Physical Sciences Experiment Concepts on the Moon

CBPSS – Space Science Week

March 24, 2021

BPS - Biological and Physical Sciences Division

Francis Chiaramonte

Program Scientist for Physical Sciences

Brad Carpenter

Program Scientist for Fundamental Physics

National Aeronautics and Space Administration

Contributors

- John McQuillen
- Dan Dietrich
- Mike Sansoucie
- Kevin Sato

Agenda

- CLPS Information
- Dust Remediation
- Lunar Cement
- Fire Safety in Partial Gravity
- Water-Ice for Consumables

Commercial Lander Payload Services (CLPS) Solicitation Information

- **Expect one PRISM call per year.**
- **ESSIO plans to release a solicitation in mid-year 2021.**
- **Recommended: Go into your NSPIRES account to confirm that you have an email subscription to Science Mission Directorate, Planetary Science Division. This will ensure you receive the PRISM call notifications. If you don’t have an account, please go to INSPIRES to create one.**

Dust Remediation

Lunar dust unknowns, potential remediation, and research opportunities – being assessed by a Science Definition Team

- **Christine Hartzell, University of Maryland, USA - chair**
- **Paul Bellan, California Institute of Technology, USA**
- **Dennis Bodewits, Auburn University, USA**
- **Gian Luca Delzanno, Los Alamos National Laboratory, USA**
- **Masatoshi Hirbayashi, Auburn University, USA**
- **Truell Hyde, Baylor University, USA**
- **Uwe Konopka, Auburn University, USA**
- **Edward Thomas, Auburn University, USA**
- **Hubertus Thomas, German Aerospace Center DLR**

Dust remediation technologies under evaluation by the Science Definition Team

1. Electrostatic Dust Clearing

When an alternating current is passed through wires embedded below the surface of a material, dust lofting occurs, causing particles to hop off of the treated surface.

2. Use of Attractive Surfaces

Dust lofting prompted by passing an electrically biased plate or wand above a dusty surface, thereby attracting dust to the biased plate or wand.

3. UV/Electron-beam Induced Lofting

The charge on individual dust grains is increased due to the impingement of UV or an electron beam. The natural electrostatic lofting phenomena of grain-grain repulsion is accentuated, causing dust lofting.

4. Tribocharging Induced Lofting

If dust grains are mobile on a surface, it may be possible to promote electrostatic lofting by first shaking a surface to induce tribocharging.

Key science objectives for dust remediation assessment

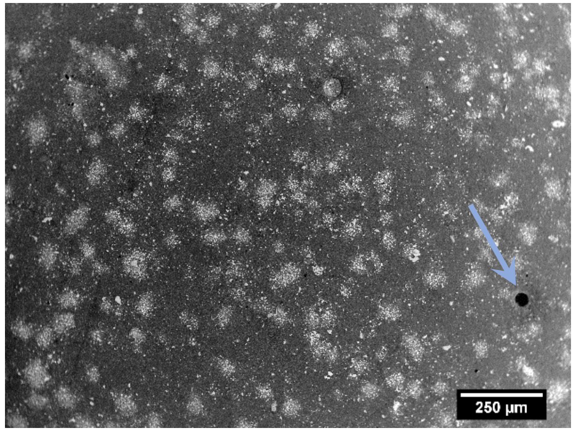
1. Measure plasma properties near the lunar surface
2. Determine if electrostatic lofting occurs naturally
3. Determine if electrostatic levitation occurs
4. Measure cohesion/adhesion of regolith
5. Evaluate the hazard posed by electrostatically lofted/levitated dust
6. Characterize the effects of plume impingement of dust properties and interactions with plasmas
7. Measure the triboelectric charging of lunar regolith
8. Characterize the size and shape of regolith particles from relevant lunar sites

Lunar Cement

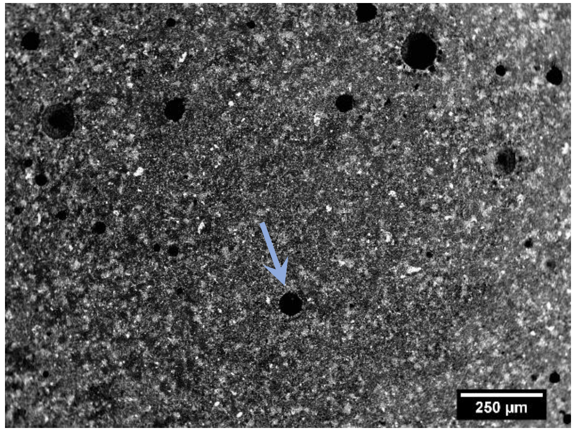
Production of a binder from lunar regolith

- Previous ISS experiments on cement solidification in reduced gravity (the Microgravity Investigation of Cement Solidification (MICS) experiment) generally showed more and larger air voids than seen on samples made on Earth.

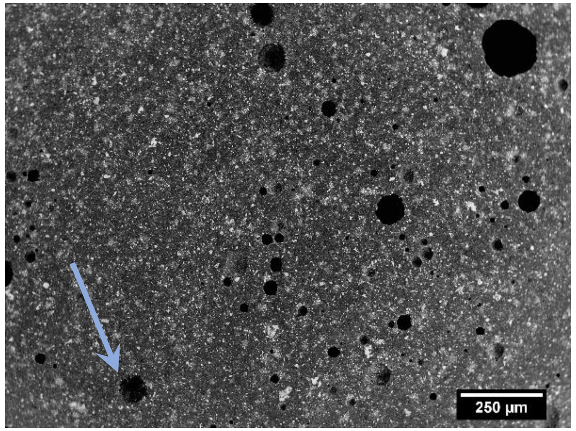
- Reduced gravity will likely influence the strength of concrete solidified in Space (most likely, the samples are weaker)
  - As the gravity level decreases the amount of trapped air and porosity in the samples increases.
  - Crystals tend to grow larger and more uniform in reduced gravity.



