

# Lunar Module Environmental Control System Design Considerations & Failure Modes Part II



## Prerequisite

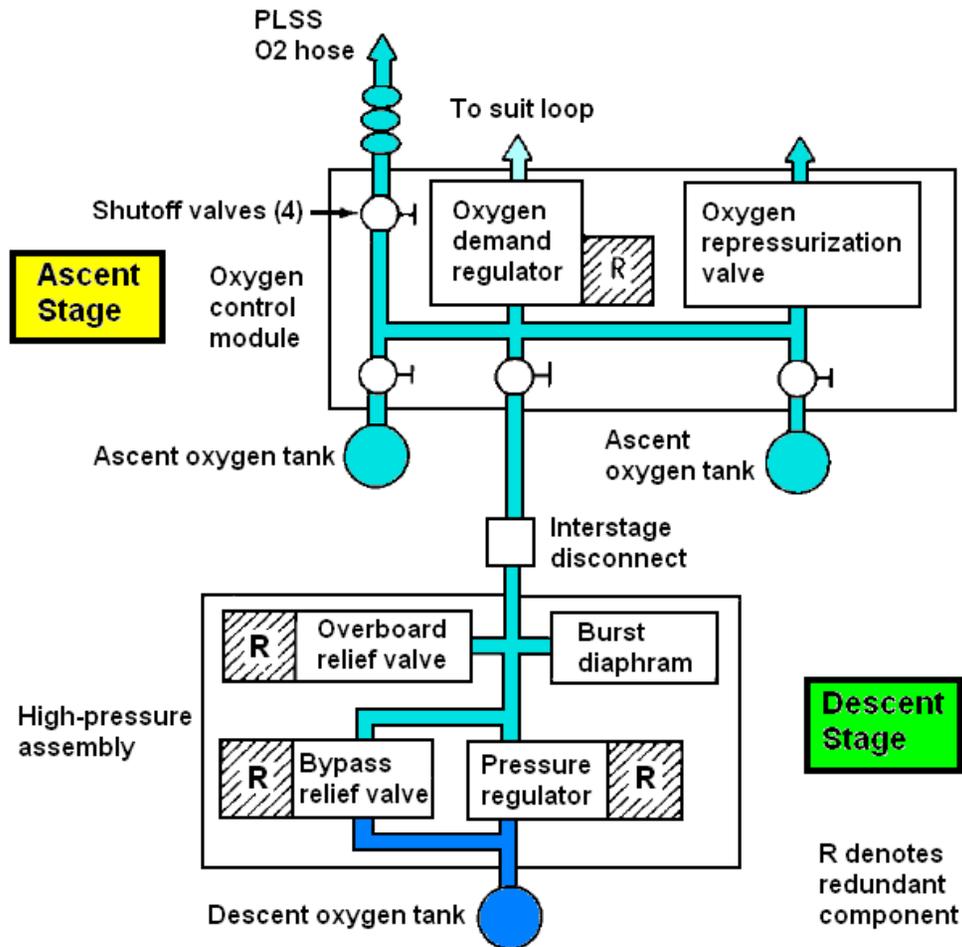
- ❑ The Lunar Module (LM) Environmental Control System (ECS) Design Considerations and Failure Modes Lesson, Part I is a prerequisite to this lesson.

# Objectives

- ❑ Describe the Lunar Module (LM) Environmental Control System (ECS) subsystem testing and redesign.
- ❑ Summarize the Lunar Module (LM) Environmental Control System (ECS) in-flight failures.

# Subsystem Redesign Considerations -- OSCPS

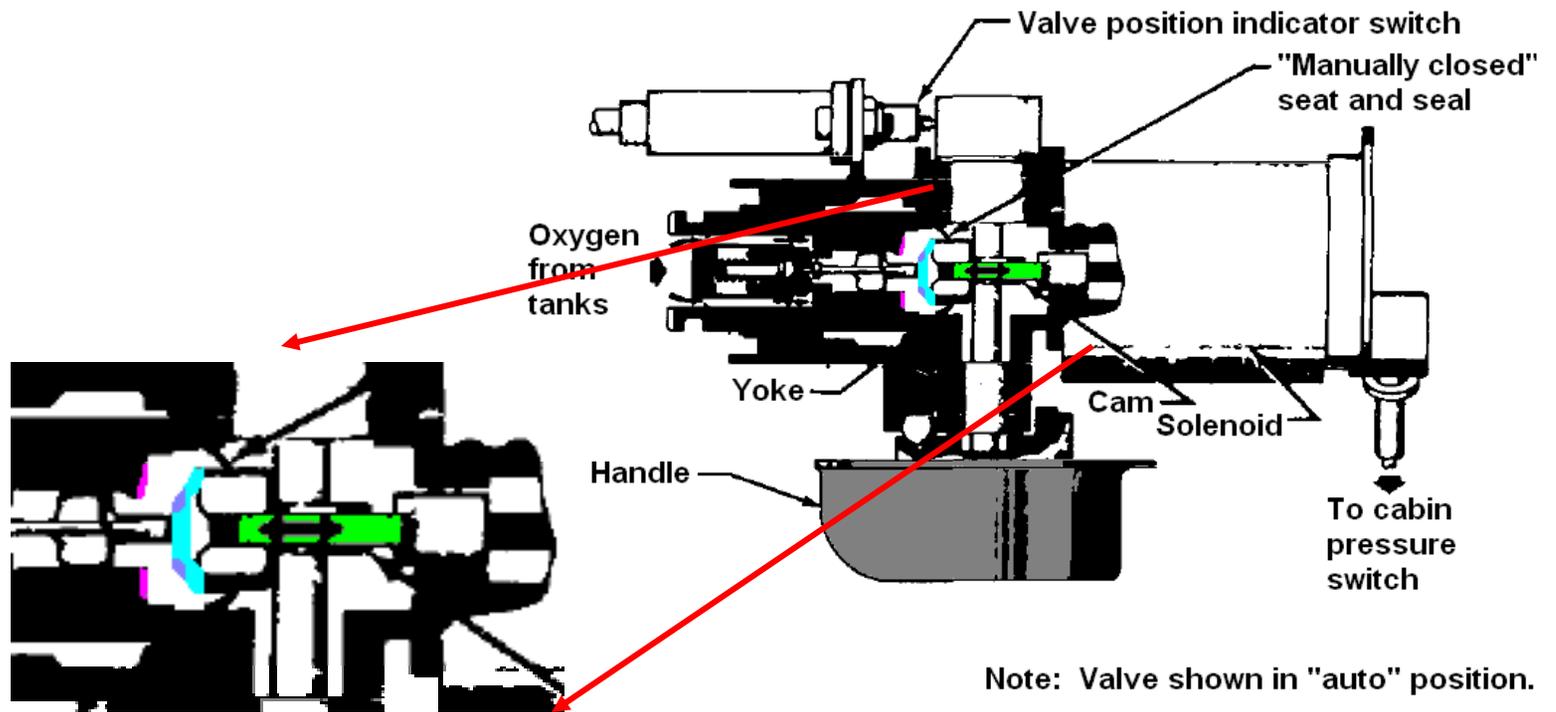
- The Oxygen Supply and Cabin Pressurization Section provided source O2 and cabin pressure.



Oxygen Supply and Cabin Pressurization Section

# Subsystem Redesign Considerations -- OSCPS

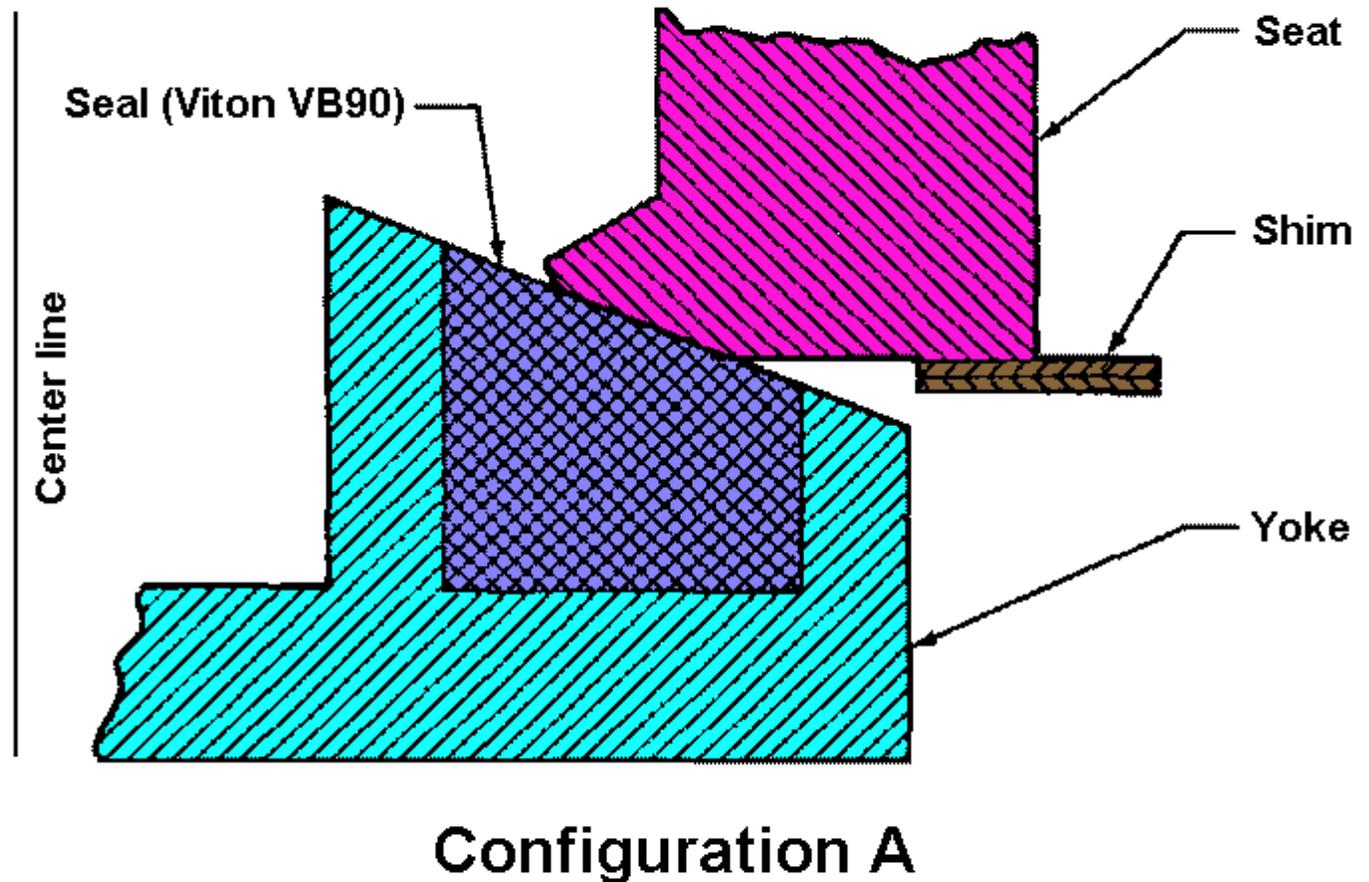
- The Cabin Repress and Emergency Oxygen Valve had some problems during feasibility testing, showing the valve seat to be susceptible to permanent seating.



Cabin Repressurization and  
Emergency Oxygen Valve

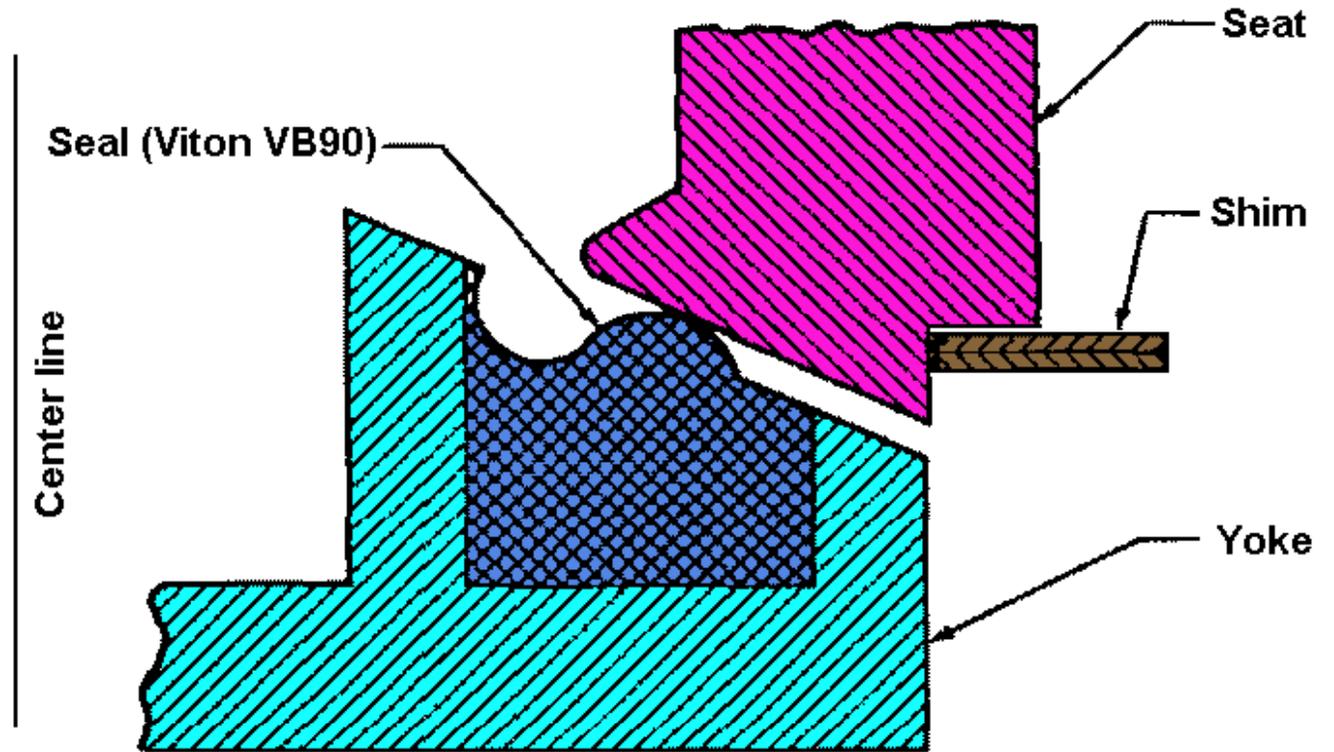
# Subsystem Redesign Considerations -- OSCPS

- First, they changed the valve seal material from Viton B to Viton VB90.



# Subsystem Redesign Considerations -- OSCPS

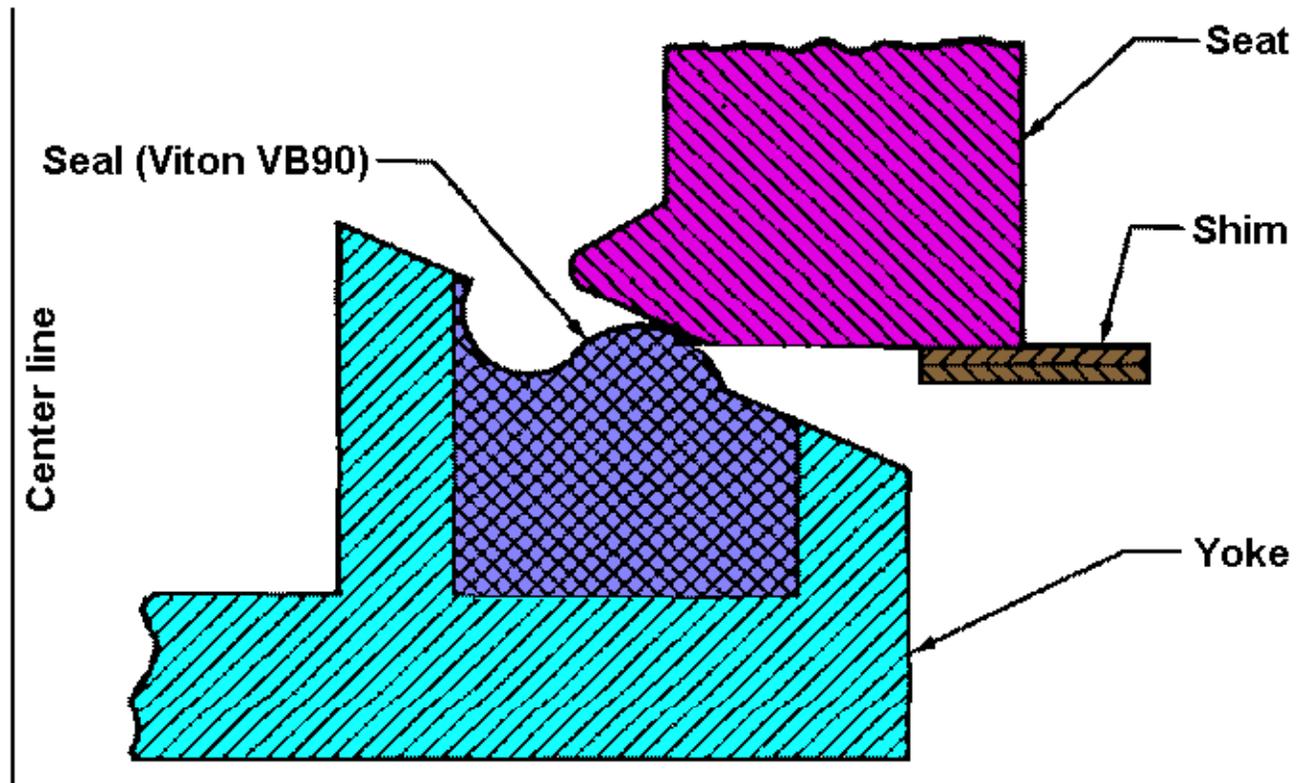
- During acceptance testing, the new seats were seen to crack. The shape of the seat and seal were changed.



Configuration B

# Subsystem Redesign Considerations -- OSCPS

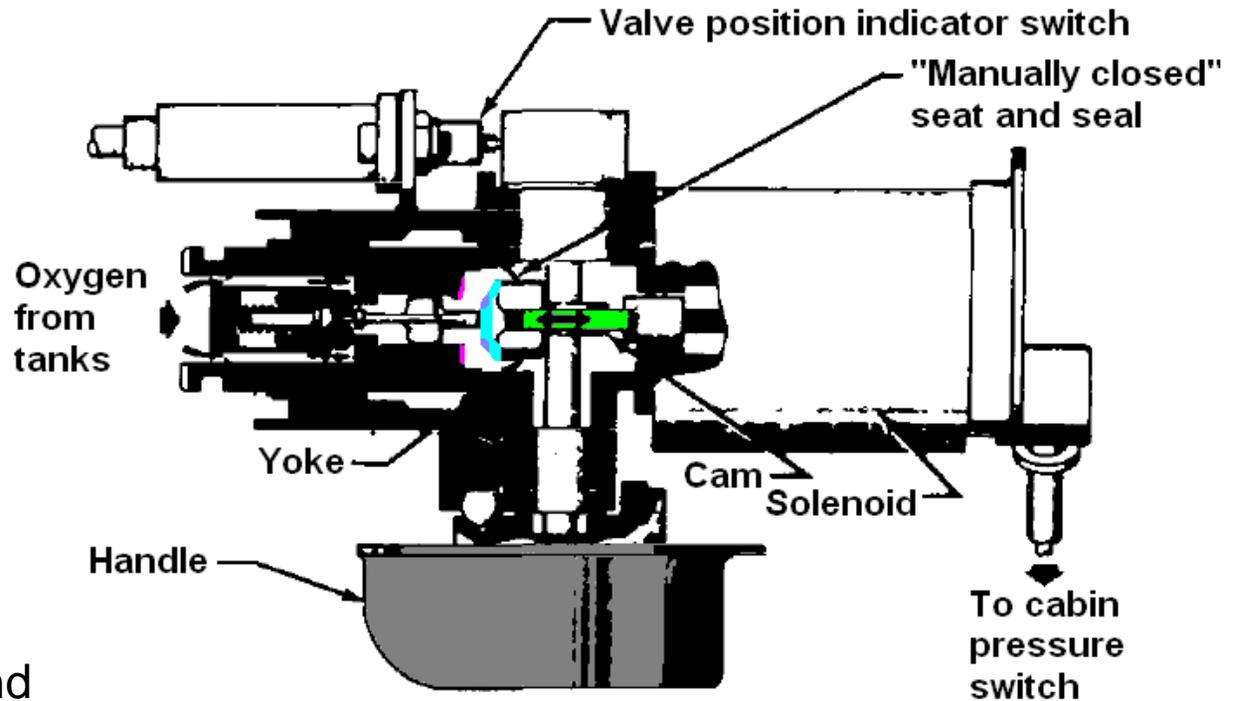
- The new design failed vibration-temperature testing. The seat was again changed to provide better centering and resist lateral movement.



Configuration C

# Subsystem Redesign Considerations -- OSCPS

- ❑ Nominal operation of the valve was accompanied by a very loud “bang” from the high-pressure gas expanding to produce a shock wave.
  - ◆ valve was not actually being damaged
  - ◆ decision was made not to change the design again

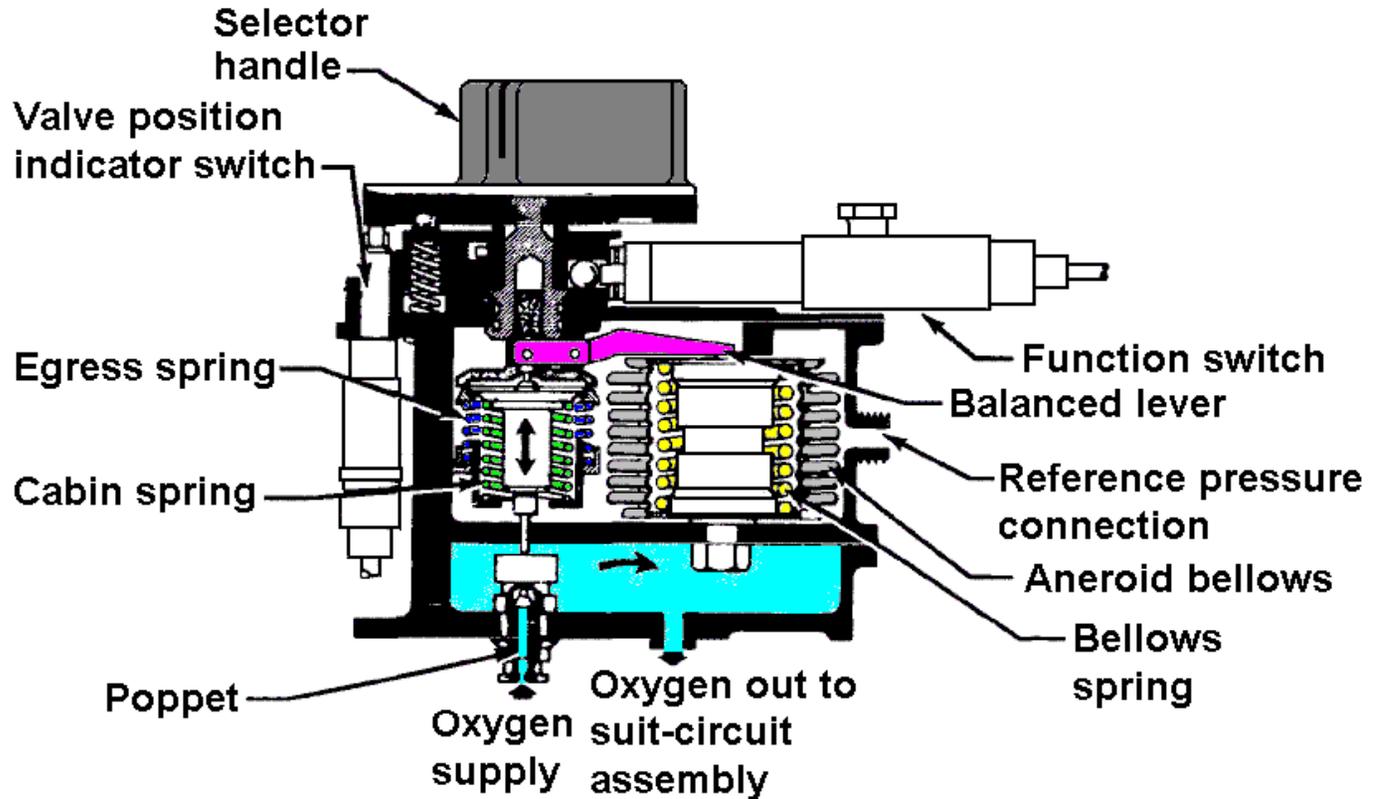


Cabin Repressurization and  
Emergency Oxygen Valve

Note: Valve shown in "auto" position.

