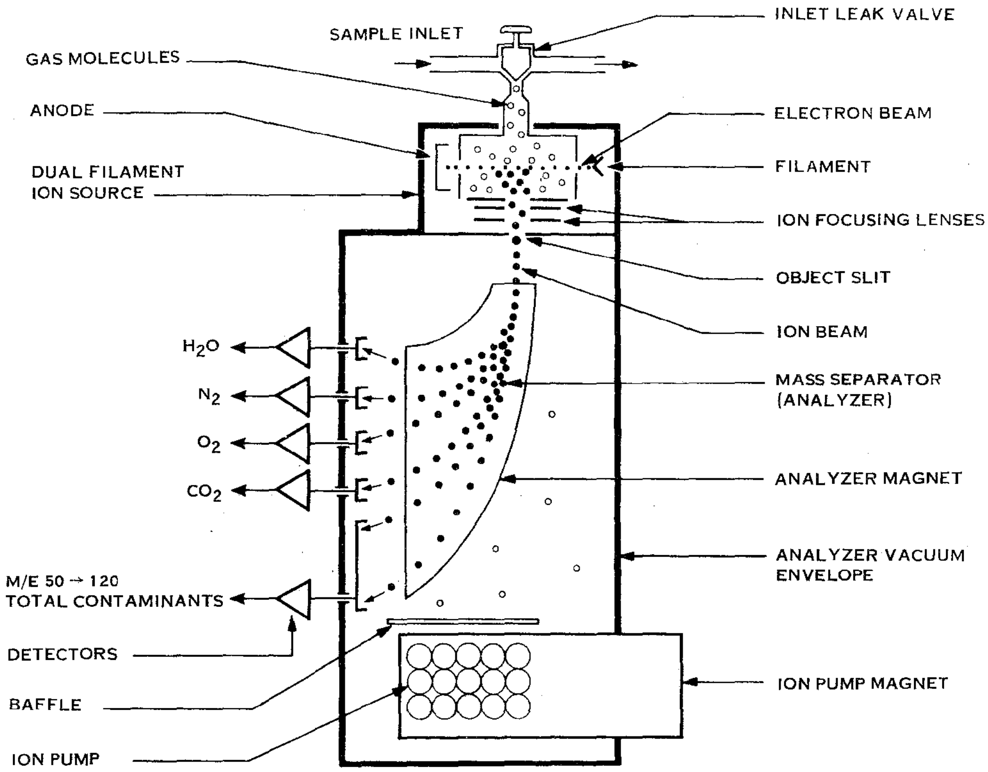

FIGURE 70. MASS SPECTROMETER OPERATION

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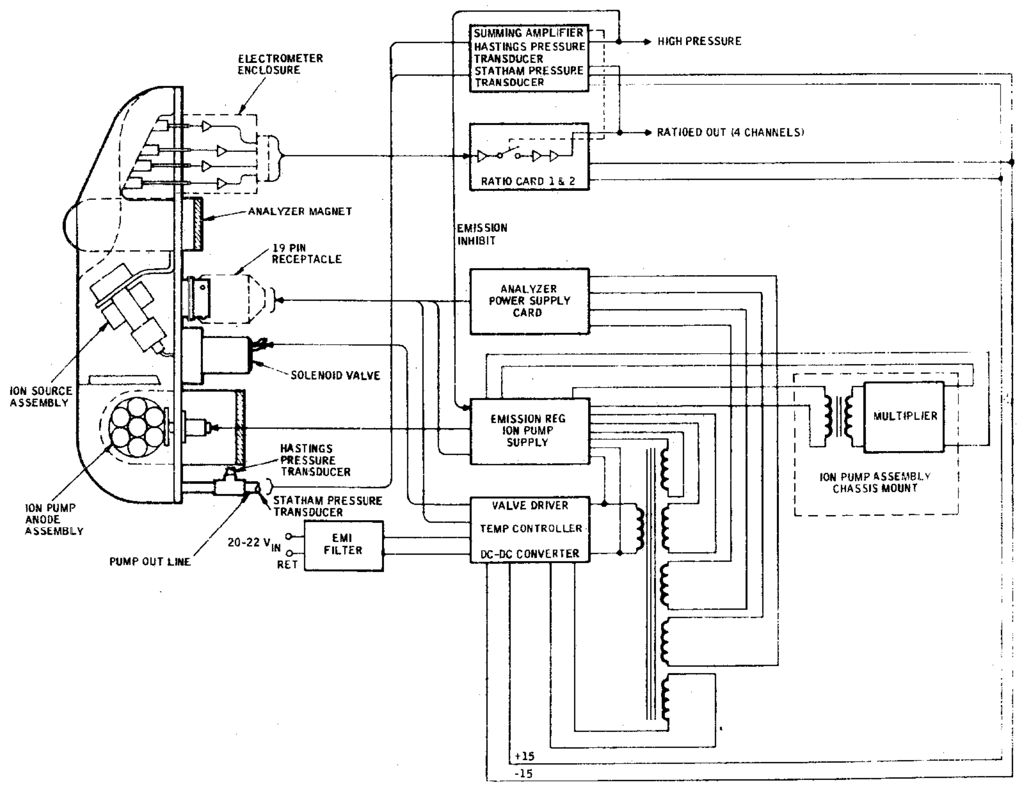

FIGURE 71. MASS SPECTROMETER FOR SHUTTLE

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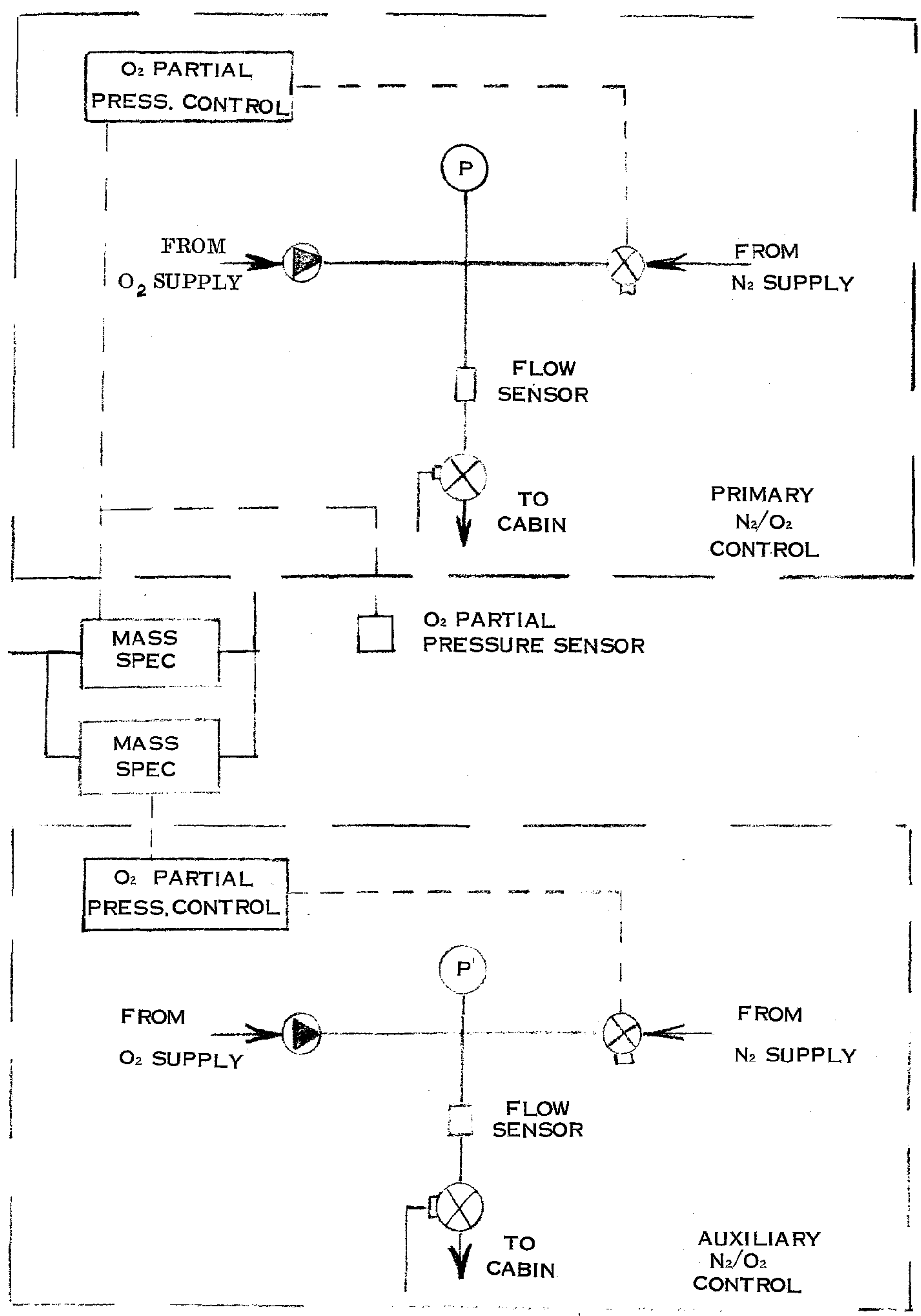

