

LSI ER-319-24

NASA CR-
160317

EXTENDED DURATION ORBITER STUDY: CO₂ REMOVAL AND WATER RECOVERY

(NASA-CR-160317) EXTENDED DURATION ORBITER
STUDY: CO₂ REMOVAL AND WATER RECOVERY
Final Report (Life Systems, Inc., Cleveland,
Ohio.) 91 p "C A05/MF A01 CSCL 06K

N80-10800

63/54 7inclas
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FINAL REPORT

by

R. D. Marshall, G. S. Ellis, F. H. Schubert
and R. A. Wynveen

May, 1979

Prepared Under Contract NAS9-15218

by

Life Systems, Inc.
Cleveland, OH 44122

for

LYNDON B. JOHNSON SPACE CENTER
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FOREWORD

The work described herein was conducted by Life Systems, Inc. for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center in accordance with the requirements of Contract NAS9-15218. The objective of the program was to evaluate the Electrochemical Depolarized Carbon Dioxide Concentrator and the Vapor Compression Distillation Subsystem for Extended Duration Orbiter application. The period of performance for the program was April, 1978 to May, 1979.

The overall Program Manager for the contract was F. H. Schubert with the Extended Duration Orbiter study activities directed by R. D. Marshall. Technical support for the Extended Duration Orbiter study was provided by G. S. Ellis and Dr. R. A. Wynveen.

The contract Technical Monitor was Mr. Nick Lance, Jr., Crew Systems Division, Lyndon B. Johnson Space Center, Houston, TX 77058.

All measurements and calculations contained within this report are expressed in SI (metric) units; conventional units are given in parenthesis.

The authors wish to acknowledge the important technical contributions and program guidance offered by the personnel of Crew Systems Division, NASA Johnson Space Center, in particular N. Lance, F. H. Samonski, D. W. Morris, Jr. and W. F. Reveley and the personnel of the Orbiter Environmental Control/Life Support Systems Group, Advanced Shuttle Projects Department of Rockwell International, in particular J. W. Gibb, O. T. Stoll, G. E. Laubach, A. L. Jones and D. C. Gore.

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LIST OF ACRONYMS

ACIDD	Advanced Combined Iodine Dispenser/Detector
ARS	Air Revitalization Subsystem
CCA	Coolant Control Assembly
C/M I	Control/Monitor Instrumentation
DAS	Data Acquisition System
EC/LSS	Environmental Control/Life Support Subsystem
EDC	Electrochemical Depolarized CO ₂ Concentrator
EDCM	Electrochemical Depolarized CO ₂ Concentrator Module
EDO	Extended Duration Orbiter
FCA	Fluid Control Assembly
PEP	Power Extension Package
RLSE	Regenerative Life Support Evaluation
SA/BA	Solar Array/Battery
SA/FC	Solar Array/Fuel Cell
SSP	Space Station Prototype
STS	Space Transportation System
VCDS	Vapor Compression Distillation Subsystem
WCL	Water Coolant Loop
WMS	Water Management System
WQM	Water Quality Monitor
WRS	Water Recovery Subsystem
WVE	Water Vapor Electrolysis

SUMMARY

The National Aeronautics and Space Administration is presently evaluating methods to enhance the space Shuttle Orbiter mission capabilities. Significant savings can be attained by retrofitting the Orbiter with a regenerable Carbon Dioxide Removal Subsystem and a Water Recovery System. The Electrochemical Depolarized Carbon Dioxide Concentrator for carbon dioxide removal and the Vapor Compression Distillation Subsystem for water recovery were evaluated for Extended Duration Orbiter missions.

The Electrochemical Depolarized Carbon Dioxide Concentrator is an advanced carbon dioxide removal concept that can offer significant weight savings through reduced expendables for projected enhanced capability Orbiter missions. The Electrochemical Depolarized Carbon Dioxide Concentrator can be integrated with existing Shuttle resources or, as mission profiles require, combined with Water Vapor Electrolysis for oxygen regeneration to further reduce mission expendables. The two Electrochemical Depolarized Carbon Dioxide Concentrator Subsystems were evaluated for (a) the baseline Orbiter when expanded to accommodate a crew of seven (Mission Option One), (b) an Extended Duration Orbiter with a power extension package to reduce fuel cell expendables (Mission Option Two) and (c) an Extended Duration Orbiter with a full capability power module to eliminate fuel cell expendables (Mission Option Three). Weight savings attainable using the electrochemical carbon dioxide removal concept versus baseline lithium hydroxide are 59 kg (130 lb), 218 kg (480 lb) and 363 kg (800 lb), respectively, for the three mission options evaluated.

The Electrochemical Depolarized Carbon Dioxide Concentrator was also compared to the solid amine regenerable carbon dioxide removal concept for the three enhanced Orbiter mission options evaluated. The electrochemical technique was selected for all three missions since it had 5 to 55% lower weight, 50% lower power and was the lowest weight carbon dioxide removal concept for each mission.

The Vapor Compression Distillation Subsystem can reclaim wastewater for use in the Shuttle flash evaporators for supplementary heat rejection, or, when combined with additional Water Management System components, can produce potable water as will be required for missions when fuel cells are not used for power generation. Water recovery is not required for Mission Option One since sufficient water is generated by the fuel cells. The Vapor Compression Distillation Subsystem was evaluated for Mission Options Two and Three only. Weight savings of 696 kg (1,533 lb) and 1,092 kg (2,405 lb), respectively, are attainable using the Vapor Compression Distillation Subsystem for water recovery versus on-board water storage.

Combined carbon dioxide removal and water recovery was evaluated to determine the affect on regenerable carbon dioxide removal subsystem selection. Mission Option One was not considered since water recovery is not required. For Mission Option Two, two levels of water recovery for supplemental heat rejection were considered: condensate recovery only and total water recovery (condensate, urine and wash water). The Electrochemical Depolarized Carbon Dioxide Concentrator Subsystem had weight savings of 61 kg (134 lb) and 64 kg (141 lb), respectively, over the solid amine and Electrochemical Depolarized Carbon Dioxide Concentrator/Water Vapor Electrolysis Subsystems. For Mission Option

Three total water recovery was considered to meet potable water requirements. The weight savings obtained using the Electrochemical Depolarized Carbon Dioxide Concentrator Subsystem versus the solid amine was 331 kg (729 lb). The combined functions of carbon dioxide removal and water recovery favored the Electrochemical Depolarized Carbon Dioxide Concentrator concept since it generates additional water, in the form of condensate, as part of the carbon dioxide removal process.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) is presently evaluating methods to extend the Space Shuttle Orbiter Mission Duration. (1-8) Two changes in the existing orbiter Environmental Control and Life Support System (EC/LSS) are desirable. The first is to replace the existing lithium hydroxide (LiOH) cartridges with a Regenerable Carbon Dioxide (CO₂) Removal Subsystem and the second is to reclaim waste water (urine, wash water and condensate) for supplementary heat rejection and eventually potable water requirements. To perform these functions, two subsystems have evolved through NASA sponsorship over the past ten years: the Electrochemical Depolarized CO₂ Concentrator (EDC) for CO₂ removal and the Vapor Compression Distillation Subsystem (VCDS) for wastewater recovery.

The EDC is being developed by NASA through its Contractor, Life Systems, Inc. (LSI). (7-12) The EDC can be integrated with existing Shuttle resources or to further reduce expendables, combined with Water Vapor Electrolysis (WVE). (13-15) The VCDS is being developed by NASA through two contractors: Lockheed Missiles and Space Corporation and LSI. The VCDS can be used to generate water for supplementary heat rejection or combined with an Advanced Combined Iodine Dispenser/Detector (ACIDD) (16) and a Water Quality Monitor (WQM) (17) to generate potable water. The EDC, the EDC/WVE and the VCDS have been evaluated for Shuttle application by first sizing representative subsystems and then comparing them to baseline Shuttle CO₂ removal and water/wastewater storage concepts. The CO₂ removal subsystems were also compared to an alternate regenerable CO₂ removal concept, solid amine, for projected Extended Duration Orbiter (EDO) mission options. This report presents the EDC, EDC/WVE and VCDS flight subsystems and the results of the evaluation and comparison.

Background

Extensive NASA planning in recent years has been directed towards a program that maximizes the effective utilization of the Space Transportation System (STS) and sets forth a growth plan for new space systems and capabilities. Increased energy requirements will be satisfied by a solar power module and various configurations are presently under consideration. The initial power module concept will begin with a Power Extension Package (PEP) which utilizes solar cells during lightside operation and the Shuttle fuel cells during darkside operation. The PEP will then be replaced by a full capability power module using solar cells and batteries thereby eliminating the need for oxygen (O₂) and hydrogen (H₂) expendables for on-orbit power generation. Several NASA supported studies are currently being conducted to further define these power system configurations and power level capabilities. (1-3)

(1) References cited listed at end of report.

In parallel with the evolutionary growth of the power module concept, the EC/LSS design approach must also evolve from the orbiter baseline expendable design to intermediate designs which require reduced expendables through the use of selected regenerative techniques and finally to a fully regenerative system installed in manned habitability modules. As with the power module, these regenerative life support systems should also be evolutionary in nature resulting in an orderly enhancement of Orbiter life support capabilities.

Electrochemical CO₂ Removal

The EDC concept for CO₂ removal has evolved over the past 11 years. During this time the concept has passed from single cell operation through the fabrication and testing of several multi-person, self-contained subsystems for spacecraft application. The success of the completed development programs resulted in selection of the EDC concept for the Air Revitalization Subsystem (ARS) portion of the Regenerative Life Support Evaluation (RLSE).⁽¹¹⁾

Major accomplishments highlighting the overall EDC development efforts were the design, fabrication and testing of a one-person EDC (1970),⁽⁷⁾ two six-person EDC's (1973, 1974)^(8,9) with the second one delivered for testing as part of the Space Station Prototype (SSP) program, a three-person preprototype for the RLSE,⁽¹²⁾ a one-person EDC/WVE⁽¹⁴⁾ and a three-person EDC/WVE for the RLSE.⁽¹⁵⁾ As a result, in excess of 1.5 million cell operating hours have been accumulated with LSI-developed EDC hardware.

The major advantages of the EDC concept for CO₂ removal are:

- a. significant weight savings over LiOH,
- b. flexible hardware that can easily increase or decrease capacity by adding or removing cells or changing operating conditions,
- c. a process that generates needed water as a product,
- d. a CO₂ removal process that can expand to remove water vapor and regenerate O₂ when combined with a WVE, and
- e. NASA development costs are reduced since it has next step application - the EDC is applicable⁽¹⁸⁾ to Intermediate Life Support Systems and Habitability Modules⁽¹⁹⁾ and has been previously selected for Space Station application.

Vapor Compression Distillation for Water Recovery

The VCDS has been selected as the preferred^(19,20) approach to wastewater reclamation onboard long-term manned spacecraft. The VCDS concept has been in existence since 1958 and efforts⁽²¹⁻²⁶⁾ to adapt the concept to manned spacecraft application began in 1961. The concept has evolved from laboratory testing to the construction of operating preprototypes. The first attempt to fully automate the VCDS was made during the development of the SSP VCDS. The concept was subsequently selected for demonstration as part of the RLSE efforts and two, three-person preprototype VCDS's were developed for RLSE.

The VCDS primarily recovers water from urine and wash water. Condensate can also be processed through the VCDS but is typically treated by multifiltration. The VCDS produces water acceptable for supplementary heat rejection and, with the addition of an ACIDD and WQM, produces potable water. The capacity of the

baseline Shuttle Orbiter water and wastewater storage tanks is sufficient to accommodate baseline mission durations of up to seven days. The integration of the VCDS into the Shuttle Orbiter, therefore, begins with the addition of a power module to increase mission duration beyond seven days.

The baseline Shuttle Orbiter, when enhanced by the PEP, uses fuel cells and therefore will not require an additional potable water source. Initially, when used with the PEP, the VCDS will recover water for supplementary heat rejection. Potable water is generated by the fuel cell operation. When the PEP is replaced by a full capability power module which does not use fuel cells, the VCDS will recover water to meet potable water requirements.

Study Method

The methodology used for the EDO study is shown in Figure 1. The specific study objectives were to:

1. Design the EDC and EDC/WVE Subsystems for Shuttle Orbiter integration.
2. Design a VCDS for Shuttle Orbiter integration.
3. Evaluate/compare designs to alternate EC/LSS subsystem configurations.
4. Make recommendations for EDO EC/LSS.

Based on NASA inputs and literature, ground rules were established and initial designs completed. The integration into the Shuttle Orbiter was then evaluated and review meetings held with NASA/Johnson Space Center (JSC) and Rockwell International (RI) personnel. Comments were received and the ground rules, initial designs and vehicle integration assumptions upgraded. Subsystem conceptual designs were then generated and quantified for EDO mission options. The subsystem designs were then compared with baseline and alternate CO₂ removal and baseline water storage concepts, and recommendations made for future EDO EC/LSS.

Two basic EDC subsystem designs were evaluated for EDO application. The first was a liquid cooled EDC which uses a small amount of H₂ from the existing shuttle cryogenic H₂ supply to perform the CO₂ removal function. The second EDC concept uses a WVE to generate the H₂ for the EDC process to eliminate the need for using spacecraft cryogen resources. These two concepts were then compared to baseline LiOH and the solid amine regenerable CO₂ removal concept.

The VCDS concept for water recovery was evaluated and compared to water storage. The VCDS has previously been compared to and selected over other regenerable water recovery techniques.⁽²⁰⁾ The primary objective of the VCDS evaluation, was to determine at what point in the overall Enhanced Shuttle Orbiter Development Program, a Water Recovery Subsystem would prove beneficial or necessary to enhanced shuttle operations.

Ground Rules

The ground rules used for this study were:

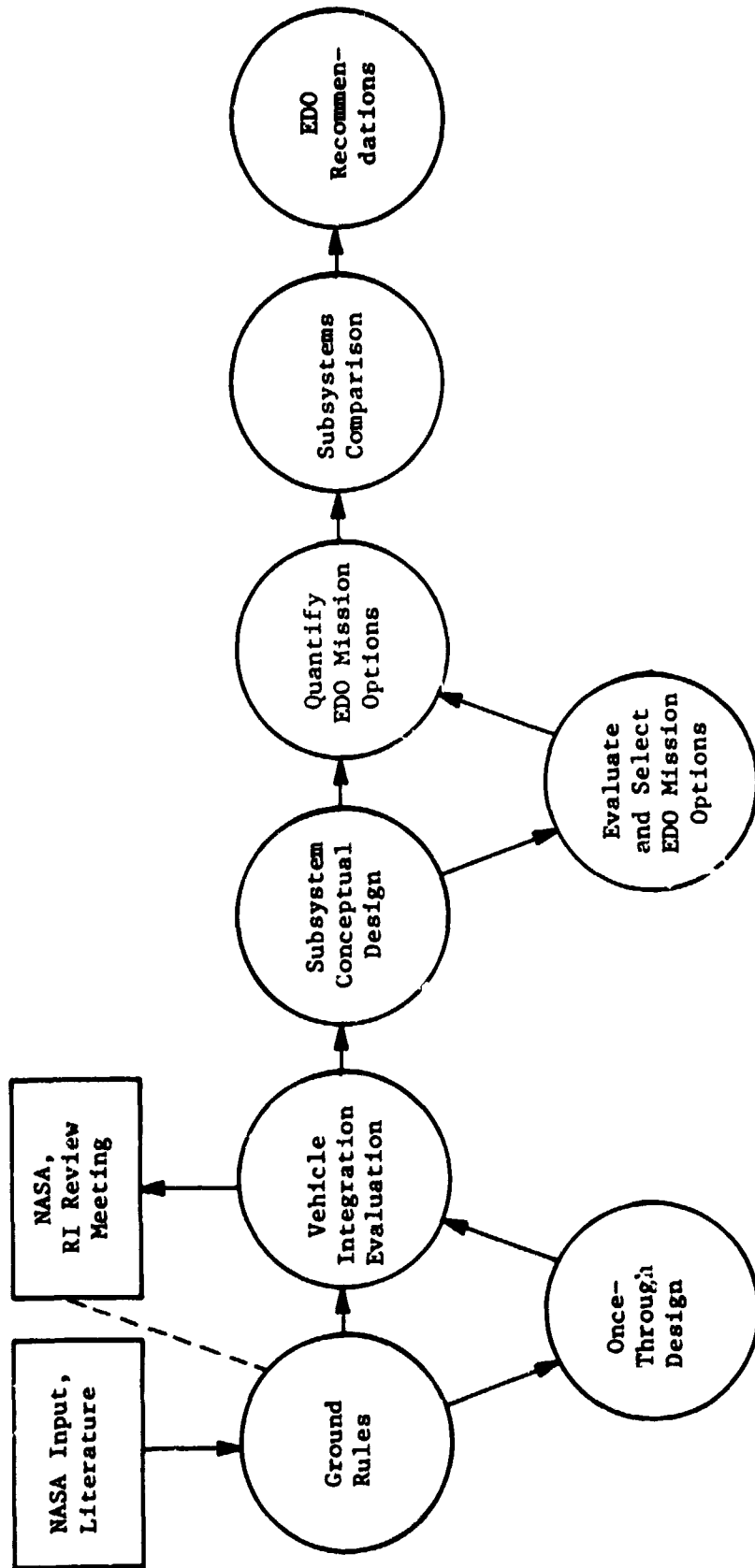


FIGURE 1 EDO STUDY METHOD

1. The EDC and VCDS were designed to meet the EDO design data presented in Table 1. (5,27,28)
2. The subsystems will interface with the existing Shuttle Orbiter EC/LSS with minimum changes to baseline Shuttle equipment.
3. Overboard venting is allowable but a scheduled no-dump period of up to 24 hours may be required depending on specific mission objectives. All concepts studies would require an equal number of LiOH canisters to meet the no-dump requirement. Since the specific no-dump period duration requirements have not been defined, no penalty was assessed to the CO₂ removal concepts for the comparative purposes of this study.
4. The subsystems are designed to meet fail-safe criteria which is defined as a suitable backup or redundancy to provide 20 hours of EC/LSS contingency time. This contingency time is sufficient for a CO₂ removal or water recovery subsystem failure. To achieve the required vehicle 96-hour contingency time, the CO₂ removal and water recovery subsystems will be designed to operate during a vehicle emergency and rescue operation.
5. In-flight maintenance to replace expended items, limited life items and failed components was considered permissible to enhance overall reliability. The subsystems were designed so that maintainable items are accessible, maintenance results in reduced system penalties and the downtime does not impact system performance significantly.
6. The baseline crew size is seven persons with a ten-person rescue mission requirement. A crew size of four persons with a seven-person rescue mission requirement was also considered.
7. Cabin CO₂ partial pressure (pCO₂) will be maintained below 1,013 Pa (7.6 mm Hg) with a daily average of 667 Pa (5.0 mm Hg).
8. Urine and waste water will be processed by VCDS, condensate will generally not be distilled. No fecal water will be recovered.
9. All EC/LSS subsystems will be designed for an O₂/nitrogen (N₂) atmosphere at 101 Pa (14.7 psia) and will have the capability of operation at 55 Pa (8.0 psia) without damage.
10. All subsystems considered should be capable of certification for actual flight use by early 1983.

Mission Options

A separate evaluation of EDO mission options was conducted in parallel to the design evaluations. Three enhanced Shuttle mission options were selected and are presented in Table 2. The baseline Shuttle mission characteristics are also given for reference. The primary difference between the mission options is the power system which determines the expendables penalty for power usage and the amount of water available on-board the Orbiter.

TABLE 1 EXTENDED DURATION ORBITER DESIGN DATA

Crew Size	4 or 7 ^(a)
Mission Duration, d	7 to 120
Metabolic Consumption, kg/person-d (lb/person-d)	
Oxygen	0.80 (1.76)
Water, Food/Drink	2.59 (5.70)
Wash Water	1.16 (2.55)
Metabolic Production, kg/person-d (lb/person-d)	
Carbon Dioxide	0.96 (2.11)
Condensate	1.58 (3.49)
Urine	1.56 (3.44) ^(b)
Feces	0.12 (0.27)
Orbiter Leakage, kg/d (lb/d)	
Cabin	2.72 (6.0)
Air Lock	0.45 (1.0)
Tunnel Adapter	0.45 (1.0)
Waste Management	0.82 (1.8)
EVA Requirements, ^(c) kg/d (lb/d)	
Oxygen	0.91 (2.0)
Water	9.08 (20.0)
Power Source, kW	
Fuel Cells	21
Power Module	25 to 35 ^(d)

(a) Short-term operation at a 10-person level required.

(b) Includes 1.50 kg/d (3.31 lb/d) water and 0.06 kg/d (0.13 lb/d) solids.

(c) Assumes 12 h EVA per day (2 persons for 6 h).

(d) Depending on Power Module configuration.

TABLE 2 ENHANCED ORBITER MISSION OPTIONS

Mission Option	Baseline	1	2	3
Crew Size	4	7	4 or 7	4 or 7
Maximum Duration, d	7	7	19	≤120
Cryogen Kits	7	7	7	2 to 7
Power Module	None	None	PEP	Full Capability
Power System	Fuel Cells	Fuel Cells	Solar Array/ Fuel Cells	Solar Array/ Batteries
Power Available, kW	21	21	29	25 to 35
Thermal Control System	Orbiter Radiators ^(a)	Orbiter Radiators (a)	Orbiter Radiators (a)	Power Module Radiators
Heat Rejection Available, kW (Btu/h)	28 (96,000)	28 (96,000)	28 (96,000)	25 to 35 ^(b) (85,250 to 119,350)

(a) Flash evaporators supplement.

(b) In addition to Shuttle radiator capability.

For Mission Option One, the baseline Shuttle mission is simply expanded to a crew size of seven. Fuel cells are still used for power and heat rejection is attained using the Shuttle radiators and flash evaporators. Baseline mission duration is seven days.

Mission Option Two is for crew sizes of four or seven and uses a PEP to increase the power capability of the Orbiter. The PEP uses a solar array/fuel cell (SA/FC) power system with the fuel cells operated during darkside operation and only idled during solar cell operation. Cryogen expendables for power generation are greatly reduced using the solar arrays. Heat rejection is still provided by the Orbiter radiators and flash evaporators. Baseline mission duration at the 29 kW power level is 19 days. ⁽²⁾

Mission Option Three is for crew sizes of four or seven and uses a full capability power module to further increase Orbiter power capability. The power module uses a solar array/battery (SA/BA) power system which completely eliminates expendables for on-orbit power generation. The fuel cells are shutdown and are not idled on-orbit as is the case with the PEP. Mission duration is limited only by cryogen boil-off since fuel cells are used for power generation on descent from orbit. Present estimates indicate that with improved insulation, cryogen can be stored for up to 120 days. ⁽⁴⁾ The power module also has its own heat rejection radiators which should eliminate the need for on-orbit flash evaporator operation.

The EDC and EDC/WVE subsystem designs generated as part of this study were evaluated for application to all three missions. The VCDS was evaluated for EDO with the PEP where the VCDS water would only be used for supplementary heat rejection and with the full capability power module for potable water recovery.

Program Organization

The study program was organized into three tasks:

1. Carbon Dioxide Removal Subsystems evaluation for EDO.
2. Water Recovery Subsystems evaluation for EDO.
3. Combined CO₂ removal and water recovery.

The following sections summarize the program results and the conclusions and recommendations made.

CARBON DIOXIDE REMOVAL SUBSYSTEMS

The primary function of the CO₂ Removal Subsystem is to control cabin pCO₂ to an average partial pressure of 667 Pa (5.0 mm Hg). The EDC and the EDC/WVE were evaluated for Shuttle application. Table 3 shows the specific CO₂ Removal Subsystem design specifications used. The Shuttle air humidity specifications and actual projected humidity conditions ⁽²⁷⁾ for possible EDC subsystem air interfaces are presented in Figures 2 and 3. The following sections describe the EDC and EDC/WVE design. The two EDC subsystems are then compared to alternate CO₂ removal concepts for the three EDO mission options selected.

