Abstract #1686

English

Preliminary Test Results from the Helium Extraction and Acquisition Testbed

At the University of Wisconsin-Madison, research is ongoing to develop a prototype lunar volatiles extraction system that will demonstrate a process for acquiring valuable volatile gases that can be used for power, fuel or life support in space. The prototype system is called the Helium Extraction and Acquisition Test bed (HEAT) and is based on past lunar volatiles miner designs that were developed at the University of Wisconsin Fusion Technology Institute. Testing of HEAT is focused on measuring the rate of gas extraction from the processed lunar simulant and measuring the thermal energy recovery can be achieved in this kind of volatile extraction system with the use of a heat pipe heat exchanger. Preliminary results of the testing of the HEAT system will be presented.

French

No abstract title in French

No French resume

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Aaron Olson earned a B.S. in Mechanical Engineering in 2012, completed his M.S. in Engineering Mechanics and Astronautics in May of 2014 and is expecting to complete a Ph.D. in this same field in 2017. During his undergraduate education, He studied abroad at the Institut Supérieur de l'Aéronautique et de l'Espace in Toulouse, France for a semester, had internships at both NASA Goddard Space Flight Center and NASA Langley Research Center, and was part of the 2011 winning NASA Exploration Habitat competition student team that built an expandable module for NASA'S Deep Space Habitat Prototype. Aaron was the president of the UW-Madison chapter of Students for the Exploration and Development of Space, participated in NASA's Undergraduate Microgravity Research program and was also a crew member of the 110th Mars Desert Research Station Crew. Now, as a Ph.D. candidate and NASA Space Technology Research Fellow, Aaron is researching the acquisition of lunar volatiles for future power generation and in-space life support and propellant purposes with Professor Gerald Kulcinski and the collaboration of NASA Kennedy Space Center's Swamp Works Lab.

Demonstration of Lunar Volatiles Extraction Technology: Helium Extraction and Implantation

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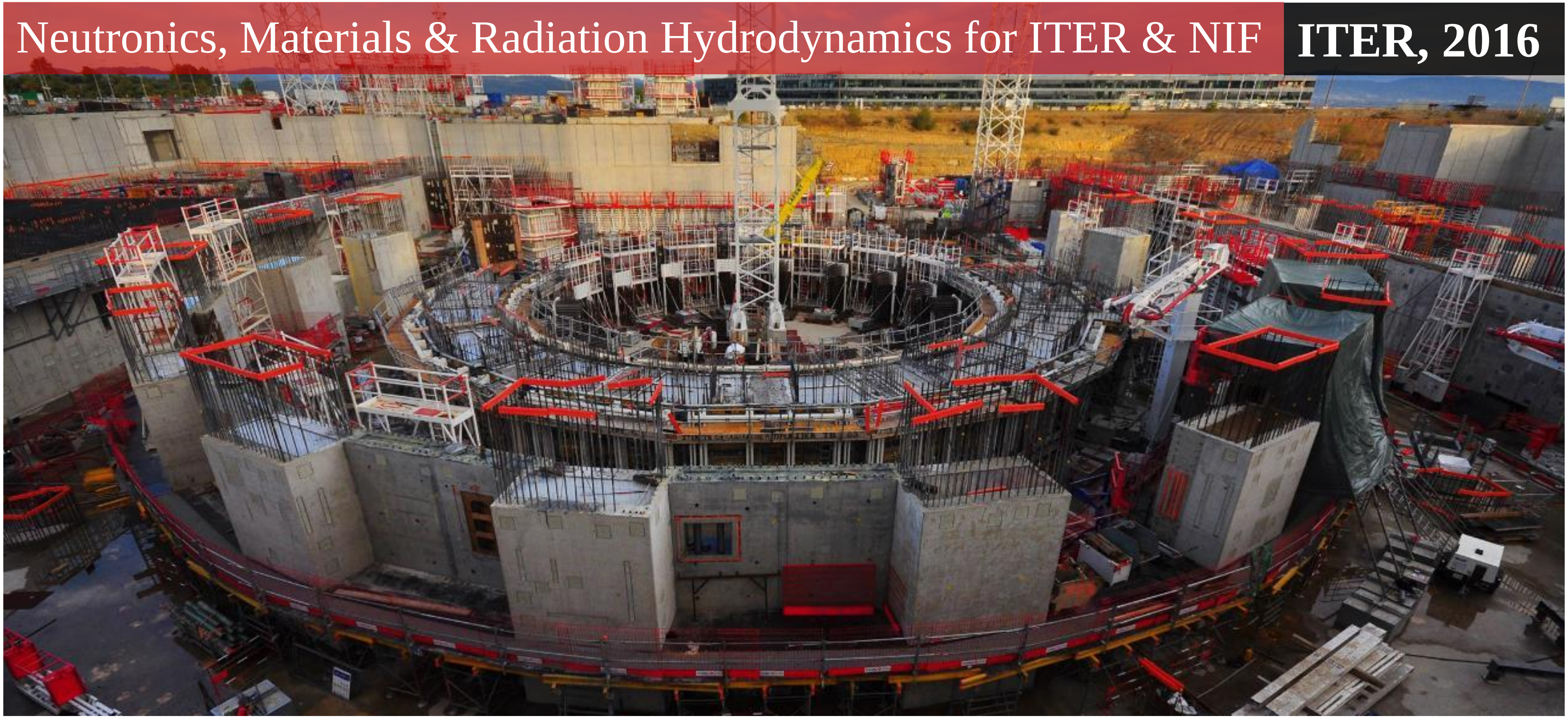
Outline

- Background: Research at the Fusion Technology Institute
- Motivation and Context for the Presented Research
- Overview of Research to Demonstrate Lunar Volatiles Extraction
- Helium Extraction and Acquisition Testbed (HEAT)
- Solar Wind Implanter (SWIM)
- Conclusion: Progress and Future Work

Fusion Technology Institute

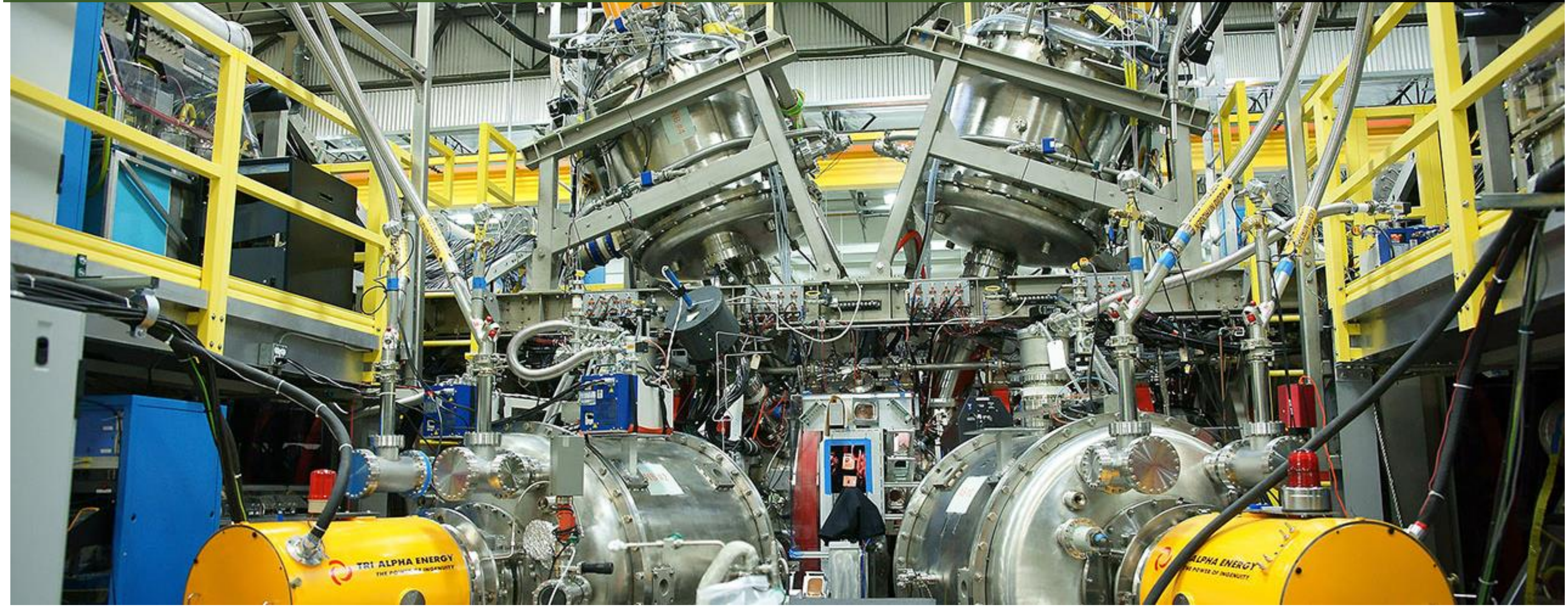


Fusion Technology Institute

Fusion Technology Institute

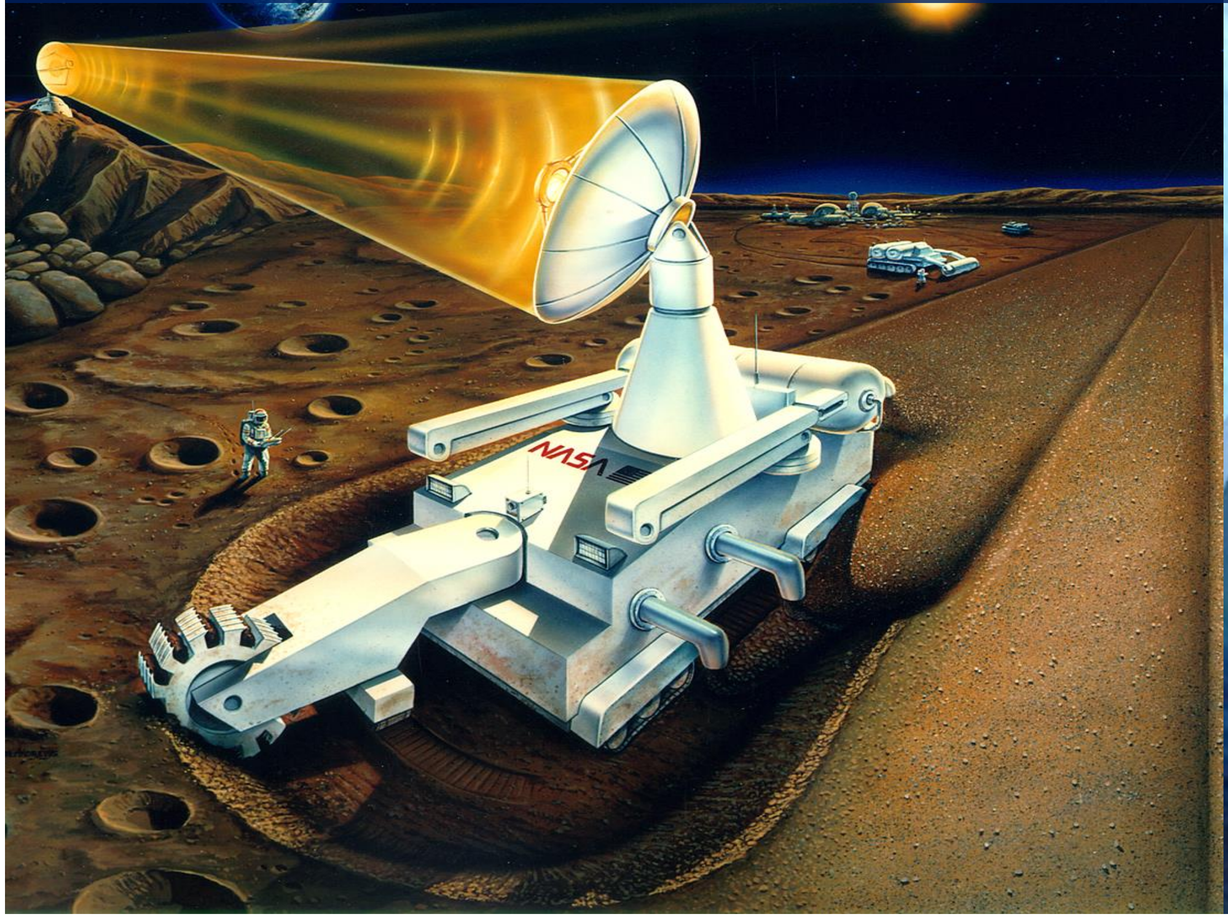
Analysis & testing for commercial fusion projects

Tri Alpha Energy, 2016

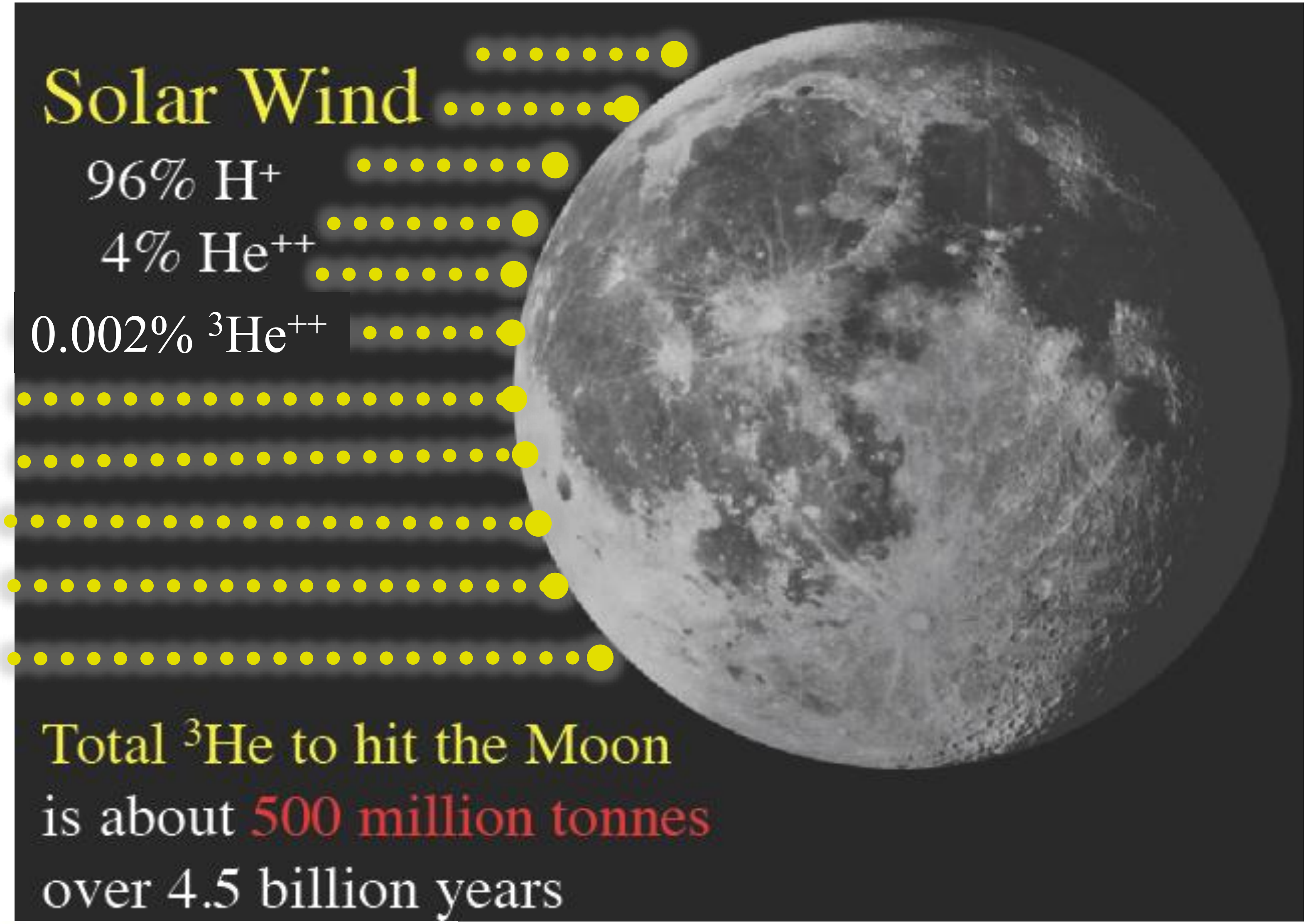


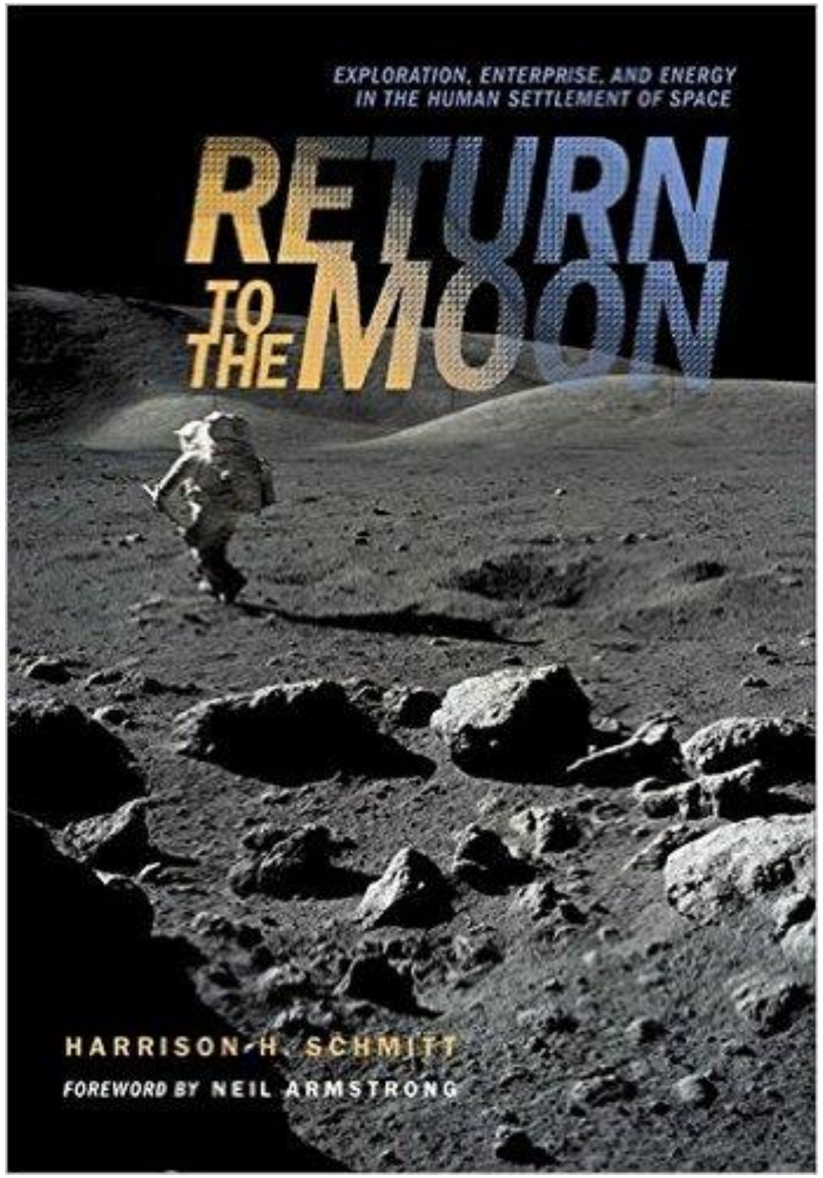
Helium-3 & Lunar Volatiles for Fuel & Life Support

