

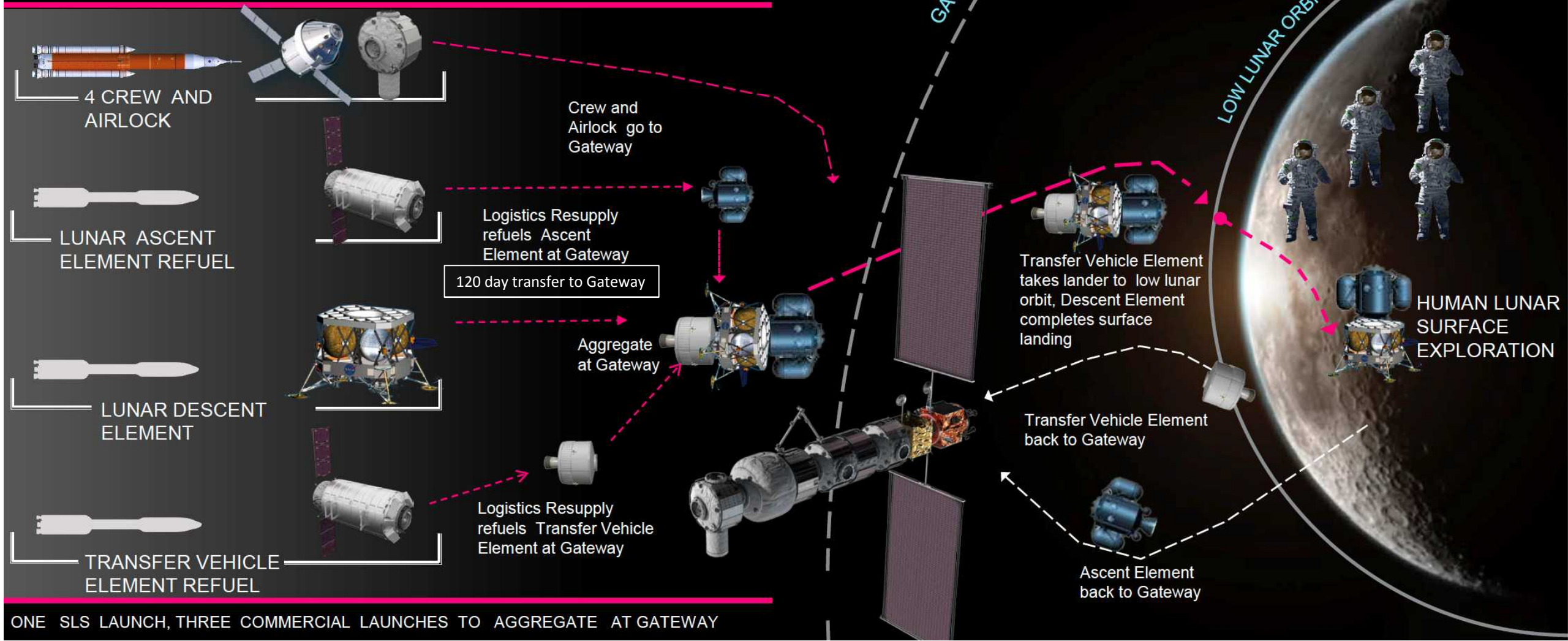
In-Space Cryogenic Propellant Storage and Transfer Systems for Crewed Exploration: *A Boiling (Prevention) Challenge*

