Shuttle
Environmental/Thermal Control
& Life Support System

W. Guy

Shuttle Orbiter
Environmental/Thermal Control & Life Support System

- **Cabin Atmospheric Revitalization Subsystem**
- **Cabin Atmospheric Pressure and Composition Control Subsystem**
- **Water and Waste Management Subsystem**
- **Cabin Thermal Control Subsystem**
- **Spacecraft Active Thermal Control Subsystem**
- **EVA Airlock Support Subsystem**

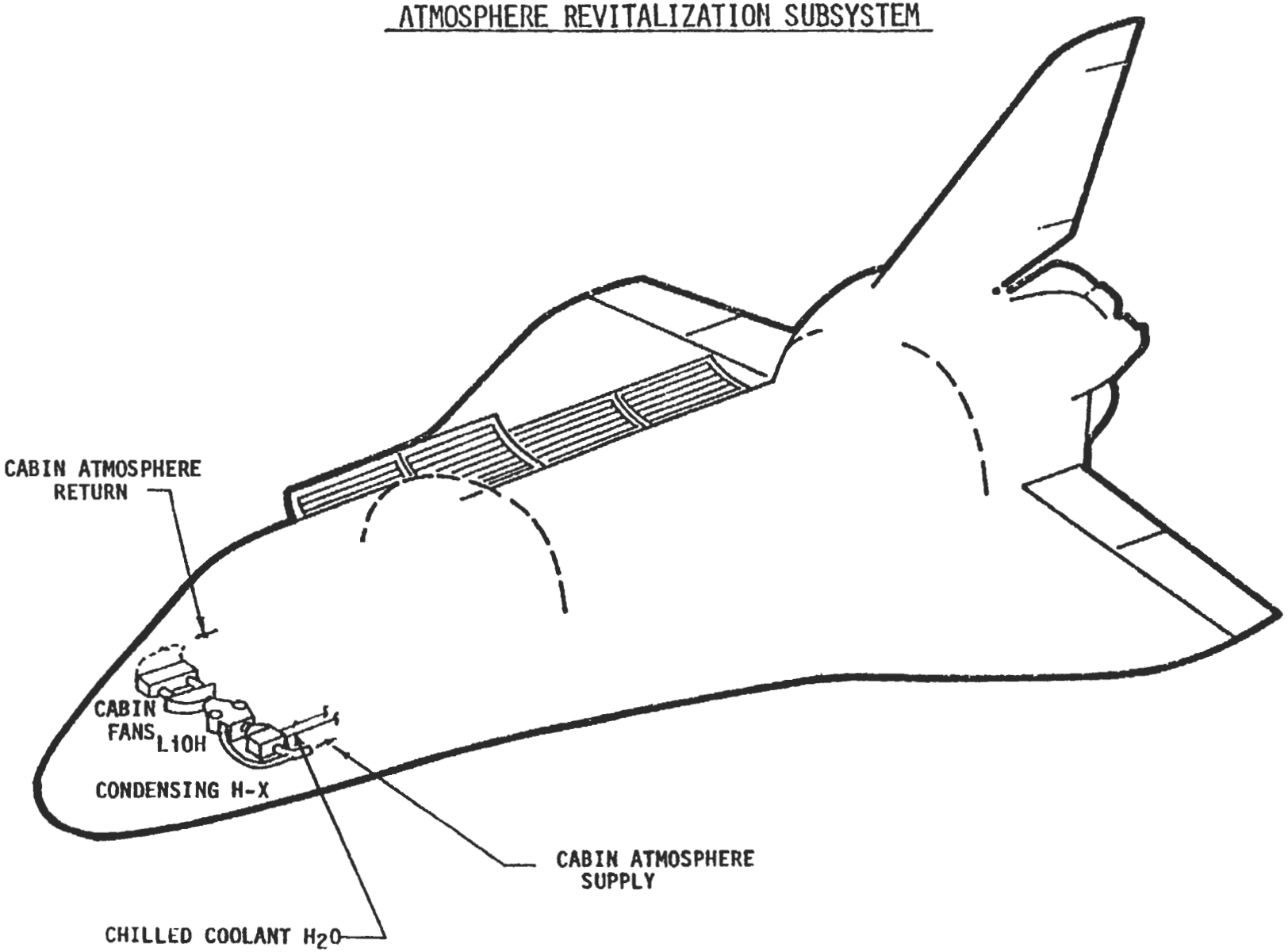
Shuttle Orbiter
Environmental/Thermal Control & Life Support System

Subsystem Elements:

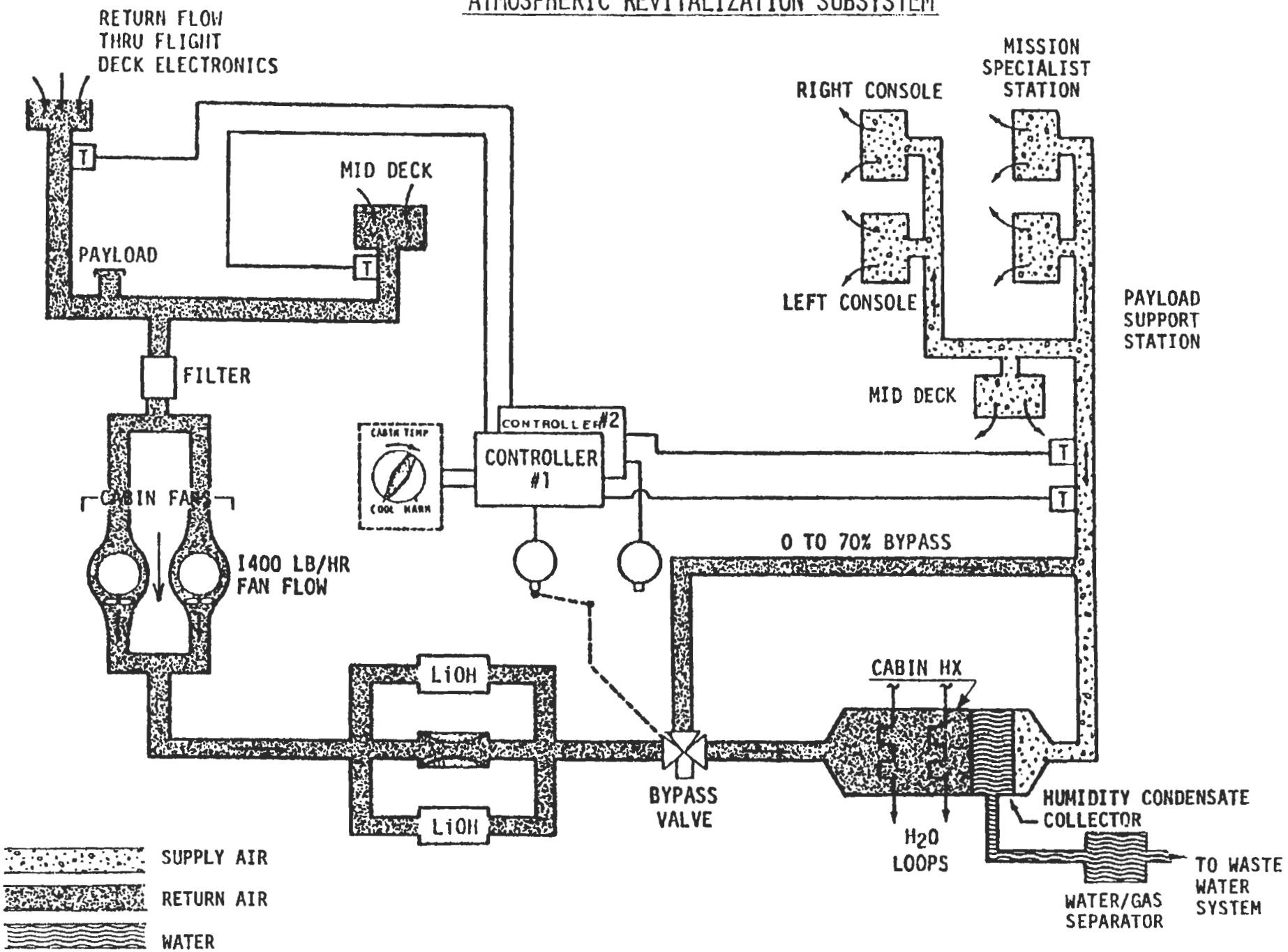
- **CABIN ATMOSPHERIC REVITALIZATION**
  - **CO_2 and trace gas removal**
  - **Humidity control**
  - **Environmental cooling**
  - **Atmospheric circulation/ventilation**