1g



0.17g (Lunar)



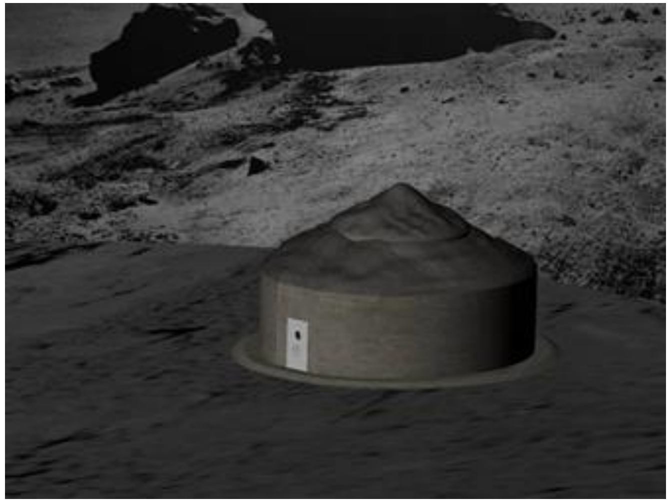
µg

Arrows indicate trapped air

Production of a cement-free binder from lunar regolith

- Lunar Simulant Experiment- Initial experiment would use lunar simulant and conducted in a **CLPS Lander**. Automated mixing on the lunar surface. Samples returned to Earth for analysis.
- Actual Lunar Regolith Experiment - There is very limited data regarding the creation of a concrete with actual lunar regolith.
  - Materials needed for creation of lunar concrete samples on the moon can be sent to the surface of the Moon during **Artemis 4**.
  - This will prove the feasibility of mixing the material in the lunar environment and with actual lunar regolith.
  - Lunar regolith will be activated by alkalis forming a geopolymer concrete
  - A small quantity of water will be required.
  - After the materials have been mixed and placed in the mold, they can be removed from the mold a few hours later. Samples can be retrieved on subsequent missions for return to Earth and analysis
- Exposure Experiments – Both the lunar simulant and actual lunar cement can remain on lunar surface for exposure studies and returned to earth for analysis.
- Future construction will be performed using robots (3D printing)
  - It is necessary to study concrete formation on the lunar surface prior to attempting to build habitats and other structures.
- The NASA-funded Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) project is also exploring cementitious materials and various sintering processes for processing lunar regolith into construction materials. Lunar technology development experiment in 2026.


Concept of additive construction on the lunar surface.

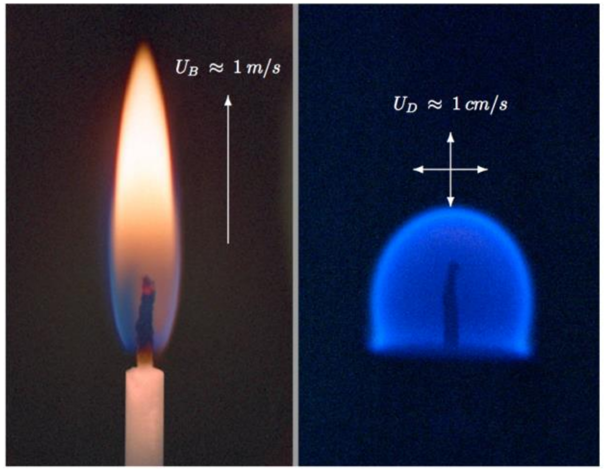

3D-printed habitat concept design

Fire Safety in Partial Gravity

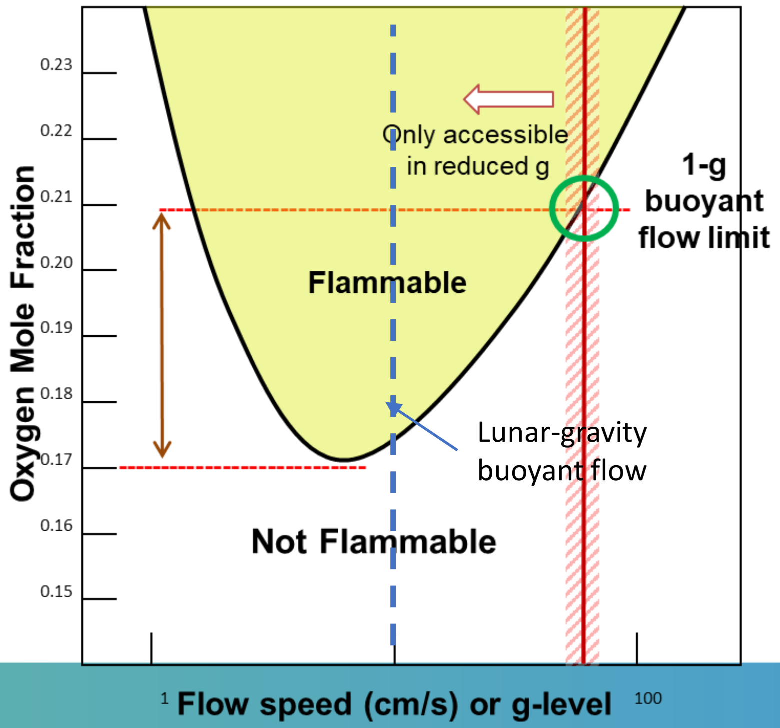
Partial Gravity Fire Safety

- Future exploration activities will occur in a 34% O_2, 8 psia, partial gravity (e.g., lunar) environment
  - **Minimize pre-breathe time for EVA on the lunar surface** while maintaining O_2 partial pressure for human health (normoxic conditions)
- Fire is VERY sensitive to oxygen percentage
  - Heat release (burning) rate is directly proportional to O_2 percentage
  - **Some materials not flammable at 21% O_2 will be flammable at 34%**
- Heat release rate (as well as fire growth) is not a monotonic function of flow so you can't 'interpolate' between normal and quiescent microgravity to get partial gravity behavior
  - Heat release rate peaks at a convective velocity in the 5 – 30 cm/s range – the range of the buoyant flow caused by Lunar gravity !!!

A spacecraft/habitat at 34% O_2, 8 psia in a lunar gravitational field has (1) increased number of flammable materials, (2) higher burning rate because of increased O_2 percentage and (3) peak burning rate caused by the buoyant flow – a triple whammy !!!