NASA SLPSRA Fluid Physics Workshop
October 16-17, 2019

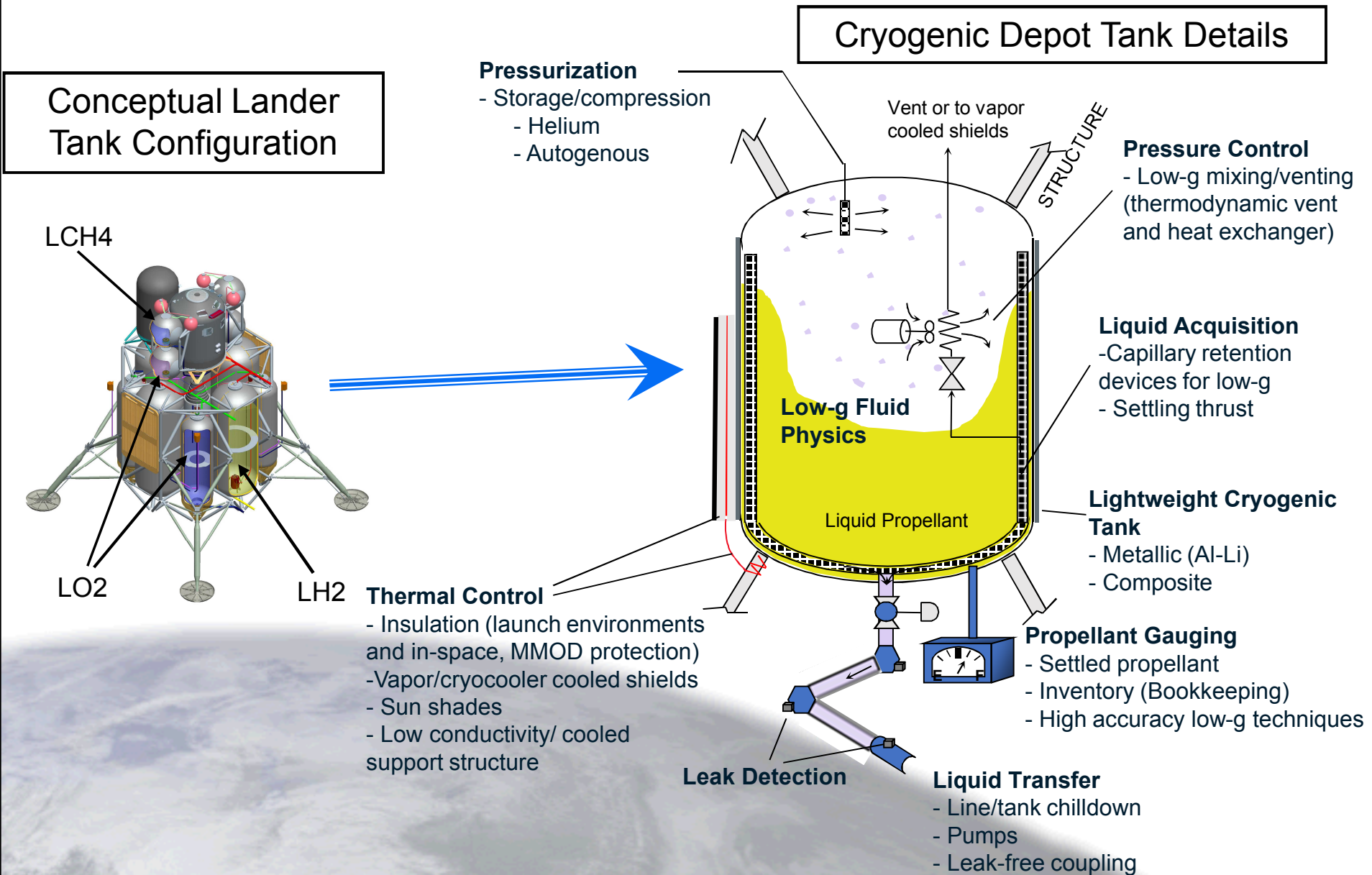
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Buildup of Notional Human Landing System Reference Architecture