TABLE 3 CO₂ REMOVAL SUBSYSTEM DESIGN SPECIFICATIONS

Crew Size	4 or 7
CO ₂ Removal Rate, kg/h (lb/h)	0.279 (0.615)
Cabin pCO ₂ , Pa (mm Hg)	
Daily Average	667 (5.0)
Maximum	1,013 (7.6)
Cabin pO ₂ , kPa (psia)	22.1 (3.2)
Cabin Temperature, K (F)	291 to 300 (65 to 80)
Cabin Dew Point, K (F)	277 to 289 (39 to 61)
Cabin Pressure, kPa (psia)	101 (14.7)
Process Air Humidity Range	See Figures 2 and 3
Liquid Coolant Temperature, K (F)	275 to 297 (35 to 71)
H ₂ Supply Flow Rate, kg/h (lb/h)	0.018 (0.040)
H ₂ Relative Humidity, %	0 to 5
Purge Gas	N ₂
Purge Gas Pressure, kPa (psia)	173 or 1,484 (25 or 215)
Electrical Power, VAC ^(a) , VDC	115/200 27.5 to 32.5
Gravity	0 to 1
Noise Criteria, db	55

(a) 400 Hz, 3Ø

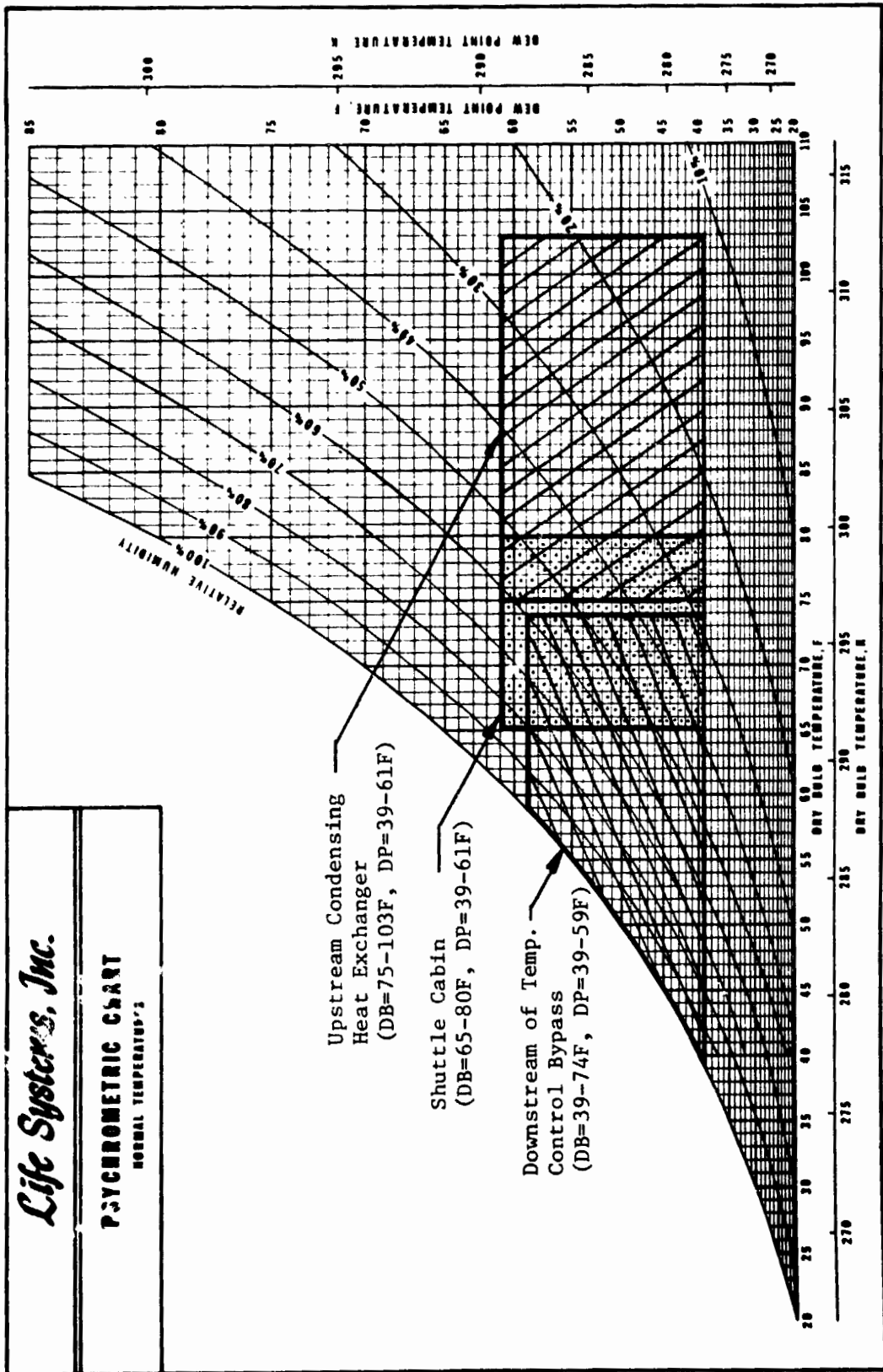


FIGURE 2 SHUTTLE AIR HUMIDITY SPECIFICATIONS

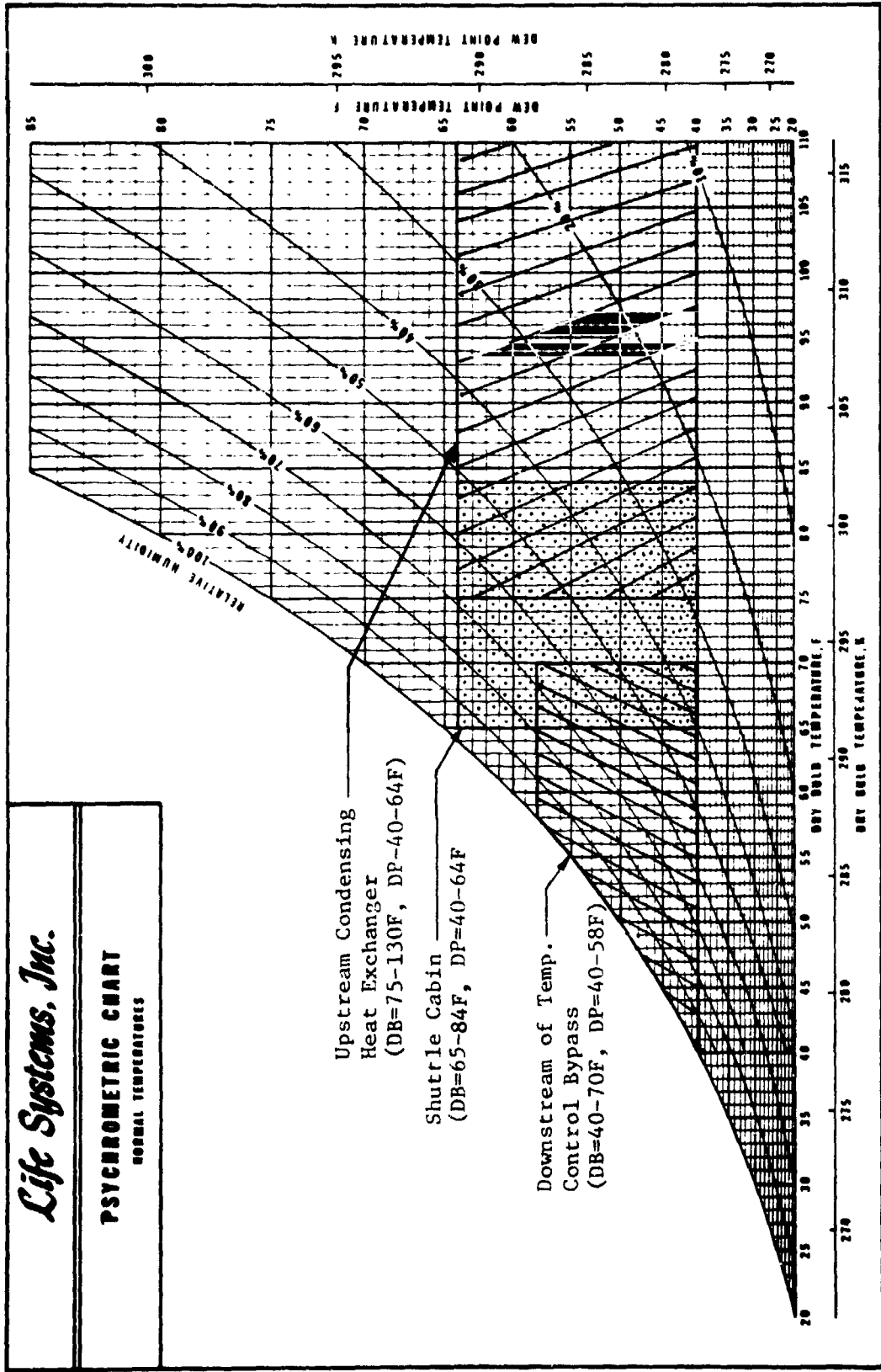


FIGURE 3 PROJECTED SHUTTLE AIR HUMIDITY RANGES

EDC Flight Concept

The EDC Subsystem consists of an electrochemical module which performs the actual CO₂ removal process, ducting and plumbing to manifold the process fluids streams into and out of the EDC Module (EDCM) and the peripheral mechanical and electrical components required to control and monitor subsystem performance. The EDC concept utilizes the fuel cell reaction between H₂ and O₂ in a base electrolyte to remove CO₂ from an air stream and vent it overboard. The electrochemical CO₂ removal process takes place in a series of cells stacked to form a module. Carbon dioxide is removed from a flowing air stream as it passes through the cathode compartments of the EDC cells. The CO₂ that is removed from the air stream is concentrated into a H₂ stream which is fed to the anode compartments of the cells. The H₂/CO₂ effluent from the anode compartments of the EDCM is vented overboard. Electrical energy, water and waste heat are byproducts of the CO₂ removal process the same as energy, water and waste heat are produced by fuel cells.

Subsystem Description

Figure 4 is the Shuttle EDC schematic showing the subsystem components and assemblies. The detailed EDC schematic showing subcomponents required to perform the control and monitoring functions is presented in Figure 5.

Operation. Process air is bypassed from the Orbiter ARS ducting through the EDC Subsystem. Process air flows through a filter/isolation valve, an RH sensor and an air/liquid heat exchanger prior to reaching the cathode compartments of the EDCM cells. Process air, depleted in CO₂, is returned to the ARS through a relative humidity (RH) sensor and a filter/isolation valve. The RH sensors are used to control EDCM temperature as a function of process air relative humidity conditions. Liquid coolant is used to remove waste heat generated and control EDCM temperature. The liquid coolant loop temperature is adjusted using the diverter valve contained within the Coolant Control Assembly (CCA) which controls the amount of coolant flowing through and bypassing the liquid/liquid heat exchanger. An air/liquid heat exchanger is used upstream of the EDCM to cool the process air thereby matching the process air humidity conditions with the optimum conditions for EDCM operation. The heat removed by the air/liquid heat exchanger lessens the requirement for heat removal by the Orbiter condensing heat exchanger. The liquid/liquid heat exchanger interfaces directly with the Orbiter Water Coolant Loop (WCL) downstream of the cabin temperature control heat exchanger.

The H₂ required for the EDCM is supplied to the EDCM through the Fluids Control Assembly (FCA). Flow and pressure control/monitoring are provided by the FCA. Shutoff valves isolate the EDCM from the cryogenic H₂ supply and the H₂/CO₂ overboard vent. Nitrogen is used to purge the H₂-carrying lines of H₂ following a shutdown, and of air prior to startup (assuming maintenance was performed). A triple redundant combustible gas sensor is mounted to the subsystem.

Process control is provided by the Control/Monitor Instrumentation (C/M I). The C/M I interfaces with the subsystem sensors and actuators, provides automatic control of the CO₂ removal process, provides mode transition sequences for automatic startup and shutdown, and monitors sensor levels to initiate an

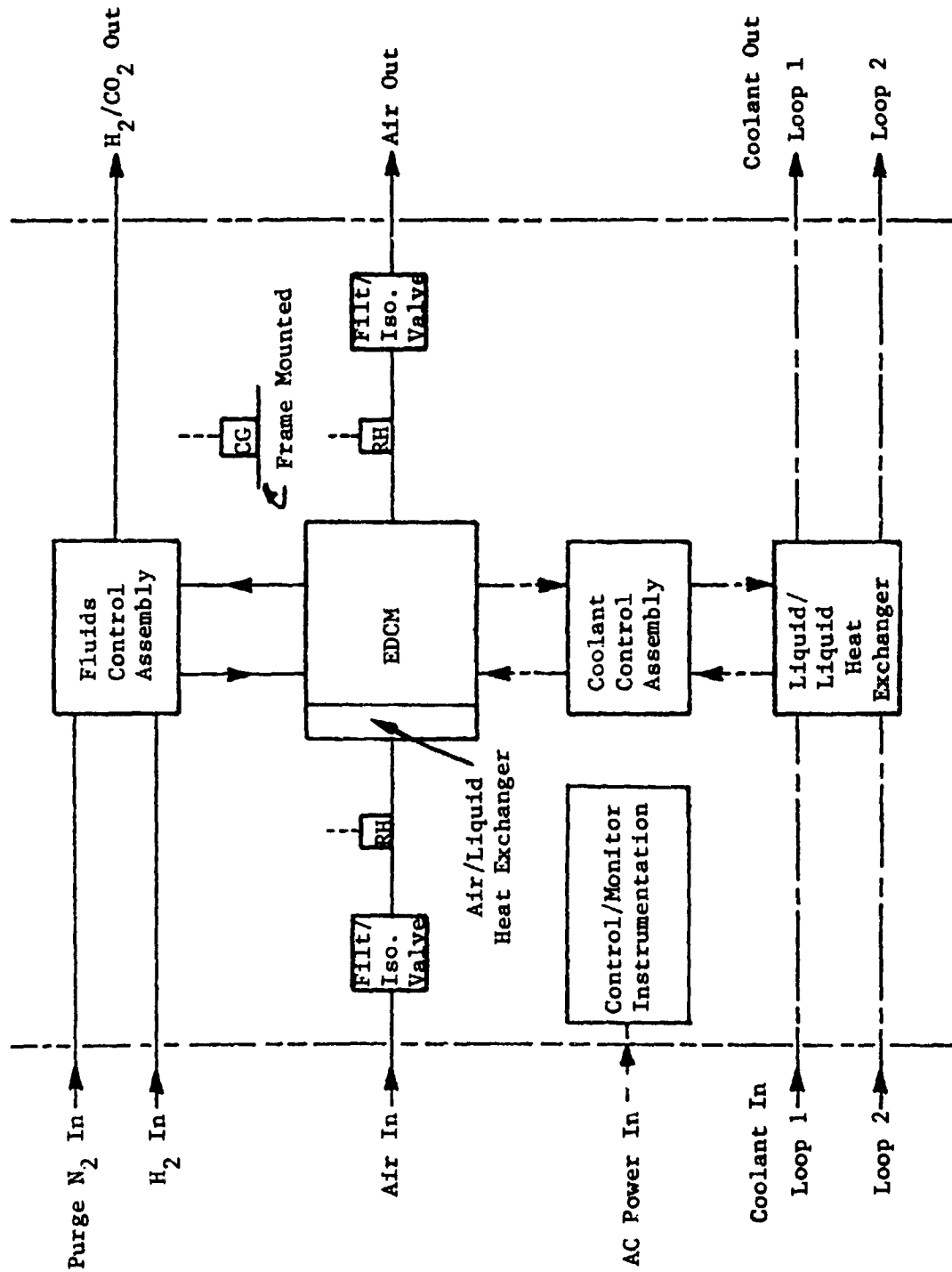


FIGURE 4 SHUTTLE EDC SCHEMATIC

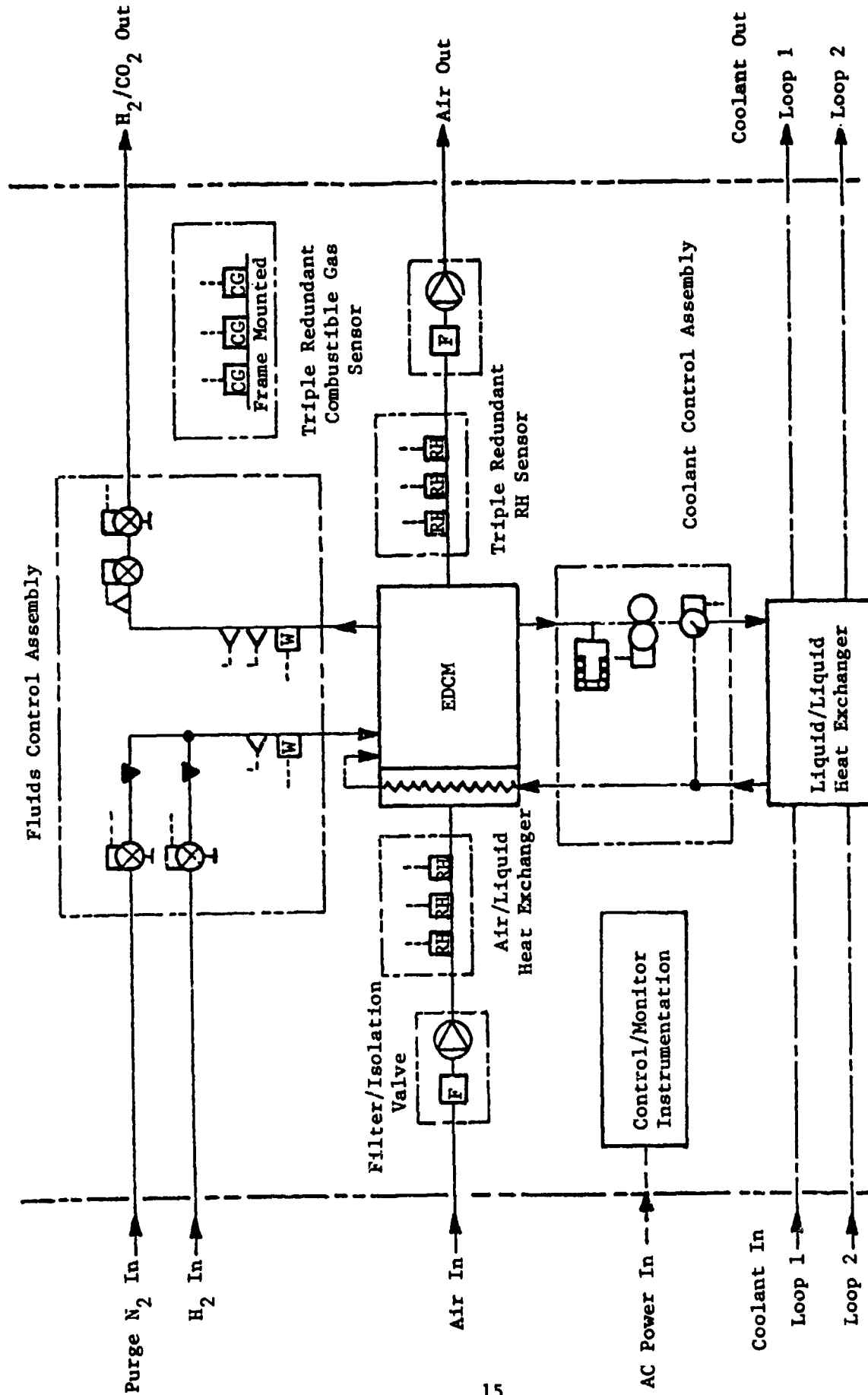


FIGURE 5 SHUTTLE EDC DETAILED SCHEMATIC

automatic subsystem shutdown should a critical parameter exceed a preset level. The C/M I provides totally automatic operation and is capable of interfacing with the Shuttle Data Acquisition System (DAS).

Design Flexibility/Options. The EDC Subsystem is flexible to changes in mission requirements. The EDC can operate over the entire four to ten-person range by simply changing the operating current for the electrochemical cells. Should a more optimized design be desired, the number of cells in the EDCM can be reduced or increased to optimize the CO₂ removal function over a smaller specified range in crew size.

The EDC Subsystem is capable of being liquid or air cooled. The air cooled subsystem design is presented in Appendix 1. The liquid cooled design was selected because it requires only 13% of the power and generates less than 50% of the heat of the air cooled subsystem. The air cooled subsystem is also 5% larger than the liquid cooled subsystem by weight, 18% larger by volume and would require an additional process air fan to achieve the required cooling air flow rate.

All 11 components shown in Figure 4 are flight maintainable to the component level. Depending on mission length and reliability goals, redundant components or spares can be included in the design to enhance reliability. Fail-safe operation is accomplished using backup LiOH canisters. In-line redundant components or spares could be selectively used to make a "fail-practical" subsystem, i.e., one not likely to cause the mission to be aborted.

Design Data. The design point for the EDC Subsystem is a seven-person crew size and a nominal cabin pCO₂ level of 667 Pa (5.0 mm Hg). The design is capable of short term operation at a ten-person level at the maximum allowable cabin pCO₂ level of 1,013 Pa (7.6 mm Hg). Operation at a four-person level is easily met by lowering the operating current density. The EDCM size required for seven persons is a 28-cell unit.

A lower weight four-person EDC design is possible by reducing the number of electrochemical cells in the EDCM. The four-person design handles the nominal CO₂ removal requirements of four persons at 667 Pa (5.0 mm Hg) and is capable of short term operation at a seven person level at 1,013 Pa (7.6 mm Hg). The EDCM size required for four persons is a 20-cell unit. The EDCM operating characteristics for the four-person and seven-person designs are presented in Table 4.

Component Weight, Power and Heat Rejection. Component weight, power and heat rejection estimates for the four-person and seven-person EDC Subsystem designs are given in Table 5. The EDCM accounts for approximately 50% of the subsystem weight. The other major weight factor is the ducting and frame which was estimated at 20% based on EDC subsystem hardware designs previously fabricated. (12) The power requirements were divided into AC and DC power. An effort was made to use DC power wherever possible to utilize the EDCM generated power. In addition, DC power is preferred since the Shuttle and future power module configurations will generate DC power which must then be converted to AC power at only 76% conversion efficiency. The CCA is the only component which uses AC power since it contains a liquid coolant pump. The AC power supply was selected to increase pump reliability and operating life.

TABLE 4 SHUTTLE EDCM OPERATING CHARACTERISTICS

Crew Size	4	7
Number of Cells	20	28
Current (Nominal), A	10.6	14.2
Cell Voltage (Nominal), V	0.48	0.41
Power Generated, W	102	163
Waste Heat Produced, W	163	334
CO ₂ Removed, kg/d (lb/d)	3.83 (8.44)	6.72 (14.8)
O ₂ Consumed, kg/d (lb/d)	1.52 (3.35)	2.85 (6.28)
H ₂ Consumed, kg/d (lb/d)	0.19 (0.42)	0.35 (0.78)
H ₂ O Generated, kg/d (lb/d)	1.71 (3.77)	3.21 (7.06)

TABLE 5 EDC SUBSYSTEM COMPONENT WEIGHT, POWER AND HEAT GENERATION SUMMARY

Component	No. Req'd	4-Person			7-Person		
		Weight, kg (lb)	Power, W AC	Heat Gen., W DC	Weight, kg (lb)	Power, W AC	Heat Gen., W DC
EDCM	1	19.1 (42)	-- (-102)	163	24.1 (53)	-- (-163)	334
Fluids Control Assembly	1	2.3 (5)	-- 10	10	2.3 (5)	-- 10	10
Coolant Control Assembly	1	1.8 (4)	50 --	50	1.8 (4)	50 --	50
Heat Exchanger (Liq/Liq)	1	2.3 (5)	-- --	--	2.3 (5)	-- --	--
Heat Exchanger (Air/Liq)	1	2.3 (5)	-- --	--	2.3 (5)	-- --	--
Filter/Isolation Valve	2	0.9 (2)	-- --	--	0.9 (2)	-- --	--
RH Sensor	2	0.9 (2)	-- 10	10	0.9 (2)	-- 10	10
Combustible Gas Sensor	1	0 (0)	-- 5	5	0 (0)	-- 5	5
Instrumentation	1	3.2 (7)	-- 15	15	3.2 (7)	-- 15	15
Ducting/Frame (20%)	7	6.4 (14)	-- --	--	7.7 (17)	-- --	--
Total	11	39.0 (86)	50 (-62)	253	45.4 (100)	50 (-123)	424

Packaging

Figure 6 shows the Shuttle seven-person capacity EDC packaging configuration. The overall subsystem dimensions are 48 x 43 x 38 cm (19 x 17 x 15 in). The subsystem is designed to fit under the mid-deck floor and interface directly with the Orbiter ARS ducting. The EDC subsystem easily fits within the packaging envelope presently occupied by the LiOH canister storage racks. The seven-person EDC requires a volume of 0.08 m³ (2.8 ft³) which is only 13% of the 0.65 m³ (23 ft³) reserved for storage of the Shuttle LiOH canisters.

Subsystem Characteristics

The EDC Subsystem characteristics for the seven-person design are presented in Table 6. For comparison, the characteristics for a four-person design compatible with the baseline Orbiter requirements are also presented. The two designs differ only in the operating cell current and in the number of cells contained in the EDCM. Ancillary components are identical. The four-person design is capable of operation at the seven-person level and the seven-person design can be operated at both the four-person and ten-person level. The required increase in performance level is attained by increasing EDCM cell current and allowing the cabin pCO₂ to rise to the upper allowable level of 1,013 Pa (7.6 mm Hg).

The power requirements are divided into AC and DC requirements. The EDCM generates DC power through the fuel cell reaction and this power is available to DC powered ancillary components. For both the four-person and seven-person design, excess DC power is generated by the EDCM which would be available for Shuttle usage.

Both sensible and latent heat rejection requirements are considered. The sensible heat load consists of the waste heat generated by the electrochemical cell reactions and the heat generated by power consuming ancillary components. The latent heat load results from the water generated by the electrochemical cell reaction and is approximately the same as the latent heat load generated by an LiOH CO₂ Removal Subsystem.

Expendables are required to perform the CO₂ removal function. The EDC consumes H₂ and O₂ (from cabin air) during the CO₂ removal process. Water vapor is produced as the product of the fuel cell reaction and is removed by the process air stream.

Vehicle Integration

The EDC subsystem is designed to interface directly with the existing Shuttle ARS presented in Figure 7. The location of the EDC within the Shuttle ARS is shown in Figure 8. The EDC takes air downstream of the ARS fan package in parallel with the existing LiOH location. The LiOH canisters are replaced with odor control canisters and the orifice, which determines the flow through the parallel flow paths, is adjusted to yield the proper flow through both the odor cartridges and the EDC Subsystem. The location of the process air return to the ARS is flexible and can be either upstream (as shown in Figure 8) or downstream of the cabin temperature control heat exchanger.