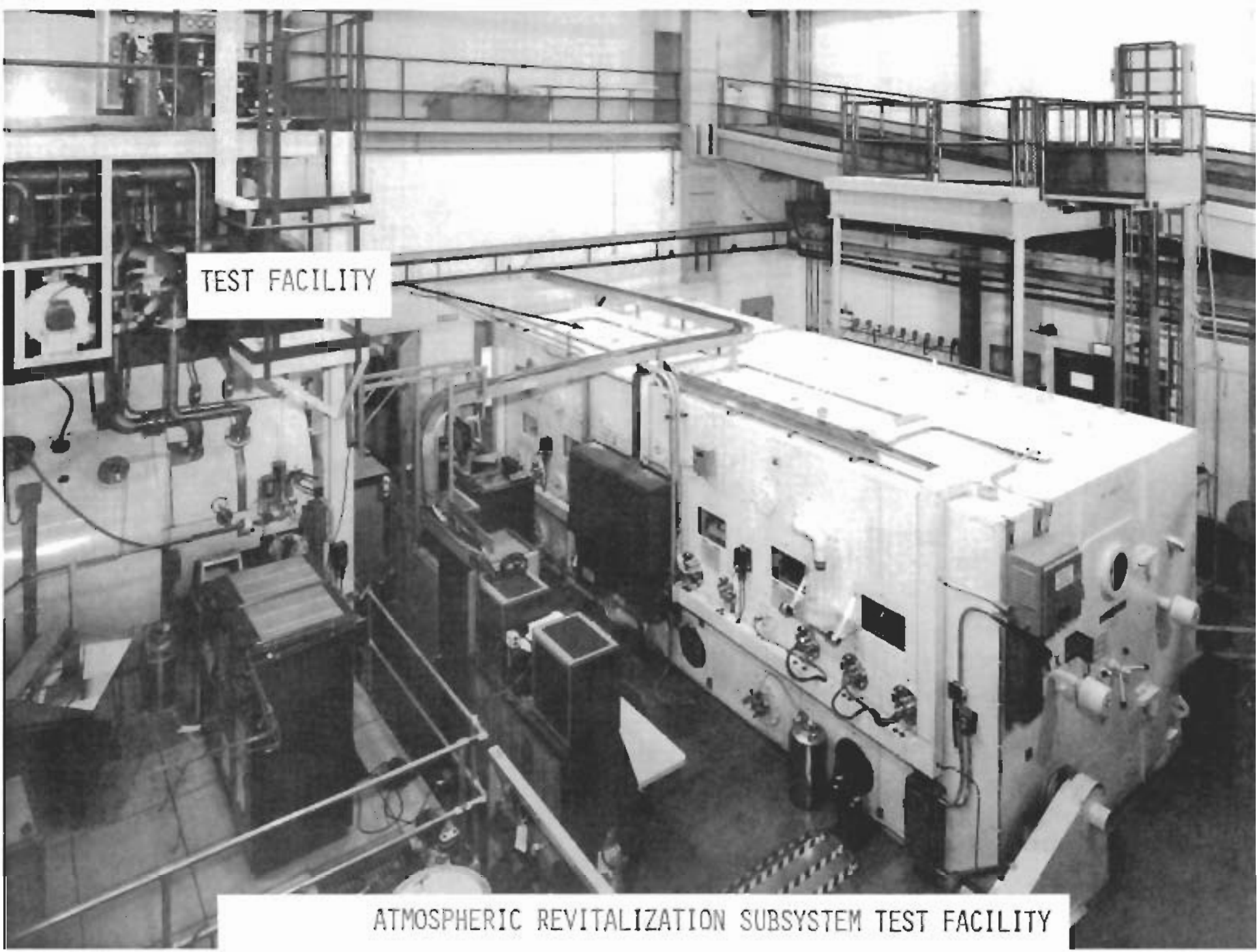
SPACE SHUTTLE

ATMOSPHERE REVITALIZATION SUBSYSTEM

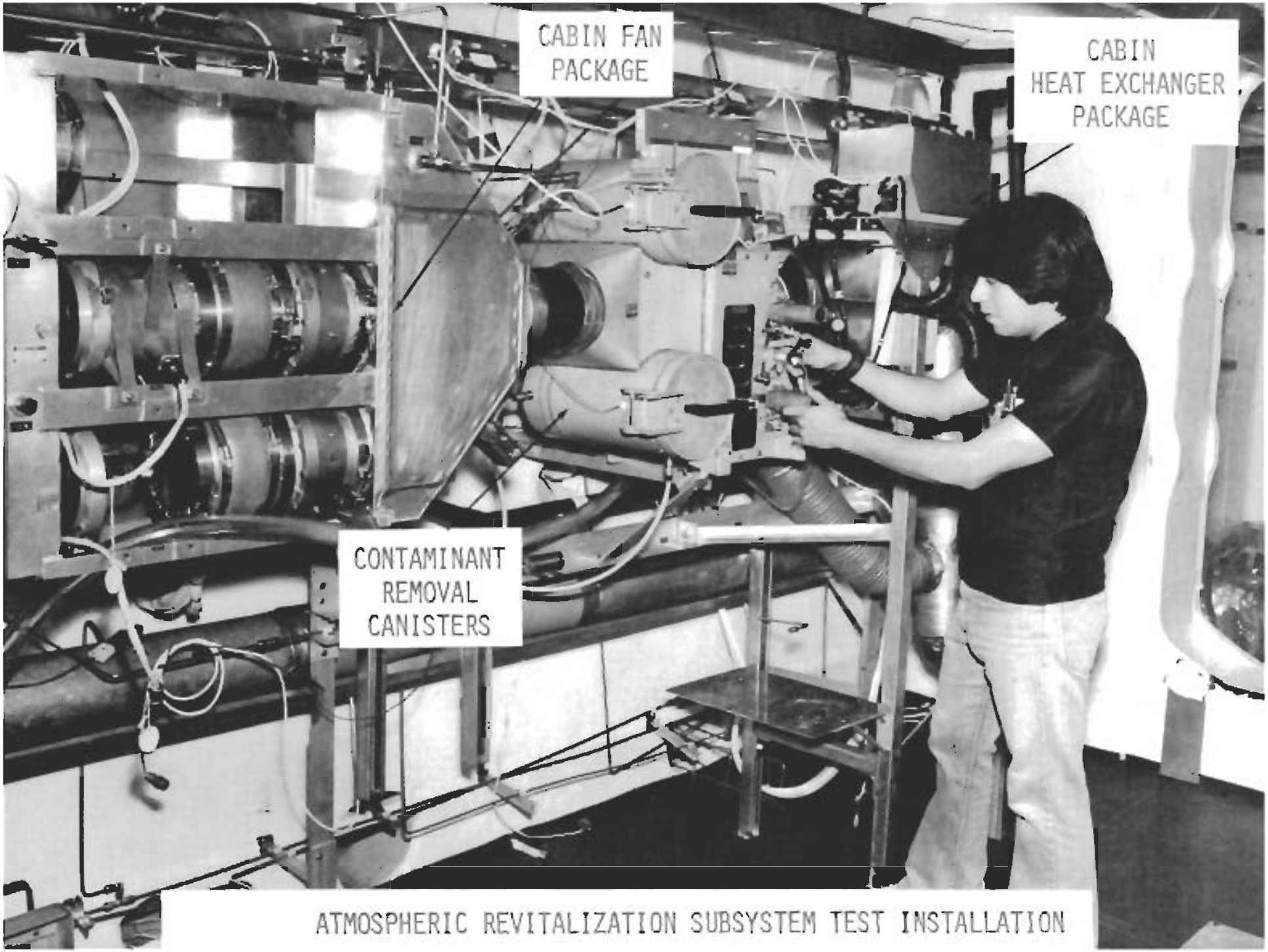


ATMOSPHERIC REVITALIZATION SUBSYSTEM





ATMOSPHERIC REVITALIZATION SUBSYSTEM TEST FACILITY

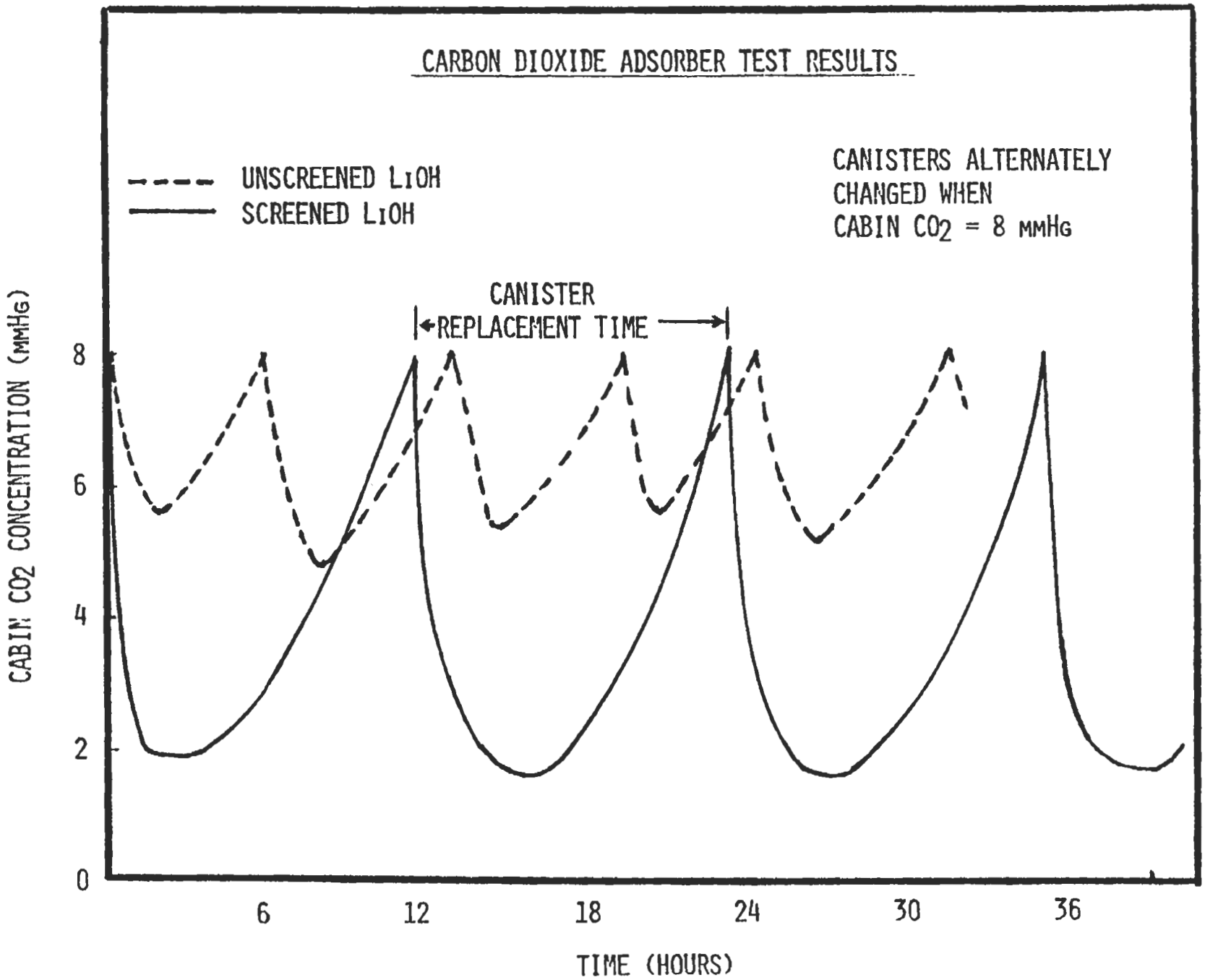


ATMOSPHERIC REVITALIZATION SUBSYSTEM TEST INSTALLATION

Cabin Atmospheric Revitalization

CO_2 and Trace Gas Removal:

- CO_2 Acceptable level $\leqq$ 7.6 mmHg
- CO_2 Absorption (from humidified cabin gas)
  - Absorbent: Lithium Hydroxide (LiOH)
  - $LiOH + CO_2 \rightarrow LiCO_3 + H_2O + heat$
  - Single use (expendable)


CARBON DIOXIDE ADSORBER TEST RESULTS
UNSCREENED LiOH
SCREENED LiOH
CANISTERS ALTERNATELY CHANGED WHEN CABIN CO_2 = 8 mmHg
CANISTER REPLACEMENT TIME
CABIN CO_2 CONCENTRATION (mmHg)
0
2
4
6
8
6
12
18
24
30
36
TIME (HOURS)

Cabin Atmospheric Revitalization

CO_2 and Trace Gas Removal:

- **CO_2 Absorption (from humidified cabin gas)**
  - **Absorbent: solid amine (polymerized ethyleneimine: RNH)**
  - **Absorb**

    $RNH + H_2O \rightarrow RNH^+_2 + OH^-$

    $OH^- + CO_2 \rightarrow HCO^-_3 + heat$
  - **Desorb**

    $RNH^+_2 + HCO^-_3 + heat + vacuum \rightarrow RNH + H_2O + CO_2$
  - **Multi-use (regenerative)**

Cabin Atmospheric Revitalization

CO_2 and Trace Gas Removal:

- Trace gas removal -
  - Activated charcoal
  - Single use (expendable)

Environmental Cooling and Humidity Control:

- Cabin atmospheric heat-exchanger
- Condensing heat-exchanger
- Centrifugal water/gas separator

Cabin Atmospheric Revitalization

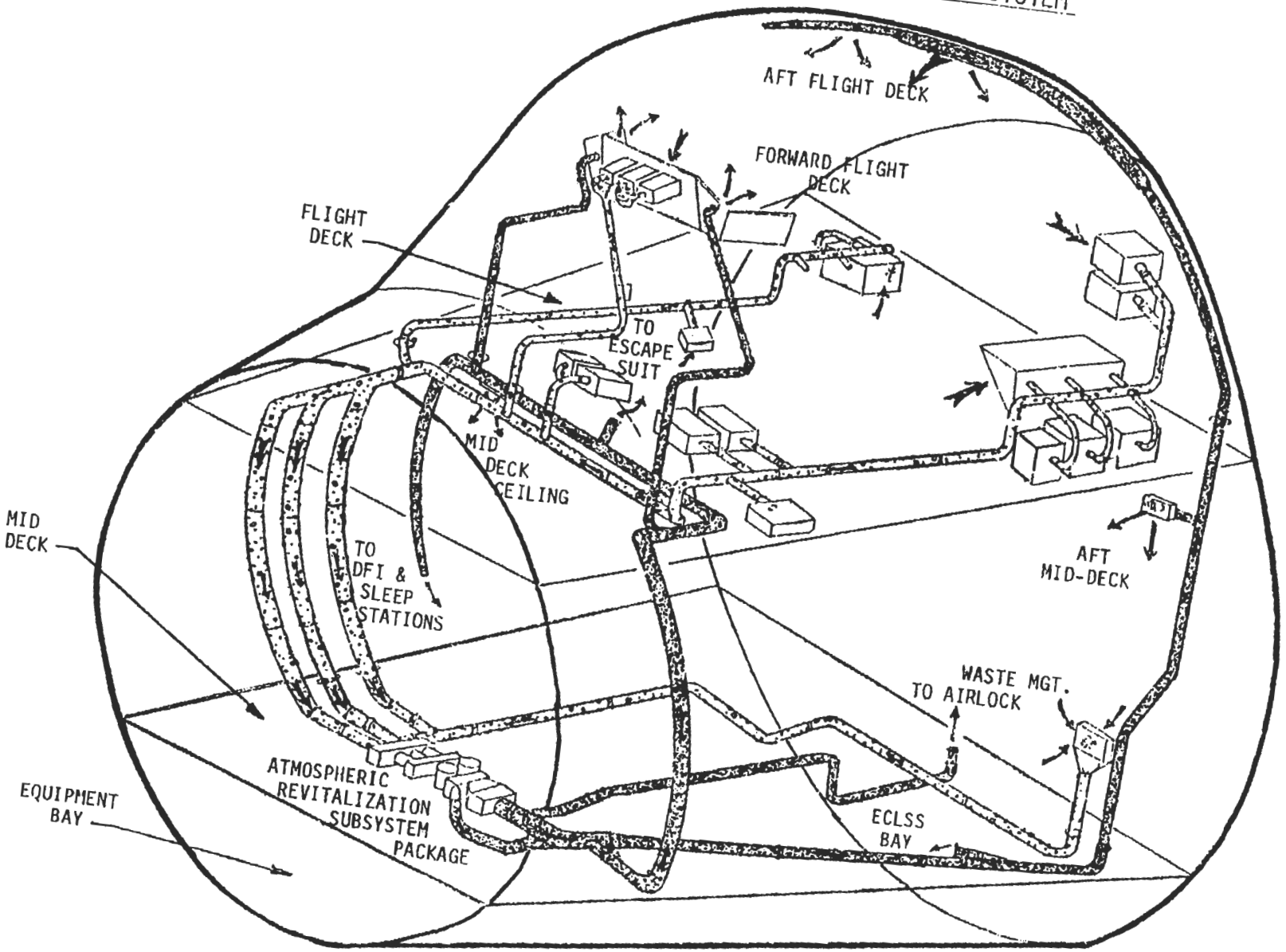
Atmospheric Circulation/Ventilation:

- **Redundant cabin fans**
- **Flight-deck and mid-deck duct system**

SUPPLY

RETURN

ORBITER AIR DISTRIBUTION SYSTEM



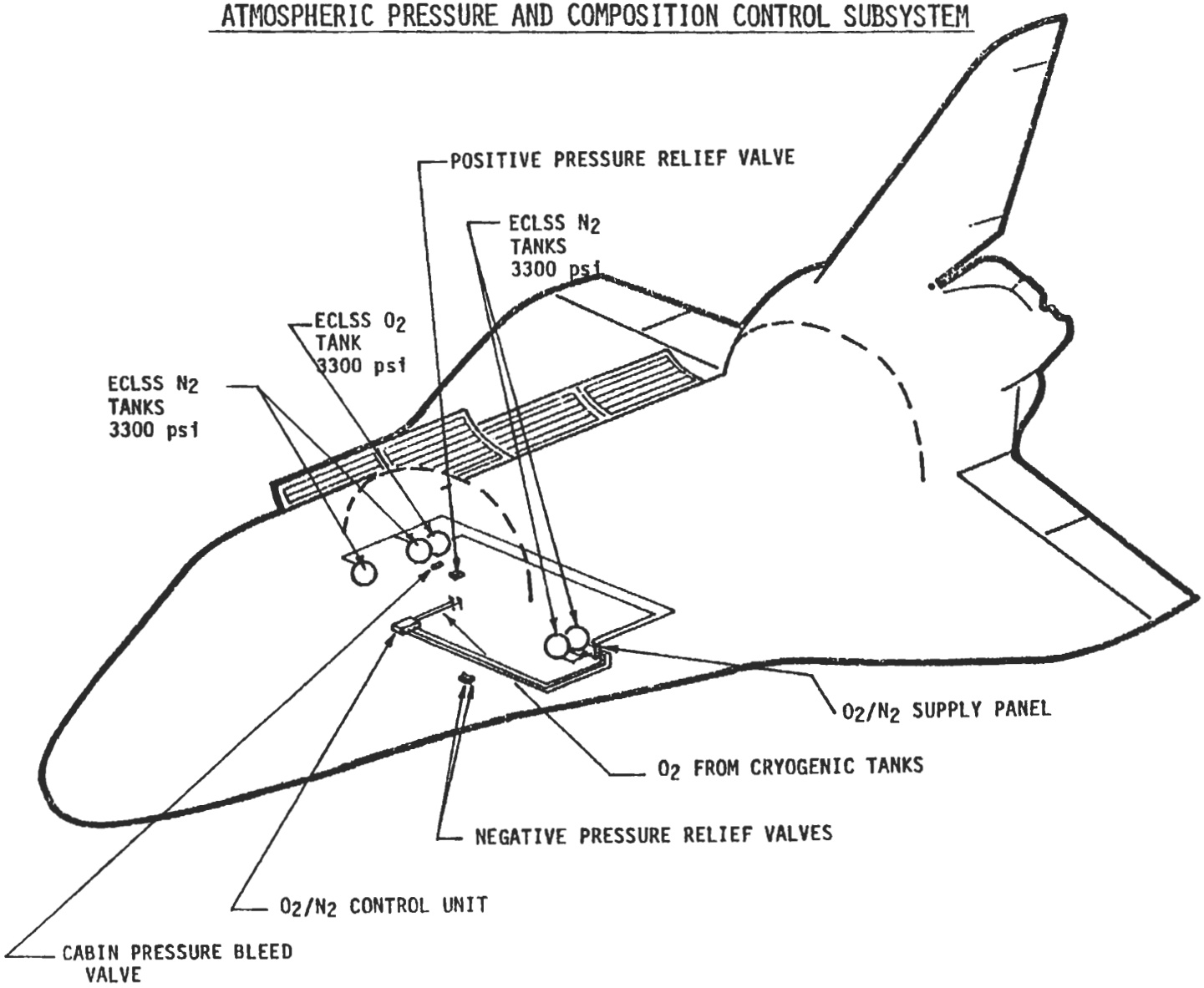
Shuttle Orbiter
Environmental/Thermal Control & Life Support System

Subsystem Elements:

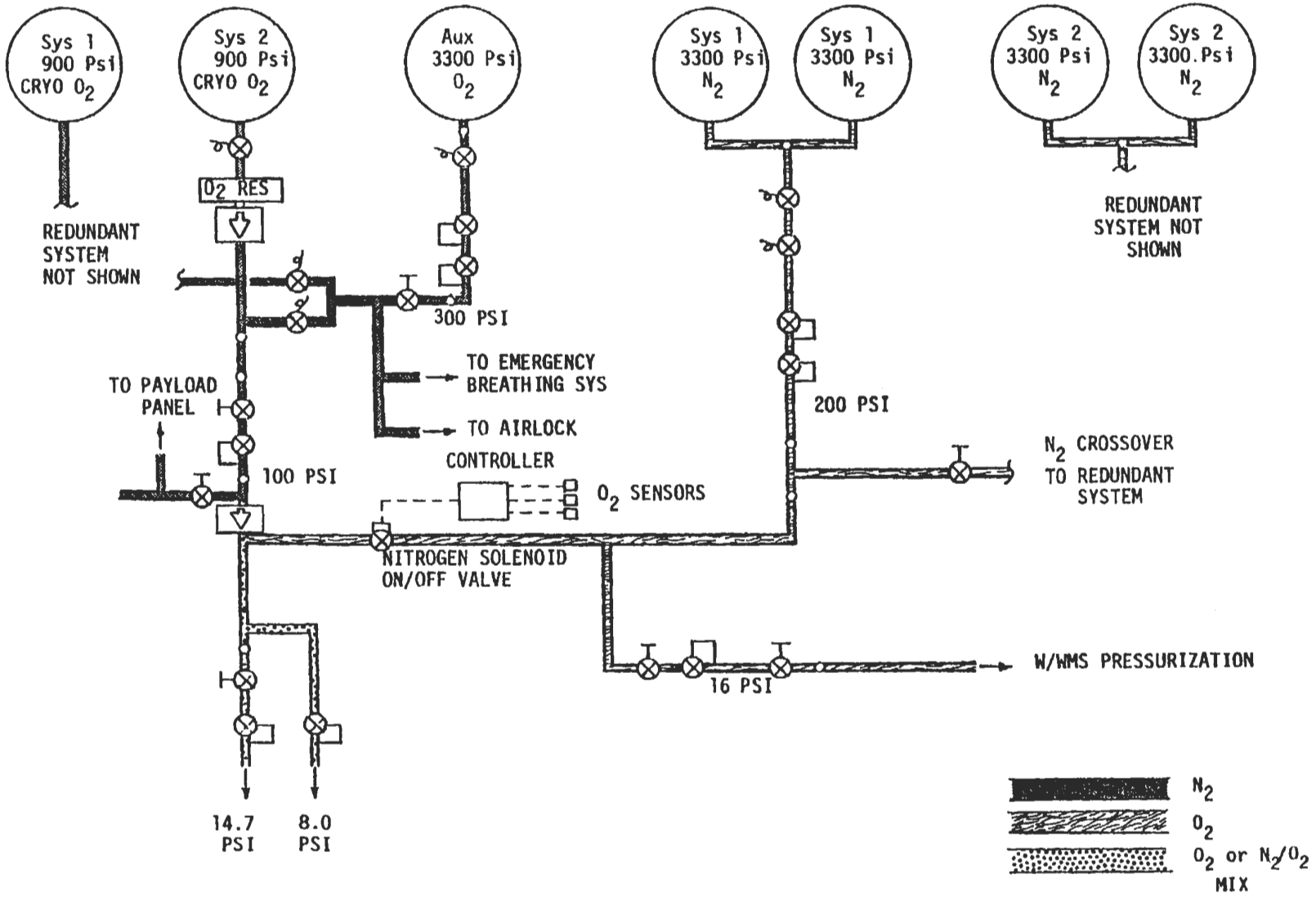
- **CABIN ATMOSPHERIC PRESSURE & COMPOSITION CONTROL**
  - **14.7 psia total pressure control (normal)**
  - **8 psia total pressure control (emergency de-orbit)**
  - **O_2/N_2 partial pressure control**
  - **Crew O_2 breathing masks**
  - **Positive and negative cabin pressure relief (anomaly)**
  - **Gaseous O_2/N_2 storage**
  - **Pressurization N_2 for Water & Waste Management**

SPACE SHUTTLE

ATMOSPHERIC PRESSURE AND COMPOSITION CONTROL SUBSYSTEM



ATMOSPHERIC PRESSURE AND COMPOSITION CONTROL SUBSYSTEM



Cabin Atmospheric Pressure & Composition Control

Normal Operations:

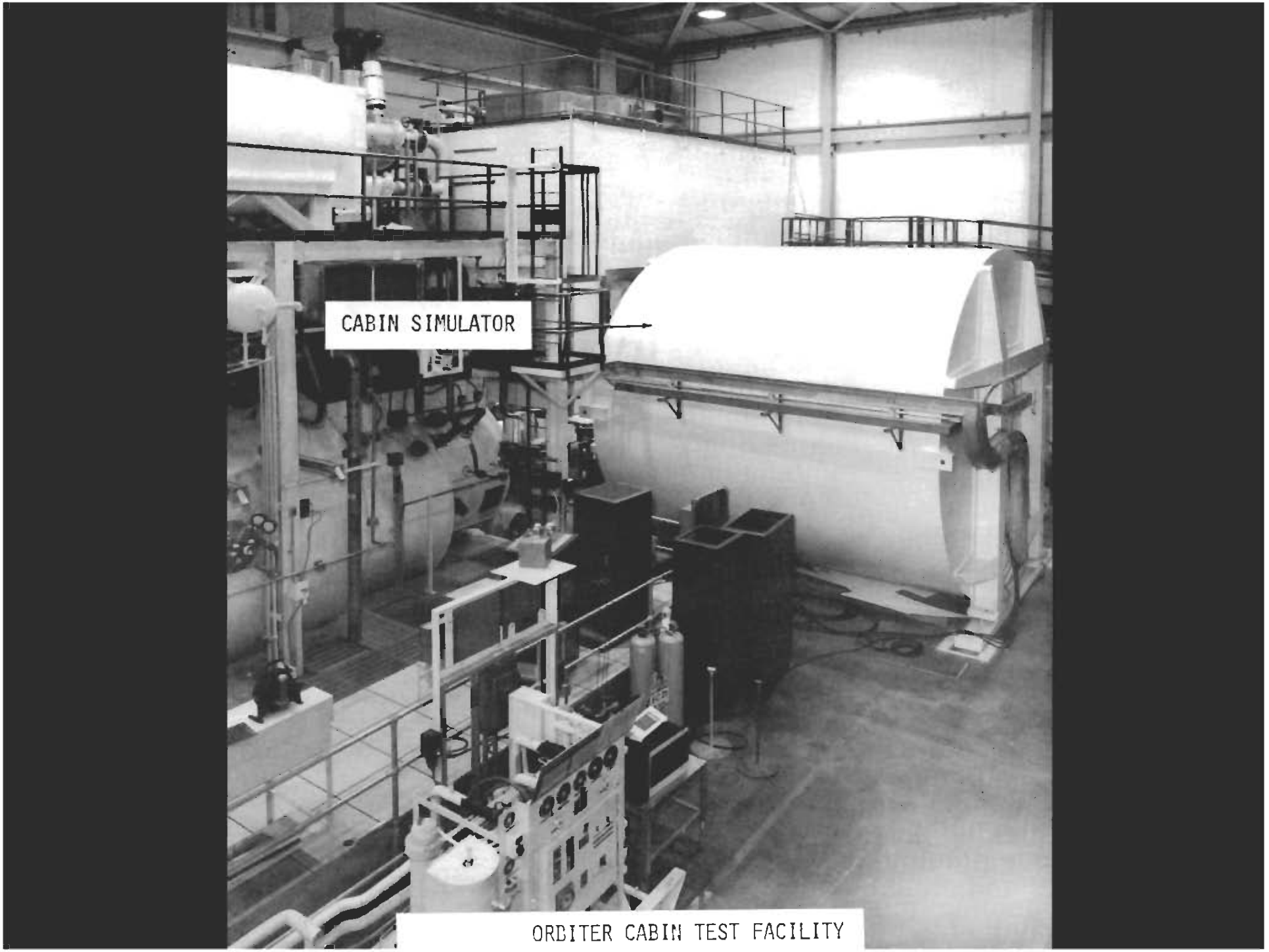
- **Total pressure control (gaseous N_2)**
  - **14.7 psia ("automatic" pressure regulator)**

- **O_2 partial pressure control (cryogenic O_2)**
  - **3.2 psia ("on-off" solenoid valve)**

Cabin Atmospheric Pressure & Composition Control

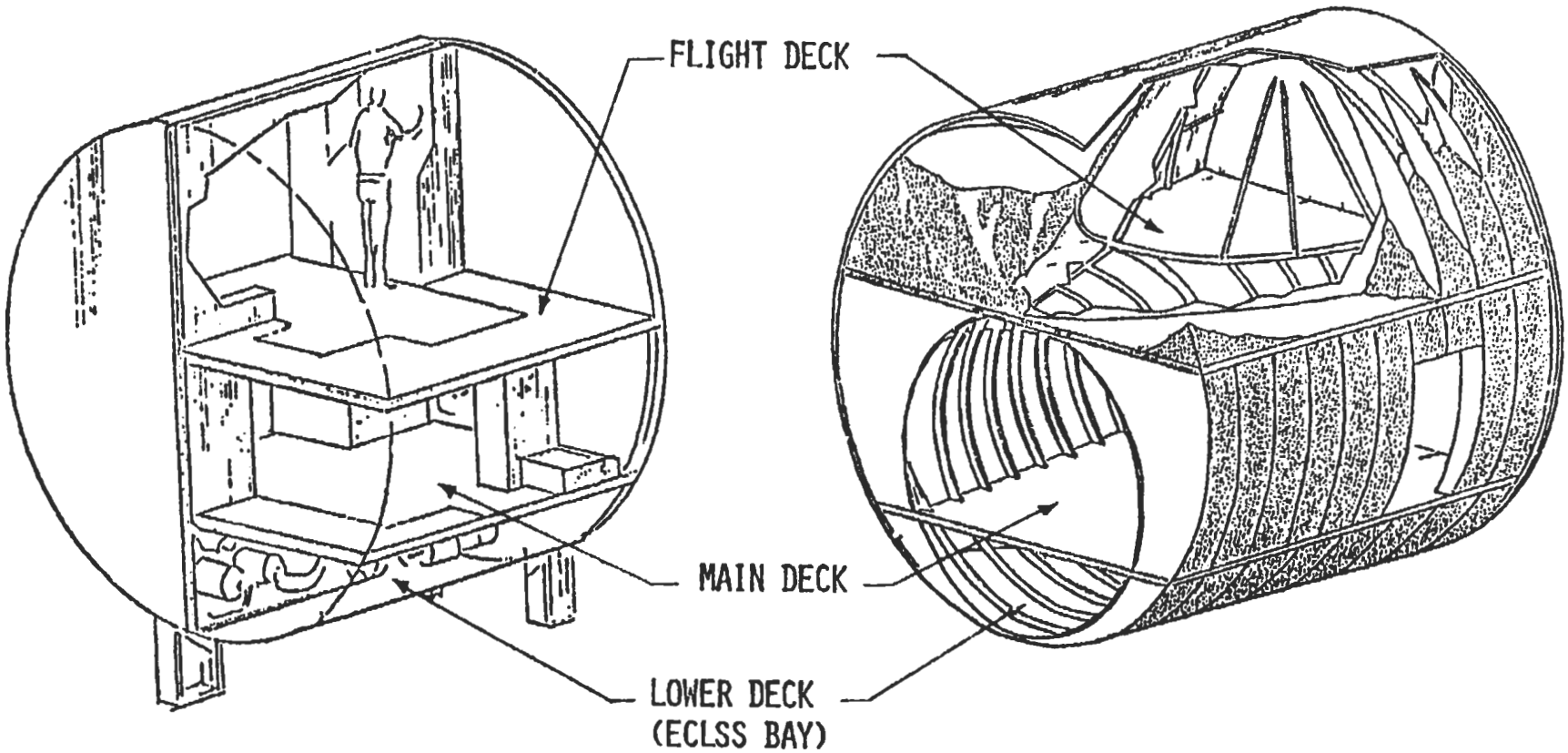
Cabin Pressure Relief:

- **Over pressure protection – 16.2 psid - 3 relief values (only two needed)**
- **Negative pressure protection – 8 psid - 3 relief values (only two needed)**