Schmitt and Olson, 2013



The Moon has retained over 1 million tonnes of ^{3}He



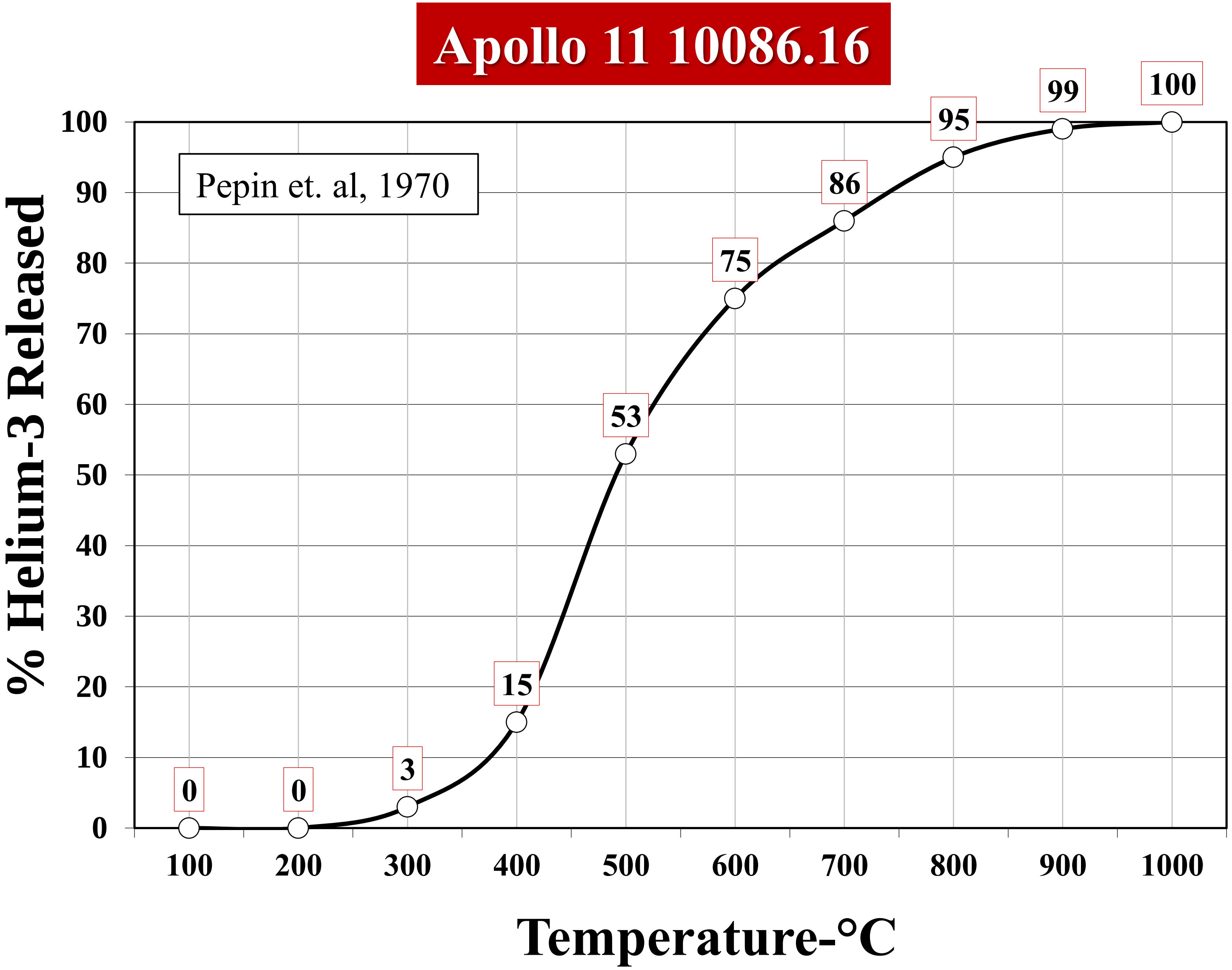


Heating Regolith Releases ^3He

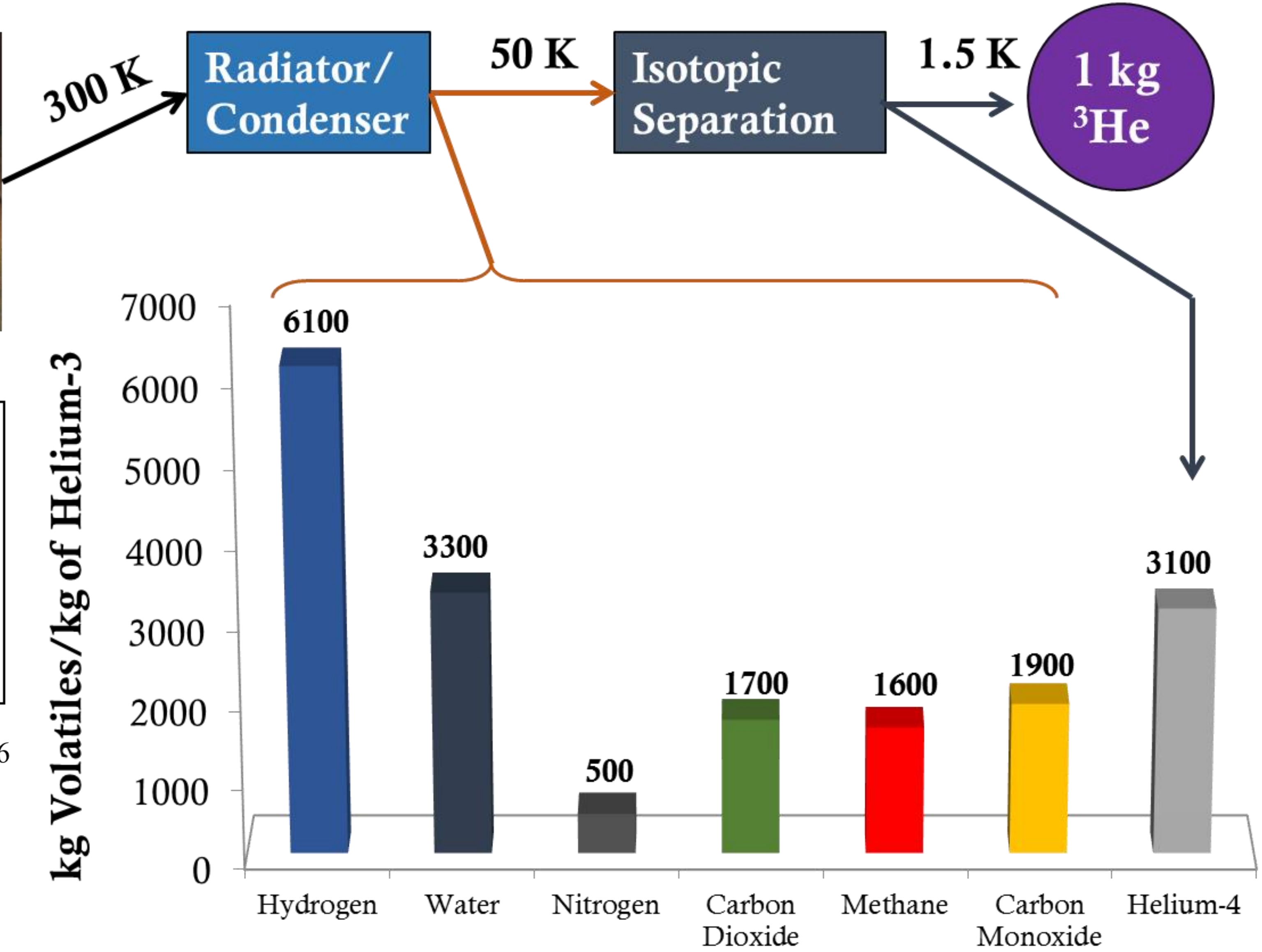
- Heat to 700 °C to release 86% of embedded ^3He

- Peak release rate ~ 500 °C

- Agitation release?



Heating Regolith Releases a Number of Valuable Volatiles



- Fuel: H_2, CH_4, H_2O
- Life support:

CO_2, CH_4, N_2, H_2O

- Cryogenics: ^4He

Results from Apollo 11 sample 10086.16

Three Iterations of Helium-3 Miners Designed at the UW FTI

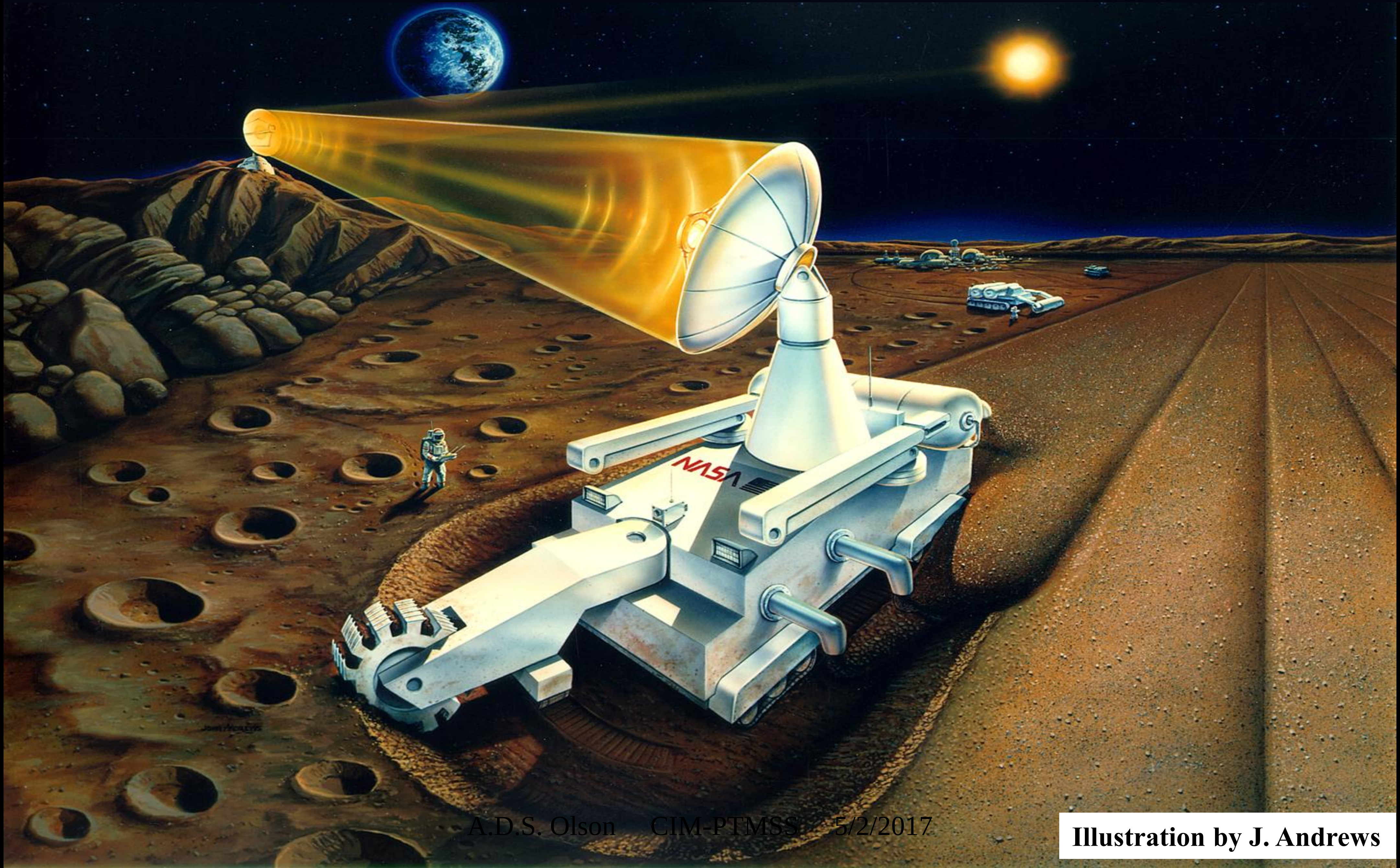
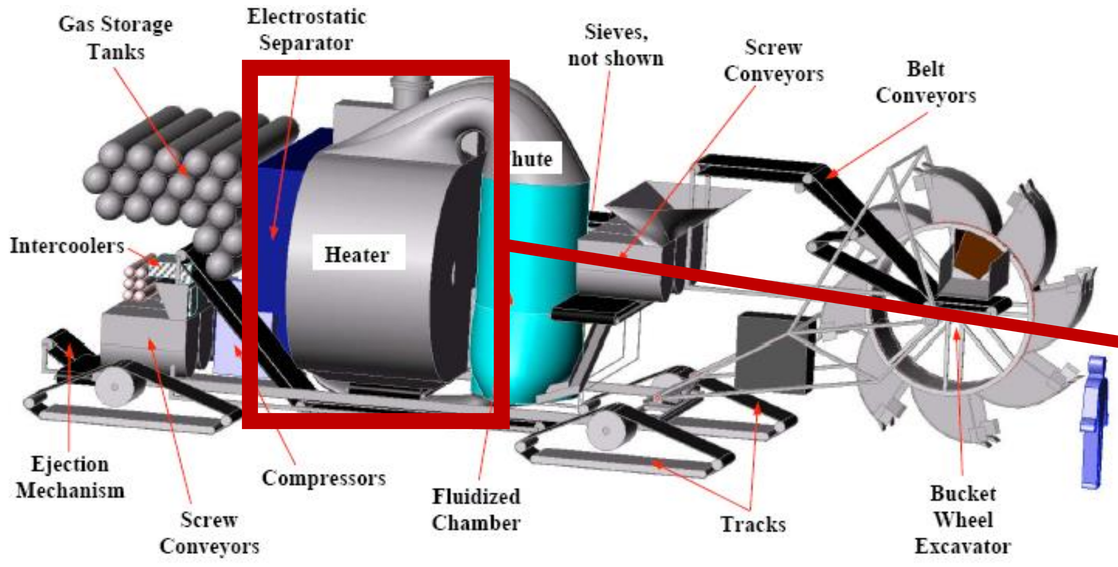


Illustration by J. Andrews

Research Toward Demonstration of Volatile Extraction

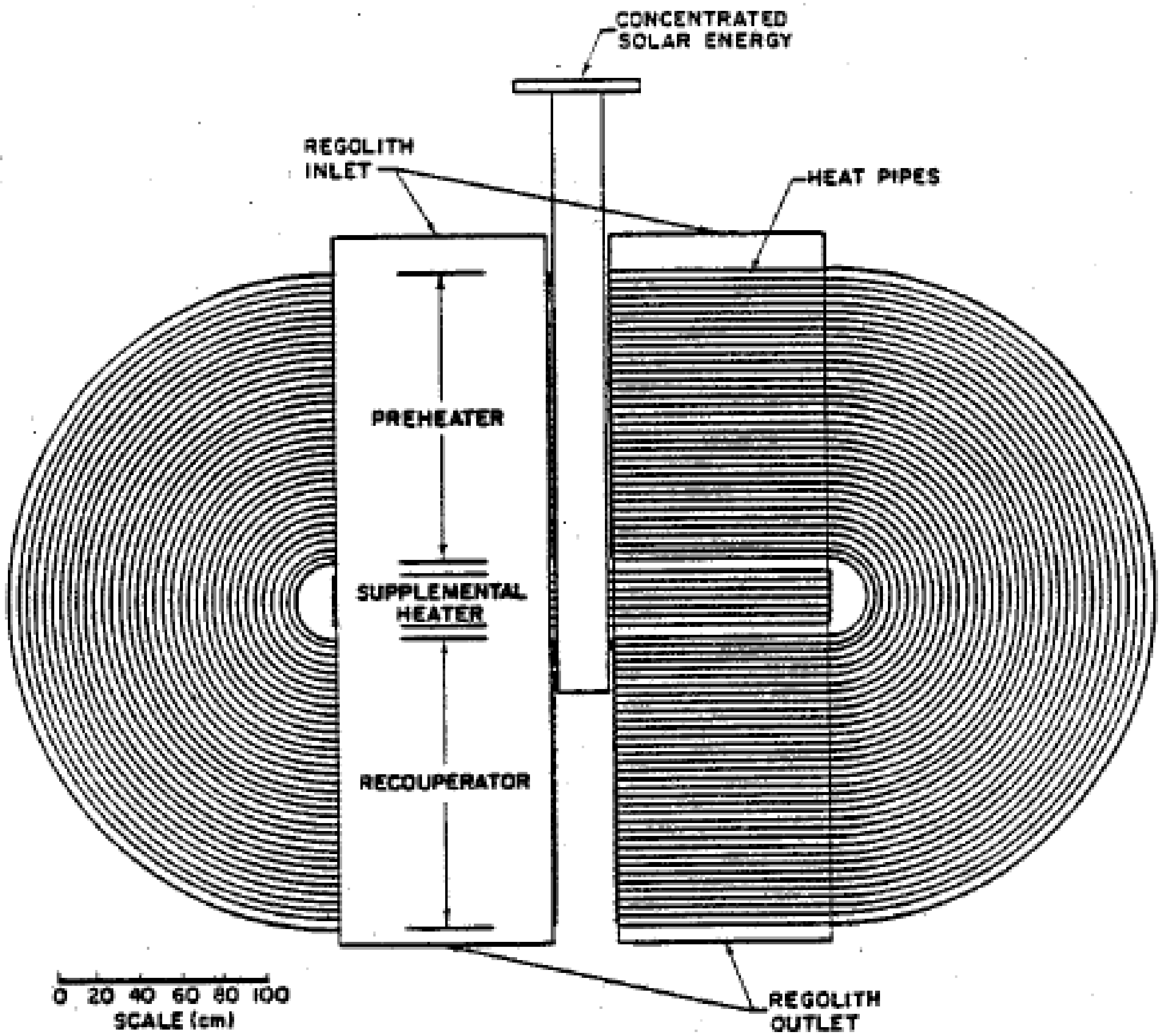
- A testbed for ^3He and volatile extraction inside of a heat pipe heat exchanger
- Laboratory scale (TRL 4)

Helium Extraction & Acquisition Test bed (HEAT)



