

BIOTECHNOLOGY

SPACE SHUTTLE ORBITER ENVIRONMENTAL CONTROL_____

AND____

LIFE SUPPORT SYSTEMS

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ABSTRACT

The Space Shuttle Orbiter Environmental Control and Life Support System is presented. The rationale leading to selection of concepts is stressed. The concept trades were based on an anticipated 1977 initial orbiter flight, ten years operation and a baseline mission support requirement of four men for seven days. The paper reflects a summary of concept selection work completed by the North American Rockwell Space Division Team, under contract to NASA, Manned Spacecraft Center. Hamilton Standard provided support to this study.

THE SPACE SHUTTLE

The Space Shuttle is to be a fully reusable two-stage transportation system for manned earth orbiting operations. It is designed to take off vertically and land horizontally. The Space Shuttle will consist of two vehicles - a booster and an orbiter. The booster carries the cargo-filled orbiter piggy-back to the fringe of space, then separates and flies back to a landing site and lands horizontally.

The orbiter, with its payload, continues into earth orbit to provide space station support operations or perform independent space operations. After completion of the mission, deorbit takes place and the orbiter lands horizontally. Figure 1 illustrates the basic shuttle mission. The primary purpose of the shuttle is to reduce the expense of space travel to less than 1/10th of today's cost.

PHASE B STUDY TASKS

The functional requirements of the orbiter Environmental Control and Life Support Station (ECLSS) can be satisfied by a number of alternate concepts. The primary tasks of the first six months of the Phase B study contract were to determine design requirements and criteria, establish a baseline system, and evaluate alternate concepts to the various requirements. This paper provides a description of the chosen ECLSS concepts and their selection rationale.

REQUIREMENTS AND DESIGN CRITERIA

The primary requirement for the ECLSS and all other systems is to provide a low cost reusable system. The cost of development is of particular concern and for this reason, whenever possible, previously developed concepts will be utilized. The concepts are to be based on 1972 state-of-art criteria, and require minimum maintenance and refurbishment, provide turn-around in two weeks or less, and support 100 missions over a ten-year period.

The ECLSS must provide the following functions:

- A. Shirt-sleeve environment for the crew and passenger compartment.
- B. Food, water, oxygen and storage and disposal of trash and human waste. Where required, provide environmental control of equipment in and outside the crew compartment.

The subsystems that provide these functions must have the performance capabilities to meet the requirements of Table 1.

TRADEOFF STUDIES

The functions of the ECLSS can be satisfied by more than one concept or method. Therefore, to trade the alternates against each other, a concept was selected as the baseline and the others traded against this concept. The baseline concept and the alternates are shown in Table 2.