Typical Flammability Boundary for a Solid Fuel



Experiments to Evaluate Lunar Fire Safety

ISS rack type experiments

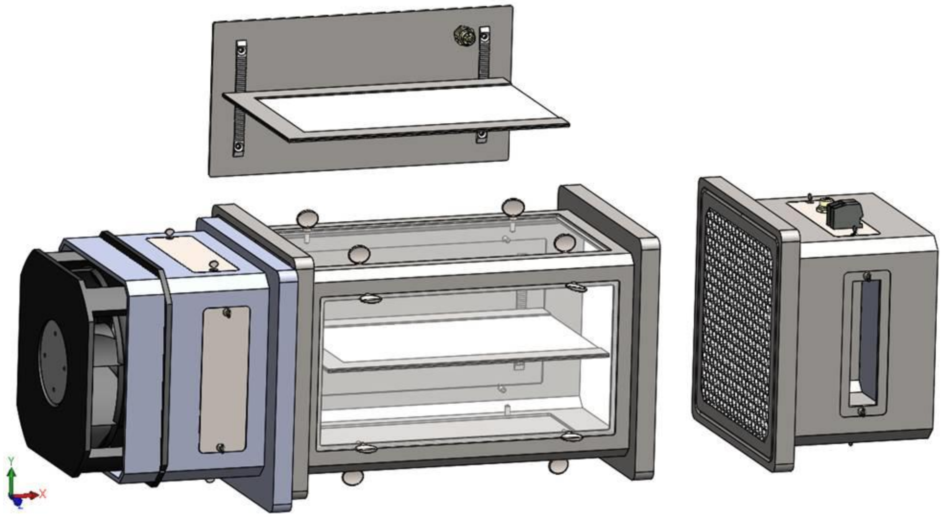
- Large samples, vary environmental conditions
- Suite of potential diagnostics
- Limited crew intervention

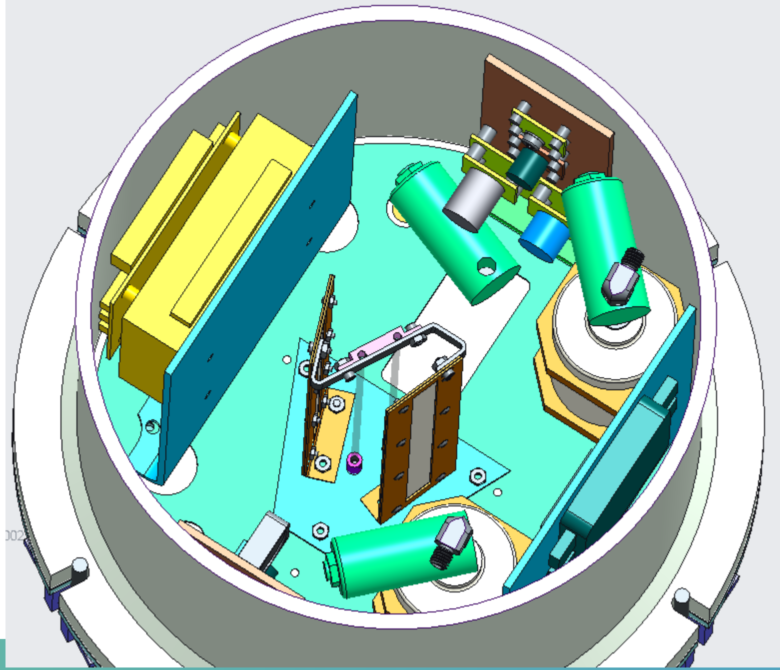
MSG type experiments

- Limited environmental conditions
- Limited diagnostics
- Significant crew intervention

CLPS payloads

- No crew intervention
- Limited number of samples and diagnostics
- Compliant with mass, power and volume

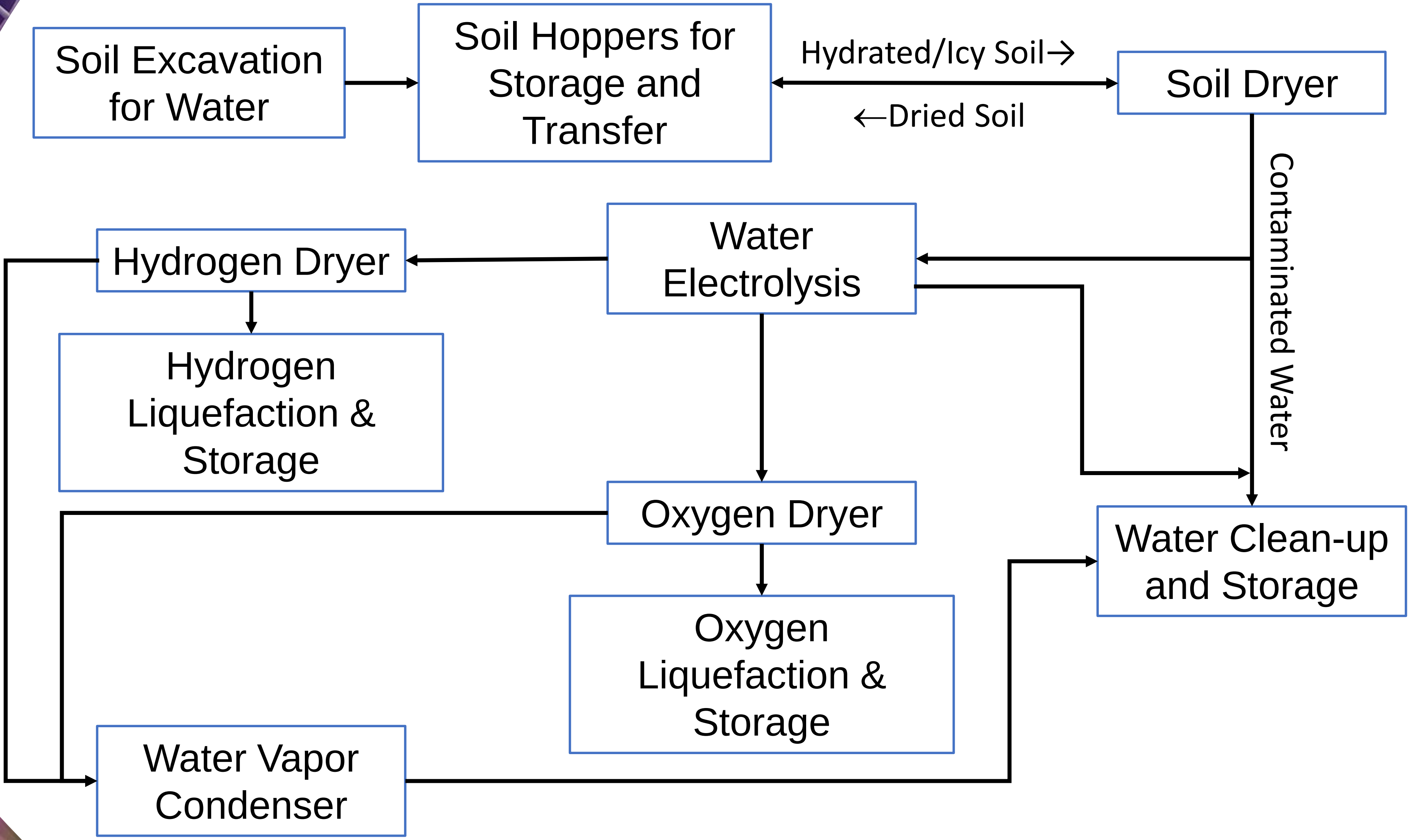




15 L
15 kg
25 W peak power

Water Ice for Consumables

Soil Processing into Water and Propellants



Water-Ice Processing & Electrolysis

Auger used to move regolith through reactor.