# Subsystem Redesign Considerations -- OSCPS

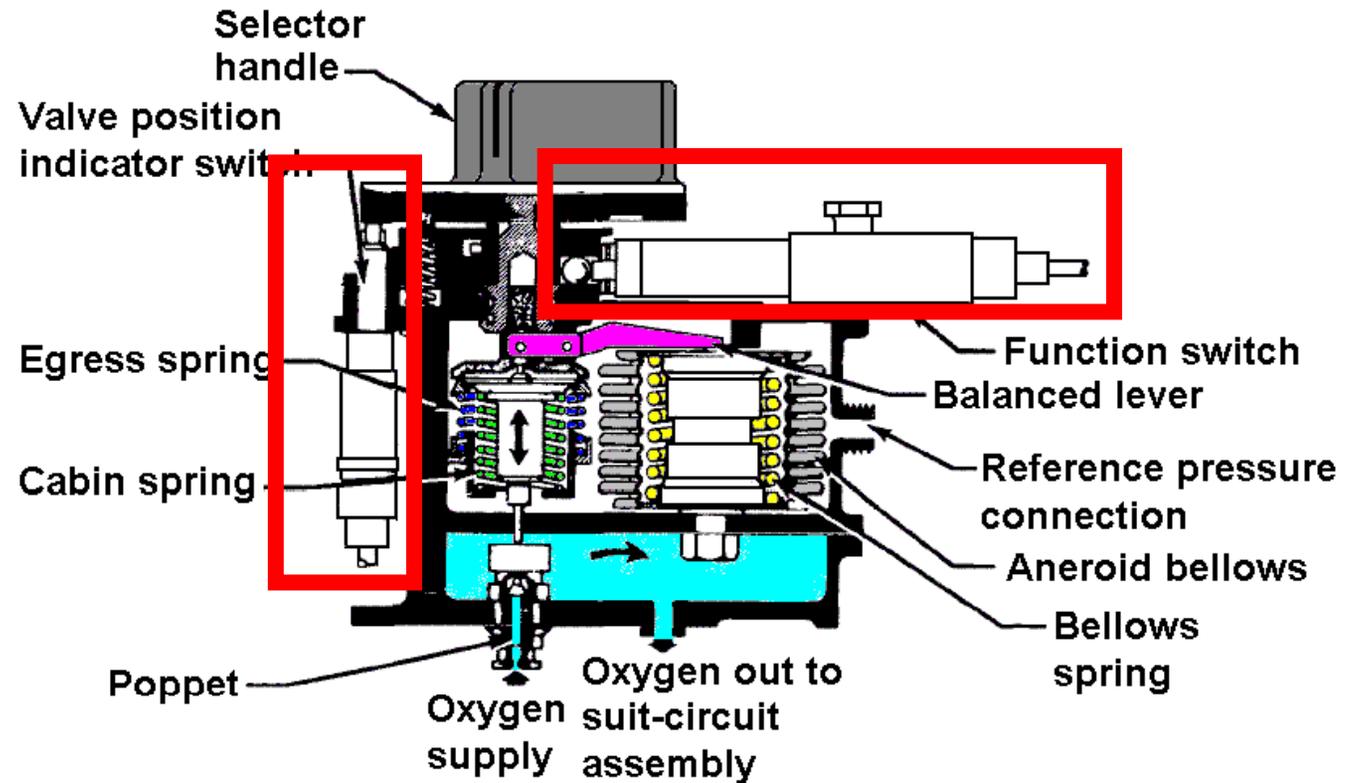
- ❑ The **Oxygen Demand Regulators** provided suit loop pressure regulation.
  - ♦ original design sensitive to vibration
  - ♦ various aneroids and mass-balancing techniques reduced the leakage to acceptable levels



Cutaway View of Oxygen Demand Regulator

# Subsystem Redesign Considerations -- OSCPS

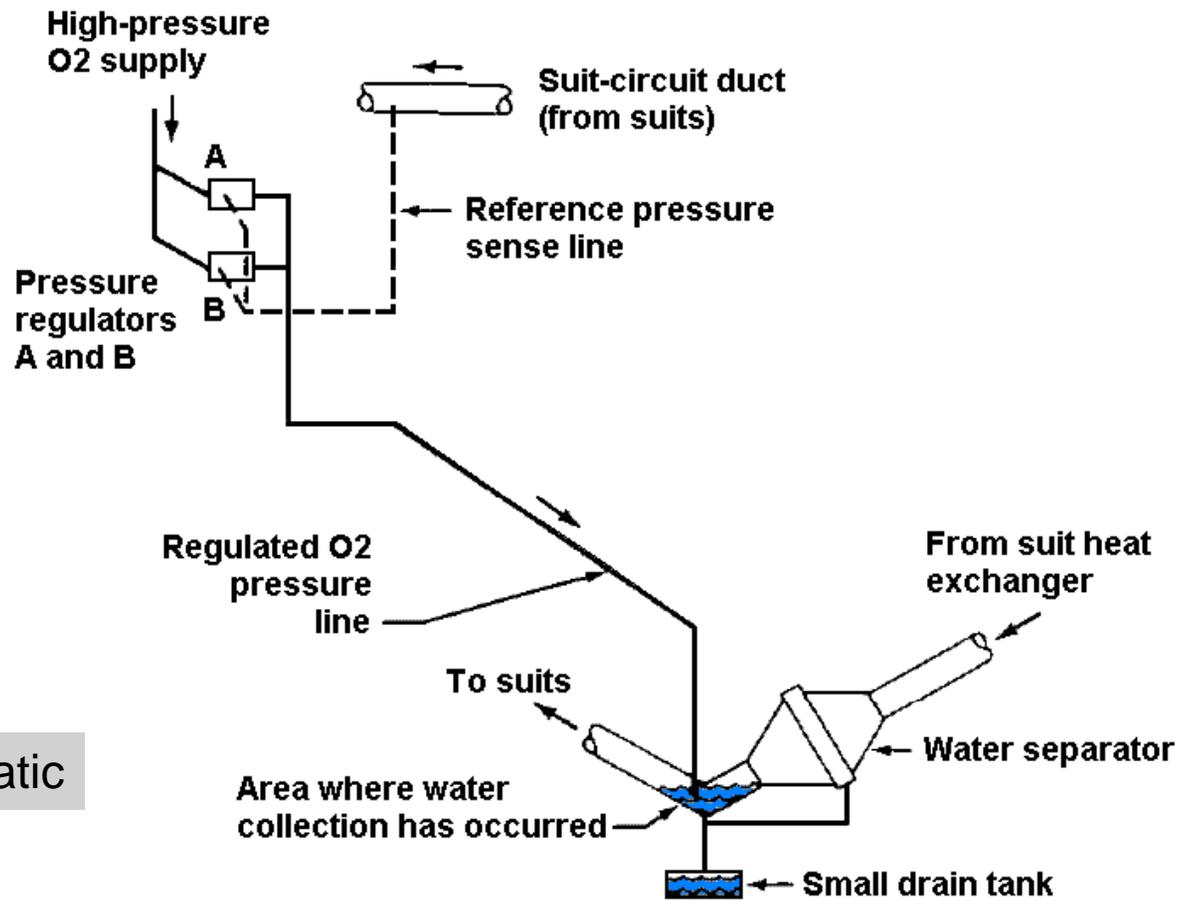
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Cutaway View of Oxygen Demand Regulator

# Subsystem Redesign Considerations -- OSCPS

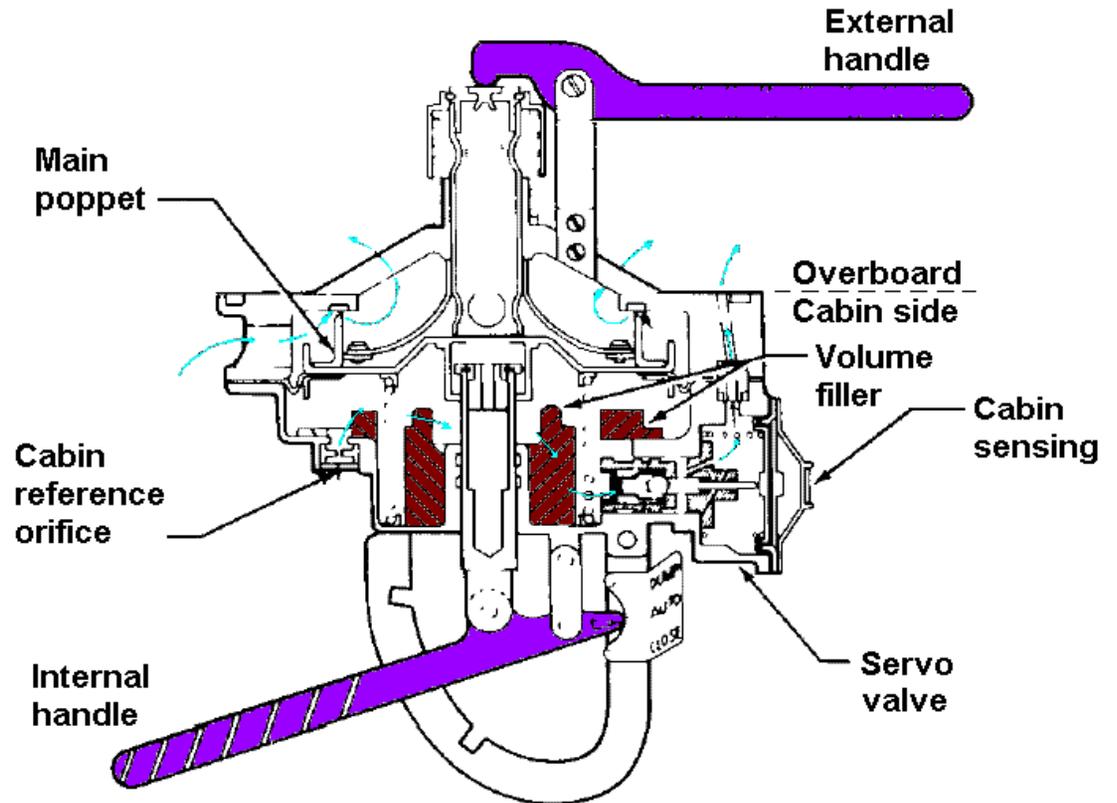
- The regulators were contaminated by water when steam was injected into the system for tests.
  - ♦ water collected at the point shown in the system
  - ♦ blown up into the regulators when the 34.5 KPa (5 psia) system was returned to sea level



LM Suit Line Elevation Schematic

# Subsystem Redesign Considerations -- OSCPS

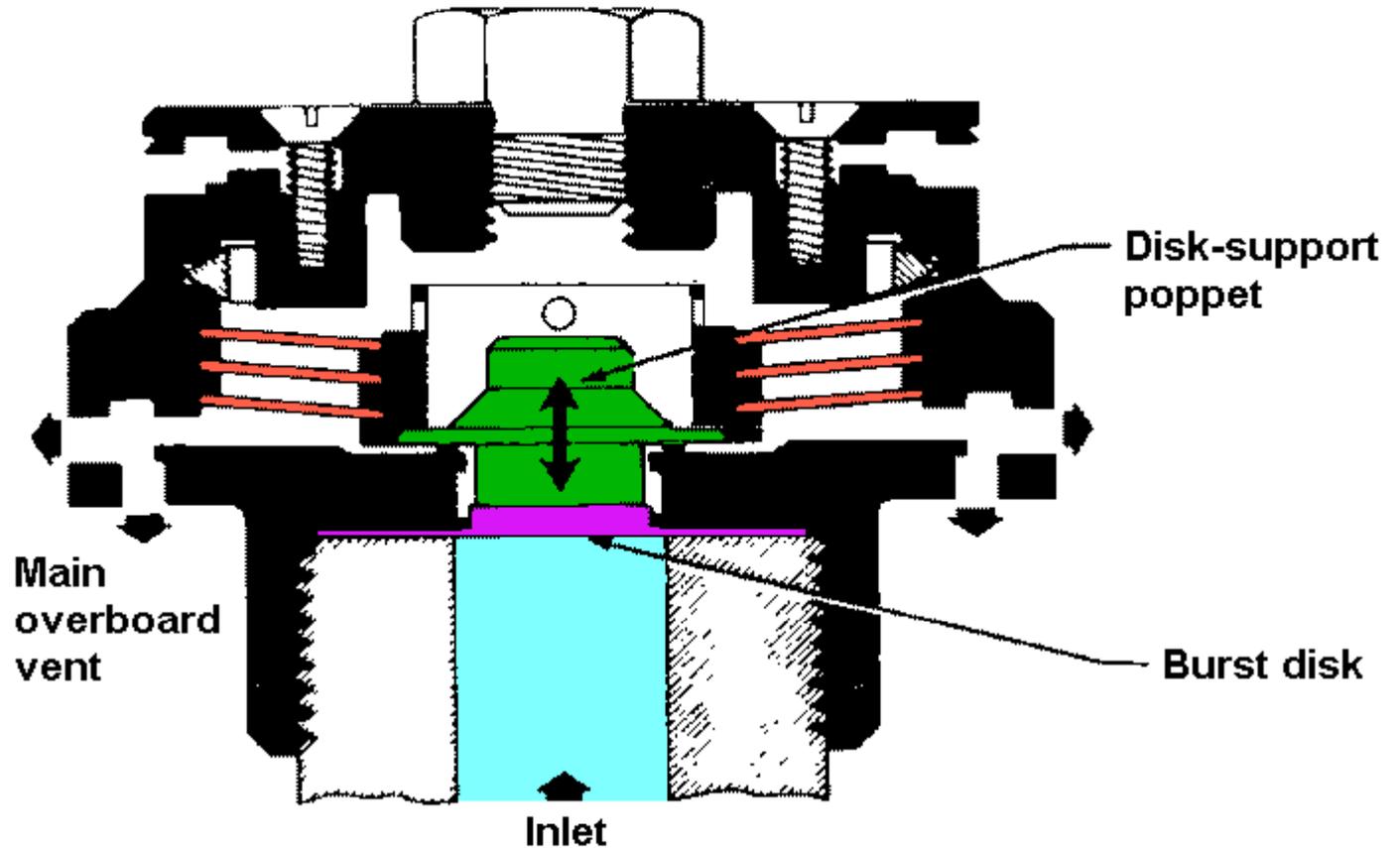
- The **Cabin Dump and Relief Valves** provided cabin pressure relief at 38.9 KPa (5.6 psi) and allowed manual cabin depress.
  - ♦ vibration testing -- the valves leaked
  - ♦ volume filler in the servo chamber generating particle contaminants
  - ♦ filler was changed to molded silicone rubber gaskets



Cabin Dump Relief Valve

# Subsystem Redesign Considerations -- OSCPS

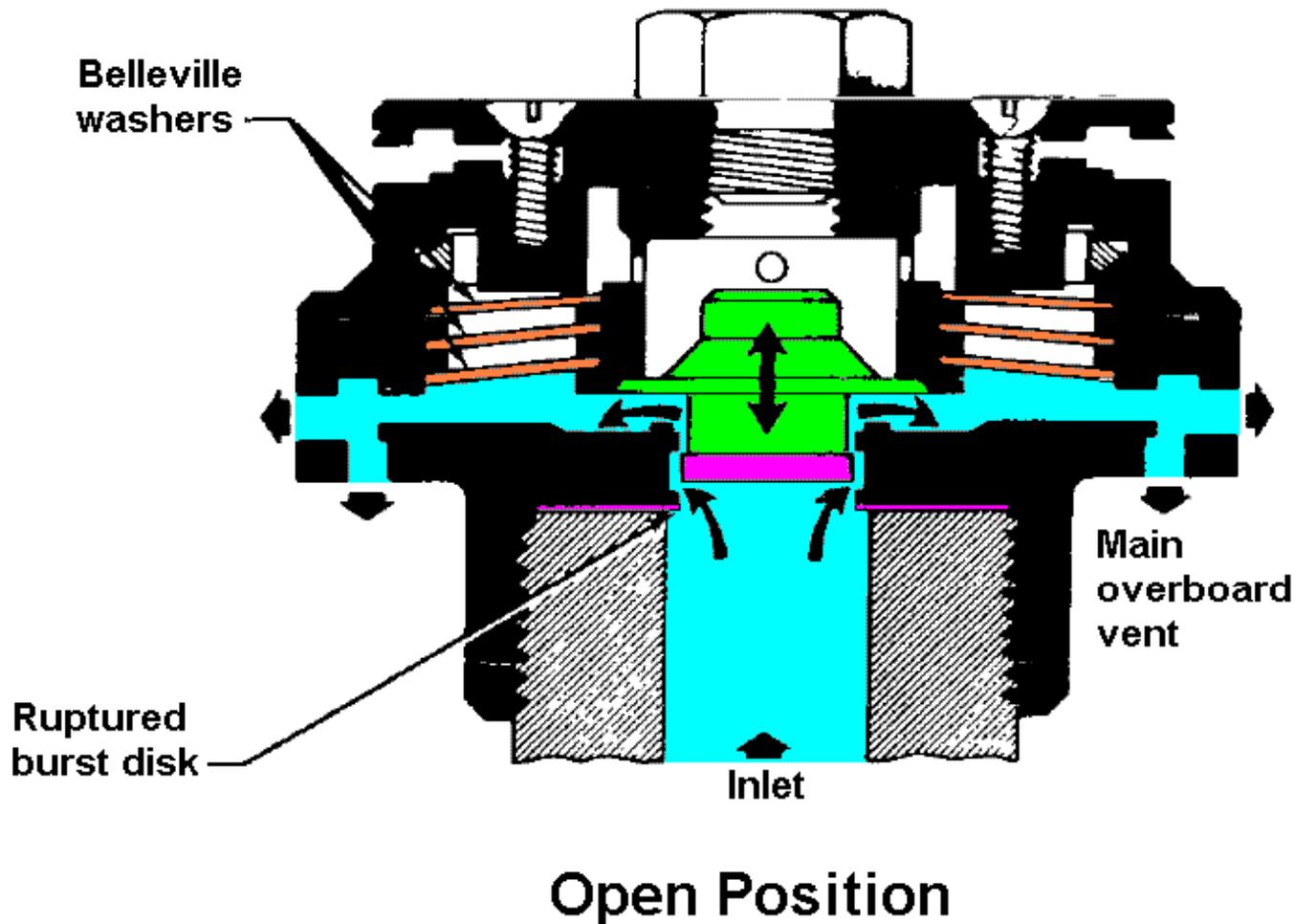
- The **Reseating Burst Disks** in the descent stage high-pressure O2 system provided worst-case pressure relief for tank overpressure.



Normal Sealed Position

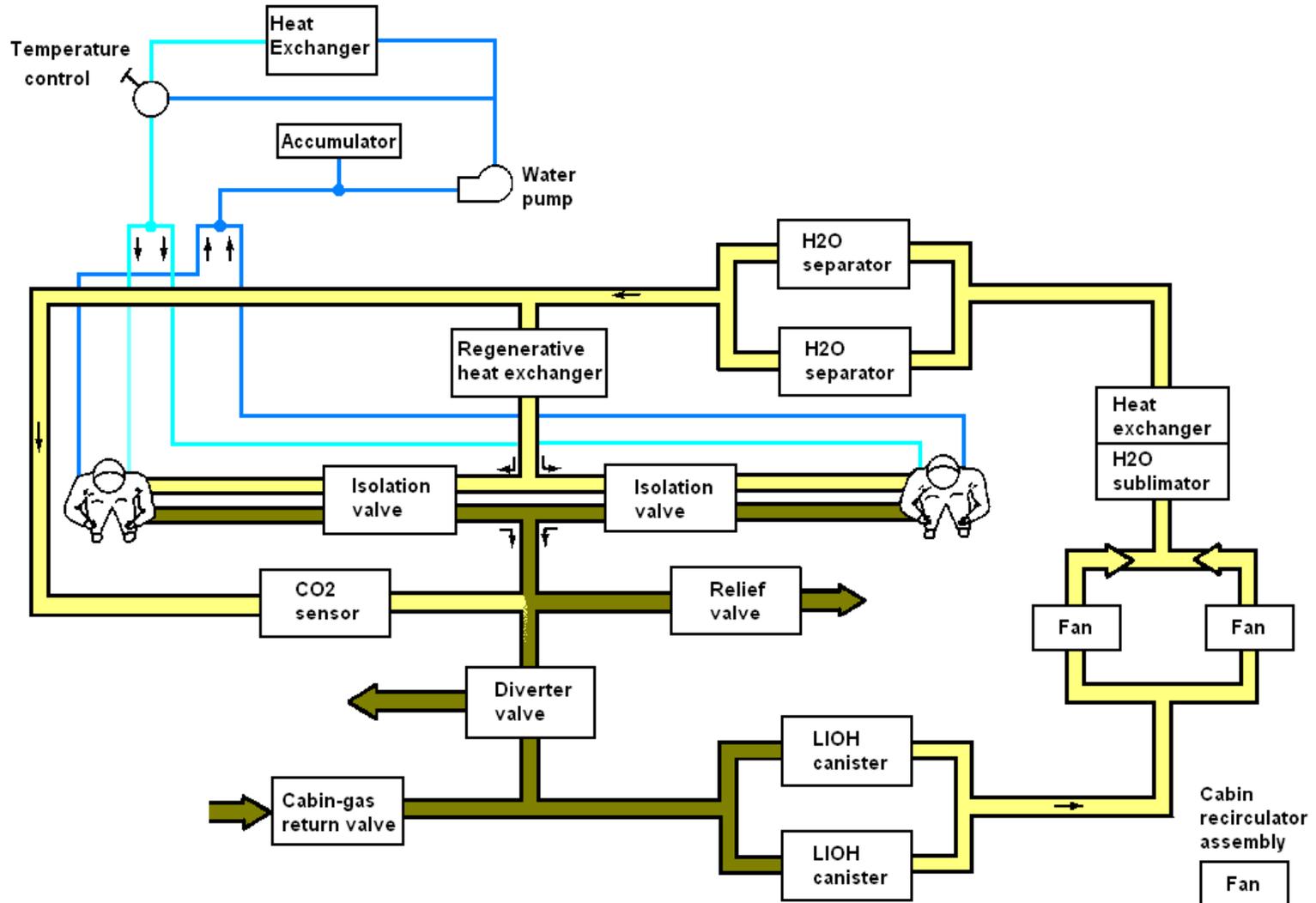
# Subsystem Redesign Considerations -- OSCPS

- ♦ allowed enough O2 for one cabin repress after a burst disk rupture
- ♦ poppet would reseal, once the pressure was low enough for the Belleville washers to push it closed



# Subsystem Redesign Considerations -- ARS

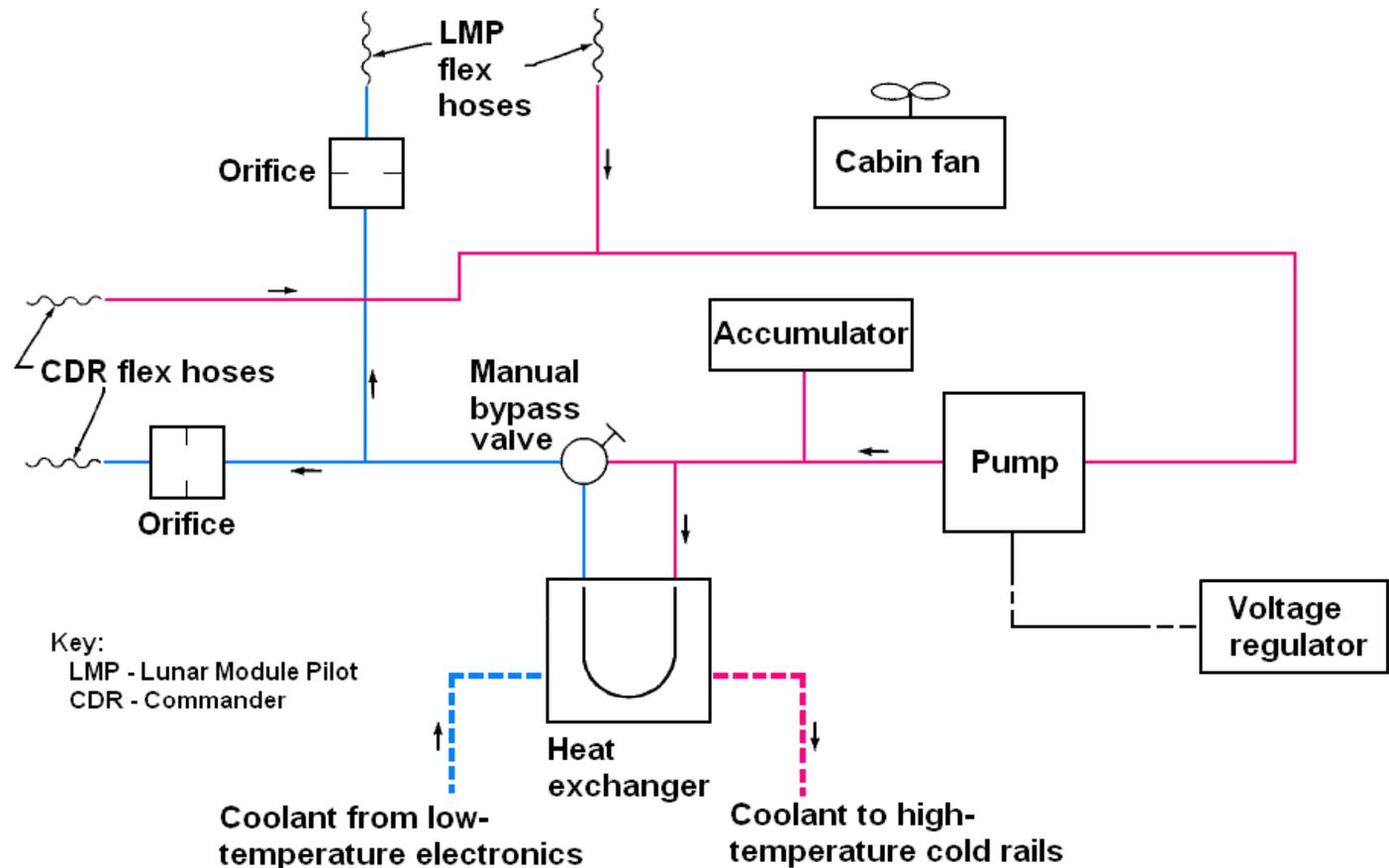
- The Atmosphere Revitalization Section removed CO<sub>2</sub> and water from the air.