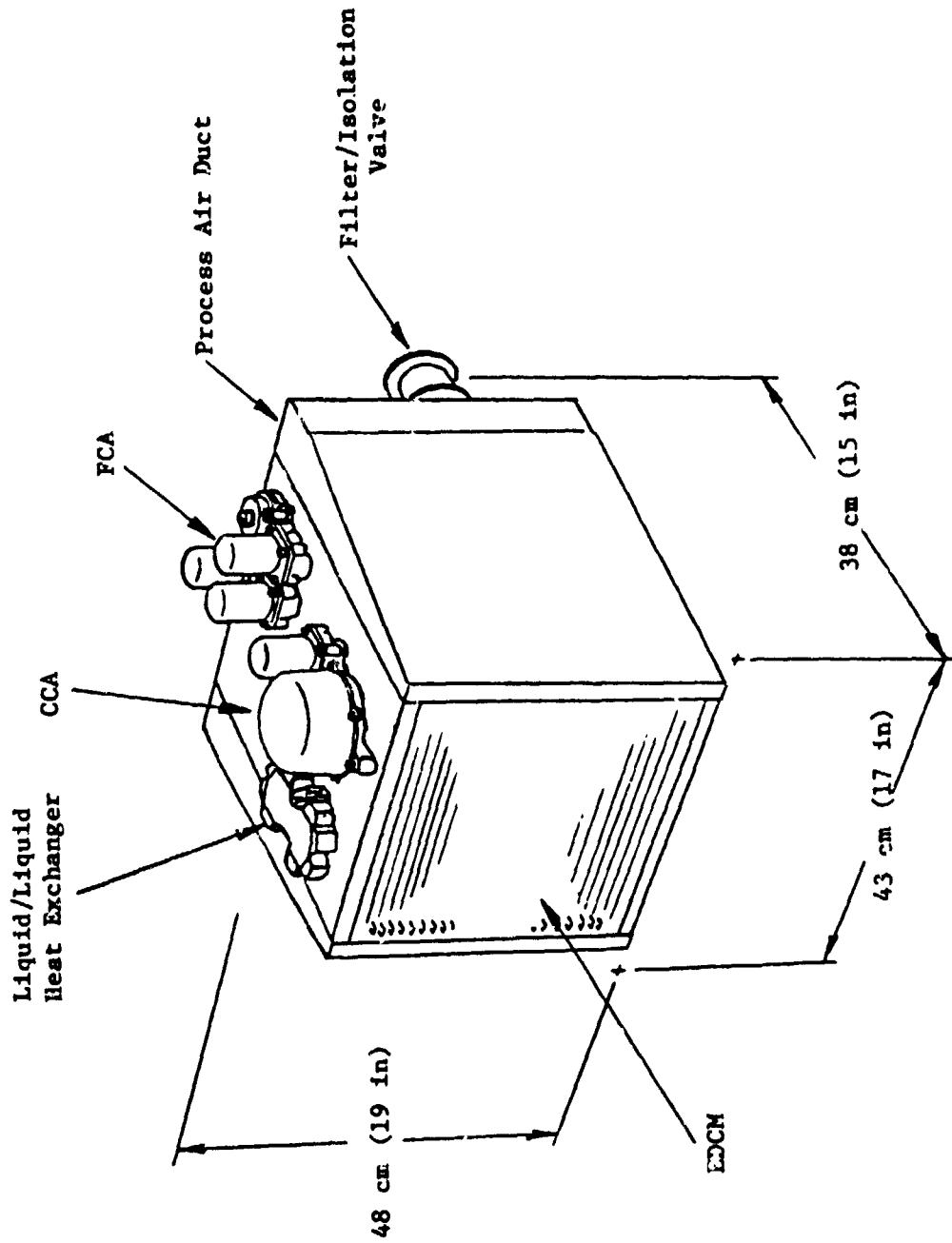


FIGURE 6 SHUTTLE EDC CONFIGURATION (SEVEN PERSON)

TABLE 6 SHUTTLE EDC SUBSYSTEM CHARACTERISTICS SUMMARY

Crew Size	4	7
Fixed Hardware Weight, kg (lb)	39.0 (86)	45.4 (100)
Overall Dimensions, cm (in)	41 x 43 x 38 (16 x 17 x 15)	48 x 43 x 38 (19 x 17 x 15)
Volume, m ³ (ft ³)	0.07 (2.4)	0.08 (2.8)
Power Required, WAC , WDC	50 -62 ^(a)	50 -123 ^(a)
Heat Load, W		
Sensible	253	424
Latent	46	86
CO ₂ Removed, kg/d (lb/d)	3.85 (8.44)	6.72 (14.8)
O ₂ Consumed, kg/d (lb/d)	1.52 (3.35)	2.85 (6.28)
H ₂ Consumed, kg/d (lb/d)	0.229 (0.504) ^(b)	0.425 (0.936) ^(b)
H ₂ O Generated, kg/d (lb/d)	1.71 (3.77)	3.21 (7.06)

(a) Excess power generated by EDC available to Shuttle

(b) At 1.2 times the stoichiometric H₂ requirement

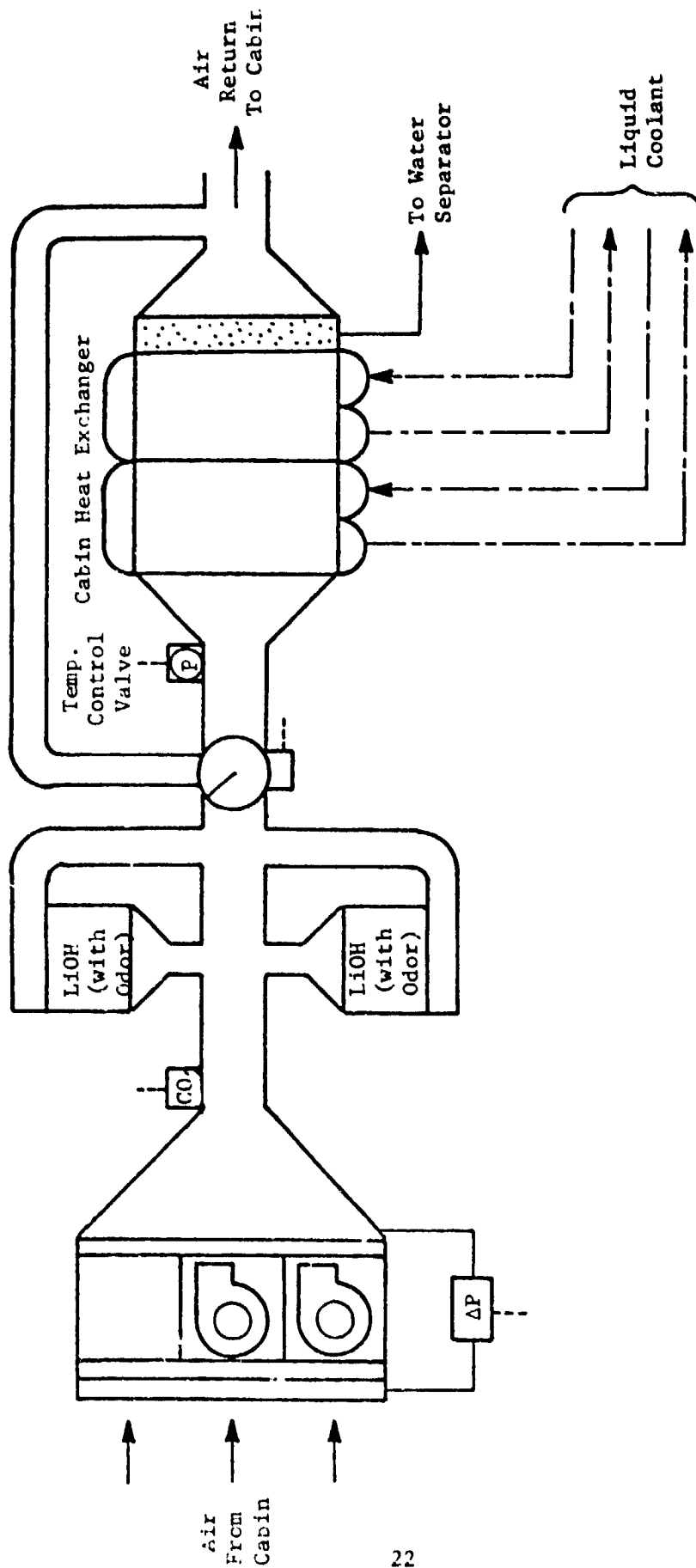


FIGURE 7 EXISTING SHUTTLE AIR REVITALIZATION

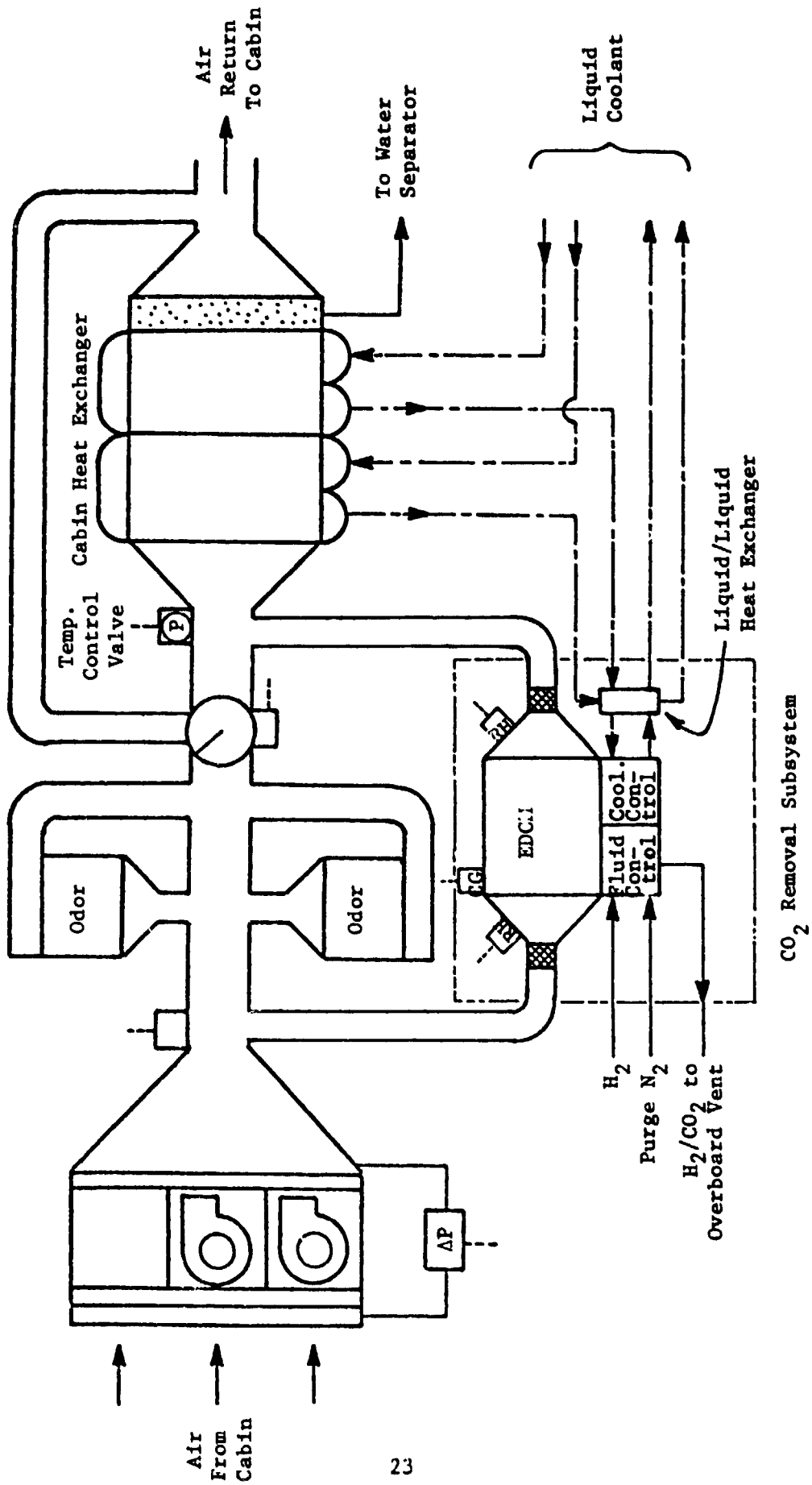


FIGURE 8 EDC LOCATION WITHIN SHUTTLE ARS

The EDC requires five Shuttle mechanical interfaces: air, liquid coolant, N₂, cryogenic H₂ and overboard vent. All required resources presently exist on the Shuttle.

Development Status

The EDC subsystem technology is well established. Two preprototype units have been fabricated and delivered to NASA: the six-person SSP EDC Subsystem⁽⁹⁾ and the three-person RLSE EDC Subsystem (referred to as the CS-3).⁽¹²⁾ A photograph of the CS-3 is presented in Figure 9. The EDC Subsystem can be available for flight application by 1983.

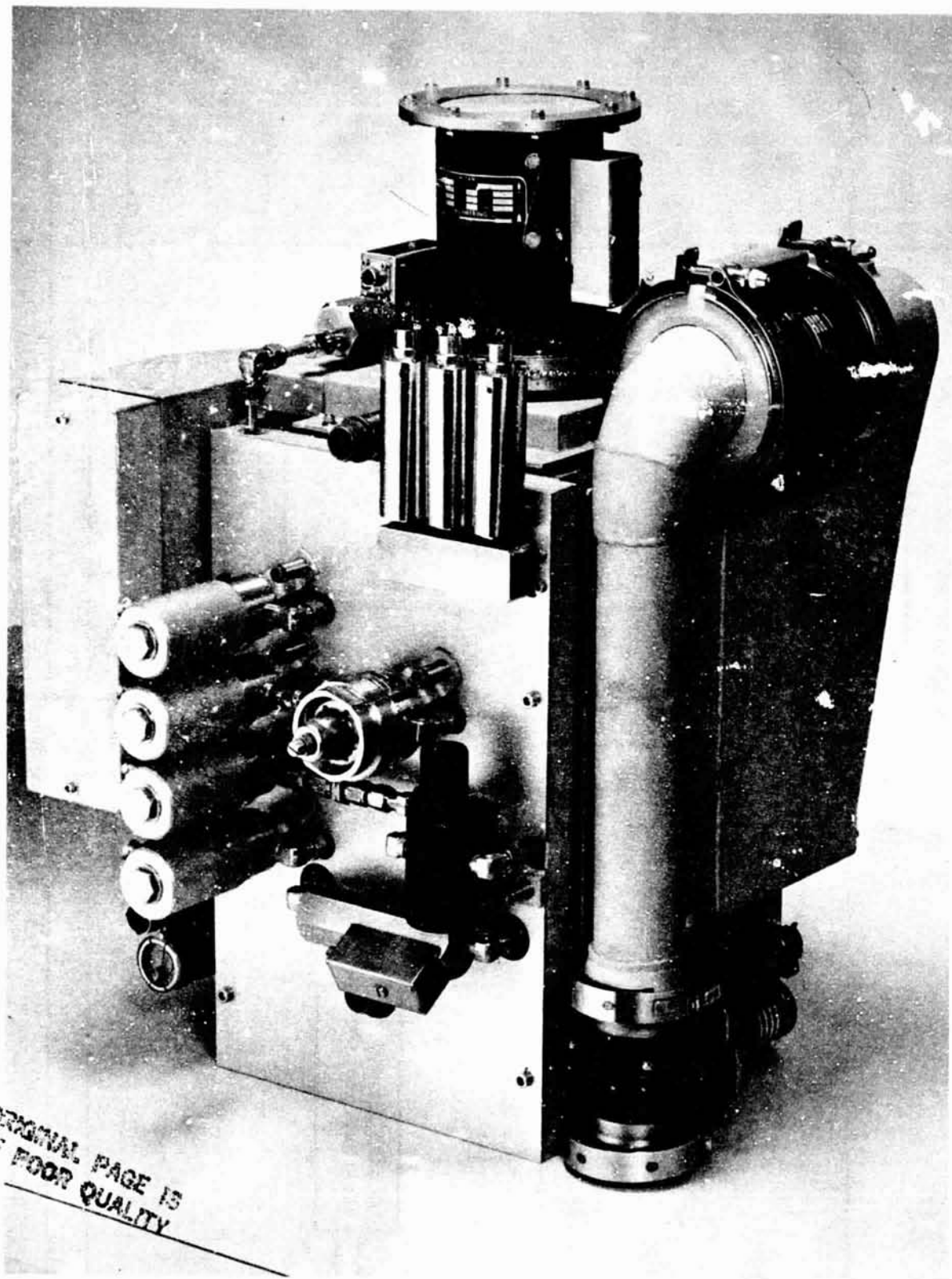
EDC/WVE Flight Concept

The EDC/WVE Subsystem consists of an EDCM which performs the CO₂ removal process, a WVE Module (WVEM) which generates the O₂ and H₂ consumed by the EDC for the CO₂ removal process, ducting and plumbing to manifold the process gases in to and out of the electrochemical modules and the peripheral mechanical and electrical components required to control and monitor subsystem performance. The EDC concept is as described previously. The WVE concept electrolyzes water vapor contained in the air stream to generate H₂ for use in the EDC and O₂ which is generated directly into the air stream. The electrolysis process takes place in a series of electrochemical cells stacked to form a module. Water vapor is removed from a flowing air stream as it passes through the anode compartments of the WVE cells. The O₂ generated at the anode is removed with the process air. The H₂ generated at the cathode is manifolded from the WVEM to the EDCM. The WVEM generates 1.2 times the O₂ and H₂ consumed, and consumes 1.2 times the water generated in the EDC process. The 20% additional H₂ which is not consumed by the EDCM is vented overboard with the CO₂. The excess O₂ generated reduces Orbiter metabolic O₂ requirements. The additional water consumed reduces the latent heat removal load on the condensing heat exchanger. The electrolysis process requires electrical energy and waste heat is generated as a byproduct.

Subsystem Description

Figure 10 is the Shuttle EDC/WVE schematic showing the subsystem components and assemblies. The detailed EDC/WVE schematic showing the subcomponents required to perform the control and monitoring functions is presented in Figure 11.

Operation. Process air is bypassed from the ARS ducting to the EDC/WVE subsystem. Process air flows through a filter/isolation valve, an RH sensor and an air liquid heat exchanger prior to reaching the EDCM and the WVEM. Process air flows through both modules in parallel. Separate RH sensors are used on the outlet air stream from each module. The air is then recombined and exhausts the subsystem through a second filter/isolation valve. The RH sensors are used to control EDCM and WVEM temperature as a function of process air RH conditions. Liquid coolant is used to remove waste heat generated and to control module temperatures. The liquid coolant loop temperature is adjusted using a diverter valve contained within the CCA which controls the amount of coolant flowing through and bypassing the liquid/liquid heat exchanger. An air/liquid heat exchanger is used upstream of the electrochemical modules to



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FIGURE 9 THREE-PERSON PREPROTOTYPE EDC

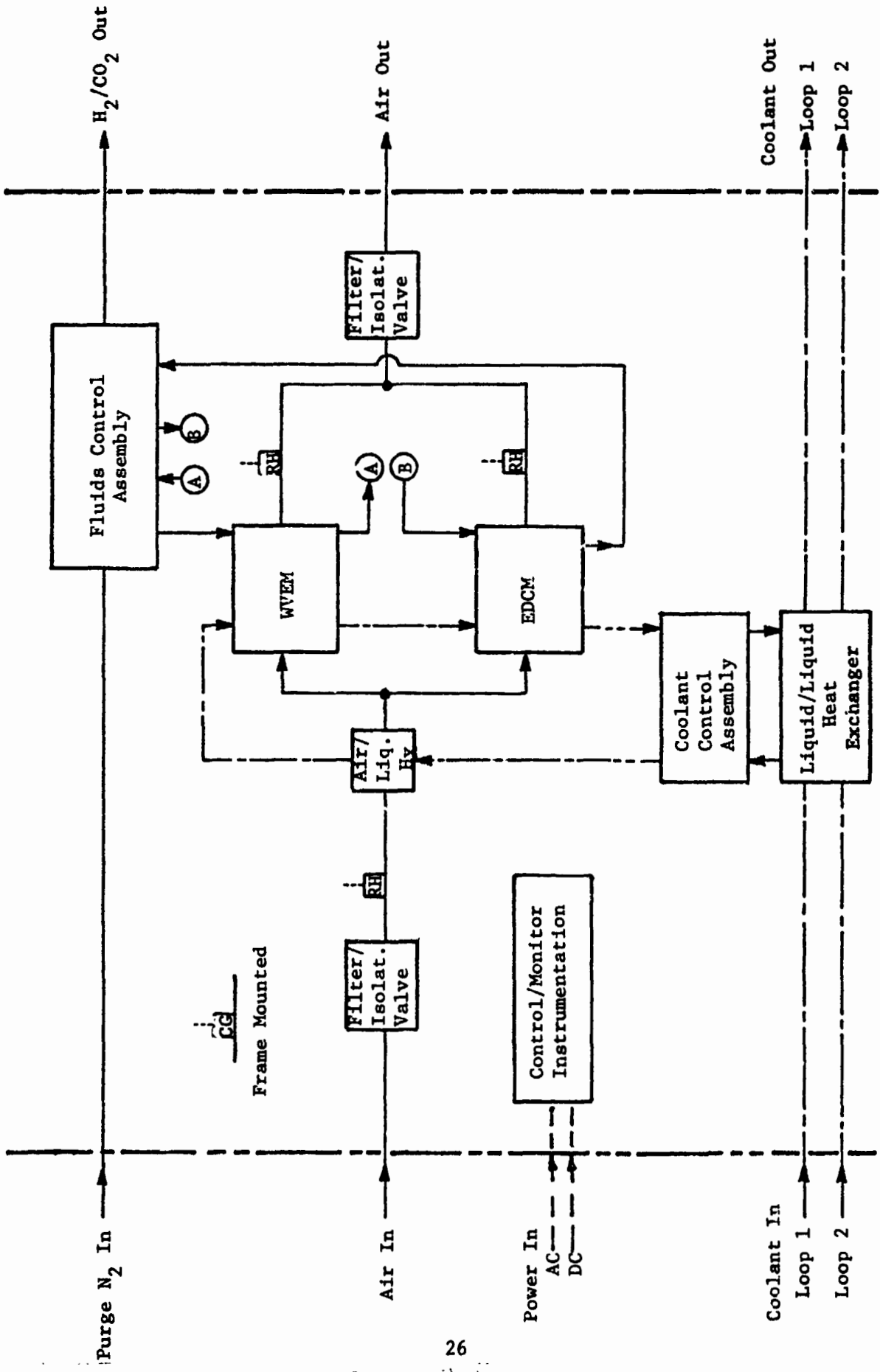


FIGURE 10 SHUTTLE EDC/WVE SCHEMATIC

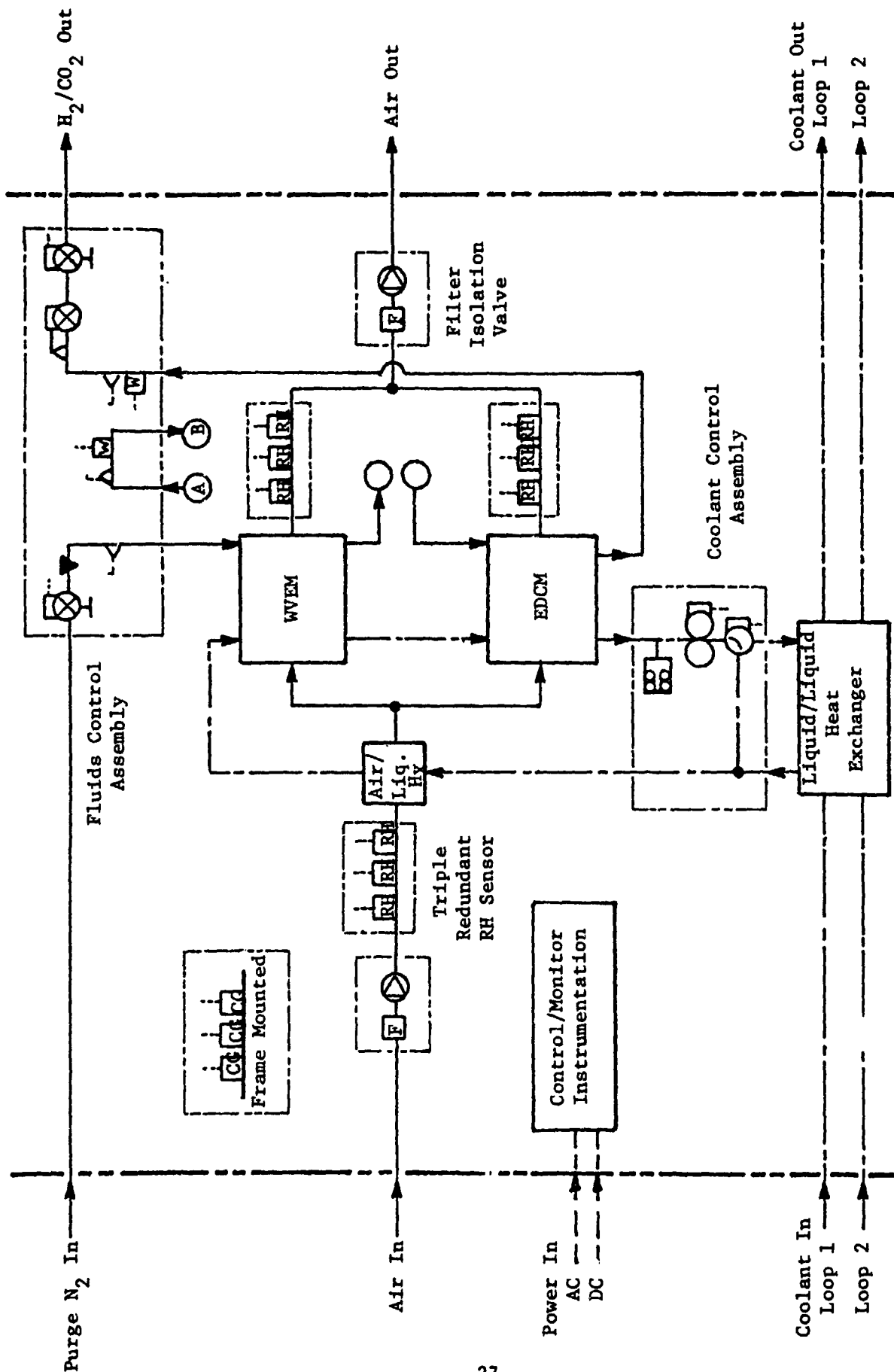


FIGURE 11 SHUTTLE EDC/WVE DETAILED SCHEMATIC

cool the process air thereby matching the process air humidity conditions with optimum conditions for EDCM and WVEM operation. The liquid/liquid heat exchanger interfaces directly with the Orbiter WCL downstream of the shuttle cabin temperature control heat exchanger. Again, the Orbiter's condensing heat exchanger load is lessened by the amount of heat removed by the air/liquid heat exchanger upstream of the modules.

The H_2 generated in the WVEM is used directly by the EDCM. Pressure and flow measurements between the two modules are provided by the FCA. The FCA also interfaces with the N_2 purge source and the overboard H_2/CO_2 vent. The FCA provides all H_2 flow path control and monitoring functions including N_2 purge. A triple redundant combustible gas sensor is located on the subsystem frame.

Process control is provided by the C/M I. The C/M I interfaces with the subsystem sensors and actuators, provides automatic control of the water electrolysis and CO_2 removal processes, provides mode transition sequences for automatic startup and shutdown, and monitors sensor levels to initiate an automatic subsystem shutdown should a critical parameter exceed a preset level. The C/M I provides totally automatic operation and is capable of interfacing with the Shuttle DAS.

Design Flexibility/Options. The EDC/WVE Subsystem is flexible to changes in mission requirements. The EDC/WVE can operate over the entire four to ten-person range by simply changing the operating current for the electrochemical cells. Should a more optimized design be desired, the number of electrochemical cells in the EDCM and WVEM can be reduced or increased to provide the CO_2 removal function over a smaller specified range in crew size. The EDC/WVE² subsystem is capable of being either liquid cooled or air cooled. The air-cooled subsystem design is presented in Appendix 2. The liquid-cooled design was selected because it requires only 50% of the power and generates less than 50% of the heat of the air cooled subsystem. The air-cooled subsystem is also 7% larger than the liquid cooled system by weight, 17% larger by volume and would require an additional process air fan to achieve the required cooling air flow rate.

All 13 components shown in Figure 10 are flight maintainable to the component level. Depending on mission length and reliability goals, redundant components or spares can be included in the design to enhance reliability. Fail-safe operation is accomplished using backup LiOH canisters. In-line redundant components or spares could be selectively used to make a "fail-practical" subsystem.

Design/Data. The design point for the EDC/WVE Subsystem is a seven-person crew size and a nominal cabin pCO_2 level of 667 Pa (5.0 mm Hg). The design is capable of short-term operation at a ten-person level at the maximum allowable pCO_2 level of 1,013 Pa (7.6 mm Hg). Operation at a four-person level is easily met by lowering the operating current for the electrochemical modules. The EDCM size required to perform this function is a 28-cell unit. The WVEM size required is a 24-cell unit.

A lower weight four-person EDC/WVE design is possible by reducing the number of electrochemical cells in the EDCM and WVEM. The four-person design handles the nominal CO_2 removal requirements for four-persons at 667 Pa (5.0 mm Hg) and is capable of short-term operation at the seven-person level at 1,013 Pa

(7.6 mm Hg). The EDCM size required for four persons is a 20-cell unit. The four person WVEM contains 17 cells. The EDCM and WVEM operating characteristics are presented in Table 7.

Component Weight, Power and Heat Rejection. Component weight, power and heat rejection estimates for the four-person and seven-person EDC/WVE Subsystem designs are given in Table 8. The EDCM and WVEM account for approximately 50% of the subsystem weight. The other major weight factor is the ducting and the frame weight which was estimated at 25% based on previous EDC/WVE Subsystem hardware designs. (15) The power requirements were divided into AC and DC power. An effort was made to use lower penalty DC power wherever possible. The EDCM generated power is used by the WVEM to reduce its power requirements. The only component requiring AC power is the CCA.

Packaging

The packaging concept for the seven-person capacity EDC/WVE Subsystem is presented in Figure 12. The overall subsystem dimensions are 81 x 43 x 38 cm (32 x 17 x 15 in). The subsystem is designed to fit under the mid-deck floor and interface directly with the Orbiter ARS ducting. The EDC/WVE Subsystem easily fits within the packaging envelope presently occupied by the LiOH₃ canister storage racks. The EDC/WVE requires a volume of 0.13 m³ (4.7 ft³) which is only 20% of the volume presently reserved for LiOH canister storage.

Subsystem Characteristics

The subsystem characteristics for the four-person and the seven-person EDC/WVE designs are presented in Table 9. Again, the two designs differ only in the operating cell currents and in the number of EDCM and WVEM cells. Ancillary components are identical. The four-person design is capable of operation at the seven-person level. The seven-person design can be operated at both the four-person and ten-person level. The increase in performance is attained by increasing EDCM and WVEM cell currents and allowing the cabin pCO₂ to rise to the upper allowable level of 1,013 Pa (7.6 mm Hg).