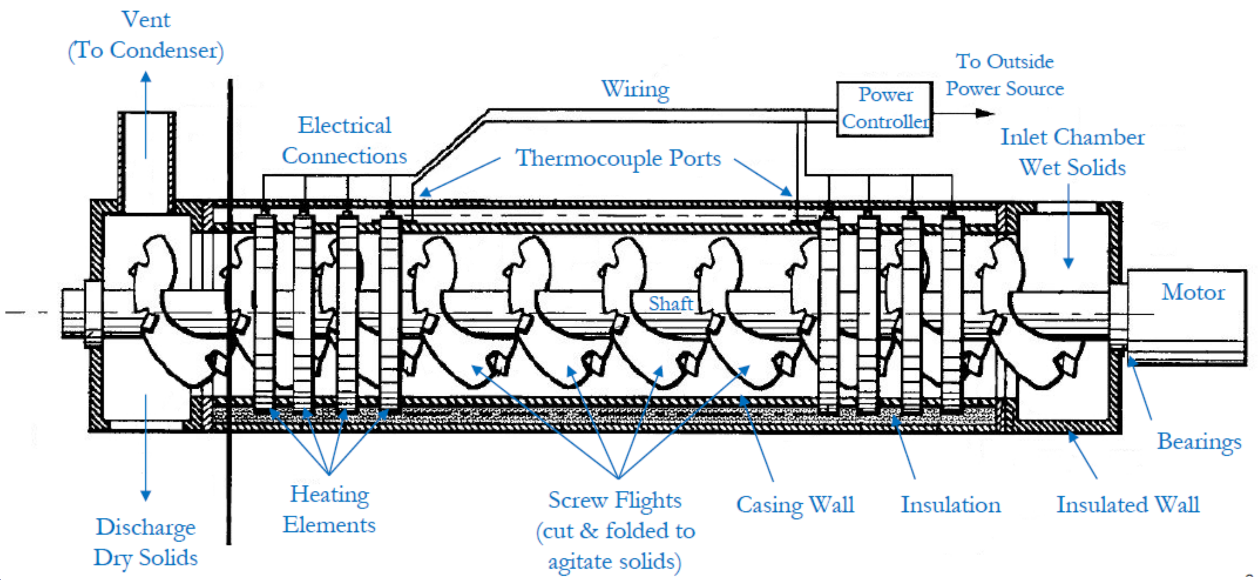
Icy Regolith heated to 100°C.

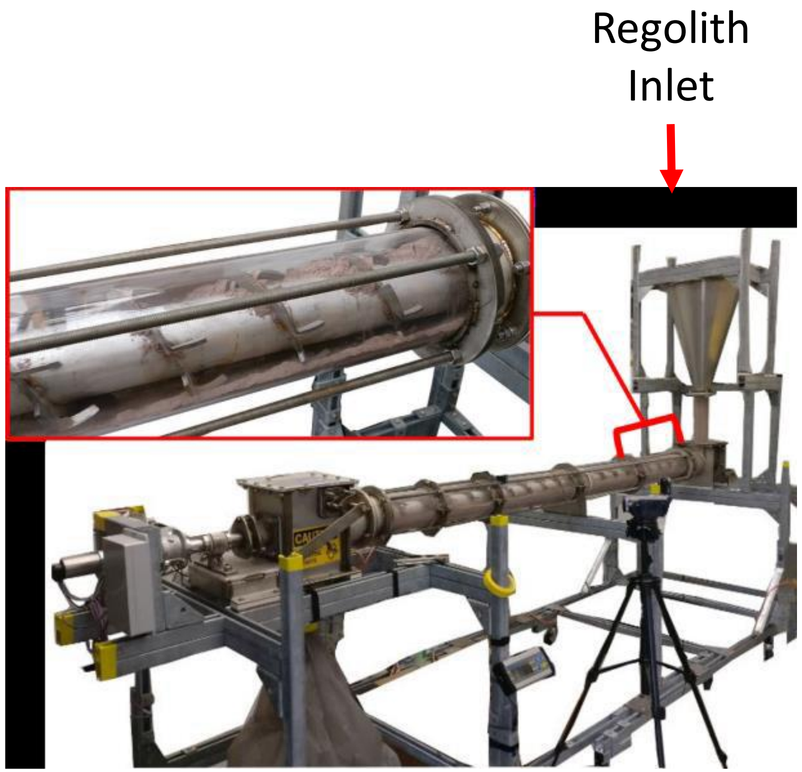
"Water vapor" sent to water collection tank.

Expect "carryover" of fine particulate matter and dissolved solids/salts.

Gravity related issues: Aerosols and droplets in Extraction Reactor.

- Formation.
- Settling and/or impaction.





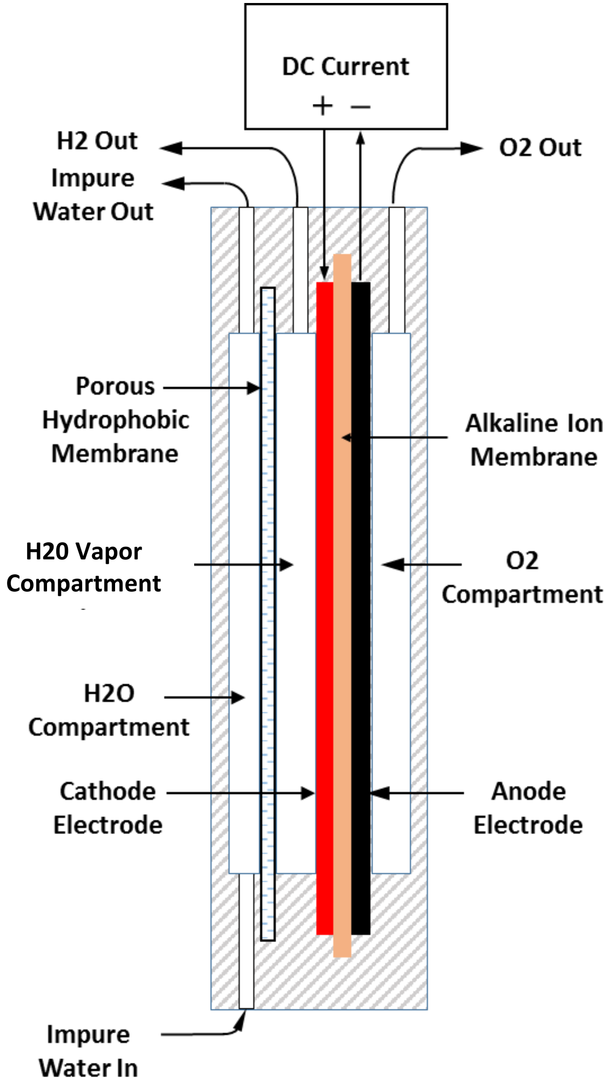
Full-scale auger-dryer test hardware at NASA JSC, shown with clear casing so regolith flow behavior can be studied.