FIGURE 72. SYSTEM 1 SCHEMATIC, TWO-GAS CONTROL

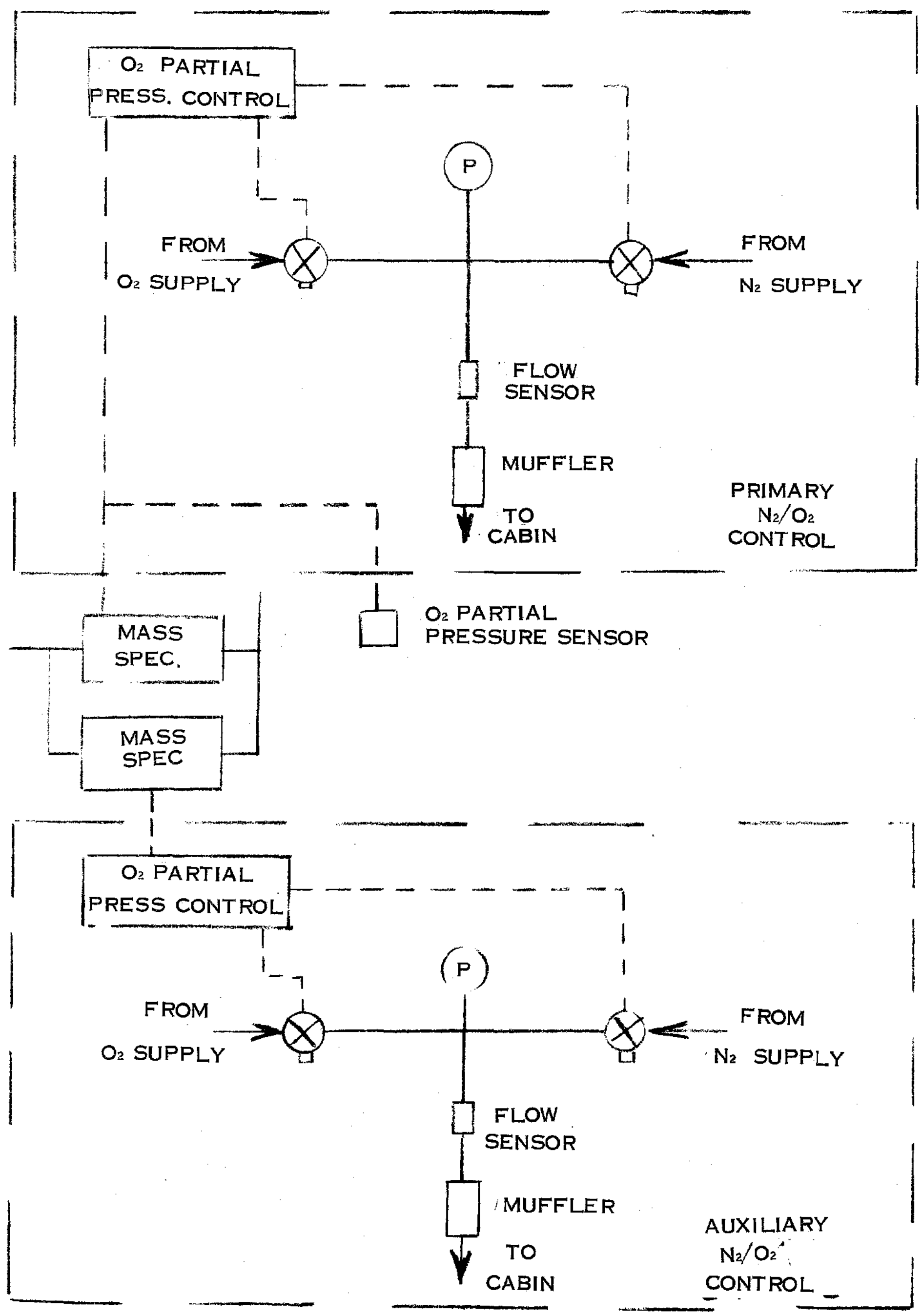

FIGURE 73. SYSTEM 2 SCHEMATIC, TWO-GAS CONTROL

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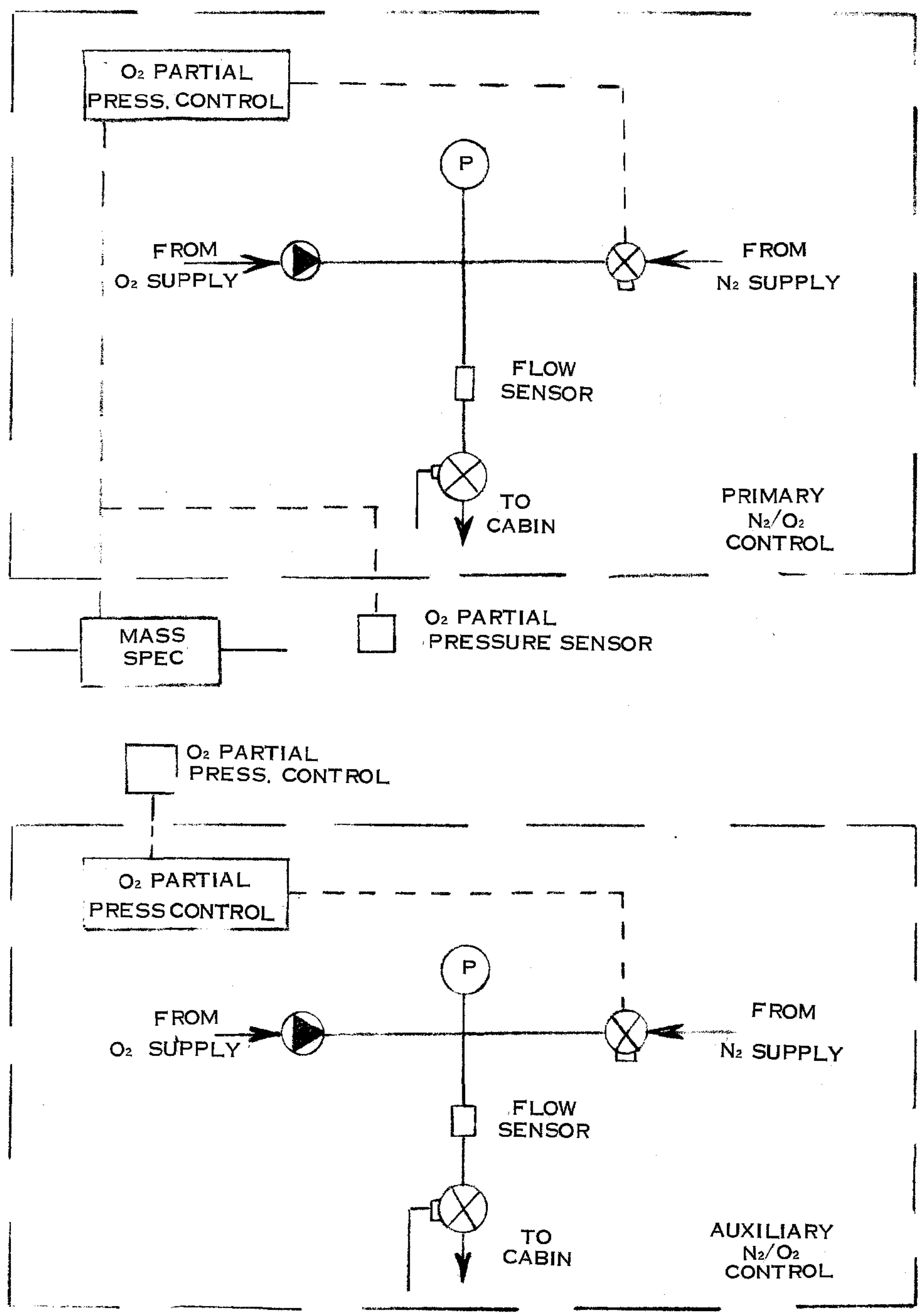

FIGURE 74. SYSTEM 3 SCHEMATIC, TWO-GAS CONTROL

O_2 partial pressure sensors. This results in gaining additional parameter readouts and an O_2 sensor with a different mode of failure with minimum weight, power and cost impact on the vehicle.

Concept Comparison

Figure 75 presents an evaluation summary for the Shuttle baseline two-gas control scheme and the selected mass spectrometer system. The weight, volume and power data shown in this table are deltas over the baseline system.

- Weight - This weight delta for the mass spectrometer system reflects the weight addition for a mass spectrometer as well as the weight decreases for removal of one oxygen partial pressure sensor (three down to two), one carbon dioxide sensor (two to one).

- Volume - The volume increase for the mass spectrometer system is essentially only the volume of the mass spectrometer.

- Cost - Development cost of the mass spectrometer would be significant relative to the baseline system.

- Power - This power increase reflects the power required to operate the mass spectrometer minus the power required to operate the deleted sensors.