0 SEVEN DAY MISSION - 270 N MI X 55 DEG INCL
0 2 CREW -- 2 PASSENGERS
0 SPACE STATION SUPPORT

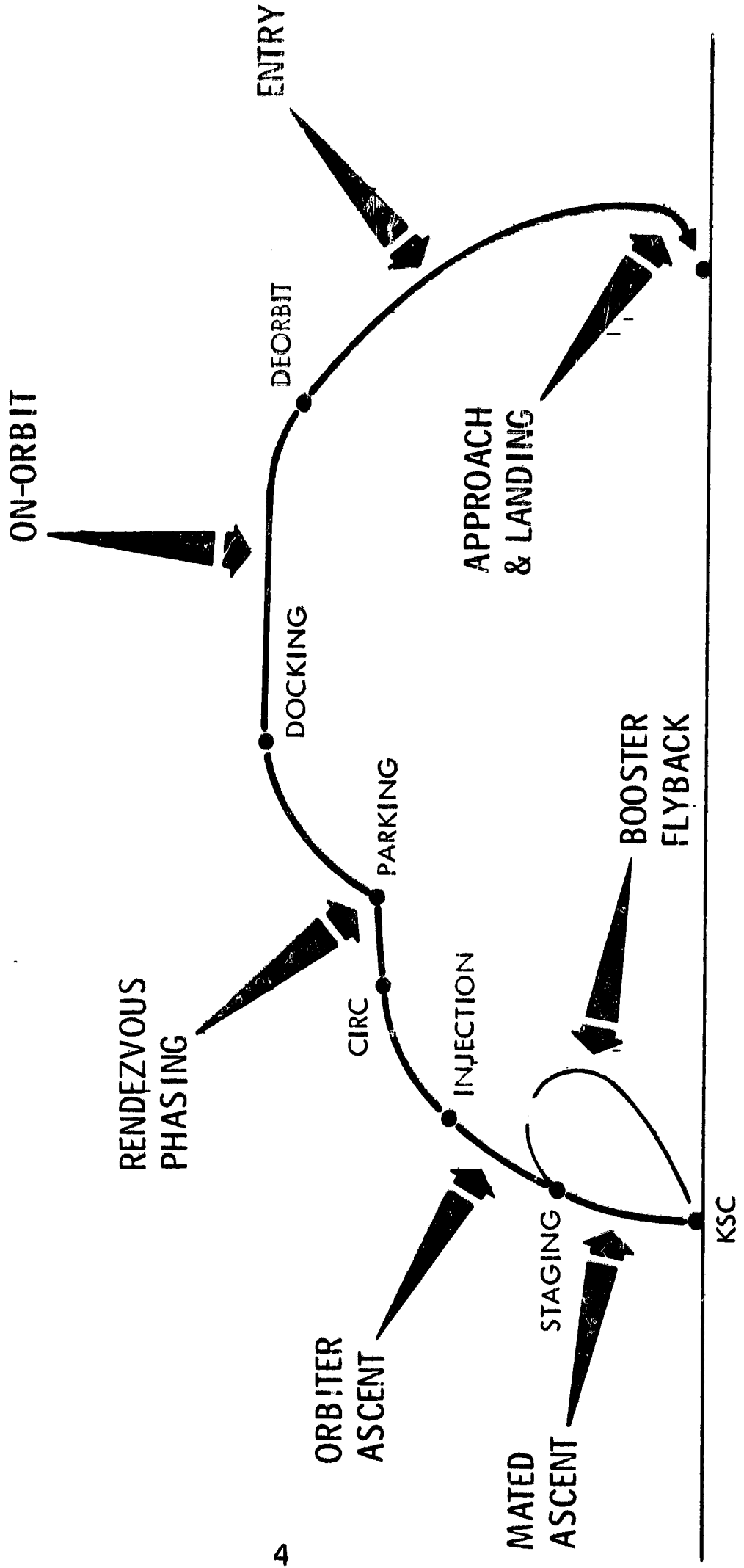


FIGURE 1 -- BASELINE REFERENCE MISSION PHASES

TABLE 1. DESIGN REQUIREMENTS & CRITERIA

Functional Requirements (Design Point)

Cabin Total Pressure (Normal)	14.7 PSIA
Oxygen Partial Pressure (Normal)	3.0 to 3.4 PSIA
Carbon Dioxide Partial Pressure (Max. Normal)	7.6 mm-Hg
Cabin Temperature (Selectable)	65 - 75°F
Cabin Humidity	46 - 57°F D.P.
Trace Contaminants (Max. on each contaminant)	0.1 TLV

Design Loads

Heat Loads

Hydraulic System (Heating) (BTU/Hr)	0 - 15,000
Fuel Cell Cooling (Max. - BTU/HR)	36,000
Metabolic Heat	
Sensible (BTU/Man-Hr)	345
Latent (BTU/Man-Hr)	205
Wall and Window	-8,800 to +2400 BTU/HR
Electronics Cold Plate Load	20,460 BTU/Hr
Electronic Air Load	12,200 BTU/Hr
Water Consumption	6.91 lb/Man-Day
Urine Production	3.58 lb/Man-Day
Feces Production	.25/lb/Man-Day
Cabin Leakage Rate	7 lb/Day

Failure Mode

The system, except for pressure vessels such as tubing and tanks, in the event of failure, shall be designed to fail operational and fail safe with the second failure.

The major trade evaluation criteria were cost (emphasizing cost prior to first orbital flight), weight, power required, and volume. These factors were determined for the baseline and alternate concepts, generally at the design point, and the evaluations made. A description of the concepts and their evaluation is provided below.

WASTE MANAGEMENT

Three Waste Management Subsystem (WMS) concepts were evaluated as possible candidates for the Shuttle orbiter. The major design consideration in this evaluation was the collection of solid human waste. The basic concepts were:

- (a) A collection bag is provided for insertion in a canister which has sufficient air flow to produce detachment and entrainment. The bag is manually sealed and placed in a storage compartment.
- (b) An integrated collection and storage container of sufficient capacity for a seven-day mission. For extended missions, it can be removed when full, replaced, and remotely stored.
- (c) A collection bag, which is manually placed in a waste receiver, is provided for waste collection. After an expended bag is sealed, the waste receiver semi-automatically rotates 90° and ejects the bag into a storage chamber. Following ejection the receiver returns to its original position.

The integrated collection and storage container was selected for the Orbiter WMS. Its stage of development is the most advanced, as well as having the greatest aesthetic attractiveness. A similar system has been proposed for the Orbital Space Station, which offers significant commonality potential for equipment as well as procedures.