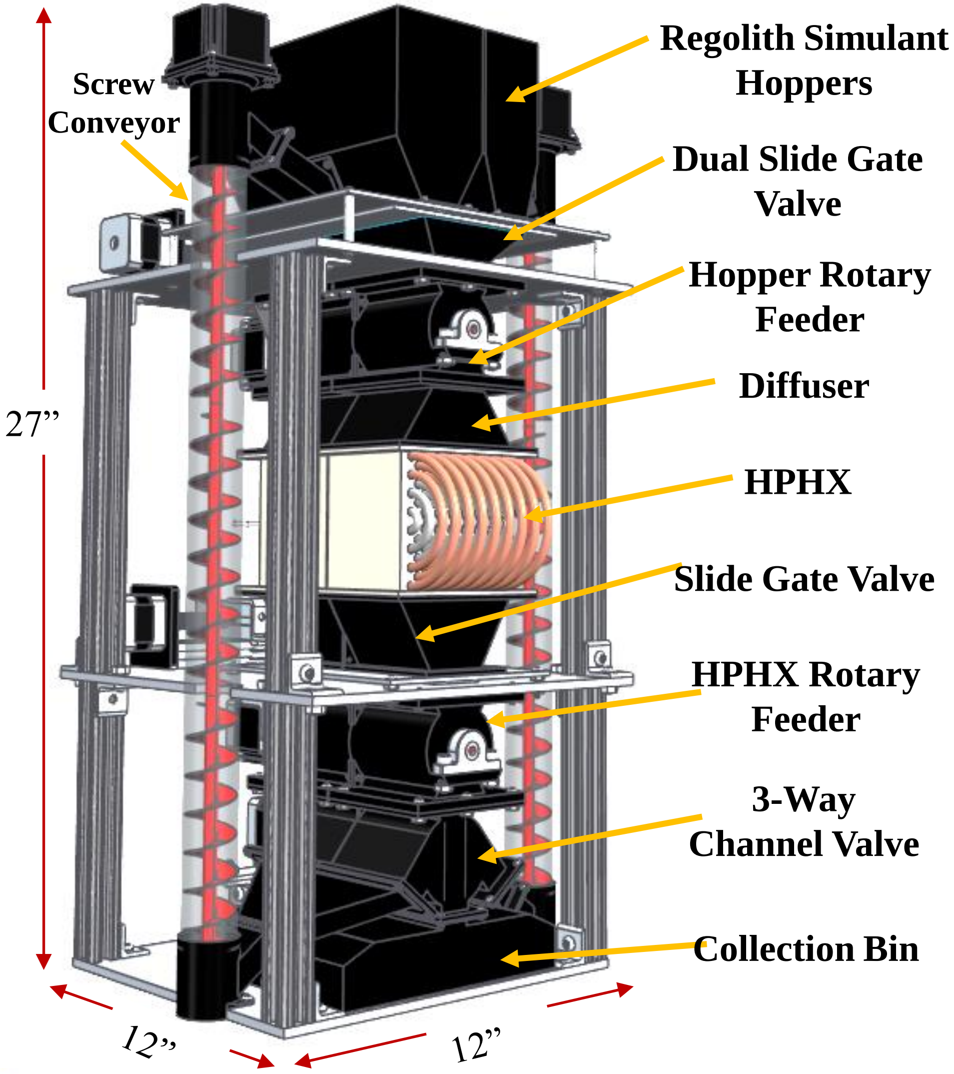
Mark 3 Lunar Miner, Credit: M. Gajda

The Heat Pipe Heat Exchanger is a Key Part of the Miner



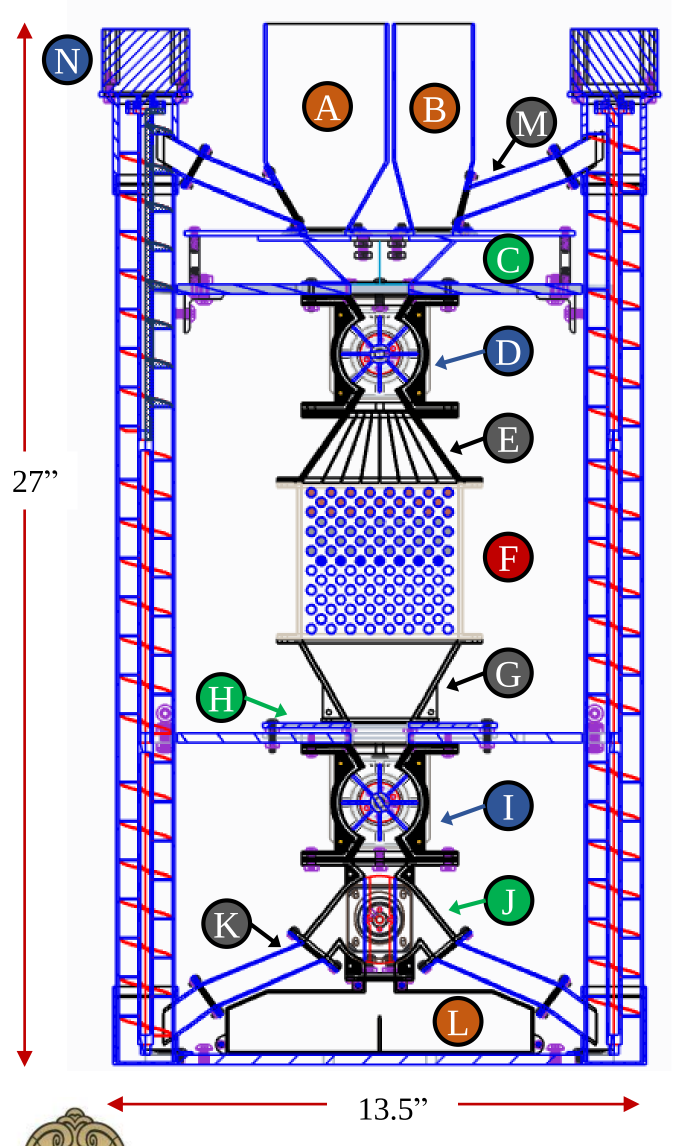
- 85% energy recovery by using heat pipes
- 12.3 MW from solar collector (70 MW reduction)
- Heats 157 kg/s of regolith from 30 °C up to 700 °C to release 85% of embedded ^{3}He
- Evolves 16.7 g/hr of ^{3}He (66 kg in 3942 hours of mining)
- Working fluid – heat pipe material combinations
  - Water in copper pipes: operating up to ~250 °C
  - Mercury in stainless steel pipes: operating between 250- 500 °C
  - Sodium and or potassium in stainless steel pipes: operating above 500 °C

This Research Will Demonstrate ^3He Extraction



- ~1:250 scale mass flow rate (0.62 kg/s) of Mark II
- Heats regolith from 30 °C up to 700 °C to release 86% of embedded ^3He
- Design for <100 μm JSC-1A regolith simulant
- Moving Bed Recuperative Heat Pipe Heat Exchanger (HPHX)
- 85% thermal energy recovery
- Thermocouple (K), Load Cell & RGA Instrumentation

This Research Will Demonstrate ^{3}He Extraction



Containers

- A — Unimplanted regolith hopper
- B — Implanted regolith hopper
- L — Collection regolith bin

Open/Close Flow Control

- C — Hopper slide gate valve
- H — HPHX slide gate valve
- J — Channel changer valve

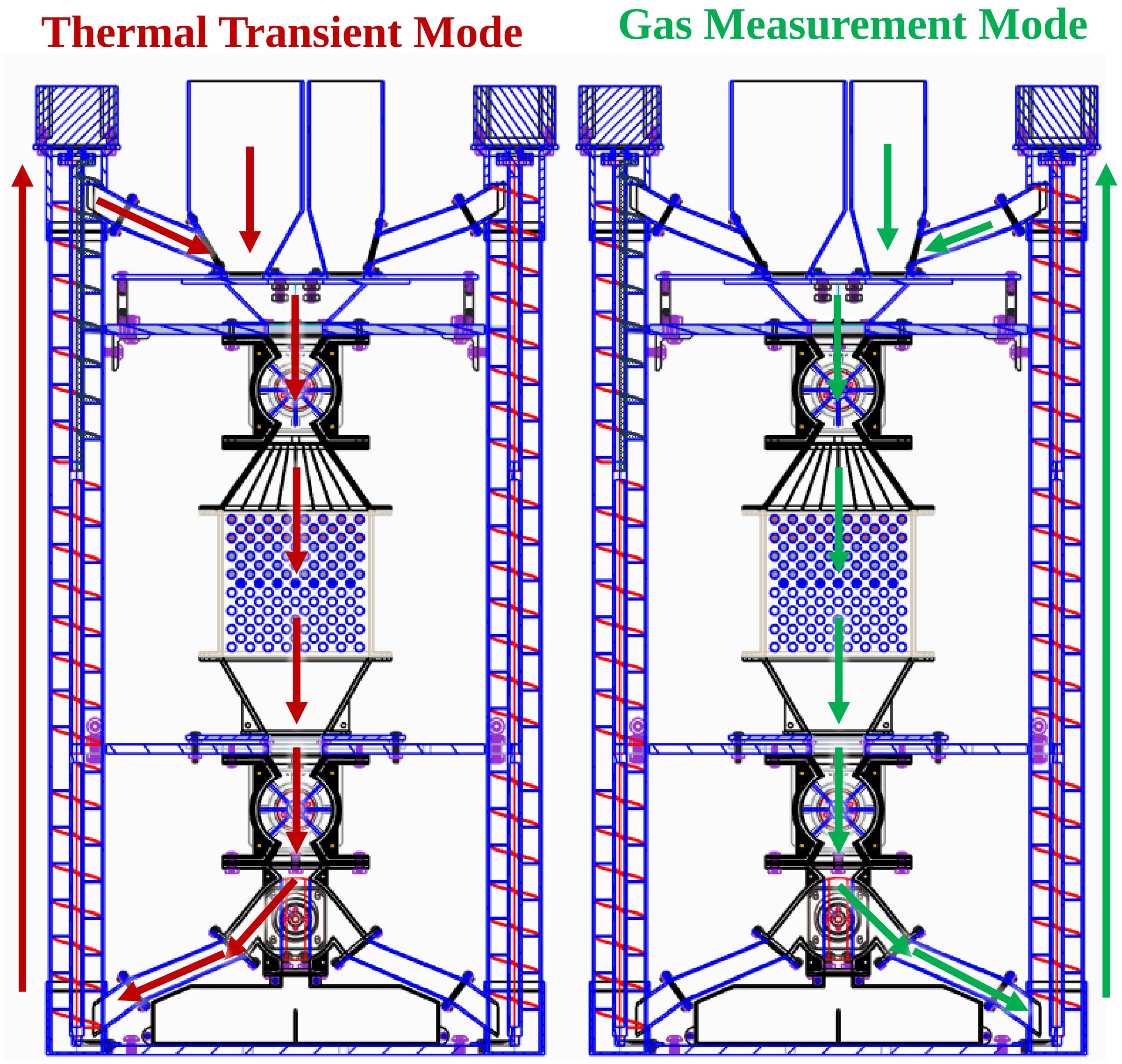
F — Heat pipe heat exchanger (HPHX)

Passive Flow Paths

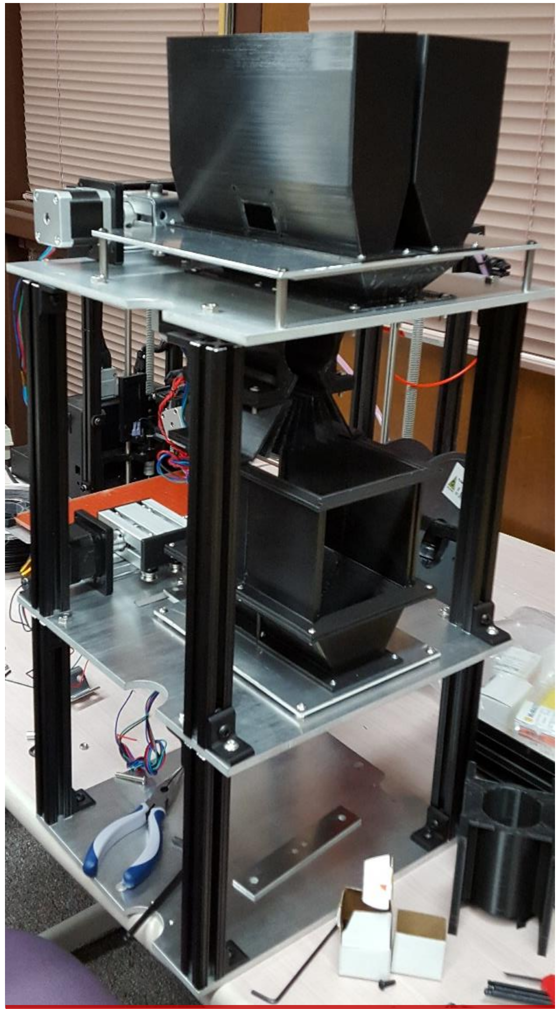
- M — Screw conveyor outlet chute (Qty: 2)
- E — HPHX Diffuser
- K — Screw conveyor inlet chute (Qty: 2)

Flow Controllers

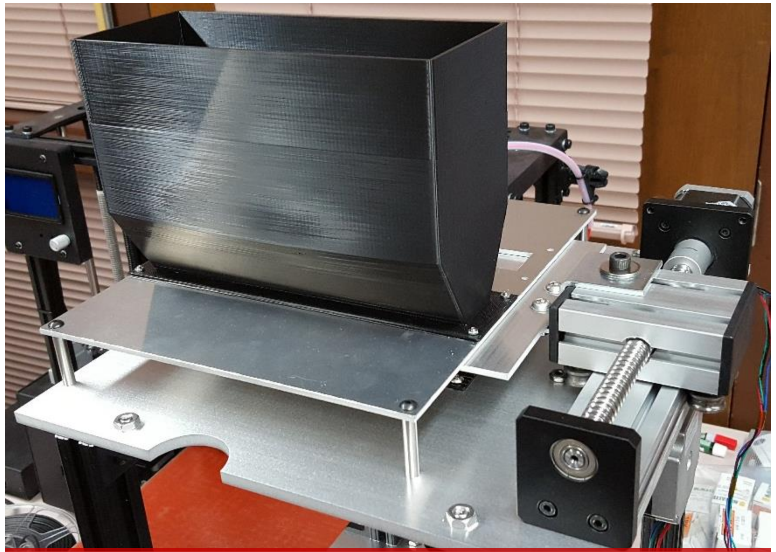
- D — Hopper rotary feeder
- I — HPHX rotary feeder
- N — Screw conveyor (Qty: 2)



Construction of the HEAT Device

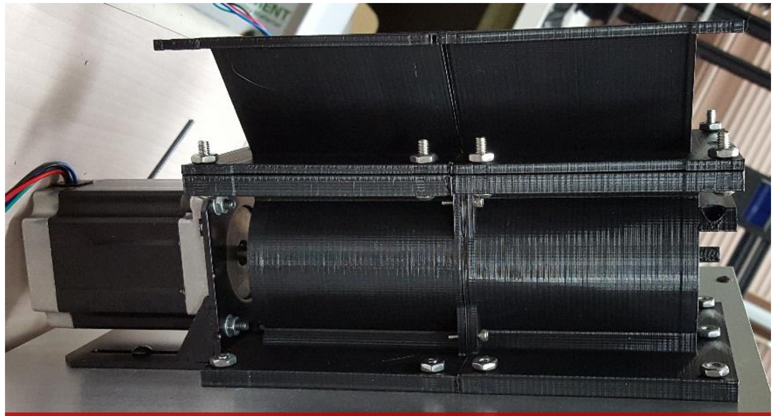


HEAT structure



Slide Gate Valve

HEAT Controller & DAQ

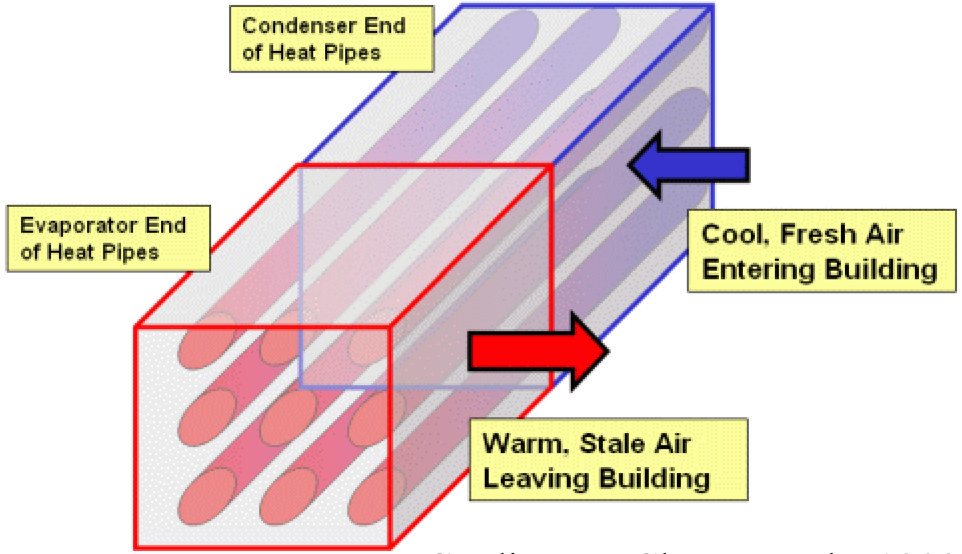


Rotary Valve Feeder & Diffuser

Rotary Valve Rotor

HPHX Design: Staged Counterflow HX Analysis

- Energy balance on cold and hot streams of regolith
- Effectiveness – NTU method
- Stage temp., effectiveness, conductance determined
- Stage change in regolith temperature determined
- HX surface area determined

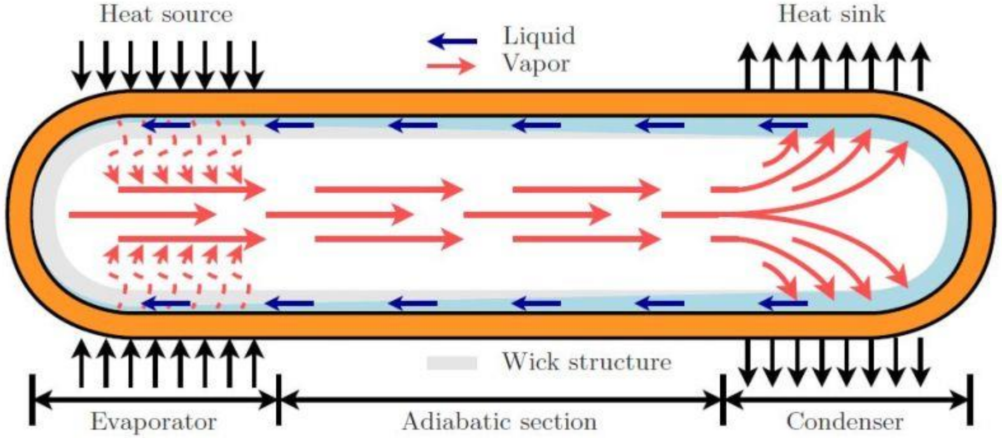


Credit: Des Champs Labs,1993

$$Q = C_h(T_{hi} - T_{ho}) = C_h\varepsilon_h(T_{hi} - T_p) = C_c(T_{co} - T_{ci}) = C_c\varepsilon_c(T_p - T_{ci})$$