- Total Equivalent Weight - The mass spectrometer system is substantially greater than the baseline. A power penalty of 0.23 kg/watt (0.51 lbs/watt) was used.

- Performance - O_2 partial pressure and total pressure control band range is not enhanced when a mass spectrometer is employed. The control bands are somewhat broadened, from 1.5% on O_2 partial pressure control and from .75% to 1% on cabin total pressure. This performance effect, however, is not significant since the selected mass spectrometer system is used only as a backup to the O_2 partial pressure sensors.

- Refurbishment - Refurbishment is judged to be simpler for the partial pressure sensor than for the mass spectrometer. Refurbishment for the partial pressure sensor only involves unscrewing the sensor head and replacing it and calibrating the new head.

Parameter	Units	Value	Comments
Weight	Kg (lb)	+ 5.55 (+12.25)	Increased weight of mass spectrometer over baseline
Volume	cm^3 (in^3)	+7450 (+ 455)	Volume of one mass spectrometer
Cost	-	Higher	Mass spectrometer requires development for flight
Power	watts	+11.5	Increased power of mass spectrometer over baseline
Total Equivalent Weight	Kg (lb)	+ 8.3 (+18.3)	
Performance	-	Equal	Essentially the same
Refurbishment	-	More Difficult	Requires more time and skill
Handling	-	Equal	Equal
Vehicle Impact	-	Yes	Increased weight, volume and power. Allows deletion of specific sensors.

The values reflected above are independent of crew size and mission duration for the ranges studied (4 and 7 men, 7-90 days)

FIGURE 75. EVALUATION SUMMARY

Item Ranking

Criteria	Baseline Shuttle Mission Duration Seconds (Days)	
	0.6×10^6 (7)	2.6×10^6 (30)
Weight Saving for Baseline Shuttle	No	No
Backup for Shuttle Baseline Concept	No	No
Cost Effective for Future Application	No	

Replacing the Shuttle oxygen partial pressure sensor with a mass spectrometer (even as just a backup) is not advantageous. It would incur added weight, power and complexity as well as increased cost.

The mass spectrometer is not regarded as a potential backup to the baseline O_2 partial pressure sensor. It is more complex and not as developed as partial pressure sensors.

The mass spectrometer is potentially useful for applications where two-gas control, trace contaminant monitoring and specific inputs to a caution and warning display are required. However, for just two-gas control, it is not potentially useful for future applications.

References

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2. Perkin-Elmer, Proposal for Space Shuttle Multi-gas Atmospheric Sensor, SPO No. 04200-00672A.

3. Jackson, John K.; Pulse-Modulated Dual Gas Control Subsystem for Space Cabin Atmosphere; McDonnell Douglas Astronautics Co., Huntington Beach, California.

HYDROGEN DEPOLARIZED CO_2 CONCENTRATOR

Summary

The CO_2 removal system operates in the Shuttle Cabin Atmospheric Revitalization System (ARS) to control CO_2, odor, and contaminant levels in the cabin atmosphere. The Shuttle baseline hardware item is a lithium hydroxide (LiOH) cartridge. The hydrogen depolarized CO_2 concentrator (HDC) is evaluated in this report as a potential improvement to the baseline subsystem.

At the present time there appears to be no merit in replacing the Shuttle baseline LiOH system with the HDC system. Although the HDC system performs adequately, it is much more complex than the flight proven baseline system and for most missions would represent a weight increase. The HDC concept does show potential for long duration manned missions of over 90 days when it is operated in a closed loop configuration (with electrolysis and CO_2 reduction systems).

Requirements

The baseline CO_2 removal system is located in the ARS air loop between the fan and debris trap assembly and the humidity control heat exchanger. The operating requirements are:

- Maintain CO_2 partial pressure within 7.6 mm Hg
- Control the levels of CO_2, NH_3, phenol, etc.

Interface requirements:

Inlet Pressure	101.4 kPa (14.7 psia) ± 5%
Inlet Temperature	7.2°C to 28.3°C (45°F to 83°F)
Flow	1.835×10^{-2} kg/s (145.6 lb/hr)avg.
Dewpoint	3.9°C to 16.1°C (39°F to 61°F)

Baseline Concept - Lithium Hydroxide CO_2 Removal

The Shuttle baseline system (Figure 76) controls CO_2, odors, and trace contaminants with LiOH/charcoal cartridges. Each cylindrical radial flow cartridge contains 2.27 kg (5 lb) of LiOH, 0.045 kg (0.1 lb) of activated charcoal, 0.068 kg (0.15 lb) of Purafil and teflon filters. The charged cartridge is sized for a two man-day capacity and weighs 2.86 kg (6.3 lb).

In addition to removing CO_2, the LiOH system will control CO, NH_3, phenol, H_2S, etc. The chemical beds are preloaded and contain teflon filters at the exit to prevent LiOH dust from entering the cabin air stream. The radial flow beds maximize flow outlet area resulting in a 249 Pa (1.0 inch H_2O) pressure drop at 1.56×10^{-2} m^3/s (33 cfm for each cartridge).

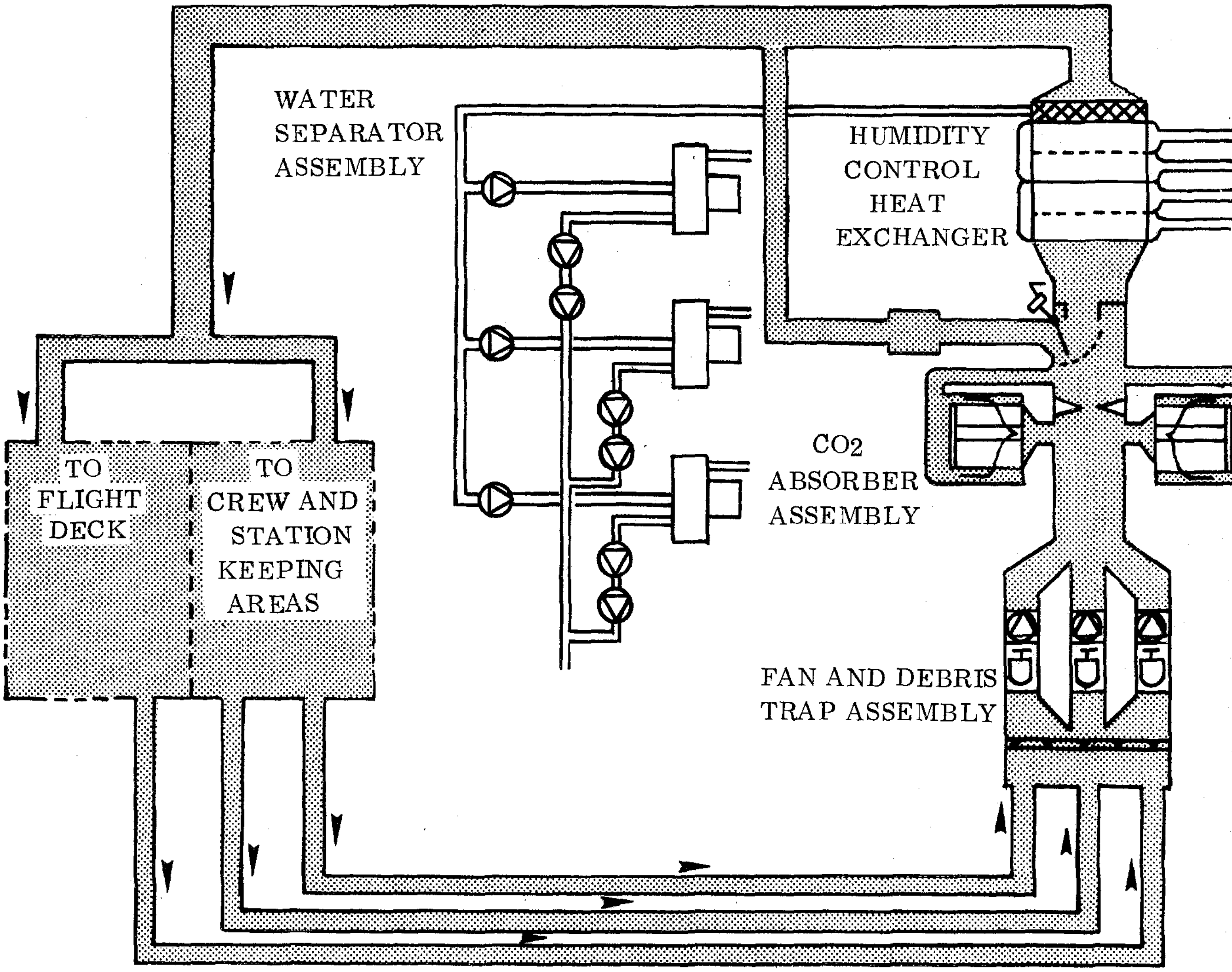


FIGURE 76. ARS SCHEMATIC

Two beds are installed in the ARS at all times. With a four-man crew, both beds are replaced once a day. With a seven-man crew, the two beds must be replaced every 11.0 hours. Because the LiOH undergoes an irreversible chemical reaction in removing CO_2, the beds cannot be regenerated. This requires storage of fresh and spent cartridges which can accumulate quickly for a long duration flight. The storage space for the baseline Orbiter mission is located below the Orbiter floor directly adjacent to the on-line ARS LiOH canisters.