Atmosphere Revitalization Section Simplified Schematic

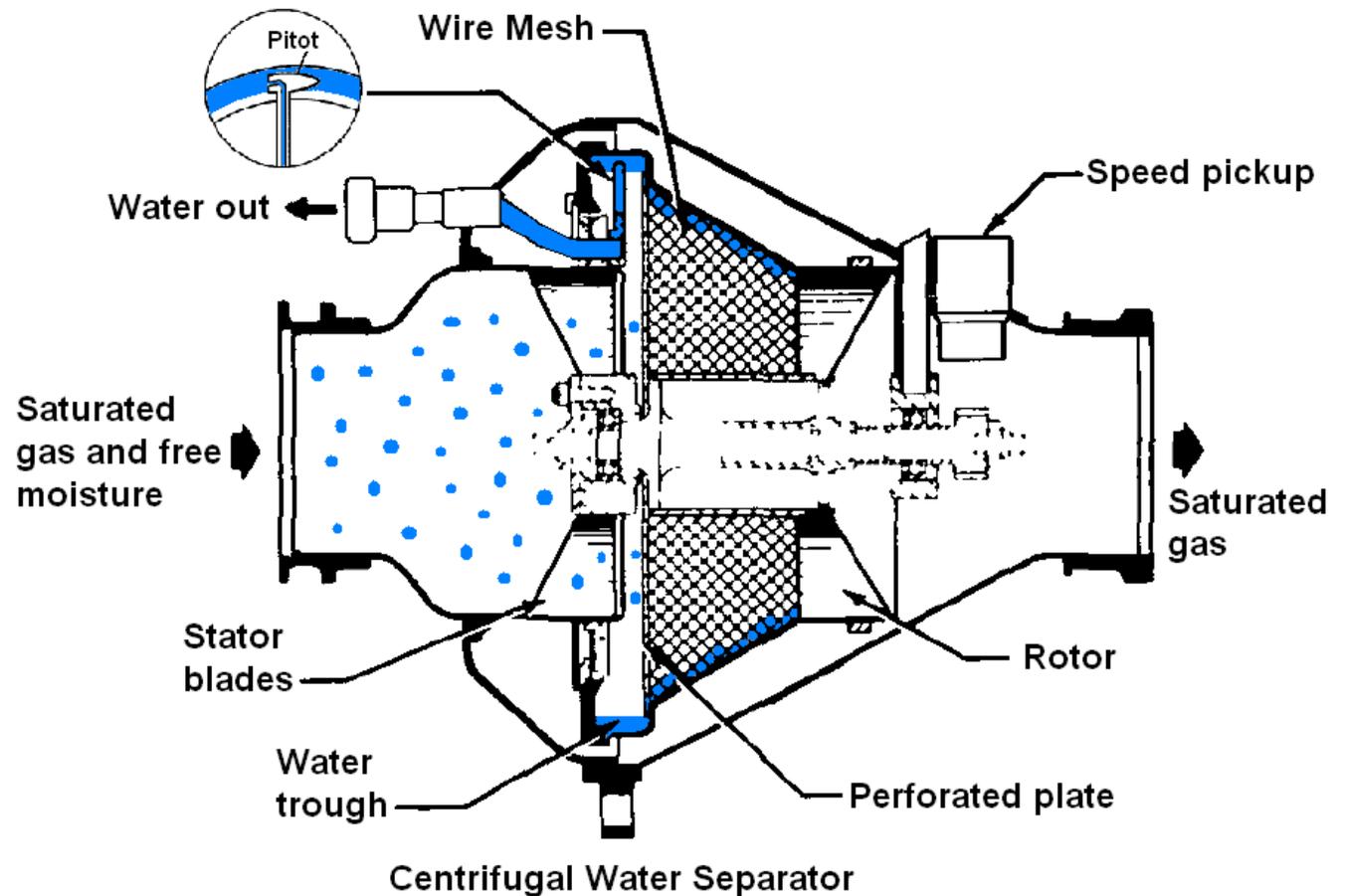
# Subsystem Redesign Considerations -- ARS

- Based on vacuum chamber tests, a rapid change to add glycol loop cooling to the flow to the [Liquid Cooling Garments](#) was made in time for LM-5 (Apollo 11).
  - ♦ deleted the cabin heat exchanger and added a suit water loop/glycol loop heat exchanger
  - ♦ emphasis was on minimum changes, not efficiency



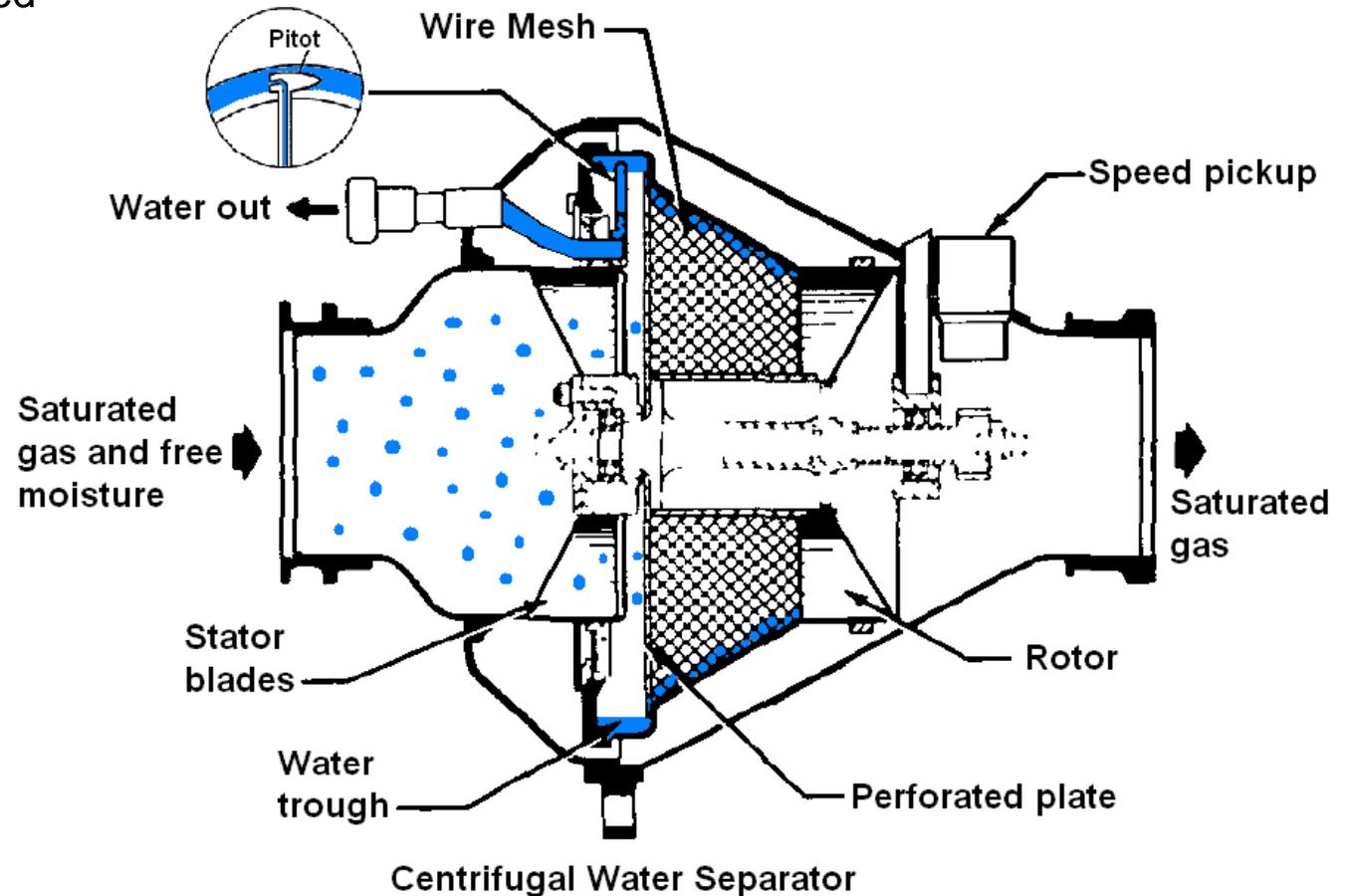
# Subsystem Redesign Considerations -- ARS

- ❑ The **Water Separators** underwent several changes:
  - ◆ gas-side pressure drop was reduced
  - ◆ pitot tube improved
  - ◆ bearing supports upgraded
  - ◆ assembly method changed



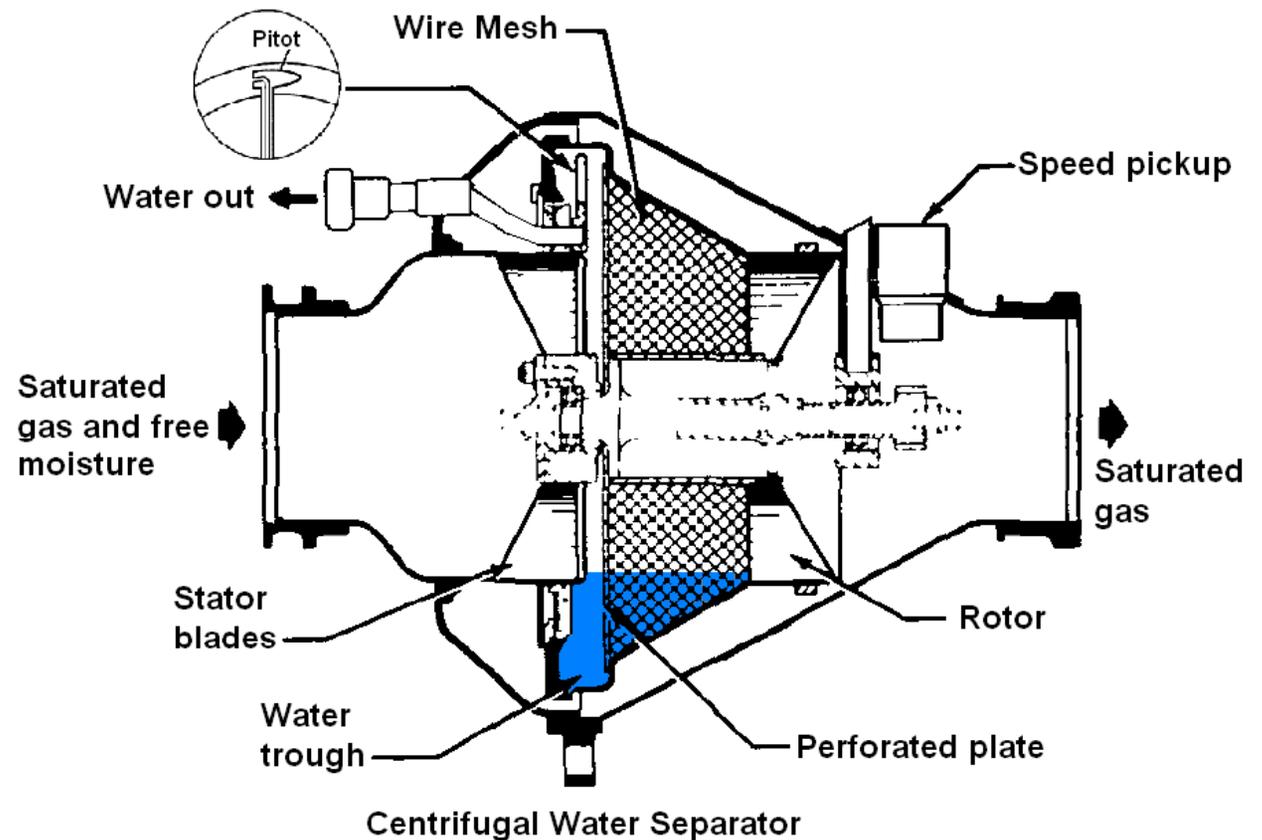
# Subsystem Redesign Considerations -- ARS

- In the later stages of development:
  - ◆ several stator blades were blocked to increase the speed of the gas into the turbine blades
  - ◆ blade angle was changed
  - ◆ wire mesh added



# Subsystem Redesign Considerations -- ARS

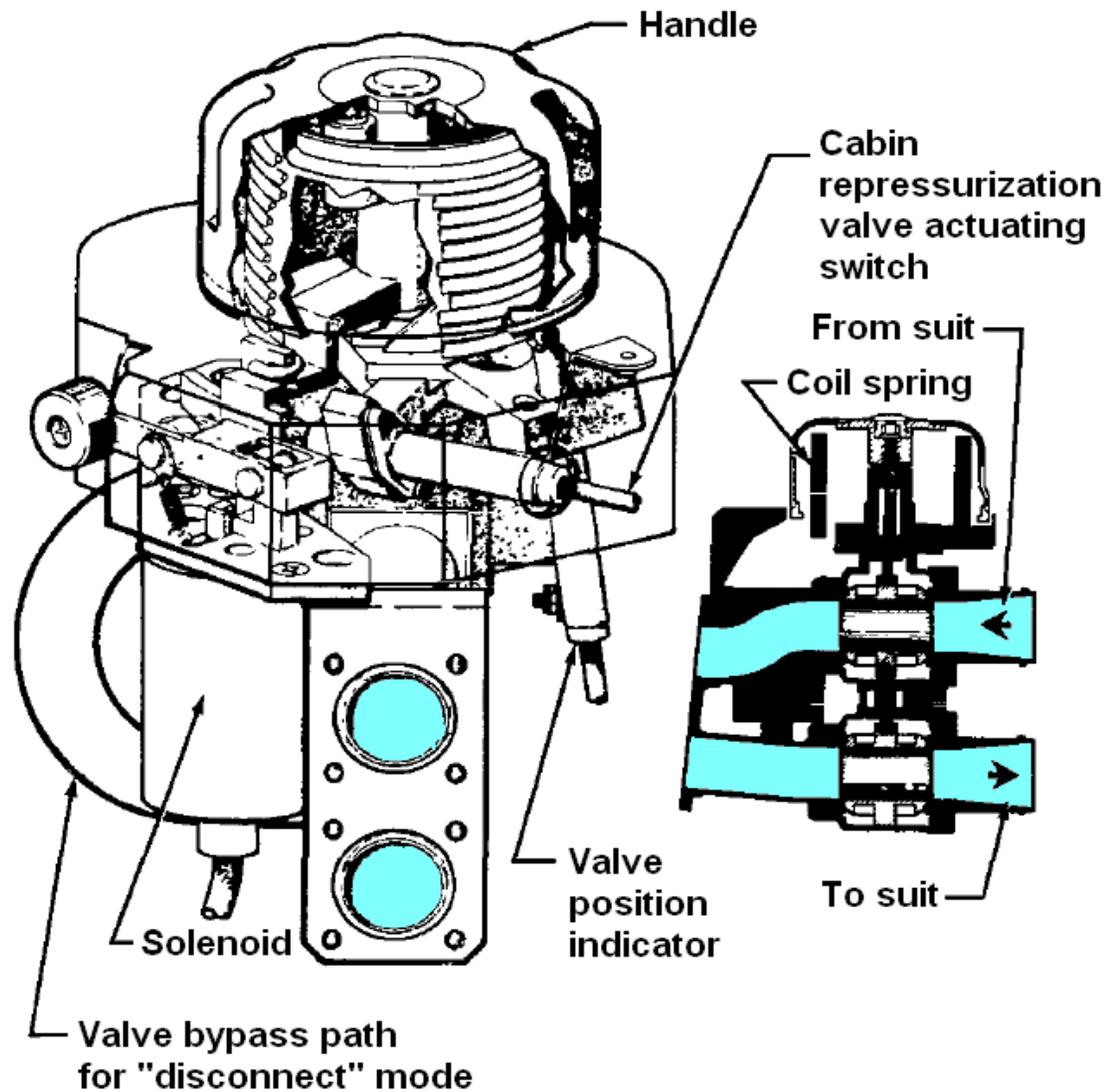
- ❑ Changes aimed at improving the pumping capability with lower total gas flow. During qual testing, the unit failed to restart after shutdown. Ullage water retained in the unit had settled to the bottom and created resistance.
  - ◆ clearances revised
  - ◆ drains added
  - ◆ additional stator blades blocked



# Subsystem Redesign Considerations -- ARS

❑ Post the Apollo 1 fire, the **Suit Isolation Valve** changed to a fast-acting automatic electric valve.

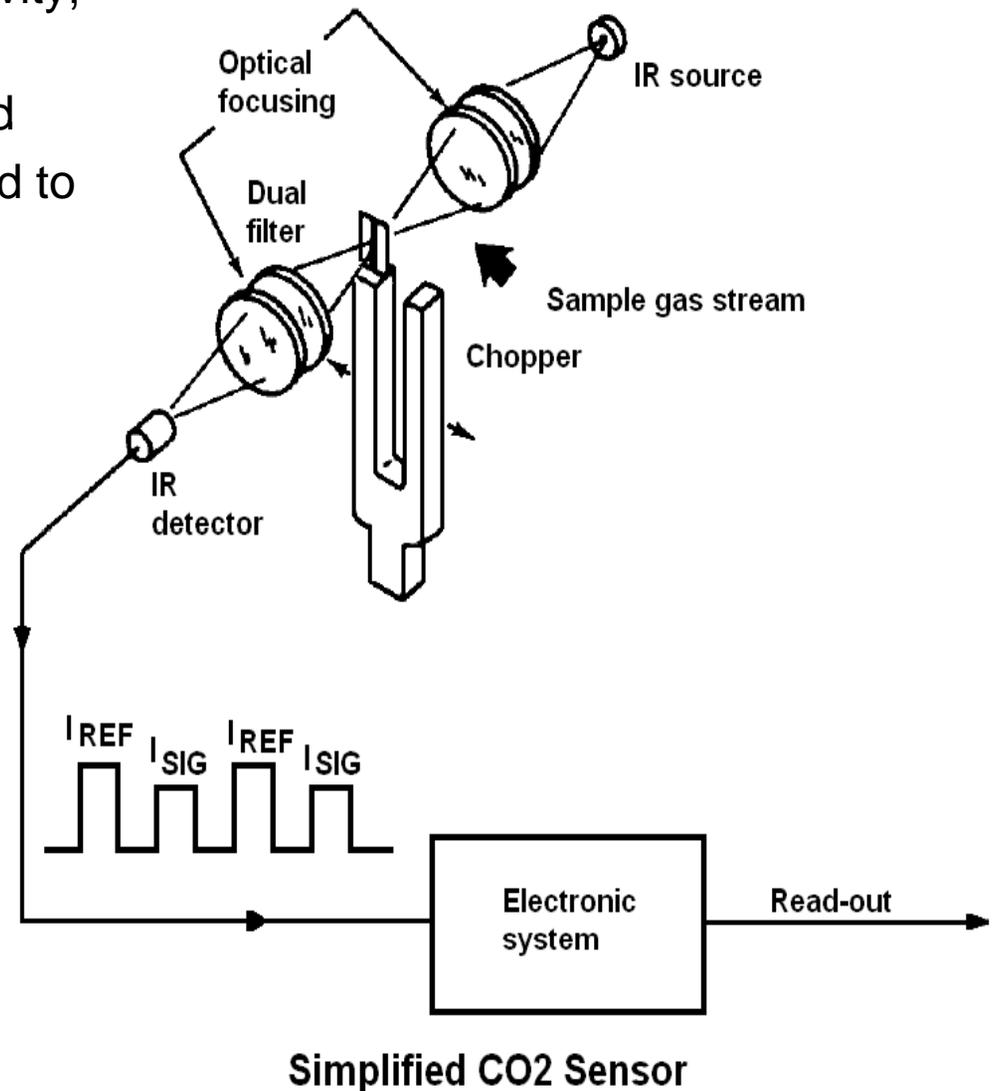
- several units became sluggish after repeated actuations
- minor materials change was required



**Suit Isolation Valve**

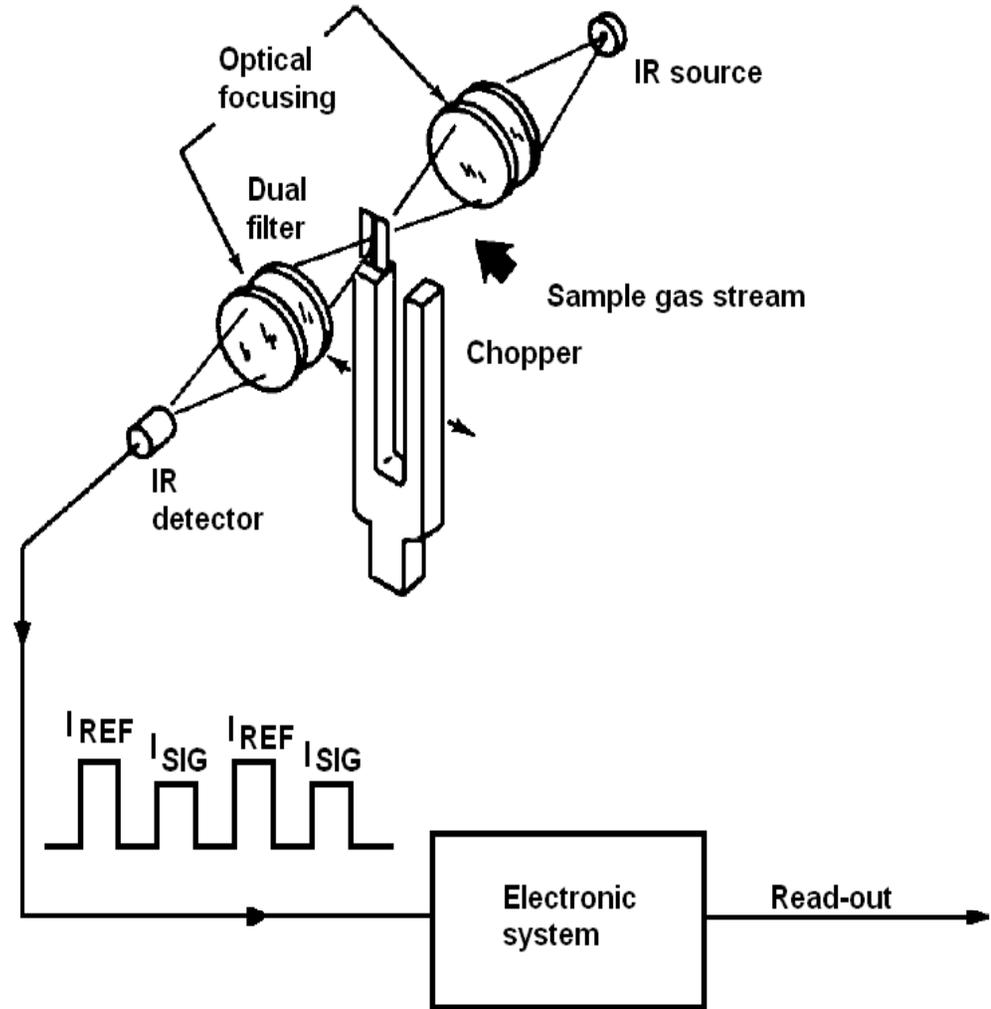
# Subsystem Redesign Considerations -- ARS

- The **CO2 Sensor** had several problems:
  - ♦ to compensate for vibration sensitivity, was mounted on isolators
  - ♦ a more rugged IR source was used
  - ♦ an AC ground (R-C network) added to eliminate EMI



# Subsystem Redesign Considerations -- ARS

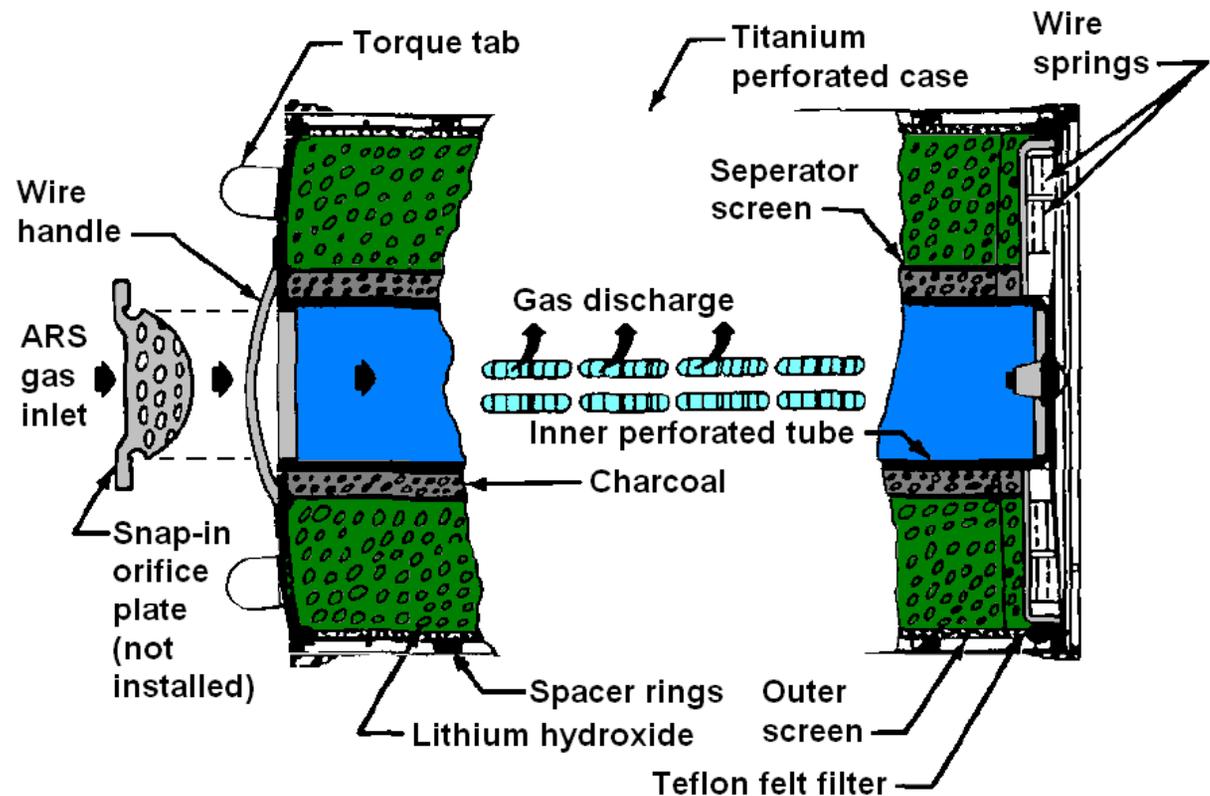
- ♦ to prevent corrosion from water exposure, metal surfaces were epoxyed.
- ♦ cal changes due to out-gassing from the conformal coating required it be changed
- ♦ thermistor added to compensate for temperature changes



Simplified CO2 Sensor

# Subsystem Redesign Considerations -- ARS

- ❑ The original LiOH Cartridge design had granular LiOH that abraded under vibration and released “dust”, which was very caustic to eyes, nose, and throat.
  - improved manufacturing techniques
  - compressing the granules (originally with polyurethane foam, but changed to a metallic spring design after the Apollo 1 fire)
  - cartridge filler material changed from Dacron to Teflon
  - snap-in orifice was added after Apollo 11 to regulate air flow rate and prevent water separator overspeed