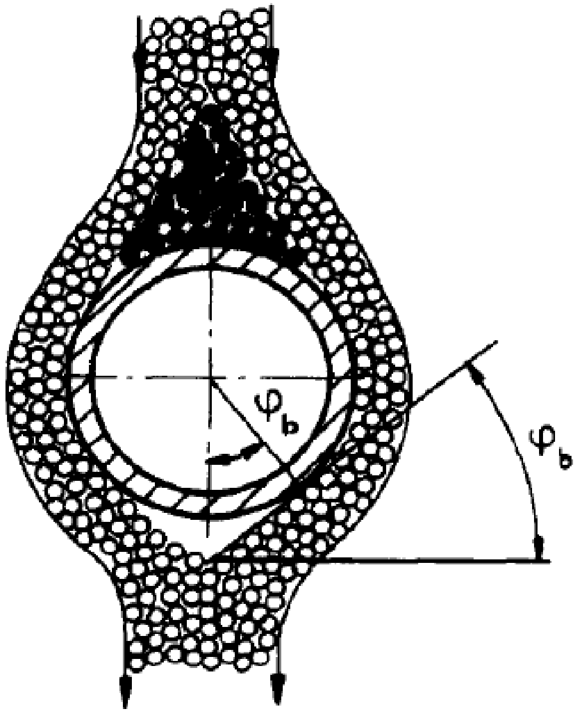
$$\varepsilon_h = \frac{T_{hi} - T_{ho}}{T_{hi} - T_p} = 1 - e^{-NTU_h} \qquad \varepsilon_c = \frac{T_{co} - T_{ci}}{T_p - T_{ci}} = 1 - e^{-NTU_c}$$

$$NTU_h = \frac{h_h A_h}{\dot{C}_h} \qquad NTU_c = \frac{h_c A_c}{\dot{C}_c}$$



HPHX Design: Moving Bed Flow and Heat Transfer

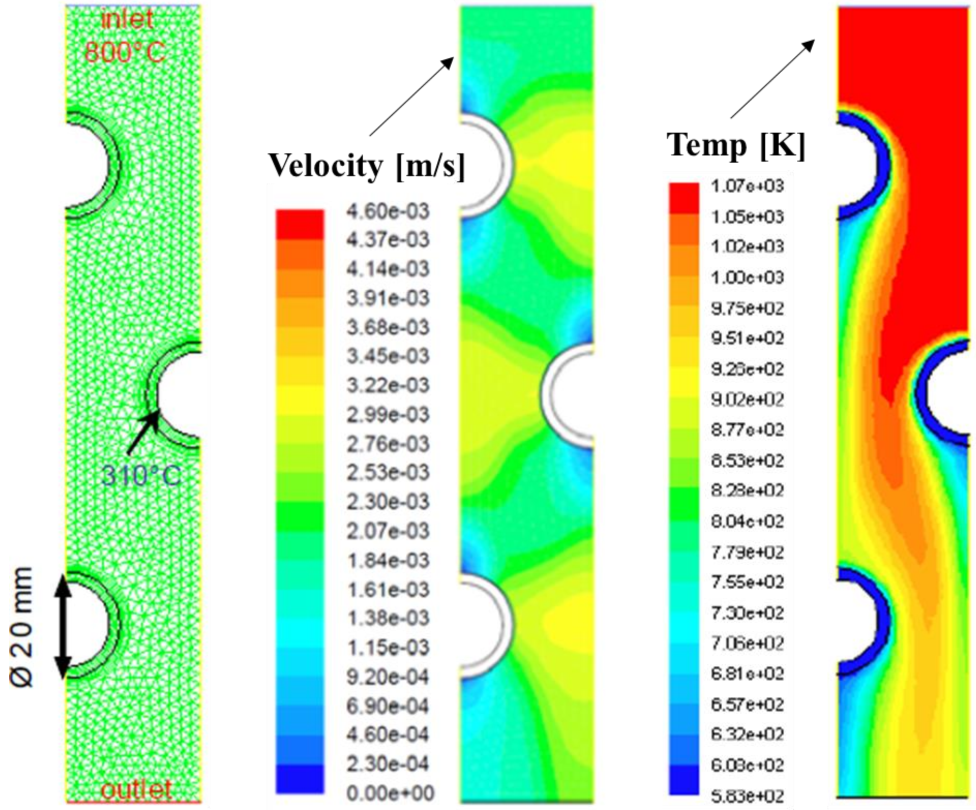
1-Phase - Analytical



Credit: Niegsch et al.,1994

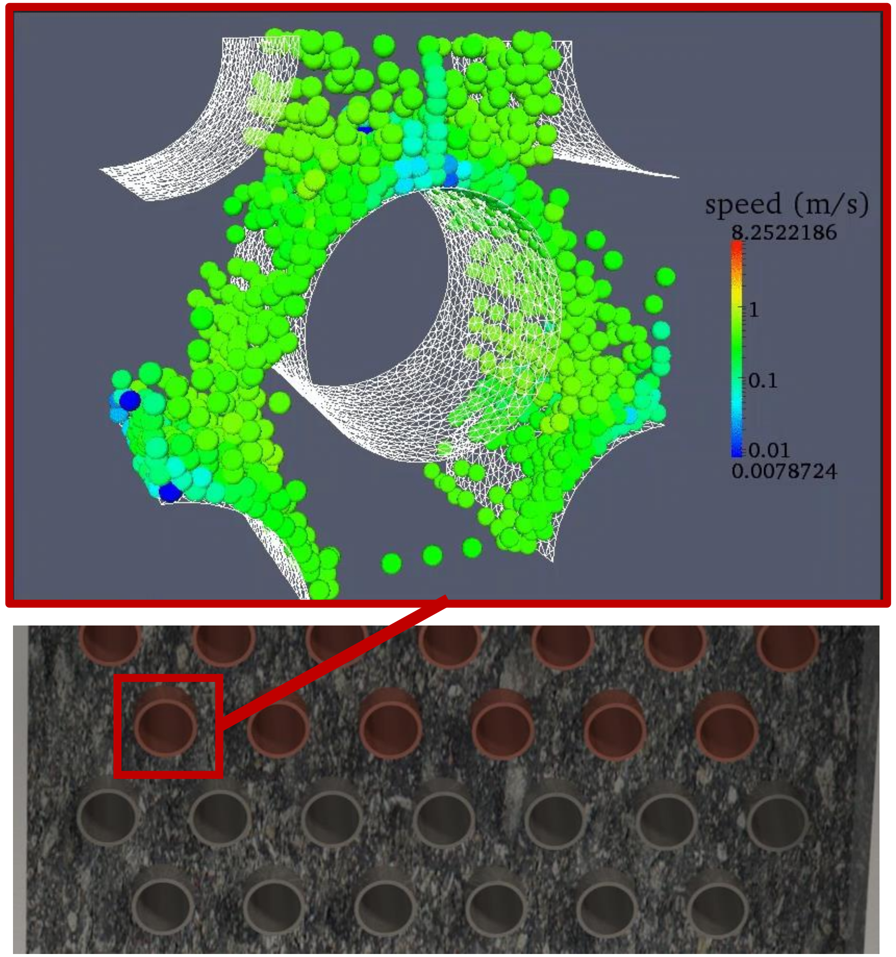
2-Phase - CFD

Done in ANSYS Fluent®



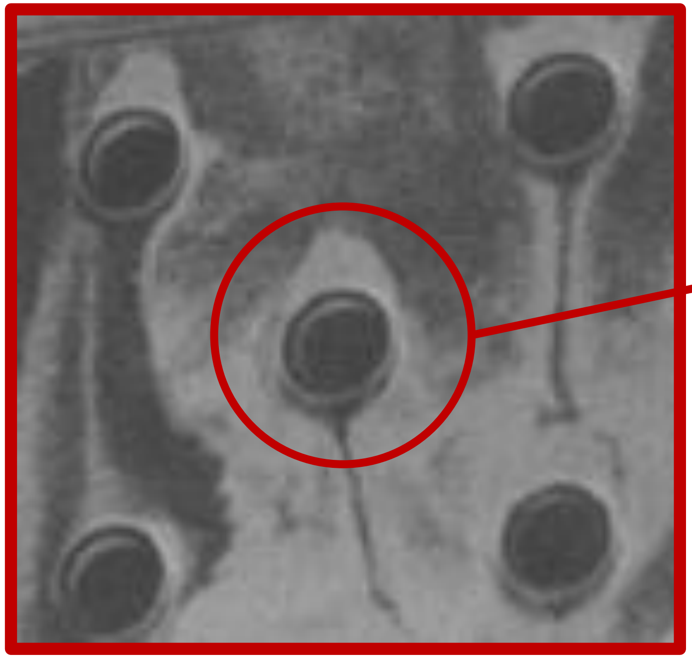
Credit: Baumann et al.,2014

Discrete Element Method (DEM)

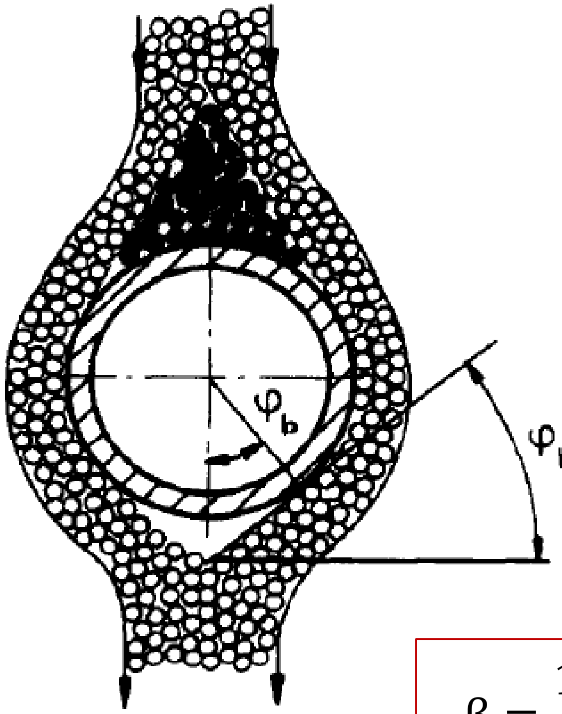


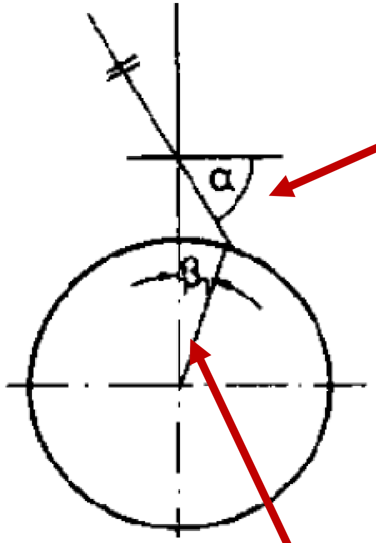
HPHX Design: Moving Bed Flow Model

- The granular friction properties influence the flow channel shape
- The Niegsch model (Niegsch et al., 1994) incorporates the stagnation and void areas of flow



Credit: Niegsch et al.,1994



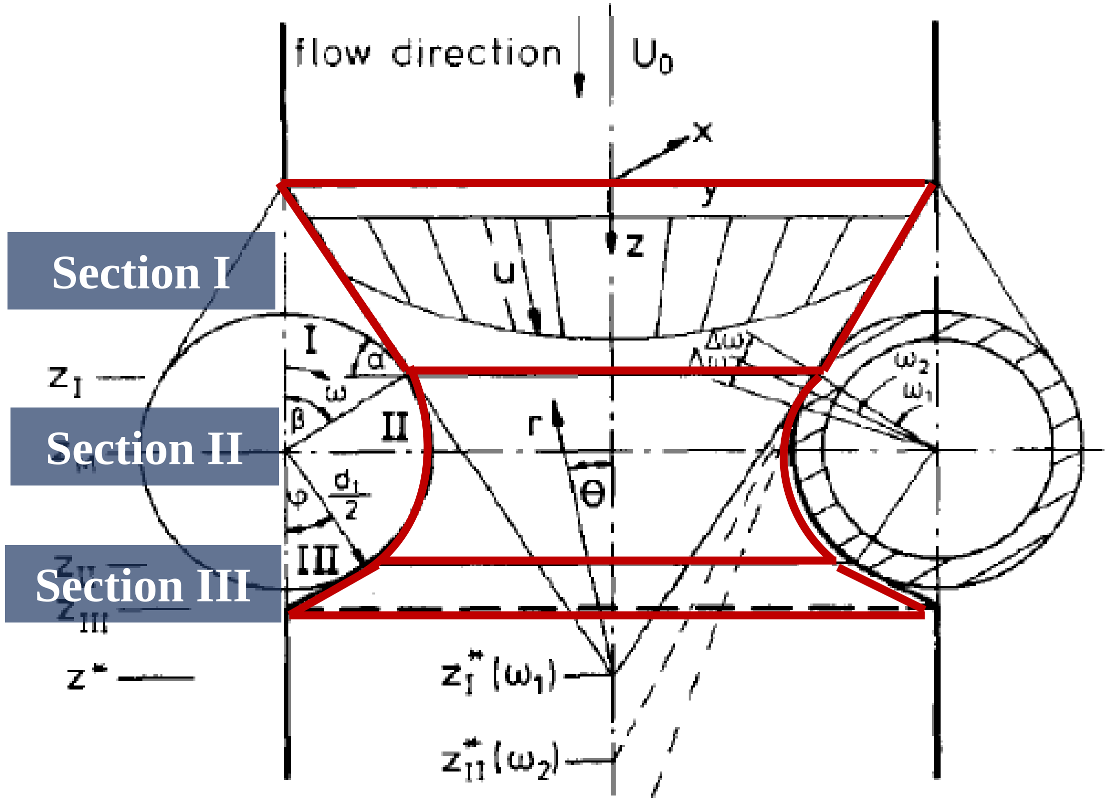


$$\alpha = \frac{\pi}{4} + \varphi_e$$

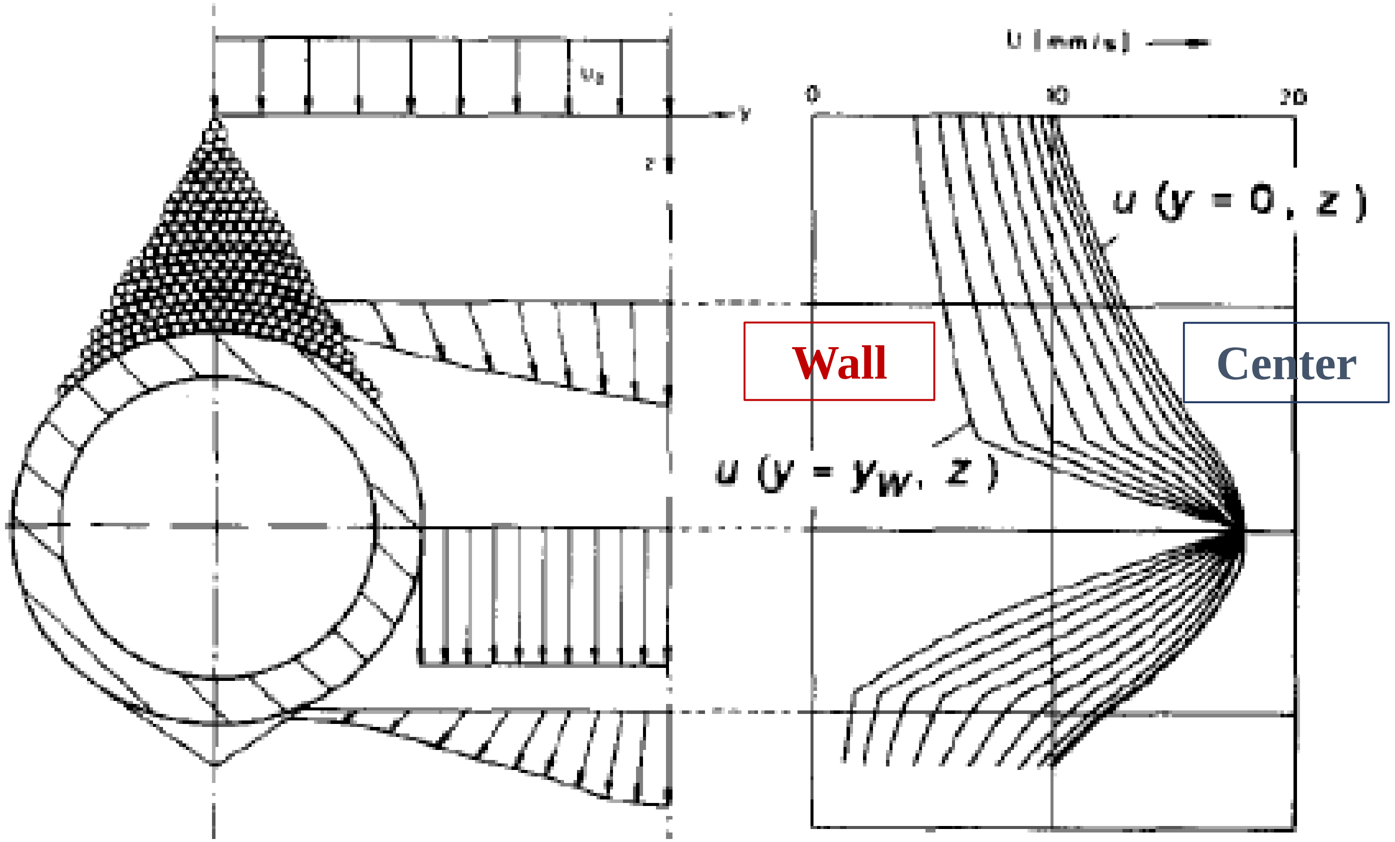
$$\beta = \frac{1}{2}\left[\cos^{-1}\left(\frac{1-\sin(\varphi_e)}{2\sin(\varphi_e)}\right) + \sin^{-1}\left(\frac{\sin(\varphi_w)}{\sin(\varphi_e)}\right) + \varphi_w\right]$$

HPHX Design: Moving Bed Velocity Field Solution

- Steady 2D flow, material is described as an isotropic, incompressible continuum fluid