2028



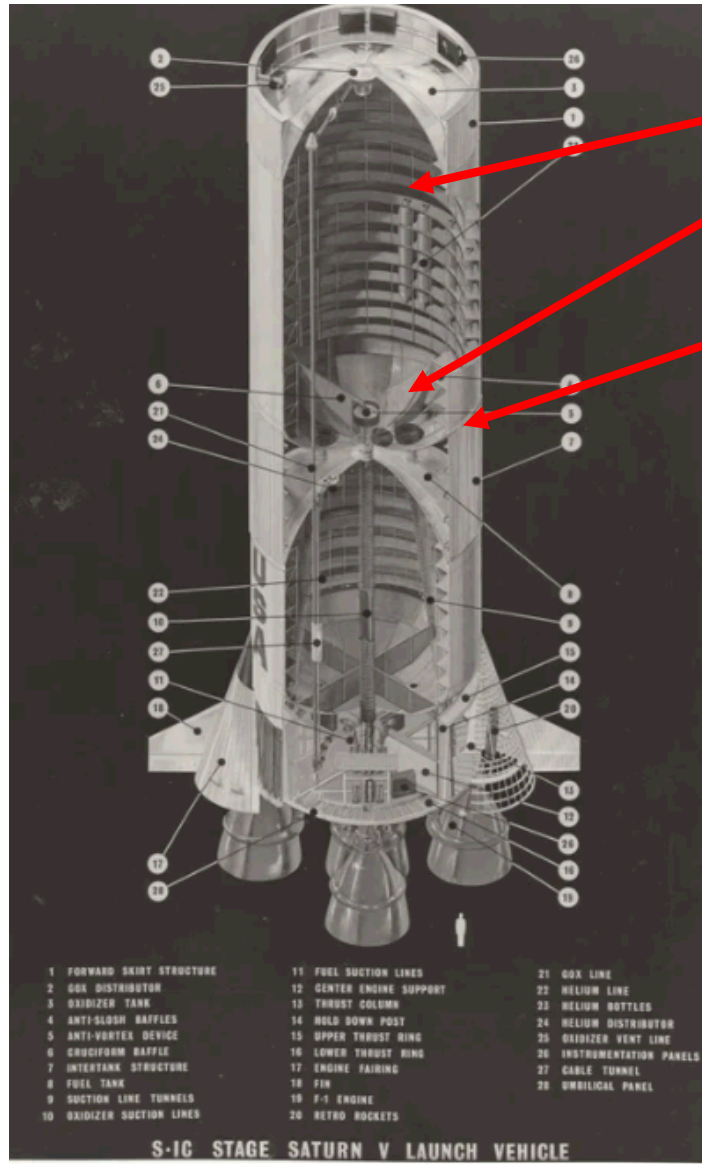
Vehicle Cryogenic Propellant Storage and Distribution



Critical Functions Affected by Phase Change

- Propellant tank pressure control
- Bubble free liquid (below saturation temp) to the engines
 - Avoid two-phase flow/cavitation
- Propellant transfer
 - Line and tank chill-down via various flow methods
 - Flow rate measurement
 - Receiver tank pressure control

Real Vehicle Complexities



Tank internal structures

- Ring baffles
- Anti-vortex baffles
- Common bulkhead tanks with large temperature difference
- Large structure/tank interfaces (hot spots)
- Propellant management devices
- Ortho-/iso-grid tank walls