ORBITER CABIN TEST FACILITY

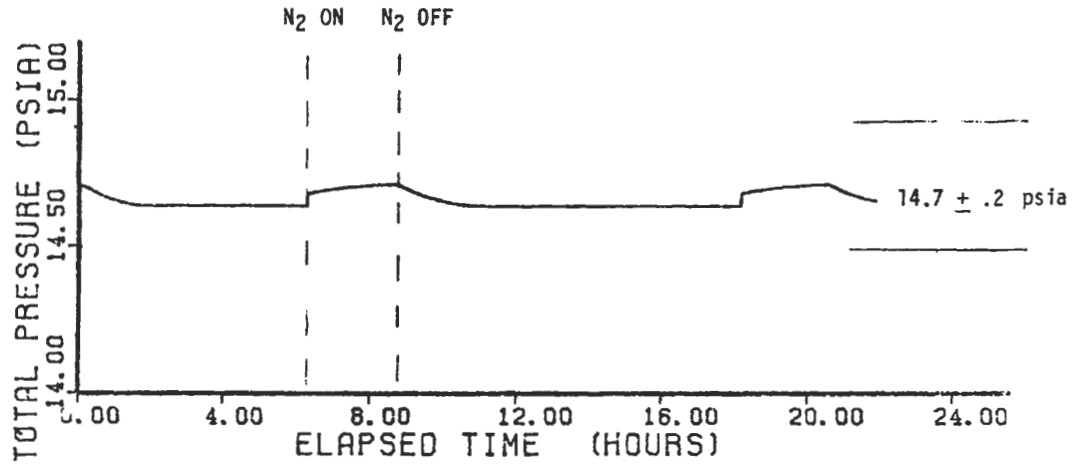
SHUTTLE CABIN TEST FACILITY

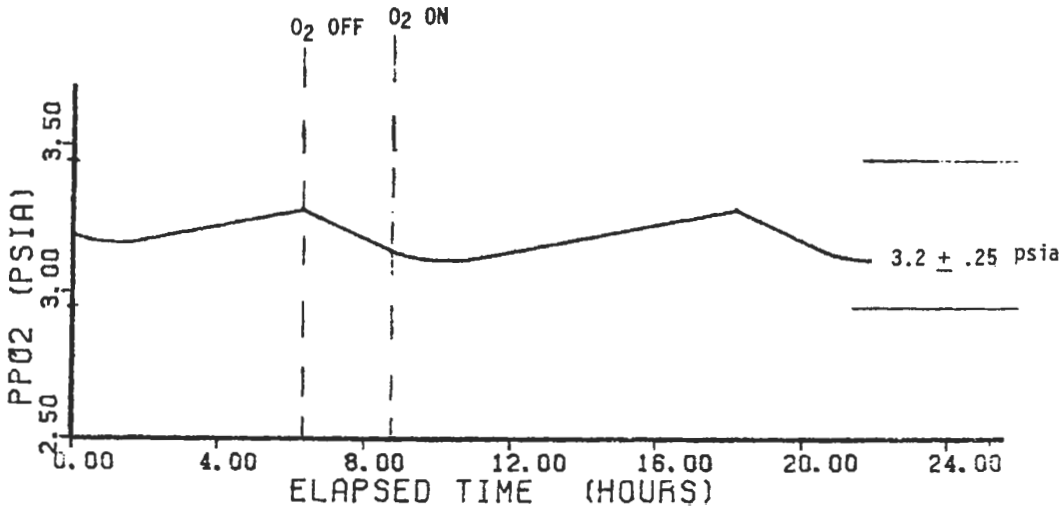


ORBITER CABIN TEST FACILITY INTERIOR

TYPICAL OPERATION OF ATMOSPHERIC PRESSURE AND COMPOSITION CONTROL SUBSYSTEM

- o NOMINAL LEAKAGE
- o 7 CREWMEN



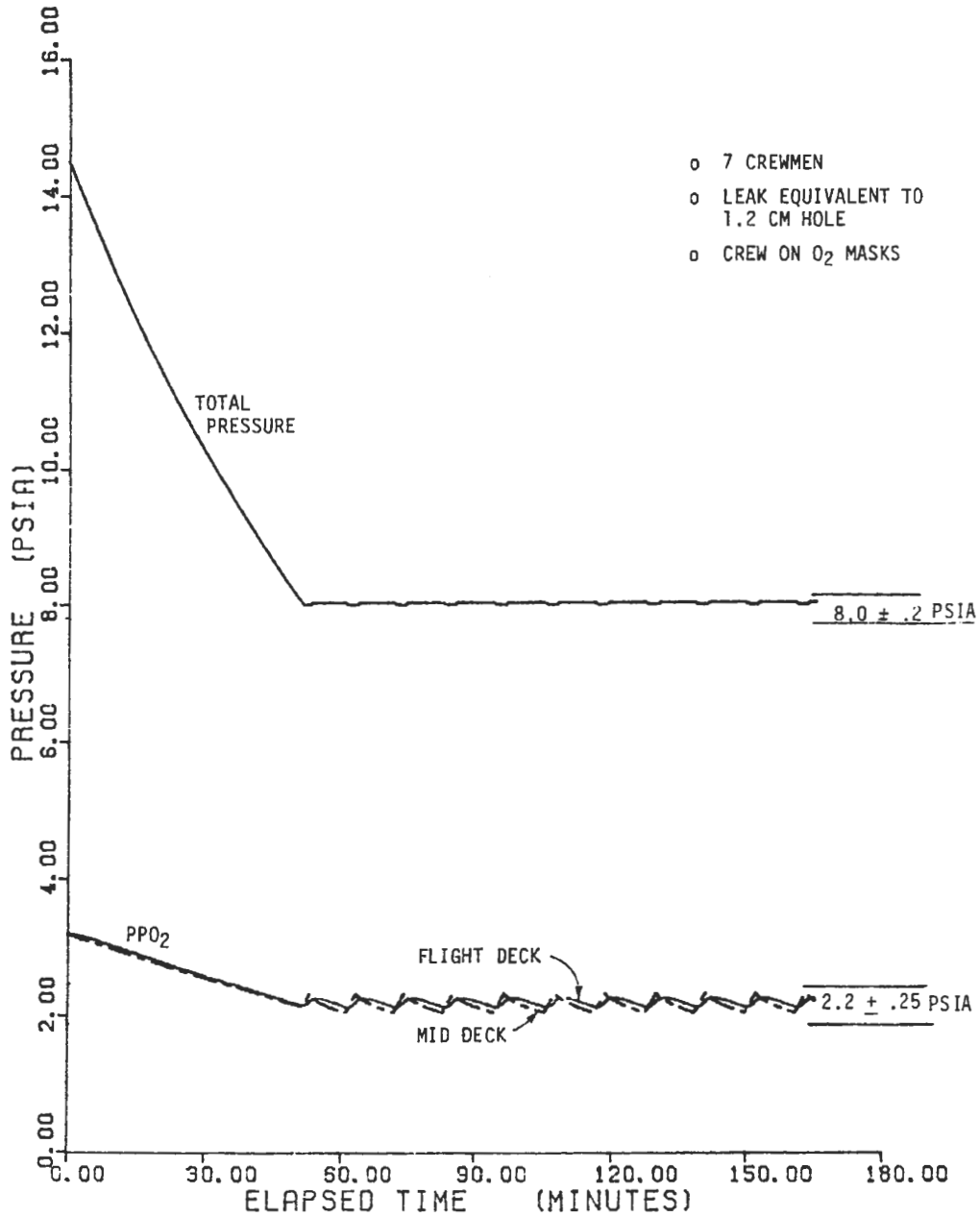


Cabin Atmospheric Pressure & Composition Control

Crew Emergency Breathing Equipment:

- **Plug-in face masks**
- **Purge-type breathing masks**
- **For use with a contaminated cabin atmosphere**
- **For use with a low concentration of O_2 in cabin**

TYPICAL CABIN PRESSURE PROFILE
FOR 8 PSIA EMERGENCY RETURN



Cabin Atmospheric Pressure & Composition Control

9 psia Cabin Pressure Control for Pre EVA

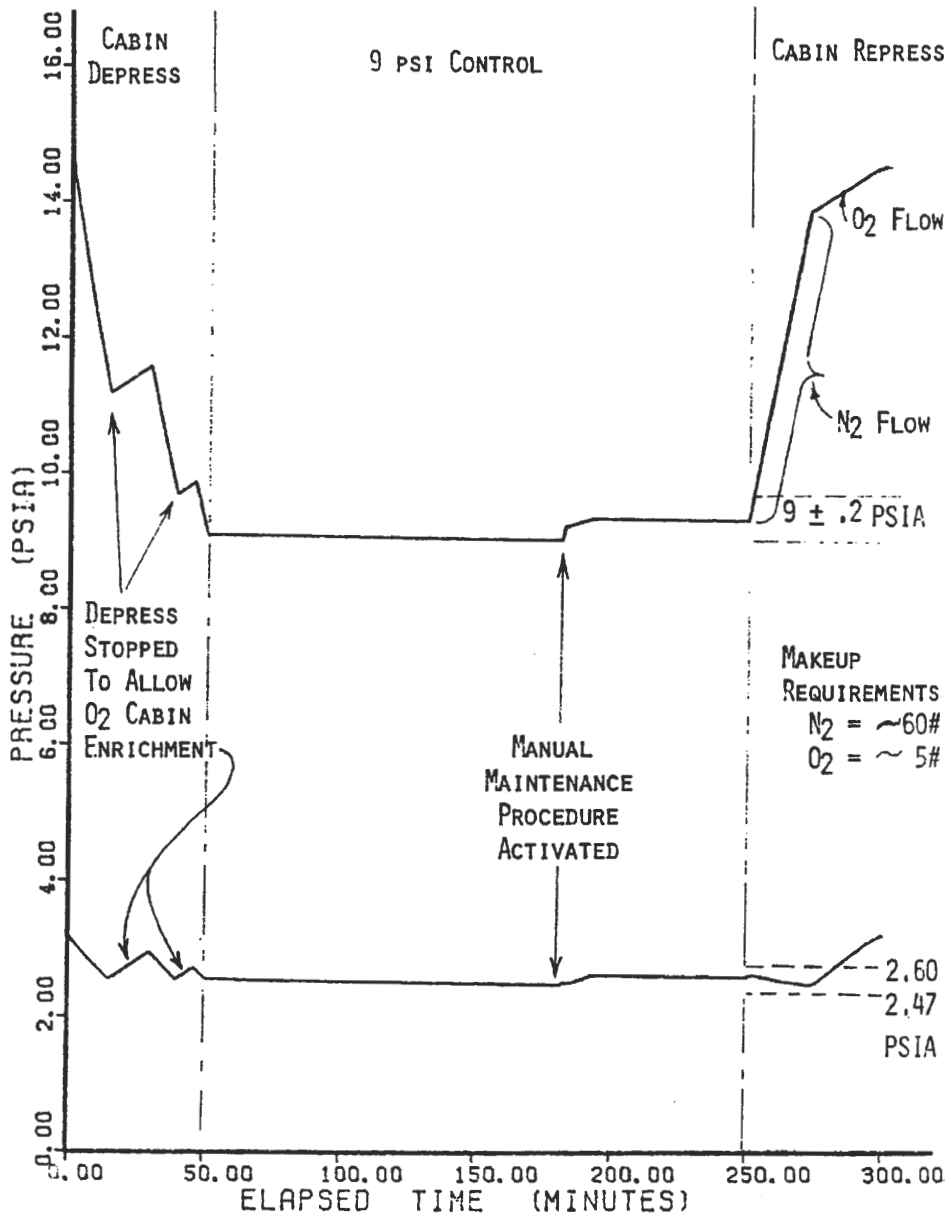
- Shuttle spacesuits operate on 100% O_2
- Normally, ~four hours of 100% O_2 pre-breath @ 14.7 psia required to prevent "bends"
- However, subsequent to 12 hours acclimatization at 9 psia, only a short pre-breath required
- The short pre-breath (~ 30 minutes) is accommodated by suit-up and EVA preparation procedures
- But cabin atmospheric pressure and composition control not designed for automatically maintaining 9 psia
- Thus, a manual operational procedure for the crew was required

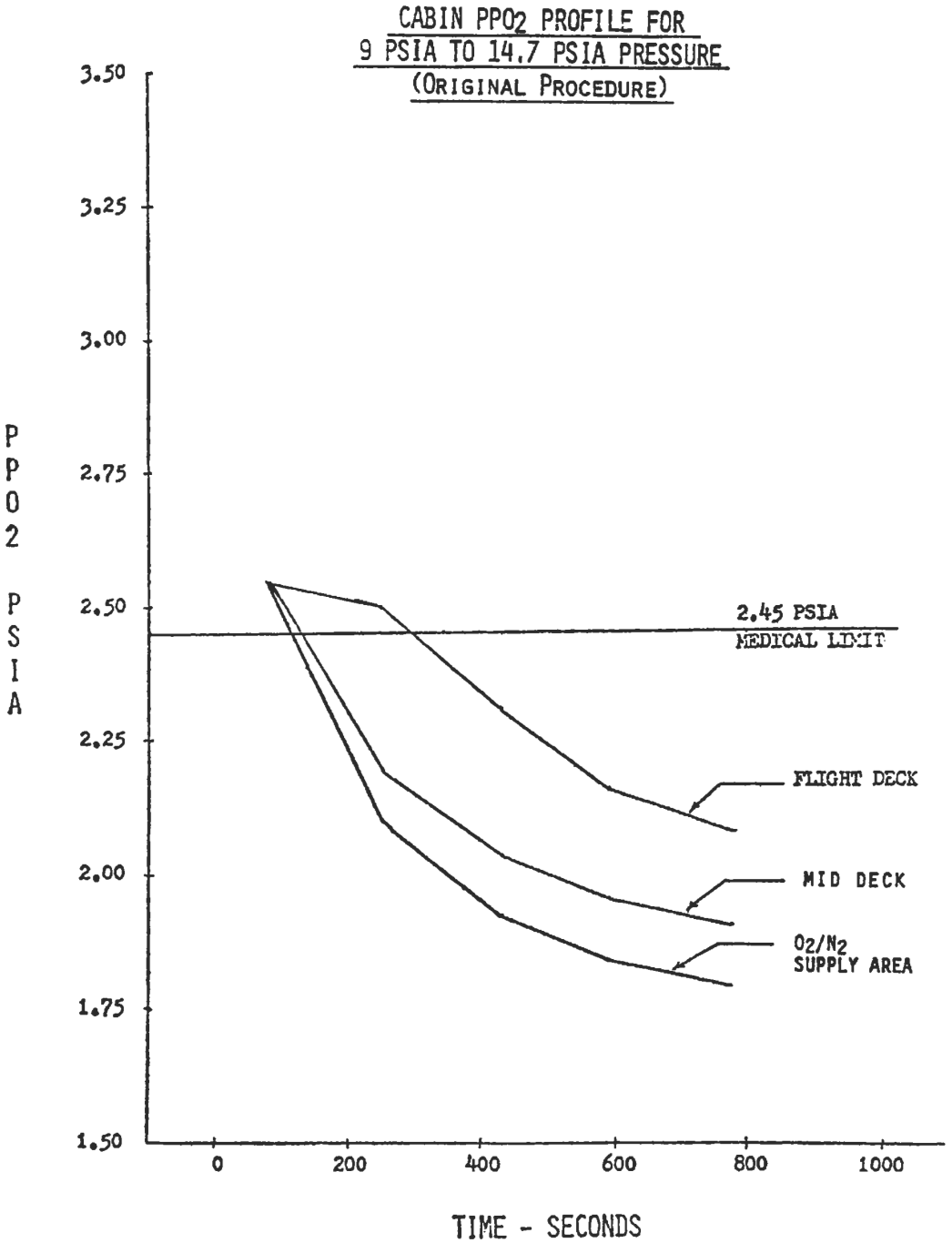
Cabin Atmospheric Pressure & Composition Control