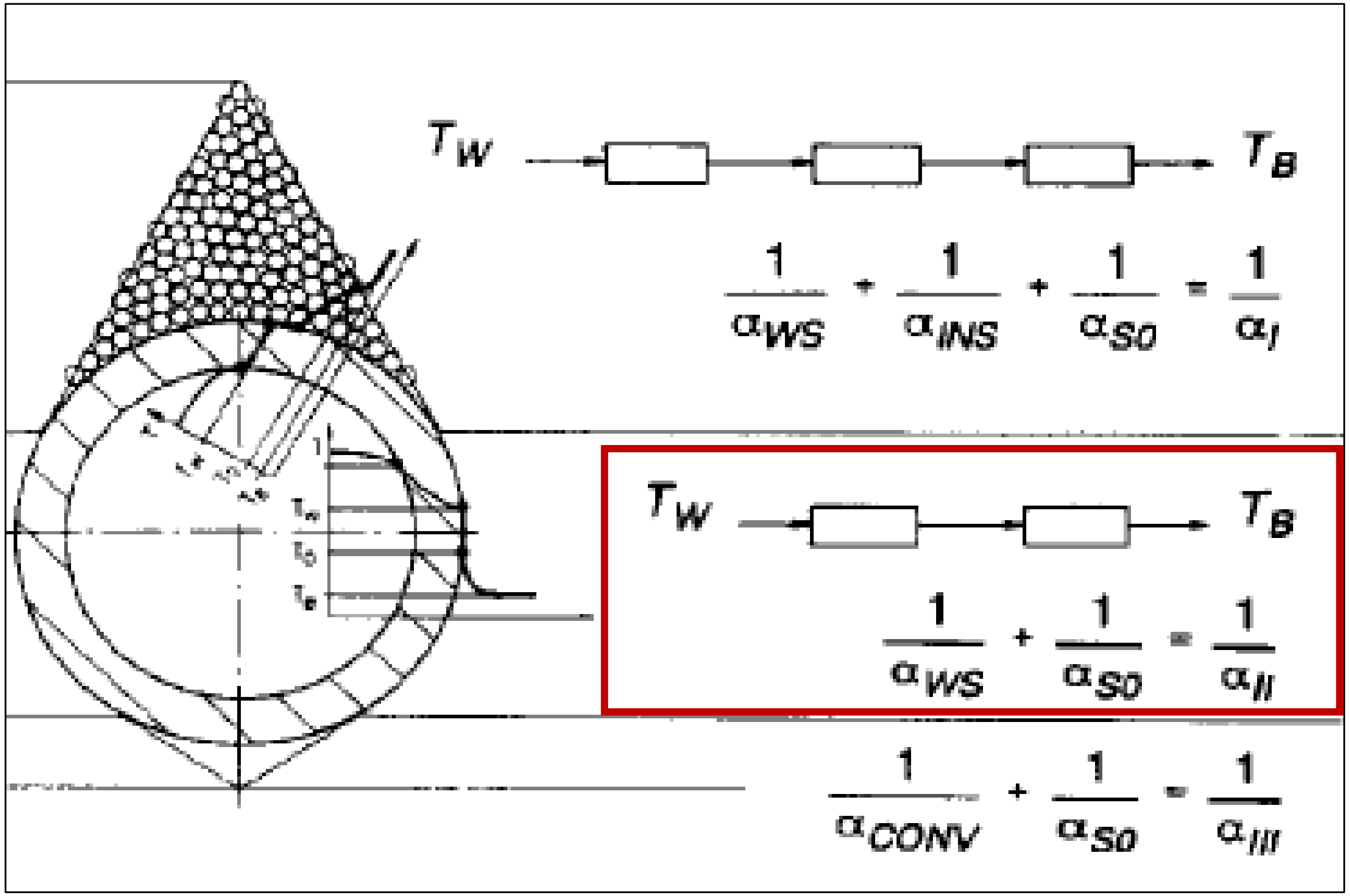
Credit: Niegsch et al.,1994



Credit: Niegsch et al.,1994

HPHX Design: Moving Bed Heat Transfer

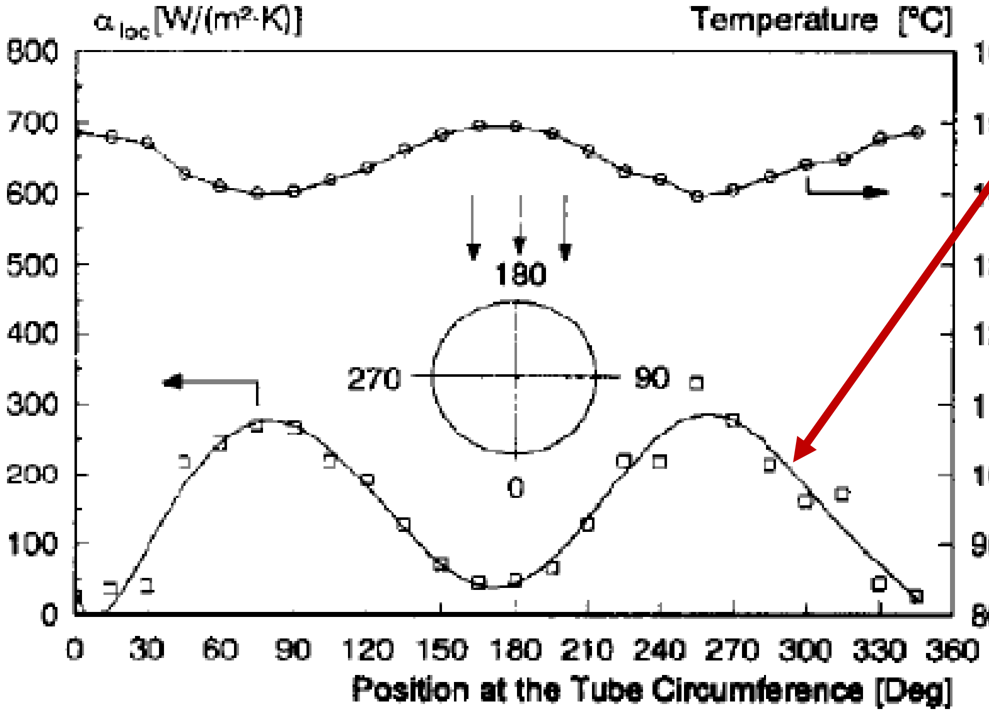
- Thermal resistances vary by section
- Section II has the greatest influence
- Surface heat transfer coefficient
- Heat penetration into the bulk



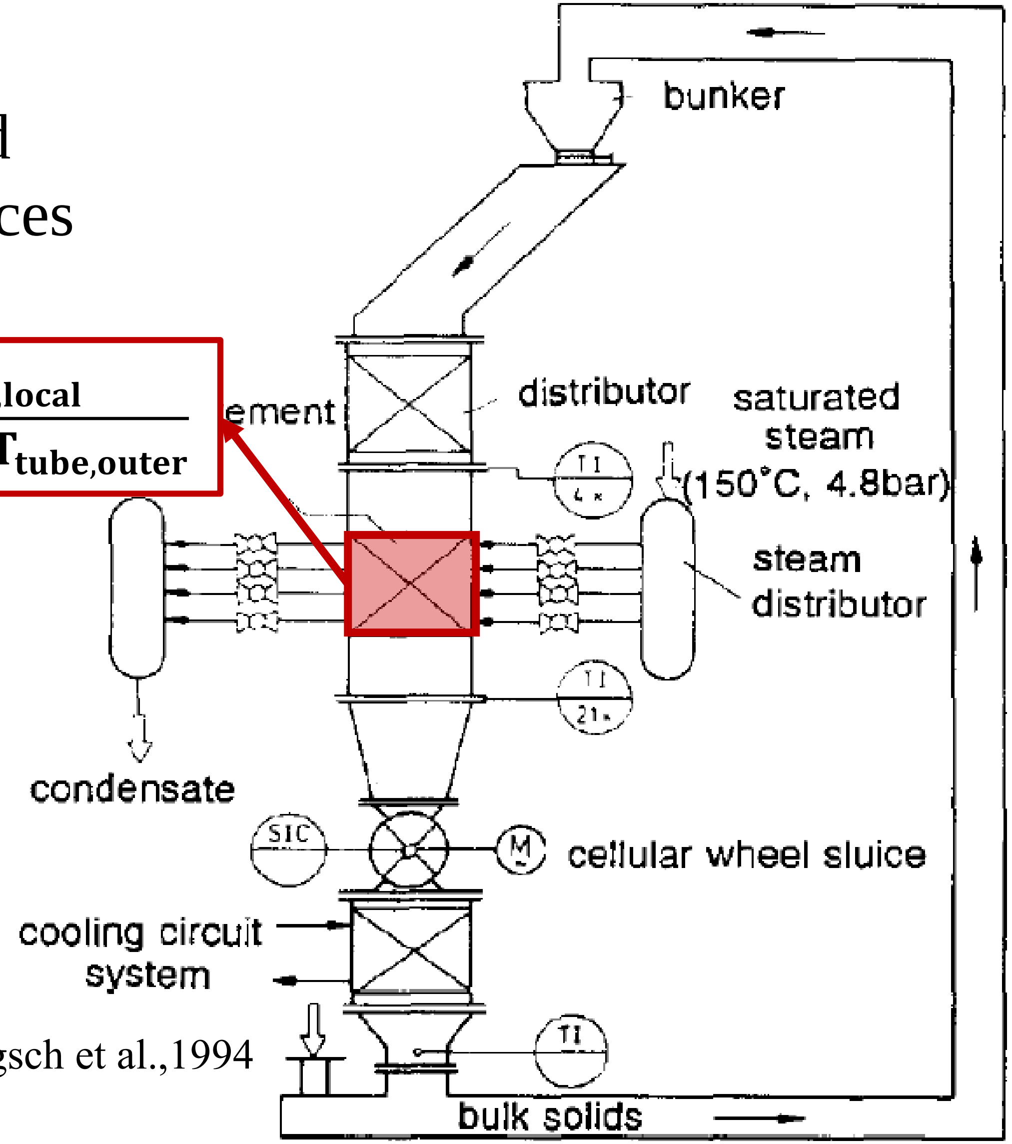
Credit: Niegsch et al.,1994

HPHX Design: Moving Bed Experimental Results

- Niegsch Model matches experimental results
- Heat transfer coefficients measured with a steam heated tube with thermocouples on its inside and outside surfaces



$$h_{local} = \frac{q''_{tube,local}}{T_{bulk,\infty} - T_{tube,outer}}$$



Credit: Niegsch et al.,1994

JSC-1A Lunar Regolith Simulant Will be Used

JSC-1A Merriam Crater Cinders (left) and ground regolith simulant (right), Credit: ORBITEC

Chemical Composition

Oxide	Weight % (Average)
SiO_2	47.1
TiO_2	1.87
Al_2O_3	17.1
Fe_2O_3	3.41
FeO	7.57
MnO	0.18
MgO	6.9
CaO	10.3
Na_2O	3.3
K_2O	0.86
P_2O_5	0.76
LOI	0.01
Total	100.2

Minerals	JSC-1A
Plagioclase	37.83
Clinopyroxene	18.77
Orthopyroxene	0.66
Olivine	12.44
Glass	26.67
Magnetite	0.01
Chromite	0.00
Ilmenite	0.11
Sulphides	0.17
Iron	0.00
MgFeAl Silicate	3.06
K Feldspar	0.07
Quartz	0.01
Calcite	0.11
Others	0.07
Total	100.00

Property	Range	Value/Function Used
Density	1400 – 1800 [kg/m^3]	1700 [kg/m^3]
Mean particle size	180-200 μm	185 μm
Mean particle size (<100 μm)	50-70 μm	60 μm
Specific heat	700- 1400 [J/kg-K]	1047.41 log(Temp) – 1848.15 [J/kg-K]
Thermal Conductivity @20 kPa	0.15 - 0.40 [W/m-K]	3.9e^{-4}(Temp) + 0.1588 [W/m-K]
Cohesion	1 kPa	1 kPa
Angle of Internal Friction	40-55 degrees	45 degrees

Thanks to Dr. James Mantovani for 8kg of JSC-1A from NASA KSC

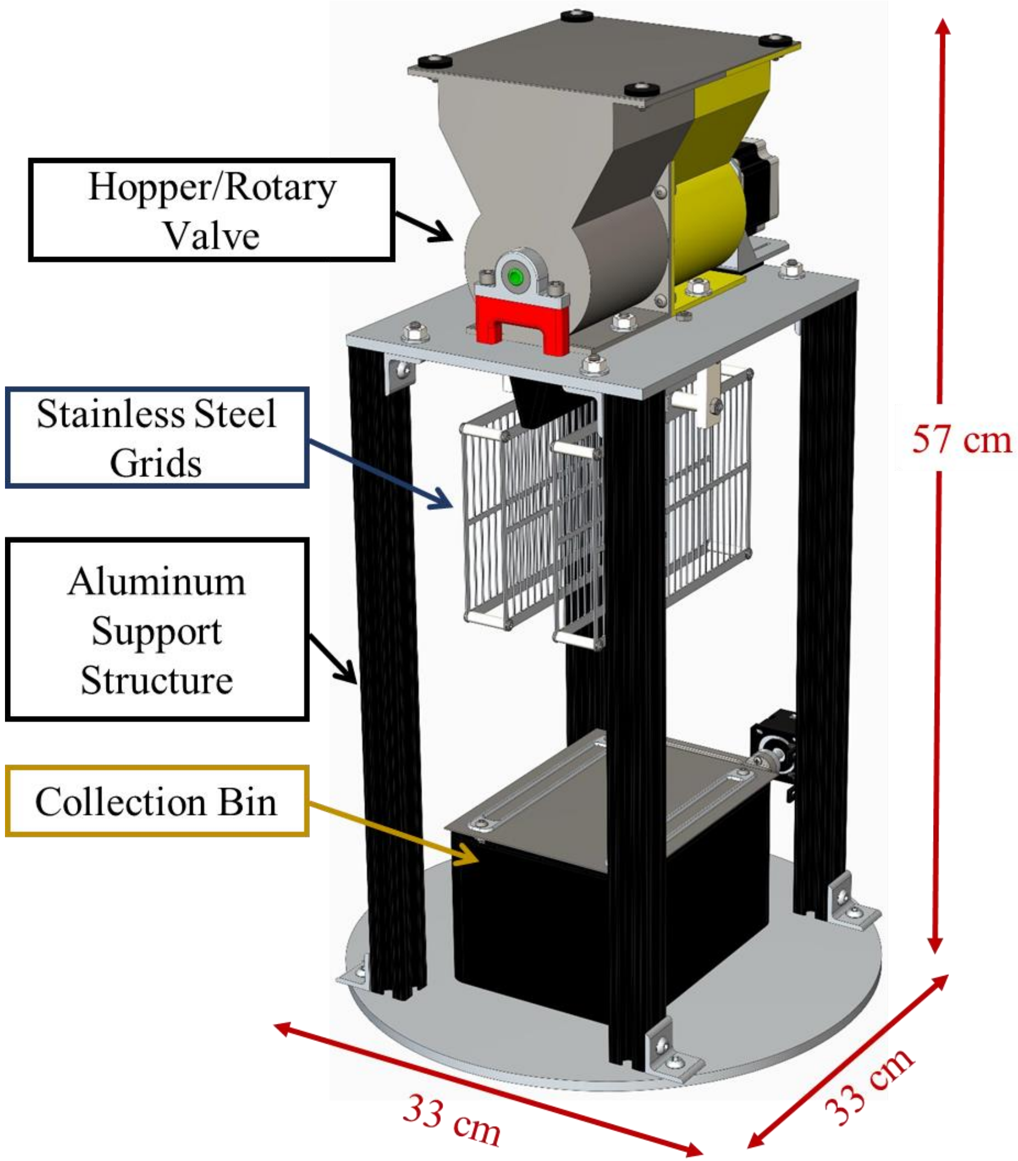
Solar Wind Implanter (SWIM) Objectives

Implantation Goals

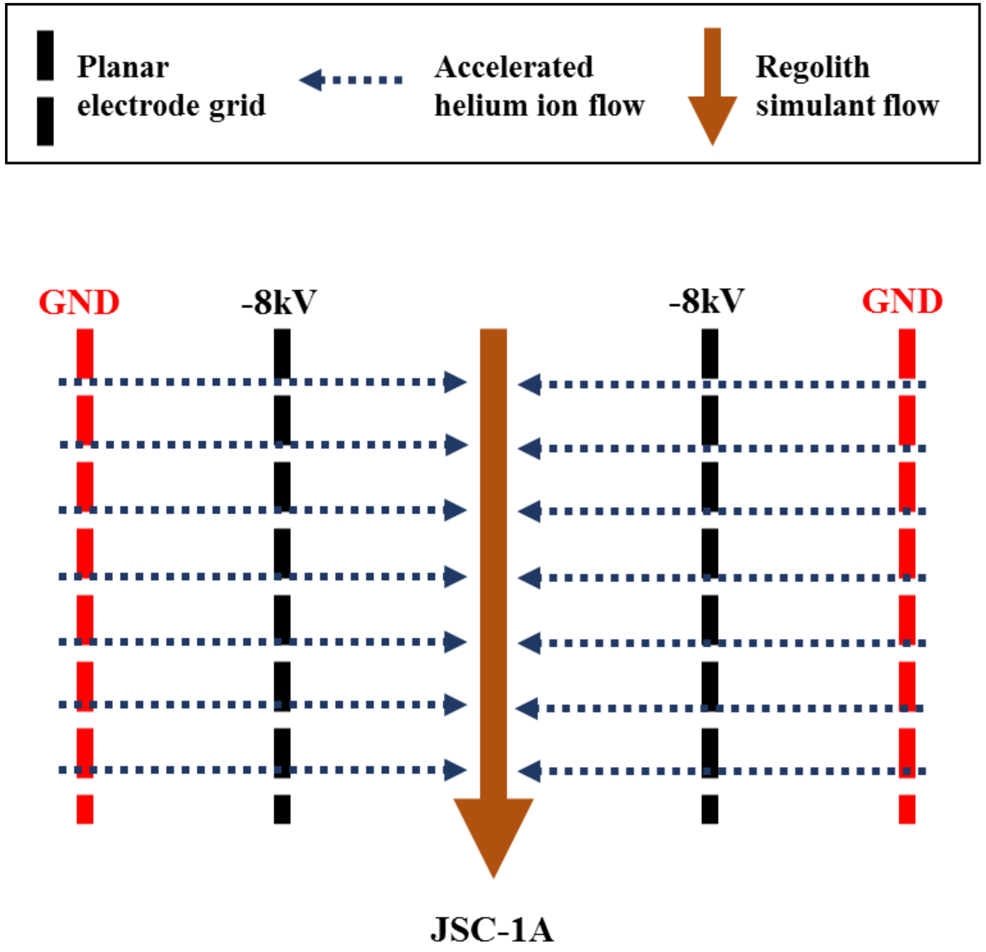
- Implantation energy: ~1 keV/amu (solar wind)
- Aim for 20 ppb ^4He concentration
- ^4He diffuses out of regolith like ^3He (use ^4He for cost)