Water Electrolysis

Expect “carryover” of fine particulate matter and dissolved solids/salts in water supply.

Electrolysis membranes and electrodes need to be tolerant of “dirty water.”

Gravity related issues: Particulate motion and salt precipitation in Electrolysis Cell.
- Settling.
- Membrane blockage.
- Electrode degradation.



Electrolysis Cell

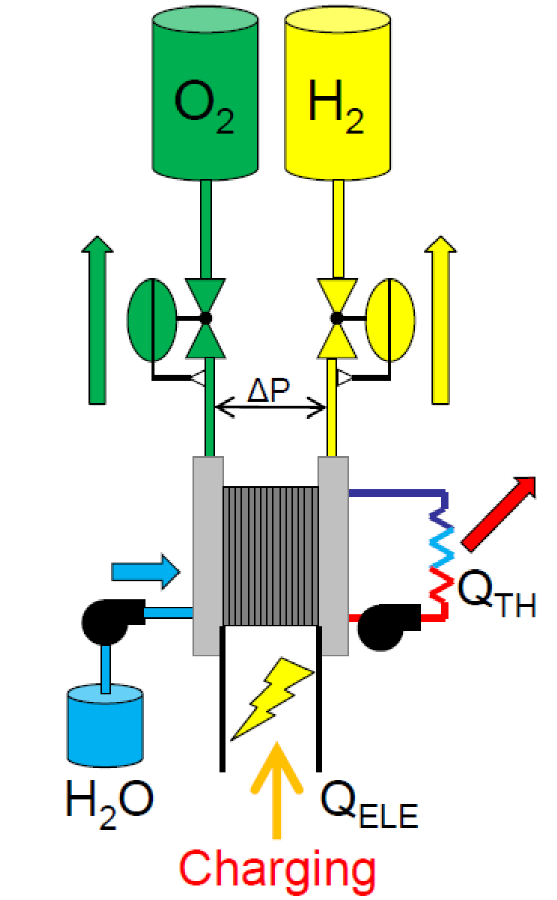
Water Electrolysis

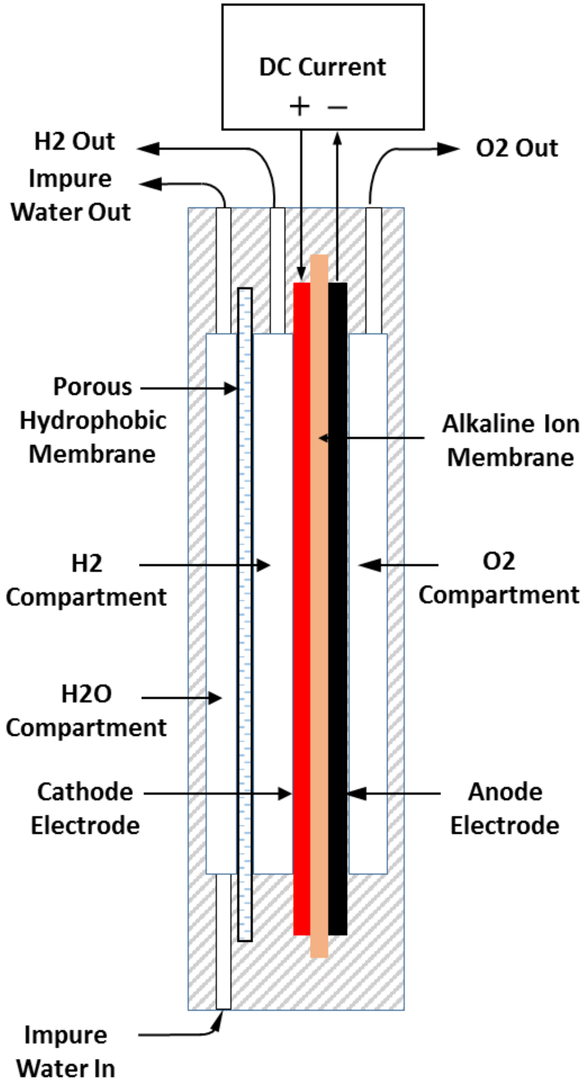
Expect “carryover” of fine particulate matter and dissolved solids/salts in water supply.

Electrolysis membranes and electrodes need to be tolerant of “dirty water.”

Gravity related issues: Particulate motion and salt precipitation in Electrolysis Cell.
- Settling.
- Membrane blockage.
- Electrode degradation.