A rotary separator urine collection concept was selected over the hydrophobic bag separator/collection approach for two reasons: 1) handling requirement is undesirable; 2) Skylab program has not been successful in developing this concept. The rotary separator concept requires no handling by the crew, is being developed by Hamilton Standard for Skylab, and has been selected for SSP. Urine collection tanks may or may not be employed, depending upon overboard dumping limitations.

HUMIDITY CONTROL

The following Humidity Control Concepts were evaluated:

- (a) Condensing heat exchanger
- (b) Desiccant adsorption with vacuum desorption
- (c) Desiccant adsorption with vacuum desorption and ullage save pre-pump

The condensing heat exchanger concept utilizing a 3-fluid, stainless steel heat exchanger. A wick water separator collects condensate and wicks it to a hydrophobic transfer disc from which it is pumped to the condensate collection system. The condensing heat exchanger is oversized to provide a sensible heat exchanger coolant inlet temperature high enough to prevent condensation. A single latent/sensible heat exchanger was not considered due to the associated penalty with providing a cabin heating capability.

An isothermal, vacuum regenerable, four-bed silica gel desiccant humidity control concept was considered. This concept desorbs its water vapor to space vacuum. The addition of heaters and/or pumps to achieve desorption at sea level conditions significantly increases launch weight. Humidity control is achieved by process flow bypass. A pre-desorption pump-down approach was considered to conserve ullage gas during orbital operation, but provided no advantage for the baseline 7-day mission.

The condensing heat exchanger concept has the advantages of being lighter and less complex than the desiccant approach. Additionally, the condensing heat exchanger will perform normally for all phases of orbiter missions, including ferry flight. During space station docked operation, the condensing system can inhibit its overboard dumping by storing its condensate, whereas the desiccant cannot desorb without dumping its collected water vapor to space vacuum. Studies have shown that although increasing the heat transport loop radiator outlet temperature, as is allowed by the use of the desiccant, decreases the radiator fixed weight; the increased fixed weight of the desiccant over the condensing heat exchanger and the added weight of other heat exchangers more than offsets the radiator weight savings and causes the total system weight to increase. The desiccant system also requires significant specialized GSE to dry the beds out between flights. For these reasons, a condensing heat exchanger is selected for humidity control.

CARBON DIOXIDE ODOR AND TRACE CONTAMINANT CONTROL

Two flight qualified concepts for CO₂ control were evaluated. Lithium Hydroxide (LiOH) has flown on BIOS, Apollo LM and Apollo CM. Canisters can be designed to contain LiOH and activated charcoal to control CO₂, odors and trace contaminants. The reaction of LiOH with CO₂ produces water vapor and some heat.

Molecular sieve CO₂ control systems have been developed for the MOL and Skylab programs. The 3 bed concept investigated uses a two-section bed, the front section being a silica gel pre-dryer and the back section the CO₂ adsorber section. The pre-dryer bed is operated isothermally by use of 80°F coolant. The molecular sieve (Linde 5A) section desorbs adiabatically. This concept requires separate charcoal canisters for odor and trace contaminant control. With the use of the molecular sieve concept, supplemental CO₂ control is required for atmospheric operation, i.e., Ferry, Pre-Launch, Atmospheric flight. An ullage save pump-down version of the molecular sieve system was also investigated because of the relatively high amount of nitrogen co-adsorbed and subsequently lost on the molecular sieve at 14.7 psi cabin operating conditions.

The major disadvantages of the molecular sieve concept relative to LiOH are:

1. Higher development cost
2. Higher weight has an impact on total vehicle weight
3. Development of the Lithium Hydroxide elements is still required since the elements are required for ground operations, pre-launch, loading and ferry.
4. The system cannot be "off loaded" for short flights or when only the crew will be aboard.
5. More complex than the LiOH system.

The major advantages of the Molecular Sieve are:

1. Lower recurring costs (only charcoal canisters required for each flight)
2. Lower payload penalty for the long duration missions

The major advantages of the Lithium Hydroxide system are:

1. Lower development cost
2. Lower weight
3. More flexible elements can be off-loaded for short missions and when the passengers are not carried or added for longer or passenger carrying missions.

Both systems will meet the requirements; however, the Lithium Hydroxide system provides less weight and DDT&E costs. It is recommended that initially the LiOH system be employed. However, since the molecular sieve system is being developed for Skylab and other Space Station programs, it is recommended that the vehicle design not preclude installation of this system later in the program for longer duration flights.

THERMAL CONTROL

The Shuttle Orbiter Crew Compartment requires temperature control to remove sensible heat from the crewmen, walls, windows, and electrical and electronic equipment. The heating of the compartment air may be required particularly in the local areas near the tunnel heat shorts and windows.