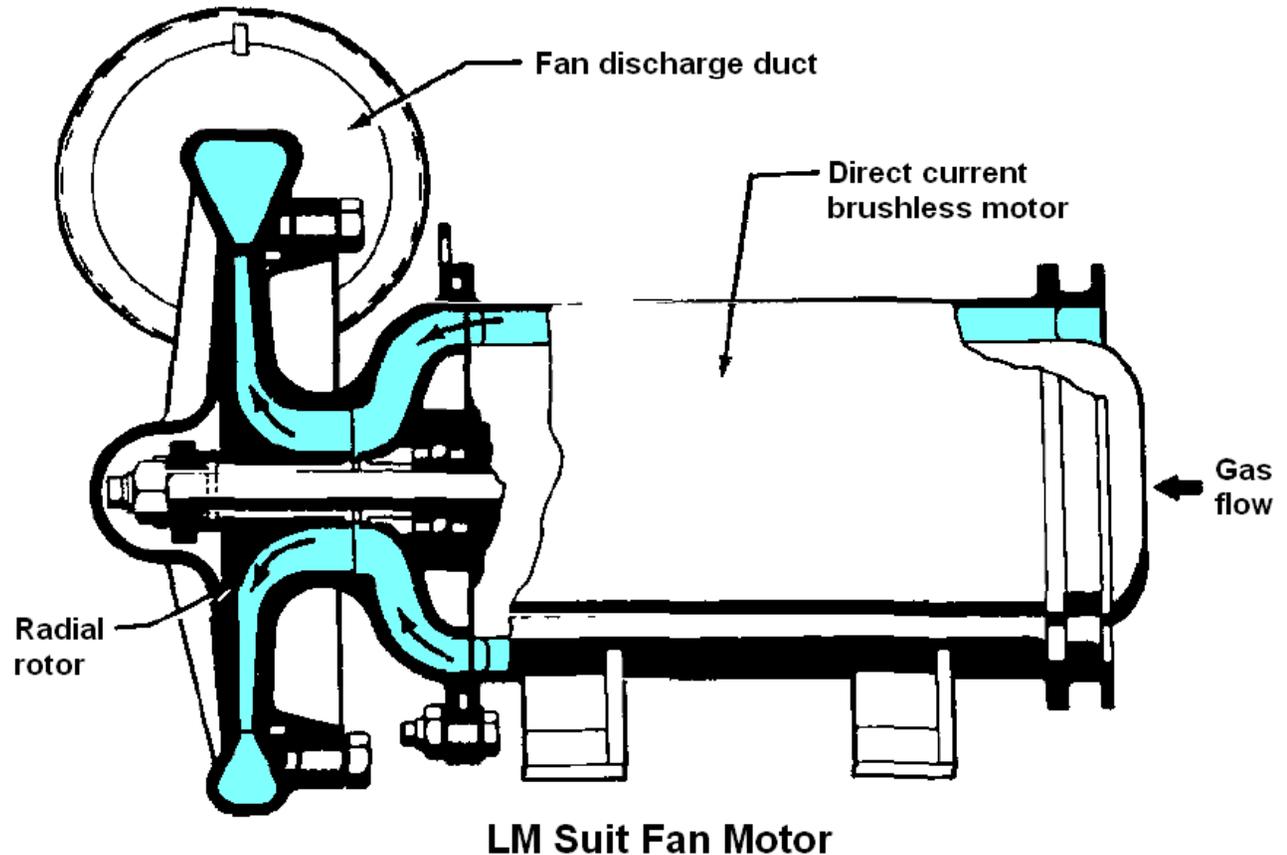


Primary LiOH Cartridge

# Subsystem Redesign Considerations -- ARS

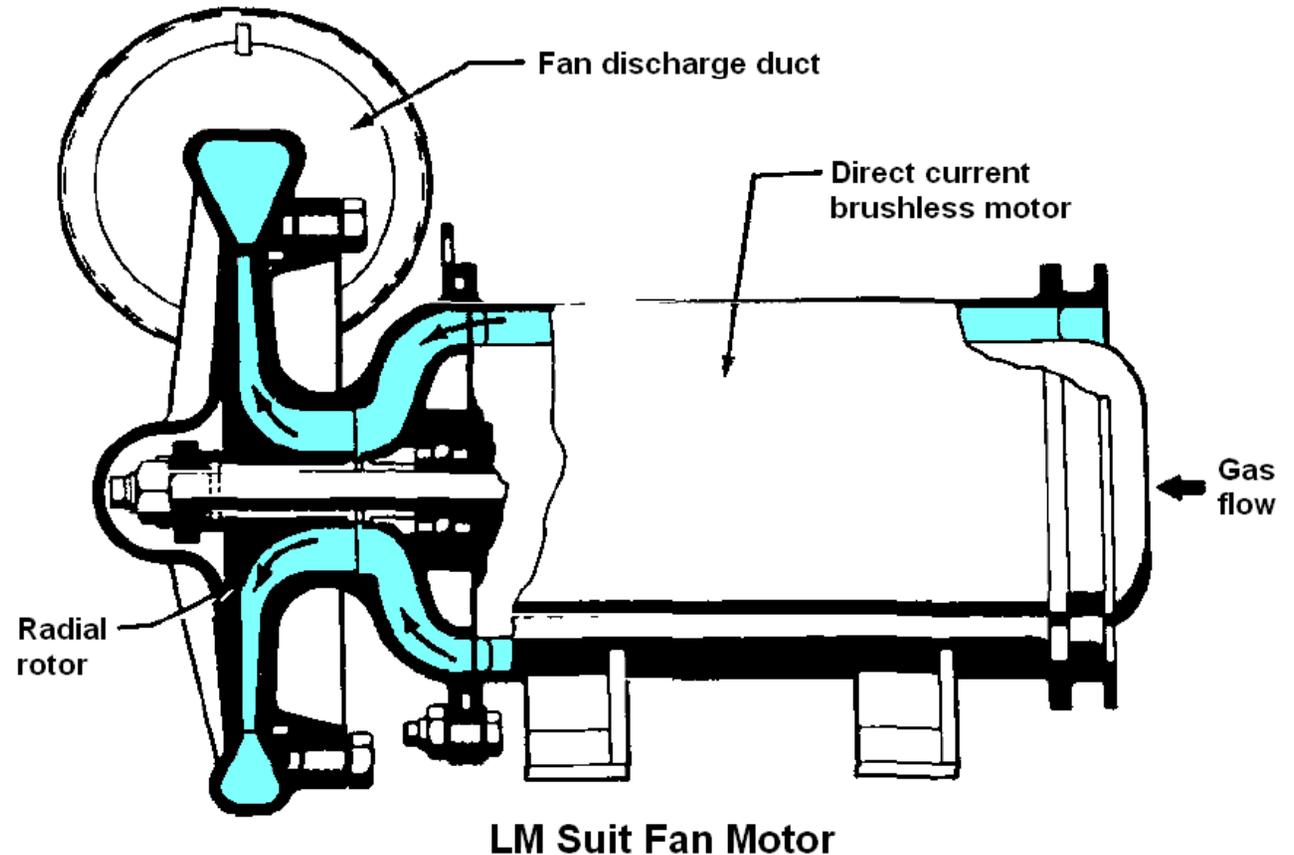
## □ The Suit Fan Motors had:

- failures of power transistors
- a tendency to start rotating the wrong direction
- fan wheel rubbed during testing and the clearances were changed



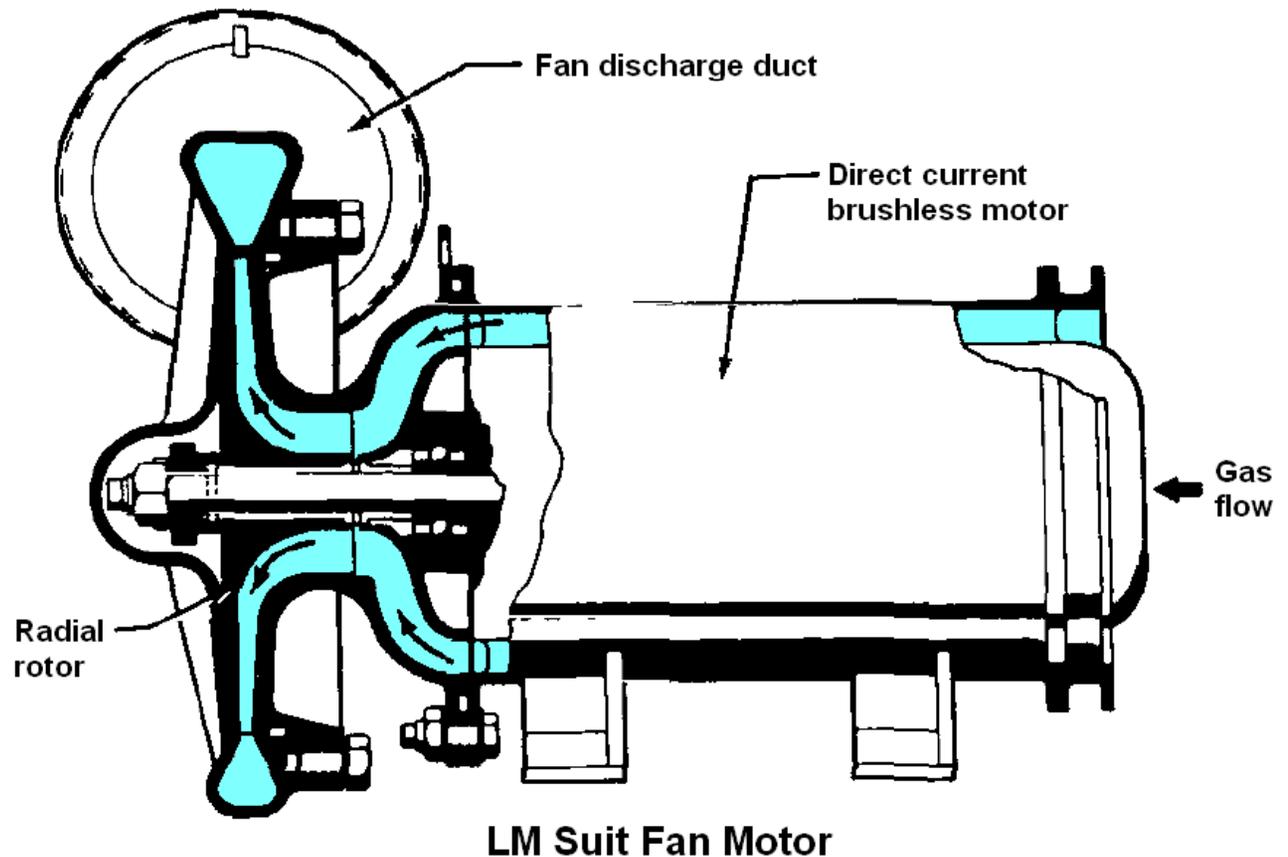
## Subsystem Redesign Considerations -- ARS

- bearing problems from contamination, inadequate lubrication, and bearing race brinelling. These were fixed by:



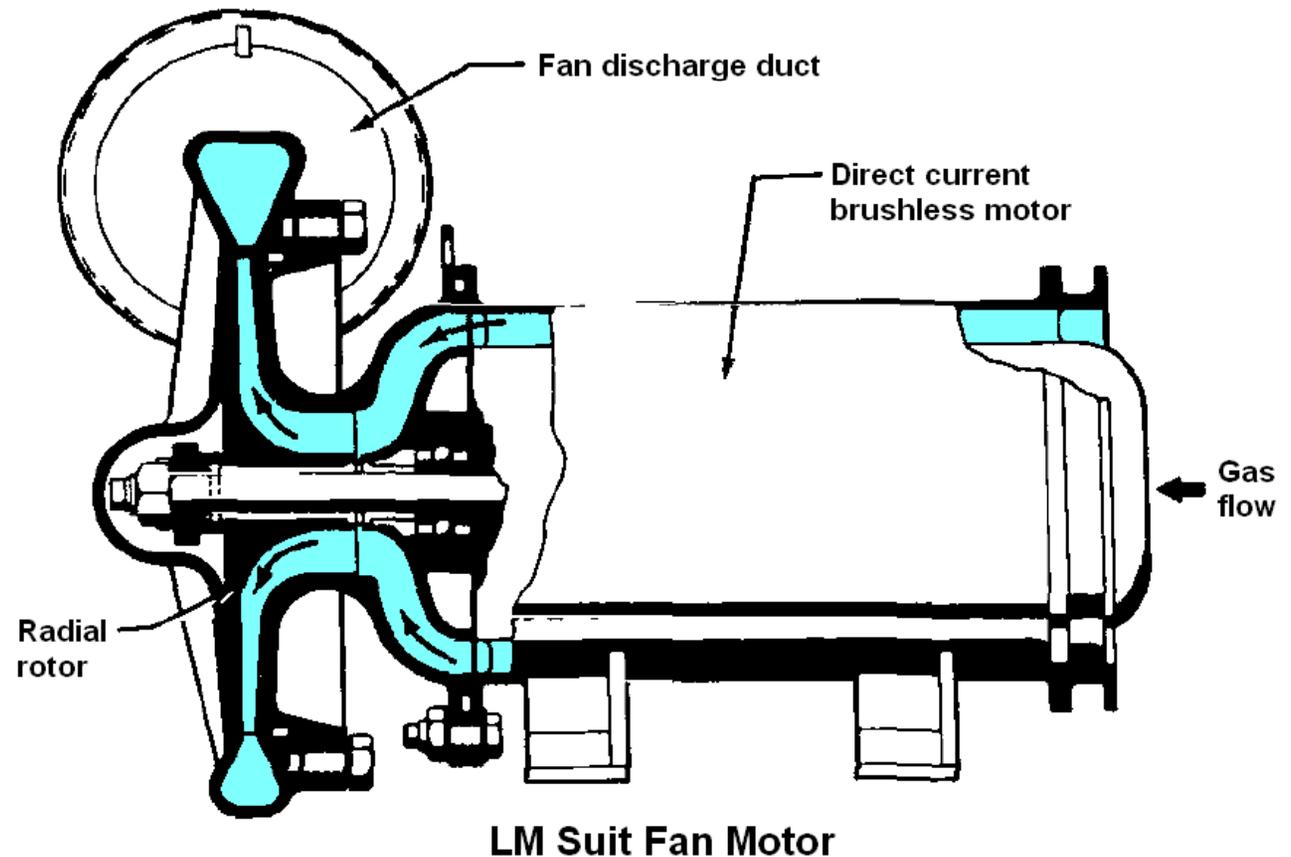
## Subsystem Redesign Considerations -- ARS

- bearing problems from contamination, inadequate lubrication, and bearing race brinelling. These were fixed by:  
better cleaning



## Subsystem Redesign Considerations -- ARS

- bearing problems from contamination, inadequate lubrication, and bearing race brinelling. These were fixed by:
  - better cleaning
  - a different grease



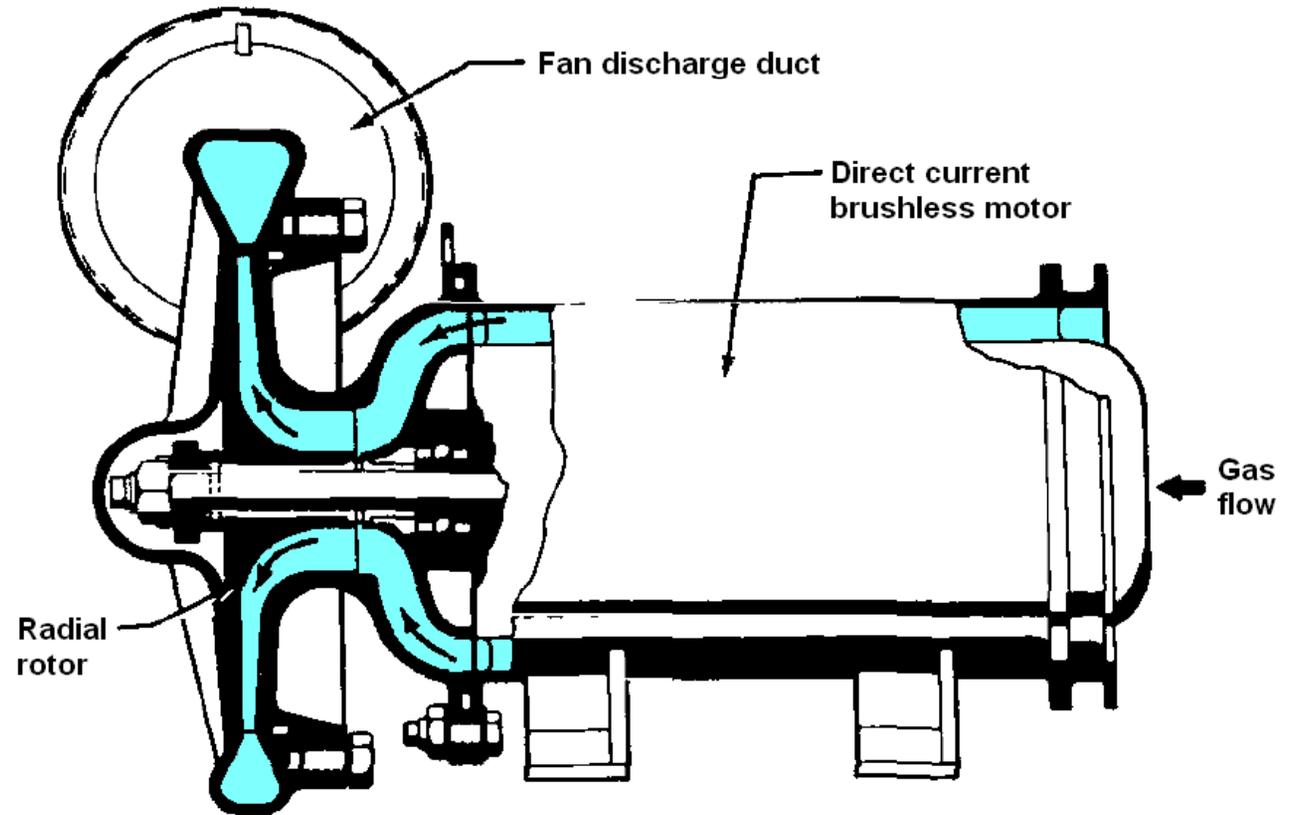
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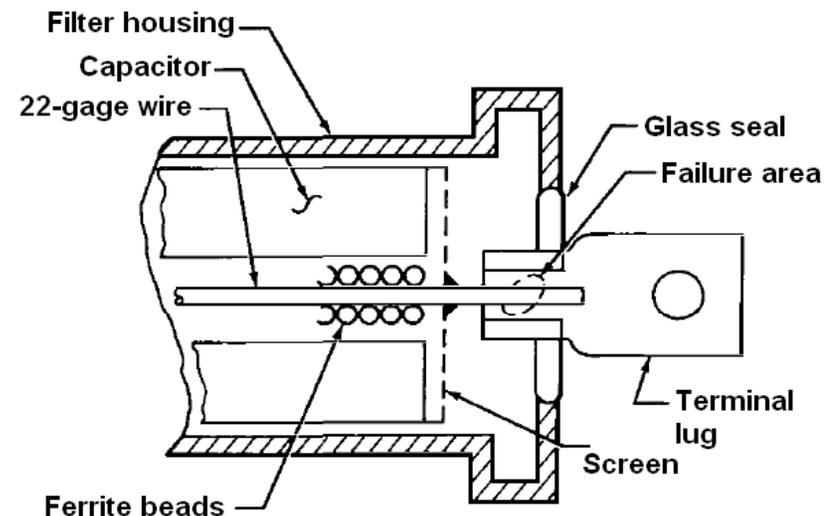
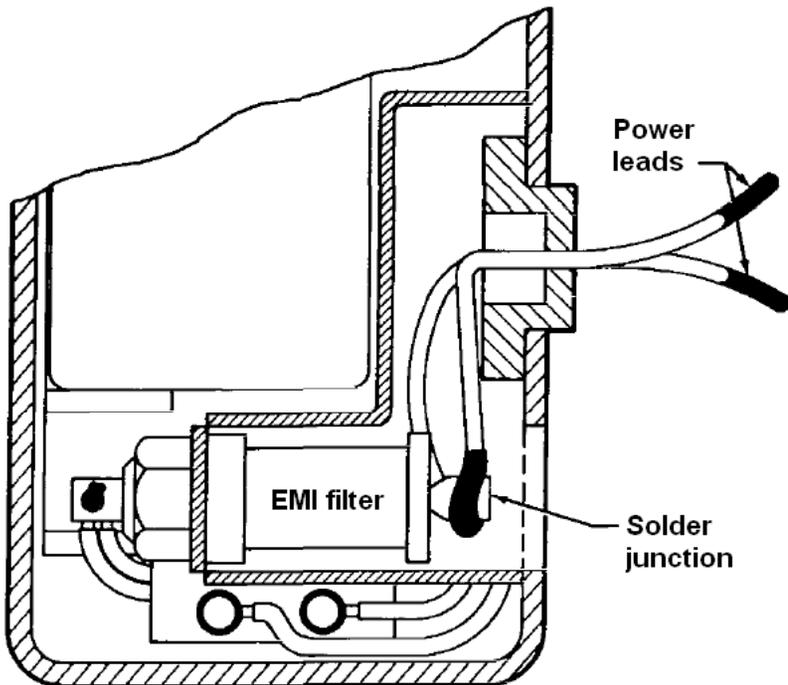
- an improved bearing pull fixture



LM Suit Fan Motor

# Subsystem Redesign Considerations -- ARS

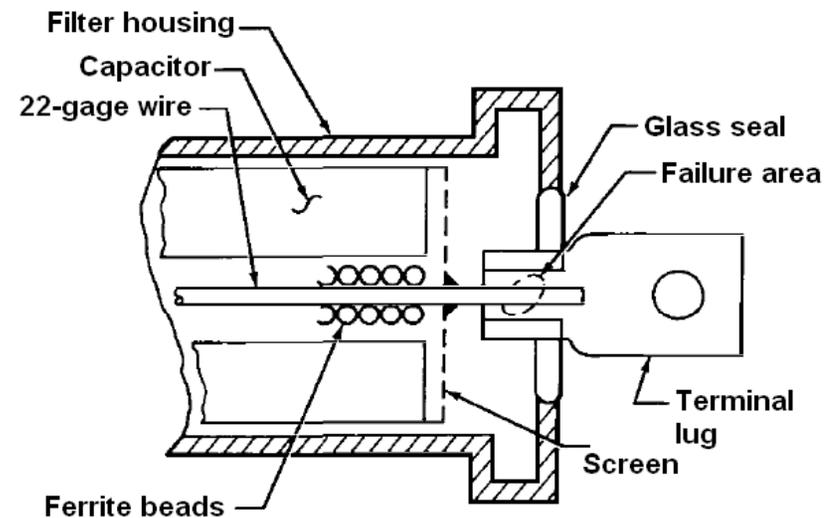
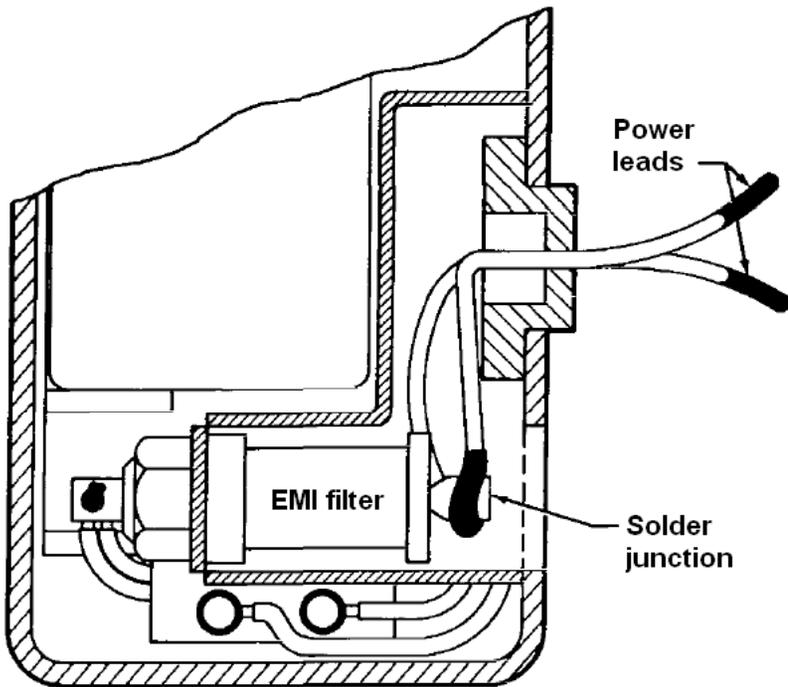
- ❑ Shimming was used to prevent inducing EMI into the fan ductwork, and the fans had to have an **EMI filter**
  - filters were getting damaged by the soldering process
  - to fix this, moved the heavy wire solder connection point farther away from the capacitor lead



**Suit Fan EMI Filter Configuration**

# Subsystem Redesign Considerations -- ARS

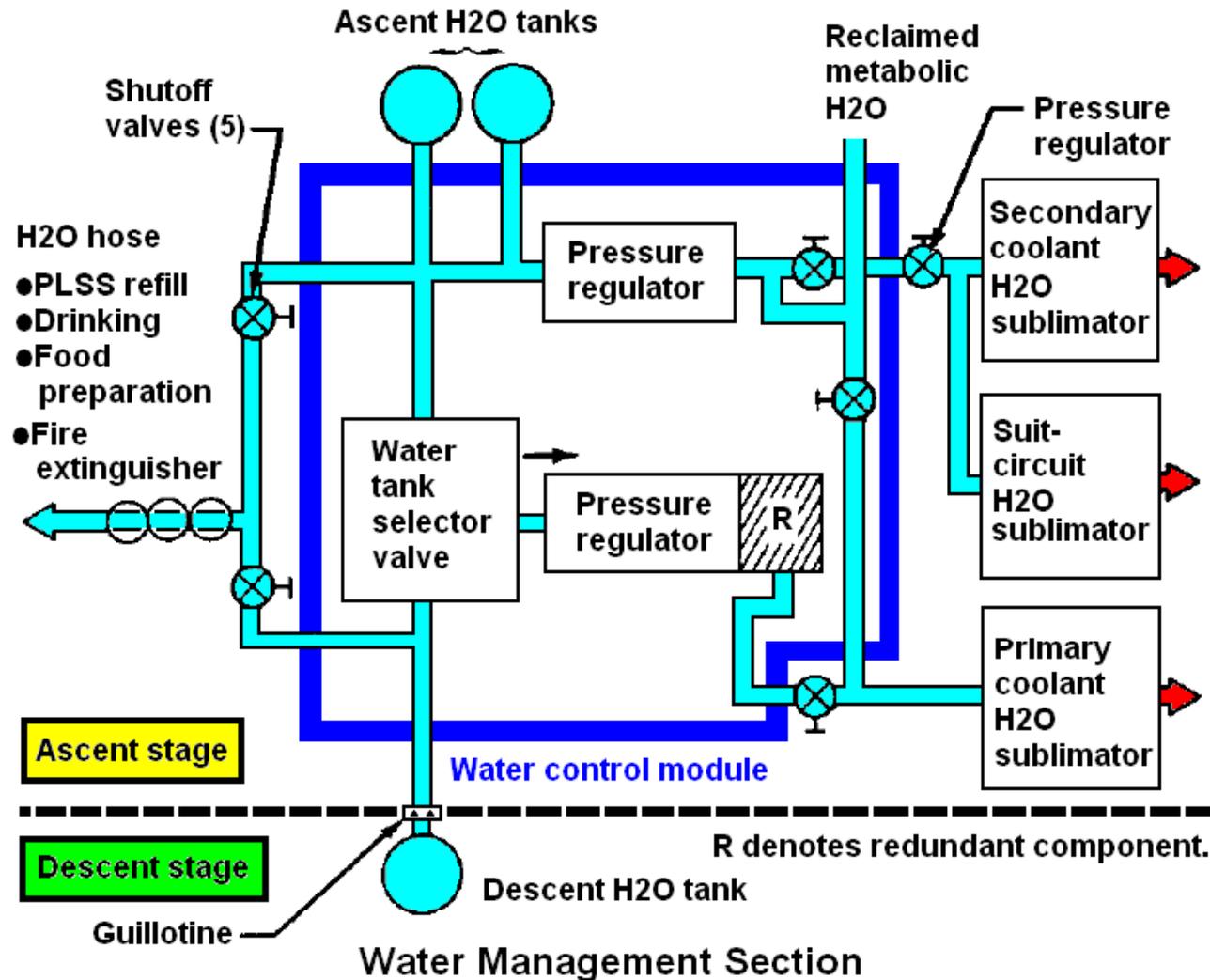
- ❑ Replacement of the old type units already installed in vehicles was only successful when performed by one specific, meticulous technician. The highly skilled technician was awarded a Snoopy award for his efforts.