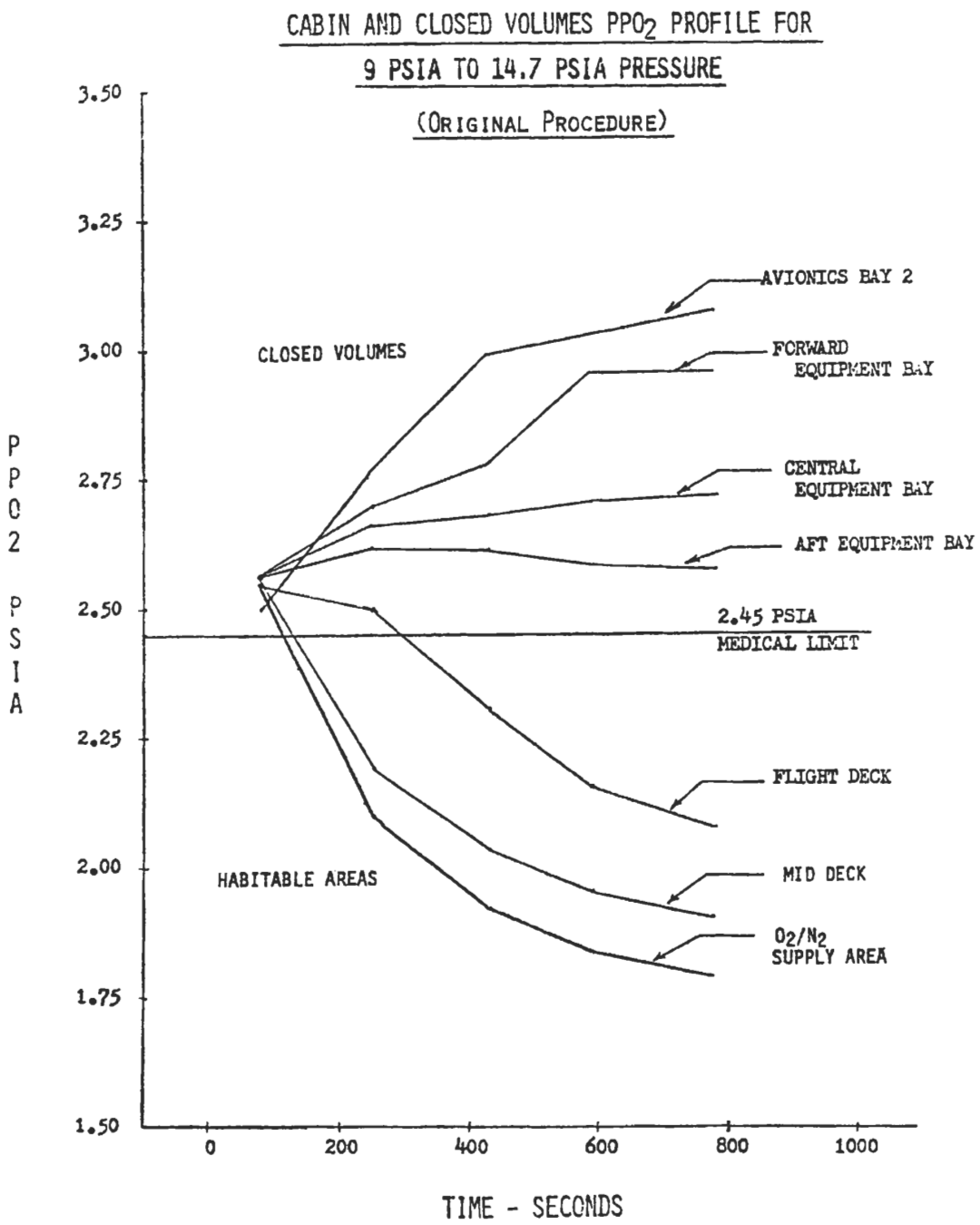
Issues with 9 psia Cabin Pressure Operation

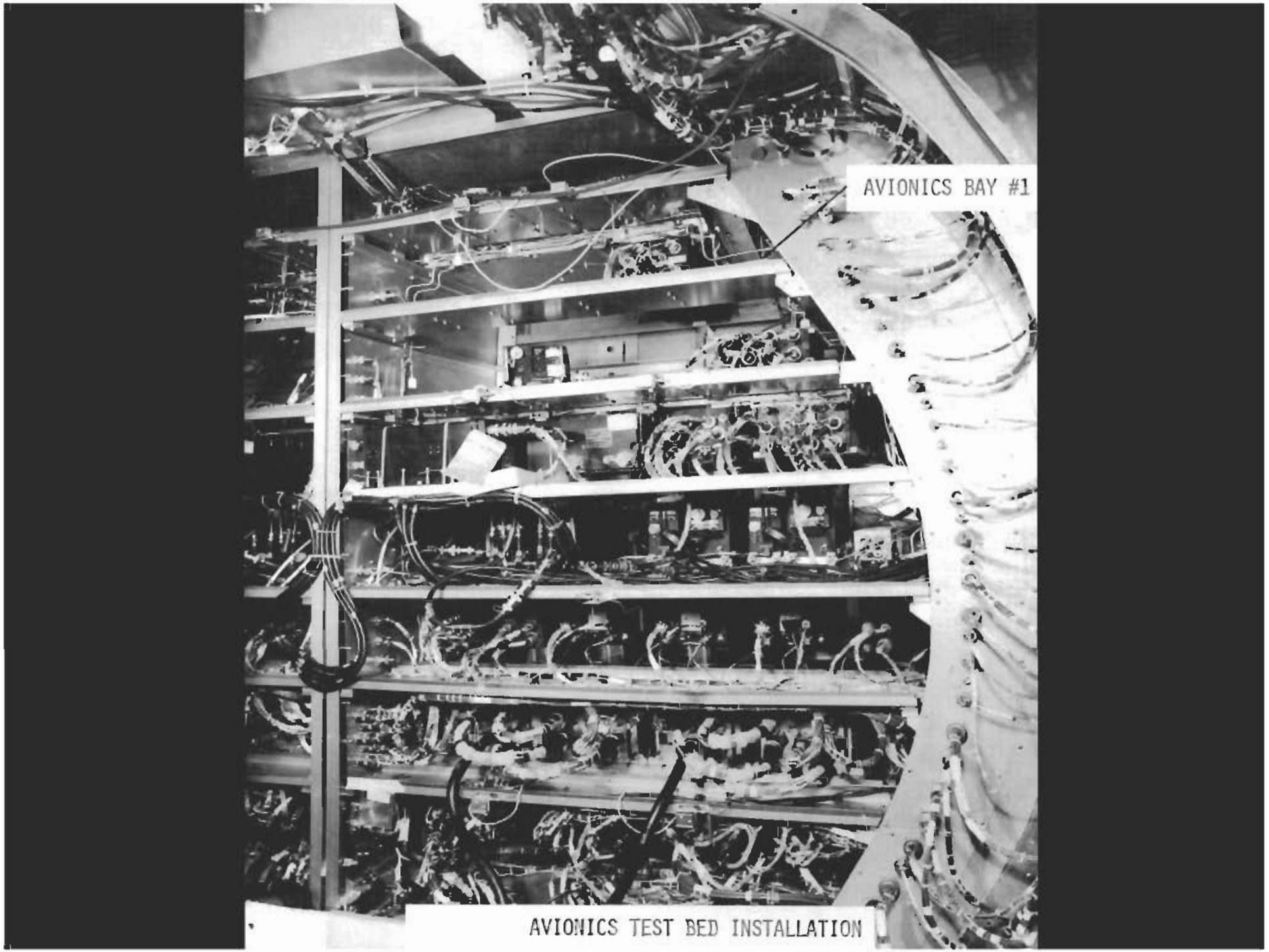
- **Flow-rate acceptability of fans at 9 psia**
- **Thermal acceptability of fans at 9 psia**
- **CO_2 absorption performance of LiOH at 9 psia**
- **Cabin ventilation adequacy for O_2/N_2 mixing with press/depress operation**

ORBITER CABIN PRESSURE PROFILE
FOR 9 PSI OPERATION



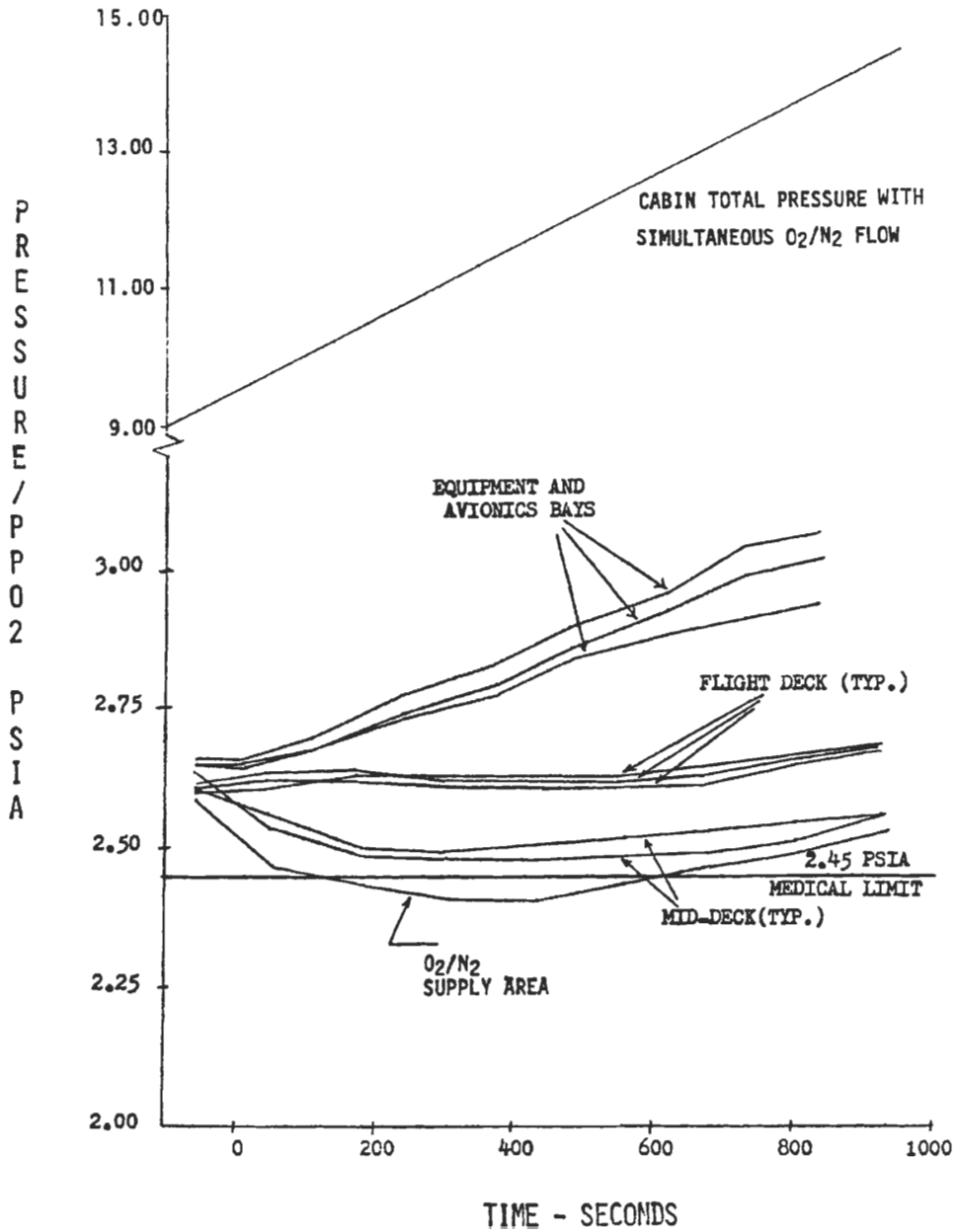

CABIN PPO2 PROFILE FOR
9 PSIA TO 14.7 PSIA PRESSURE
(ORIGINAL PROCEDURE)
PPO2 PSIA
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
2.45 PSIA
MEDICAL LIMIT
FLIGHT DECK
MID DECK
O2/N2
SUPPLY AREA
0
200
400
600
800
1000
TIME - SECONDS


CABIN AND CLOSED VOLUMES PPO2 PROFILE FOR
9 PSIA TO 14.7 PSIA PRESSURE
(ORIGINAL PROCEDURE)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
PPO2 PSIA
CLOSED VOLUMES
AVIONICS BAY 2
FORWARD EQUIPMENT BAY
CENTRAL EQUIPMENT BAY
AFT EQUIPMENT BAY
2.45 PSIA
MEDICAL LIMIT
FLIGHT DECK
MID DECK
O2/N2 SUPPLY AREA
HABITABLE AREAS
0
200
400
600
800
1000
TIME - SECONDS



AVIONICS TEST BED INSTALLATION

CABIN PPO_2 PROFILE FOR 9 PSIA TO 14.7 PSIA PRESSURE (ALTERNATE PROCEDURE)



Shuttle Orbiter
Environmental/Thermal Control & Life Support System

Subsystem Elements:

- **WATER & WASTE MANAGEMENT**
  - **Potable/waste water inventory management**
  - **Potable water storage for drinking and food preparation**
  - **Waste water storage for dumping to space**
  - **Commode and urinal for human waste collection**
  - **Supply water for flash evaporators**

Water & Waste Management

Water Sources:

Potable Water

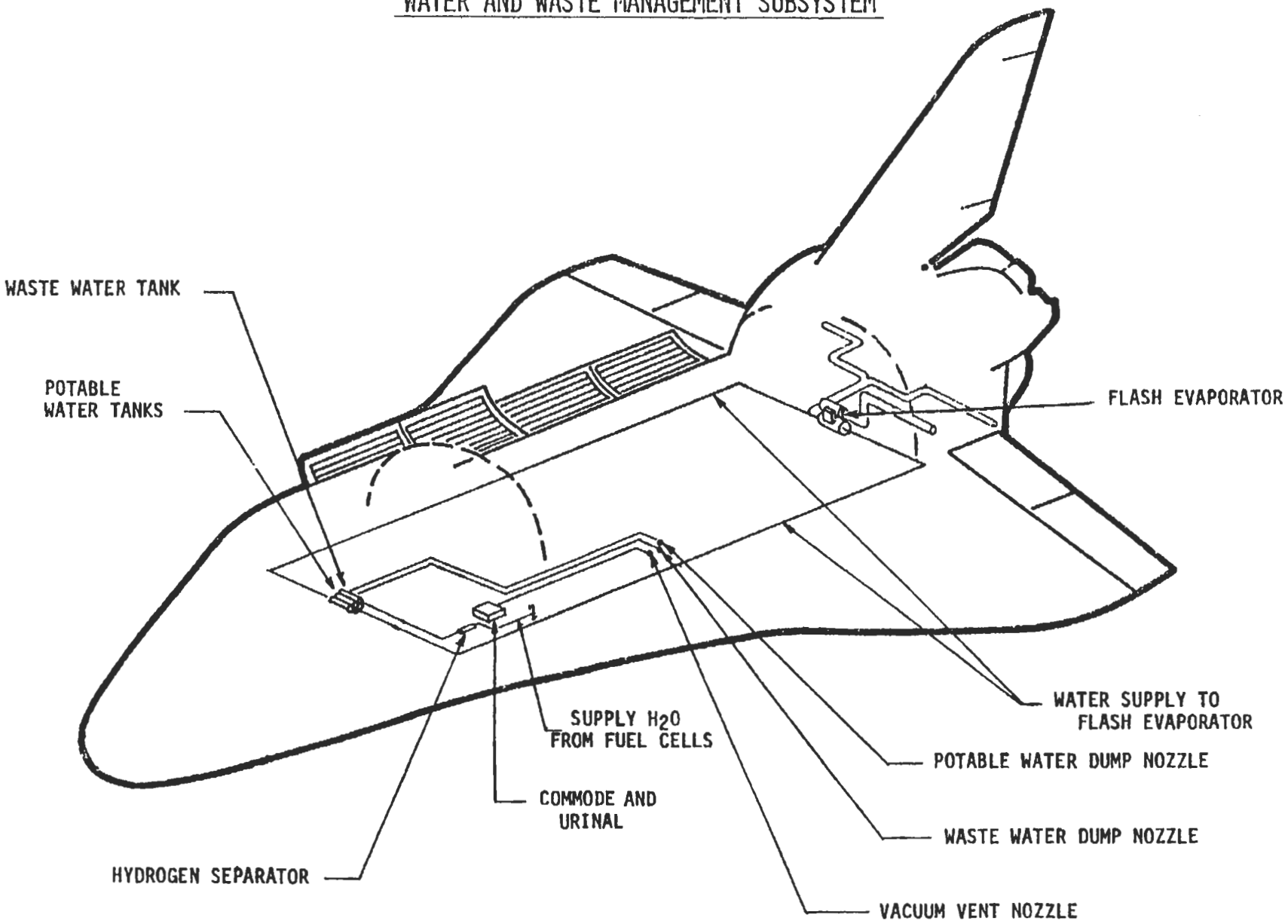
- Fuel cell byproduct H_2O
- Launch storage of H_2O
- Drinking water sterilization