Extreme large scale

- Scaling effects from small experiments

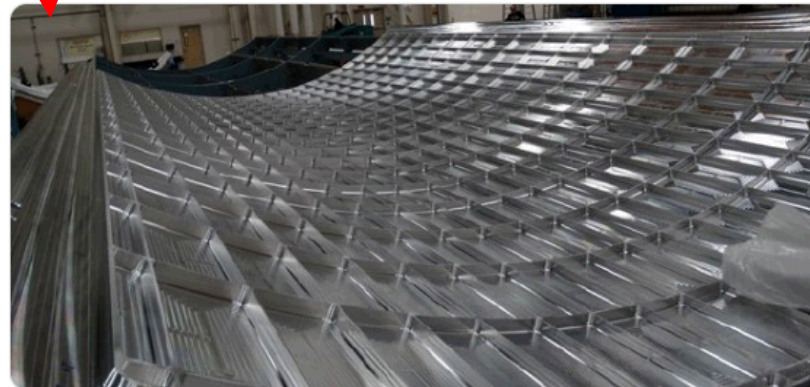
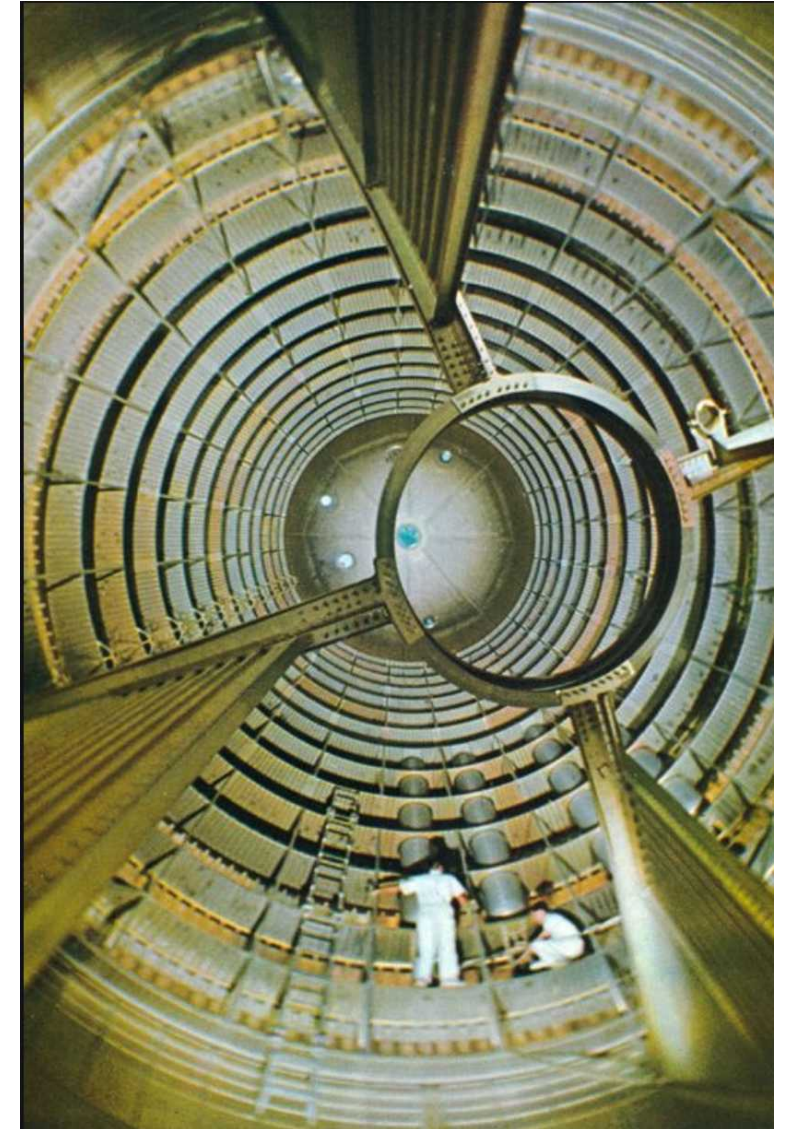