**Suit Fan EMI Filter Configuration**

# Subsystem Redesign Considerations -- WMS

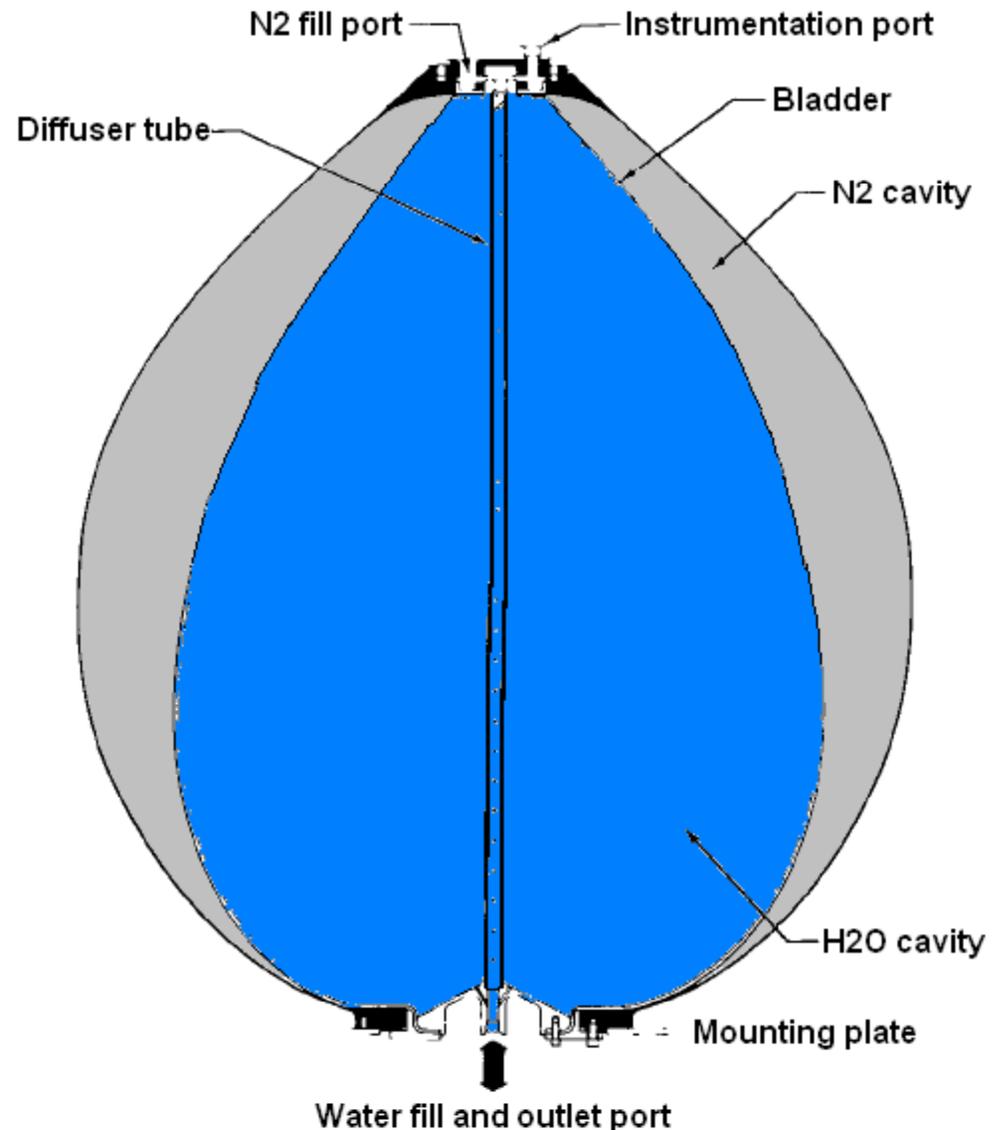
- The **Water Management Section** provided the crew's drinking water and the water to the sublimators for cooling.



# Subsystem Redesign Considerations -- WMS

## □ The Water Tank bladders:

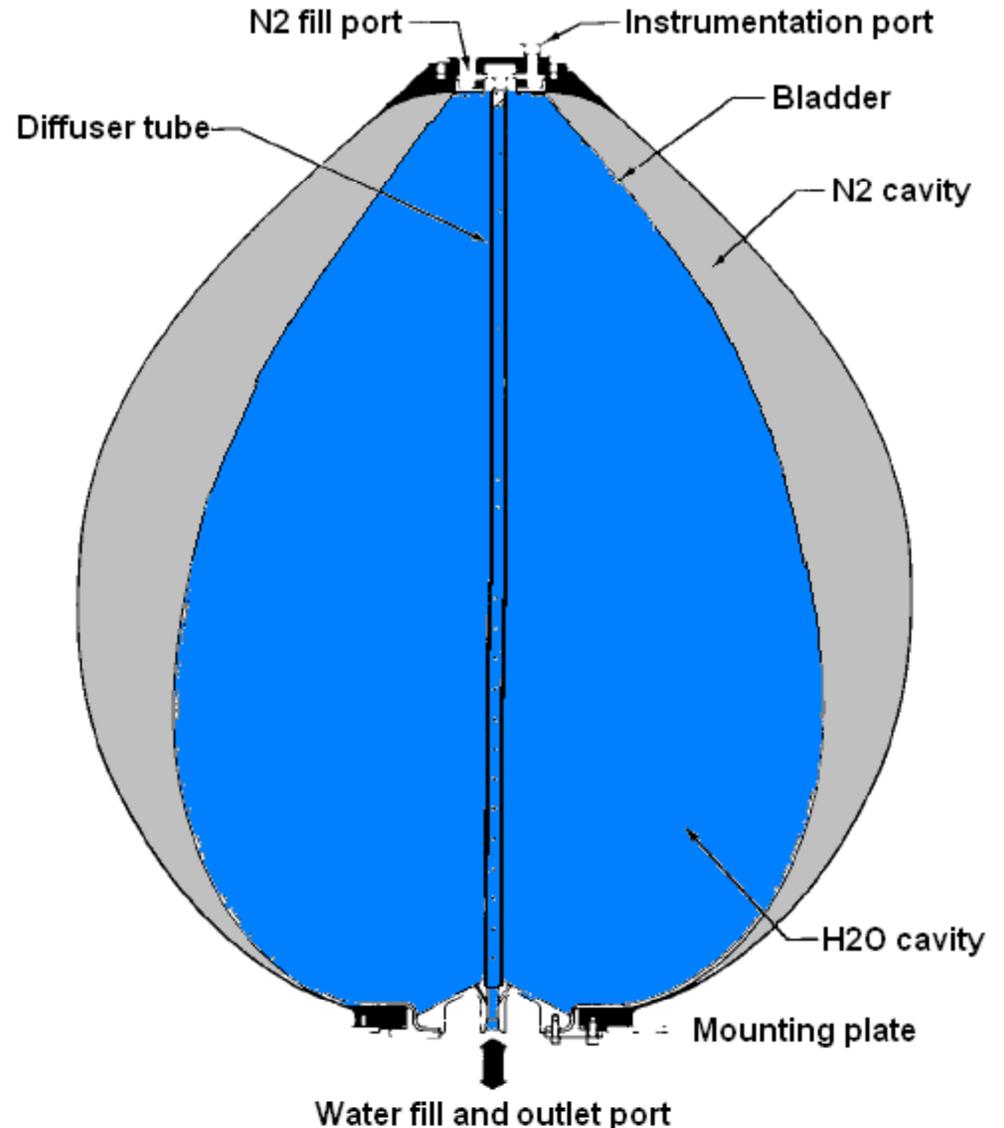
- ♦ found to adhere between folds when stored collapsed
- ♦ prevented by storing the tanks with the water side pressurized with several psi of dry nitrogen
- ♦ a bladder tear was found on LM-7 (no specific cause ever identified)
- ♦ X-rays and gas leakage tests were used after that



**Descent Water Tank**

# Subsystem Redesign Considerations -- WMS

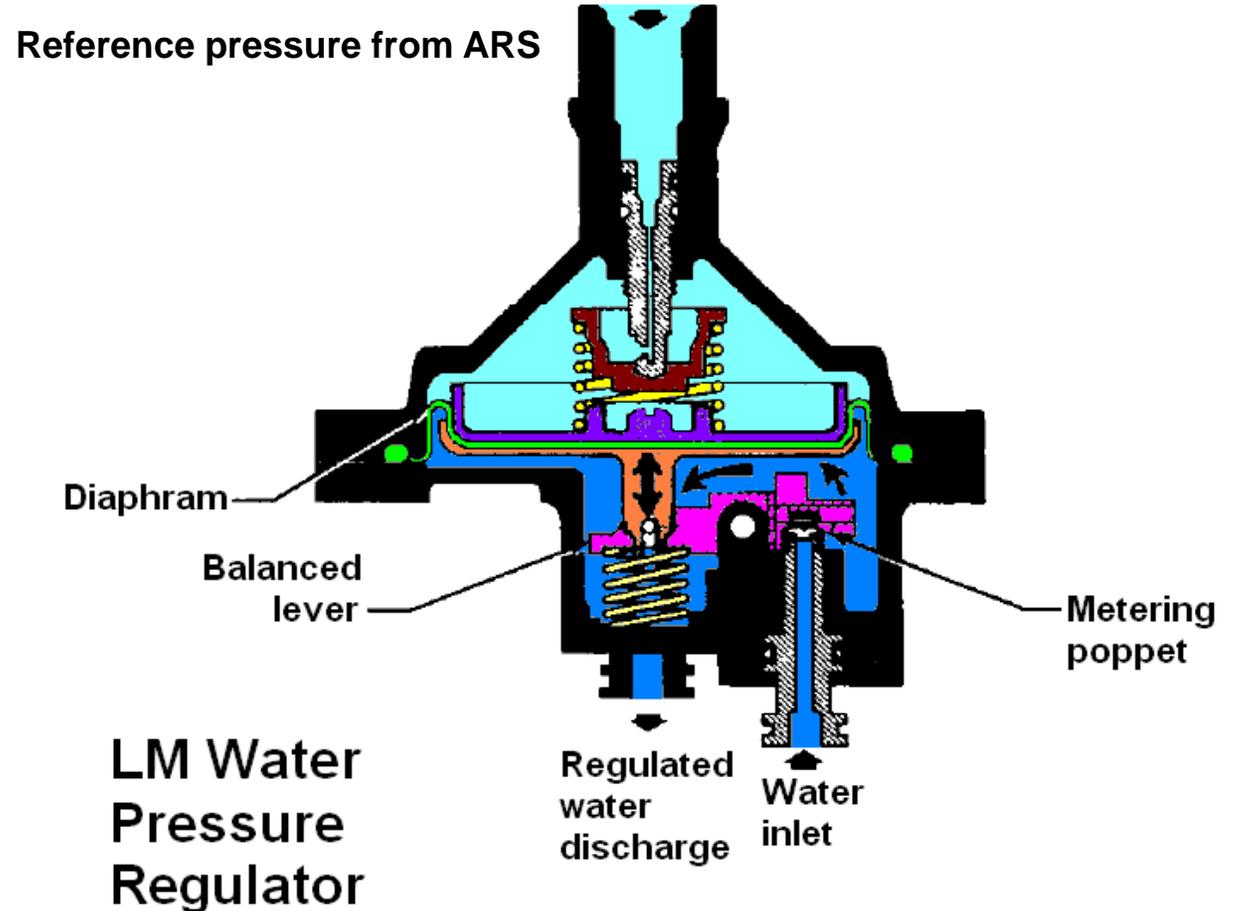
- All the LM water was loaded before launch:
  - ◆ chlorine could not be used as a bacteriocide -- incompatible with the sublimators
  - ◆ iodine was introduced
  - ◆ iodine depletion (via diffusion of iodine vapor from the water through the bladder) rate increased with each iodine addition
  - ◆ the only iodine-containing water introduced into the tank was the flight load



**Descent Water Tank**

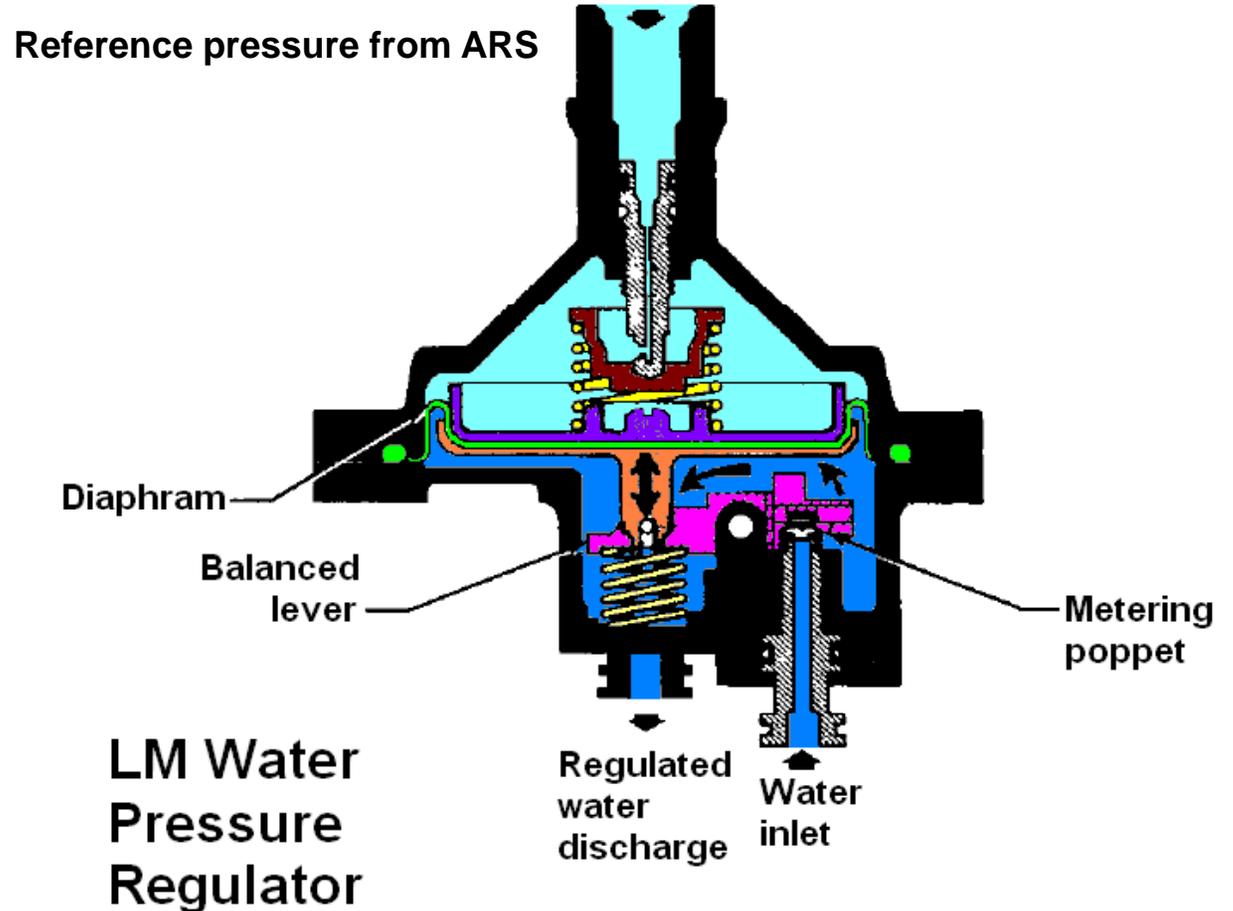
## Subsystem Redesign Considerations -- WMS

- The Water Pressure Regulator experienced particulate contamination and corrosion. Corrective measures were to:
  - minimize exposure time to water during testing
  - dry the system thoroughly



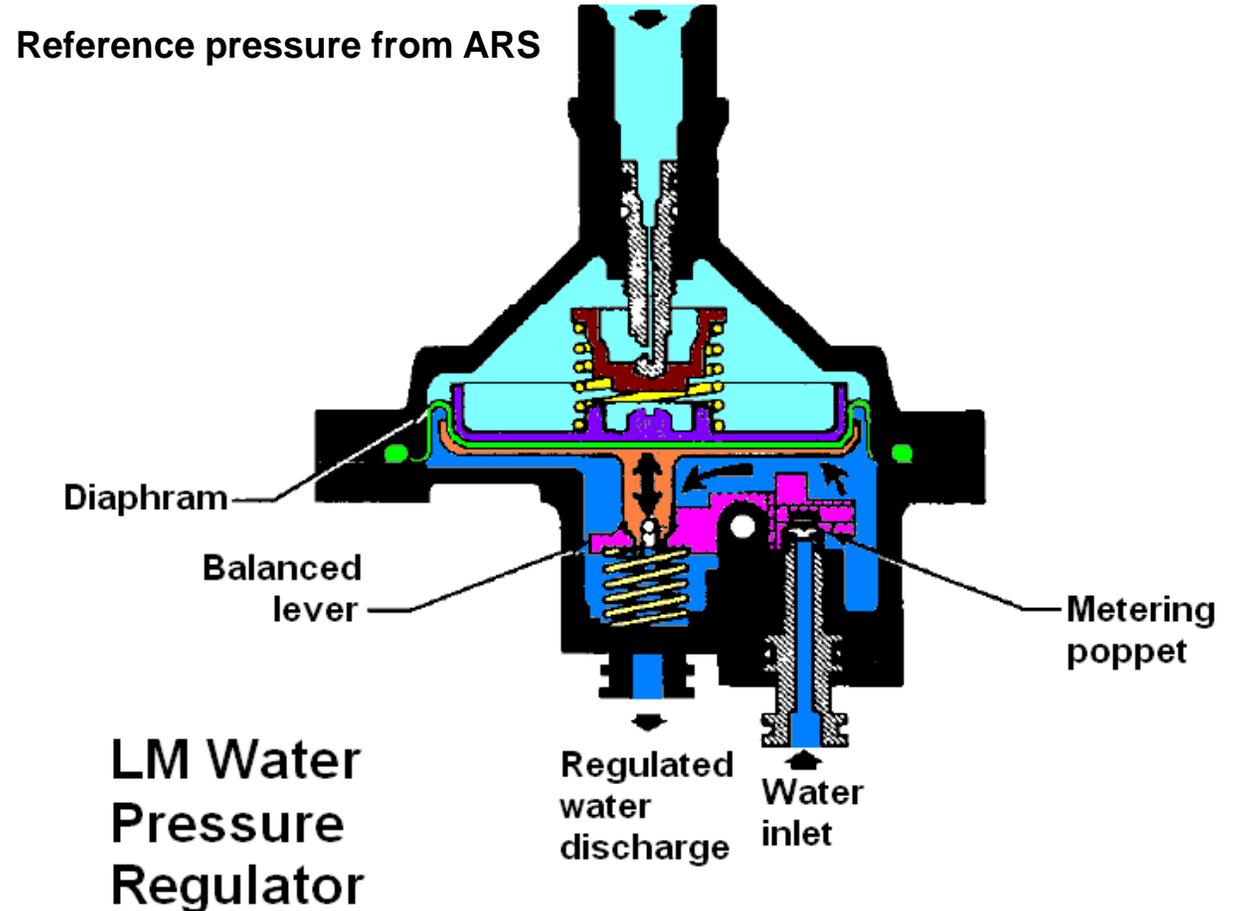
## Subsystem Redesign Considerations -- WMS

- During checkout of LM-4, one regulator failed, due to corrosion and particulates
  - redundant regulator added to the backup system for subsequent vehicles



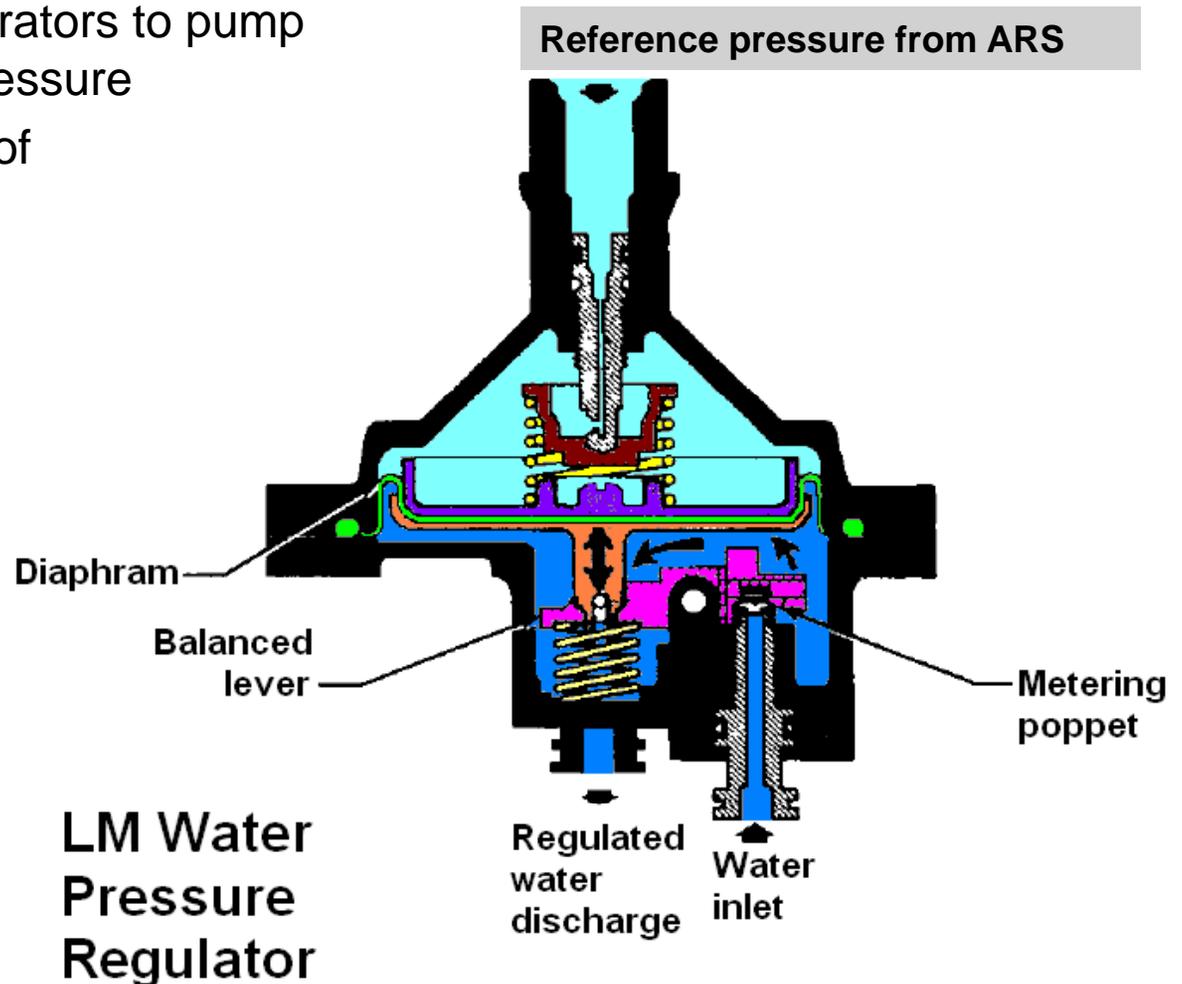
## Subsystem Redesign Considerations -- WMS

- Set to regulate to 3.45 to 6.9 KPa (0.5 to 1 psi) over suit pressure.
  - reference pressure line contained small orifices



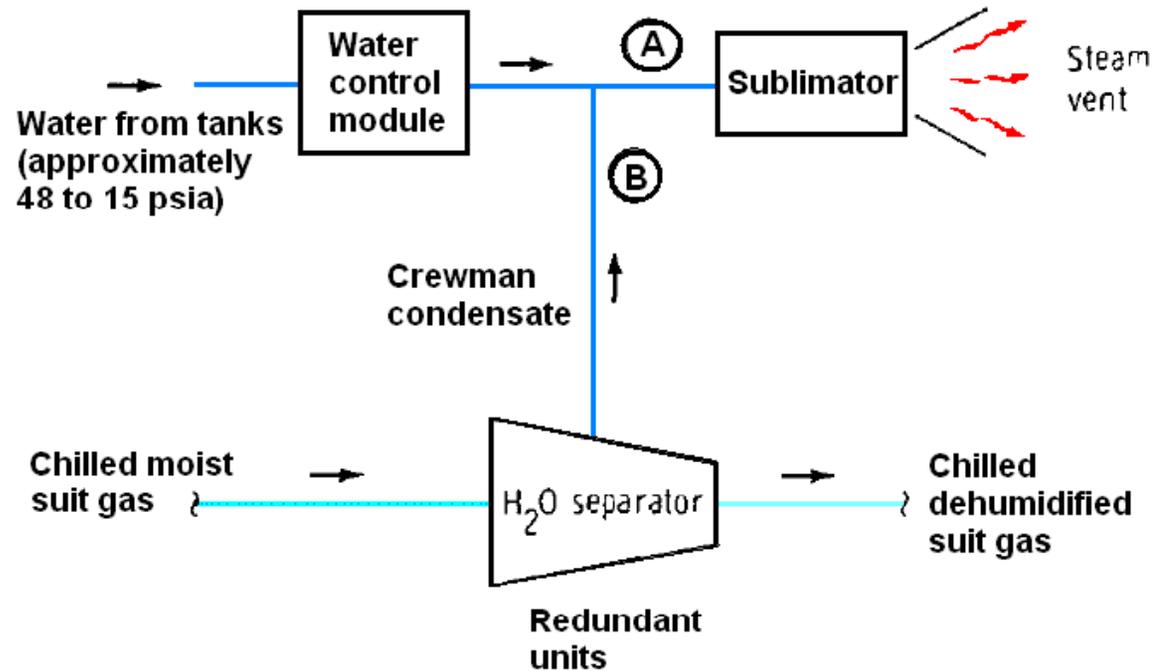
# Subsystem Redesign Considerations -- WMS

- ❑ The orifices became plugged.
  - caused an improper reference pressure and a high water pressure to the sublimators
  - caused the water separators to pump against a high head pressure
  - water not pumped out of the suit circuit
  - orifices were removed



# Subsystem Redesign Considerations -- WMS

- ❑ The requirement that no viable organism be deposited on the moon called for a **Bacteria Filter** in the water system.
  - ♦ gas from N<sub>2</sub> dissolved in the water blocked the 0.22 micron filter
  - ♦ requirement was relaxed for the sublimator line
  - ♦ bacterial filter was used on the cabin dump valve for Apollo 11
  - ♦ requirement was dropped for subsequent missions

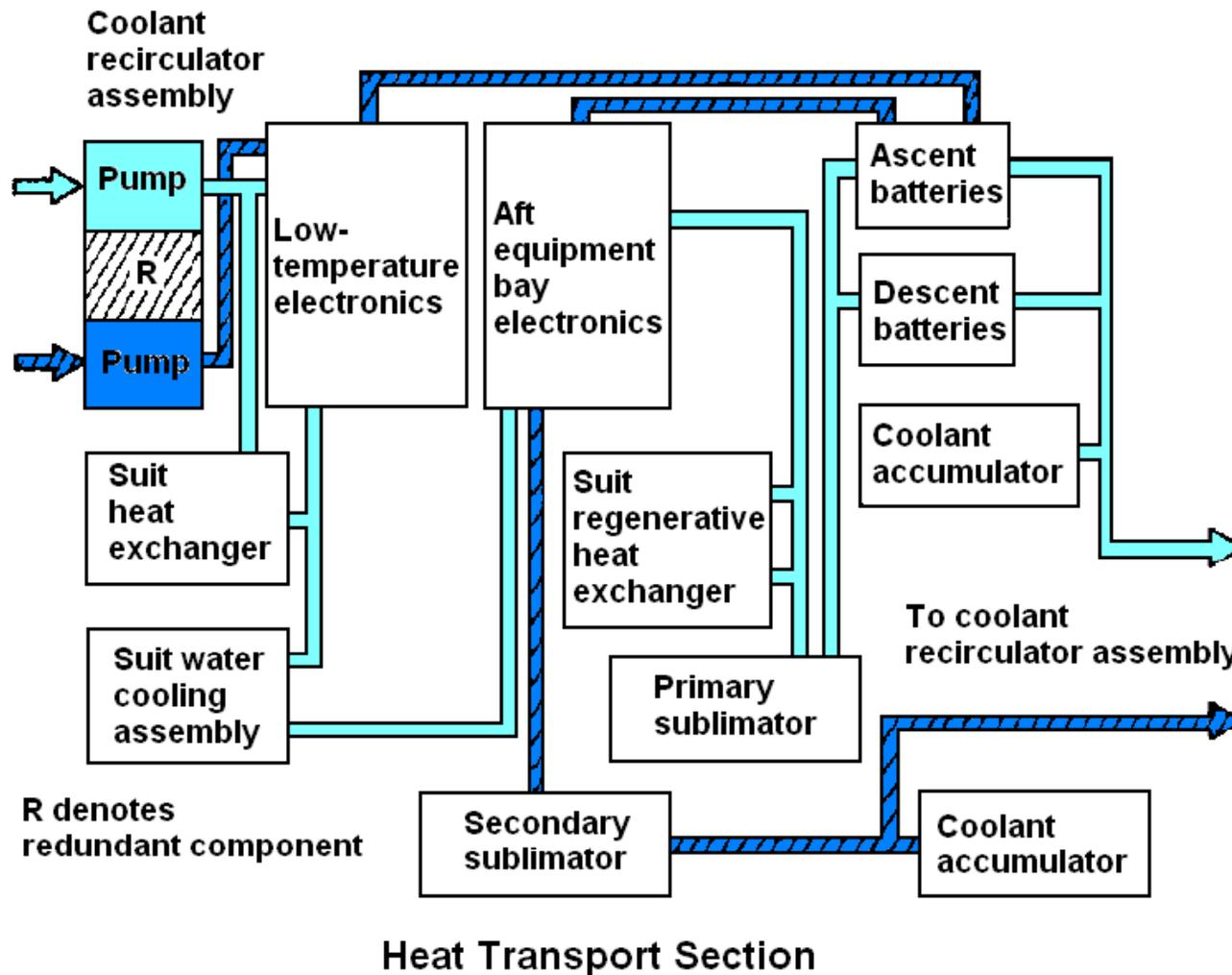


Water Bacterial Filter

(A) and (B) represent possible water filter locations

# Subsystem Redesign Considerations -- HTS

- The **Heat Transport Section** removed the excess heat from the LM through a water/glycol coolant loop feeding water sublimators.