Alternate Concept - Hydrogen Depolarized CO_2 Concentrator

The hydrogen depolarized CO_2 concentrator is a fuel cell type device which can be used in the air loop of the ARS to remove CO_2 generated by the crew (Figure 77). It consists of cell pairs exposed on the cathode side to the cabin atmosphere and on the anode side to a hydrogen supply. The electrolyte is tetramethylammonium carbonate. CO_2 is adsorbed at the cathode where there is a high hydroxyl ion concentration. It is then transferred to the anode where the pH is low. Water is formed at the anode through the electrochemical reaction and is evaporated into the cabin air stream through the cell cathode. The CO_2 concentrated at the anode is vented overboard with any unreacted hydrogen and some water vapor.

A schematic of the basic cell showing the overall reactions at both the cathode and the anode is shown on figure 78. It should be noted from the reaction equation that oxygen is required for the reaction to take place. This oxygen is absorbed from the cabin air supply and for this study must be replaced from cryogenic oxygen tanks. A sketch of the cell pair is shown in figure 79.

During operation, each hydrogen depolarized cell produces a low voltage DC power of approximately 5 watts per cell and releases heat at the rate of approximately 14.6 watts (50 Btu/hour). No credit or penalty is assessed for the electrical power generation at this time because it is not known if a continuous low voltage DC power requirement exists in the vehicle.

The hydrogen depolarized cells are subject to fluctuations in the concentration of the electrolyte depending on the cabin humidity level. An electrolyte reservoir is used to compensate for these various concentrations which affect electrolyte volume.

Sixteen cell pairs are required for a four-man crew and 28 are required for a seven-man crew. The HDC cell bank should be located downstream from the cabin condensing heat exchanger and the air loop circulation fan as shown in the Figure 77 flow schematic. This arrangement is required in order to provide air to the cells at a controlled temperature and dewpoint.

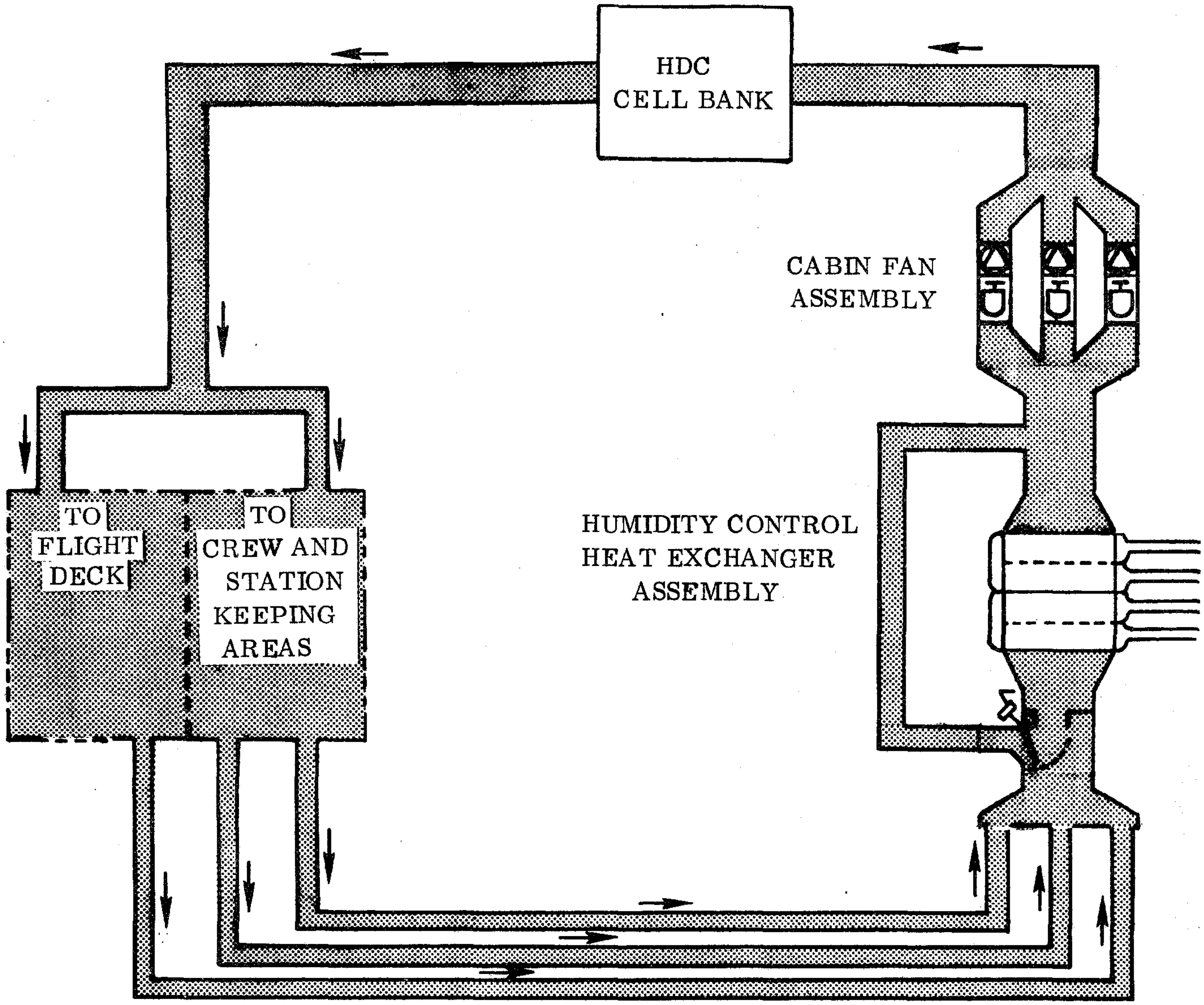
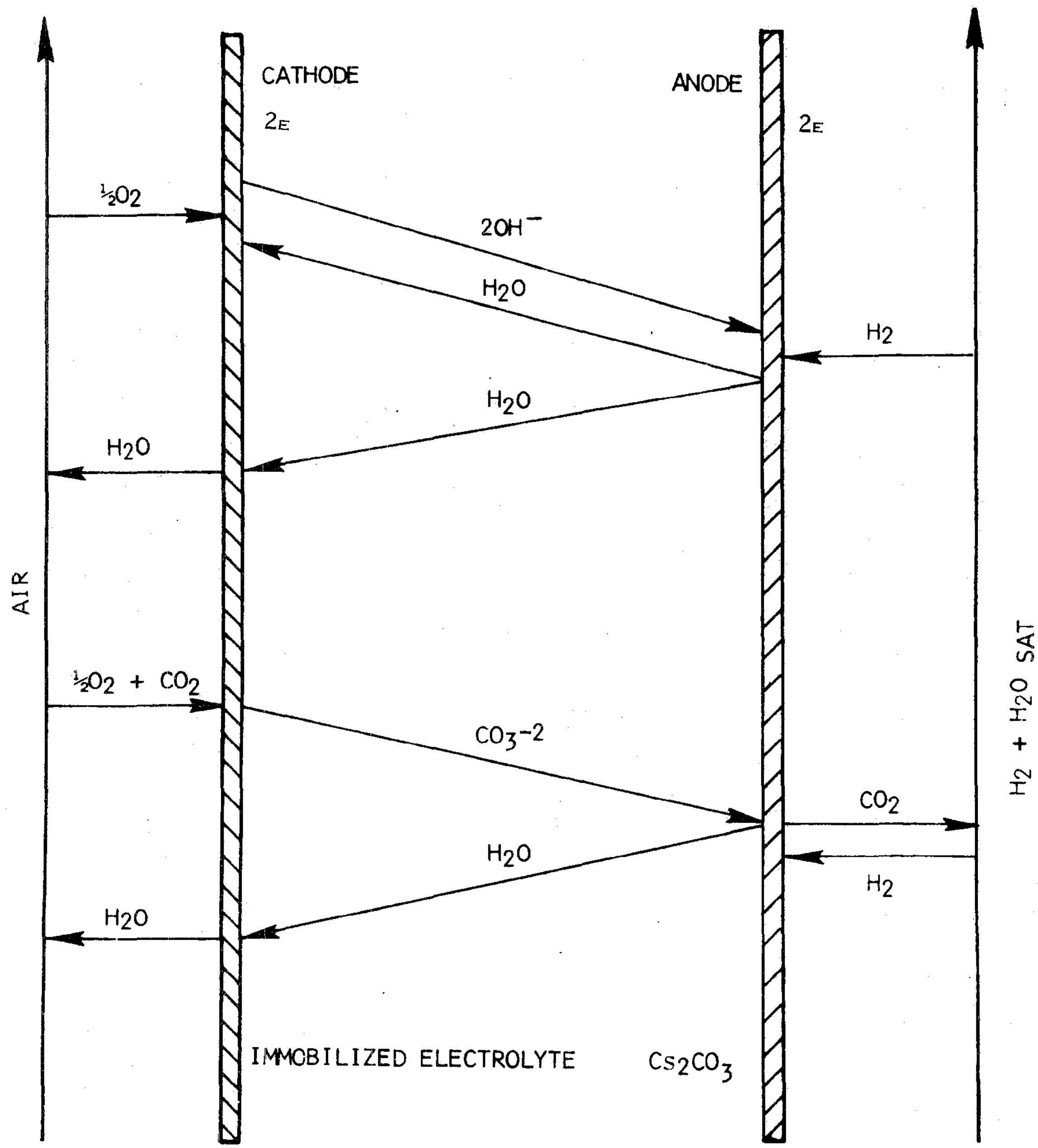