$$2H_2O + 4e^- \rightarrow 2H_2 + O_2 + \text{Heat}$$

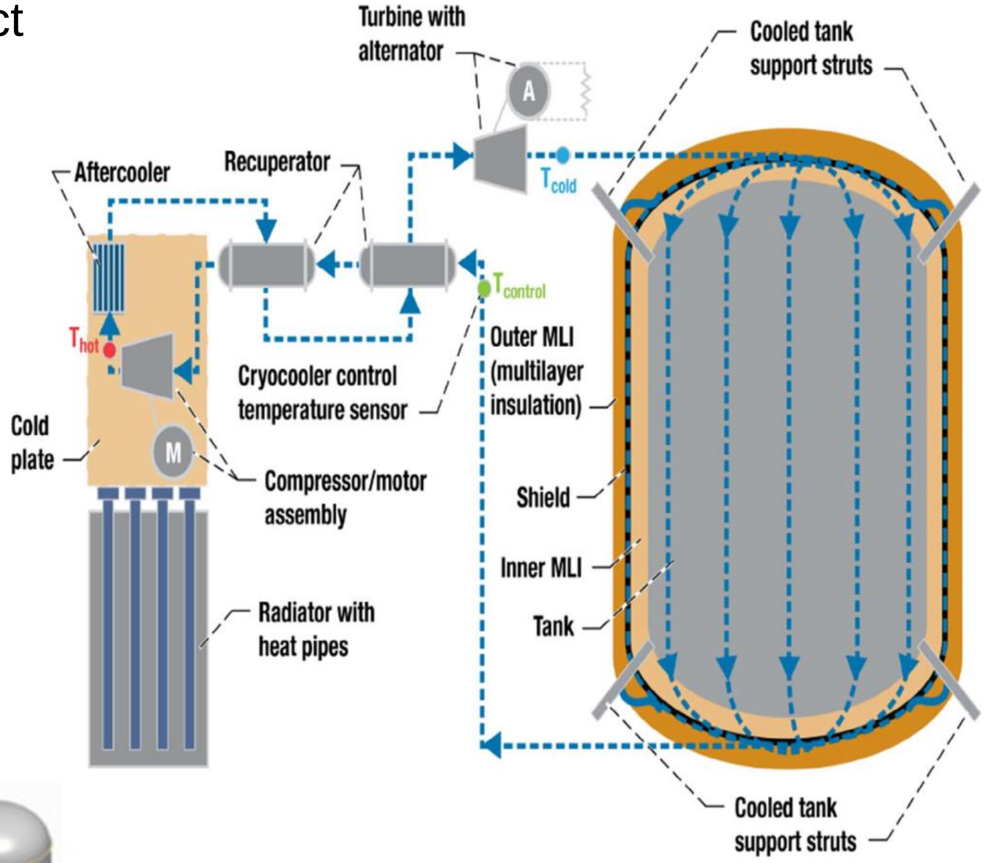




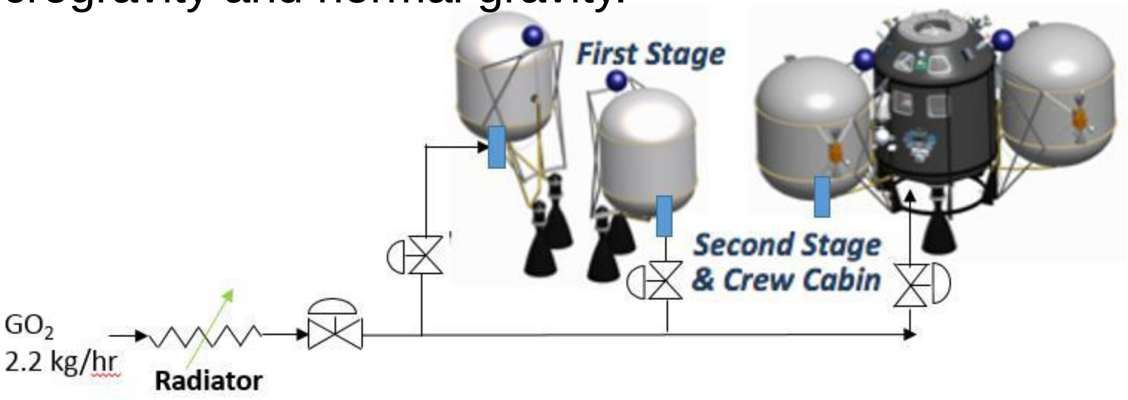
Electrolysis Cell

Liquefaction

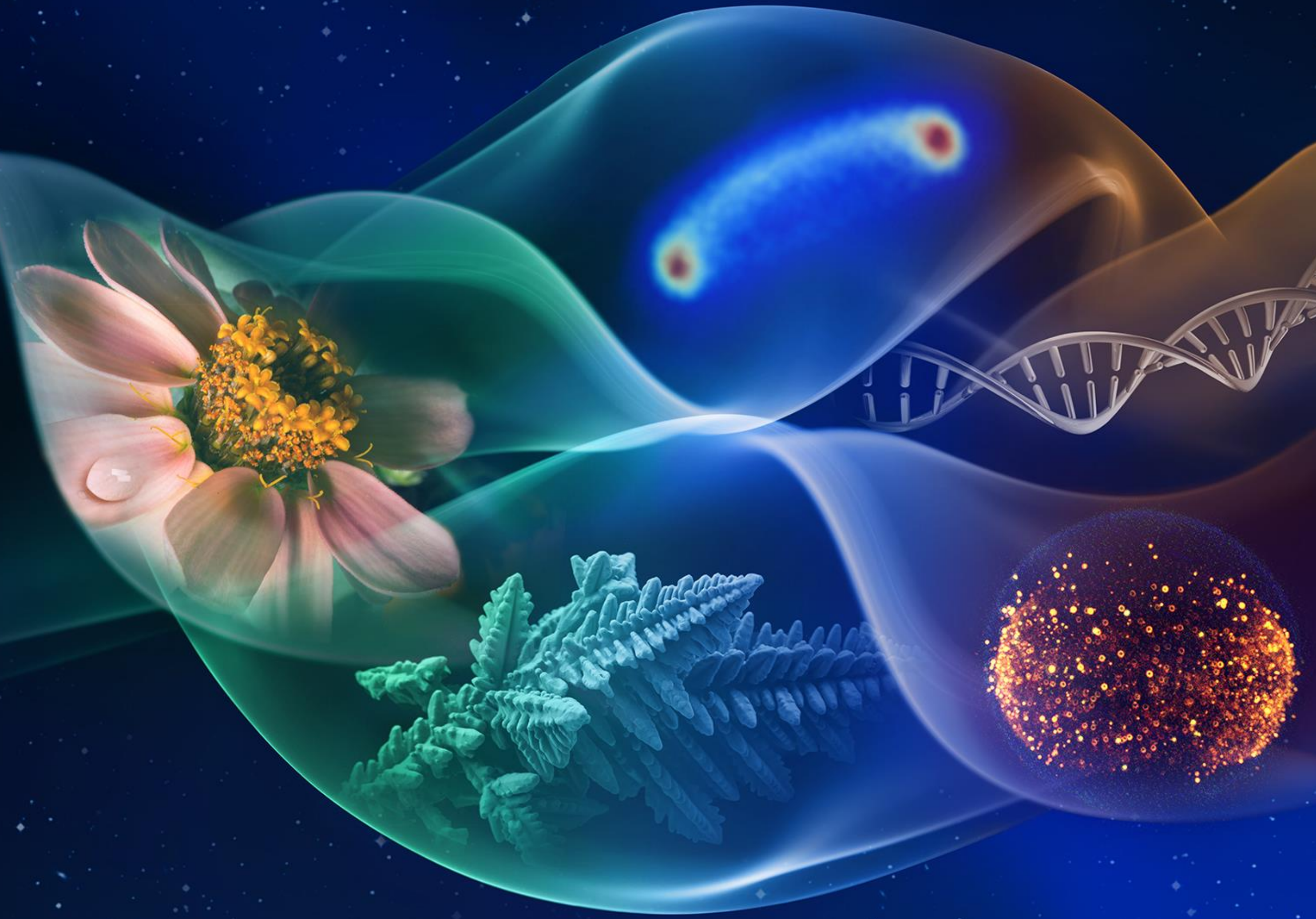
- Trade studies to minimize overall system mass indicate best option is liquefy directly into end product tank.
- Neon is the working fluid for the oxygen system cryocooler.
  - Neon Boiling Point is 24K.
  - Oxygen Boiling Point is 90K.
- Helium is the working fluid for the Hydrogen system cryocooler.
  - Helium Boiling Point is 22K.
  - Hydrogen Boiling Point is 20K.
- Heat pipes are a proven technology in both microgravity and normal gravity.