## Subsystem Redesign Considerations -- HTS

- The original cooling fluid mix was to be identical to that used in the CSM.

Material	Percent
Ethylene glycol	62.5
Distilled water	35.0
Triethanolamine phosphate	1.6
Sodium mercaptobenzothiazole (NaMBT)	0.9

# Subsystem Redesign Considerations -- HTS

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  - did not have sufficient heat transport capacity for the LM's needs

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  - raised the freezing point of the coolant from -54 degC (-65 degF) to -19 degC (-2 degF)

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  - did not have sufficient heat transport capacity for the LM's needs
  - a greater percentage of water was needed
  - raised the freezing point of the coolant from -54 degC (-65 degF) to -19 degC (-2 degF)
  - still below temperatures the LM coolant would experience

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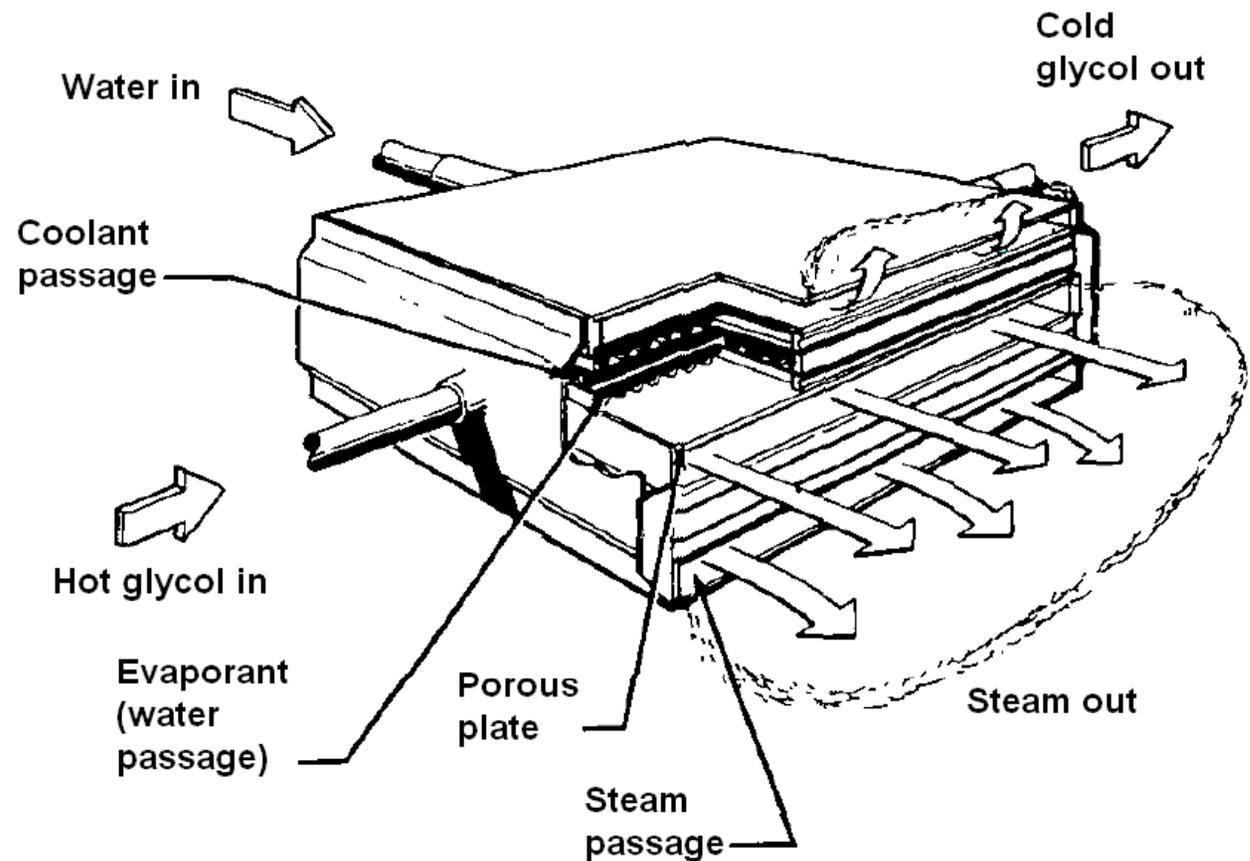
- ❑ The change also required a change in pH.
  - prior to flight for LM-5 (Apollo 11) a crystalline precipitate was found in the fluid
  - determined to have been caused by a change in the NaMBT used
  - crystals were so soft and fragile that they caused no problems with the orifices, pumps, etc. of the HTS
  - LM-5 was flown with this mix
  - previous grade of NaMBT was used for subsequent vehicles, without crystal formation

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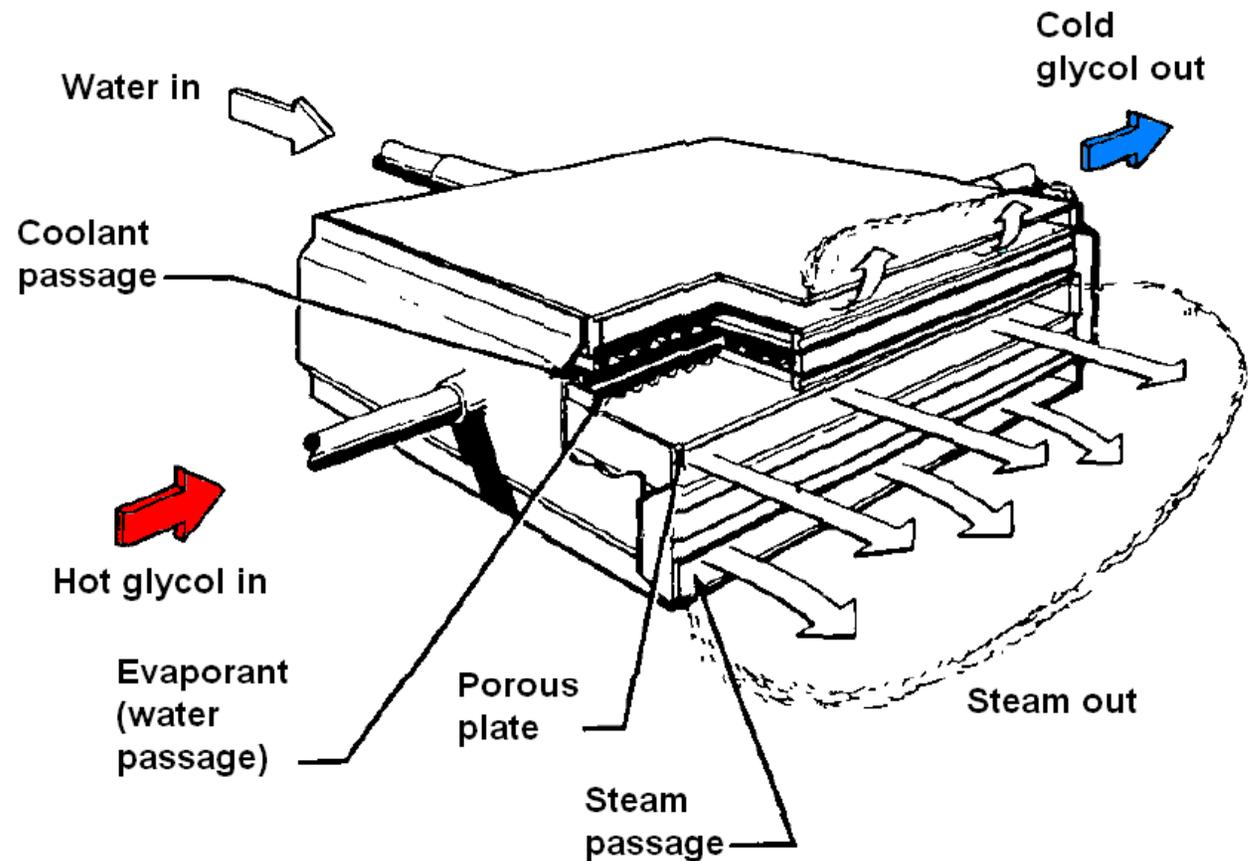
# Subsystem Redesign Considerations -- HTS

- The heart of the heat rejection capability of the HTS was its **Water Sublimators**.



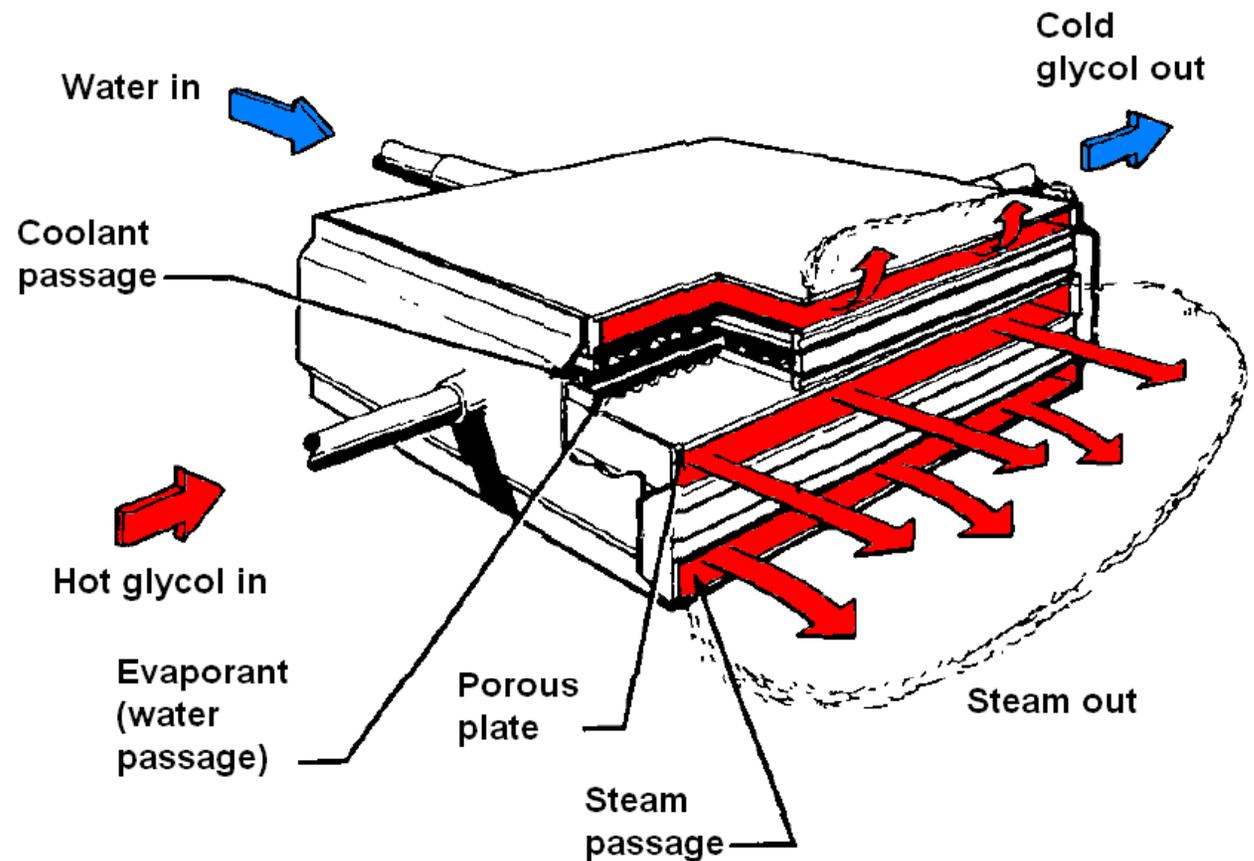
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  - ♦ hot glycol solution passed through channels beside other channels containing pressurized water



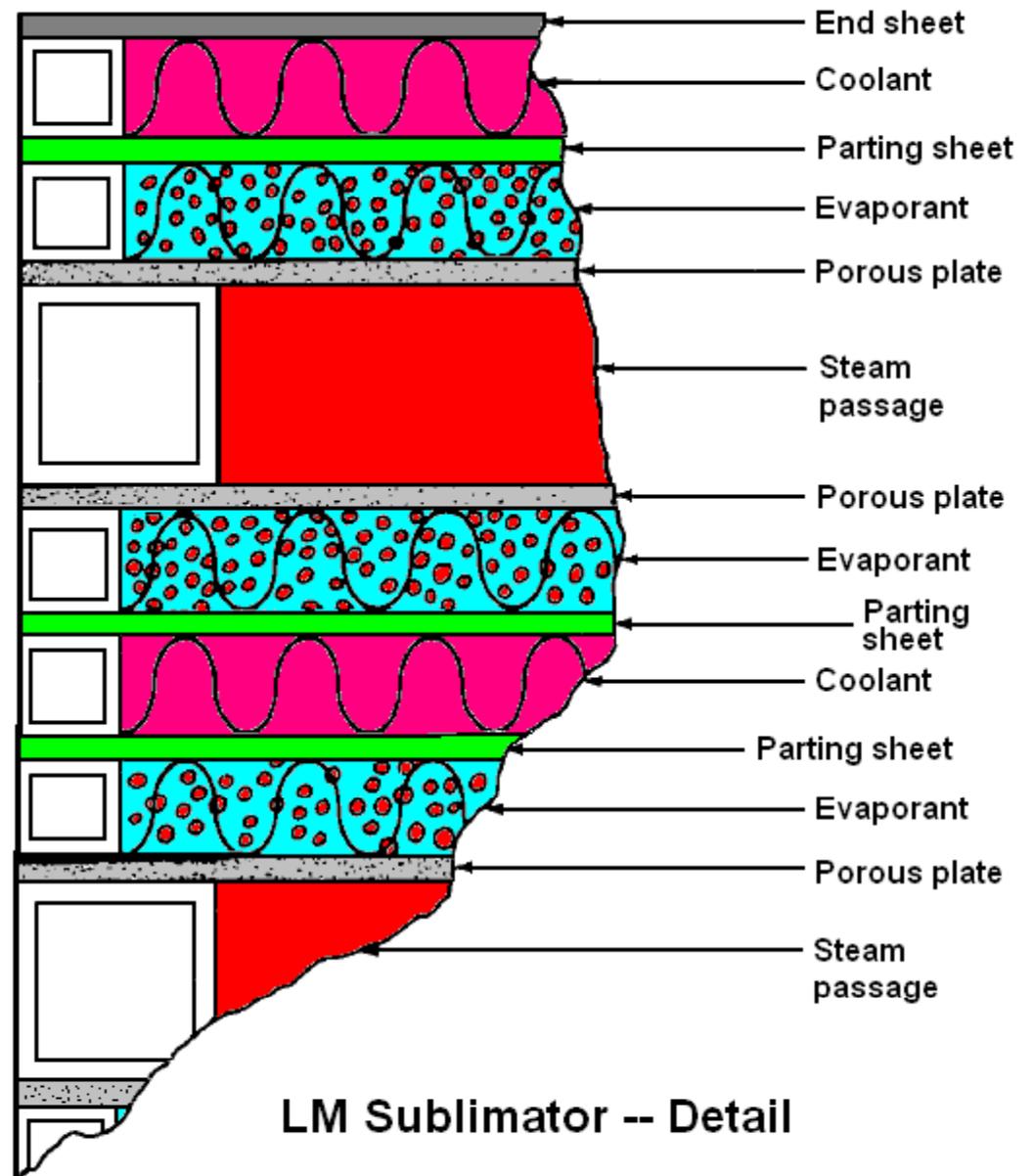
# Subsystem Redesign Considerations -- HTS

- The heart of the heat rejection capability of the HTS was its Water Sublimators.
  - ♦ hot glycol solution passed through channels beside other channels containing pressurized water
  - ♦ the other wall of the water channels was porous, allowing water to seep into vacuum channels, freeze, and then sublimate to provide the cooling



## Subsystem Redesign Considerations -- HTS

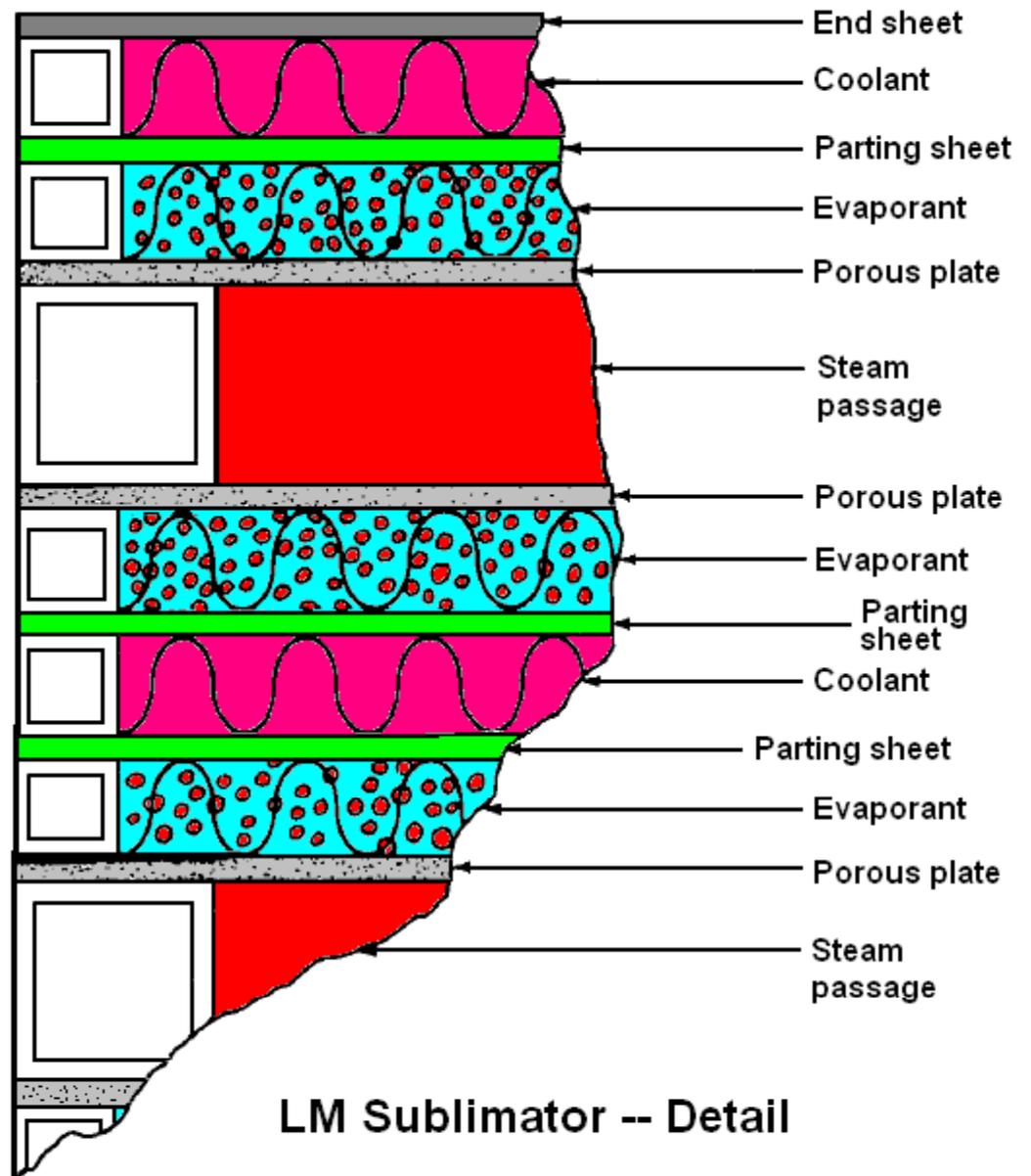
- ◆ Difficulty was encountered in brazing the porous plates without plugging the pores
- ◆ the early units degraded with usage time and had insufficient total capacity
- ◆ tried porous plates with higher porosity
- ◆ welded fins to the plates to eliminate brazing problems
- ◆ increased the density of the heat-transfer fins in the coolant passages
- ◆ implemented better quality controls to ensure that the porous plates were installed facing the right direction



LM Sublimator -- Detail

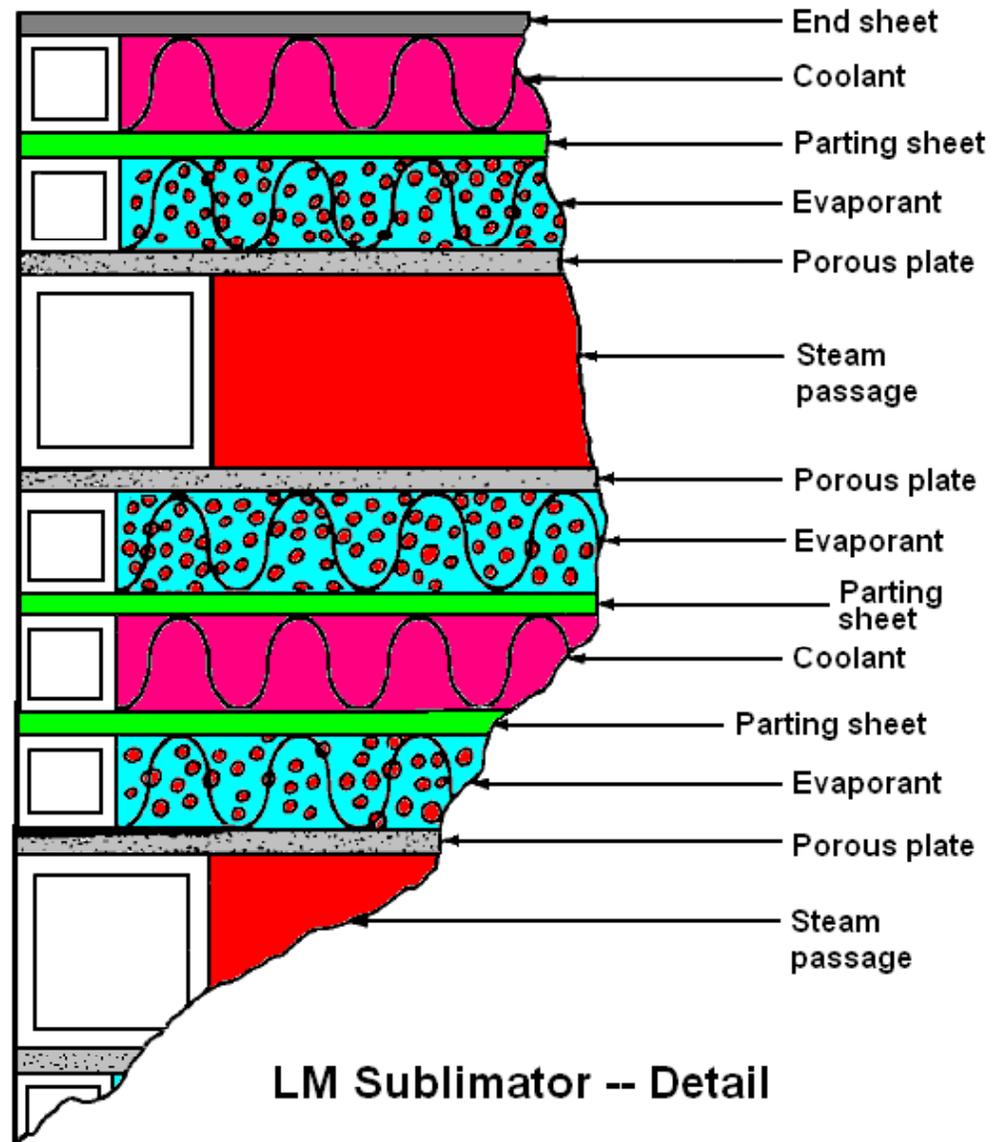
# Subsystem Redesign Considerations -- HTS

- ❑ Originally, **chlorine** was being added to the water as a bactericide.
  - ♦ caused a buildup of a residue on the steam passage side of the porous plates
  - ♦ resulted in a depression of the freezing point and water breakthrough
  - ♦ forced the LM program to go to iodine as the biocide in the water system