FIGURE 77. HDC SCHEMATIC



$\frac{1}{2}O_2 + CO_2 + 2E \rightarrow CO_3^{-2}$ $\qquad$ $H_2 + CO_3^{-2} \rightarrow H_2O + CO_2 + 2E$

$2OH^- + CO_2 \rightarrow CO_3^{-2} + H_2O$ $\qquad$ $H_2O + CO_3^{-2} \rightarrow 2OH^- + CO_2$

FIGURE 78. HDC REACTIONS AND MASS TRANSPORT PROCESSES

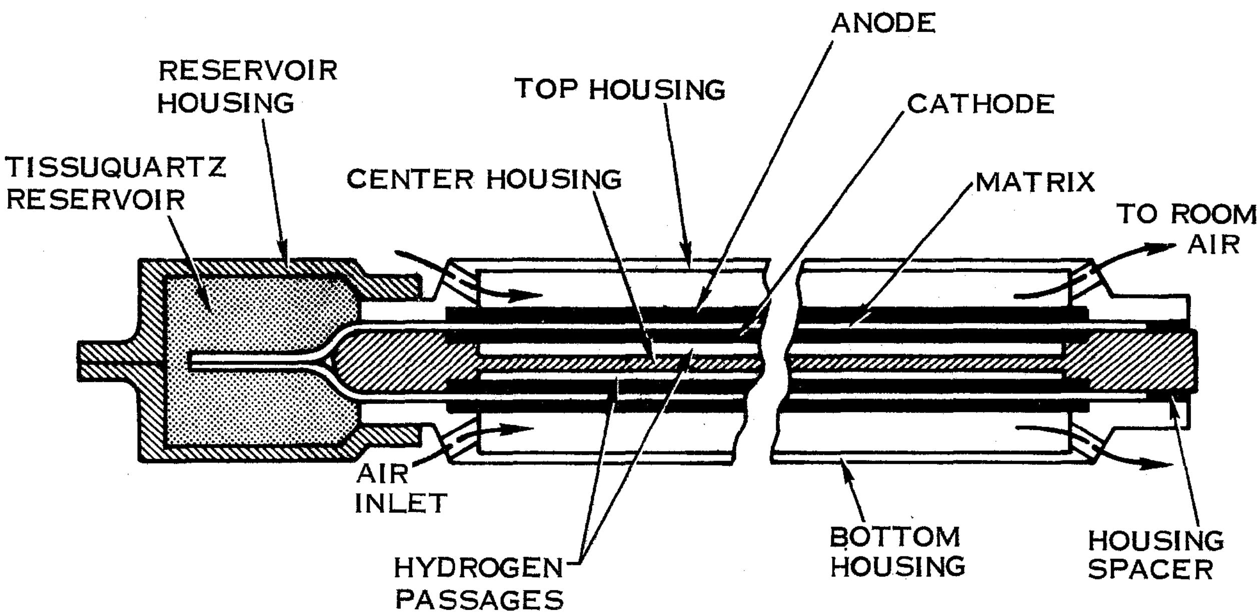


FIGURE 79. HDC CELL PAIR

Refurbishment of the HDC requires changing the bacteria and particulate filters only. For this study the expendable hydrogen and the oxygen supply is drawn from on-board tankage.

Concept Comparison

Figure 80 shows the evaluation summary for the two concepts.

- Weight - The large fixed weight of the HDC subsystem makes it outweigh the LiOH baseline system for all but the longest missions.
- Volume - The large fixed volume of the HDC makes it larger than LiOH for all but the seven-man 7.8×10^6 second (90 day) mission.
- Power - Both systems require the same amount of fan power to operate. The HDC system generates low voltage DC power, but this has not been considered an asset because use of this power is dubious.
- Refurbishment - Refurbishment is judged to be easier for the LiOH system. The spent cartridges are simply removed and refilled with a fresh supply of chemical reactants. The HDC operates with an electrolyte in a cell matrix and requires more time and skill to refurbish.
- Handling - The LiOH system requires replacement whenever the cartridge becomes depleted. For a four-man crew this means replacement every 12 hours. A seven-man crew would have to replace the LiOH cartridge approximately every seven hours. The HDC system requires refurbishment only for the bacteria and particulate filters.
- Vehicle Impact - The general impact of the HDC system is increased weight and volume. Because of the generation of water vapor by the HDC system, a larger condensing heat exchanger is required.

Item Ranking

Criteria	Baseline Shuttle Mission Duration Days	
	Seven	Thirtv
Weight Saving for Baseline Shuttle	No	No
Backup for Shuttle Baseline Concept	No	No
Cost Effective for Future Application	No	

CREW/PASSENGERS	4			7			COMMENTS
PARAMETER / MISSION LENGTH DAYS	7	30	90	7	30	90	(HDC Relative to LiOH)
WEIGHT	143/38 (315/84)	237/163 (522/359)	484/489 (1067/1078)	188/66.7 (414/147)	354/286 (780/631)	785/857 (1731/1889)	Heavier below 7.8 x 10^6 s (90 days)
VOLUME	0.51/0.09 (18/3)	0.68/0.38 (24/13)	1.1/1.1 (39/39)	0.55/0.67 (19/24)	0.85/0.67 (30/24)	1.6/2.0 (57/71)	Larger below about 7.8 x 10^6 s (90 days)
POWER	Same	Same	Same	Same	Same	Same	Same
PERFORMANCE	Same	Same	Same	Same	Same	Same	Same
REFURBISHMENT	More Difficult	More Difficult	More Difficult	More Difficult	More Difficult	More Difficult	HDC is a more complex system
HANDLING	Less Frequent	Less Frequent	Less Frequent	Less Frequent	Less Frequent	Less Frequent	Requires changing bacteria and particulate filters only
VEHICLE IMPACT	Yes	Yes	Yes	Yes	Yes	Yes	Increased weight, volume; condensing heat exchanger change

FIGURE 80. CONCEPT COMPARISON

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Replacing the Shuttle LiOH CO_2 control system with an HDC system is not advantageous. It would result in added weight and volume, as well as increased cost, and reconfiguration of the baseline ARS schematic and resizing of the relative humidity heat exchanger and other hardware. The baseline concept is entirely adequate and proven in actual flight. Hence, no backup is required.

For long duration missions where the HDC system weight and volume trade favorably, the continuous hydrogen vent becomes an undesirable mode of operation. The attractiveness of this system for long duration missions is restored only when the system is operated in a closed loop configuration using electrolysis and CO_2 reduction systems.

References

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3. Huddleston, J. C.; and Aylward, J. R.; Hydrogen Depolarized Carbon Dioxide Concentrator Performance Improvements and Cell Pair Structural Tests; Report SVHSER 6285; September, 1973.

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FLASH EVAPORATOR

Summary

The determination of the optimum heat rejection system for the Space Shuttle is a complex task involving both the type of heat sink and the system configuration (heat sink location). A study considering various system configurations and considering both the sublimator and the flash evaporator as heat sink has been conducted for Rockwell International. For the comparison made herein it was agreed between NASA and Hamilton Standard that only the Shuttle ARS water loop re-entry heat rejection requirement would be considered for a sublimator versus flash evaporator trade as the flash evaporator concept had already been baselined for radiator top-off in this Freon 21 loop.

The function of evaporative cooling in the ARS is to reject heat from the cooling water loop during ascent and re-entry, when the radiator is inoperative. The baseline concept for the ARS water loop is water vaporization in a porous plate sublimator. The flash evaporator is considered here as a potential alternate to the baseline ARS approach and for other potential Shuttle applications.

Replacing the water loop sublimator with a flash evaporator in the water loop is not cost effective for Shuttle. As a backup, the flash evaporator is not appropriate for the baseline mission (4 hours/flight) because sublimator life for this type of service was verified by test on the LM program. For longer duration missions the flash evaporator may have value as a backup since sublimator life for continuous service in a 30-day application has not been verified by test.

Requirements

The device is located in the primary and secondary cooling water loops, downstream of the Freon-water interchanger and upstream of the LCG heat exchanger as illustrated in Figure 81.