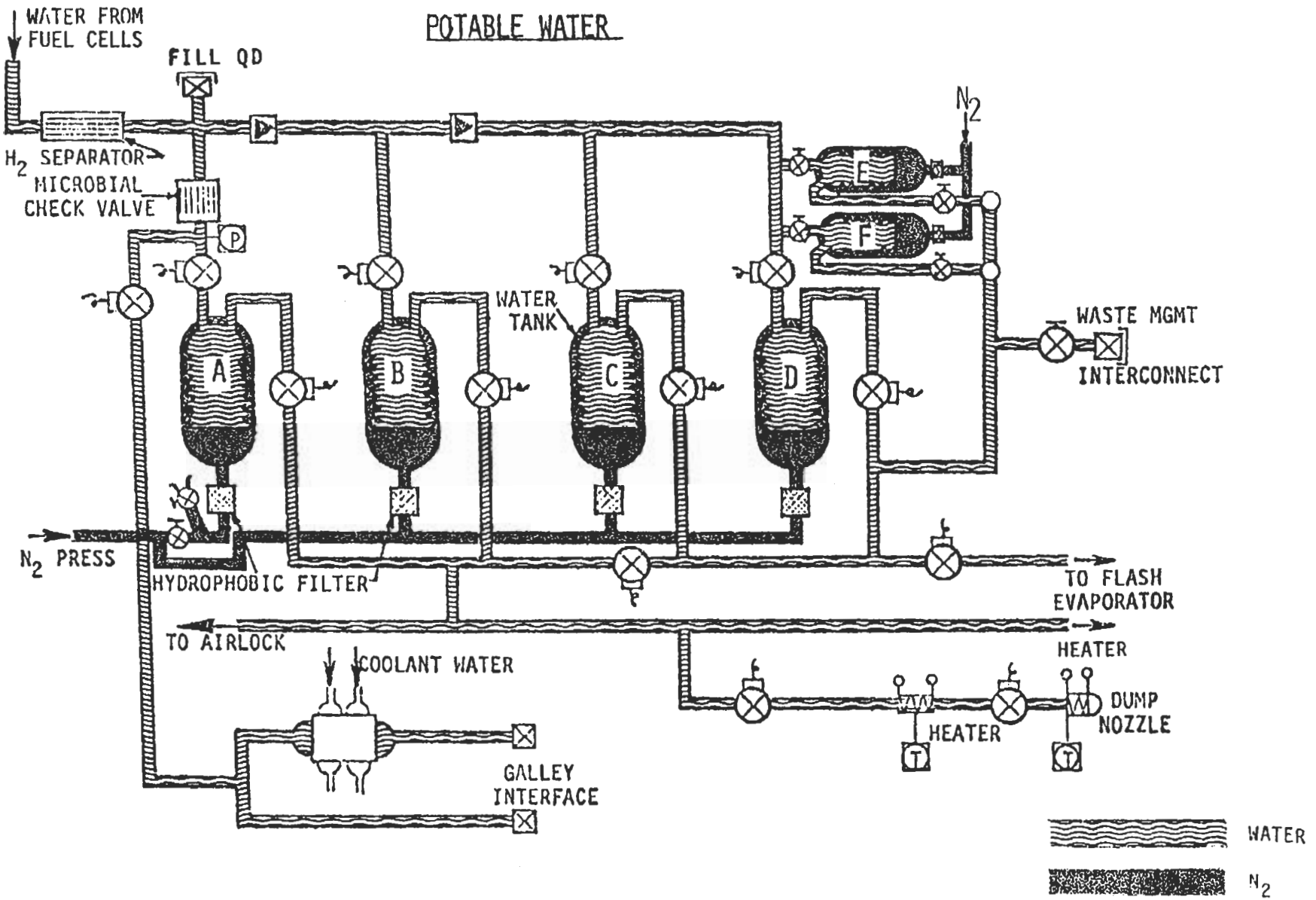
Waste Water

- Condensate from cabin humidity control
- Urine
- Urine pre-treat for NH_3

SPACE SHUTTLE

WATER AND WASTE MANAGEMENT SUBSYSTEM



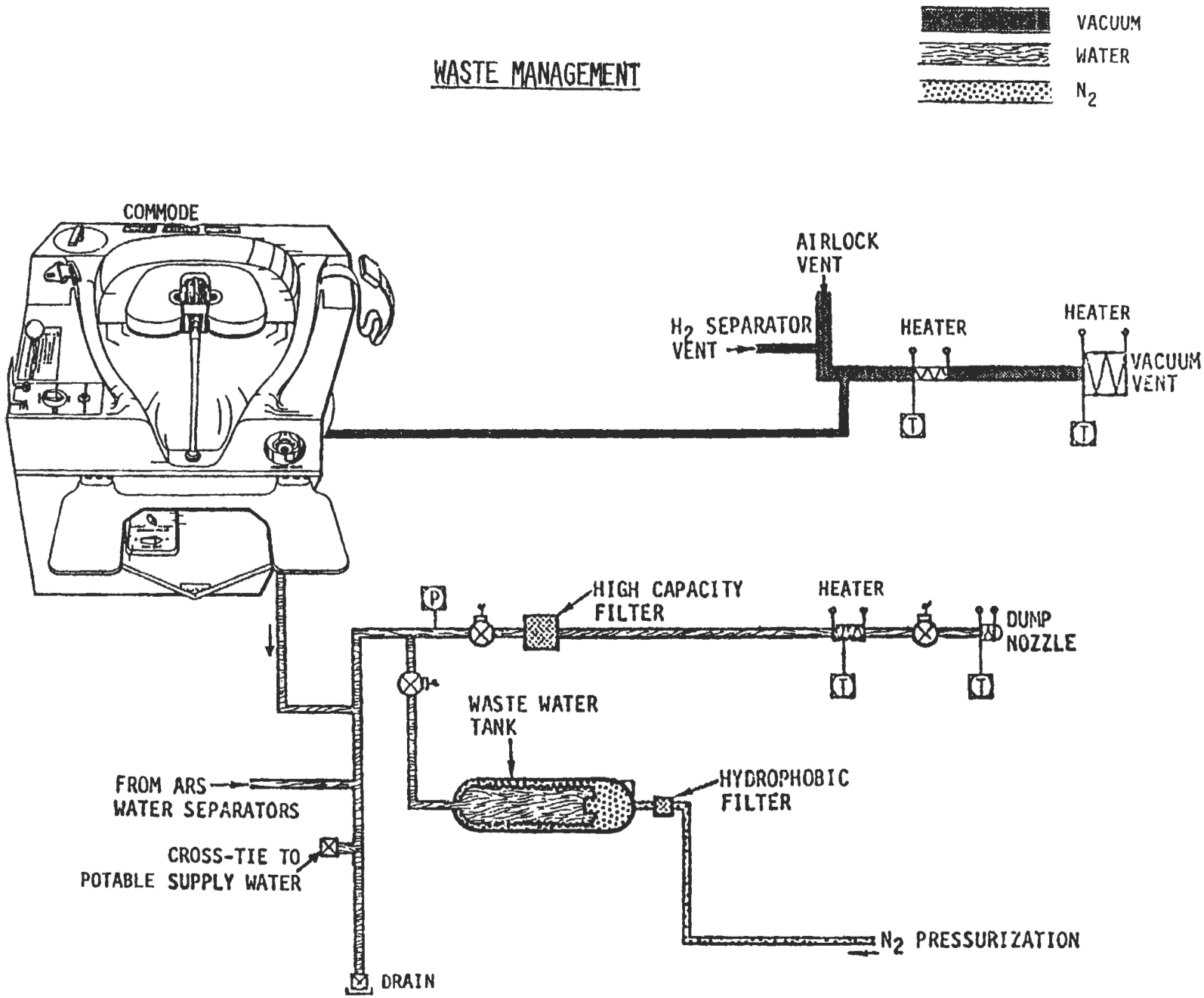

POTABLE WATER
WATER FROM FUEL CELLS
FILL QD
H_2 SEPARATOR
MICROBIAL CHECK VALVE
P
N_2
E
F
WATER TANK
A
B
C
D
WASTE MGMT
INTERCONNECT
N_2 PRESS
HYDROPHOBIC FILTER
TO FLASH EVAPORATOR
TO AIRLOCK
COOLANT WATER
HEATER
DUMP NOZZLE
HEATER
T
T
GALLEY INTERFACE
WATER
N_2

Water and Waste Management

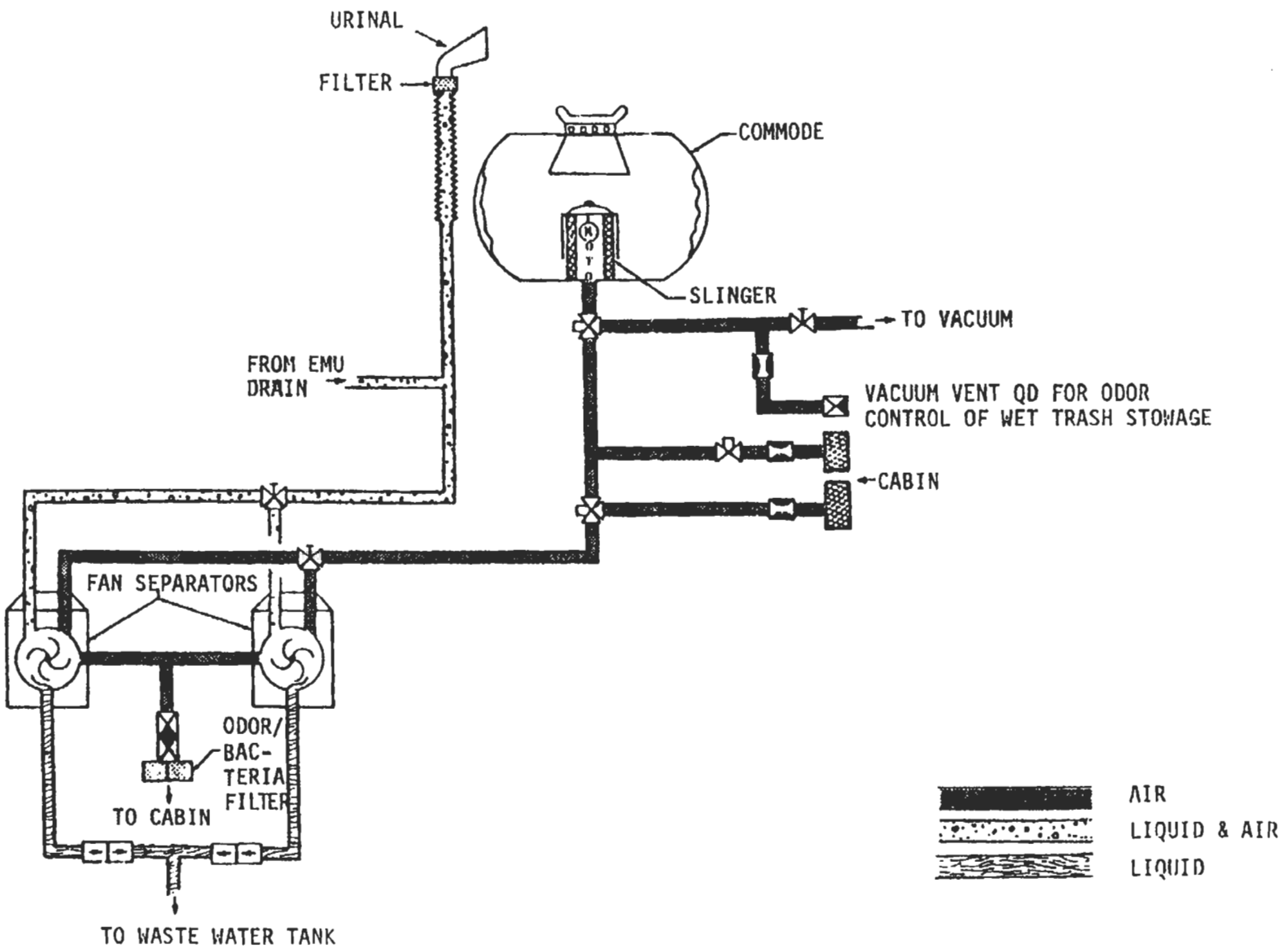
Solid Waste:

- **On-orbit trash storage (overboard dump for odor control)**
- **Human solid waste collection and storage (vacuum dried/stabilized)**