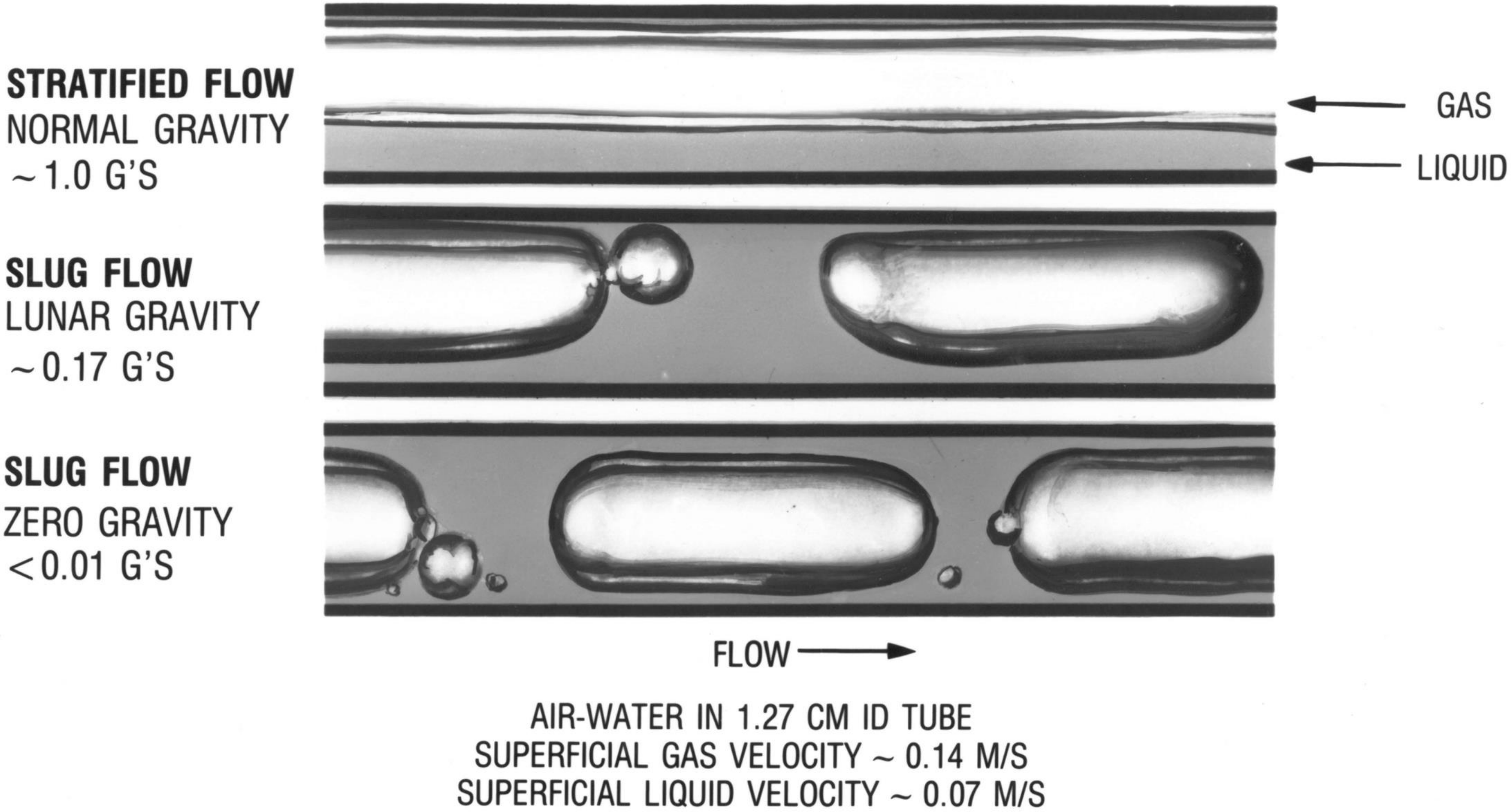
Broad Area Cooling Tube-on-Tank Schematic.