The power requirements are divided into AC and DC requirements and include the power required for ancillary components, the power required by the WVEM and the power generated by the EDCM. The EDCM generated power is used directly by the WVEM to offset a portion of the water electrolysis power requirements. (15)

Both sensible and latent heat rejection requirements are considered. The sensible heat load includes that due to the power required for the ancillary components and waste heat generated in the electrochemical cell reactions. The net water removal from the cabin air by the EDC/WVE process results in the negative latent heat load.

The EDC/WVE does not require any expendables except those used by the fuel cells to generate power for the subsystem. The use of the WVEM to generate the EDC consumables eliminates the need for using Shuttle O₂ and H₂ expendables. Since the WVEM generates 20% more O₂ than is used by the EDCM, the EDC/WVE actually has a negative consumables factor for comparison purposes since O₂ is added to the cabin air for metabolic consumption.

TABLE 7 SHUTTLE EDC/WVE MODULE OPERATING CHARACTERISTICS

	<u>EDCM</u>	<u>WVEM</u>	<u>EDCM</u>	<u>WVEM</u>
Crew Size	4	4	7	7
Number of Cells	20	17	28	24
Current, A	10.6	15	14.2	19.8
Cell Voltage (Nominal), V	0.48	1.64	0.41	1.68
Power Consumed, W	-102	418	-163	798
Waste Heat Produced, W	163	105	334	214
CO ₂ Removed, kg/d (lb/d)	6.72 (8.44)	--	3.83 (14.8)	--
O ₂ Consumed, kg/d (lb/d)	1.52 (3.35)	1.83 (-4.03)	2.85 (6.28)	-3.41 (-7.50)
H ₂ Consumed, kg/d (lb/d)	0.19 (0.42)	0.23 (-0.50)	0.35 (0.78)	-0.43 (-0.93)
H ₂ O Generated, kg/d (lb/d)	1.71 (3.77)	2.06 (-4.53)	3.21 (7.06)	-3.83 (-8.44)

TABLE 8 EDC/WVE SUBSYSTEM COMPONENT WEIGHT, POWER AND HEAT GENERATION SUMMARY

Component	No. Req'd	4-Person			7-Person		
		Weight, kg (lb)	Power, W AC	Heat Gen., W DC	Weight, kg (lb)	Power, W AC	Heat Gen., W DC
EDCM	1	19.1 (42)	-- (-102)	163	24.1 (53)	-- (-163)	334
WVEM	1	16.8 (37)	-- 418	105	21.3 (47)	-- 798	214
Fluids Control Assembly	1	2.3 (5)	-- 10	10	2.3 (5)	-- 10	10
Coolant Control Assembly	1	1.8 (4)	50	50	1.8 (4)	50	50
Heat Exchanger (Liq/Liq)	1	2.3 (5)	--	--	2.3 (5)	--	--
Heat Exchanger (Air/Liq)	1	2.3 (5)	--	--	2.3 (5)	--	--
Filter/Isolation Valve	2	0.9 (2)	--	--	0.5 (2)	--	--
RH Sensor	3	1.4 (3)	-- 15	15	1.4 (3)	-- 15	15
Combustible Gas Sensor	1	0 (0)	-- 5	5	0 (0)	-- 5	5
Instrumentation	1	4.1 (9)	-- 20	20	4.1 (9)	-- 20	20
Ducting/Frame (25%)	7	12.7 (28)	-- 366	368	14.5 (33)	-- 685	648
Total	13	63.6 (140)	50	366	75.4 (166)	50	685

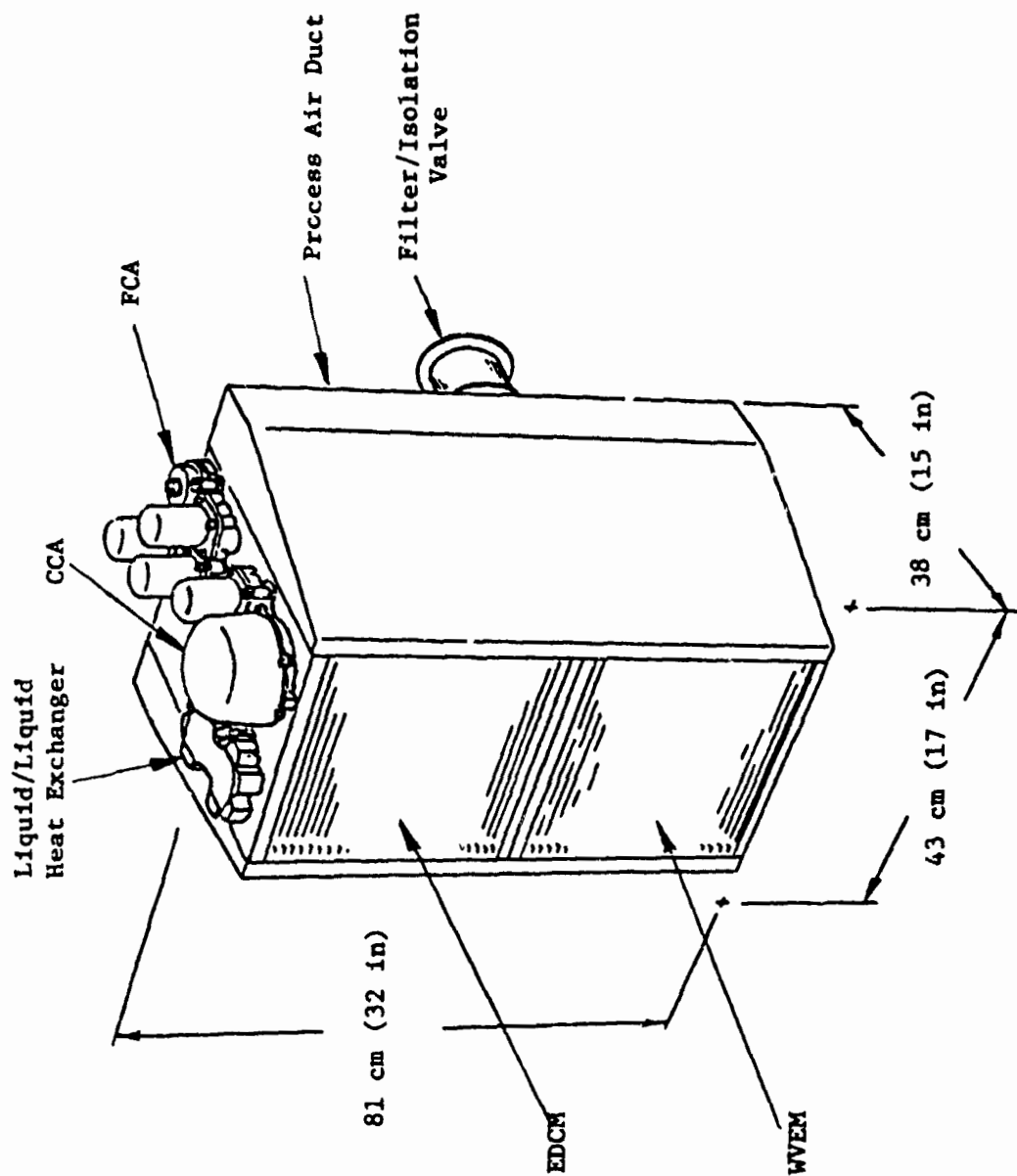


FIGURE 12 SHUTTLE EDC/WVE CONFIGURATION (SEVEN PERSON)

TABLE 9 SHUTTLE EDC/WVE SUBSYSTEM CHARACTERISTICS SUMMARY

Crew Size	4	7
Fixed Hardware Weight, kg (lb)	63.6 (140)	74.4 (166)
Overall Dimensions, cm (in)	66 x 43 x 38 (27 x 27 x 15)	81 x 43 x 38 (32 x 17 x 15)
Volume, m ³ (ft ³)	0.11 (3.8)	0.13 (4.7)
Power Required, WAC , WDC	50 366	50 685
Heat Load, W Sensible Latent	368 -9	648 -17
CO ₂ Removed, kg/d (lb/d)	3.83 (8.44)	6.72 (14.8)
O ₂ Consumed, kg/d (lb/d)	-0.31 (-0.68)	-0.55 (-1.22)
H ₂ Consumed, kg/d (lb/d)	0	0
H ₂ O Generated, kg/d (lb/d)	-0.35 (-0.76)	-0.63 (-1.38)

Vehicle Integration

The EDC/WVE Subsystem is designed to interface directly with the existing Shuttle ARS. The location of the EDC/WVE within the Shuttle ARS schematic is shown in Figure 13. The EDC/WVE takes air downstream of the ARS fan package and in parallel with the existing LiOH location. The LiOH canisters are replaced with odor control canisters and the orifice which determines the flow through the parallel flow paths is adjusted to yield the proper flows through both the odor cartridges and the EDC/WVE Subsystem. Process air can be returned to the ARS either upstream (as shown in Figure 13) or downstream of the cabin temperature control heat exchanger.

The EDC/WVE Subsystem requires four mechanical Shuttle interfaces: air, liquid coolant, N₂ and overboard vent. All resources exist and are presently used within the Shuttle EC/LSS.

Development Status

The EDC/WVE subsystem technology is well established. A three-person EDC/WVE, designed to provide total metabolic O₂ and CO₂ control, was built for NASA under the RLSE program.⁽¹⁵⁾ A photograph of the preprototype EDC/WVE is shown in Figure 14. The EDC/WVE Subsystem can be available for flight application by 1983.

CO₂ Removal Subsystems Comparison

The EDC and EDC/WVE subsystems were compared to LiOH and two solid amine CO₂ Removal Subsystems: HS-C/RH Control and HS-C/Water Save.⁽¹⁸⁾ The enhanced Orbiter mission options used in comparing the five CO₂ Removal Subsystems were presented in Table 2.

For enhanced Orbiter Mission Options One and Two, sufficient potable water exists so that water removed by a CO₂ Removal Subsystem and vented overboard is not considered an expendable penalty. Mission Option Three, however, does not generate any potable water since fuel cells are not used. Any water vented overboard by the CO₂ Removal Subsystem must be considered an expendable for the mission since it would have to be replaced by water recovery or additional water storage.

Table 10 summarizes the CO₂ Removal Subsystems' characteristics for comparison. The weight and volume estimates include contingency LiOH canisters and vehicle ducting. Table 11 summarizes the subsystem power consumption expendables for Mission Options One and Two. The total mission expendables required are presented in Table 12 for each of the three mission options as characterized by the power system configuration. Expendables include process consumables and cryogen for power generation. A tankage penalty of 100% was assumed for O₂, H₂ and N₂. Expendables for Mission Option Three also include water vented overboard with a tankage penalty of 22.4% of the water loss.⁽²⁸⁾

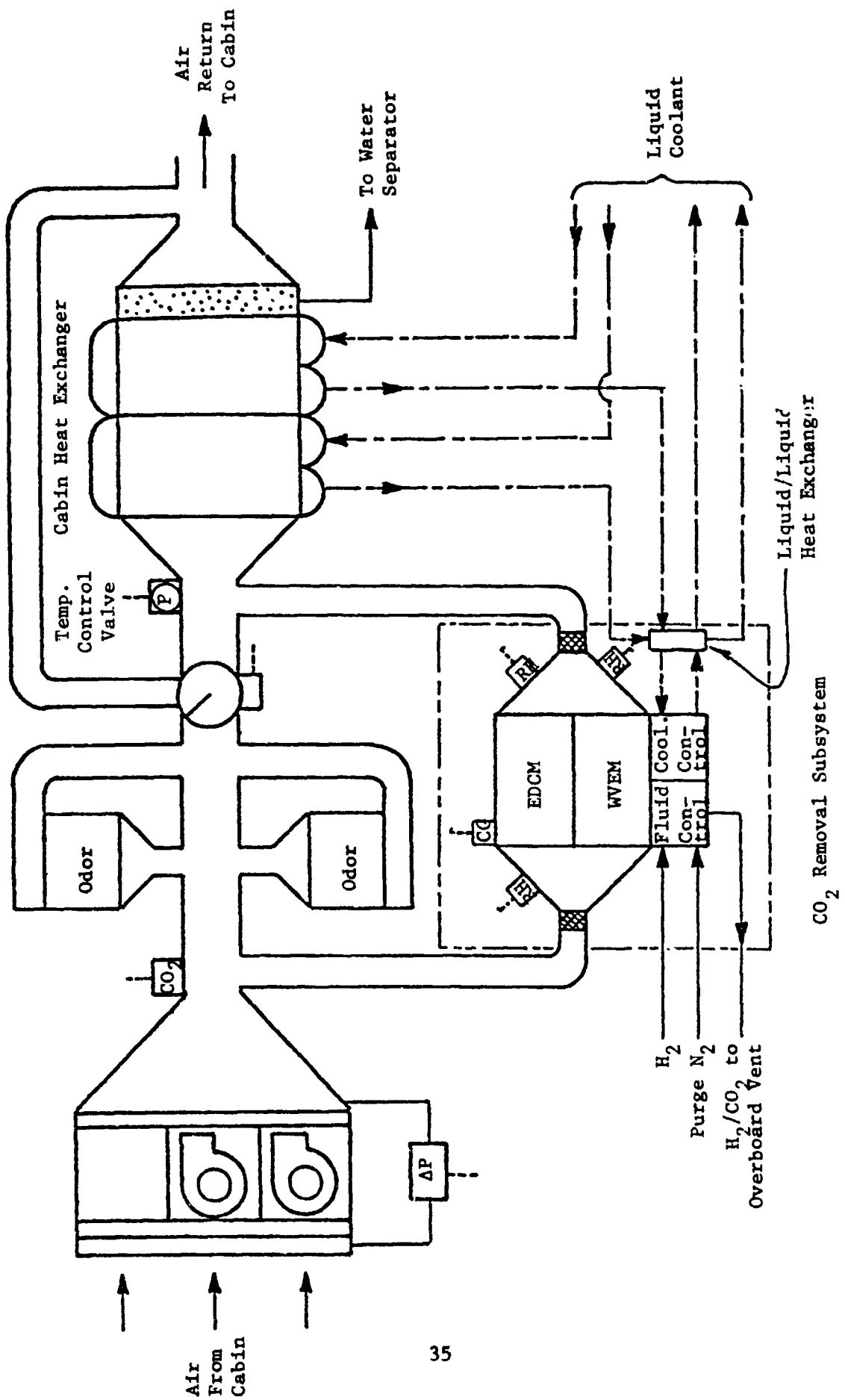


FIGURE 13 SHUTTLE EDC/WVE LOCATION

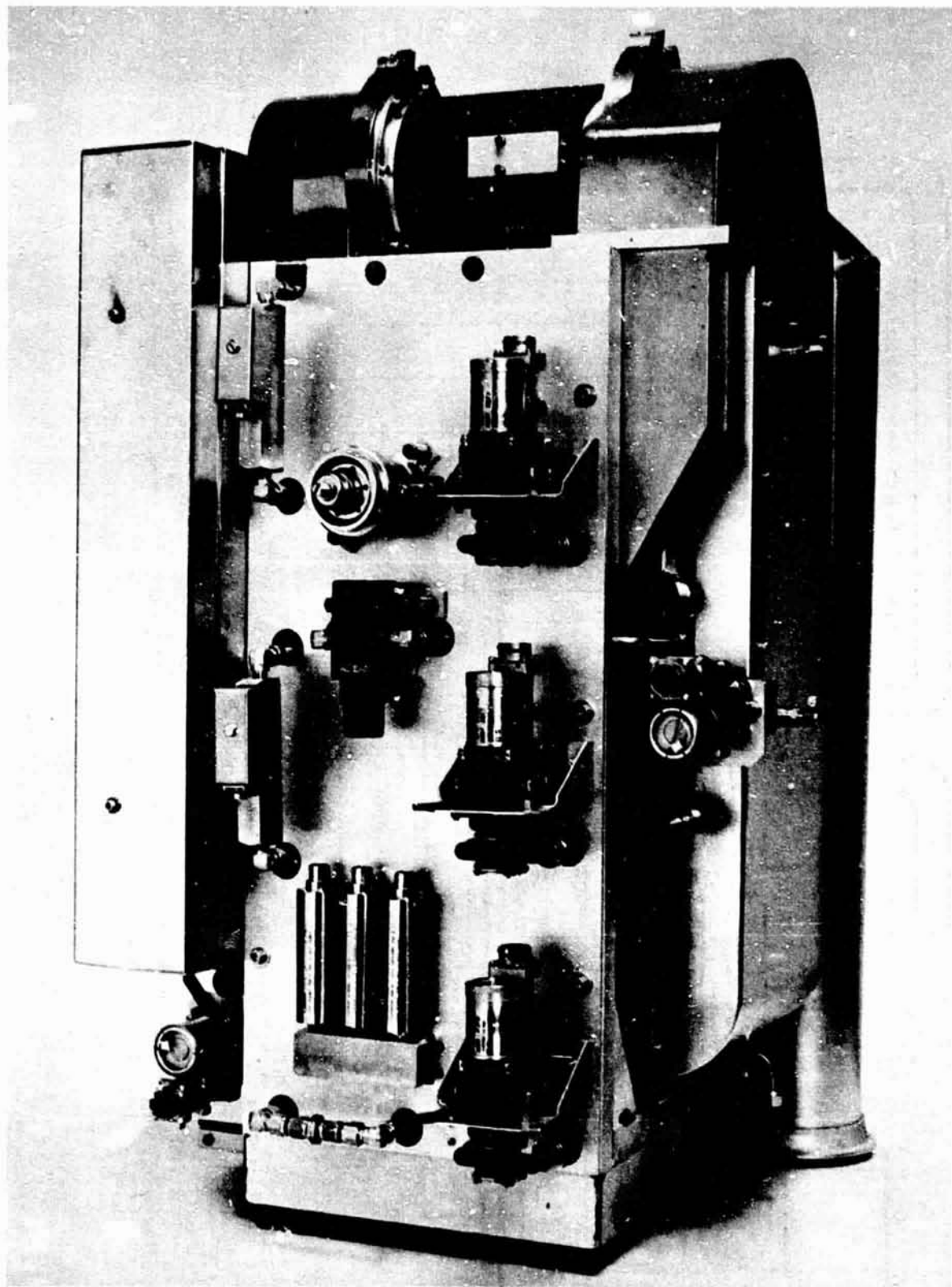


FIGURE 14 RLSE PREPROTOTYPE EDC/WVE

TABLE 10 COMPARISON OF SHUTTLE CO₂ SUBSYSTEM CHARACTERISTICS: SEVEN-PERSON

Subsystem	(a) Weight, kg (lb)		Power, W		Vg ₃ (ft ³) m ³	(a) Heat Rejection, W		(b) Expendables, kg/d (lb/d)				
	kg (lb)	(c)	AC	DC		Sensible	Latent	Water	O ₂	H ₂	N ₂	LiOH
LiOH	35 (76)	(c)	11	--	0.07 (2.6)	157	74	-2.74 (-6.04)	--	--	--	18.9 (41.6)
HS-C/RH	151 (332)		115	23	0.59 (21)	153	-298	11.09 (24.43)	0.06 (0.14)	--	0.20 (0.44)	--
HS-C/Water Save	180 (397)		76	19	0.54 (19)	100	-120	4.46 (9.83)	0.14 (0.30)	--	0.45 (0.95)	--
EDC	71 (157)		50	-123	0.17 (6)	424	86	-3.21 (-7.06)	2.85 (6.28)	0.425 (0.936)	--	--
EDC/WVE	101 (223)		50	685	0.23 (8)	648	-17	0.63 (1.38)	-0.55 (-1.22)	--	--	--

- (a) Includes contingency LiOH and vehicle ducting.
- (b) Does not include tankage for cryogen for power generation.
- (c) Contingency LiOH canisters (8) at 3.06 kg₃ (6.73 lb₃) plus 41.7% for packaging weight.
- (d) Contingency LiOH canisters (8) at 6.36 dm³ (388 in³) plus 42.5% for packaging volume.
- (e) Expendable volume for LiOH canisters is 0.040 m³/d (1.40 ft³/d).

TABLE 11 EXPENDABLES FOR POWER CONSUMED: SEVEN-PERSONS

Subsystem	Power, (a) W		Baseline Orbiter Expendables, (b) kg/d (lb/d)		Orbiter with PEP Expendables, (c) kg/d (lb/d)	
	AC	DC	O ₂	H ₂	O ₂	H ₂
LiOH	11	--	0.11 (0.25)	0.014 (0.031)	0.04 (0.09)	0.005 (0.012)
HS-C/RH	115	23	1.37 (3.01)	0.172 (0.378)	0.52 (1.14)	0.065 (0.143)
HS-C/Water Save	76	19	0.93 (2.05)	0.117 (0.258)	0.35 (0.78)	0.044 (0.098)
EDC	50	-123	-0.45 ^(d) (-0.99)	-0.056 ^(d) (-0.124)	-0.17 ^(d) (-0.37)	-0.021 ^(d) (-0.047)
EDC/WVE	50	685	5.88 (12.96)	0.740 (1.629)	2.22 (4.90)	0.280 (0.616)

(a) Power conversion efficiency of 76% for AC power.

(b) Fuel cell O₂ and H₂ consumption at 7.84 kg/kW-d (17.26 lb/kW-d) and 0.99 kg/kW-d (2.17² lb/kW-d), respectively.

(c) Fuel cell O₂ and H₂ consumption at 2.96 kg/kW-d (6.52 lb/kW-d) and 0.37 kg/kW-d (0.82² lb/kW-d), respectively.

(d) Assumes EDC power generated is used on-board the Shuttle.

TABLE 12 CO₂ REMOVAL SUBSYSTEMS' TOTAL MISSION EXPENDABLES

Subsystem	Expendables, kg/d (lb/d)		
	FC ^(a)	SA/FC ^(b)	SA/BA ^(c)
LiOH	19.1 (42.2)	19.0 (41.8)	15.5 (34.2)
HS-C/RH	3.6 (7.9)	1.7 (3.7)	14.1 (31.1)
HS-C/Low Dump	3.2 (7.1)	1.9 (4.3)	6.6 (14.5)
EDC	5.5 (12.2)	6.2 (13.6)	2.6 (5.8)
EDC/WVE	12.1 (26.7)	3.9 (8.6)	-0.3 (-0.8)

- (a) Mission Option One
- (b) Mission Option Two
- (c) Mission Option Three

Mission Option One

Figure 15 shows the launch weight versus mission duration for EDO Mission Option One for the five CO₂ removal concepts evaluated. The launch weight savings attainable using the EDC subsystem versus baseline LiOH at the baseline mission duration is 59 kg (130 lb). The EDC Subsystem is the only regenerable CO₂ Removal Subsystem that has lower launch weight for the seven-day, seven-person mission. Reentry weight savings for the four regenerable subsystems are even greater since the CO₂ is vented to space vacuum whereas the CO₂ absorbed by LiOH is retained within the chemical. The total reentry weight savings attributed to the EDC for seven days is 106 kg (233 lb).

Mission Option Two

Figure 16 shows the launch weight comparison for EDO Mission Option Two. The EDC/WVE Subsystem has the lowest launch weight at the baseline mission duration of 19 days. A launch weight savings of 218 kg (480 lb) is attainable over the baseline LiOH. The reentry weight savings attributed to the EDC/WVE for a 19-day mission is 345 kg (760 lb).

Mission Option Three

Figures 17 and 18 show the launch weight and equivalent launch weight comparisons, respectively, for EDO Mission Option Three. Equivalent weight was used for the full capability power module since power and heat rejection penalties must be considered when comparing the various approaches. For missions with the full capability power module where water is not being generated by the fuel cells, those subsystems which generate or conserve water are the most competitive. The EDC has the lowest equivalent launch weight for a 30-day mission duration. The weight savings of the EDC over baseline LiOH is 363 kg (800 lb). The reentry weight savings attributed to the EDC is 563 kg (1240 lb).

The EDC/WVE equivalent weight curve slopes downward since O₂ is generated as a byproduct. Since the EDC/WVE performs part of the spacecraft O₂ generation function, credit is given to the subsystem via the negative expendables rate. The EDC and EDC/WVE subsystems are equivalent for a mission duration of approximately 80 days. For mission durations less than 80 days the EDC subsystem is preferred. For mission durations longer than 80 days the EDC/WVE subsystem is preferred.

CO₂ Removal Subsystem Evaluation Conclusions

Two EDC CO₂ Removal Subsystems for EDO application, the EDC and the EDC/WVE, have been evaluated and compared to baseline LiOH and two solid amine CO₂ Removal Subsystems for three EDO mission options. The regenerable CO₂ Removal Subsystems were shown to have significant weight savings when compared to the baseline LiOH CO₂ Removal Subsystem. The EDC Subsystems were shown to be better than the solid amine subsystems since the EDC Subsystem is applicable to all EDO mission options, has lower launch weight, volume and power, and has lower equivalent weight.