WASTE MANAGEMENT



COMMODE AND URINAL

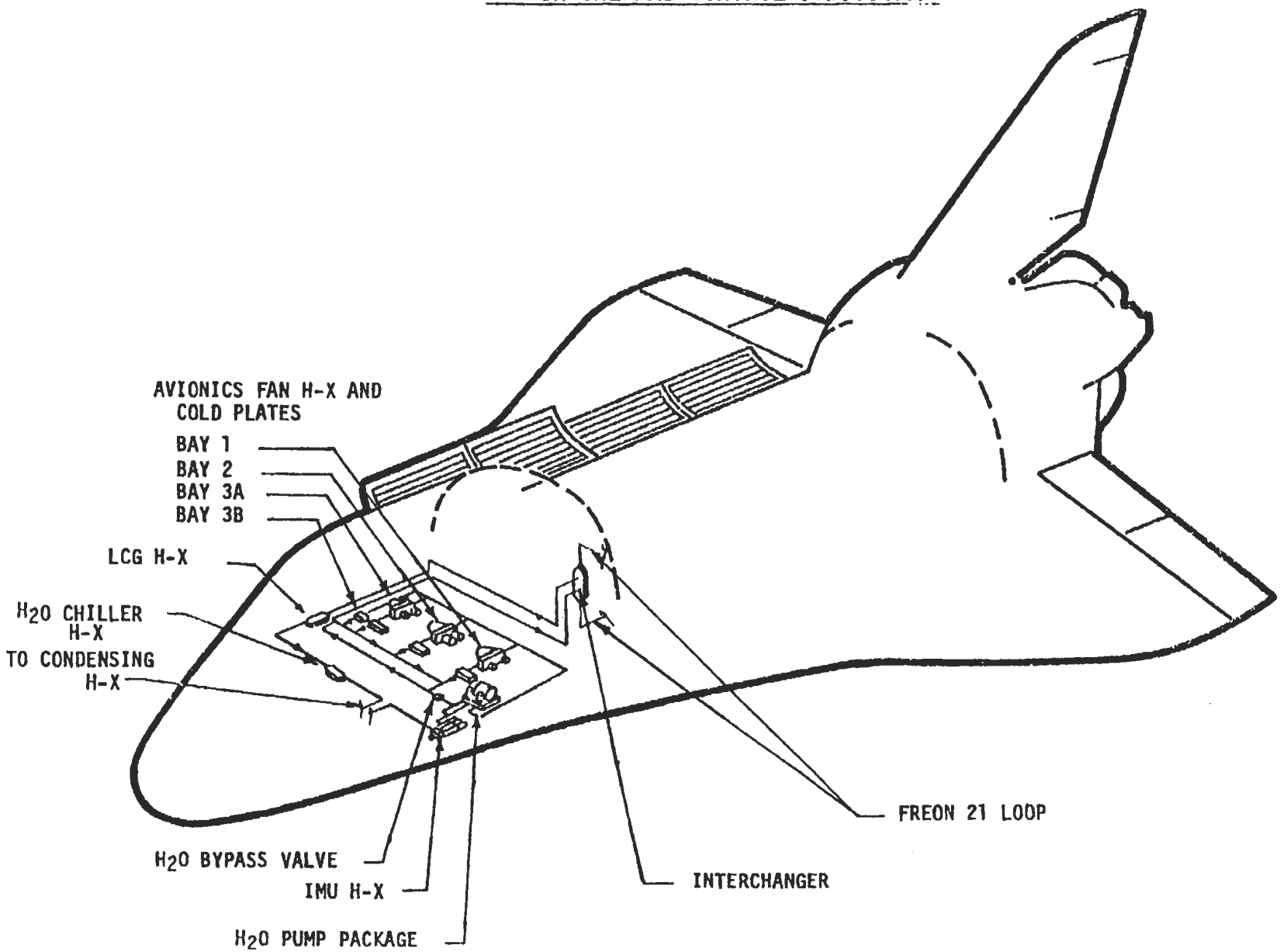


Shuttle Orbiter
Environmental/Thermal Control & Life Support System

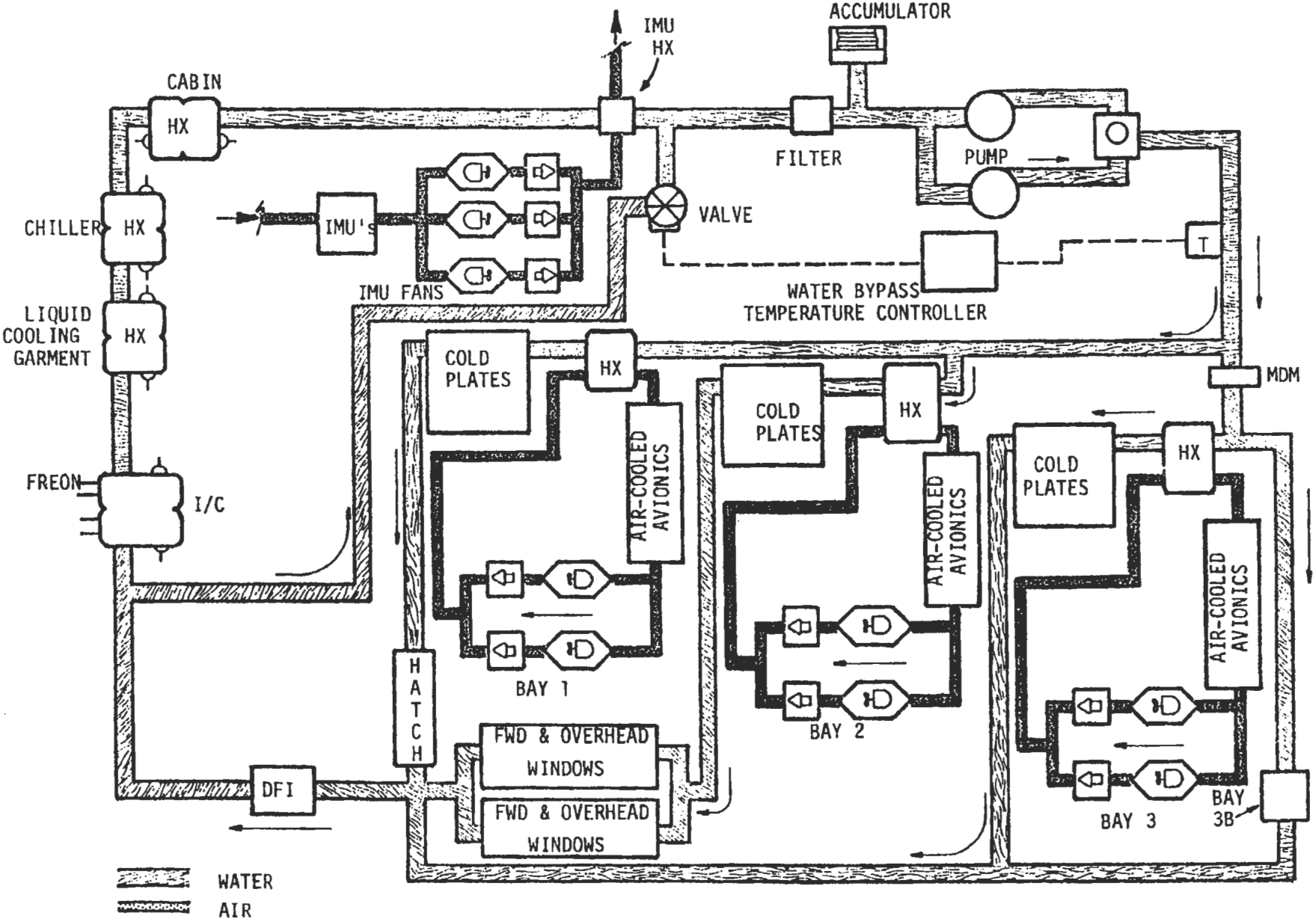
Subsystem Elements:

- **CABIN THERMAL CONTROL**
  - **Cabin circulating liquid cooling system**
  - **Atmospheric heat sink**
  - **Cabin heat rejection to spacecraft cooling system**
  - **Avionics cold-plate heat rejection**
  - **Air-cooled avionics-bay heat rejection**
  - **EVA crew cooling in airlock**
  - **Crew potable water chiller**

SPACE SHUTTLE
CABIN THERMAL CONTROL SUBSYSTEM



CABIN THERMAL CONTROL SUBSYSTEM



Cabin Thermal Control System

Cabin Thermal Control Subsystem Functions:

- Cool cabin atmospheric
- Cool atmosphere in avionics bays
- Remove heat from cold-plated electronics
- Cool IMU
- Thermal control of windows & hatch
- Provide water chiller for crew
- Cool space-suited crew in airlock
- Reject cabin thermal energy to vehicle heat rejection system

Cabin Thermal Control System

Cabin Circulating Liquid Cooling Loop:

- H_20 as coolant
- Redundant pumps
- Liquid/gas heat-exchangers for atmospheric cooling
- Cold-plates for electronics cooling
- Window-mount/hatch-mount thermal control

Avionics Circulating Gas Cooling Loop:

- Cabin atmospheric used as coolant
- Redundant fans in avionics bays
- Double redundant fans for IMU cooling

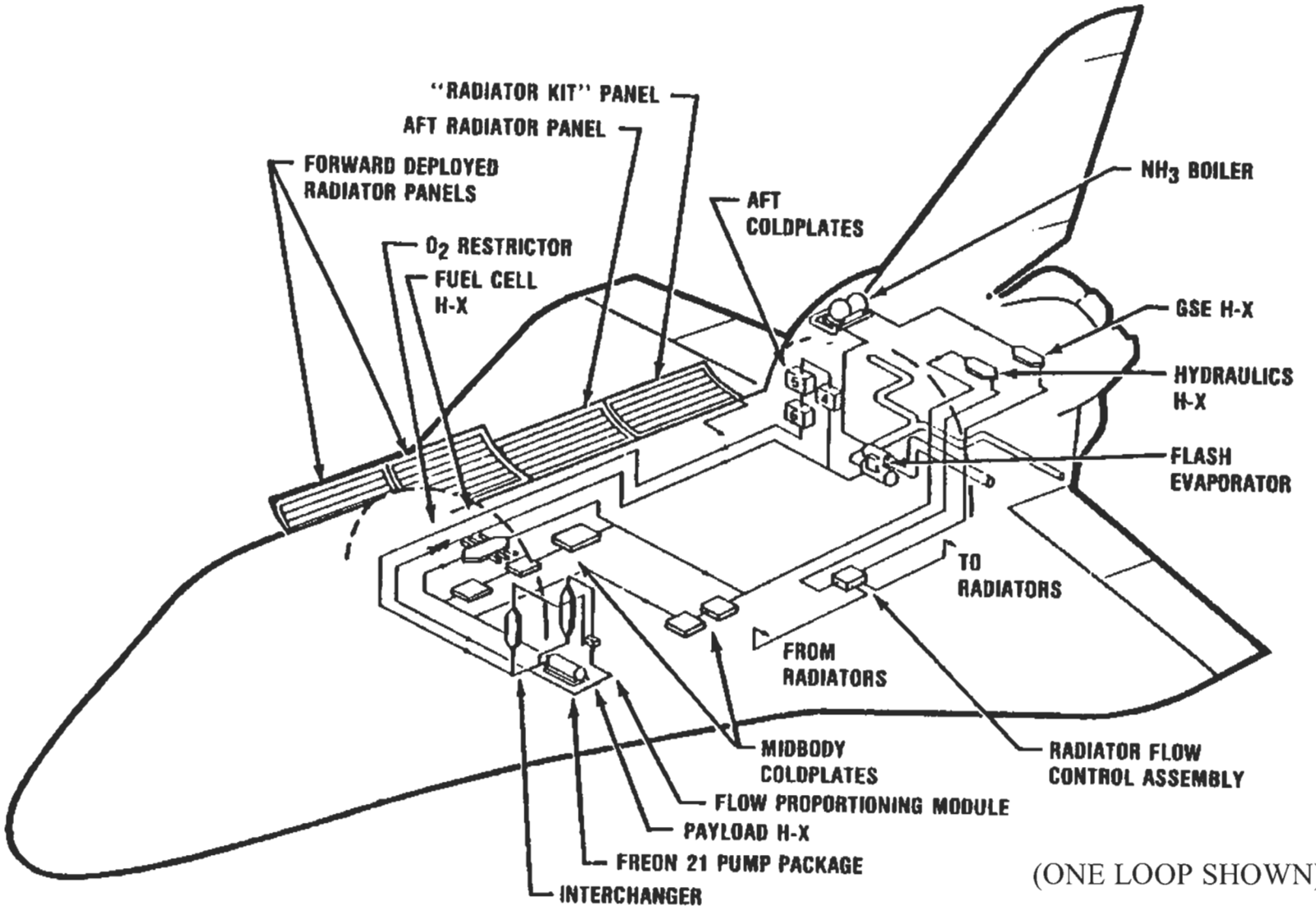
Shuttle Orbiter
Environmental/Thermal Control & Life Support System

Subsystem Elements:

- **SPACECRAFT ACTIVE THERMAL CONTROL**
  - **On-orbit radiative heat sink**
  - **On-orbit evaporative heat sink**
  - **Ascent/entry evaporative heat sinks**
  - **Vehicle circulating liquid cooling system**
  - **Cabin heat sink**
  - **Fuel cell heat sink**
  - **Hydraulics heat sink**
  - **Cold-plate electronics heat sink**
  - **Payload heat sink**

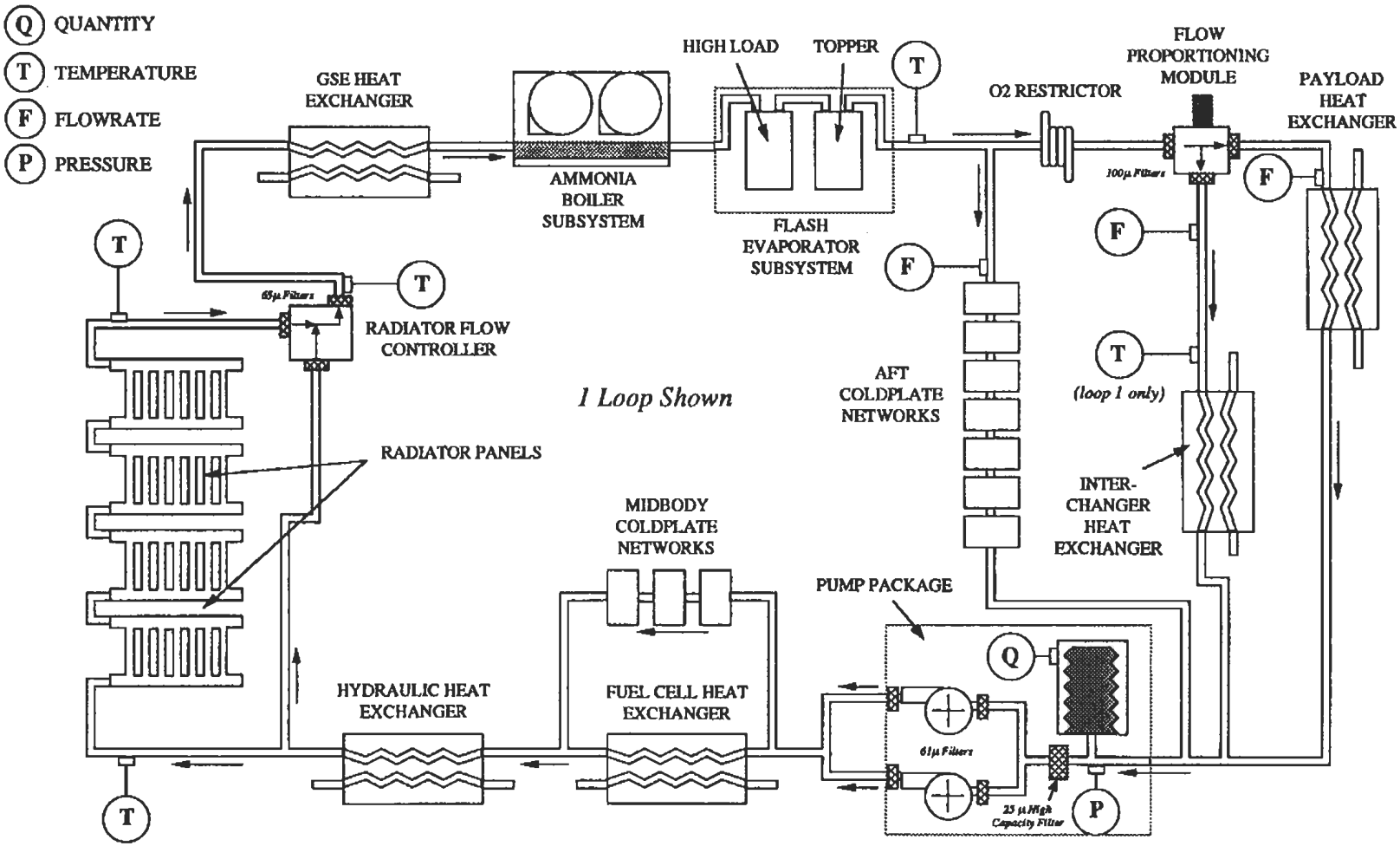
LOCATION OF ATCS COMPONENTD IN ORBITER

ACTIVE THERMAL CONTROL SYSTEM



(ONE LOOP SHOWN)