Requirements are:

- Heat Load, Watt (Btu/hr)

Minimum load abort mode	13, 179 (45,000)
Normal operation	23, 431 (80,000)

- Inlet Temperature, °C (°F),

Minimum load abort mode	49	(120)
Normal Operation	54	(129)

- Outlet Temperature, °C (°F) 7 (45)
- Cooling Water Flow Rate, Kg/s (lb/hr)

Minimum load abort mode	0.0756 (600)
Normal operation	0.1197 (950)

Baseline Concept - Sublimator

The baseline sublimator assembly includes two sublimators as shown schematically in figure 81. Both sublimators are required for normal operation, but a single unit will provide adequate emergency cooling. One sublimator has redundant regulators and shutoff valves while the other has a single set to provide fail operational/fail safe redundancy. Liquid interfaces are terminated with self-sealing disconnects to allow removal of the package without draining the coolant circuit.

The sublimators consist of a stack of several of the "sandwich" units shown in figure 82. Heat is transferred from the hot cooling water to the cold evaporant water, with the aid of finned surfaces. The evaporant exists as water in contact with an ice layer on the porous plates, the proportions of water and ice depending on the heat flux. Water rather than ice may contact the porous plate in some areas. As heat from the cooling water is absorbed, the water and ice vaporize through the porous plate into the reduced pressure environment surrounding the Orbiter. Feedwater rate to the sublimator is self-regulating with feedwater pressure maintained at about 34,000 N/m^2 (5 psia) by the regulator.

The weight breakdown for the sublimator assembly is as follows:

COMPONENT	KILOGRAMS (POUNDS)
Sublimators	18.9 (41.7) *
Steam Duct	2.7 (6.0)
Valves	2.8 (6.2)
Disconnects	3.3 (7.2)
Water Supply Line	1.4 (3.0)
TOTAL	29.1 (64.1)

* Two dual loop sublimators designed for emergency operation.