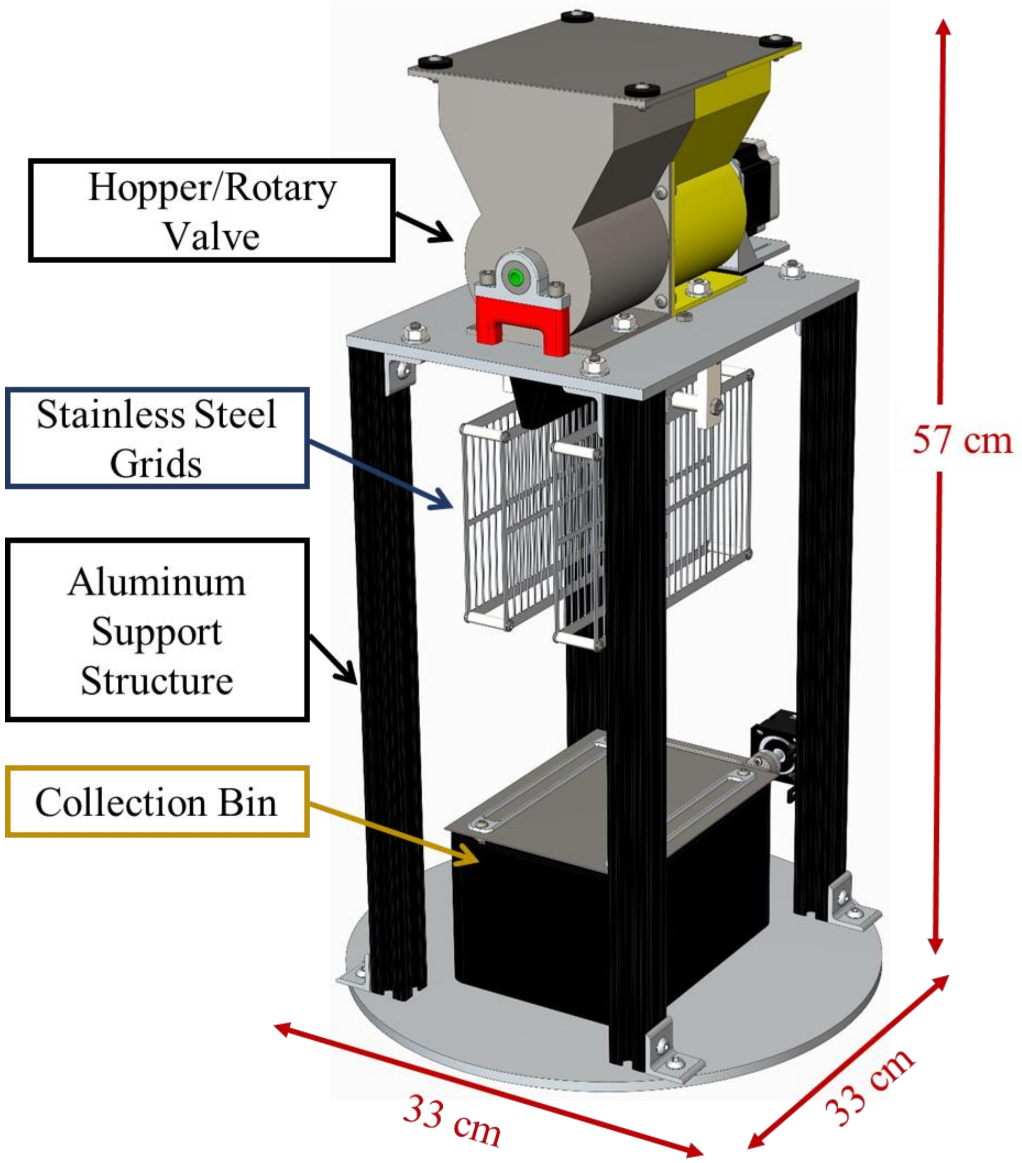
Implantation Characterization

- Helium release vs. temperature
- Measure the released helium relative to any background ^4He concentration



SWIM Concept and Components





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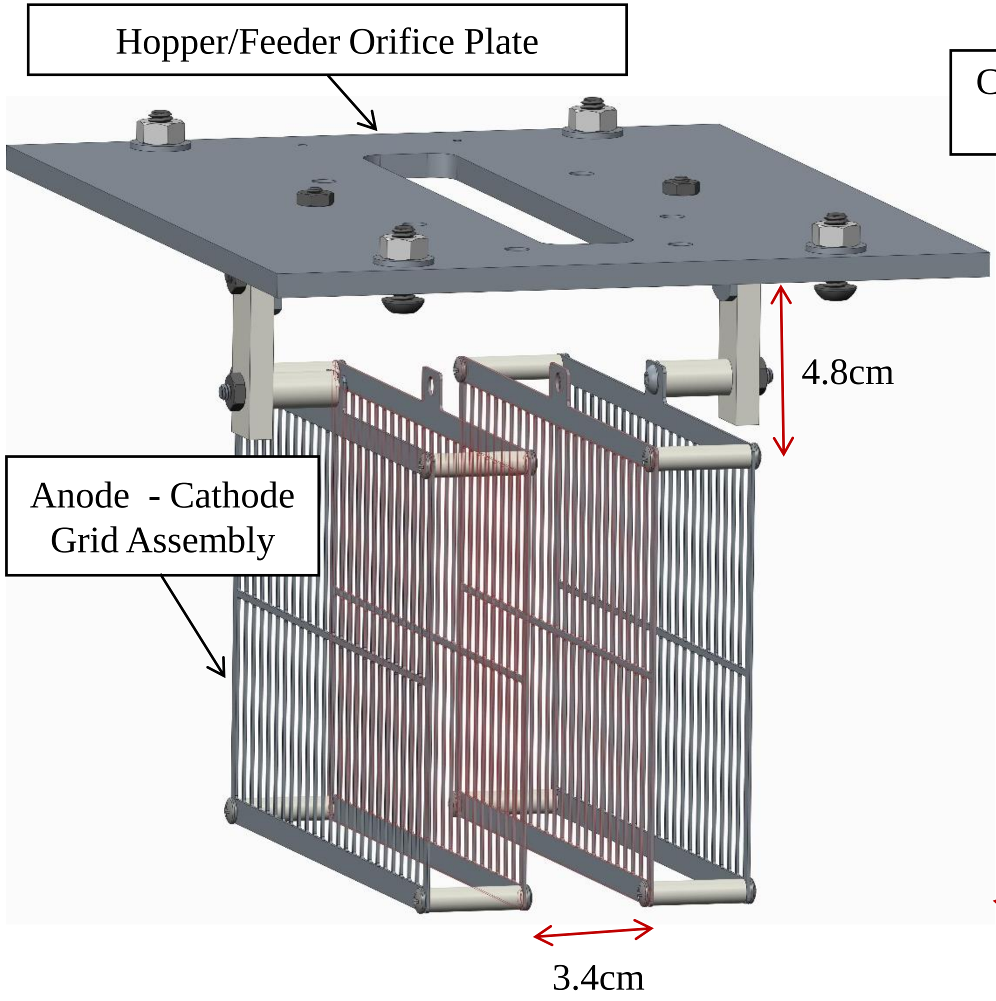
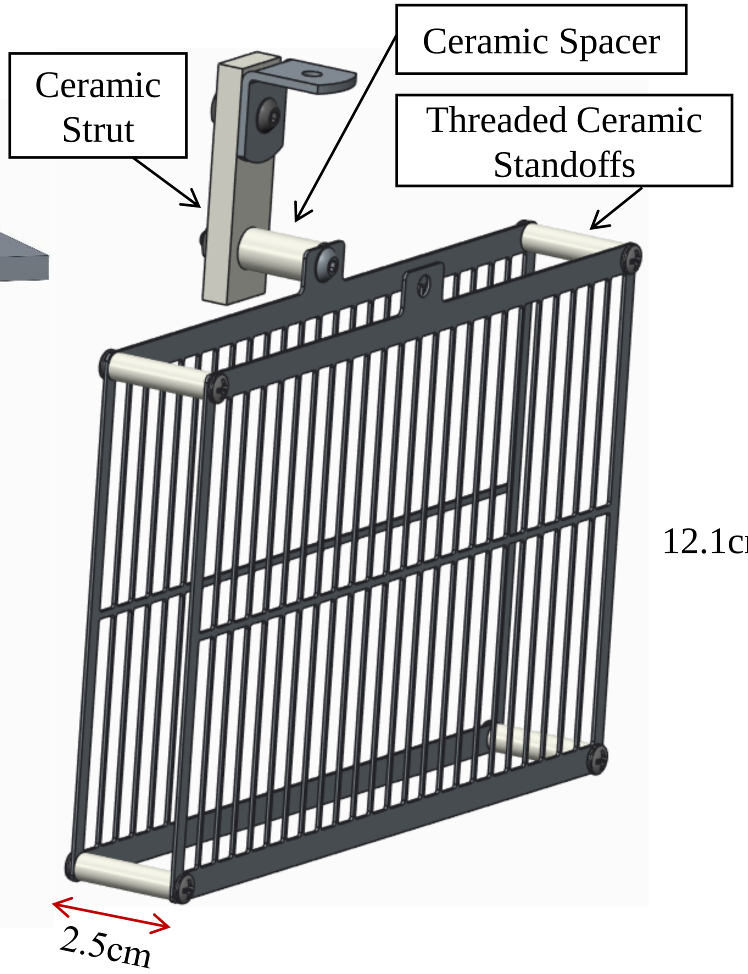
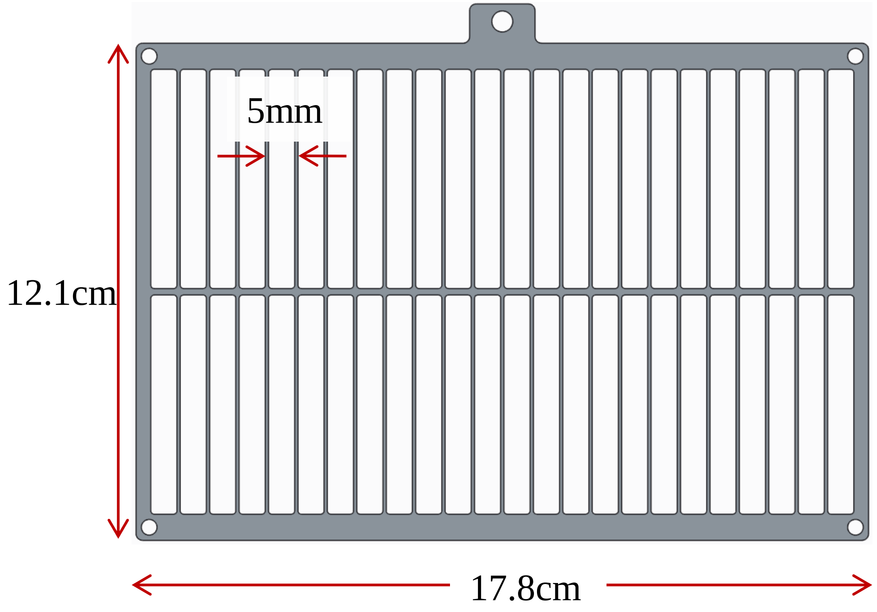
UNIVERSITY OF WISCONSIN–MADISON

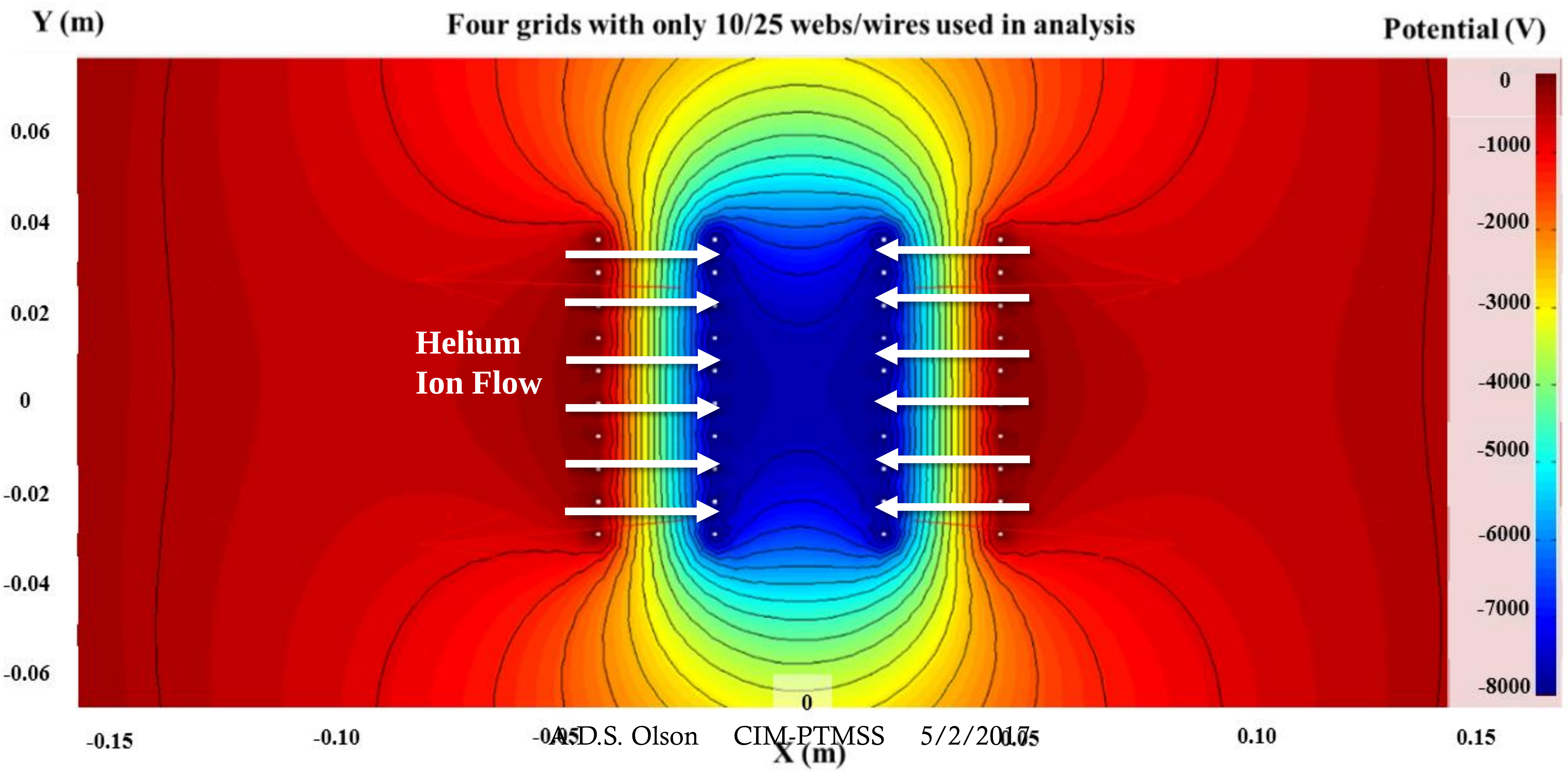
SWIM: Acceleration Grid Assembly



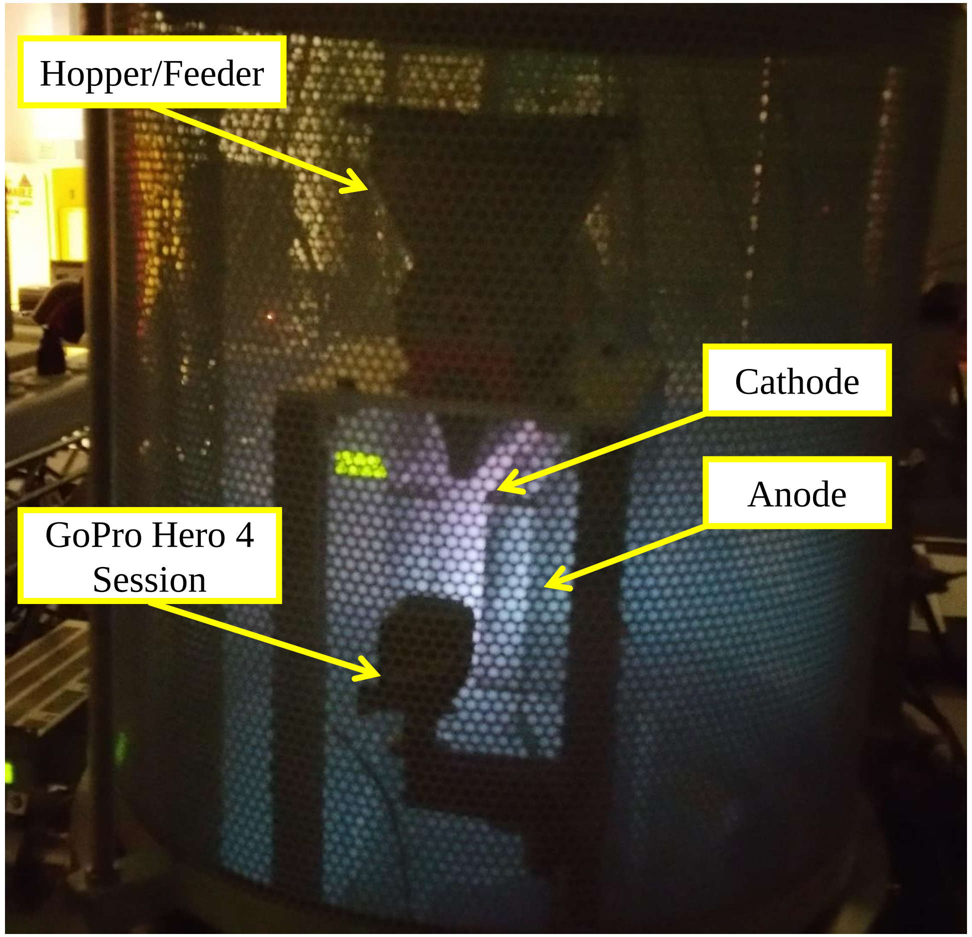




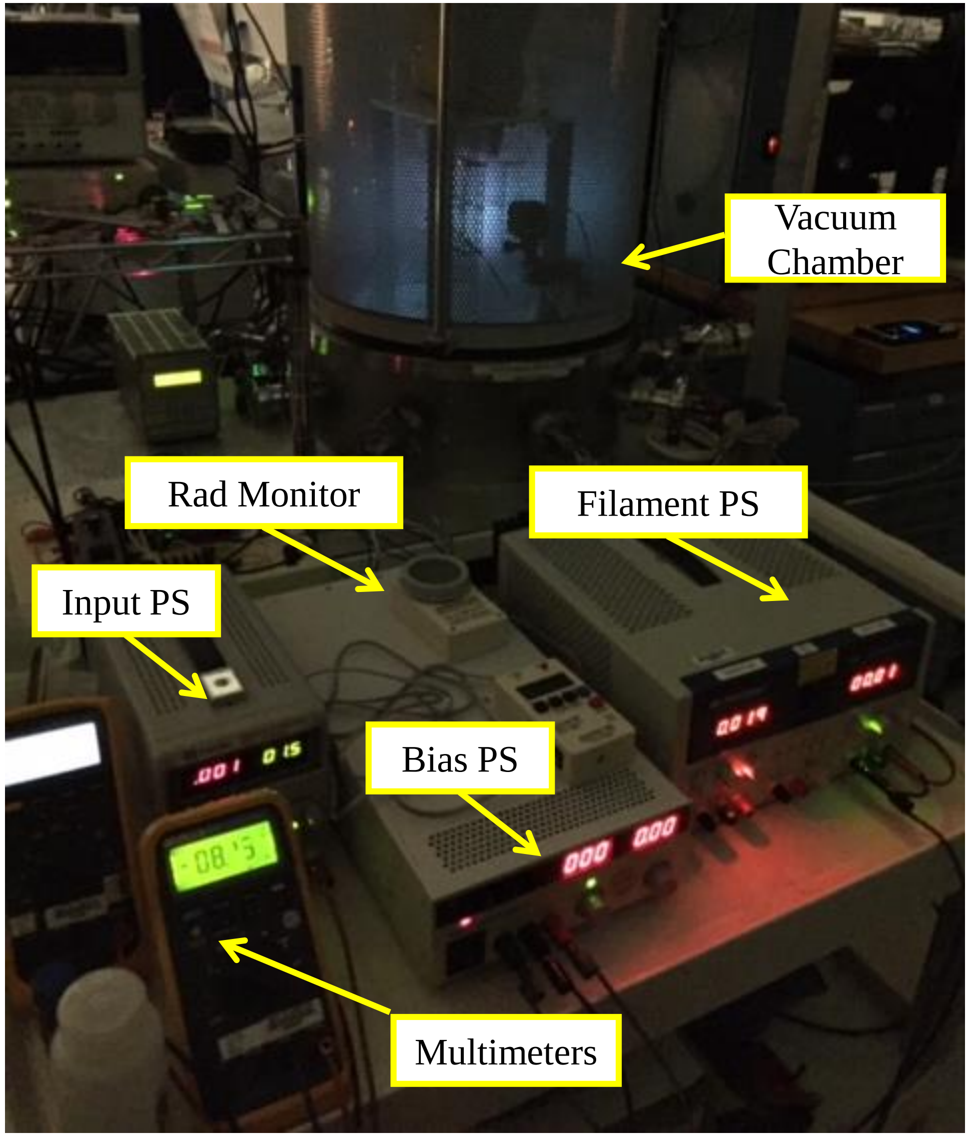
SWIM: Acceleration Grid Electrostatic Potential