Backup



“Horizontal” Flows as a Function of Gravity

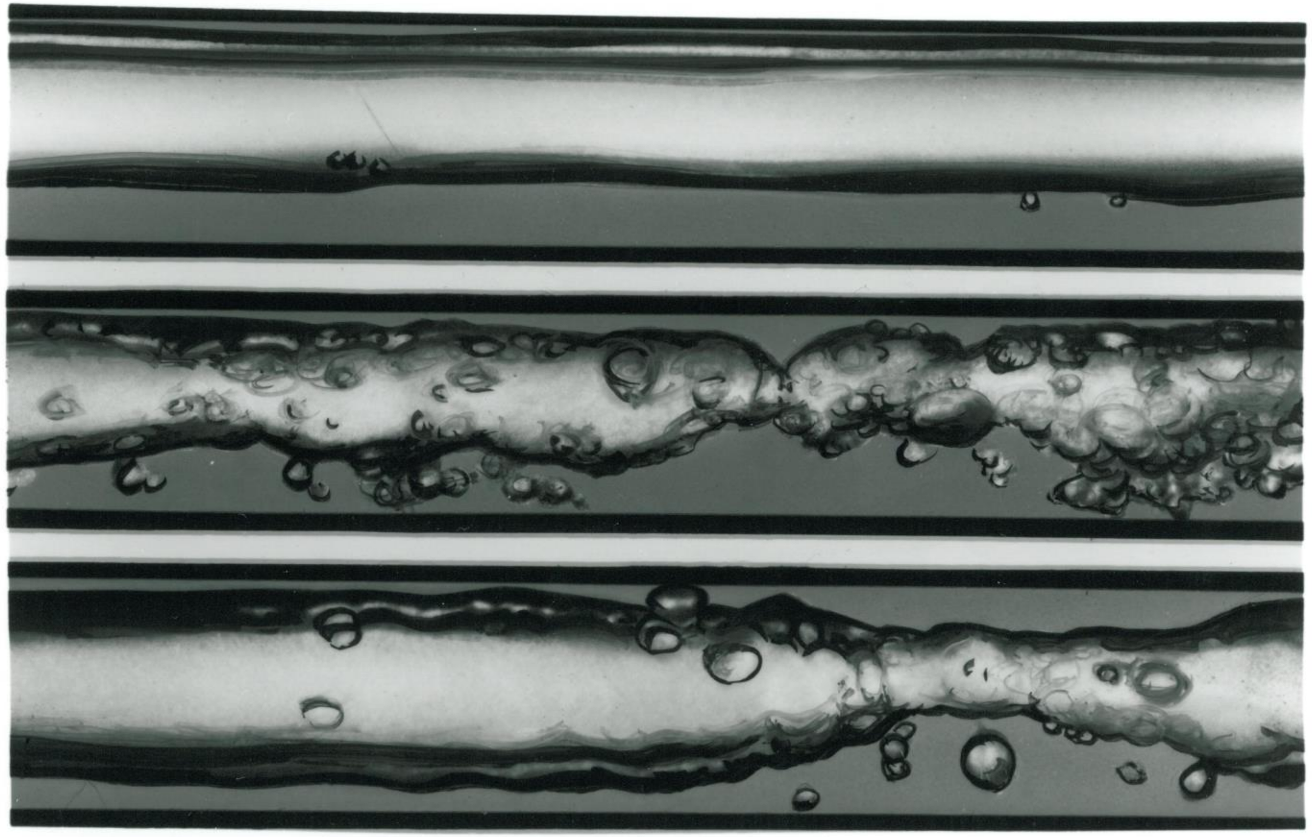


"Horizontal" Flows as a Function of Gravity

STRATIFIED FLOW
NORMAL GRAVITY
~1.0 G'S

STRATIFIED WAVY FLOW
LUNAR GRAVITY
~0.17 G'S

SLUG-ANNULAR FLOW
ZERO GRAVITY
<0.01 G'S

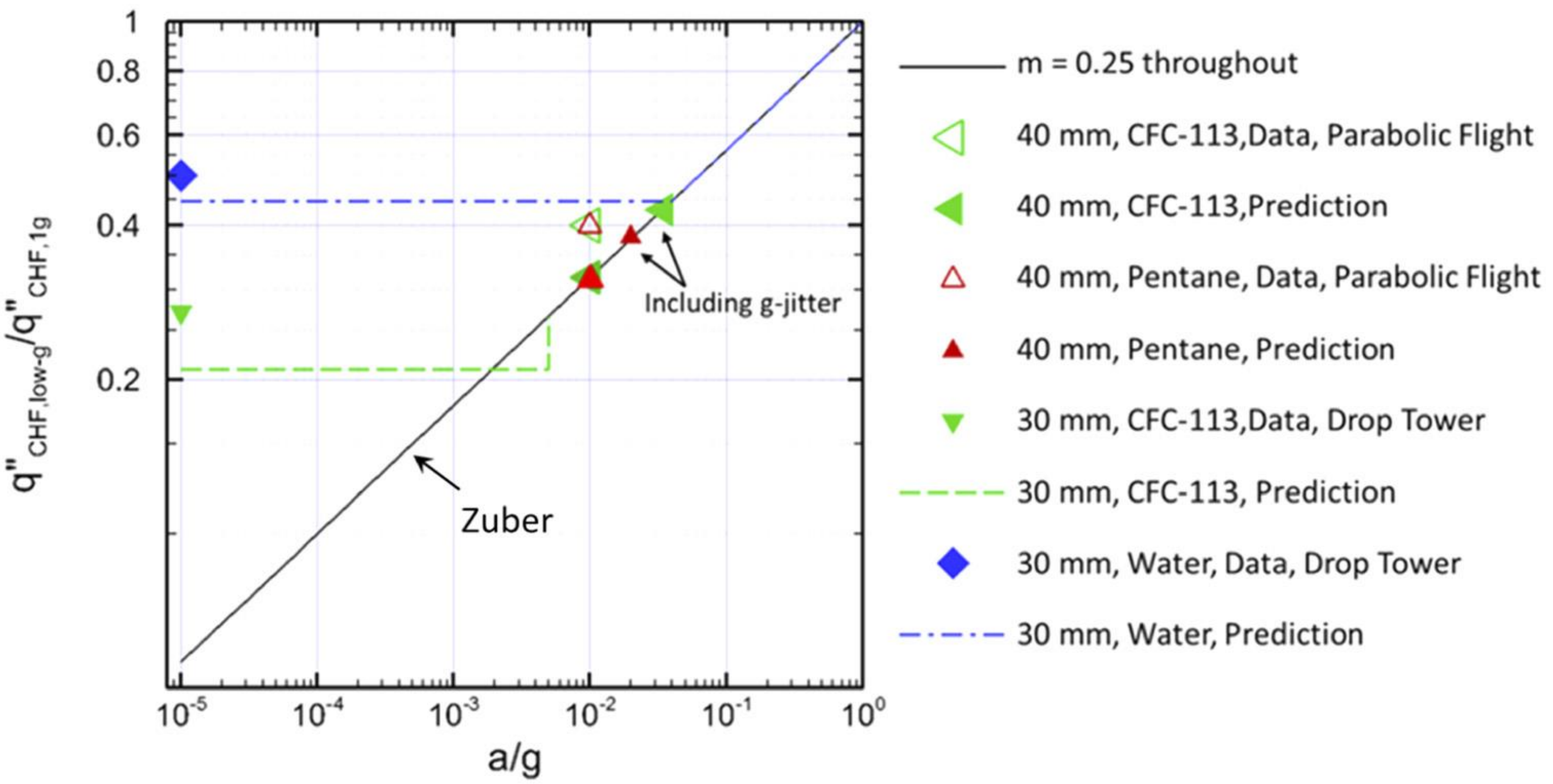


←GAS
←LIQUID

FLOW ⟶

AIR-WATER IN 1.27 CM ID TUBE
SUPERFICIAL GAS VELOCITY ~ 2.1 M/S
SUPERFICIAL LIQUID VELOCITY ~ 0.07 M/S

Normalized Critical Heat Flux versus acceleration for different fluids



$$q''_{\mathrm{SDB}} = q''_{\mathrm{BDB}} \left[\frac{a_{\mathrm{tran}}}{a_{\mathrm{BDB}}} \right]^{m_{\mathrm{BDB}}} K_{\mathrm{jump}}$$