The concepts which can collect this heat and transfer to the coolant transport loop are heat exchangers with fans, "coldwalls" with fans or a combination of both. The coldwalls consist of coolant transport tubing attached to the walls or wall panels. The heat is then directed to these panels by radiation and forced convection. For cabin heat exchangers, the heat is

transmitted to the heat exchangers by forced convection. The exchanger cools the cabin air which must collect the heat from the walls by convection. This then, by necessity, causes the walls to run, five to ten degrees or more, hotter or colder than the air. The occupants then either feel cool when the cabin air is being warmed, or warm when the cabin air is being cooled.

The cooling requirements show that a cold wall/fan concept will not supply sufficient cooling because of the high electrical heat load on the cabin air and the limited areas where cold walls can be located.

The evaluation determined that the use of cold walls could not significantly reduce the cabin heat exchanger system. However, a weight saving could be realized in the amount of insulation required to prevent overcooling the cabin prior to launch, and excessive temperatures after entry.

HEAT REJECTION

During ground operations, atmospheric flight, and orbital flight, waste heat must be removed from the compartment and rejected.

The following concepts were evaluated for waste heat rejection:

- . GSE Heat Exchanger
- . Sublimator
- . Radiator
- . Hydrogen Evaporator
- . Cryogenic Heat Exchanger
- . Ram Air Heat Exchanger
- . Freon Evaporator
- . Ammonia Evaporator
- . Air Cycle
- . Vapor Compression Cycle

It is desirable to have one unit which will serve as a heat sink for all operational phases with no supplemental cooling required. Four units which will operate for all phases are the hydrogen, Freon, and ammonia evaporators, and the vapor cycle subsystem. In order for these units to serve as a heat sink for a complete mission, a sufficient quantity of consumables would be required to be onboard at launch. The study indicated the consumable weight and program cost would be greater than using a different concept for each mission phase. Therefore, for application to the space shuttle orbiter, these units can best be used for supplemental cooling, or for atmospheric flights of short duration only.

The ram air heat exchanger and the air cycle systems can be used during atmospheric flights. The ram air system will require supplemental cooling at design flight speeds. This cooling may be supplied by a unit such as

TABLE 2

HEAT SINK PARAMETRIC COMPARISON

CONCEPT	SUBCONTRACTOR			NORTH AMERICAN			VEHICLE			TOTAL COSTS			TOTAL Cost \$x10 ⁻⁶
	Weight Lbs.	Power Watts	Volume Ft ³	Weight Lbs.	Power Watts	Volume Ft ³	Non Rec Cost \$x10 ⁻⁶	Rec Cost \$x10 ⁻⁶	Non Rec Cost \$x10 ⁻⁶	Rec Cost \$x10 ⁻⁶	Non Rec Cost \$x10 ⁻⁶	Rec Cost \$x10 ⁻⁶	
GSE HX (1)	10.0	0	0.25	20.0	0	0.06	0	0	1.400	0.860	2.260		
Sublimator (3) (2) (1)	120.0	10.0	4.0	51.0	0	0.91	0	0	2.986	3.546	6.532		
Radiator (1)	1020.0	10.0	85.0	5.0	0	0.03	-5.889	-3.533	1.517	6.719	8.236		
H ₂ Evap (1) (2)	100.0	10.0	2.5	50.0	0	0.87	0	0	4.668	9.254	13.922		
H ₂ Fuel HX	60.0	10.0	1.0	5.0	0	0	-0.618	-0.370	3.036	5.645	8.681		
Ram Air HX	35.0	0	1.0	115.0	0	7.0	0	0	4.762	1.745	6.507		
Freon Evap (2) (3)	259.0	10.0	21.0	51.0	0	0.87	+1.040	+0.624	3.638	7.471	11.109		
NH ₃ Evap (2) (3)	79.0	10.0	7.0	51.0	0	0.87	-0.130	-0.078	2.468	6.769	9.237		
Air Cycle	185.0	0	6.0	148.0	0	8.1	+1.190	+0.714	8.692	8.102	16.794		
Vapor Cycle	350.0	15000.0	3.6	40.0	0	0.8	-0.065	-0.039	3.855	6.309	10.164		

1 Baseline

2 Weights do not include consumables.

Consumables required are as follows:

Water Sublimator = 25 lbs/hr Water

H₂ Evaporator = 30 lbs/hr H₂

Freon Evaporator = 380 lbs/hr Freon 12

NH₃ Evaporator = 45 lbs/hr AmmoniaVapor Phase = 160 lbs/hr O₂ & H₂

3 Weights include tankage penalty for 4 hours operation.

the evaporators indicated above. The air cycle system will provide sufficient cooling capacity for all atmospheric flights.