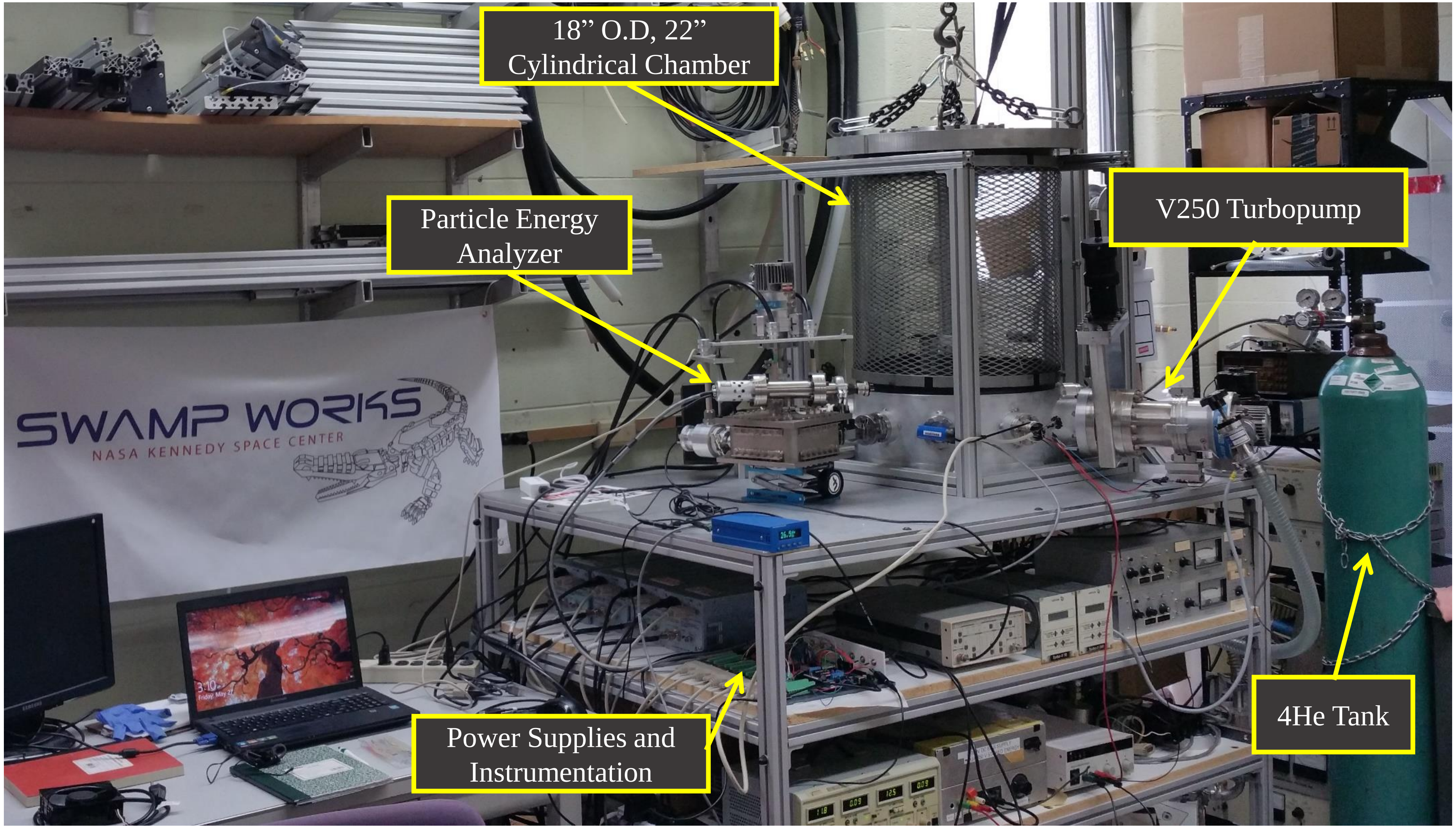
SWIM: Setup at NASA KSC ESPL



- HV amplifier (±10kV,10mA)
- HV input power supply
- Filament bias power supply (600V, 1.7A)
- Filament power supply (30V,4A)
- Multimeters to measure output voltage and current
- AdAware radiation monitor
- Varian 301 turbo pump, gate valve, and controller
- Scroll pump
- Extorr 300 RGA
- 18”x30” bell jar and 8-port feed through collar
- Helium K bottle
- Baratron gauges
- Ion gauge



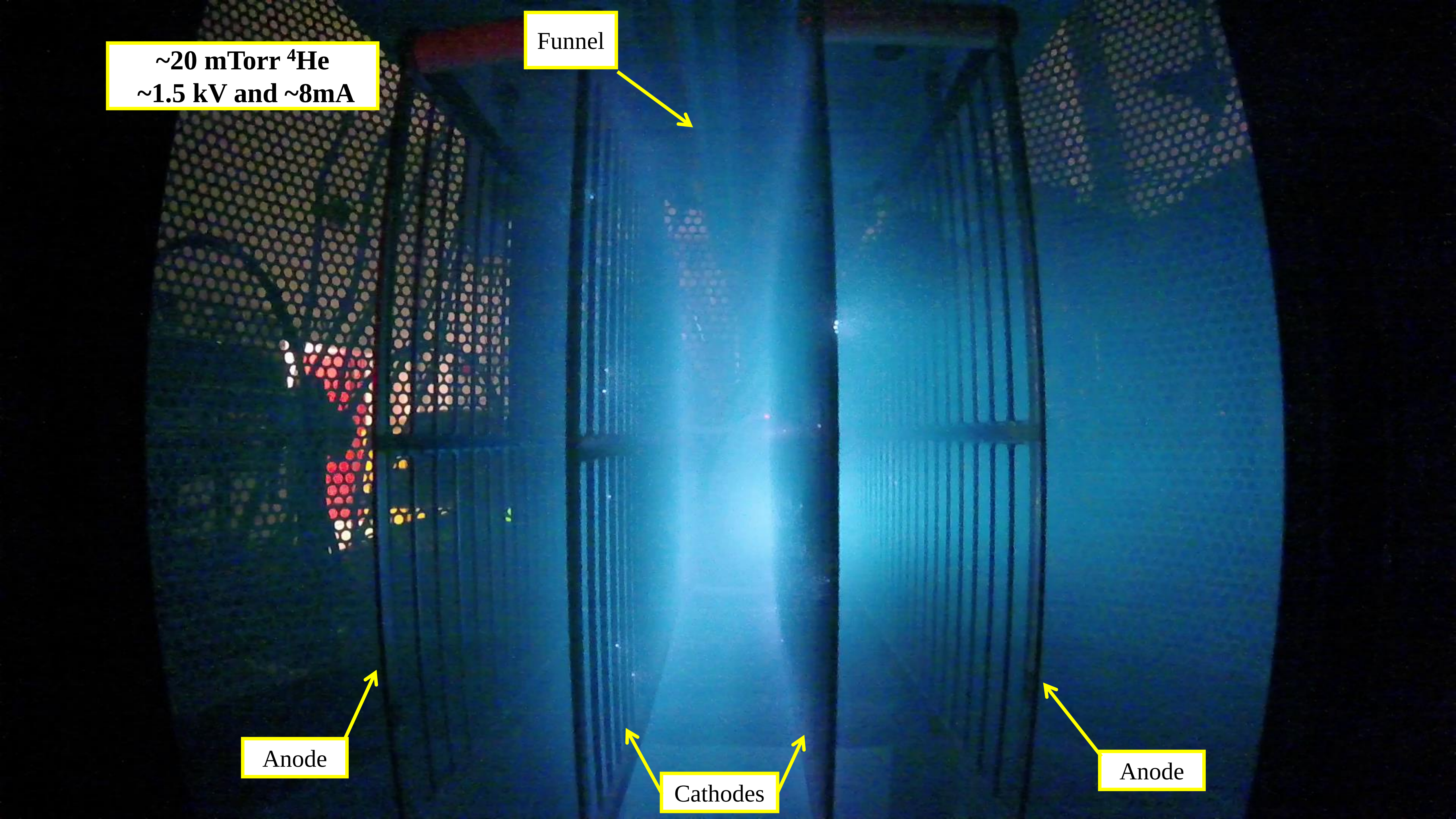
SWIM Setup Replicated in FTI Lab for Continued Testing



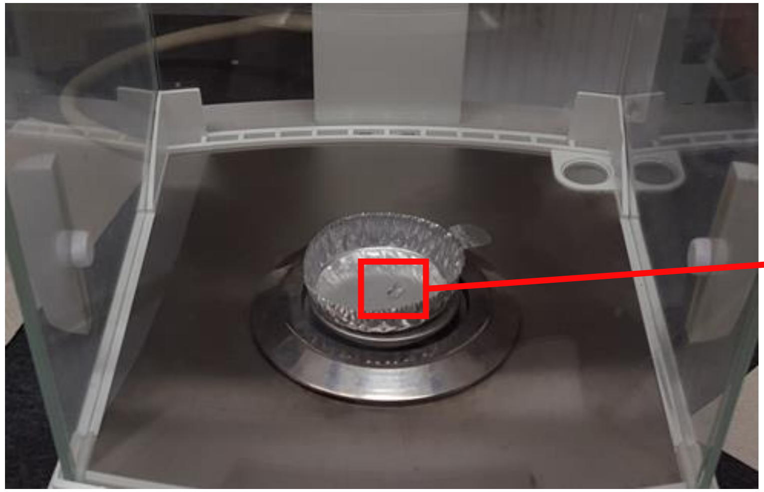

Pressure = 0.08mTorr ^{4}He
Grid Voltage = 8kV
Grid Current= 4.96mA
Filament Voltage = 19.9V
Failament Bias = -300V
72.3 g of <100 micron
JSC-1A simulant
implanted
2.5cm
Funnel
Tungsten Filament
5 mil diameter wire
Anode
Anode
Cathodes

Pressure = 0.08mTorr ^{4}He
Grid Voltage = 8kV
Grid Current= 4.96mA
Filament Voltage = 19.9V
Failament Bias = -300V

72.3 g of <100 micron JSC-1A simulant implanted
2.5cm
Simulant Flow
5 mil diameter wire
Tungsten Filament
Anode
Cathodes
Anode

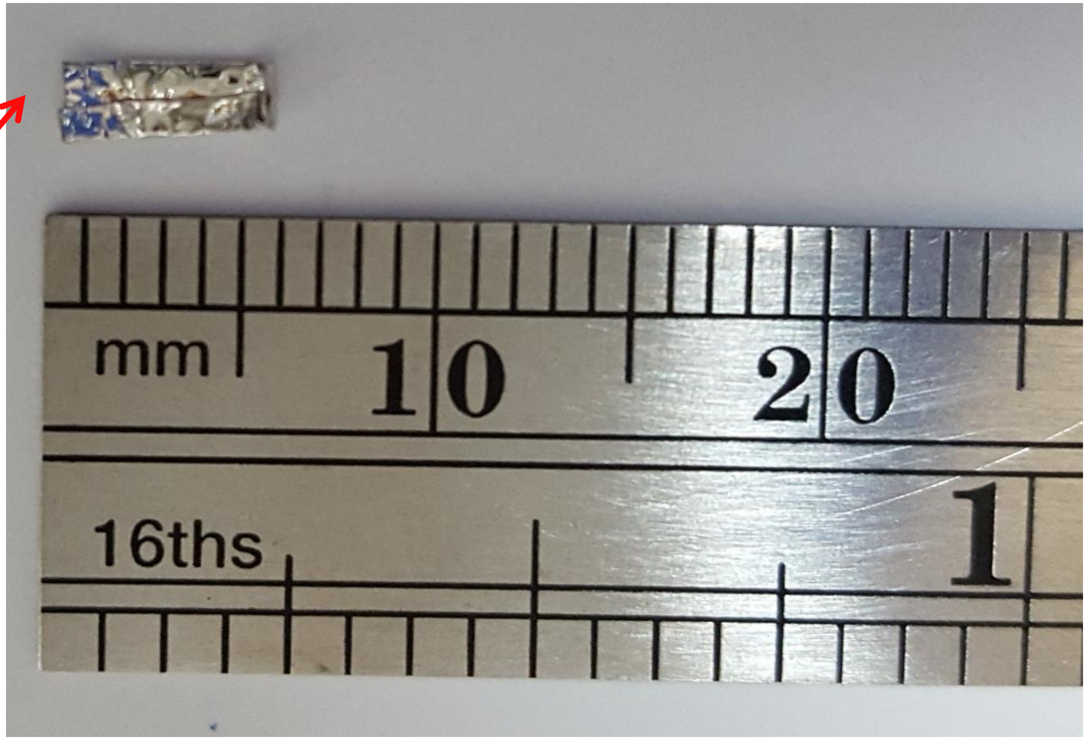

~20 mTorr ^4He
~1.5 kV and ~8mA
Funnel
Anode
Cathodes
Anode

Helium Release vs. Temperature Samples



~92 µg weighed in Pt foil

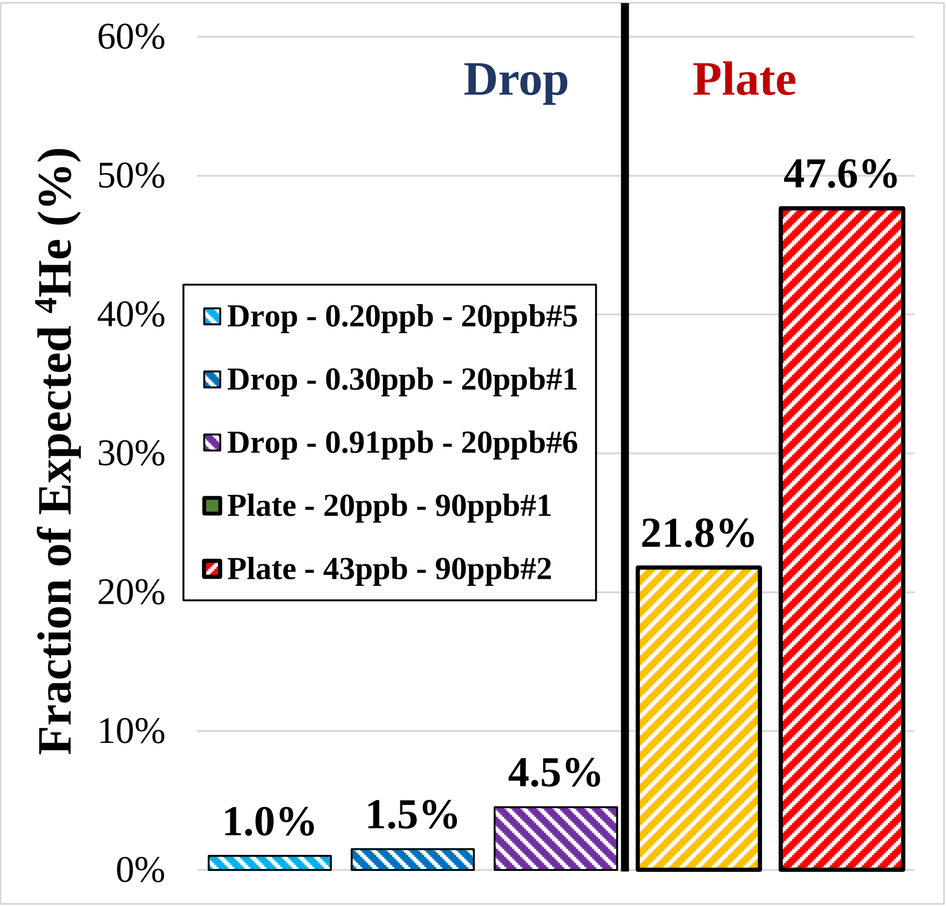
~92 µg in Pt foil

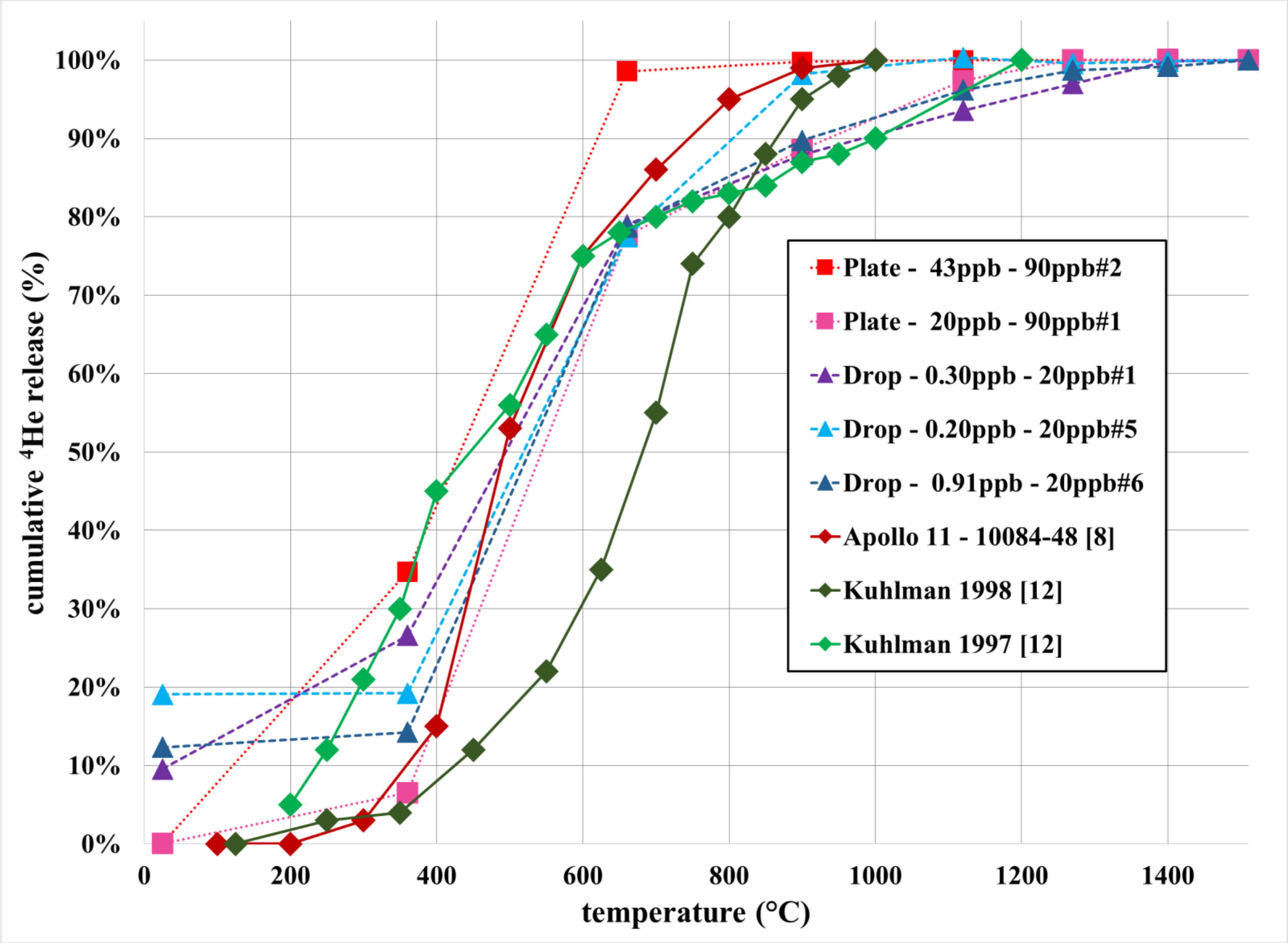


Sample wrapped 5mm x 5mm Pt foil

- Data from 6 samples wrapped in Pt foil
- Nominally 100µg (63 µg min, 214 µg max)
- Heated for 10 seconds in steps:
- 25, 360, 660, 900, 1120, 1270, 1400, 1510°C ±30°C
- Mass spectrometer data (counts/sec): 5 scans of 2 second integration time