Image: Tory Bruno Twitter

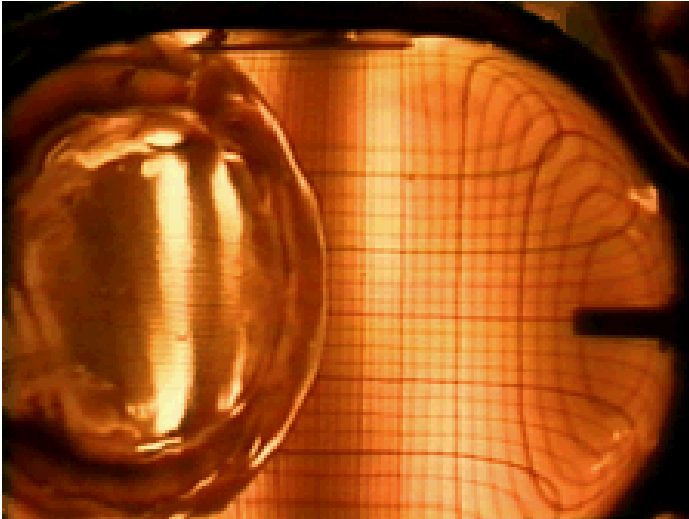


State-of-the-Art Cryogenic Propulsion Systems

- Launch Vehicle Upper Stages
 - Centaur, Delta IV Upper Stage, Ariane, H-II Upper Stage
 - Short duration missions (hours)
 - No to little super insulation – relatively high heat loads
 - High boil-off rates
 - Saturn V third stage (S-IVB)
 - Internal foam insulation: Boil-off 50-100 lbs/min, ~4 hours in orbit
 - AS-203 mission, experimental investigation of S-IVB storage of LH2
 - Imagery showed violent boiling while venting

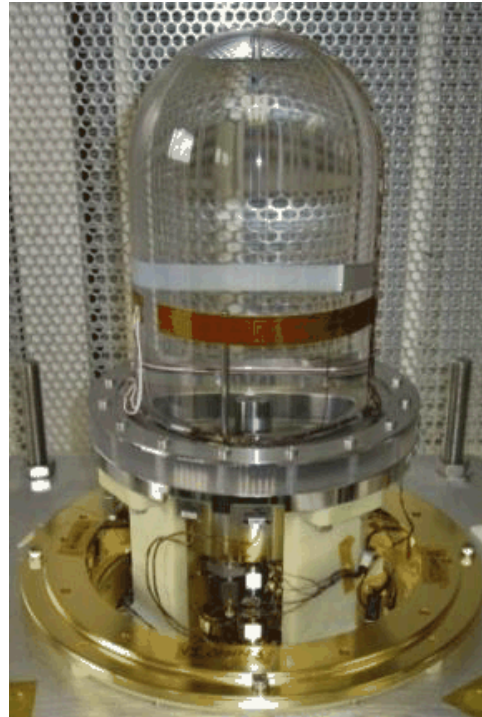
Propellant Storage Orbital Experiments: Boiling Questions

Tank Pressure Control
Experiment (TPCE)



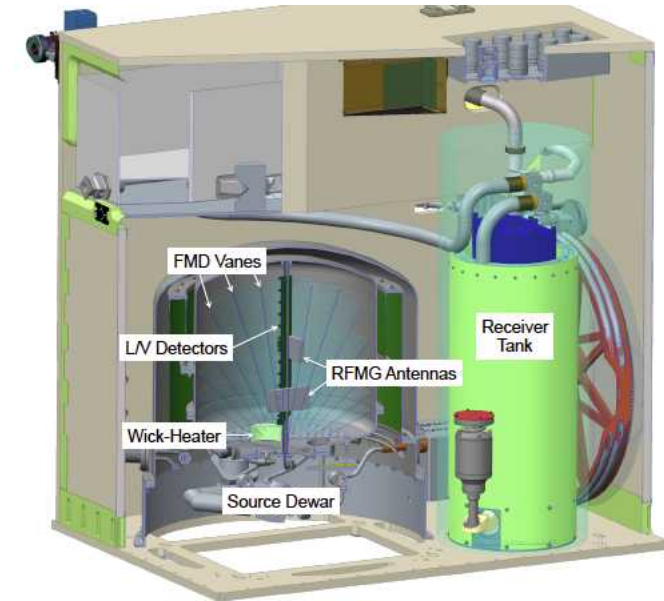
- Simulant Fluid
- Sustainability of high liquid superheats for long periods and the occurrence of explosive boiling at low heat fluxes (0.86 to 1.1 kW/m²).

Zero Boil-off Tank (ZBOT)
Experiment



- Simulant Fluid
- Potential unanticipated boiling on liquid acquisition device screen

Robotic Refueling Mission 3
(RRM3) Experiment



- Liquid Methane (50 liter tank)
- Possible undesired boiling at wick heater

Thank You!