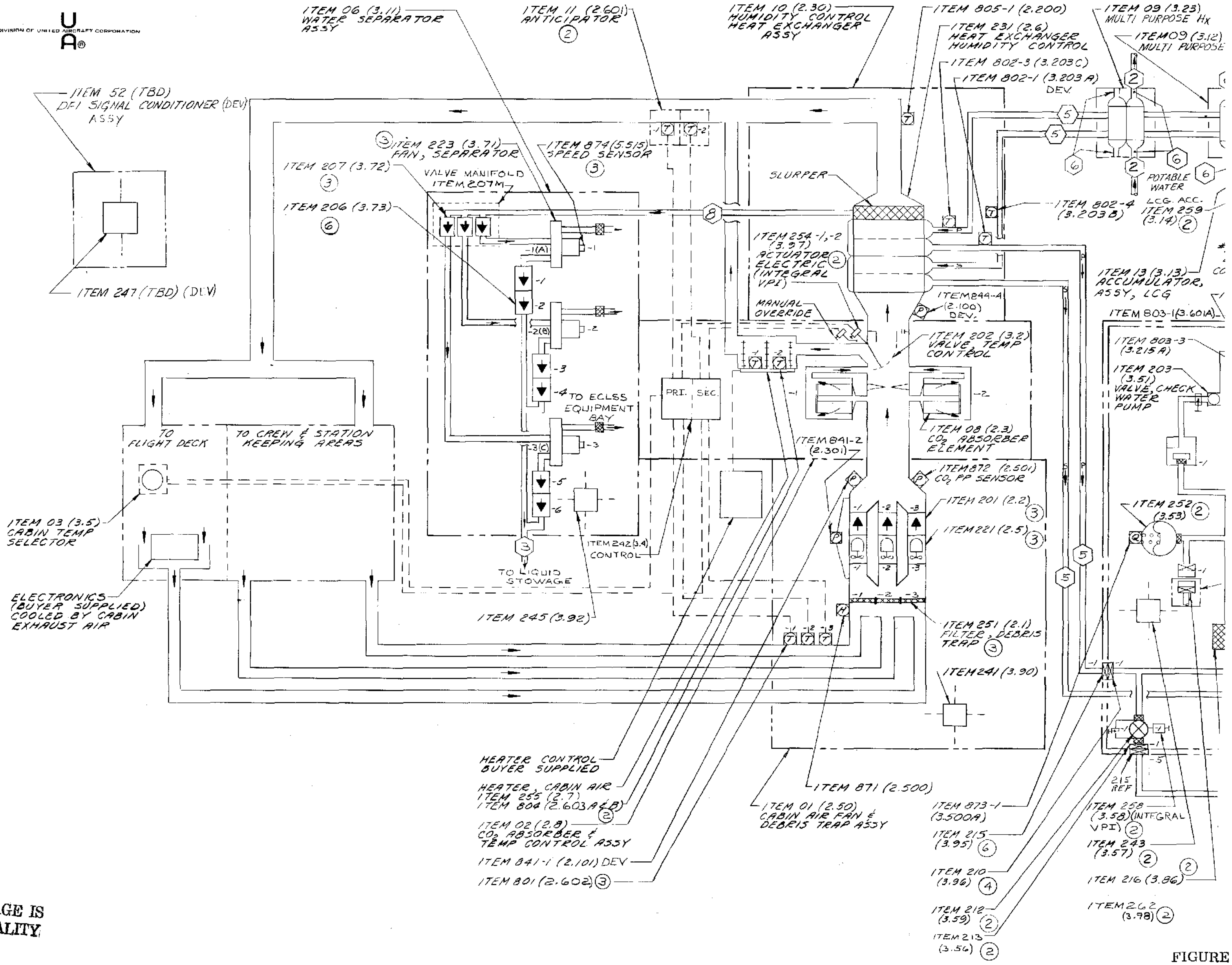

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FIGURE 81 ARS/FCL SCHEMATIC

FOLDOUT FRAME /

FOLDOUT FRAME 2

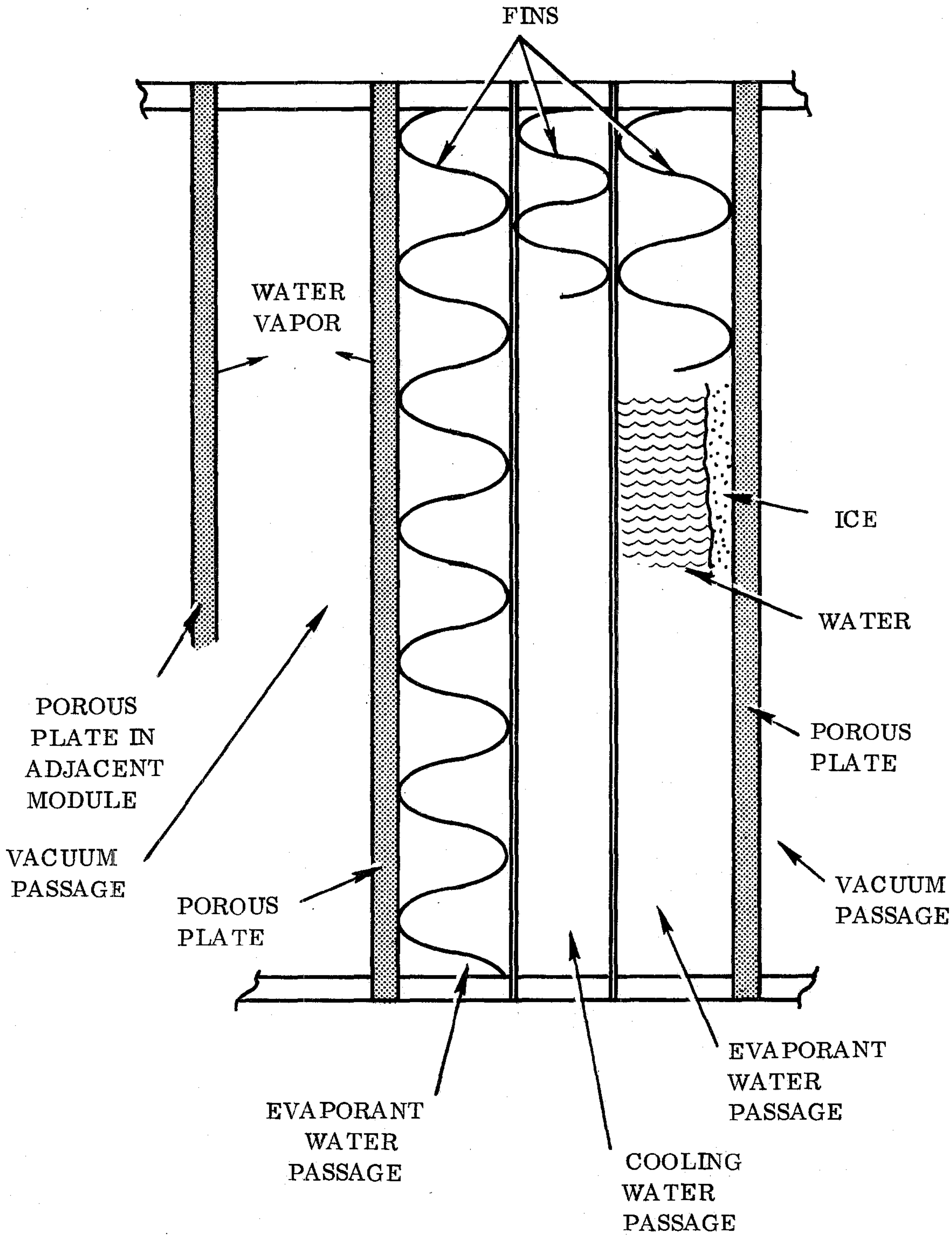

FIGURE 82. SUBLIMATOR MODULE

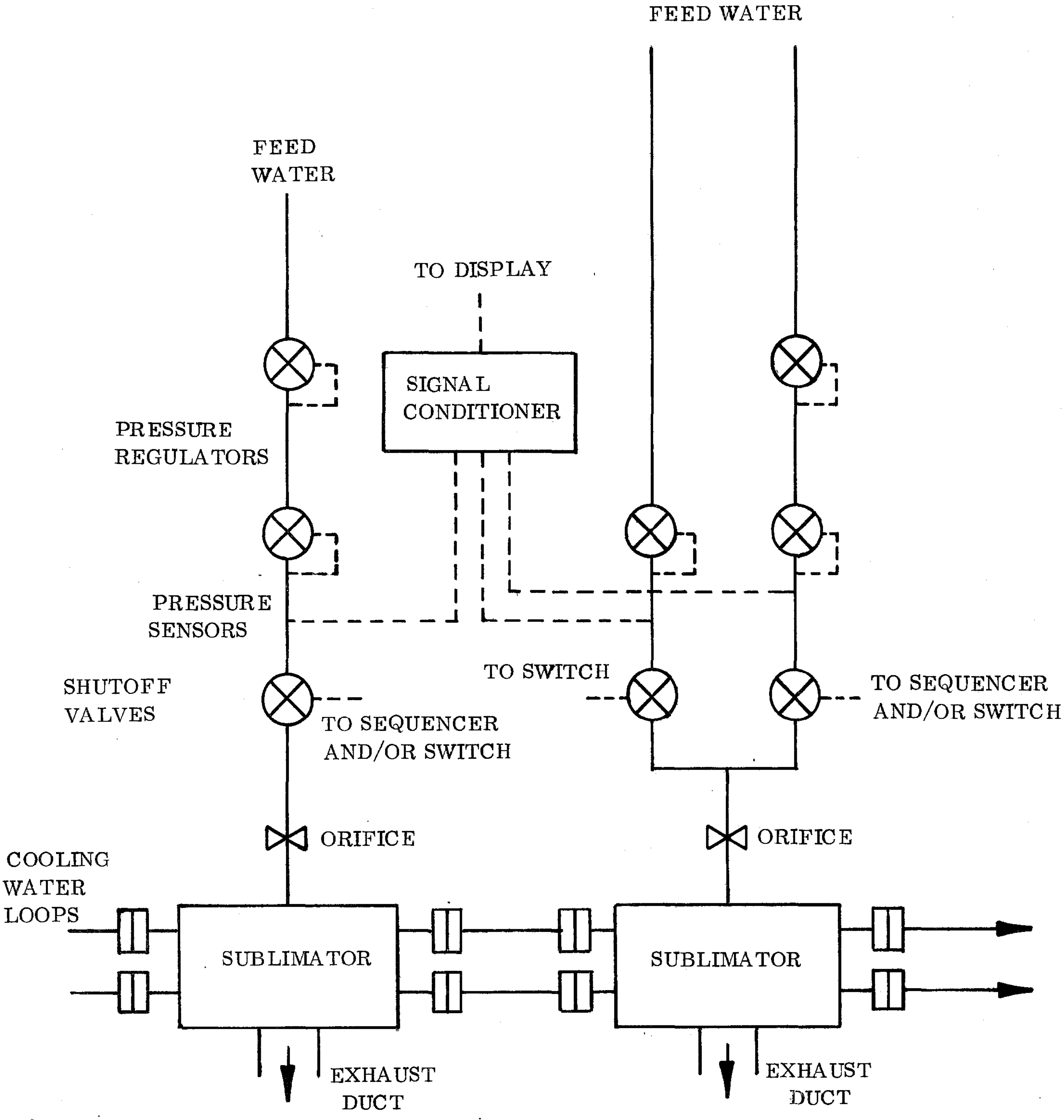

FIGURE 83. SUBLIMATOR ASSEMBLY SCHEMATIC

Alternate Concept - Flash Evaporator

The alternate concept for heat rejection is a flash evaporator. The evaporator is a three-fluid device, transferring heat from the primary or secondary Shuttle cooling water loop to the evaporant water. The unit, designed for the minimum load abort (emergency) mode, removes 13, 179 watts (45,000 Btu/hr) with a cooling water inlet temperature of 322°K (120°F), an outlet temperature of 280°K (45°F), and a flow rate of 0.0756 kg/s (600 lb/hr). It also meets the normal operating requirement of removing 23,431 watts (80,000 Btu/hr) from 0.1197 kg/s (950 lb/hr) of cooling water with an inlet temperature of 327°K (129°F) and an outlet temperature of 280°K (45°F).

A typical evaporator design is represented in figure 84, and valving arrangement for fail operational fail safe redundancy is shown in figure 85. Water is sprayed through a nozzle that breaks the liquid stream into droplets, forming a hollow cone spray. This spray impinges on the inside of a cylindrical heat transfer surface, which is finned in the water droplet impact zone to provide a more effective area for heat transfer. The chamber in which the water droplets evaporate is vented overboard. The spray nozzle contains a control valve which is cycled to maintain the desired cooling water outlet temperature of 280°K (45°F). The cooling water passages are machined into the cylindrical heat transfer surface by a standard screw thread machining process. Heat is transferred from the cooling water by conduction through the passage walls to the finned droplet impact zone, vaporizing the expendable water, which is then discharged through the overboard vent.

The weight breakdown for the flash evaporator assembly is presented in the following table. The weight is based on a single stainless steel evaporator. For fail safe redundancy, the evaporator is equipped with three spray nozzles and a separate controller (weight includes EMI suppression) is associated with each nozzle.