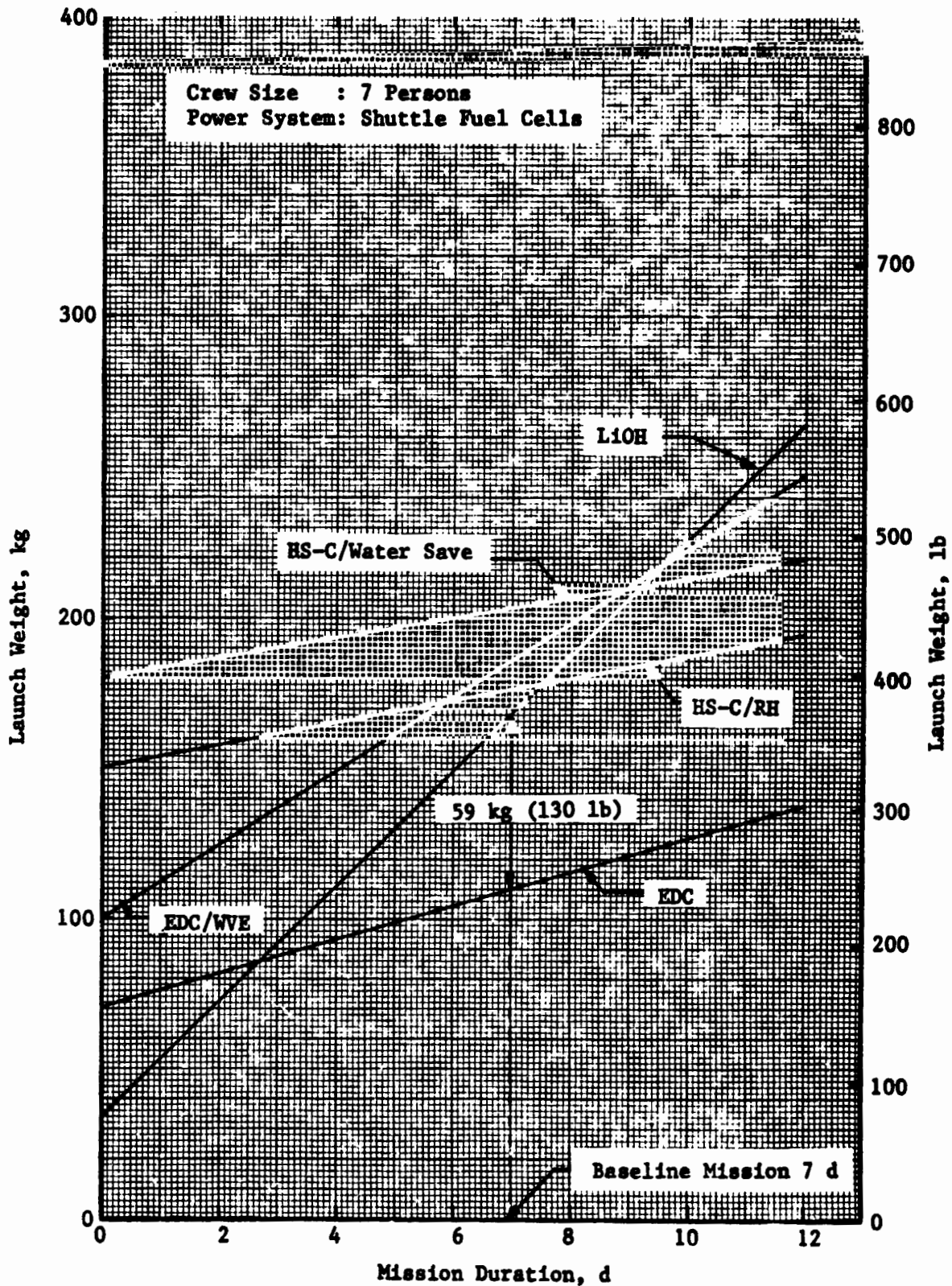


FIGURE 15 CO₂ REMOVAL SUBSYSTEMS LAUNCH WEIGHT COMPARISON: MISSION OPTION ONE

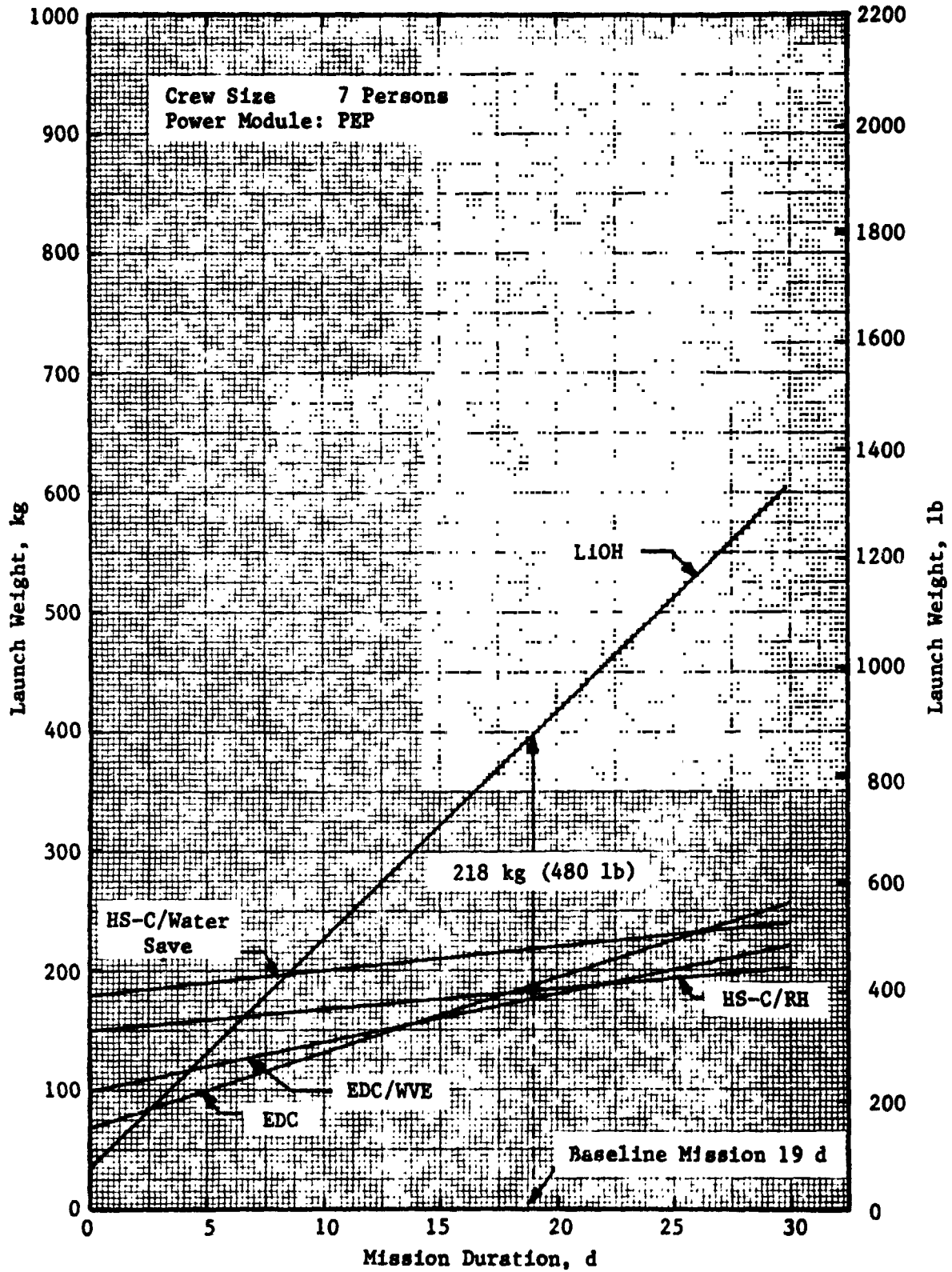


FIGURE 16 CO₂ REMOVAL SUBSYSTEMS LAUNCH WEIGHT COMPARISON: MISSION OPTION TWO

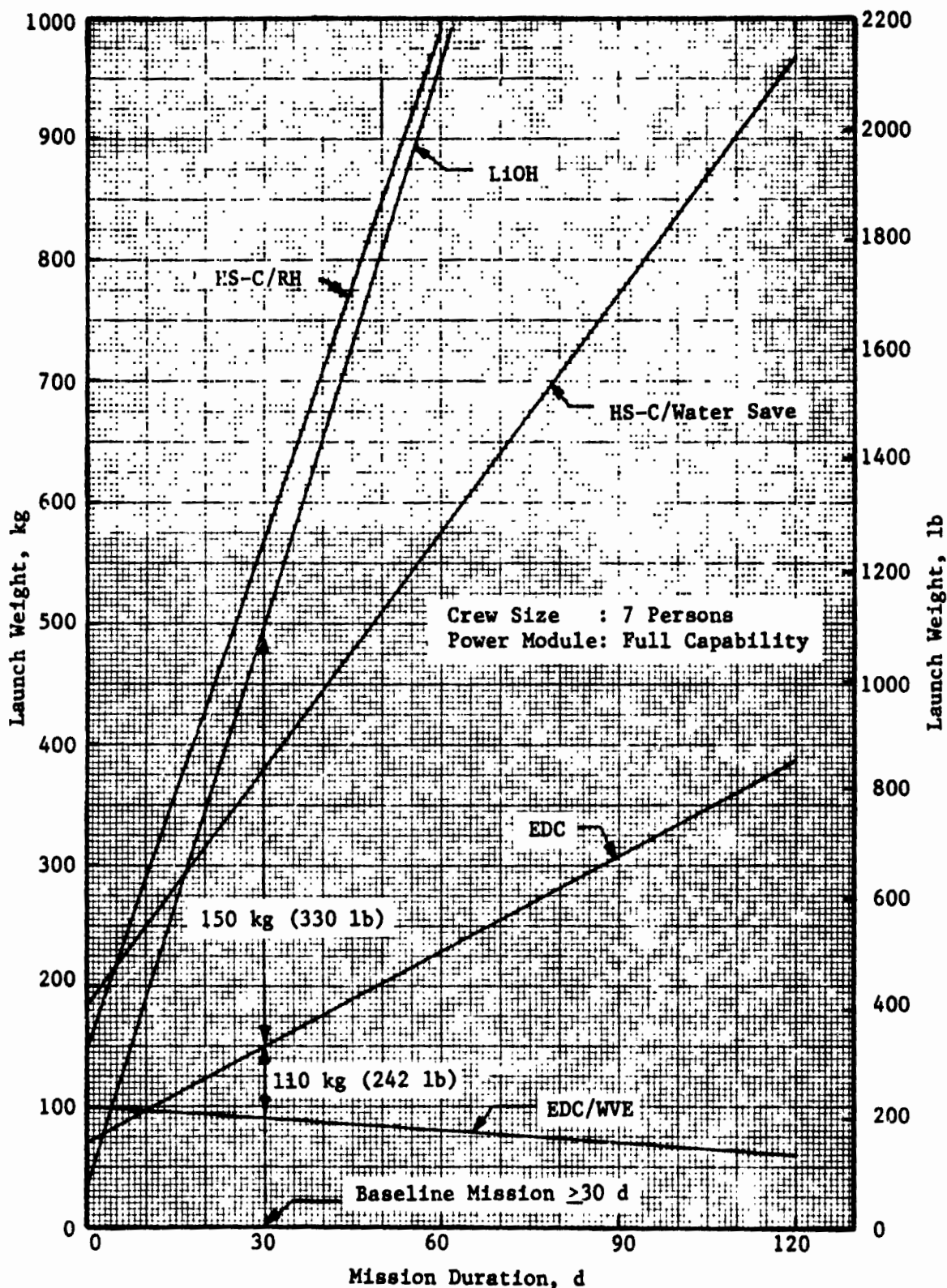


FIGURE 17 CO₂ REMOVAL SUBSYSTEMS LAUNCH WEIGHT COMPARISON:
MISSION OPTION THREE

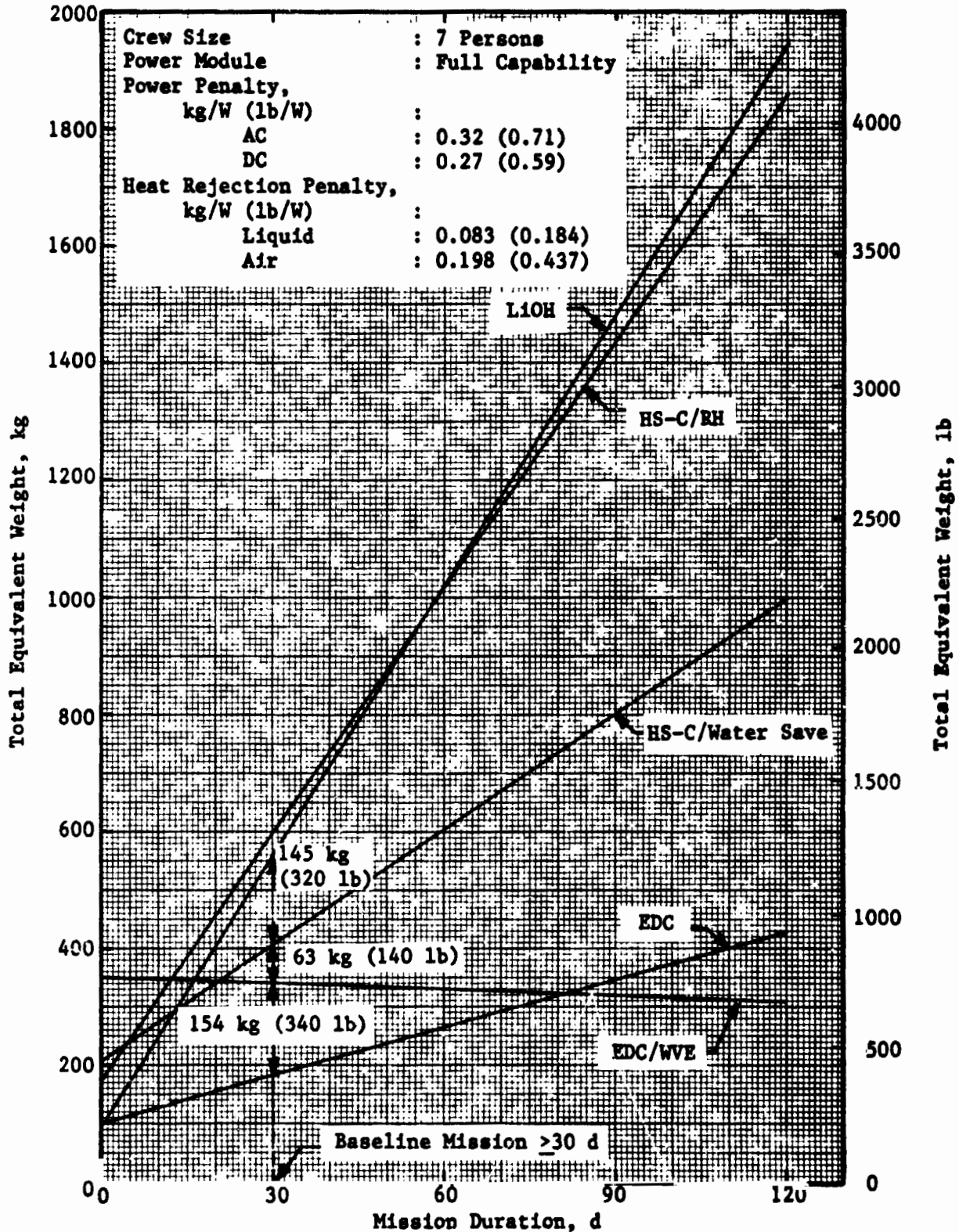


FIGURE 18 CO₂ REMOVAL SUBSYSTEM EQUIVALENT WEIGHT COMPARISON: MISSION OPTION THREE

Based on these results, the following conclusions were reached:

1. The LiOH CO₂ Removal Subsystem should be replaced by a regenerable CO₂ Removable Subsystem for EDO application.
2. Both the EDC and EDC/WVE are applicable to EDO CO₂ removal.
3. An EDC subsystem is preferred over a solid amine CO₂ Removal Subsystem for the missions evaluated.

WATER RECOVERY SUBSYSTEM

The function of a Water Recovery Subsystem (WRS) is to reclaim water from urine, wash water and condensate. The recovered water can be used by the Shuttle flash evaporators for supplemental heat rejection or, with additional treatment, used to meet potable water requirements. The VCDS was evaluated for Shuttle water recovery application. Table 13 shows the specific VCDS design specifications used. The following sections describe the VCDS design evaluation and comparison to on-board water storage.

VCDS Flight Concept

The VCDS consists of the still which performs the distillation process, the recycle tank which filters and stores the concentrated brine, plumbing to and from the subsystem components, and the peripheral mechanical and electrical components required to control and monitor subsystem performance. The principle of operation within the still is to recycle the latent heat of vaporization by compressing the vapor and condensing it on a surface in thermal contact with the evaporator. The condensing/boiling element and the condensing collector are rotated to achieve the required phase separation in zero g and facilitate liquid pickup. Electrical energy is required to compress the vapor and rotate the still.

Subsystem Description

Figure 19 is the Shuttle VCDS schematic showing the subsystem components and assemblies. The detailed VCDS schematic showing the subcomponents required to perform the control and monitoring functions is presented in Figure 20.

Operation. Pretreated wastewater from the Shuttle wastewater storage tanks enters the VCDS through the fluids control module. The fluids control module contains the valving required for the fluid streams. Wastewater is recirculated between the still and the Shuttle wastewater storage tank by the liquids pump via the fluids control module. The recycle tank is launched empty and is filled from the waste storage tank when system operation is initiated. Periodically during each day of operation the flow is diverted through the recycle tank to increase the removal rate of dissolved solids and prevent precipitation of these solids in the wastewater storage tank.

Product water from the still is pumped to the Shuttle product water storage tank by the liquids pump through the fluids control module. Product water conductivity is sensed to determine if the water is acceptable. If the conductivity exceeds the maximum limit, flow is diverted back to the recycle loop

TABLE 13 VCDS DESIGN SPECIFICATIONS

Crew Size	7
Mission Duration, d	30
Processing Rate, kg/d (lb/d)	
Urine	10.93 (24.08)
Wash Water	8.10 (17.85)
Total	19.04 (41.93)
Water Recovery Rate, kg/d (lb/d)	
Urine	10.11 (22.26)
Wash Water	8.09 (17.81)
Total	18.19 (40.07)
Solids Concentration, %	
Urine	3.8
Wash Water	0.1
Total	2.2
Product Water Pressure, kPa (psia)	170.4 (24.7)
Duty Cycle	Continuous or Intermittent
Cabin Temperature, K (F)	291 to 300 (65 to 80)
Cabin Pressure, kPa (psia)	101 (14.7)
Electrical Power, VAC ^(a) , VDC	115/200 27.5 to 32.5
Gravity	0 to 1
Noise Criteria, db	55

(a) 400 Hz, 3Ø

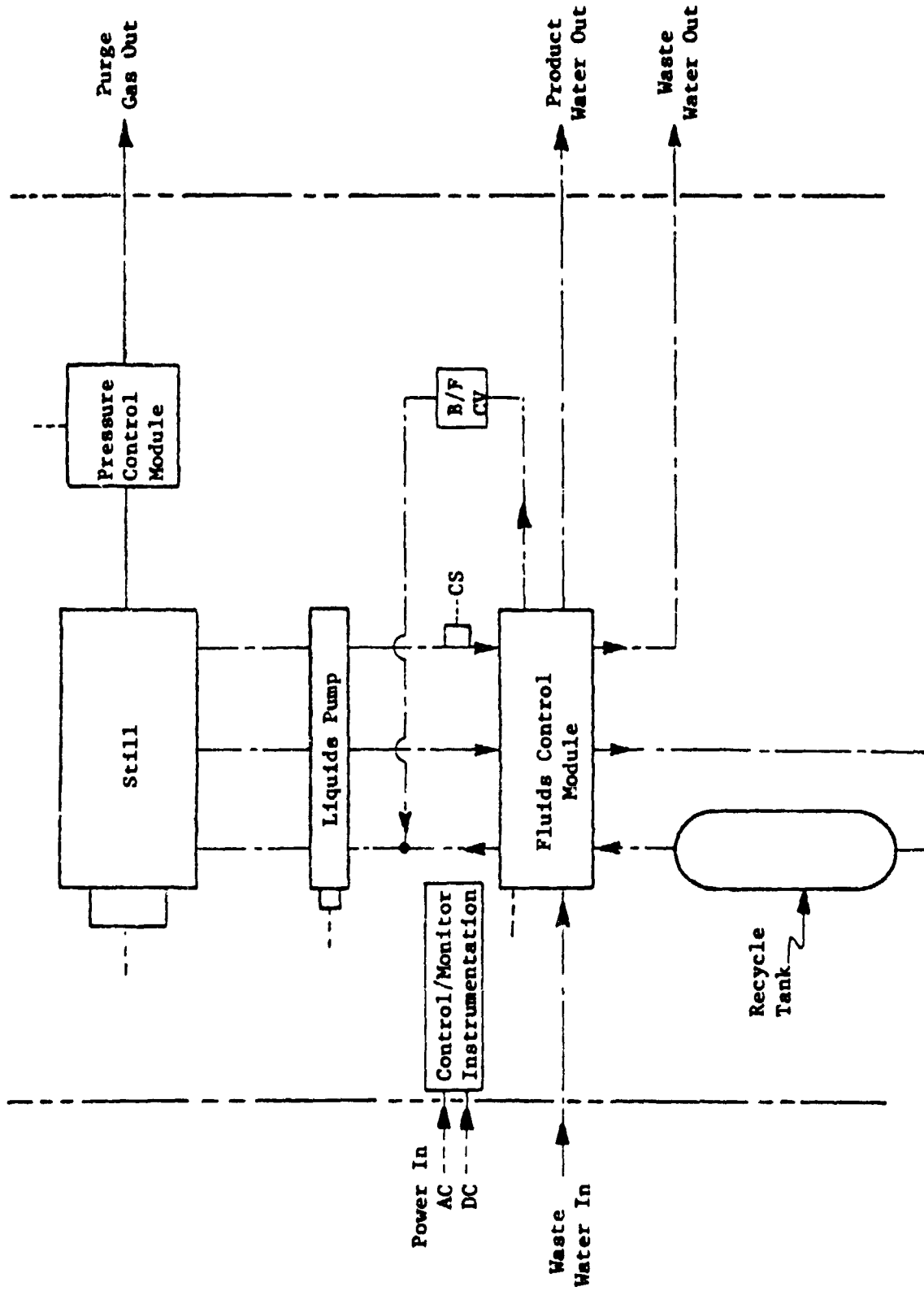


FIGURE 19 SHUTTLE VCDS SCHEMATIC

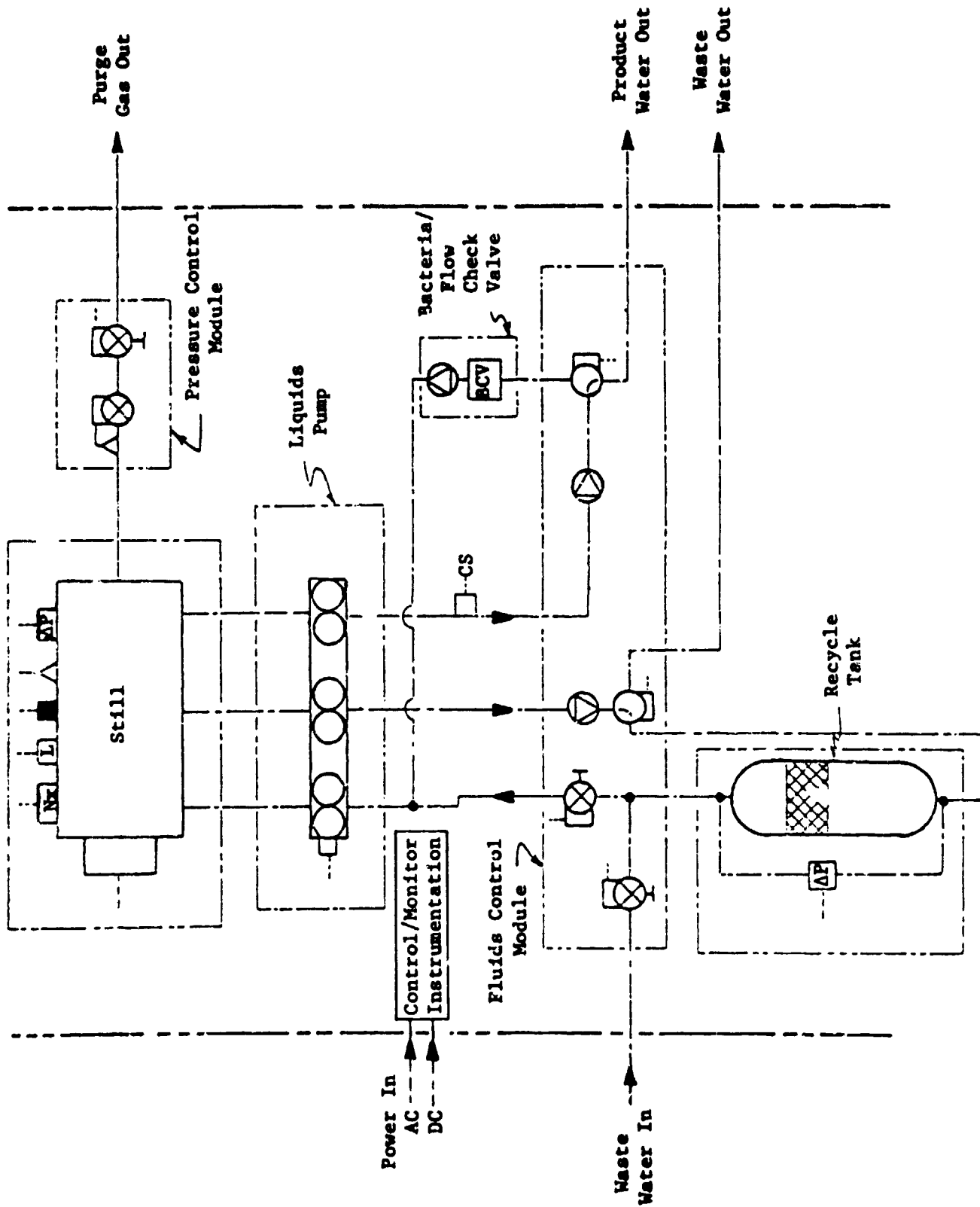


FIGURE 20 SHUTTLE VCDS DETAILED SCHEMATIC

for reprocessing. A bacteria/flow check valve is used to prevent back contamination of the product water stream.

Still pressure is maintained by the pressure control module using space vacuum. The space vacuum interface allows noncondensibles, with a small amount of water vapor, to be continuously purged from the VCDS.

Design Flexibility/Options. The VCDS is flexible to changes in mission requirements. The VCDS can operate over the entire four-person to ten-person range by simply using the wastewater storage tank as an accumulator assuming that the nominal seven-person processing rate is the average required processing rate for the mission. Should a more optimized VCDS design be desired, the compressor pressure ratio and still speed can be adjusted to optimize the water recovery function for different nominal or average processing rates.

All components shown in Figure 19 are flight maintainable to the component level assuming zero leakage liquid-line maintenance disconnect fittings are used. Depending on mission length and reliability goals, redundant components or spares can be included in the design to enhance reliability or increase mission duration. The present subsystem has been designed for 30 days and is limited by the size of the recycle tank. Fail-safe operation is accomplished using the water storage tanks on-board the Shuttle to accumulate wastewater and supply potable water when the VCDS is nonoperational.

Design Data. The design point for the VCDS is a seven-person crew size which corresponds to a urine and wash water processing rate of 19.0 kg/d (41.9 lb/d). Increases in the wastewater production rate are accommodated using the wastewater storage tank as an accumulator. Operation at less than the seven-person level is easily met by reducing the duty cycle for the VCDS. The still required for the VCDS design has a surface area of 0.19 m² (2.0 ft²). The VCDS operating characteristics are presented in Table 14.

Component Weight, Power and Heat Rejection. Component weight, power and heat rejection estimates for the seven-person VCDS design are given in Table 15. The still accounts for approximately 50% of the subsystem weight. The other major weight factors are the recycle tank, liquids pump and packaging. Packaging was estimated at 20%. The power requirements were divided into AC and DC power.

Packaging

Figure 21 shows the Shuttle seven-person capacity VCDS packaging configuration. The overall subsystem dimensions are 64 x 30 x 71 cm (25 x 12 x 28 in). The subsystem is designed to fit under the mid-deck floor and interface directly with the Orbiter wastewater and water storage tanks. This location for the VCDS assumes that the baseline CO₂ removal subsystem is replaced by the EDC thereby eliminating the need for the LiOH canisters storage racks. The VCDS is designed to mount directly to the Shuttle floor supports. The seven-person VCDS requires a volume of 0.14 m³ (4.9 ft³) which is only 21% of the 0.65 m³ (23 ft³) reserved for storage of the Shuttle LiOH canisters.