For space flights, the radiator will reject all heat unless limited by radiator area. For peak loads or radiator failure, supplemental cooling is supplied by a water sublimator. The sublimator will also provide cooling during the period of time the radiator is not on stream at the start of the orbital flight and just prior to reentry. For the sublimator, water is supplied from the water generated by the fuel cells.

Heat sink capability for ground operations may be supplied by the evaporators or by GSE. A GSE onboard heat exchanger can also be used for cooling during docked operations, with the heat from the orbital vehicle being rejected through the space station heat transport system.

The evaporator/heat exchanger discussed above utilizes cryogenic hydrogen, (300°R), from the ACPS and dumps the hydrogen overboard after using.

Table 2 provides the weight, power, volume and cost data for these heat rejection concepts. The selected heat rejection subsystem is composed of the following units:

1. A GSE heat exchanger to operate during all ground operations.
2. A hydrogen evaporator to provide heat sink capabilities during all atmospheric operations.
3. A combination radiator-sublimator be installed to operate for all space operations.

The above combinations will supply all heat rejection capabilities at the least cost and weight, and, in addition, will provide greater flexibility for meeting extended flight requirements.

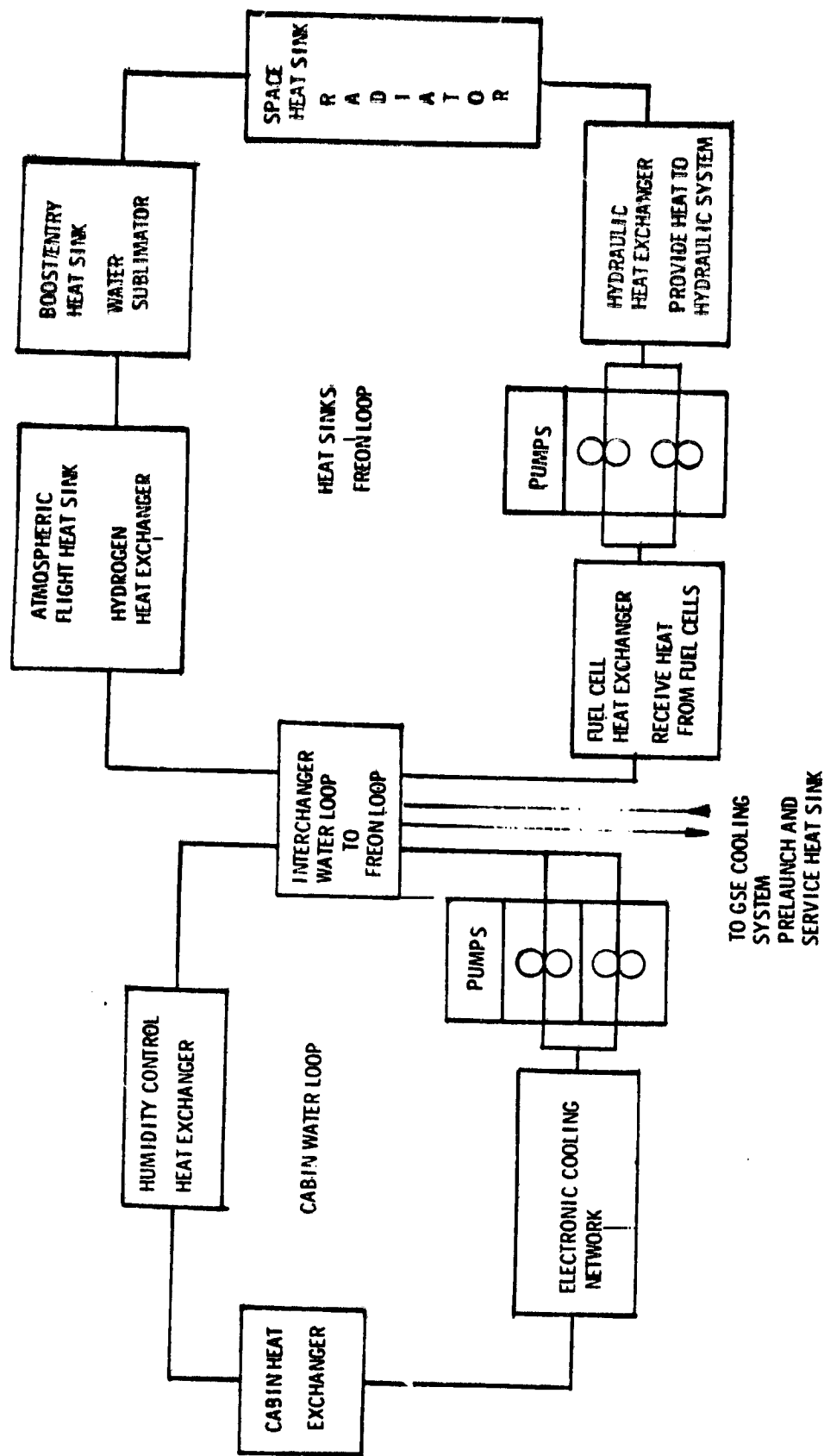
SYSTEM DESCRIPTION

The tradeoff resulted in the selection of the concept shown in Table 3.