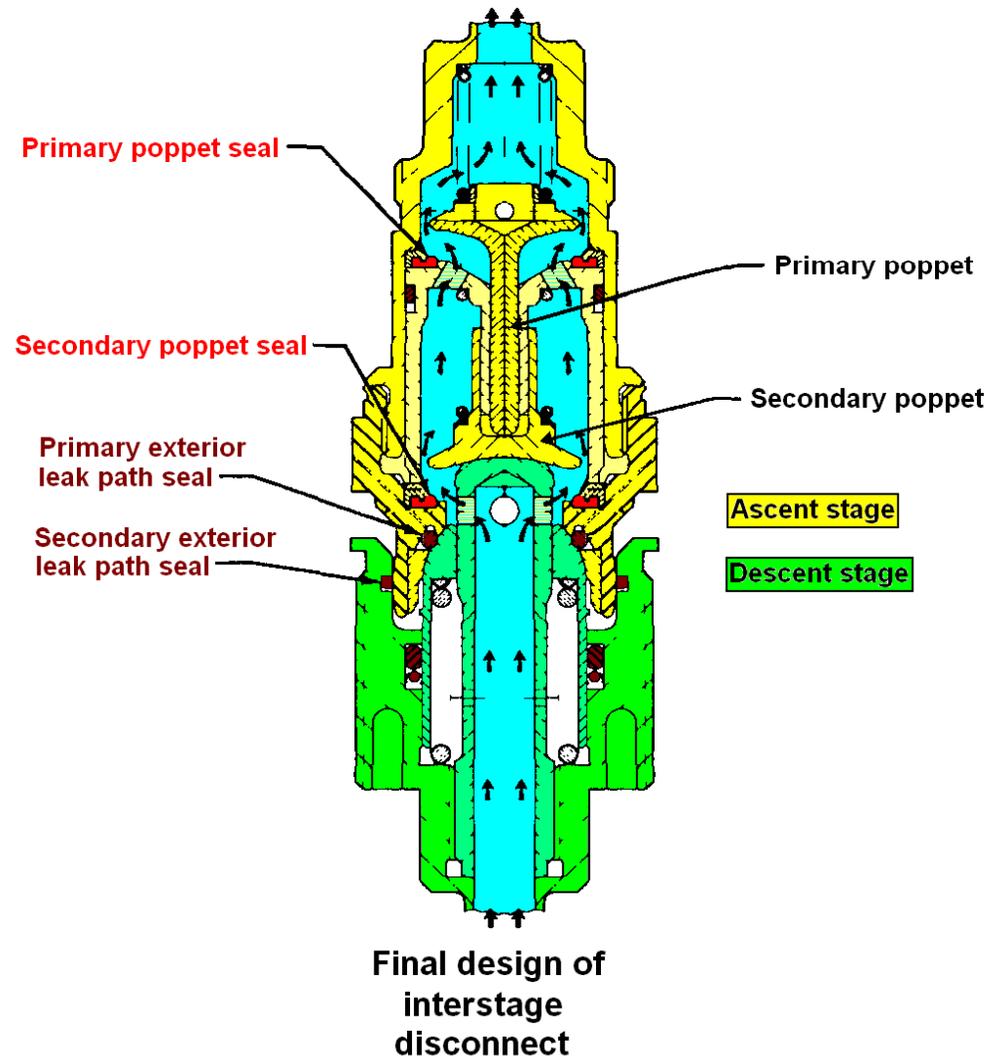
# Subsystem Redesign Considerations -- HTS

- The units tended to degrade by accumulating corrosion products during storage.
  - ◆ also during use from blockage of pores by contaminants
  - ◆ a higher performance was required at acceptance than the units would need in flight
  - ◆ the units were stored in a dry N<sub>2</sub> environment



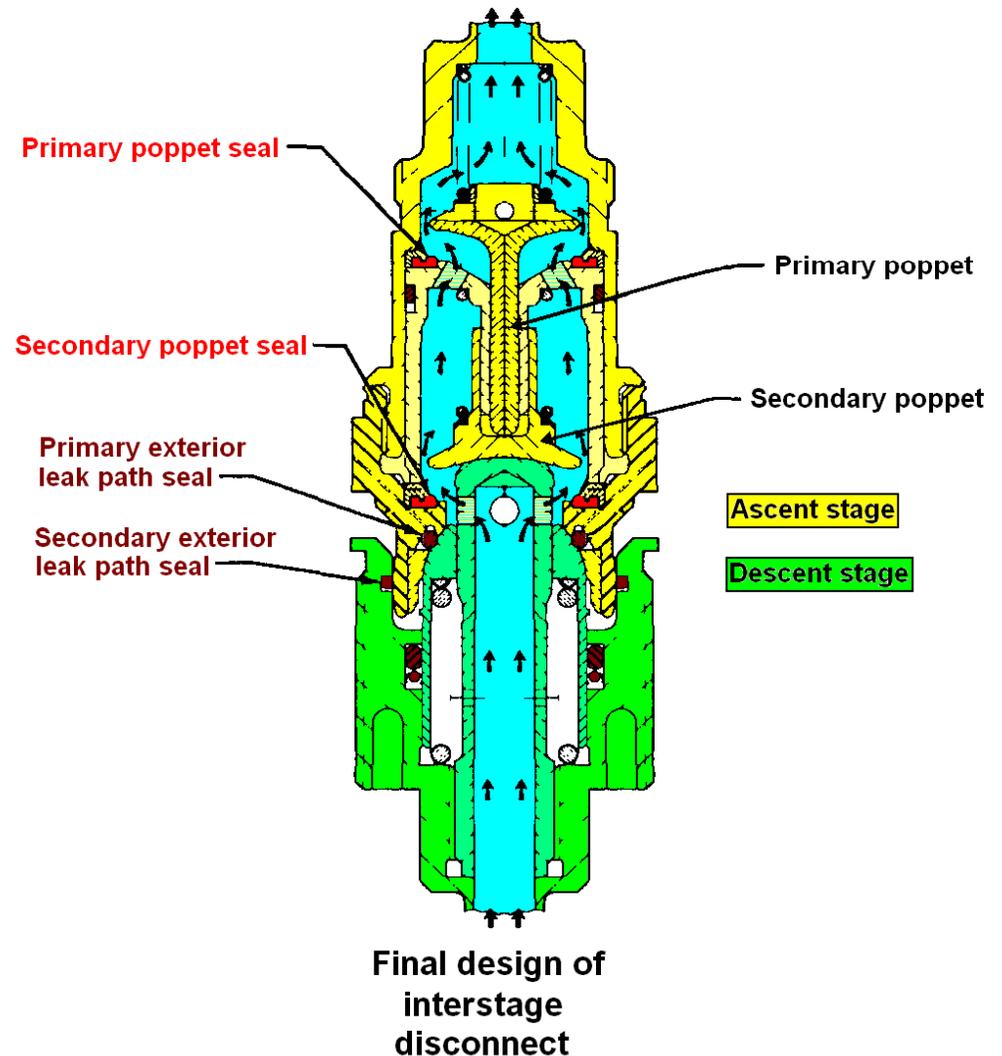
# Subsystem Redesign Considerations -- HTS

- Quick Disconnects were used for several connections in the HTS.



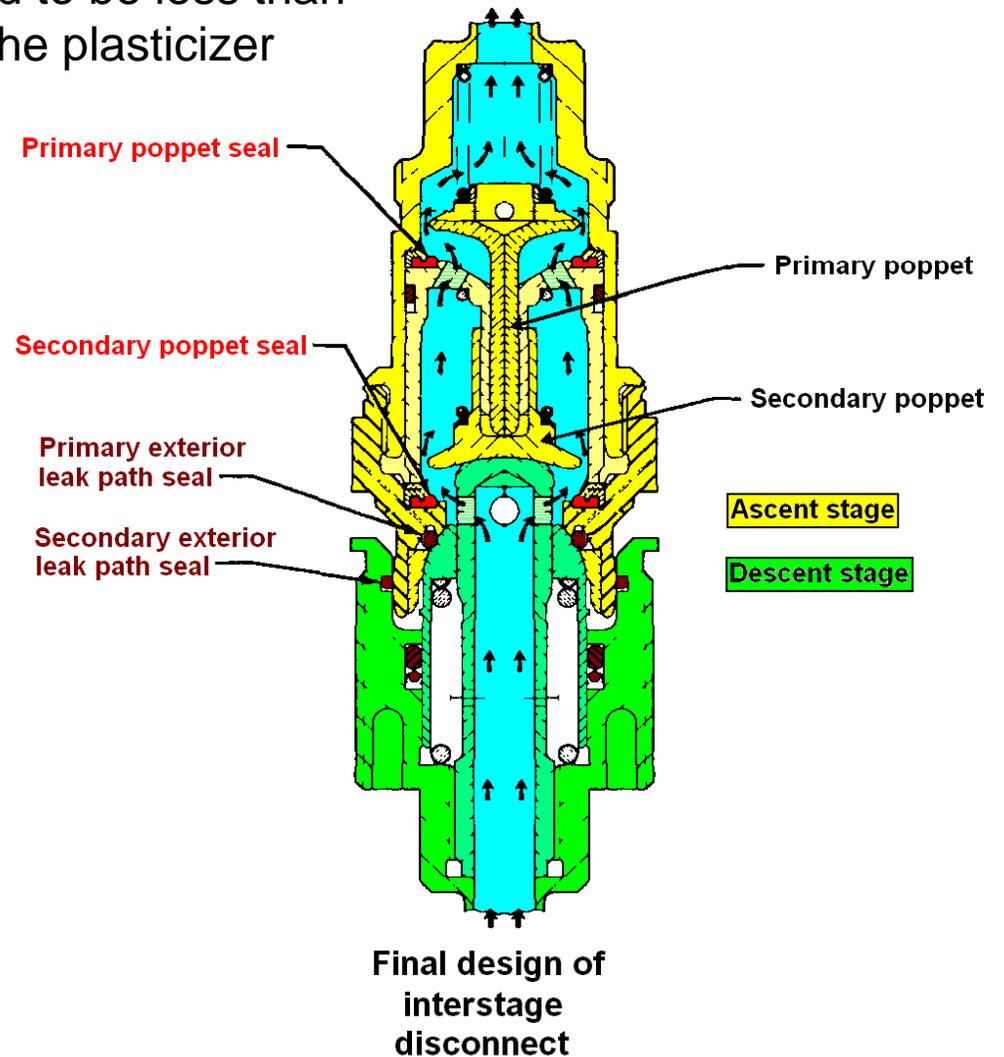
# Subsystem Redesign Considerations -- HTS

- ❑ Loss of lubricant was a problem whenever the system was drained.
  - isopropyl alcohol was used to flush the system
  - it dissolved the lubricants
  - prevented free action of the moving parts and leakage in gas leak checks
  - GSE QDs were modified to allow reapplication of lubricants
  - no QD that ever showed such a leak was allowed to fly



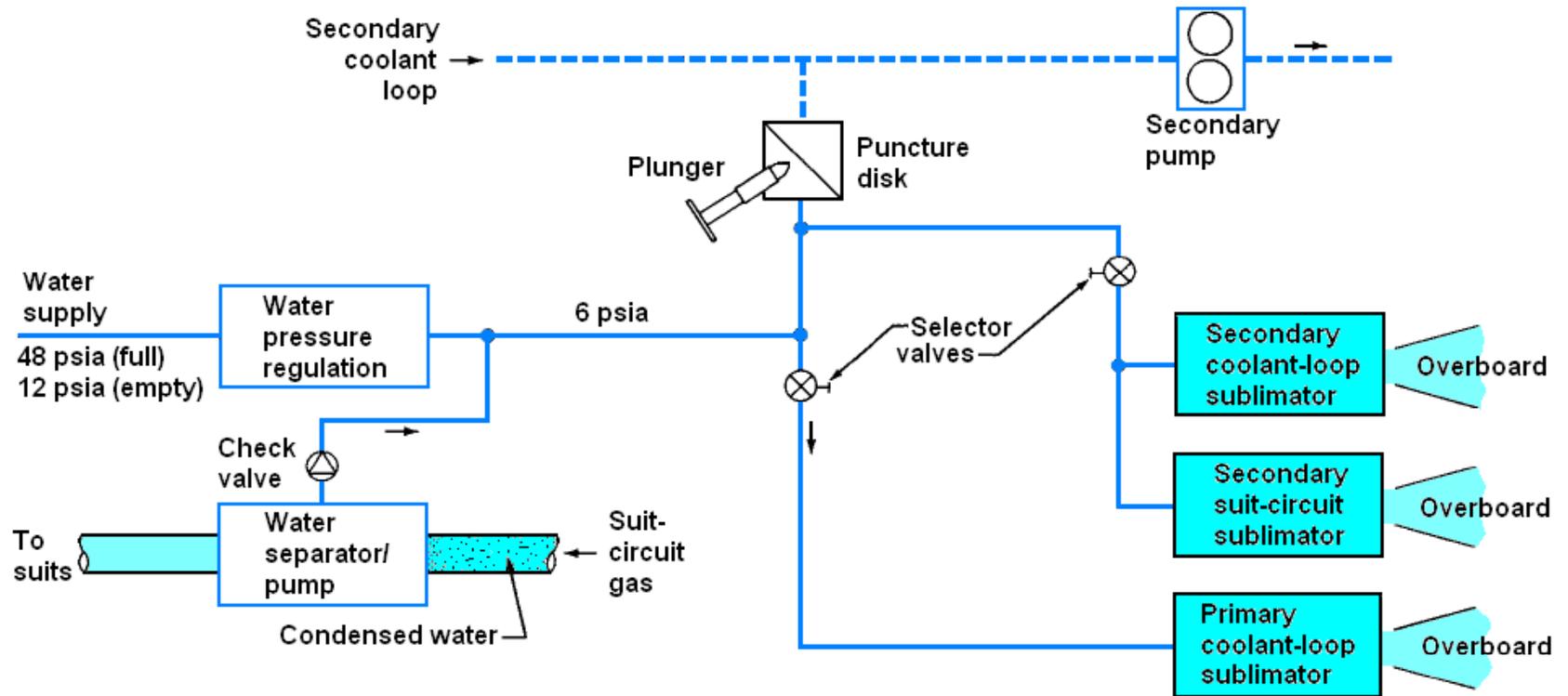
# Subsystem Redesign Considerations -- HTS

- The alcohol flushes of the system also caused a plasticizer in the polymers in the QDs to shrink.
  - ♦ alcohol flush times were controlled to be less than the minimum time seen to affect the plasticizer



# Subsystem Redesign Considerations -- HTS

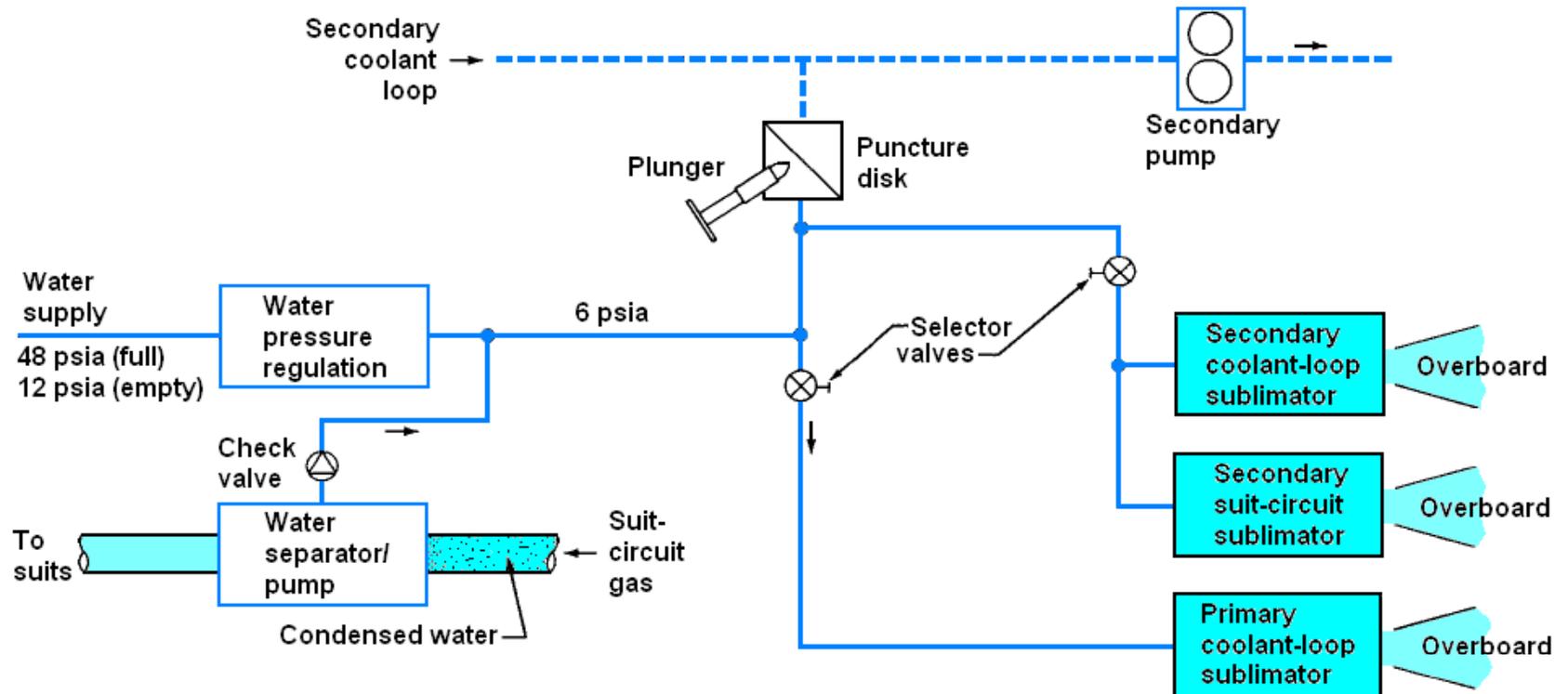
- ❑ The original design of the cooling loop did not include an accumulator.



Original Design of Cooling Loop System

# Subsystem Redesign Considerations -- HTS

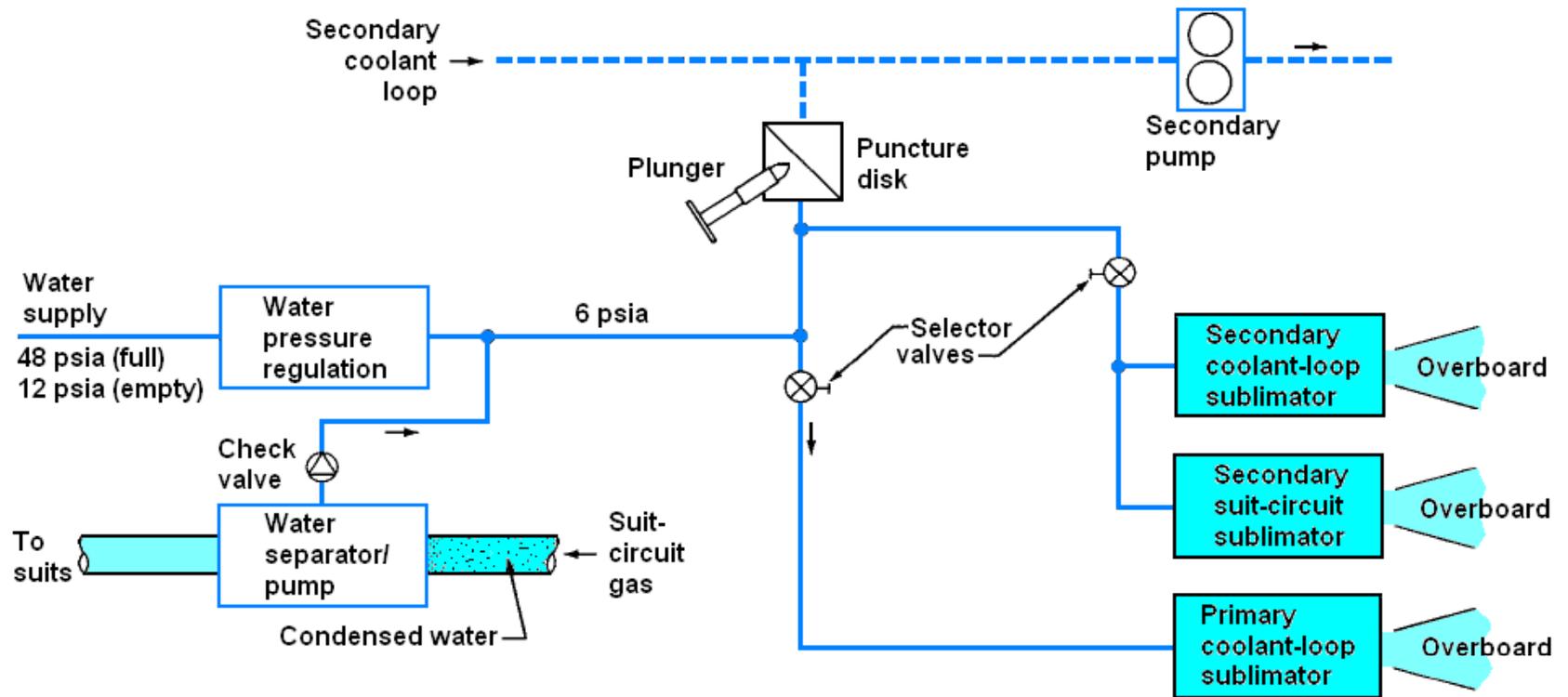
- The original design of the cooling loop did not include an accumulator.
  - ♦ had the potential to interconnect the water system with the glycol system (via a puncture disk) so that the water system could act as an accumulator, if needed



Original Design of Cooling Loop System

# Subsystem Redesign Considerations -- HTS

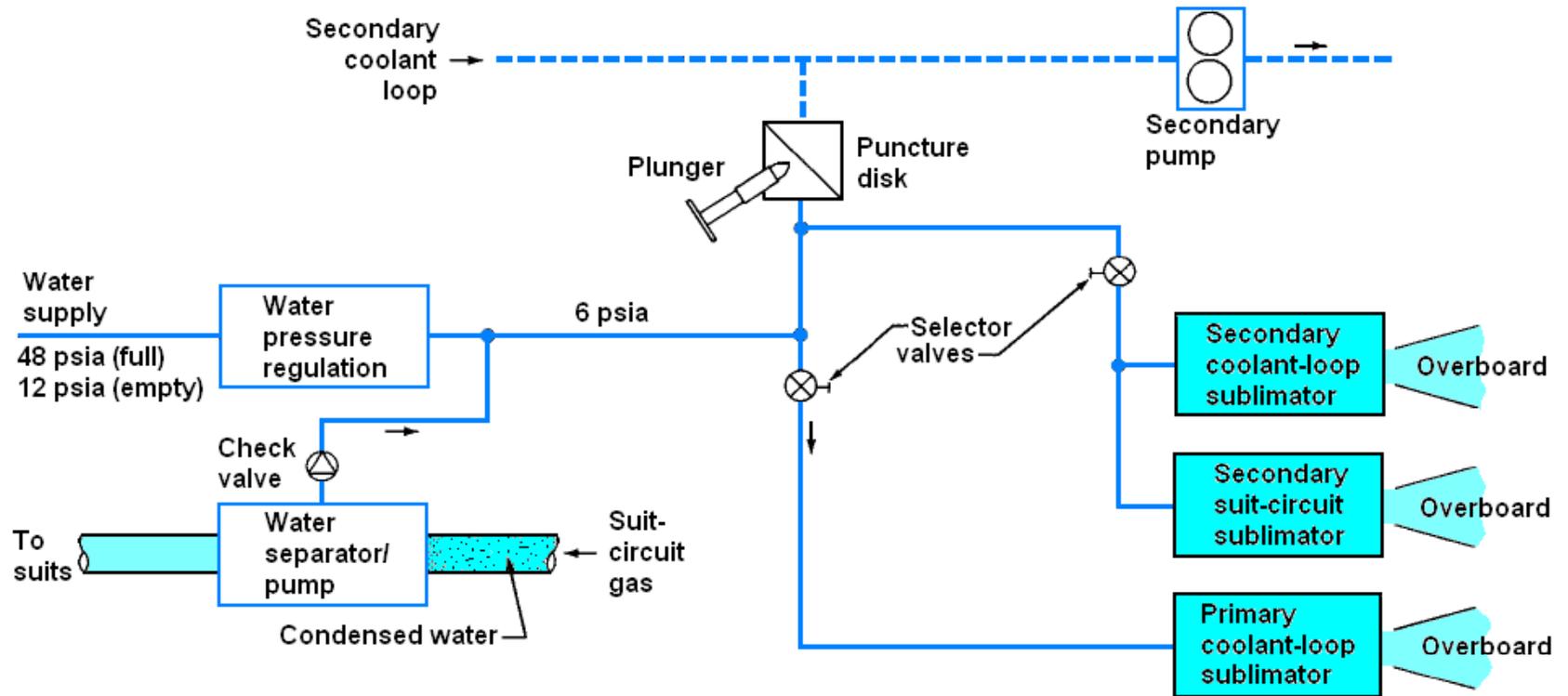
- The original design of the cooling loop did not include an accumulator.
  - ◆ not only was this irreversible, happened inadvertently several times during ground operations



Original Design of Cooling Loop System

# Subsystem Redesign Considerations -- HTS

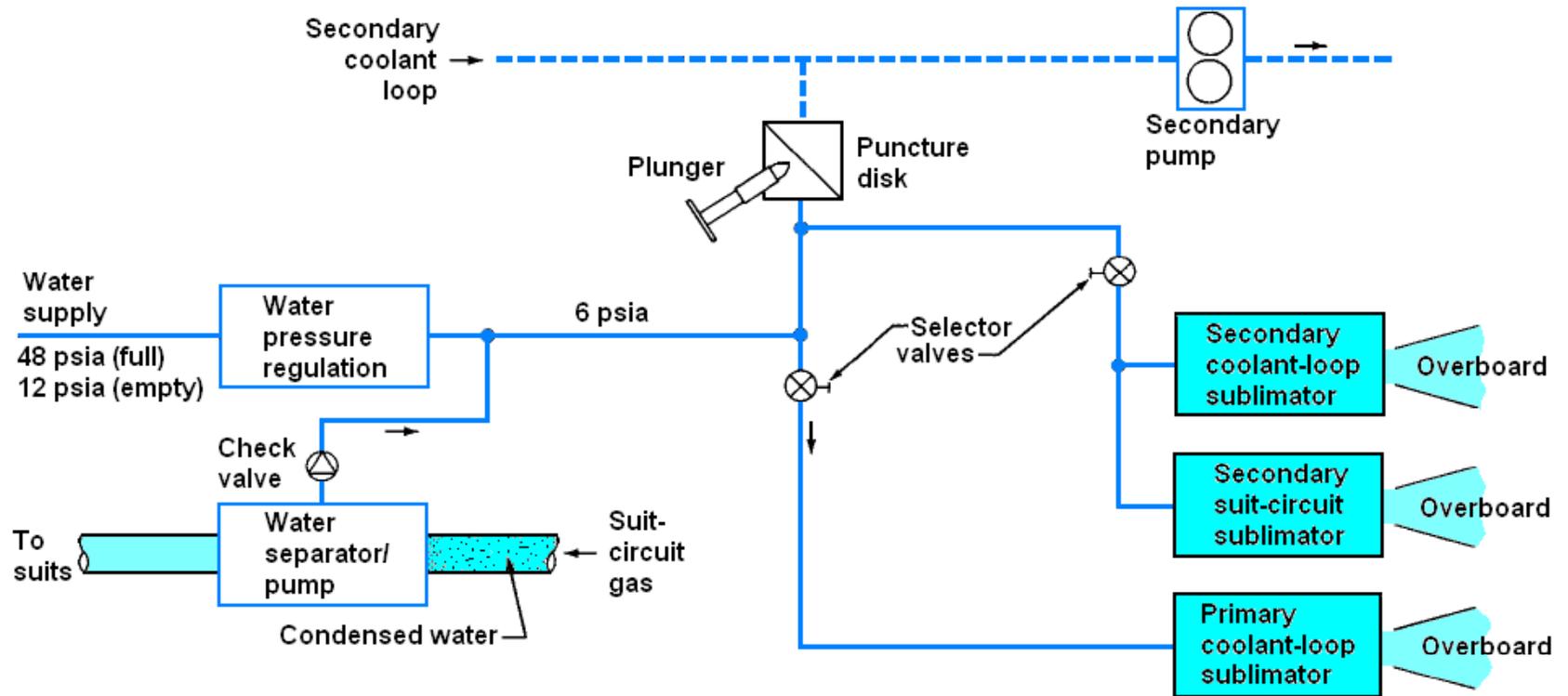
- The configuration after puncture allowed glycol to enter the water line feeding the **sublimators** (depending on relative pressures).