TABLE 14 SHUTTLE VCDS OPERATING CHARACTERISTICS

Water Recovery Rate, kg/d (lb/d)	18.2 (40.1) ^(a)
Duty Cycle, %	80
Condenser Pressure, kPa (psia)	4.8 (0.7)
Compressor Pressure Differential, kPa (psid)	0.7 (0.1)
Fluids Pump Flow Rate, kg/h (lb/h)	
Feed	4.5 (10.0)
Recycle	3.6 (7.9)
Product	0.9 (2.1)
Purge Gas Flow Rate, m ³ /h (ft ³ /h)	9.11 (3.9)
Purge Gas Water Loss, %	0.5
Subsystem Specific Energy, W-h/kg (W-h/lb)	125 (57)
Solids Concentration (Max), %	50
Recycle Tank Capacity (210 person-days), kg (lb)	25 (56)

(a) Urine and wash water only

TABLE 15 VCDS COMPONENT WEIGHT, POWER AND HEAT GENERATION SUMMARY

<u>Component</u>	<u>No. Req'd</u>	<u>Weight, kg (lb)</u>	<u>Power, W</u>		<u>Heat Gen., W</u>
			<u>AC</u>	<u>DC</u>	
Still	1	36 (80)	70	--	70
Recycle Tank (Dry)	1	7 (15)	--	--	--
Liquids Pump	1	7 (15)	25	--	25
Fluids Control Module	1	2 (5)	--	10	10
Pressure Control Module	1	1 (2)	--	--	--
Bacteria/Flow Check Valve	1	1 (2)	--	--	--
Conductivity Sensor	1	0 (1)	--	5	5
Instrumentation	1	3 (7)	--	10	10
Packaging (20%)	$\frac{1}{8}$	$\frac{11}{69}$ (25) (152)	-- 95	-- 25	-- 120

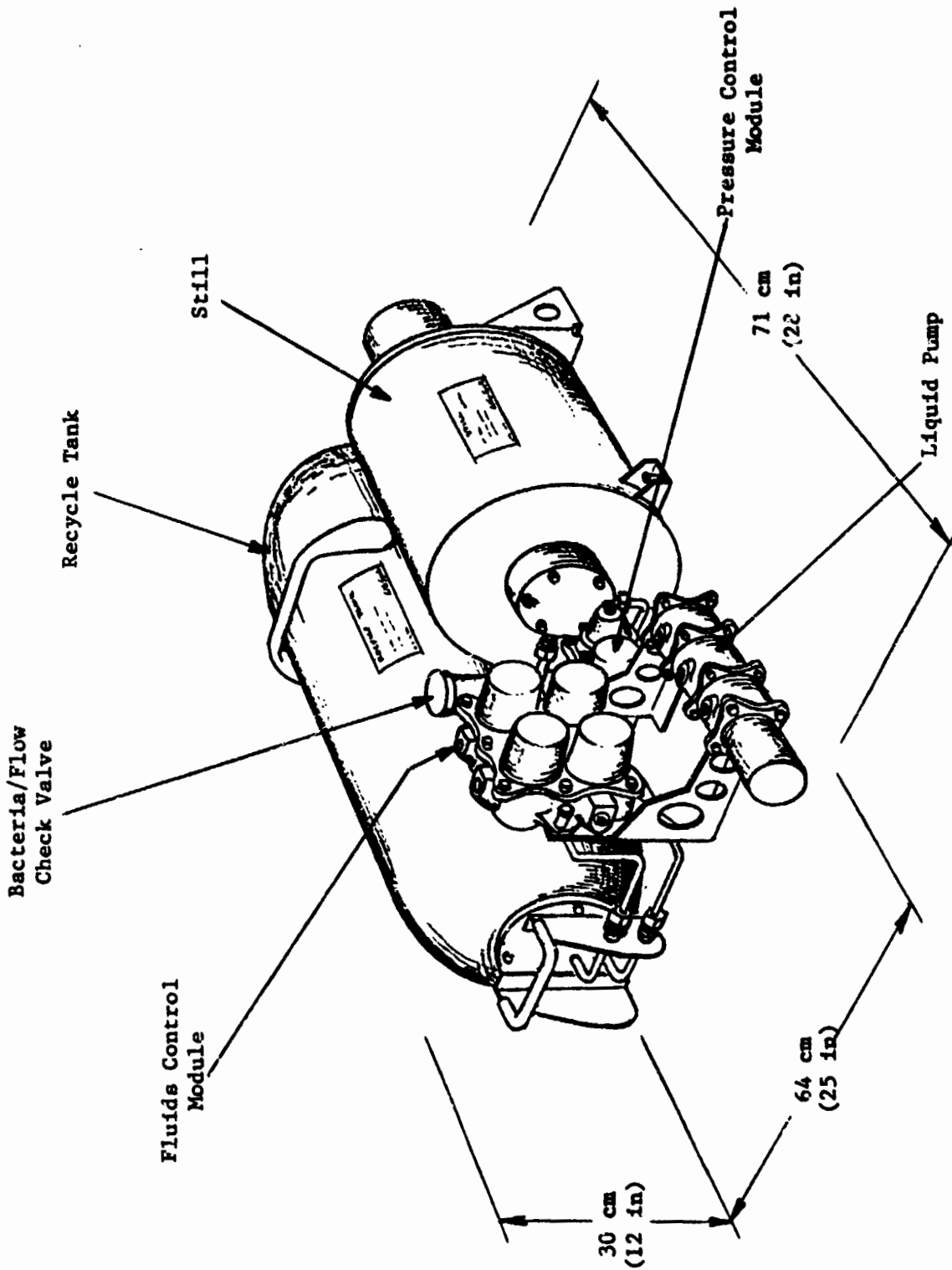


FIGURE 21 'TITLE VCDS CONFIGURATION

Subsystem Characteristics

The VCDS characteristics for the seven-person design are presented in Table 16. The VCDS recovers approximately 95% of the wastewater processed or 18.2 kg/d (40.1 lb/d). The power requirements are divided into AC and DC requirements. The heat load is the sensible heat given off by the power consuming components.

Expendables are required for the VCDS. Approximately 0.5% of the water processed is lost with the purge gas to vacuum. This amounts to approximately 0.1 kg/d (0.2 lb/d). The recycle tank can also be considered an expendable since its size varies with mission duration and water processing rate.

Vehicle Integration for Supplementary Heat Rejection

The VCDS hardware is designed to interface directly with existing Shuttle Water Management System (WMS) components. The existing Shuttle water management block diagram is presented in Figure 22. The location of the VCDS within the Shuttle WMS is shown in Figure 23. In addition to the VCDS, the Shuttle water recovery subsystem for supplementary heat rejection would require that a pretreat unit, a post-treat unit and a bacteria/filter check valve be added to the WMS components. The VCDS WRS characteristics are presented in Table 17. The VCDS obtains water for processing from one of the present Shuttle wastewater storage tanks. Urine and wash water are processed through the VCDS. Condensate is processed primarily through the pretreat although it can also be processed through the VCDS via the wastewater storage tank. The VCDS product water, along with condensate, passes through the post-treat unit and is stored in a product water storage tank until needed by the flash evaporators for supplementary heat rejection. The product water tank is a converted wastewater storage tank. The bacteria/flow check valve isolates the product water from the existing Shuttle potable water tanks. Both the VCDS product water and stored potable water can be used for supplementary heat rejection.

The VCDS requires only three Shuttle mechanical interfaces: wastewater from the storage tank, overboarded vent and product water to the storage tank via post-treat. All resources, including the required number of water tanks, presently exist on the Shuttle.

Vehicle Integration for Potable Water

The location of the VCDS within the Shuttle WMS for potable water recovery is presented in Figure 24. In addition to the VCDS, the potable Water Recovery Subsystem requires a pretreat unit, post-treat, ACIDD, WQM and a three-way valve. The VCDS interfaces with the Shuttle water management components for potable water recovery in the same manner as it did for supplementary heat rejection water recovery. The Water Recovery Subsystem requires a residual biocide and a WQM to monitor product water quality for acceptability. The Shuttle potable water recovery system component characteristics are shown in Table 18.

The VCDS interfaces as part of a potable WRS are identical to those required for supplementary heat rejection water recovery. All required resources presently exist on the Shuttle.

TABLE 16 SHUTTLE VCDS CHARACTERISTICS

Crew Size	7
Water Recovery Rate, kg/d (lb/d)	18.2 (40.1)
Fixed Dry Hardware Weight, kg (lb)	69 (152)
Overall Dimensions, cm (in)	64 x 71 x 30 (25 x 28 x 12)
Volume, m ³ (ft ³)	0 14 (4.9)
Power Required, WAC , WDC	95 25
Heat Load, W	120

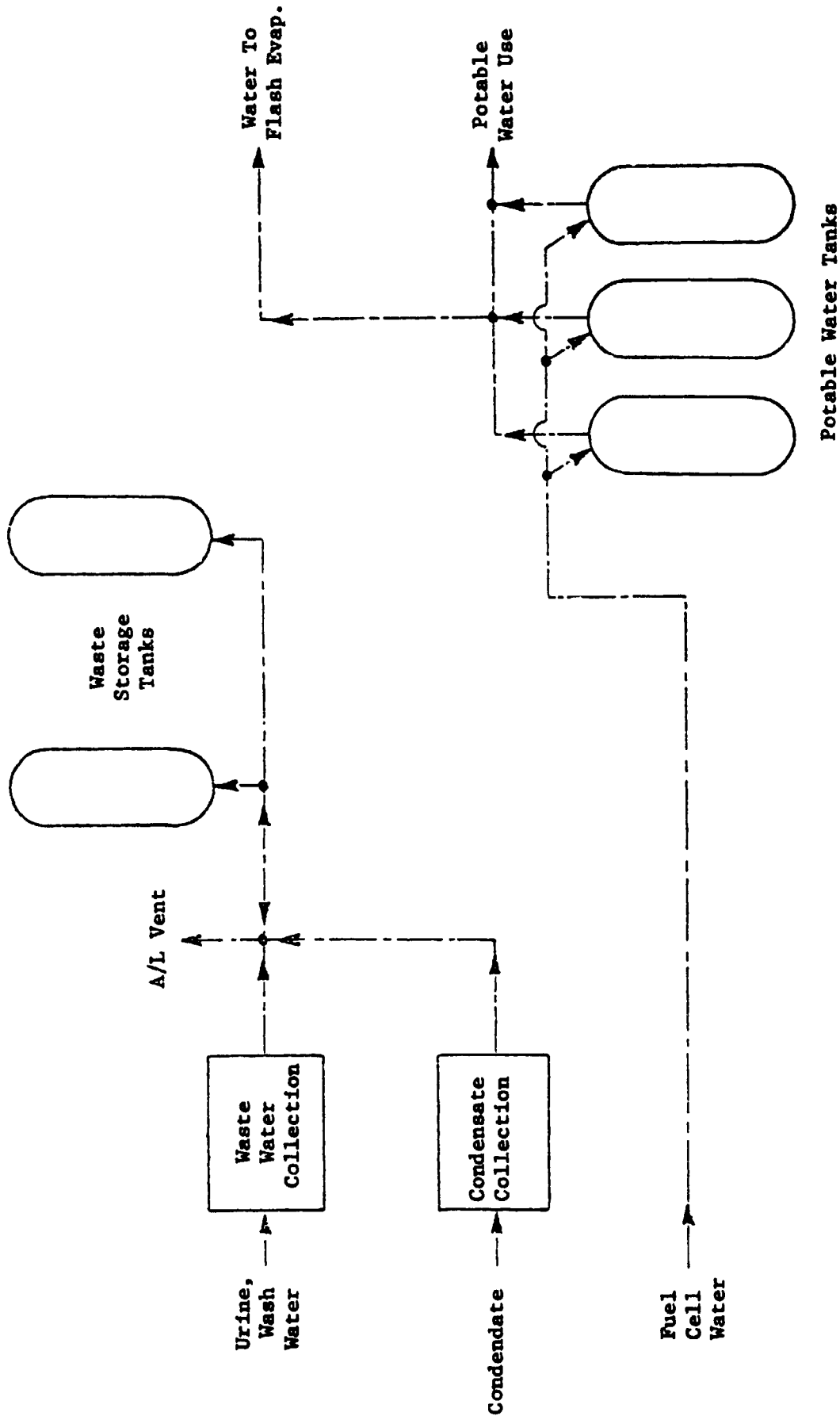
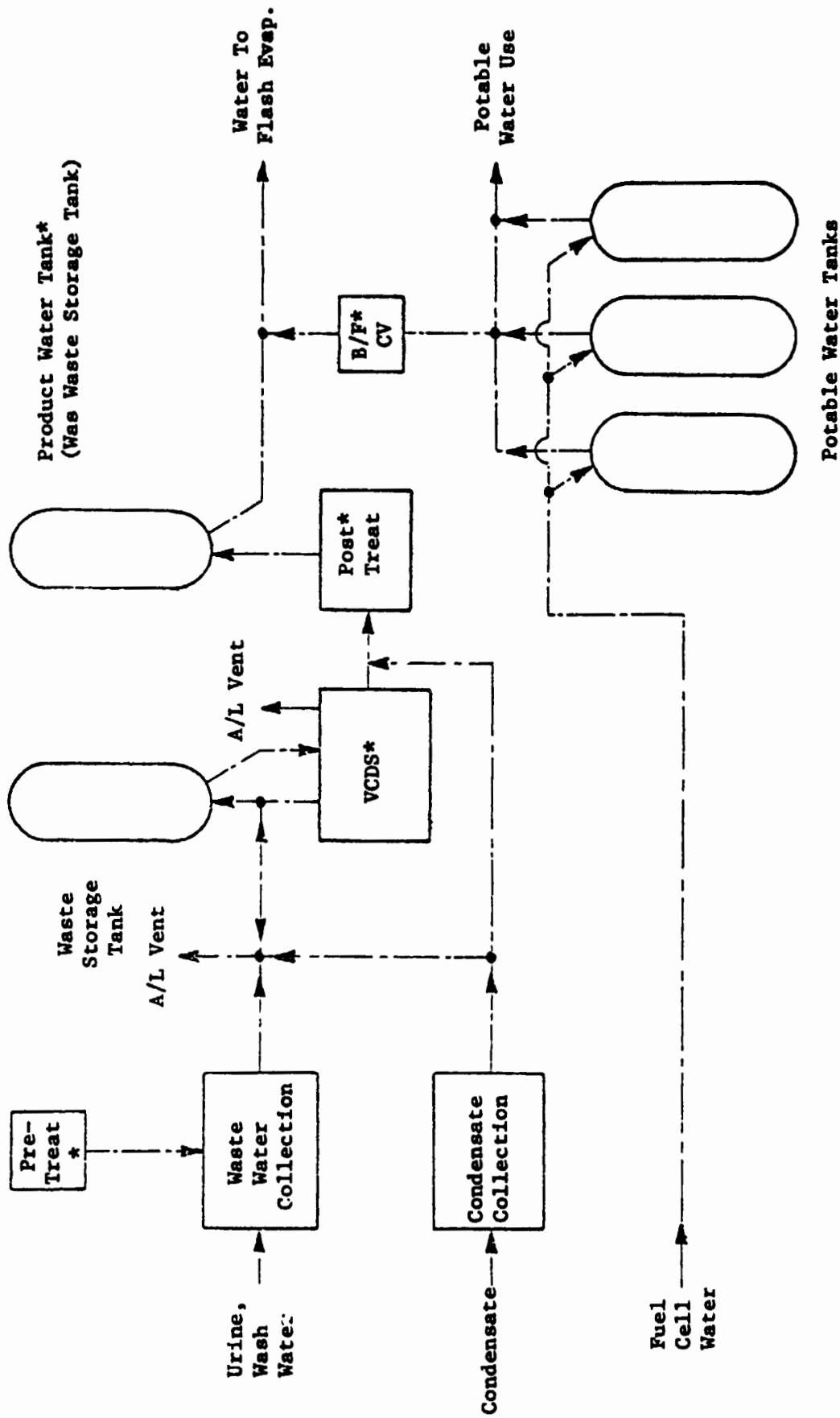


FIGURE 22 EXISTING SHUTTLE WATER MANAGEMENT BLOCK DIAGRAM



* New for EDO

FIGURE 23 SHUTTLE WATER RECOVERY BLOCK DIAGRAM FOR SUPPLEMENTAL HEAT REJECTION

TABLE 17 VCDS-BASED WATER RECOVERY SUBSYSTEM CHARACTERISTICS^(a)

System Component	Weight, kg (lb)	Volume, m ³ (ft ³)	Power, W		Heat Rej., W	Expendables, kg/d (lb/d)
			AC	DC		
VCDS	69 (152)	0.14 (4.9)	95	25	120	0.1 (0.2)
Pretreat ^(b)	14 (30)	0.02 (0.6)	0 ^(c)	--	0	--
Post-Treat ^(b)	5 (12)	0.01 (0.3)	--	--	--	--
B/F CV	$\frac{1}{89}$ ($\frac{2}{196}$)	$\frac{0}{0.16}$ ($\frac{0}{5.8}$)	$\frac{--}{95}$	$\frac{--}{25}$	$\frac{--}{120}$	$\frac{--}{0.1}$ (0.2)

(a) For supplemental heat rejection only

(b) Sized for 30-days

(c) Peak pump power 30 W; average power ~ 0 W

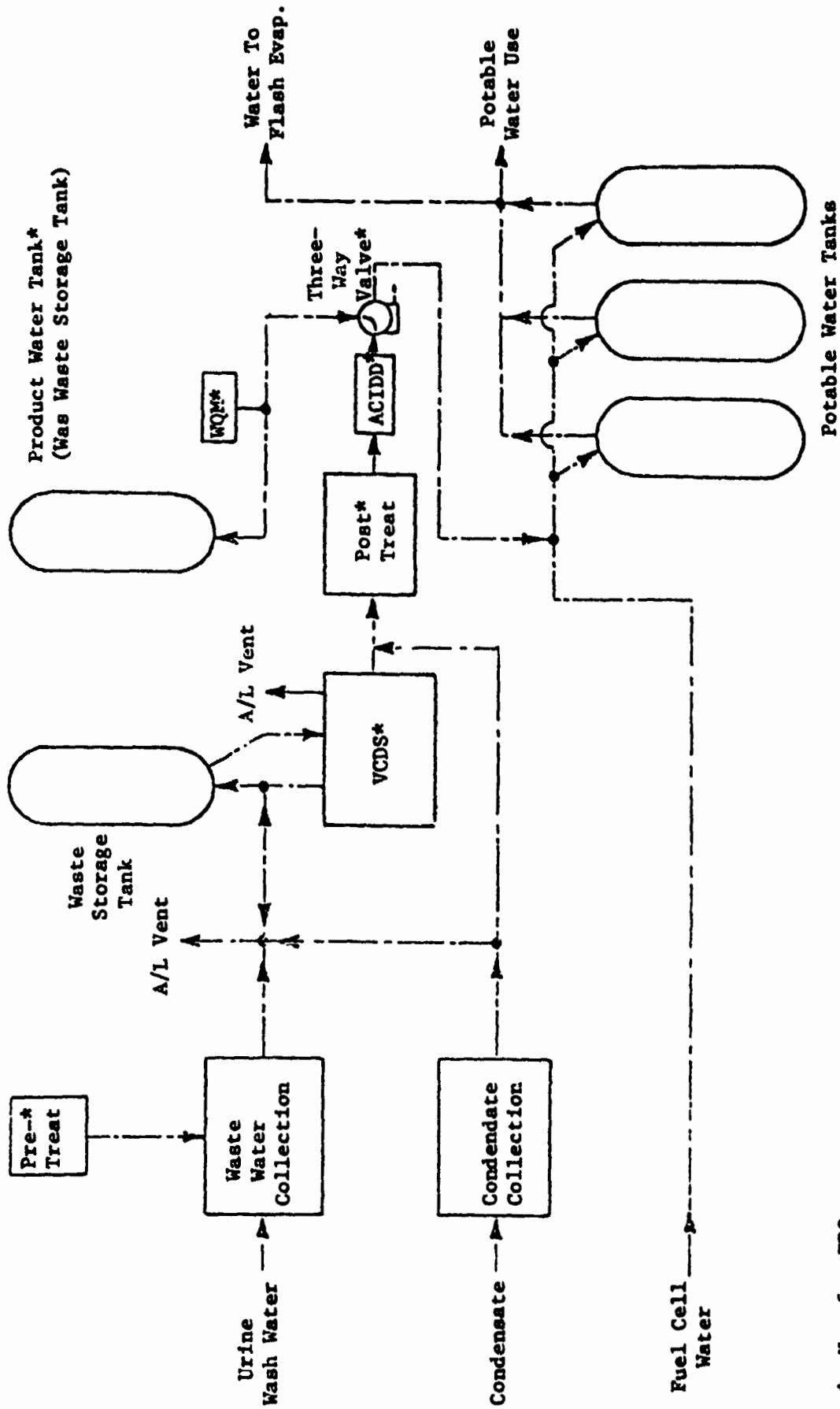


FIGURE 24 SHUTTLE POTABLE WATER RECOVERY BLOCK DIAGRAM

* New for EDO

TABLE 18 VCDS-BASED POTABLE WATER RECOVERY SYSTEM CHARACTERISTICS

System Component	Weight, kg (lb)	Volume, m ³ (ft ³)	Power, W		Heat Rej., W	Expendables, kg/d (lb/d)
			AC	DC		
VCDS	69 (152)	0.14 (4.9)	95	25	120	0.3 (0.7) ^(a)
Pretreat ^(b)	14 (30)	0.02 (0.6)	0 ^(c)	--	0	0.2 (0.5)
Post-Treat ^(b)	5 (12)	0.01 (0.3)	--	--	--	0.2 (0.4)
ACIDD	1 (3)	0 (0)	6	--	6	--
WQM	2 (4)	0 (0)	--	4	4	--
Three-Way Valve	$\frac{1}{92}$ (2) (203)	$\frac{0}{0.16}$ (0) (5.8)	--	$\frac{0}{29}$ ^(d)	$\frac{0}{130}$	$\frac{--}{0.7}$ (1.6)

- (a) Includes water vapor loss to vent and recycle tank
- (b) Sized for 30 days
- (c) Peak pump power 30 W; average power ~ 0 W
- (d) Only requires power to activate

Development Status

The VCDS technology is well established. Three prototype units have been fabricated: the six-person VCDS for SSP application and two three-person VCDSs for RLSE. A photograph of LSI's RLSE VCDS is presented in Figure 25. The VCDS can be available for flight application by 1983.

Water Recovery Subsystem Comparison

The VCDS-based WRS's for supplementary heat rejection and potable water recovery were compared to on-board storage of water for Mission Options Two and Three (see Table 2). For comparison purposes it was assumed that for on-board potable water storage, wastewater is dumped overboard as opposed to on-board wastewater storage for the mission duration. Mission Option One was not considered for water recovery since power is supplied exclusively by fuel cells and sufficient water is produced to meet vehicle needs.

For enhanced Orbiter Mission Option Two sufficient potable water exists such that the water recovered by the VCDS would be required for supplementary heat rejection only. For Mission Option Three, however, water is not generated by the fuel cells and potable water requirements must be met by on-board storage or water recovery. The water recovery rate used for comparison was 29.3 kg/d (64.5 lb/d) which equals the sum of the VCDS recovery rate (18.2 kg/d (40.1 lb/d)) and the condensate recovery rate (11.1 kg/d (24.4 lb/d)).

Mission Option Two

Table 19 summarizes the WMS characteristics for supplementary heat rejection water recovery. The values given do not include those for the existing Shuttle components such as the five water tanks. The values listed for the VCDS include the additional WRS components required that were presented in Table 17. Expendables include process expendables and cryogen for power generation at 3.33 kg/kW-d (7.34 lb/kW-d) for fuel cell generated DC power. A 76% conversion efficiency was assumed for AC power. A cryogen storage tankage penalty of 100% was added to the cryogen consumption rate.

Figure 26 shows the launch weight versus mission duration for EDO Mission Option Two for water storage and the VCDS. The launch weight savings attainable using the VCDS-based water recovery system versus baseline water storage is 696 kg (1,533 lb). Weight savings are attainable using a VCDS water recovery system after two days for a seven-person crew size.

Mission Option Three

Table 20 presents the potable WMS characteristics for water storage and a VCDS water recovery system. The values used do not include baseline Shuttle components. The VCDS WRS includes all additional components required for potable water recovery (see Table 19). Figure 27 shows the total equivalent launch weight comparisons for EDO Mission Option Three. Equivalent weight was used for the full capability power module since power and heat rejection penalties must be considered when comparing the two approaches. Equivalent weight savings attributed to the VCDS water recovery system are 1,092 kg (2,405 lb) for a nominal mission length of 30 days. The water recovery rate includes urine,

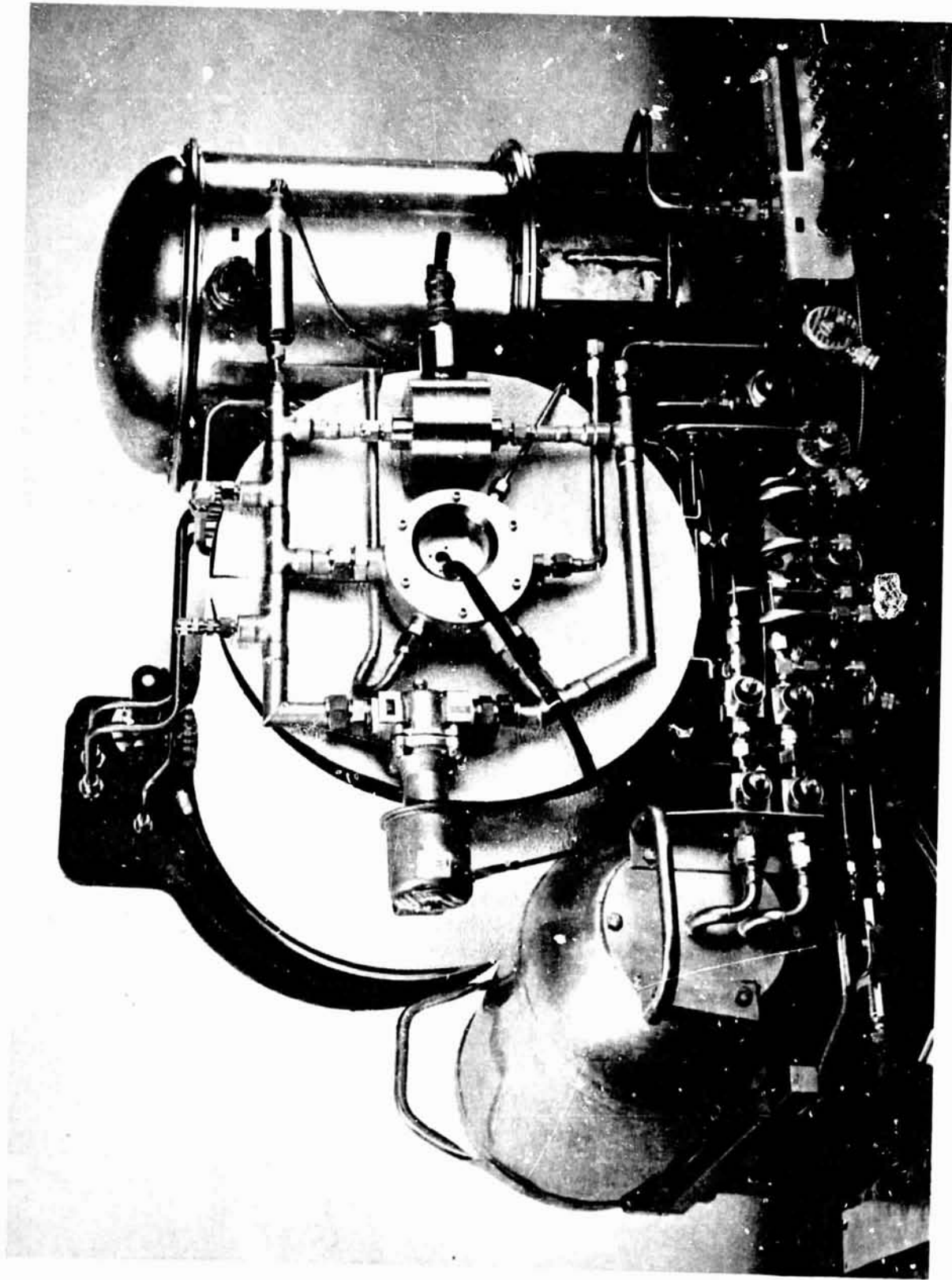


FIGURE 25 RLSE PREPROTOTYPE VCDS

TABLE 19 WATER MANAGEMENT SYSTEMS CHARACTERISTICS^(a)