Figure 2 shows the integration of the heat transport, heat rejection, temperature control, humidity control, and CO₂ control functions. With this arrangement toxic coolants are kept from the manned cabin and a low freezing temperature coolant is provided for the heat rejection equipment in a manner similar to the Space Station Prototype (SSP) approach. A single, six fluid interface heat exchanger allows either water loop to function with either F₂ loop without switching valves. The GSE function doubles as the space station interface for docked operations. The sublimators perform all heat rejection functions that the radiator cannot at altitudes of 100,000 ft or greater. The hydrogen evaporators provide heat rejection at altitudes below 100,000 feet. For Ferry Flight, if cryogenic hydrogen is not available, a Freon vapor compression package will be "strapped on", and connect at the GSE interface.

TABLE 3 - TRADE STUDY SELECTION

<u>FUNCTION</u>	<u>CONCEPT</u>
CO ₂ Control	LiOH
Humidity Control	Condensing Heat Exchanger, Replaceable wick water separator
Heat Transport	Dual loop (H ₂ O cabin loop, F21 Heat Rejection)
Trace Contaminant Control	Activated Charcoal
Temperature Control	Forced Convection Heat Exchanger
Fuel Cell Heat Rejection	Integrated with F21 Loop
Heat Rejection	Space Radiators Sublimators Hydrogen Evaporators
Atmosphere Pressure & Composition. Control	Total Pressure Regulators with selectable O ₂ or N ₂ source
Waste Management	Feces - Vacuum Dry Collector with Slinger Urine - Air Entrainment, rotary separator, overboard dump and/or holding tank
N ₂ Diluent Storage	Carbon Composite, high pressure, filament wound tanks
Food Management	Aluminum Cans, Thermostabilized, rehydratables, wafers, beverages



PRIMARY AND SECONDARY LOOP IDENTICAL EXCEPT TWO PUMPS IN EACH PRIMARY LOOP AND ONE IN EACH SECONDARY LOOP

FIGURE 2 -- COOLANT TRANSPORT LOOP

In the cabin loop, a heating mode is achieved by use of heat picked up at the electronic cold plates. Minor cold walls in the ceiling and floor of the cabin are employed to reduce insulation requirements, and have little effect on the cabin thermal requirements.

The integrated vacuum drying waste management subsystem (Figure 3) concept is selected for space shuttle. It provides feces, urine and small trash collection, processing and storage. Feces and solid wastes are collected, vacuum dried and stored in one container. Urine is collected separately stored and dumped overboard. This subsystem may be common in design to space station equipment because the concepts are a derivative of the current SSP and Skylab equipment.

The food packaging system employs the use of protective overcans, essentially cylindrical in shape in which food serving cans, dehydrates and drink packages are stored. These canisters are designed to prolong storage life and endure pressure variation, vibration, ground handling, launch and characteristic impact loads associated with the Shuttle Orbiter program.

The foods have been categorized as follows: thermostabilized, rehydratables, wafers, and beverages. Packaging concepts include aluminum cans with pull-out lids and plastic beverage packs.

The galley complex contains a unique freezer-locker compartment. This compartment serves as a locker for the 7-day mission but may be replaced by a freezer for extended missions. The galley also provides an oven, food storage, trash storage, hot and cold water supplies, and utensil storage.

The cabin pressure control subsystem shown in Figure 4 consists of plumbing, controls and regulators to provide a two gas (oxygen and nitrogen) atmosphere at 10 or 14.7 psia. Oxygen for normal makeup is supplied from the fuel cell oxygen storage system and nitrogen from 3000 psi storage tanks. Two identical systems are provided with a maximum flow rate of seven pounds per hour. An emergency oxygen supply system is provided which provides oxygen at 55#/hr from the Attitude Control Propulsion Storage System.

The fire extinguisher is a domed stainless cylinder about ten inches high with a seven inch nozzle and handle. The cylinder contains a polyethylene bladder capable of expelling two cubic feet of foam in approximately 30 seconds. The extinguishing agent, which is an aqueous gel (hydroxymethyl) cellulose), is pressurized to a maximum pressure of 250 psi at 140F. Freon is utilized on the opposing side of the bellows bladder to act as the expulsion agent. NASA has fire detection systems studies in work and the results of these studies will define the system for the orbiter.