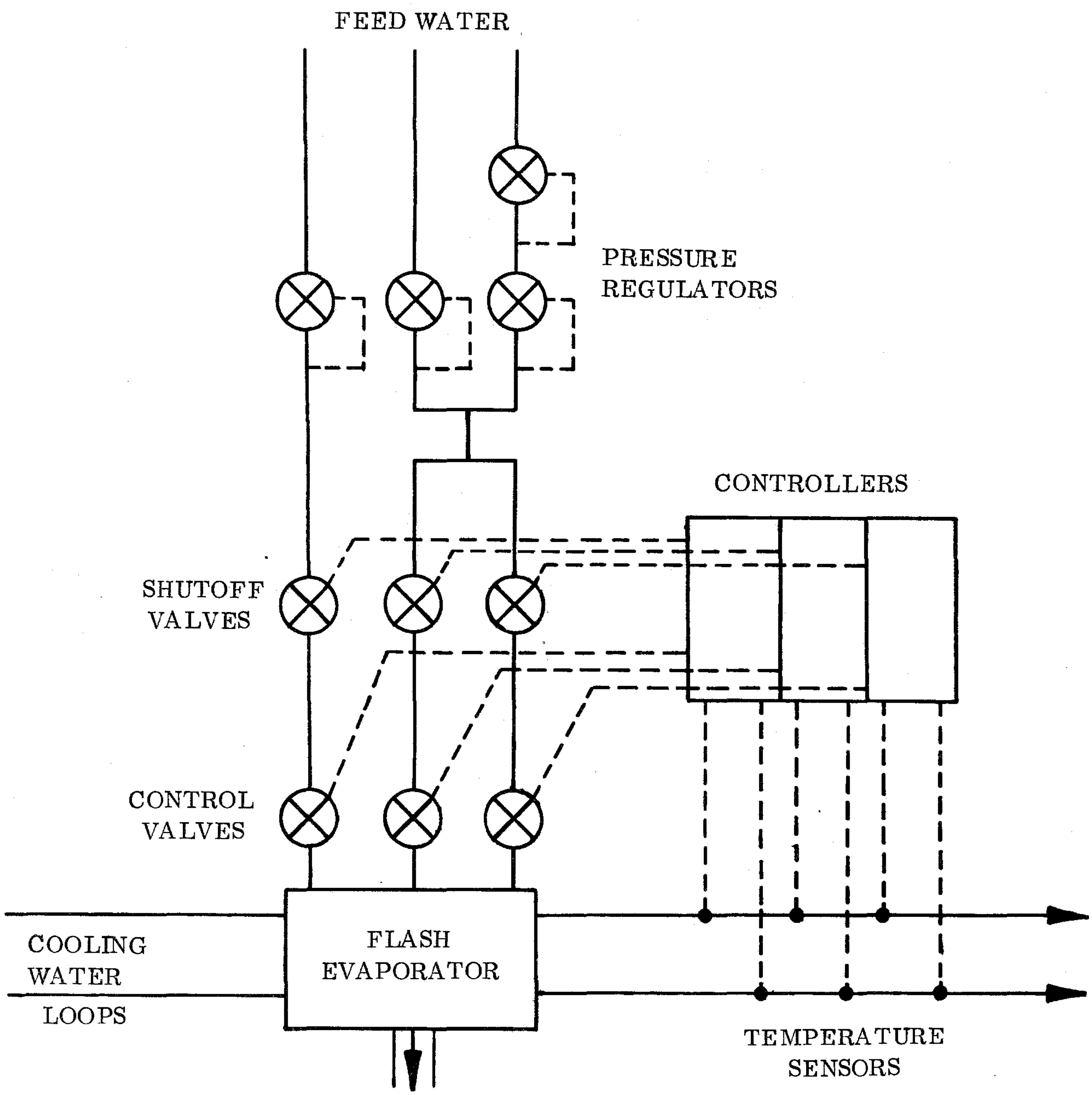

FIGURE 84. FLASH EVAPORATOR ASSEMBLY SCHEMATIC

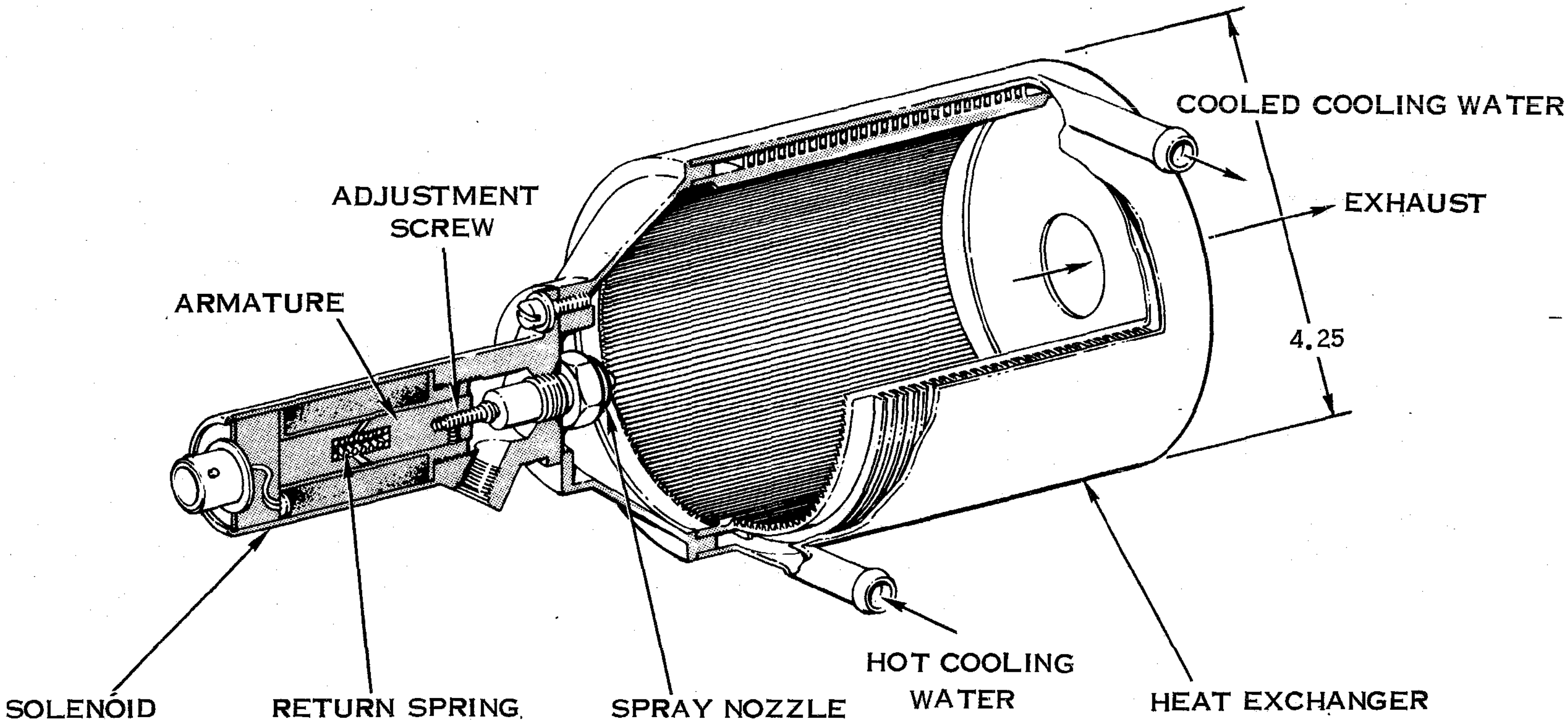

FIGURE 85. TWO-FLUID SPRAYING FLASH EVAPORATOR

C-3

COMPONENT	KILOGRAMS	(POUNDS)
Flash Evaporator	20.0	(44.0)
Controllers (3) *	7.7	(17.0)
Steam Duct	2.0	(4.5)
Valves	4.5	(10.0)
Wiring	0.5	(1.0)
Water Supply Line	1.4	(3.0)
TOTAL	36.1	(79.5)

* Three controllers packaged in a common housing

Concept Comparison

Figure 86 presents an evaluation summary for the two concepts. Data for both the Shuttle baseline sublimator and the flash evaporator assemblies are based on Hamilton Standard preliminary design calculations.

- Weight - Heat exchangers for the two concepts are about the same weight, but the added controller weight makes the flash evaporator assembly somewhat heavier.

- Volume - Volume of the flash evaporator assembly is about 25 percent greater.

- Power - Power penalty may be higher for the flash evaporator, due to the cooling water pressure drop through the helical coil tubing. In addition, if development testing should indicate that exhaust duct heating to prevent carryover freezing is needed, flash evaporator power would increase.

- Performance - With adequate development, performance of either concept is expected to be satisfactory, although only the sublimator is proven in actual space mission applications.

- Refurbishment - For the baseline application, no sublimator refurbishment will be required. In the event that gradual degradation should occur for longer duration missions a refurbishment technique exists which will fully restore performance of porous plates if degraded by clogging. The technique involves flushing with a sodium hydroxide solution. Refurbishment requirement/procedures for the flash evaporator have not been established.

- Handling - Neither concept requires normal crew attention.

- Vehicle Impact - Impact of replacing the Shuttle sublimator with a flash evaporator will require further investigation. Some increase in a dimensional envelope is expected. Power (discussed earlier) could be the biggest concern.

Item Ranking

Evaluation Of Flash Evaporator Versus Sublimator Baseline

CRITERIA	Shuttle Mission Duration Days	
	7	30
Weight Saving For Baseline Shuttle	No	No
Backup For Shuttle Baseline Concept	No	Yes
Cost Effective For Future Application	Yes	

Replacing the Orbiter water loop sublimator assembly with a flash evaporator in the same location is not advantageous. It would incur added weight and complexity as well as increased cost.

A backup is not required for the baseline Shuttle application because performance for service of this type was demonstrated on the LM program. For longer duration missions the flash evaporator may have value as a backup.

Parameters	Flash Evaporator	Sublimator	Comments (Flash Evaporator Relative to Sublimator)
Weight, kg (lb)	36.1 (79.5)	29.1 (64.1)	Heavier
Volume, m^3 (ft^3)	0.074 (2.6)	0.059 (2.12)	Larger
Power	TBD	TBD	May Be Higher
Performance	Adequate	Adequate	No Advantage
Refurbishment	None	Periodic Flushing	Some Advantage
Handling	None	None	No Advantage
Vehicle Impact	Minor	None	Possible Minor Envelope Problem if Sublimator Replaced by Flash Evaporator

FIGURE 86. ASSESSMENT DATA SHEET - FLASH EVAPORATOR VERSUS SUBLIMATOR

QUALITY ASSURANCE

In the conduct of this program, Quality Assurance participated in the design studies, tradeoff analysis, engineering assessments, and interface requirements definition. Quality Assurance effort was involved in preparation of the final report with the objective of identification and resolution of deficiencies that may impact the quality of future equipment.

RELIABILITY AND SYSTEM SAFETY

The studies presented in this report were performed in accordance with the applicable reliability and system safety requirement which were generally those of the Shuttle Orbiter.

For example, the regenerable CO_2 and humidity control system study complies with the current Shuttle Atmospheric Revitalization Subsystem requirements as adapted to the specific requirements of this subsystem. In summary, these requirements are:

- The system shall be designed to fail-safe
- No single failure shall result in a loss of cabin atmosphere
- The system shall be capable of operation in a fail-safe mode for 20 hours with a 7 man crew.
- During emergency conditions the partial pressure of CO_2 may rise to a maximum level of 2.0 k Pa (15 mm Hg); the partial pressure of CO_2 shall not be above 1.01 k Pa (7.6 mm Hg) for longer than 2 hours.

In a similar manner, reliability and system safety requirements were established and compiled with for the other subsystems studied. Throughout the program Reliability and Safety personnel participated on a consulting basis in tradeoff analysis and design studies. Reliability and Safety personnel also reviewed the final report and their comments were incorporated.