System	Weight, (b)	Volume, (b)	Power, W		Heat Rej.,	Expendables, (c)
	kg (lb)	m ³ (ft ³)	AC	DC	W	kg/d (lb/d)
Storage	0 (0)	0 (0)	0	0	0	42.4 (93.4)
VCDS	89 (196) ^(d)	0.16 (5.8) ^(d)	95	25	120	(2.4)

(a) For supplemental heat rejection only

(b) Does not include baseline Orbiter components weight

(c) Includes cryogen for power generation with tankage and process expendables

(d) Includes 30-day capacity Recycle Tank, Pretreat and Post-Treat

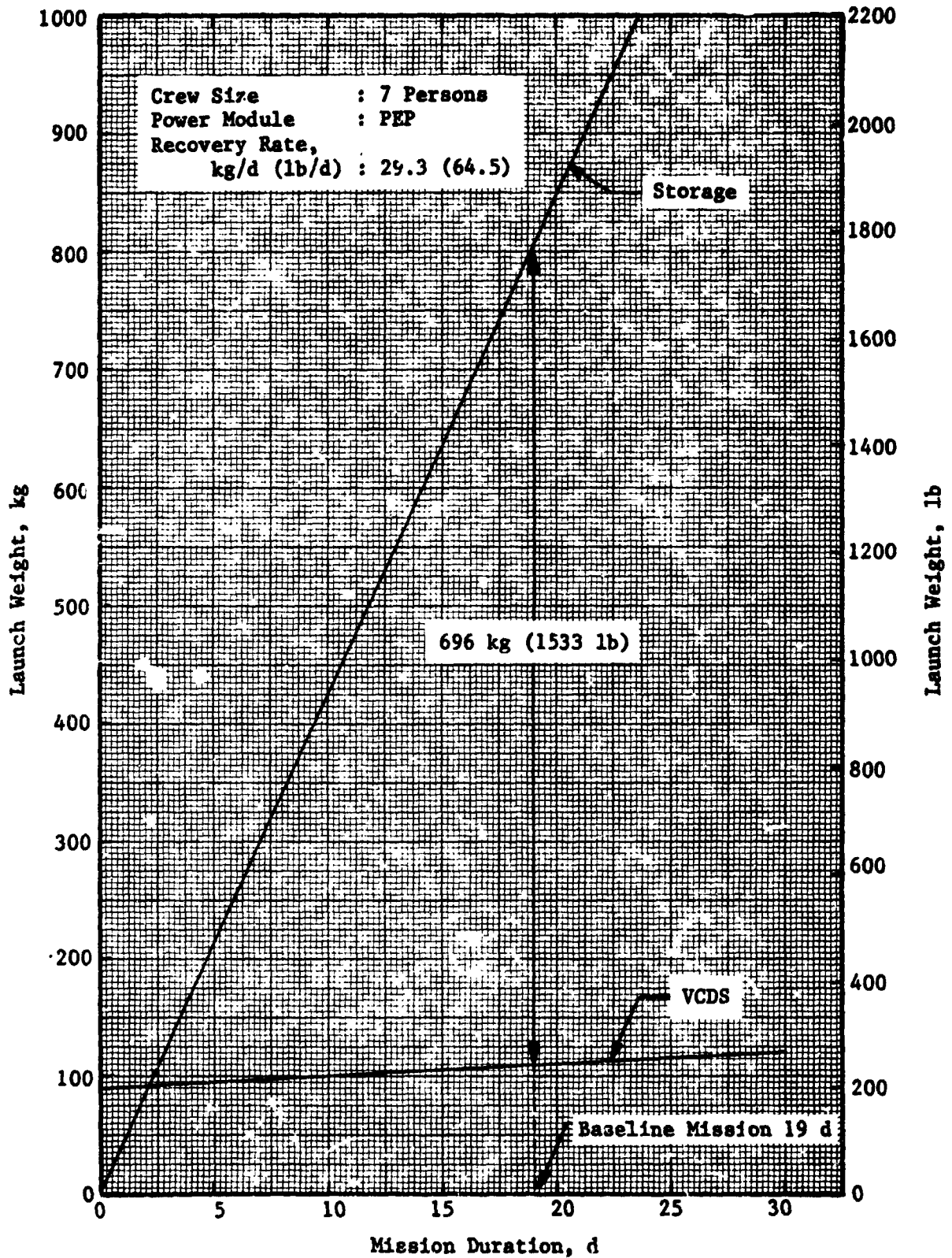


FIGURE 26 WATER MANAGEMENT SYSTEM LAUNCH WEIGHT COMPARISON:
MISSION OPTION TWO

TABLE 20 POTABLE WATER MANAGEMENT SYSTEMS CHARACTERISTICS

System	Weight, (a)	Volume, (a)	Power, W		Heat Rej., W	Expendables, (b) kg/d (lb/d)
	kg (lb)	m ³ (ft ³)	AC	DC		
Storage	0 (0)	0 (0)	0	0	0	42.4 (93.4)
VCDS ^(c)	92 (203) ^(c)	0.16 (5.8) ^(c)	101	29	130	0.7 (1.6)

(a) Does not include baseline Orbiter components weight

(b) For full capability power module; only process expendables included

(c) Includes 30-day capacity Recycle Tank, Pretreat and Post-Treat

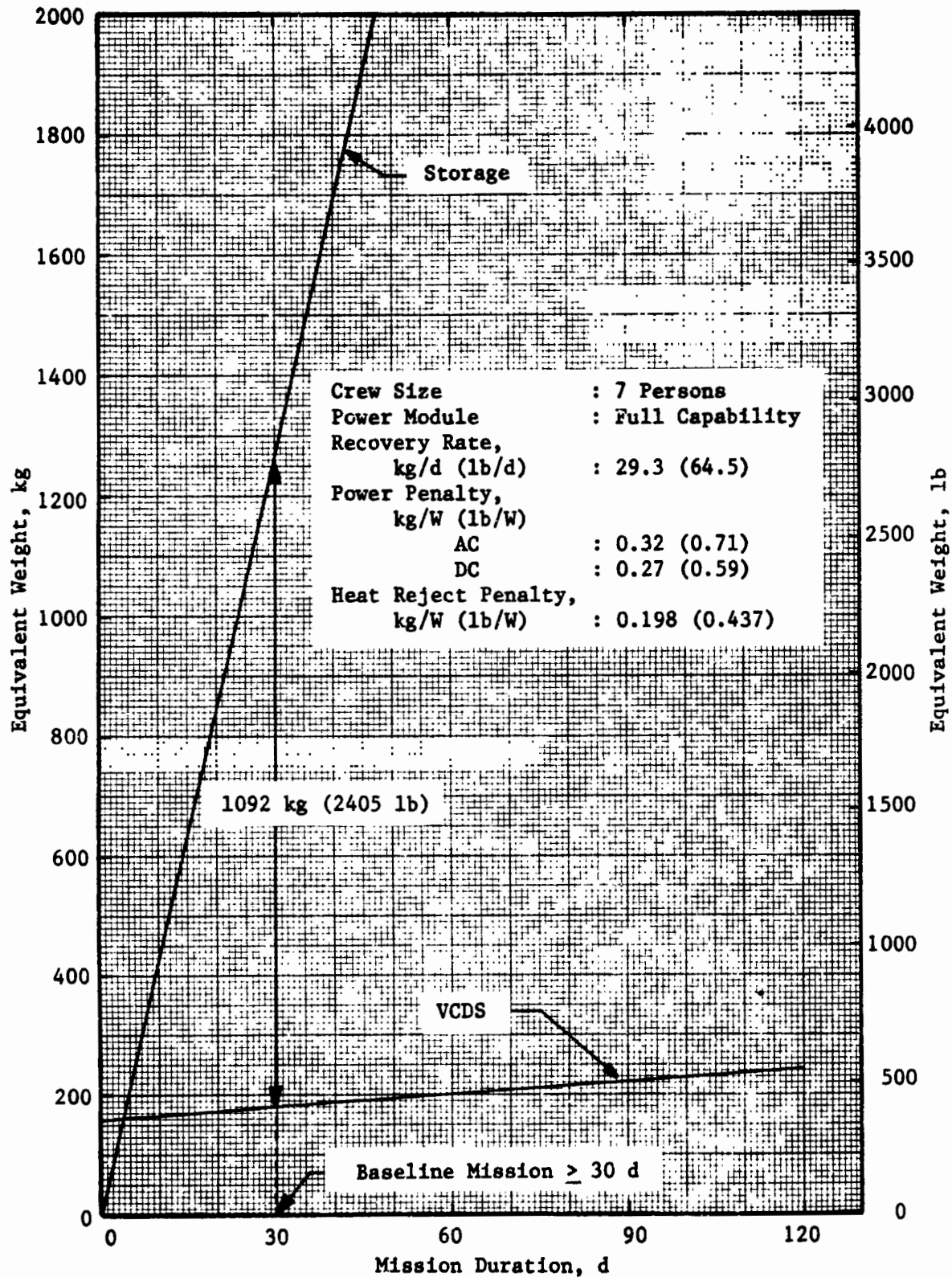


FIGURE 27 WATER MANAGEMENT SYSTEM EQUIVALENT WEIGHT COMPARISON:
MISSION OPTION THREE

wash water and condensate recovery. Weight savings for Mission Option Three occur for mission durations greater than four days for a crew size of seven.

Water Recovery Subsystem Evaluation Conclusions

The VCDS-based WRS for EDO application has been evaluated for both supplementary heat rejection and potable water recovery. The VCDS was shown to be clearly superior to on-board water storage when fuel cell water is insufficient to meet Orbiter water requirements. Weight savings occur for mission durations as brief as two days for a seven-person crew.

COMBINED CO₂ REMOVAL AND WATER RECOVERY

The CO₂ Removal and Water Recovery Subsystems evaluations for Shuttle application have been treated separately up to this section. The expendables penalty for water vented overboard by some CO₂ removal subsystems, however, is determined by Orbiter water requirements. Also, the post-treat portion of a WRS is affected by the CO₂ removal subsystem selection since the condensate processing requirements are different for each subsystem. The VCDS size remains the same since condensate is not processed by the VCDS still. Because the CO₂ removal and water recovery functions affect each other, special consideration is given in this section to the impact of the combined functions on subsystem selection.

Combined CO₂ removal and water recovery was not considered for Mission Option One since water recovery is not required. For Mission Option Three the savings associated with combined CO₂ removal and water recovery will be basically the sum of the savings for the individual functions versus baseline Shuttle LiOH and water storage. The reason for this is that water vented overboard in Mission Option Three was considered an expendable penalty to the CO₂ removal subsystems evaluated. Mission Option Two, however, is more difficult to evaluate since the amount of additional water required for supplementary heat rejection will affect whether water recovery is needed and if so, how much.

The following sections discuss the effect of combining the CO₂ removal and water recovery functions for Mission Options Two and Three. All comparison assumptions made during the individual subsystem comparisons were retained unless specifically noted to the contrary.

Mission Option Two

The CO₂ removal subsystems comparison presented earlier for Mission Option Two assumed that sufficient water would be available for supplemental heat rejection and the subsystems were not penalized for water vented overboard. The VCDS evaluation for Mission Option Two, however, assumed that additional supplemental heat rejection water would be required at a rate equal to or greater than that produced by the VCDS-based WRS. The impact of water recovery on CO₂ removal subsystem selection must therefore be considered.

Combined CO₂ removal and water recovery was considered for two levels of additional Shuttle water requirements. These levels are based on the water recovery rate available when only condensate is processed and when condensate, urine and wash water are processed. The condensate only water processing

rate was assumed to be the sum of the metabolic and EDC condensate generated or 14.3 kg/d (31.5 lb/d). The condensate, urine and wash water recovery rate was assumed to be the sum of the condensate (including EDC) and VCDS water recovery rates or 32.5 kg/d (71.6 lb/d).

Condensate Recovery

The results of the combined functions as identified by the CO₂ removal subsystem are presented in Figure 28. The EDC and EDC/WVE subsystem fixed hardware weights were increased to include the additional components required for condensate recovery including a 100% plumbing and retrofit penalty. The HS-C/RH Subsystem does not require these additional components since the water vented overboard by this process is removed from the cabin air. The removal of latent heat from the cabin reduces the vehicle's heat rejection requirements and therefore the subsystem indirectly performs supplementary heat rejection. The HS-C/Water Save Subsystem was not considered since supplementary heat rejection was assumed to be required.

The HS-C/RH Subsystem was penalized only for the additional water storage required to go from metabolic condensate requirements up to the assumed supplementary heat rejection water requirements. The EDC/WVE subsystem was penalized similarly. The EDC subsystem, however, with its additional condensate generation, did not incur any additional water storage penalty.

As shown, the EDC subsystem is favored by supplementary heat rejection requirements of greater than or equal to 14.3 kg/d (31.5 lb/d). A weight savings of 61 kg (134 lb) was attributed to the EDC over the HS-C/RH and EDC/WVE Subsystems. For water recovery rates below 11.1 kg/d (24.4 lb/d), the metabolic condensate generation rate, the results of the individual CO₂ removal subsystems comparisons for Mission Option Two previously considered remain approximately the same since the fixed hardware penalty associated for condensate recovery with the EDC and EDC/WVE are small. For water recovery rates between these two values, the EDC with its additional water generation becomes more attractive as water recovery requirements increase.

Total Water Recovery

The results of the combined CO₂ removal and water recovery functions are presented in Figure 29. The regenerable CO₂ removal subsystems include the weight of a VCDS and other WRS components. The difference in size of the post-treat units required for the HS-C and EDC concepts was taken into account. Again, the HS-C/Water Save Subsystem was not considered since supplementary heat rejection is required. The combined savings using a regenerable CO₂ removal subsystem and water recovery is significant. Again, the EDC Subsystem is slightly favored over the other CO₂ removal concepts since it produces additional condensate that the other CO₂ removal subsystems do not. A weight savings of 64 kg (141 lb) was attributed to the EDC over the HS-C/RH and EDC/WVE Subsystems.

Mission Option Three

Potable water recovery is required for Mission Option Three. The combined savings associated with a regenerable CO₂ removal subsystem and water recovery

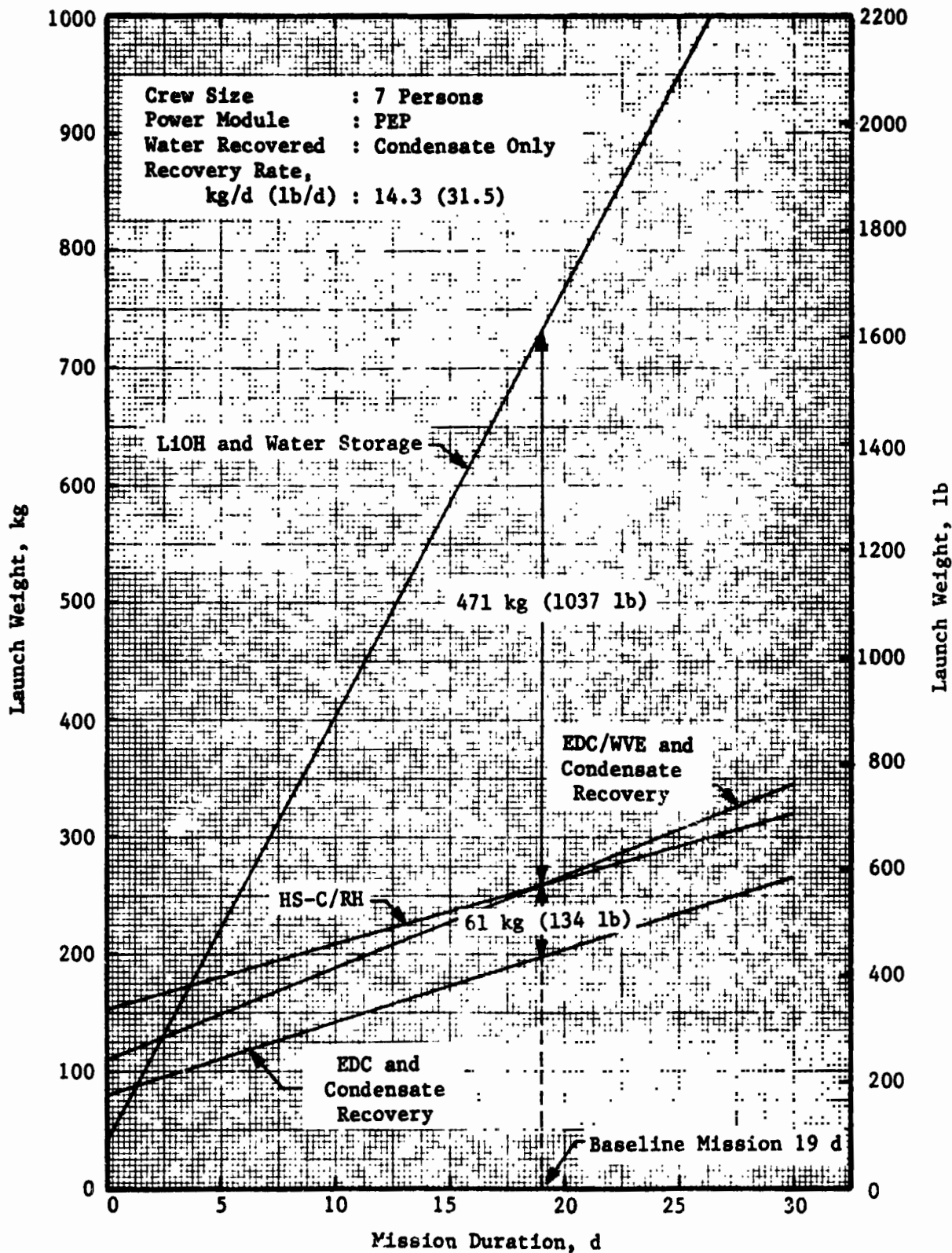


FIGURE 28 COMBINED CO₂ REMOVAL AND CONDENSATE RECOVERY:
MISSION OPTION TWO

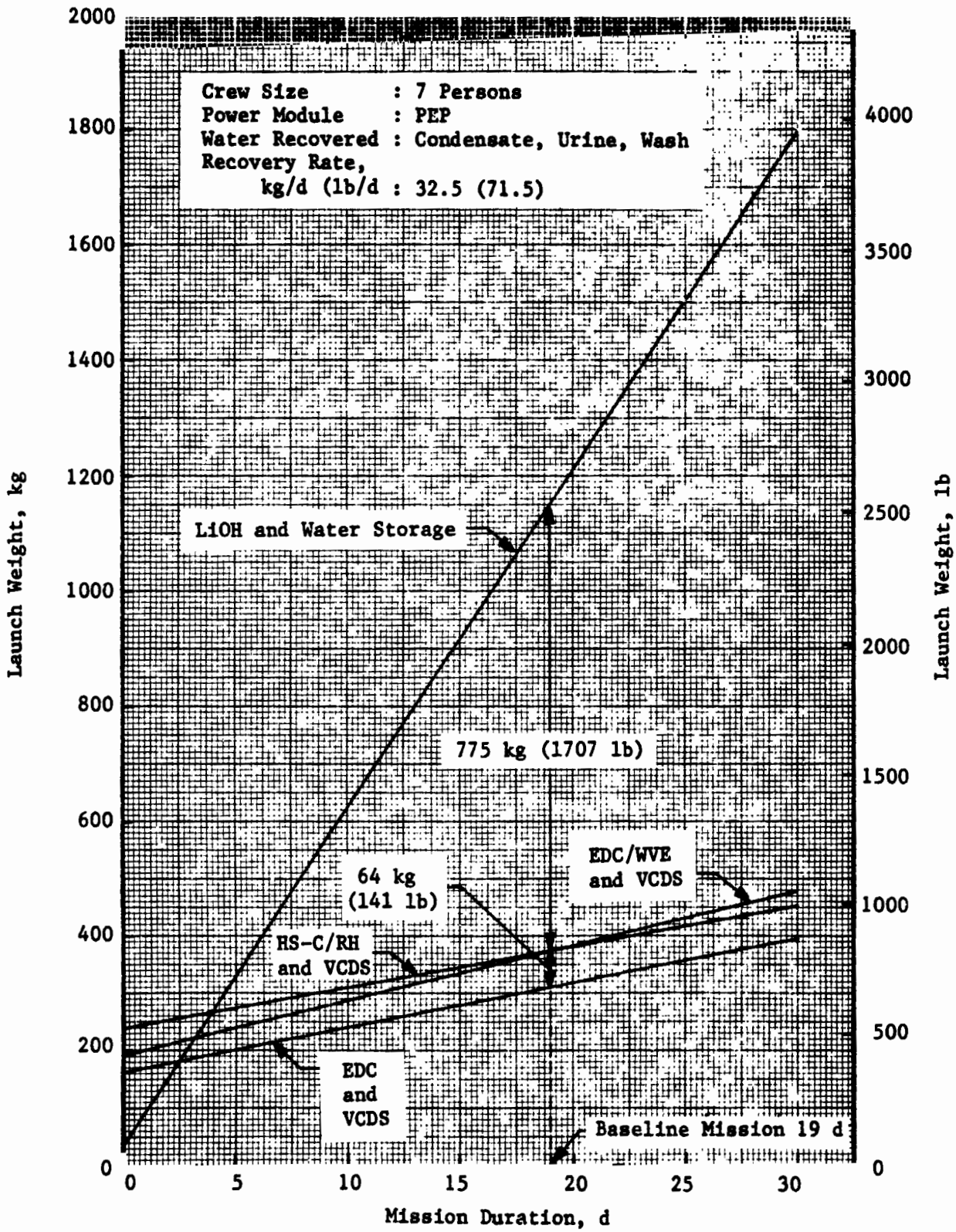


FIGURE 29 COMBINED CO₂ REMOVAL AND TOTAL WATER RECOVERY: MISSION OPTION TWO

is the sum of the individual savings per subsystem. Figure 30 shows the combined equivalent weight savings for water recovery and CO₂ removal. The amount of potable water required for seven persons is the sum of the wash water, water for food preparation and metabolic consumption or 35.4 kg/d (78 lb/d). The amount of recovered water available is 29.3 kg/d (64.5 lb/d) and increases to 32.5 kg/d (71.5 lb/d) when EDC condensate is considered. The additional water required is made up by on-board water storage. The EDC subsystem was again given credit for its additional condensate generation and is clearly the lowest equivalent weight subsystem.

CONCLUSIONS

The following conclusions were drawn based on the study completed:

1. Three enhanced Orbiter missions affect the selection of a CO₂ removal and water recovery subsystem. These mission options are characterized primarily by the power system selected which determines the availability of cryogen and water.
2. Regenerable CO₂ removal subsystems are superior to the expendable baseline LiOH CO₂ removal subsystem for all EDO applications.
3. Both the EDC and EDC/WVE concepts are applicable to EDO CO₂ removal.
4. An EDC-based CO₂ removal subsystem is preferred over a solid amine CO₂ removal subsystem for the three mission options evaluated.
5. Water recovery is superior to water storage.
6. A WRS is required for Mission Option Three to generate potable water. Water recovery requirements for Mission Option Two depend upon the supplementary heat rejection requirements which are not as yet defined.
7. Combined CO₂ removal and water recovery, when applicable, favors the EDC CO₂ removal subsystem since it produces additional condensate to satisfy the additional water requirements.

RECOMMENDATIONS

Based on the study results, the following actions are recommended:

1. Replace the LiOH CO₂ Removal Subsystem with the EDC CO₂ Removal Subsystem for EDO missions.
2. Use the VCDS for water recovery when additional water is required as defined by mission specifications.
3. Continue to develop EDC/WVE for enhanced Orbiter application. The EDC/WVE offers the user the option of not using cryogenic H₂ for the EDC.

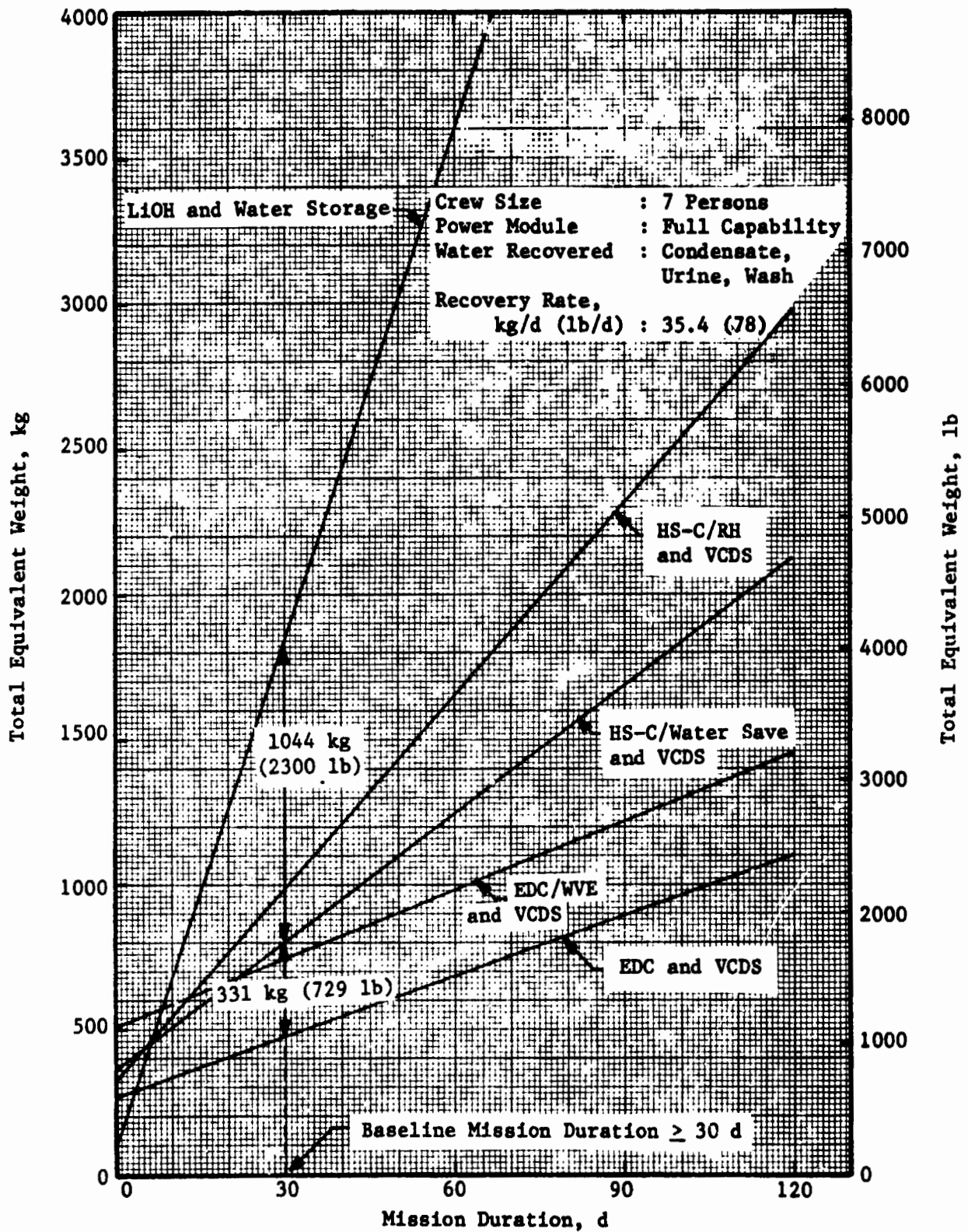


FIGURE 30 COMBINED CO₂ REMOVAL AND WATER RECOVERY:
MISSION OPTION THREE

REFERENCES

1. "Future Orbital Power Systems Technology Requirements," NASA Conference Publication 2058, Lewis Research Center Symposium, Cleveland, OH; May and June, 1978.
2. Craig, J. W. and DaRos, C. J., "An Orbital Service Module Systems Concept," AIAA Paper No. 78-1694, AIAA Conference on Large Space Platforms: Future Needs and Capabilities, Los Angeles, CA; September, 1978.
3. Mordan, G. W., "25 kW Power Module: First Step Beyond the Baseline STS," AIAA Paper No. 78-1693, AIAA Conference on Large Space Platforms: Future Needs and Capabilities, Los Angeles, CA; September, 1978.
4. Chapel, F. G; Martin, D. A. and Gore, D. C., "Extended Duration Orbiter Life Support System Options," ASME Publication 78-ENAs-31, Intersociety Conference on Environmental Systems, San Diego, CA; July, 1978.
5. "Concept Definition for an Extended Duration Orbiter ECLSS," NAS9-14782, SVHSER 7185, Hamilton Standard, Windsor Locks, CT; September, 1977.
6. Kleiner, G. N., "Extended Duration Orbiter Life Support Definition," ASME Paper No. 78-ENAs-42, Intersociety Conference on Environmental Systems, San Diego, CA; July, 1978.
7. Wynveen, R. A.; Schubert, F. H. and Powell, J. D., "One-Man Self-Contained CO₂ Concentrating System" Final Report, NASA CR-114426, ER-131-16, Life Systems, Inc., Cleveland, OH; March, 1972.
8. Powell, J. D.; Schubert, F. H.; Marshall, R. D. and Shumar, J. W., "Six-Man, Self-Contained Carbon Dioxide Concentrator Subsystem," Final Report, NASA CR-114743, ER-134-32, Life Systems, Inc., Cleveland, OH; June, 1974.
9. Kostell, G. D.; Schubert, F. H.; Shumar, J. W.; Hallick, T. M. and Jensen, F. C., "Six-Man, Self-Contained Carbon Dioxide Concentrator Subsystem for Space Station Prototype (SSP) Application," Final Report, NASA CR-114742, ER-170-34, Life Systems, Inc., Cleveland, OH; May, 1974.
10. Schneider, J. J.; Schubert, F. H.; Hallick, T. M. and Woods, R. R., "Electrochemical Carbon Dioxide Concentrator Advanced Technology Tasks," Final Report, NASA CR-137732, ER-170E-4, Life Systems, Inc., Cleveland, OH; October, 1975.
11. Schubert, F. H.; Woods, R. R.; Hallick, T. M. and Heppner, D. B., "Technology Advancement of the Electrochemical CO₂ Concentrating Process," Annual Report, NASA CR-151995, ER-258-10, Life Systems, Inc., Cleveland, OH; May, 1977.
12. Schubert, F. H.; Marshall, R. D.; Quattrone, P. D. and Wynveen, R. A., "Development of a Three-Man Preprototype CO₂ Collection Subsystem for Spacecraft Application," ASME Paper No. 77-ENAs-19, Intersociety Conference on Environmental Systems, San Francisco, CA; July, 1977.