CONCLUSIONS

The concept selection is indirectly sensitive to a number of factors which, in a phase B study, are subject to change. The length of the missions is one which, if shortened, could justify elimination of the space radiator and the water sublimators and replace the CO₂ and humidity control with an

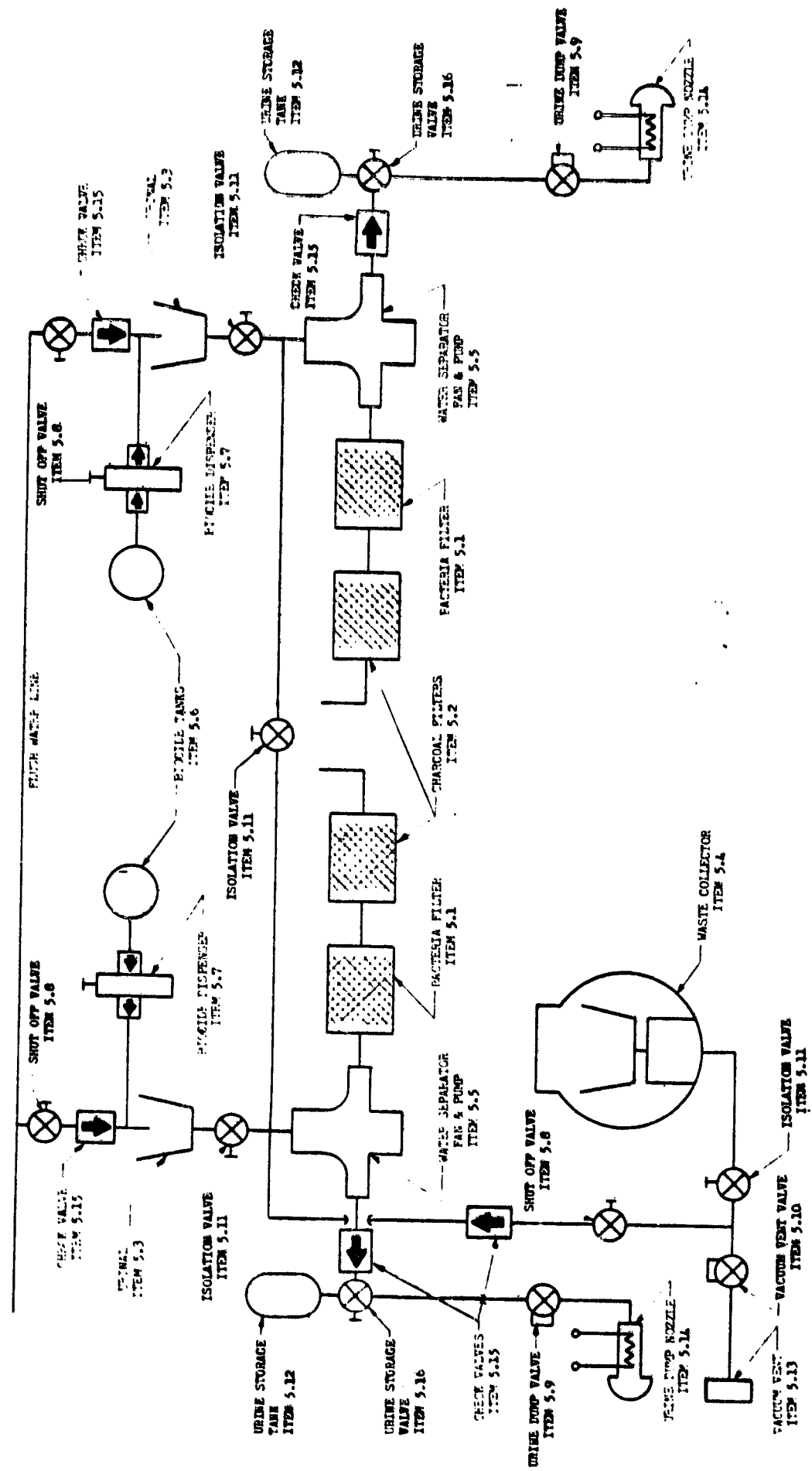


FIGURE 3 -- WASTE MANAGEMENT SUBSYSTEM

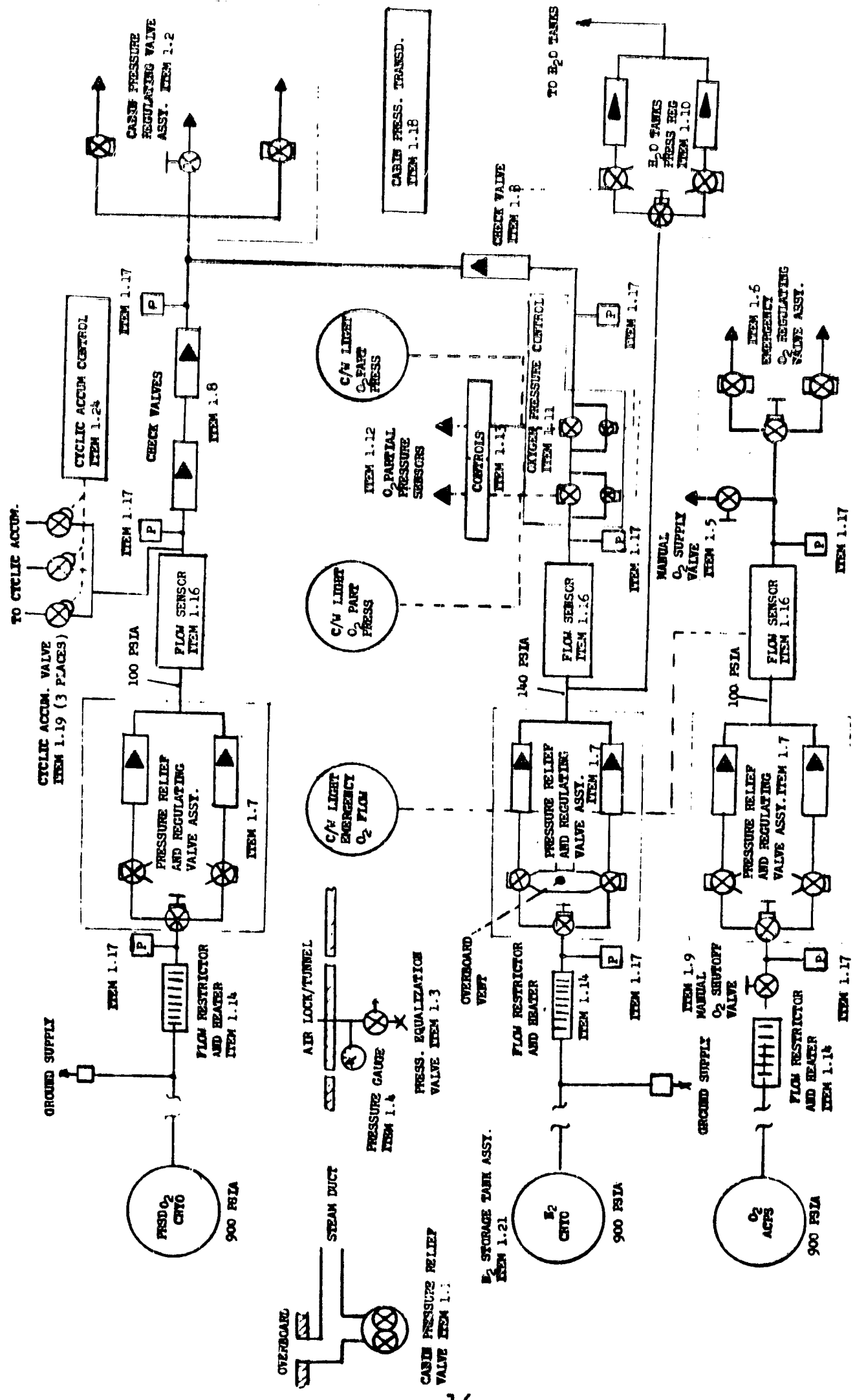


FIGURE 4 -- PRIMARY ATMOSPHERIC PRESSURE CONTROL AND SUPPLY SUBSYSTEM

open loop system. Lengthening the mission may require that the radiator be of a larger size and the CO₂ removal be accomplished by using the molecular sieve concept.

The "mission mix" (length of missions, kind of missions, number of passengers per mission), influences not only the concept selection but number of systems and system size. For example, one system with large capacity components could be installed when carrying a number of passengers and replaced with smaller components when carrying a smaller number of passengers. An alternate would be modular systems, of which two or more would be installed for maximum number of passengers and one would be used when no passengers were carried.

A number of study contracts are now in work under NASA and Air Force direction which will define the missions and dictate concept selection. The waste management is an example. Prototype development and fabrication are underway on the Space Station Prototype System Contract. The waste collector satisfies the Shuttle needs and commonality usage will reduce the cost. Another is the Fire Detection System for pressurized and unpressurized bays. Work is now underway in this area and should have an impact on the concept selection. While the major part of the concept selection is complete, effort will be continued in all areas with emphasis on Food Management, Waste Management, Fire Detection and system size.

In conclusion,

- . The ECCLS design will provide provisions for incorporation of more economical concepts as they are developed.
- . The system can be refurbished and maintained using airline maintenance concepts.
- . State-of-the-art concepts will be used and a system will be provided at costs below previous space vehicle systems.