ATCS
(Simplified Flow Schematic)



Spacecraft Active Thermal Control Subsystem

Active Thermal Control Subsystem Functions:

- **Collect waste thermal energy from orbiter subsystems**
- **Reject waste-heat radiatively to space (on-orbit)**
- **Augment space radiators with evaporative heat sink at high-load/hot-environments**
- **Throttle radiators to restrict heat rejection and utilize evaporative heat sink to consume excess fuel cell H_2O**
- **Reject waste-heat evaporatively during assent (H_2O)**
- **Reject waste-heat evaporatively during entry (NH_3)**

Spacecraft Active Thermal Control Subsystem

Heat Rejection - Radiator:

- 2 mirror-image radiator systems
- _ of the radiators located in separate cooling loops
- “Bypass-type” thermal control concept utilized
- Dual Set points - 40^{o}F & 56^{o}F
- 4 single-sided, fixed space radiators
- 4 two-sided, deployable space radiators
- Honeycomb structure with embedded tubes for coolant
- Silver-Teflon, thermal surface coating

Spacecraft Active Thermal Control Subsystem

Heat Rejection - Flash Evaporators:

- Heat sink is phase-change of H_2O
- Dual flash chambers – "high-load" and "topper"
- Non-propulsive over-board steam duct for "topper"
- Second over-board steam duct for "high-load"

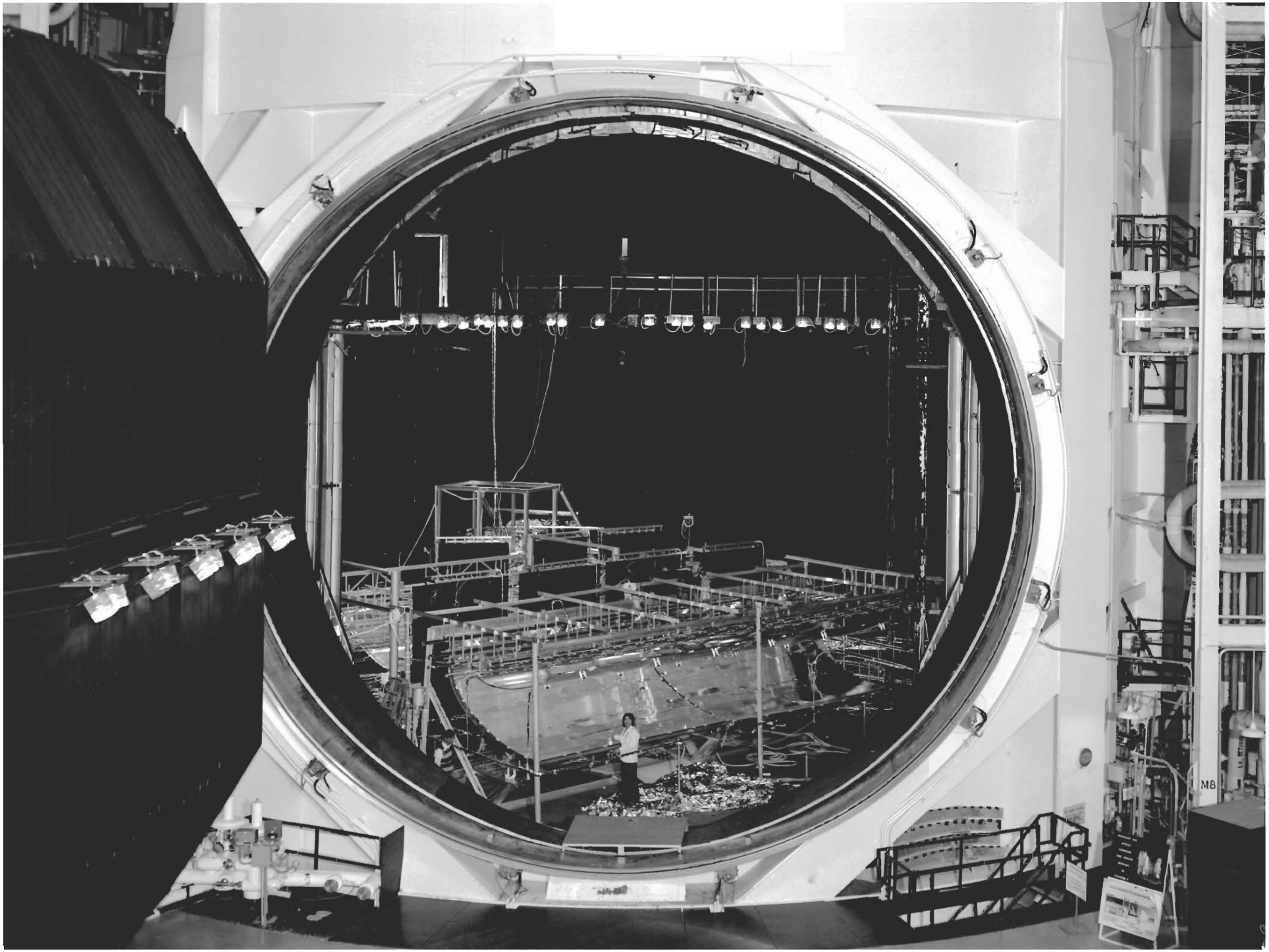
Heat Rejection – Ammonia Boiler:

- Heat sink is phase-change of NH_3
- Redundant boilers
- Utilized during entry at < 100,000 feet altitude
- Utilized on runway until ground cooling available

Spacecraft Active Thermal Control Subsystem

Circulating Liquid Cooling Loop:

- **Freon 21 as coolant**
- **Redundant pumps**
- **Liquid/liquid heat exchangers**
- **Cold-plates**

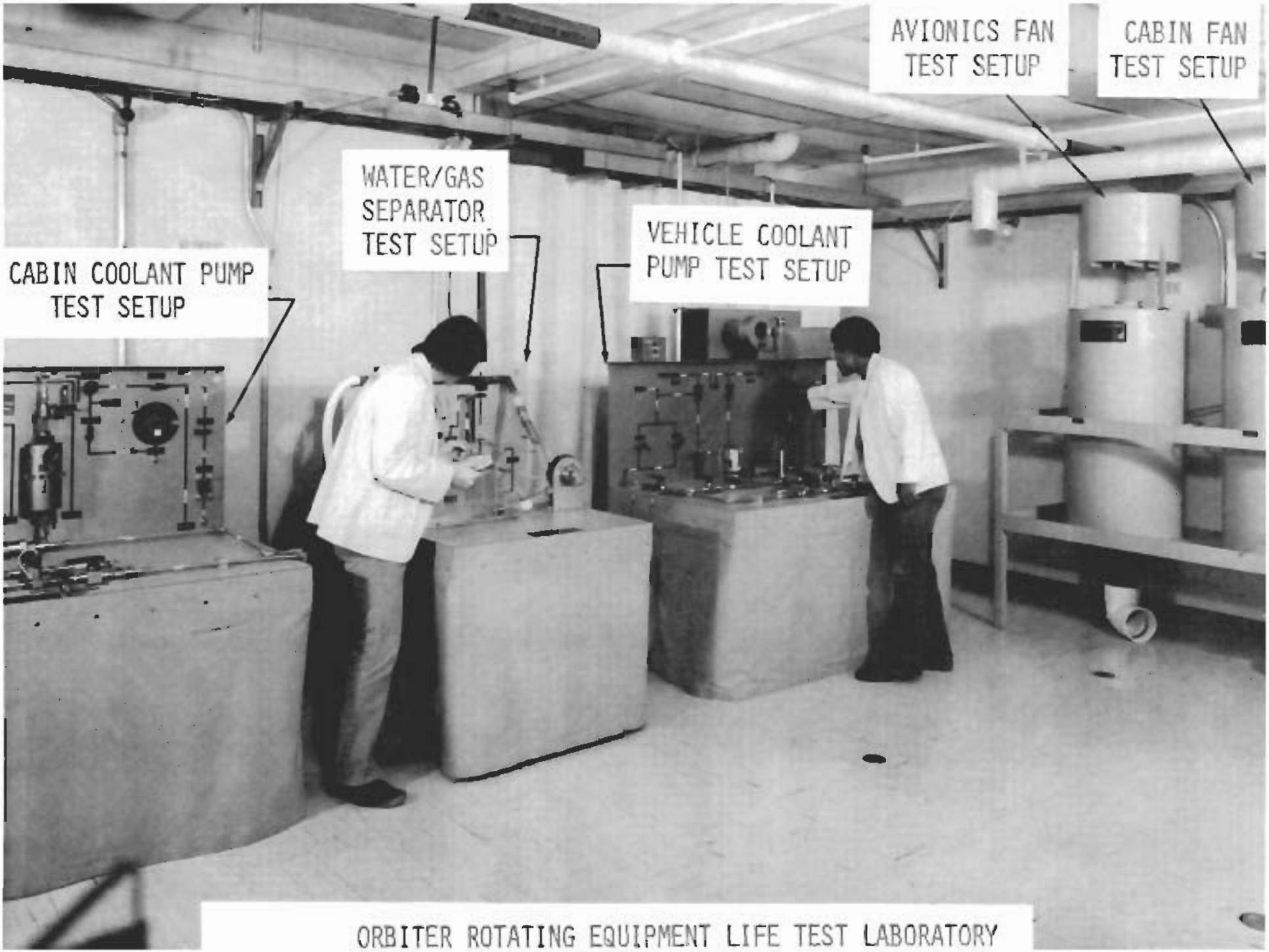


Shuttle Orbiter
Environmental/Thermal Control and Life Support System

ROTATING EQUIPMENT LIFE TEST

- **Equipment**
  - Cabin fan
  - Water/gas separator
  - Avionics bay fan
  - Cabin coolant pump
  - Vehicle coolant pump

- **Life Requirement**
  - 100 missions
  - 20,000 hours



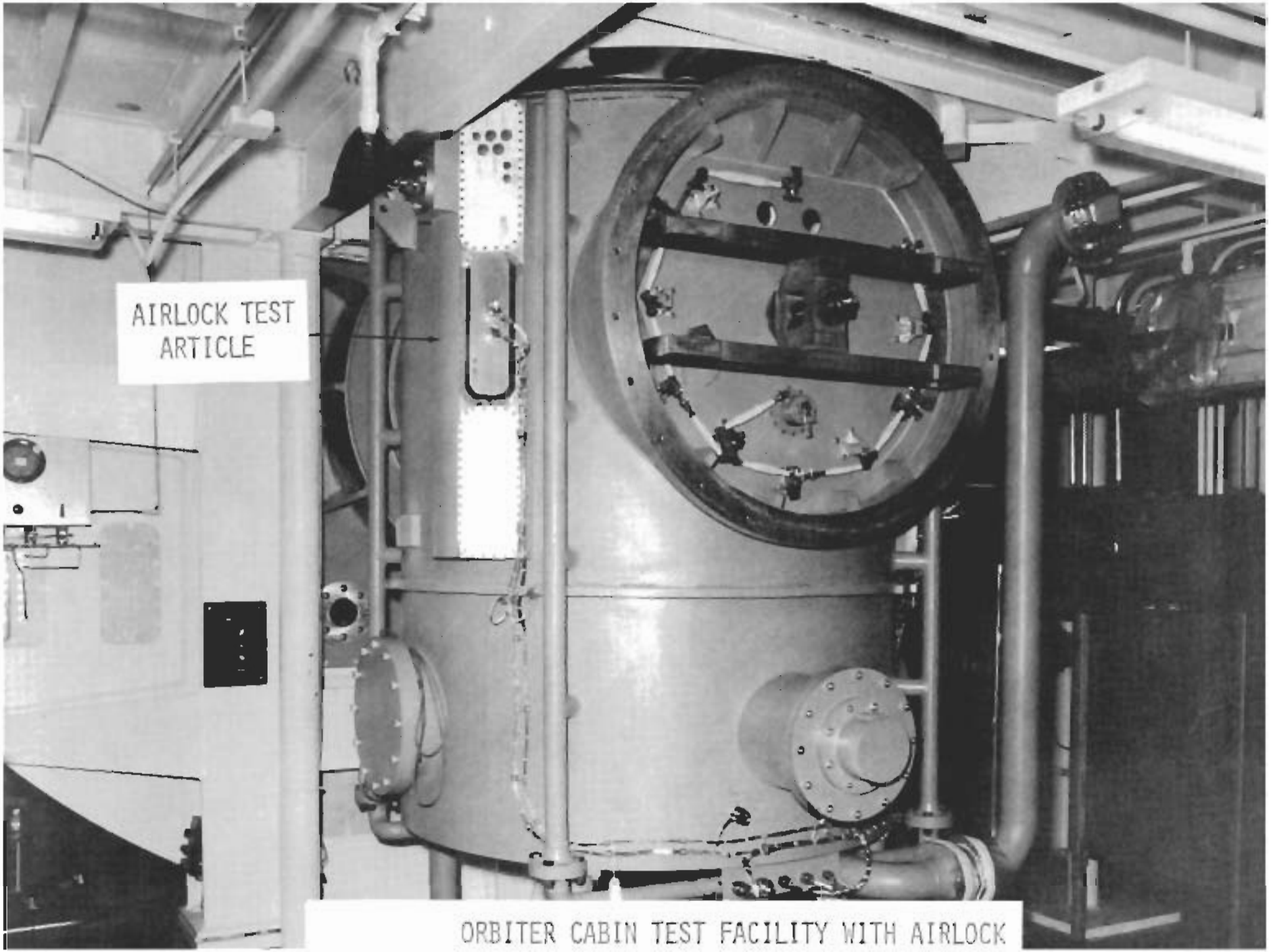
ORBITER ROTATING EQUIPMENT LIFE TEST LABORATORY

Shuttle Orbiter
Environmental/Thermal Control & Life Support System

Functional Requirements:

EVA AIRLOCK SUPPORT

- **Maintain cabin pressure & O_2/N_2 composition during airlock depress/repress**
- **Interface with EMU service and cooling umbilical**
- **Provide heat rejection for spacesuit cooling garment**
- **Supply backpack O_2 recharge (900 psia)**
- **Supply backpack H_2O recharge for sublimator**
- **Drain humidity condensate from backpack post-EVA**



ORBITER CABIN TEST FACILITY WITH AIRLOCK

AIRLOCK TEST FACILITY WITH EMU