Original Design of Cooling Loop System

# Subsystem Redesign Considerations -- HTS

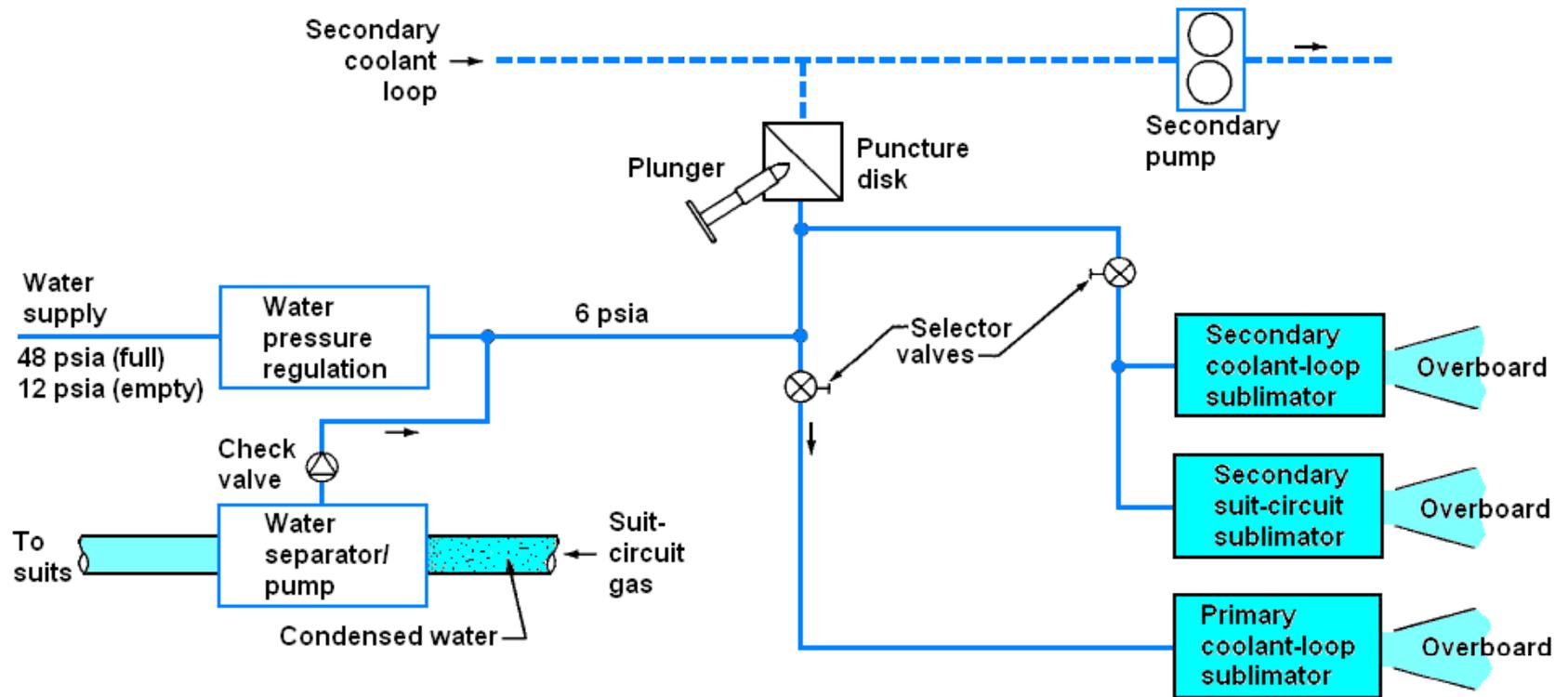
- The configuration after puncture allowed glycol to enter the water line feeding the sublimators (depending on relative pressures).
  - ♦ caused a problem in the LTA-8 Hot Case test by lowering the freezing point of the sublimator water to the point that ice would not form (sublimator breakthrough)



Original Design of Cooling Loop System

# Subsystem Redesign Considerations -- HTS

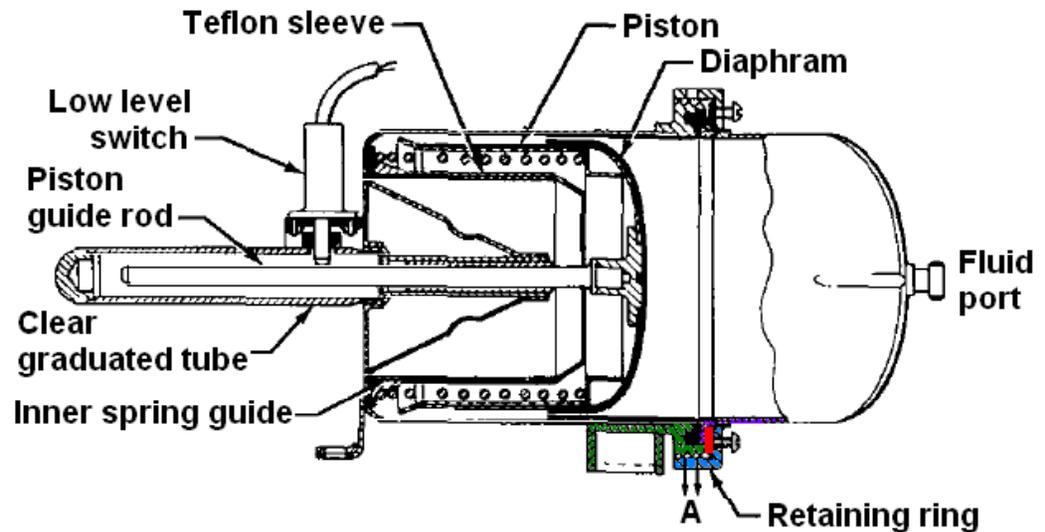
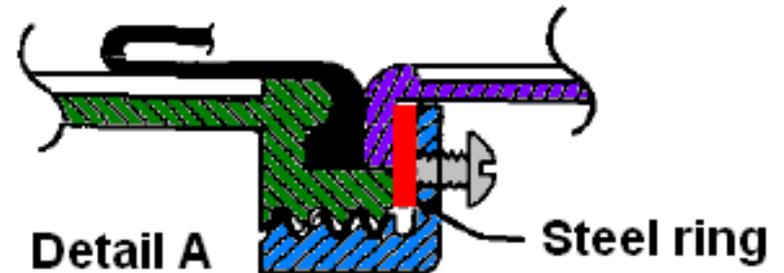
- The configuration after puncture allowed glycol to enter the water line feeding the sublimators (depending on relative pressures).
  - ◆ accumulator was added to the glycol system



Original Design of Cooling Loop System

# Subsystem Redesign Considerations -- HTS

- ❑ The **Coolant Accumulators** proved difficult to build.
  - ♦ diaphragm was the sealing gasket, and irregularities caused inadequate sealing forces
  - ♦ size of the flange groove was reduced to achieve proper bead squeeze
  - ♦ flange had to be redesigned to control the amount of squeeze
  - ♦ torquing the retaining ring to high values caused the diaphragm to wrinkle
  - ♦ had to add screws
  - ♦ finally stopped the leakage



Note: Accumulator shown full.

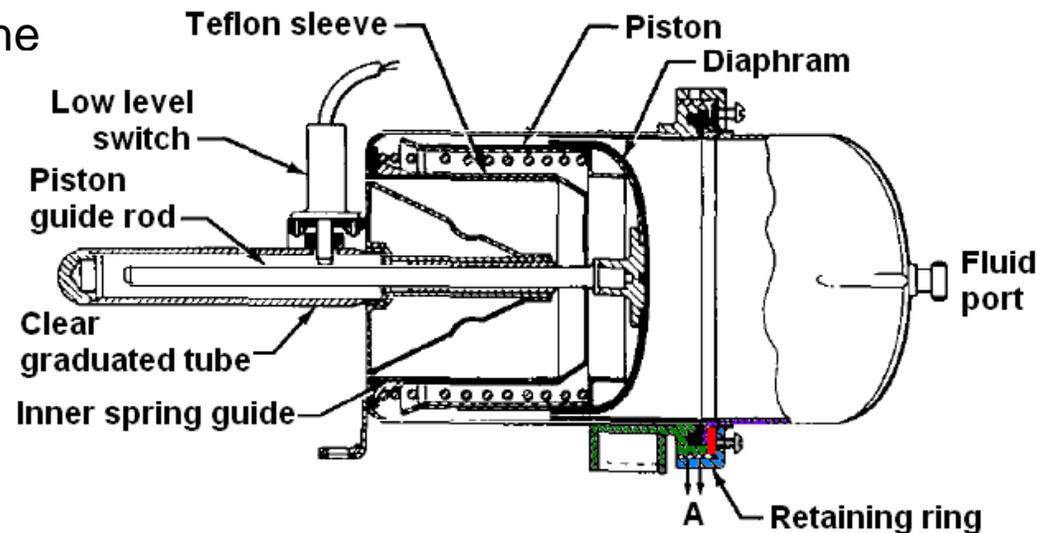
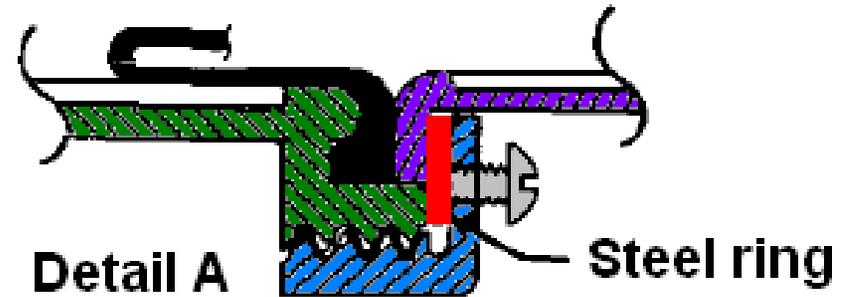
**Coolant Accumulator**

# Subsystem Redesign Considerations -- HTS

❑ After the leakage problems with the **Coolant Accumulators** was fixed, a large crack was found at the angle section of a retaining ring (blue in the diagram).

- ♦ the material (aluminum 2024T4) was being subjected to stresses greater than allowed for stress corrosion control
- ♦ alloy had to be changed and the cross-section increased.

This is an example where the solution when one problem caused another.

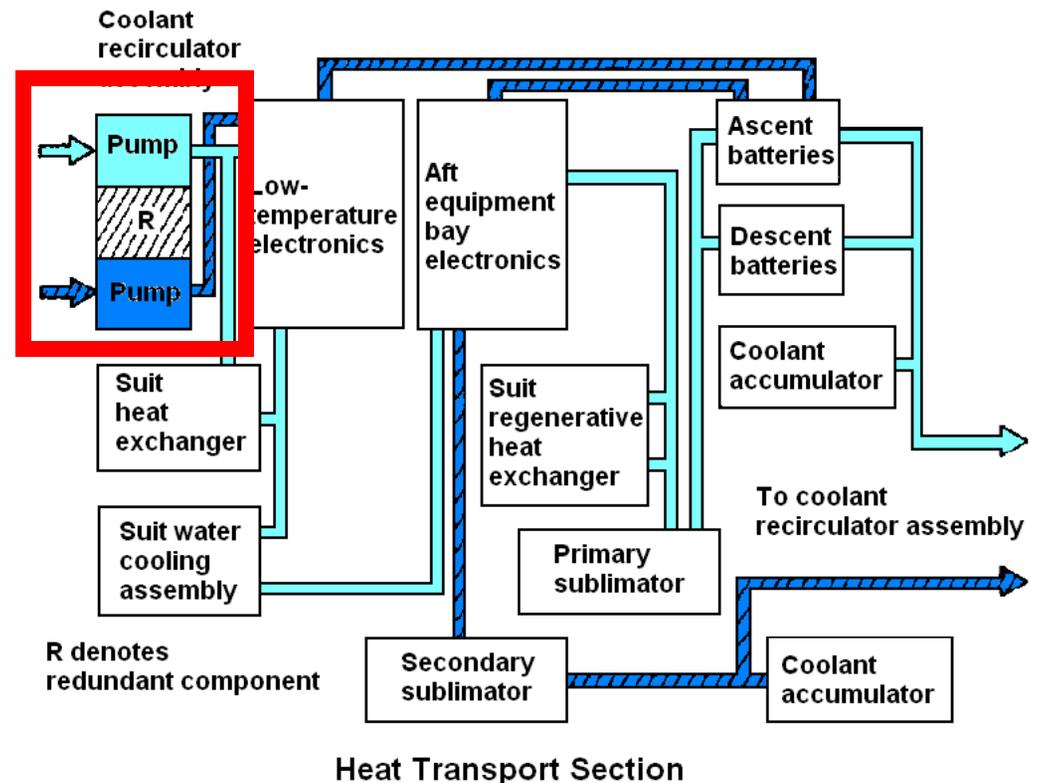


Note: Accumulator shown full.

Coolant Accumulator

# Subsystem Redesign Considerations -- HTS

- ❑ The coolant pumps were located in the cabin and produced high noise levels.
  - noise was not from the pumps themselves resonances within the lines and structures
  - expansion device (muffler) that first flew on LM-8 (Apollo 14) downstream of the pumps



# Objectives

- ❑ Describe the Lunar Module (LM) Environmental Control System (ECS) subsystem testing and redesign.
- ❑ Summarize the Lunar Module (LM) Environmental Control System (ECS) in-flight failures.

# In-Flight Failures – Apollo 5

## Apollo 05 (LM-1 Flight Verification)

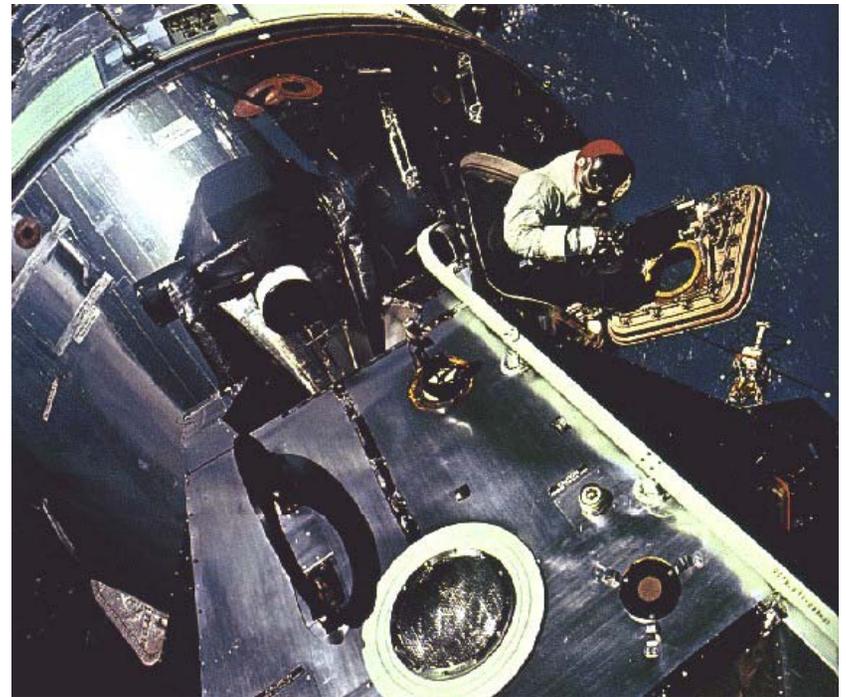
- ◆ Ascent water tank 2 leak indication, even before launch
- ◆ No leakage seen
- ◆ Tank pressurant suspected
- ◆ Quantity great enough for mission, even at leak rate; so, no action taken



# In-Flight Failures – Apollo 9

## Apollo 09 (LM-3 Earth Orbit Manned Flight Test)

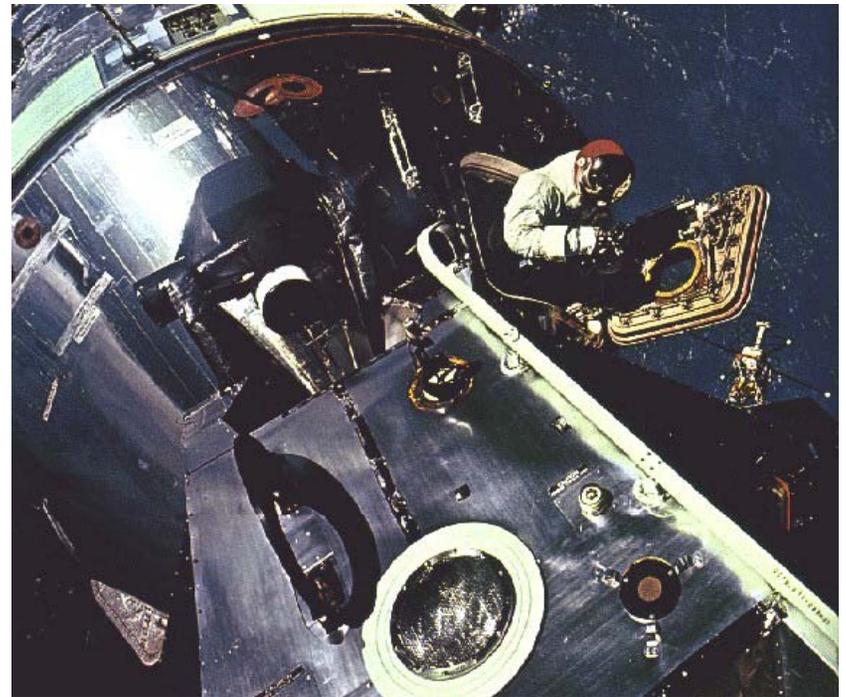
- ◆ High cabin noise level
- ◆ One crewman improvised earplugs
- ◆ Testing in another LM ID'd the glycol loop pumps
- ◆ Acoustic coupling into the lines and the pressure vessel



# In-Flight Failures – Apollo 9

## Apollo 09 (LM-3 Earth Orbit Manned Flight Test)

- ◆ Cabin fans were also contributors
- ◆ Subsequent missions used only one fan at a time
- ◆ Crew were fitted with earplugs with 10 dB noise suppression



# In-Flight Failures – Apollo 10

## Apollo 10 (LM-4 Lunar Descent Flight Test)

- ◆ High cabin noise
- ◆ Resulted in cabin fan being powered off after 30 minutes
- ◆ Post-flight tests performed on LM-8 to test use of flexible hoses to acoustically decouple the glycol pumps, but resulted in only a slight reduction



# In-Flight Failures – Apollo 10

## Apollo 10 (LM-4 Lunar Descent Flight Test)

- ◆ Oxygen purge system heater light never illuminated
- ◆ Ground tests could not repeat the signature
- ◆ Even without the heater, the minimum temperature of gas entering the helmet would be OK
- ◆ No modifications made for subsequent missions



# In-Flight Failures – Apollo 10

## Apollo 10 (LM-4 Lunar Descent Flight Test)

A drop in cabin pressure at jettison, along with 1.5 m/sec (5 fps) separation velocity (measured from video)

(5 fps) separation velocity (measured from video)

- ♦ A drop in cabin pressure at jettison,
- ♦ Indicated upper hatch opened (confirmed by flapping material in the same video)
- ♦ Docking tunnel was pressurized at the time the separation pyrotechnics were fired
- ♦ Added pressure from the pyros failed the hatch latch, allowing cabin venting
- ♦ Air outflow slammed the hatch mostly closed, except for a small area that continued to vent the cabin slowly



# In-Flight Failures – Apollo 10

## Apollo 10 (LM-4 Lunar Descent Flight Test)

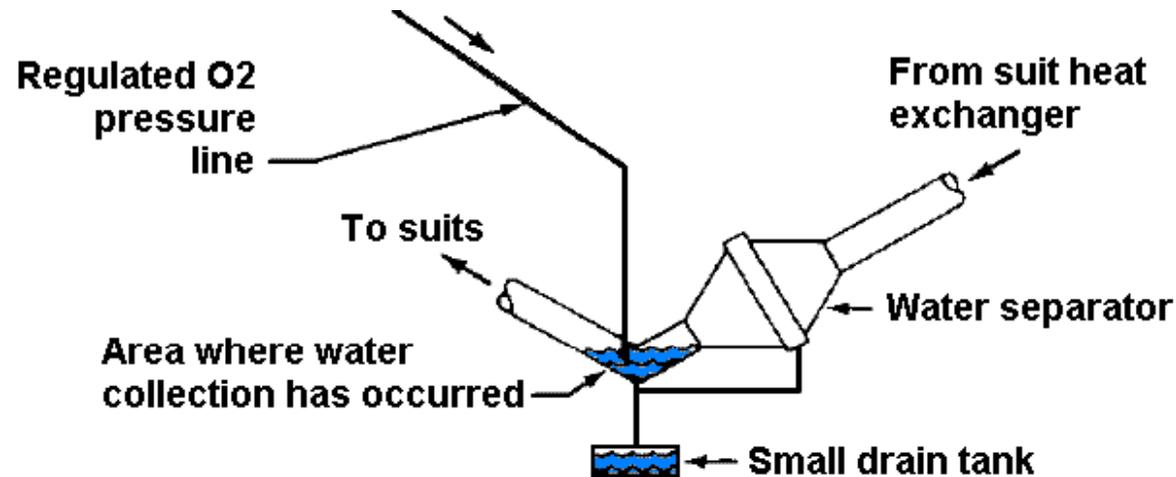
- ♦ Lithium hydroxide cartridge performance (CO<sub>2</sub> level) was anomalous
- ♦ Cartridge was returned for analysis
- ♦ Cartridge may have had variances in moisture content (the manufacturing cause for this was not fully understood)
- ♦ CO<sub>2</sub> transducer tolerance was 10% of full-scale
- ♦ In combination with the variance in the cartridge, explained the flight data



# In-Flight Failures – Apollo 11

## Apollo 11 (LM-5 Lunar Landing Flight)

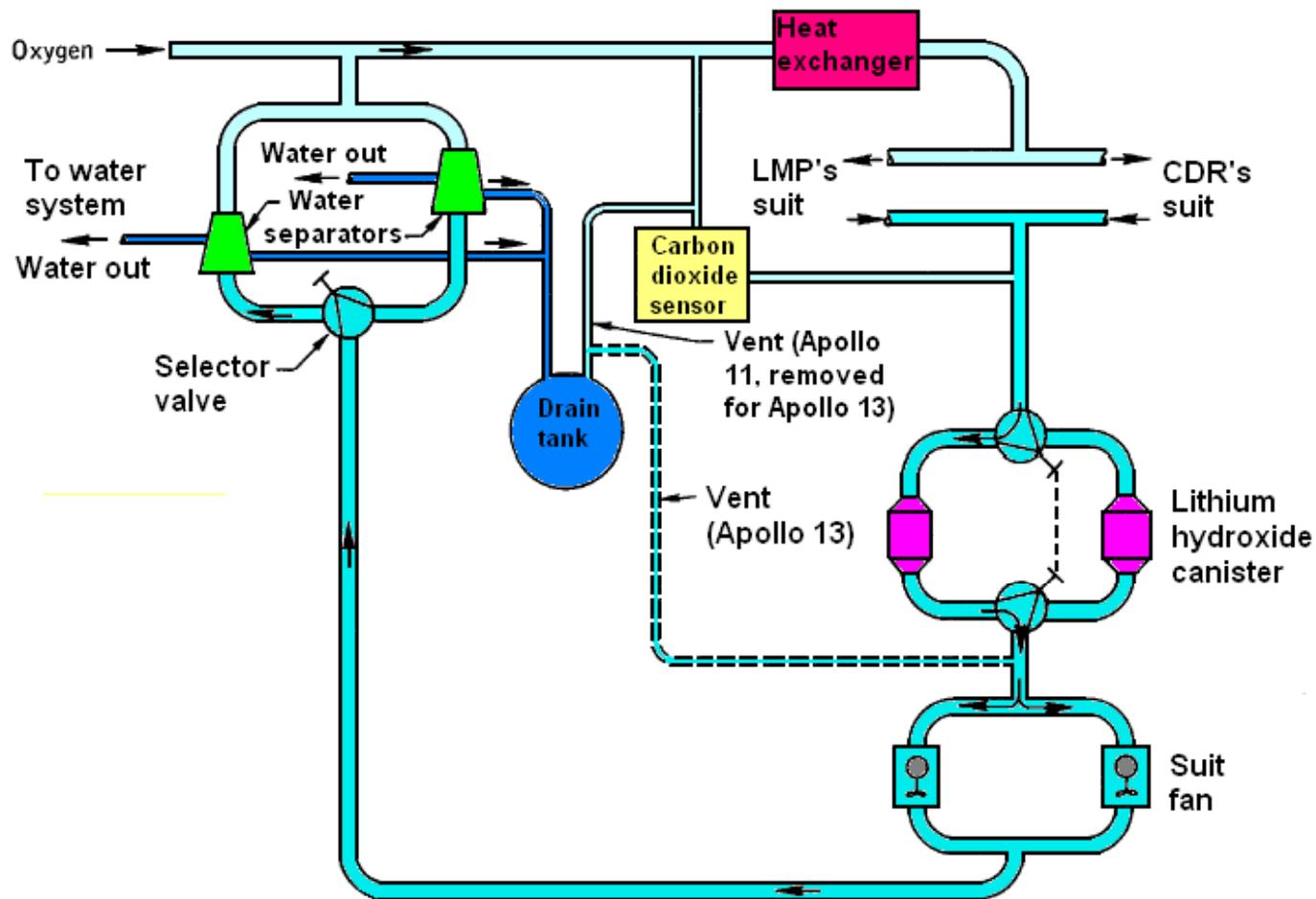
- ♦ **High CO<sub>2</sub> indicated** shortly after lunar module ascent
- ♦ Selection of secondary LiOH canister did not help
- ♦ C&W indication when primary LiOH was reselected
- ♦ Prior to lunar EVA, the ECS had been stopped
- ♦ Allowed condensate in the separator to drain into a tank
- ♦ If the tank was not quite big enough, water could enter the suit loop (CDR noted water in his suit)
- ♦ Any liquid in the line would adversely affect CO<sub>2</sub> measurements



# In-Flight Failures – Apollo 11

## Apollo 11 (LM-5 Lunar Landing Flight)

High CO<sub>2</sub> indications – continued. To preclude this, the vent line was relocated upstream of the fans, effective for Apollo 13.



# In-Flight Failures – Apollo 11

## Apollo 11 (LM-5 Lunar Landing Flight)

- ◆ **Slow cabin decompression** observed prior to EVA
- ◆ For subsequent flights, the bacteriological filter omitted
- ◆ Decompression time reduced from about 5 minutes to 2 minutes