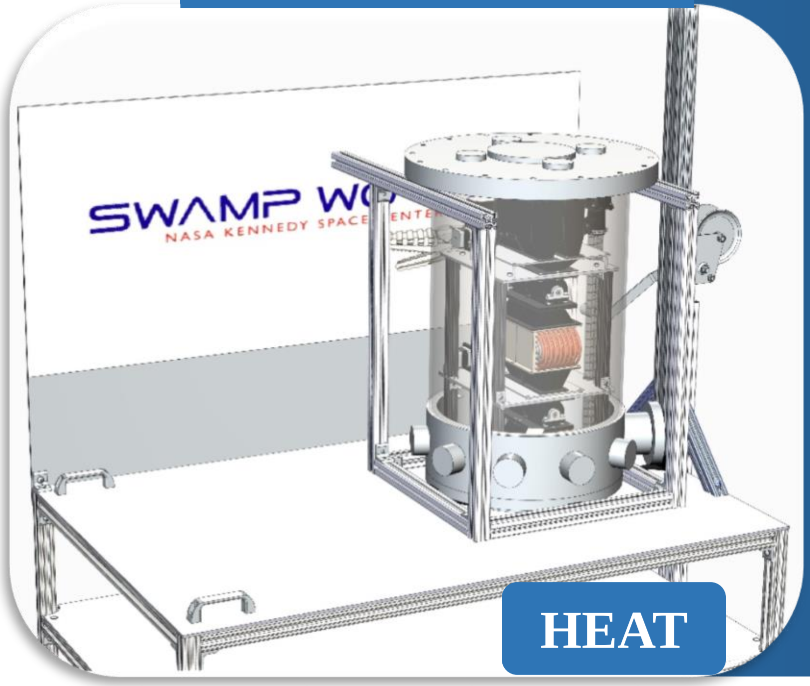
SWIM Sample Results: Helium Release vs. Temp





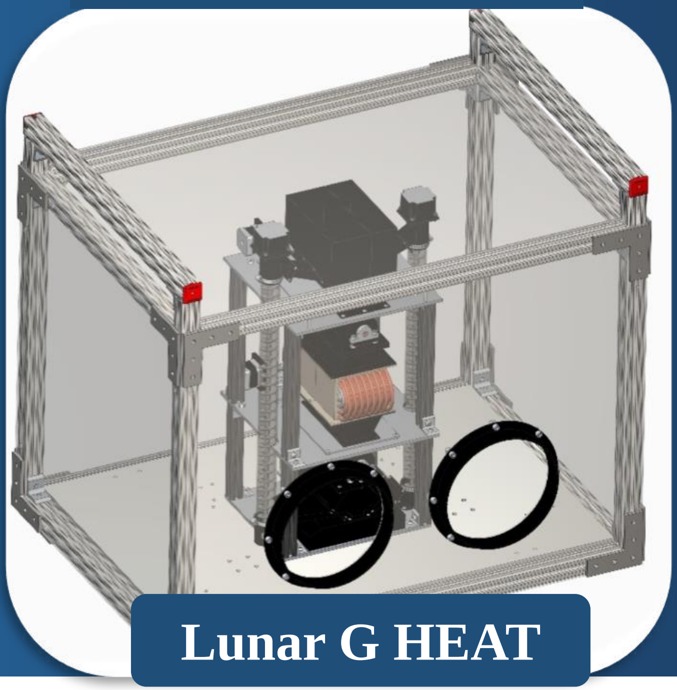
Potential Path of Research and Development

Phase 1: Lab



HEAT

Phase 2: Lunar G



Lunar G HEAT

Phase 3: Lunar Surface

Pilot Volatiles Extractor

Application to General Space Resources Field

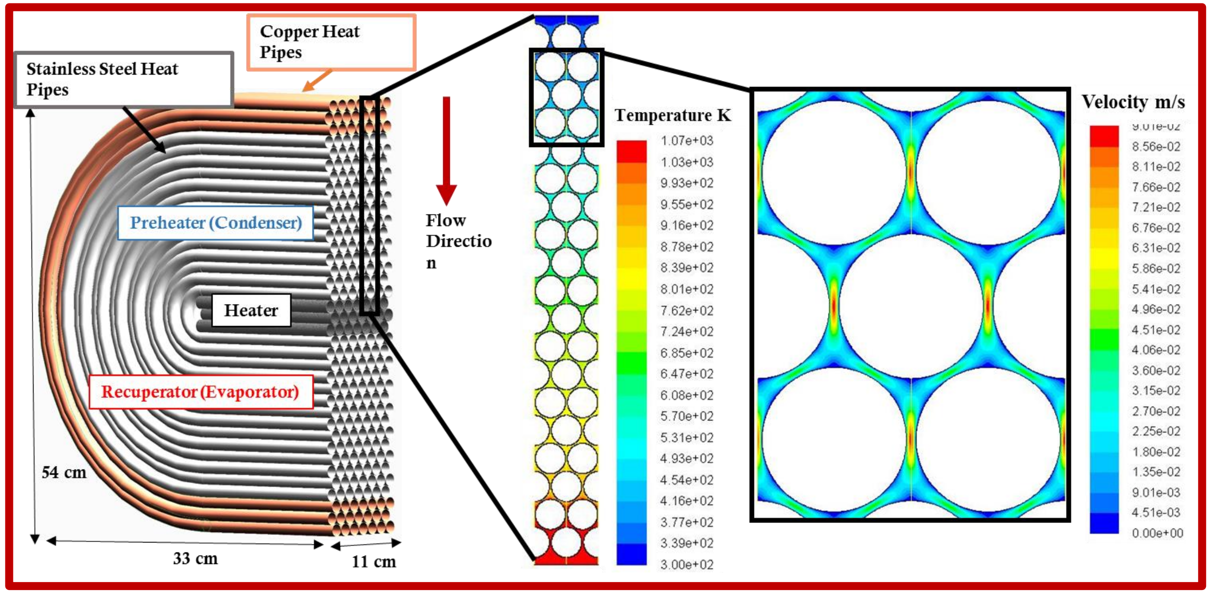
SWIM

- Implantation of other volatiles
- Simulation of space weathering effects

HEAT

- Heat recuperation with heat pipes
- Granular flow in heat exchangers
- Volatile gas release measurement with residual gas analyzers

JSC-1A Lunar Simulant
(Credit: Orbitec)



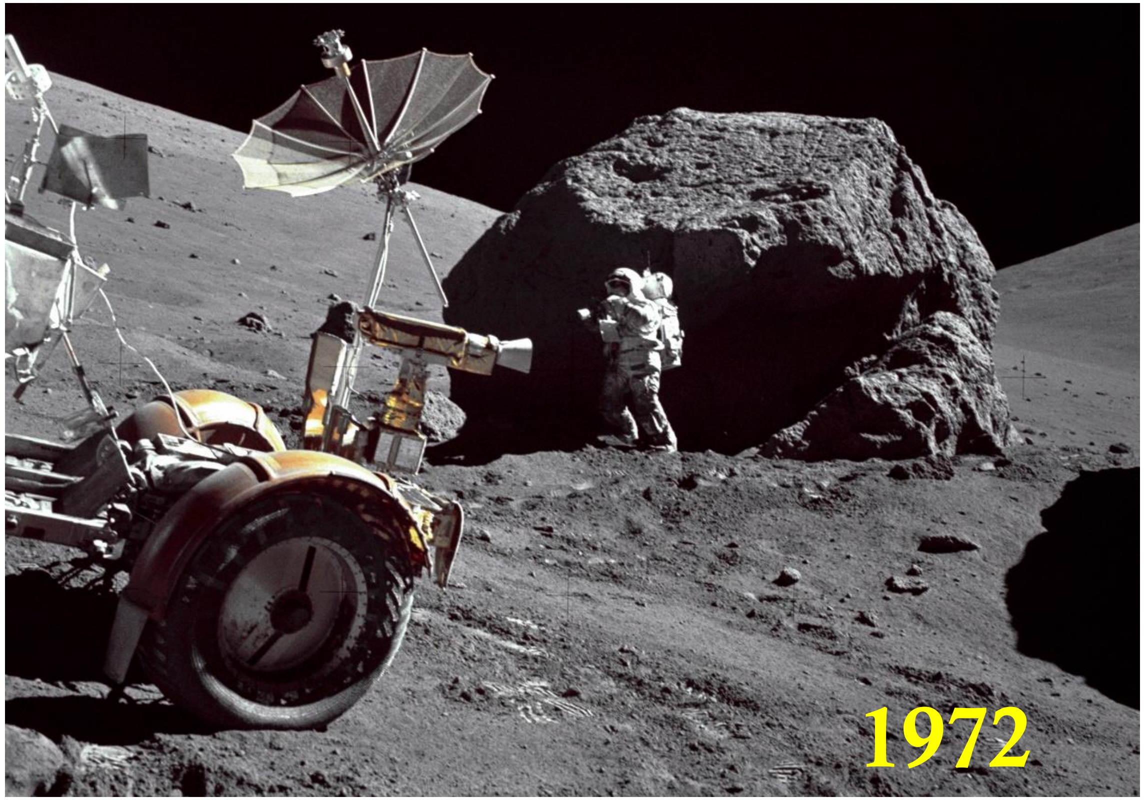
Conclusion: Progress and Future Work

- Conclusions
  - HEAT granular flow system in construction
  - SWIM designed and can produce implanted simulant
  - Samples release helium vs. temperature similarly to Apollo sample 10084-48
  - Possible to implant to and above 20ppb of helium

- Up Next:
  - HEAT HPHX modeling, assembly and testing
  - Gas release testing (RGA He vs. time measurements)

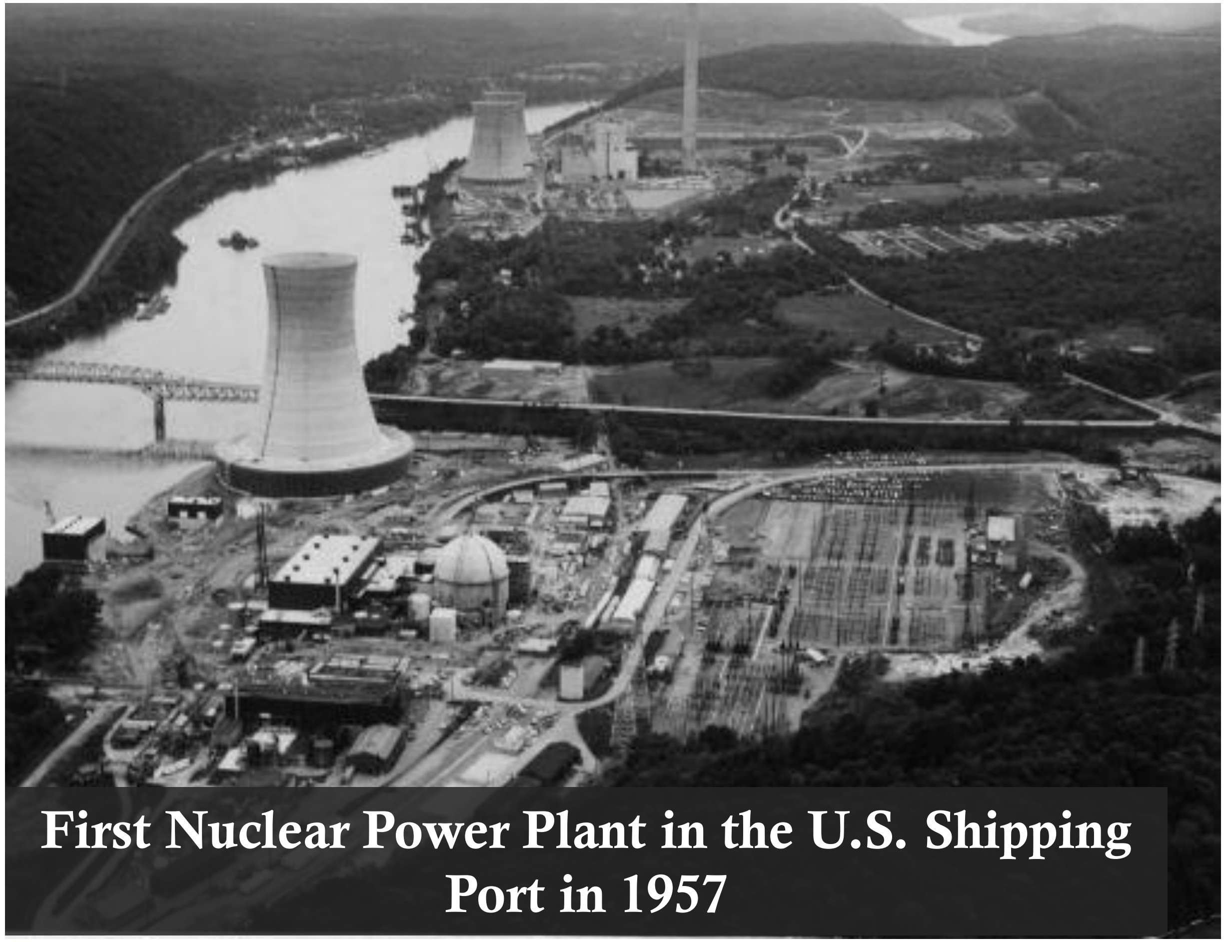
Mining ^{3}He Could Happen Sooner than you Think

"Space travel is utter bilge." –Dr. Richard Wooley, Astronomer Royal, space advisor to the British government, 1956

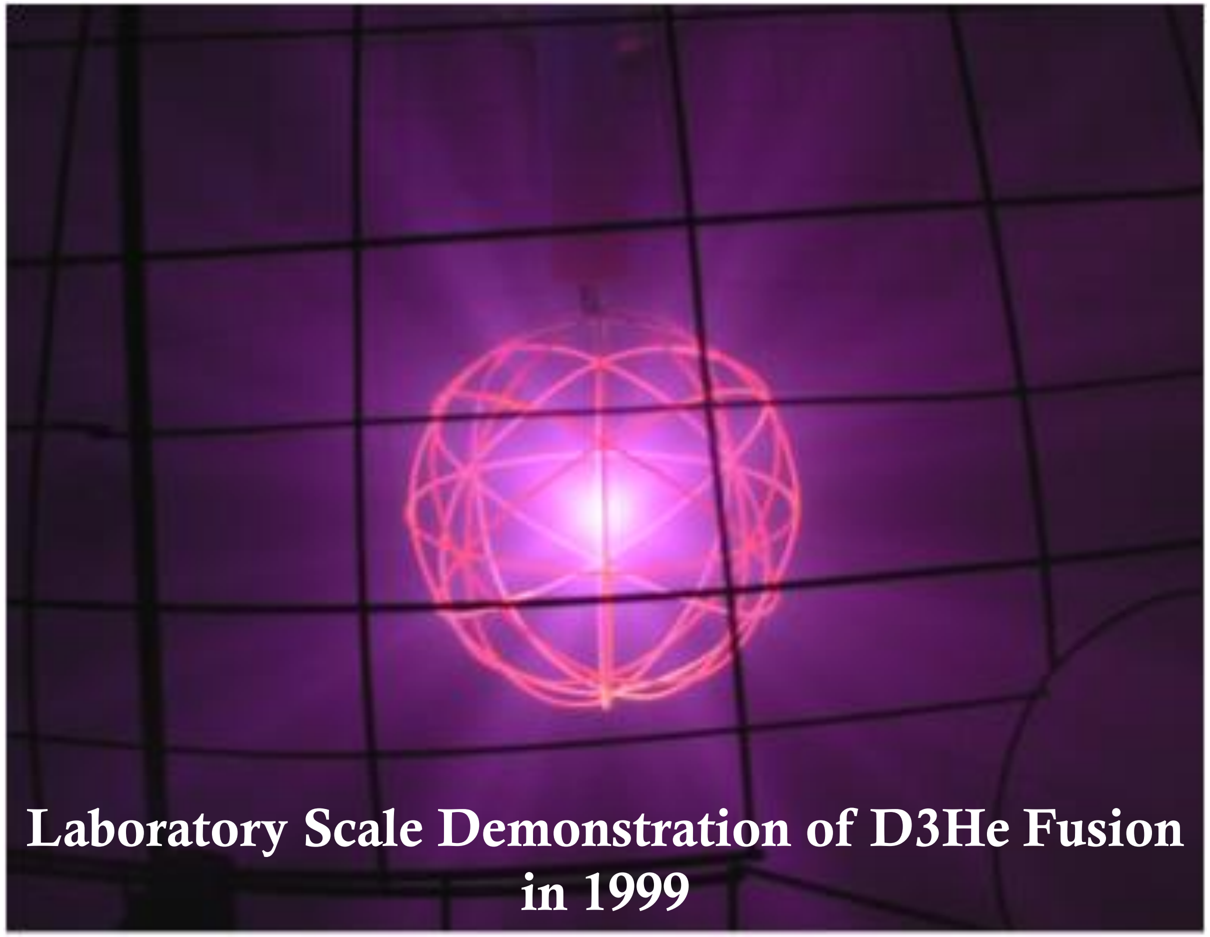


Fusion Could Happen Sooner than you Think

"Anyone who looks for a source of power in the transformation of the [nucleus of the] atom is talking moonshine." –Ernest Rutherford, 1933



First Nuclear Power Plant in the U.S. Shipping Port in 1957



Laboratory Scale Demonstration of D3He Fusion in 1999

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- Class of 2014
- Collaboration with Kennedy Space Center

SWAMP WORKS
NASA KENNEDY SPACE CENTER

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