13. Schubert, F. H. and Marshall, R. D., "Integrated Water Vapor Electrolysis and Electrochemical Depolarized Concentrator," Annual Status Report, ER-192, Life Systems, Inc., Cleveland, OH; April, 1973.
14. Schubert, F. H.; Marshall, R. D.; Hallick, T. M. and Woods, R. R., "One-Man Electrochemical Air Revitalization System Evaluation," Final Report, ER-284-4, Life Systems, Inc., Cleveland, OH; July, 1976.
15. Marshall, R. D.; Woods, R. R.; Hallick, T. M. and Schubert, F. H., "Development of a Three-Man Preprototype Independent Air Revitalization Subsystem (IARS)," ASME Paper No. 77-ENAS-31, Intersociety Conference on Environmental Systems, San Francisco, CA; July, 1977.
16. Lantz, J. B.; Schubert, F. H.; Jensen, F. C. and Powell, J. D. "Advanced Combined Iodine Dispenser and Detector," Final Report, ER-277-4, Life Systems, Inc., Cleveland, OH; January, 1977.
17. West, S.; Chrisos, J. and Baxter, W., "Water Quality Monitor," Final Report, Orion Research, Inc., Cambridge, MA; March, 1979.
18. "Extended Duration Orbiter ECLSS Study Volume I," SVHSER 7190, Rev. A, Hamilton Standard, Windsor Locks, CT; May, 1978.
19. "Modular Space Station Phase B Extension, Volume IV: Subsystems Analysis," Contract NAS9-9953, MSC 02471, North American Rockwell, Downey, CA; January, 1972.
20. "Trade Study for Water and Waste Management Concepts - Task 7, Support Special Analysis Report," MDC G5853, Contract NAS9-13404, McDonnell Douglas.
21. "Waste Management Program," Report No. 25,158, Contract NAS9-1680, The Marquardt Corporation, Van Nuys, CA; February, 1965.
22. Nuccio, P. P. and Jasionowski, W. J., "Automatic Water Recovery System," AMRL-TR-67-155, General American Research Division, General American Transportation Corporation, March, 1968.
23. Bambenek, R. A.; Nuccio, P. P.; Hurley, T. L. and Jasionowski, W. J., "Upgrading and Extended Testing of the MSC Integrated Water and Waste Management Hardware," Contract NAS9-9191, Final Report, Chemtrac, Inc., Rosemont, IL; May, 1972.
24. Bambenek, R. A.; Nuccio, P. P. and Hurley, T. L., "Extended Testing of Compression Distillation," ASME Paper No. 72-ENAV-1, Environmental Control & Life Support Systems Conference, San Francisco, CA; August, 1972.
25. Reveley, W. F. and Nuccio, P. P., "Design and the Parametric Testing of the Space Station Prototype Integrated Vapor Compression Distillation Water Recovery Module," ASME Paper No. 75-ENAS-37, Intersociety Conference on Environmental Systems, San Francisco, CA; July, 1975.

26. Johnson, K. L.; Nuccio, P. P. and Reveley, W. F., "Improved Waste Water Vapor Compression Distillation Technology," ASME Paper No. 77-ENAs-20, Intersociety Conference on Environmental Systems, San Francisco, CA; July, 1977.
27. "Requirements/Definition Document, Atmospheric Revitalization," SD72-SH-0106-1, Contract NAS9-14000, Rockwell International, Downey, CA; October, 1976.
28. "Requirements/Definition Document, Food, Water, & Waste, Volume 6-2," SD72-SH-0106-2, Contract NAS9-14000, Rockwell International, Downey, CA; June, 1976.

APPENDIX 1 SHUTTLE AIR COOLED EDC SUBSYSTEM

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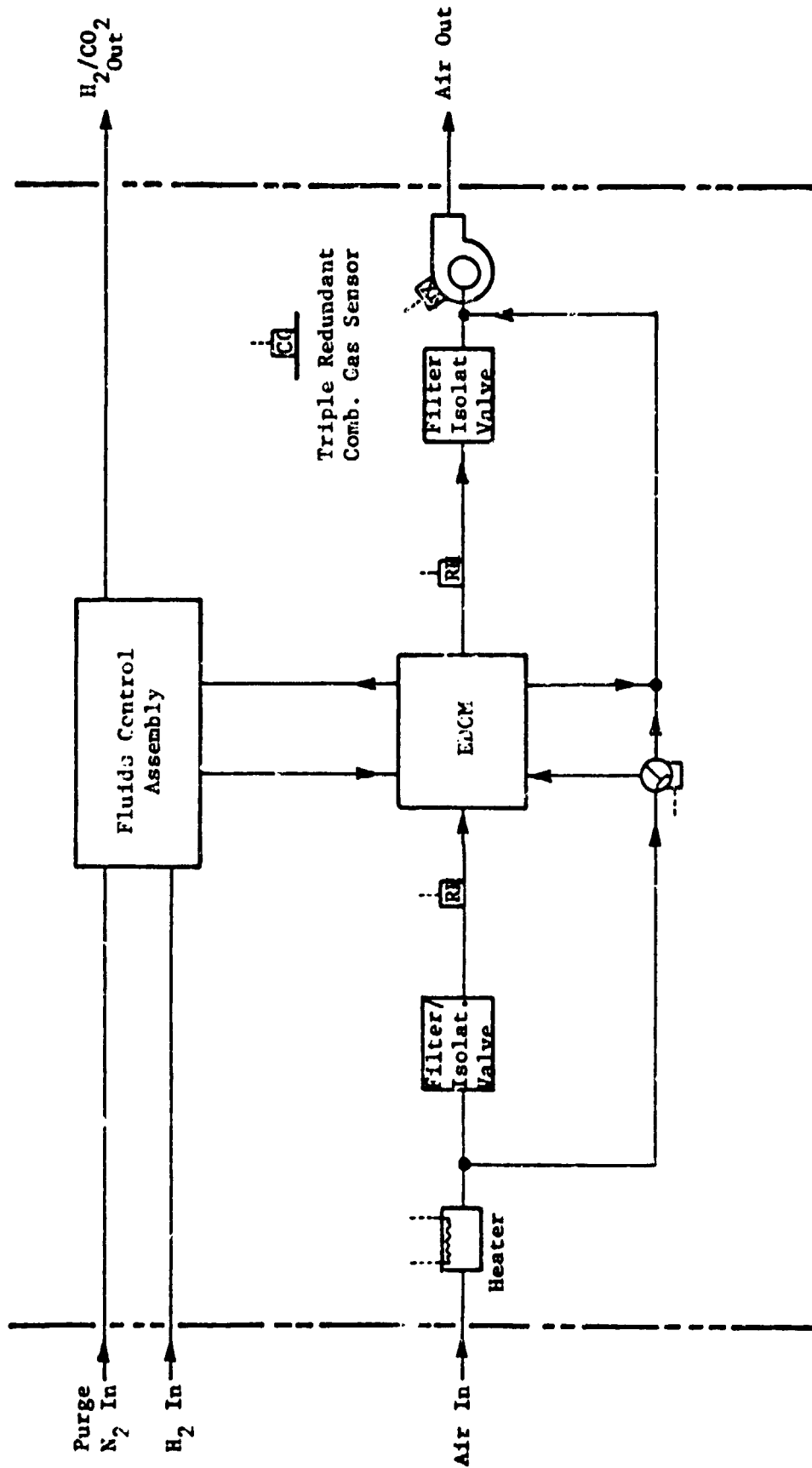


FIGURE A1-1 SHUTTLE EDC SCHEMATIC (AIR COOLED)

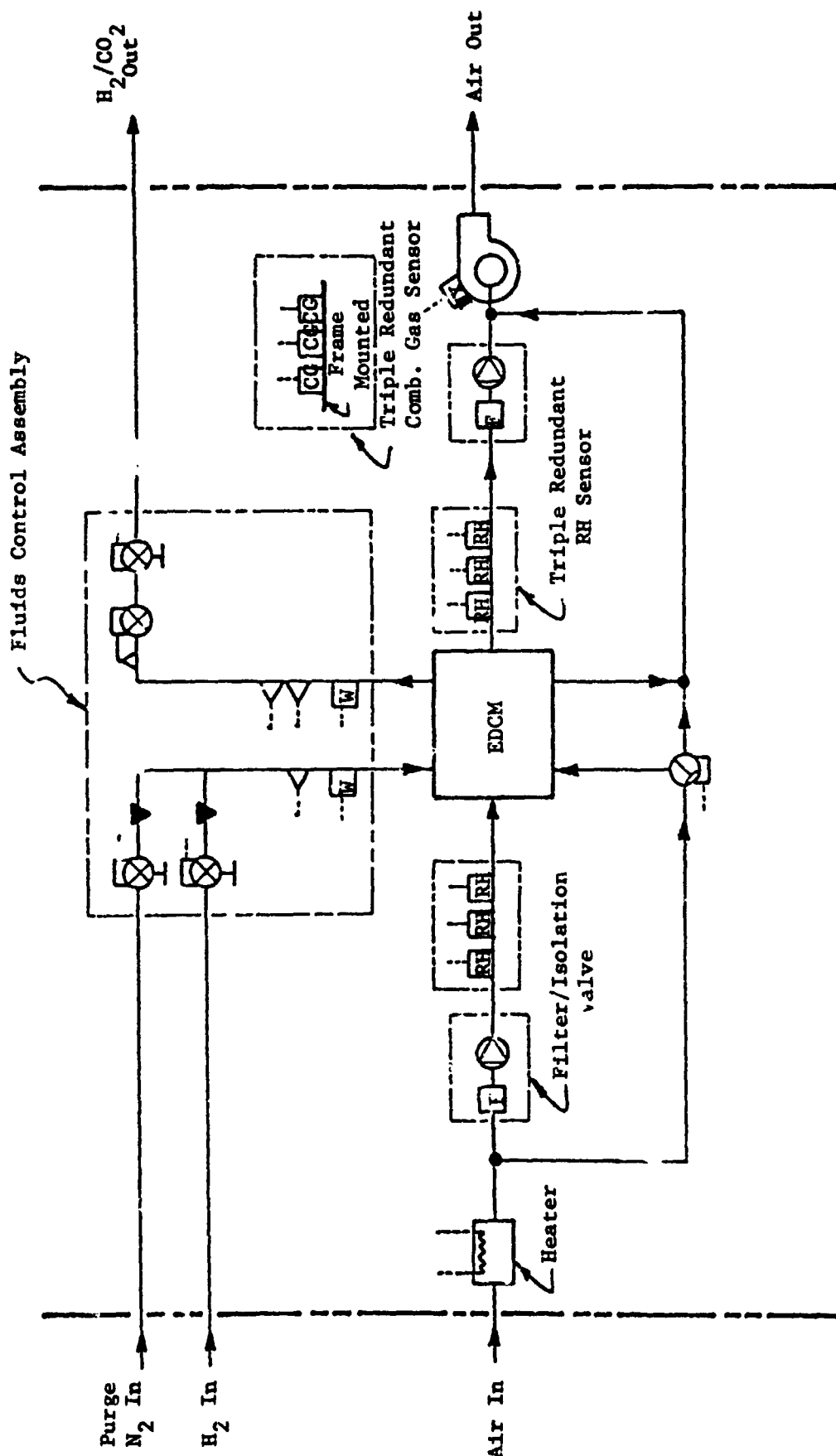


FIGURE A1-2 SHUTTLE EDC DETAILED SCHEMATIC (AIR COOLED)

TABLE A1-1 EDC SUBSYSTEM COMPONENT WEIGHT, POWER AND HEAT GENERATION SUMMARY (AIR COOLED)

Component	No. Req'd	4-Person			7-Person		
		Weight, kg (lb)	Power, W AC	Heat Gen., W DC	Weight, kg (lb)	Power, W AC	Heat Gen., W DC
EDCM	1	20.0 (44)	-- (-85)	187	26.3 (58)	-- (-131)	380
Fluids Control Assembly	1	2.3 (5)	-- 10	10	2.3 (5)	-- 10	10
Fan	1	1.8 (4)	150	150	3.2 (7)	200	200
Diverter Valve	1	0.9 (2)	-- 10	10	0.9 (2)	-- 10	10
Air Heater	1	0.5 (1)	-- 190	190	0.5 (1)	-- 275	275
Filter/Isolation Valve	2	0.9 (2)	-- --	--	0.9 (2)	-- --	--
RH Sensor	2	0.9 (2)	-- 10	10	0.9 (2)	-- 10	10
Combustible Gas Sensor	1	0 (0)	-- 5	5	0 (0)	-- 5	5
Instrumentation	1	3.2 (7)	-- 15	15	3.2 (7)	-- 15	15
Ducting/Frame (25%)	7	7.7 (28)	-- --	--	9.5 (21)	-- --	--
Total	11	38.1 (84)	150	577	47.7 (105)	200	194
							905

TABLE A1-2 SHUTTLE EDC SUBSYSTEM CHARACTERISTICS SUMMARY (AIR COOLED)

Crew Size	4	7
Fixed Hardware Weight, kg (lb)	38.1 (84)	47.7 (105)
Overall Dimensions, cm (in)	41 x 43 x 43 (16 x 17 x 17)	51 x 43 x 43 (20 x 17 x 17)
Volume, m ³ (ft ³)	0.08 (2.7)	0.09 (3.3)
Power Required, WAC , WDC	150 155	200 194
Heat Load, W Sensible Latent	577 47	905 89
CO ₂ Removed, kg/d (lb/d)	3.83 (8.44)	6.72 (14.8)
O ₂ Consumed, kg/d (lb/d)	1.56 (3.44)	2.93 (6.46)
H ₂ Consumed, kg/d (lb/d)	0.234 (0.516) ^(a)	0.441 (0.972) ^(a)
H ₂ O Generated, kg/d (lb/d)	1.76 (3.87)	3.30 (7.27)

(a) At 1.2 times the stoichiometric H₂ requirement

APPENDIX 2 SHUTTLE AIR COOLED EDC/WVE SUBSYSTEM

<u>Figure</u>		<u>Page</u>
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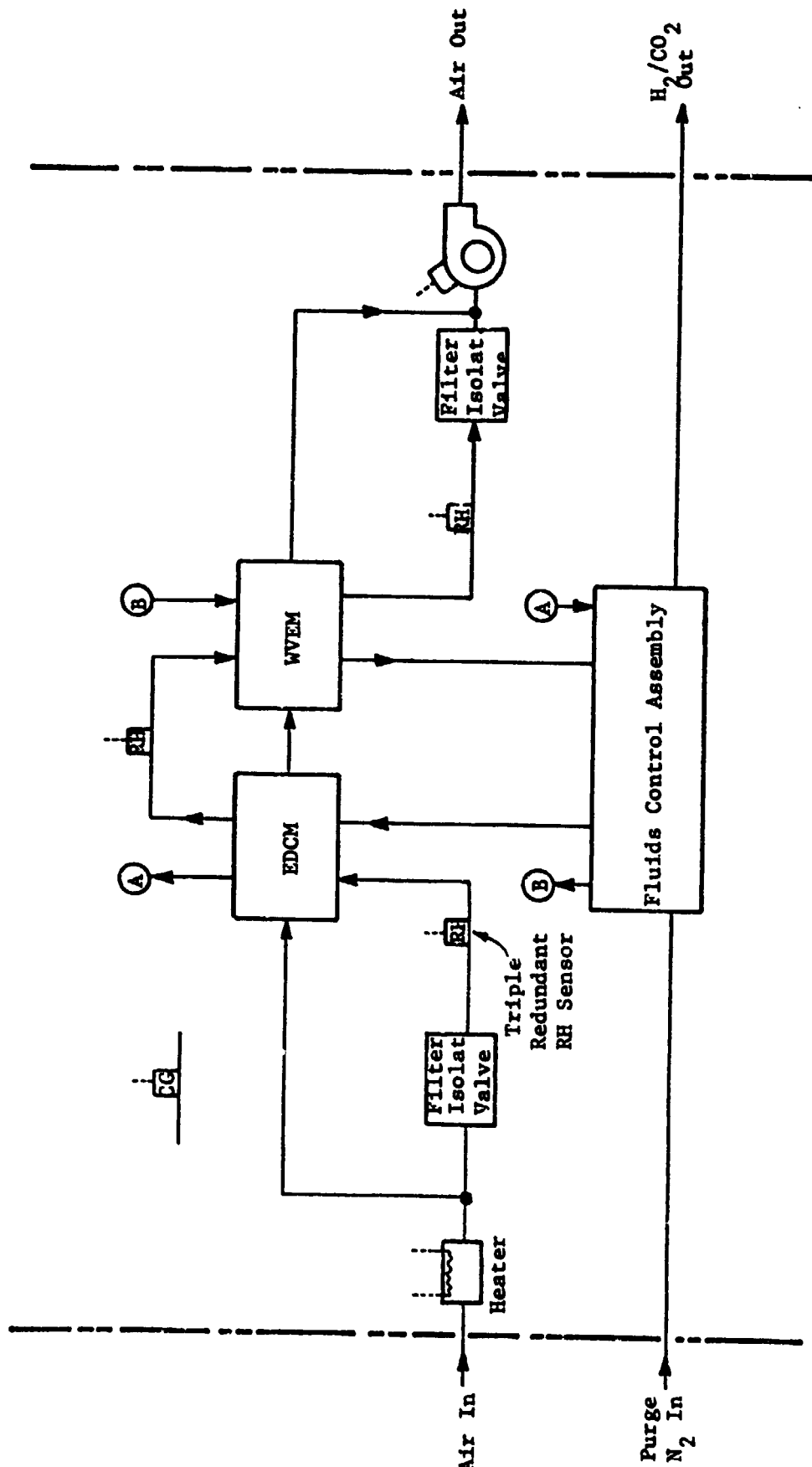


FIGURE A2-1 SHUTTLE EDC/WVE SCHEMATIC (AIR COOLED)

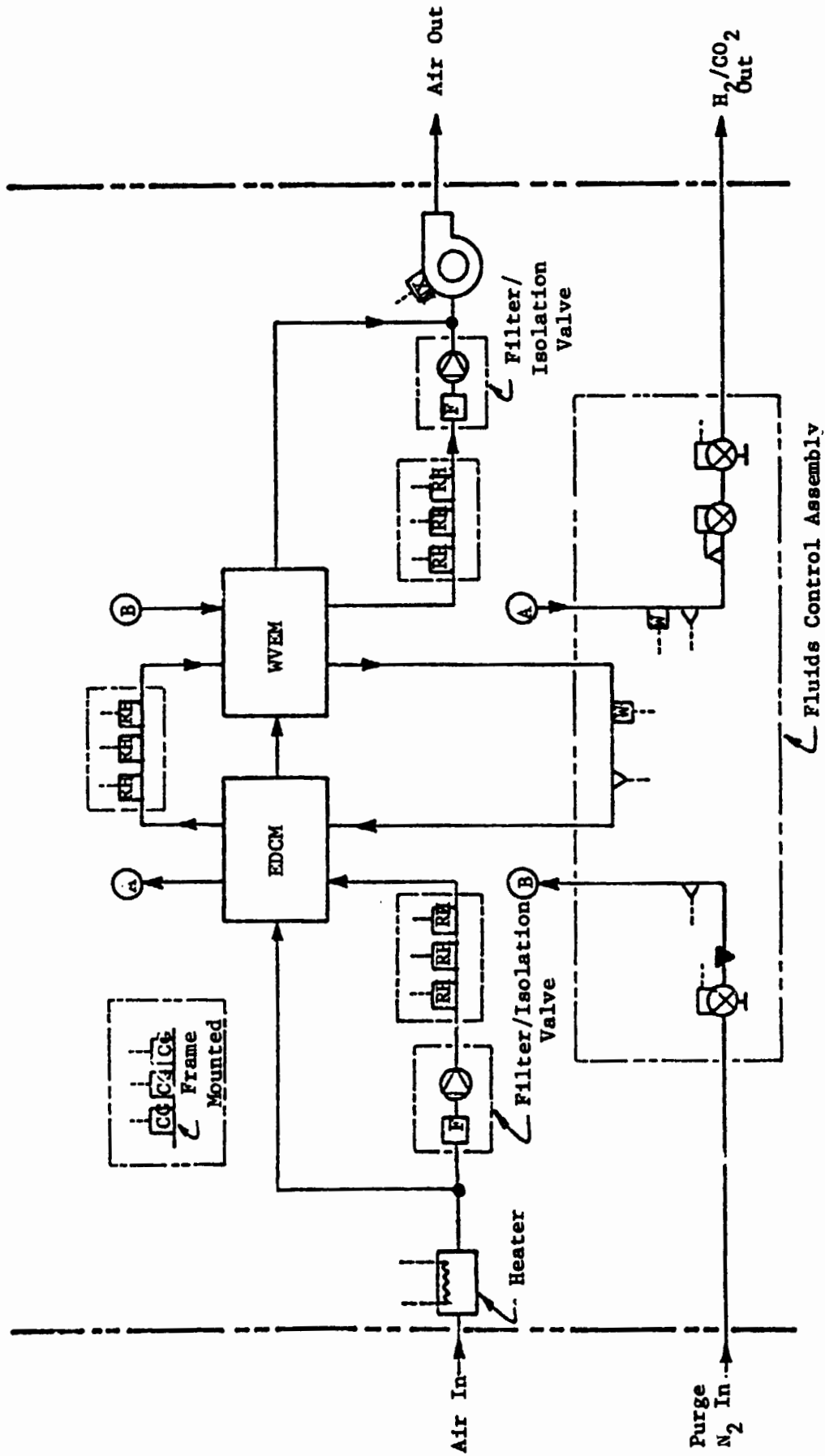


FIGURE A2-2 SHUTTLE EDC/WVE DETAILED SCHEMATIC (AIR COOLED)

TABLE A2-1 EDC/WVE SUBSYSTEM COMPONENT WEIGHT, POWER AND HEAT GENERATION SUMMARY (AIR COOLED)

Component	No. Req'd	4-Person			7-Person		
		Weight, kg (lb)	Power, W AC	Heat Gen., W DC	Weight, kg (lb)	Power, W AC	Heat Gen., W DC
EDCM	1	20.0 (44)	-- (-85)	187	26.3 (58)	-- (-131)	380
WVEM	1	18.6 (41)	-- 446	125	23.6 (52)	-- 858	255
Fluids Control Assembly	1	2.3 (5)	-- 10	10	2.3 (5)	-- 10	10
Fan	1	1.8 (4)	340	-- 340	2.7 (6)	495	-- 495
Air Heater	1	0.5 (1)	-- 190	190	0.5 (1)	-- 275	275
Filter/Isolation Valve	2	0.9 (2)	-- --	-- --	0.9 (2)	-- --	-- --
RH Sensor	3	1.4 (3)	-- 15	15	1.4 (3)	-- 15	15
Combustible Gas Sensor	1	0 (0)	-- 5	5	0 (0)	-- 5	5
Instrumentation	1	4.1 (9)	-- 20	20	4.1 (9)	-- 20	20
Ducting/Frame (30%)	--	15.0 (33)	-- --	-- --	18.6 (41)	-- --	-- --
Total	12	64.5 (142)	340	601	80.4 (177)	495	1052
				892			1455

TABLE A2-2 SHUTTLE EDC/WVE SUBSYSTEM CHARACTERISTICS SUMMARY (AIR COOLED)

Crew Size	4	7
Fixed Hardware Weight, kg (lb)	64.5 (142)	80.4 (177)
Overall Dimensions, cm (in)	66 x 43 x 38 (26 x 17 x 17)	84 x 43 x 43 (33 x 17 x 17)
Volume, m ³ (ft ³)	0.12 (4.3)	0.16 (5.5)
Power Required, WAC , WDC	340 601	495 1,052
Heat Load, W Sensible Latent	892 -9	1,455 -18
CO ₂ Removed, kg/d (lb/d)	3.83 (8.44)	6.72 (14.8)
O ₂ Consumed, kg/d (lb/d)	-0.31 (-0.68)	-0.58 (-1.28)
H ₂ Consumed, kg/d (lb/d)	0	0
H ₂ O Generated, kg/d (lb/d)	-0.35 (-0.77)	-0.65 (-1.44)