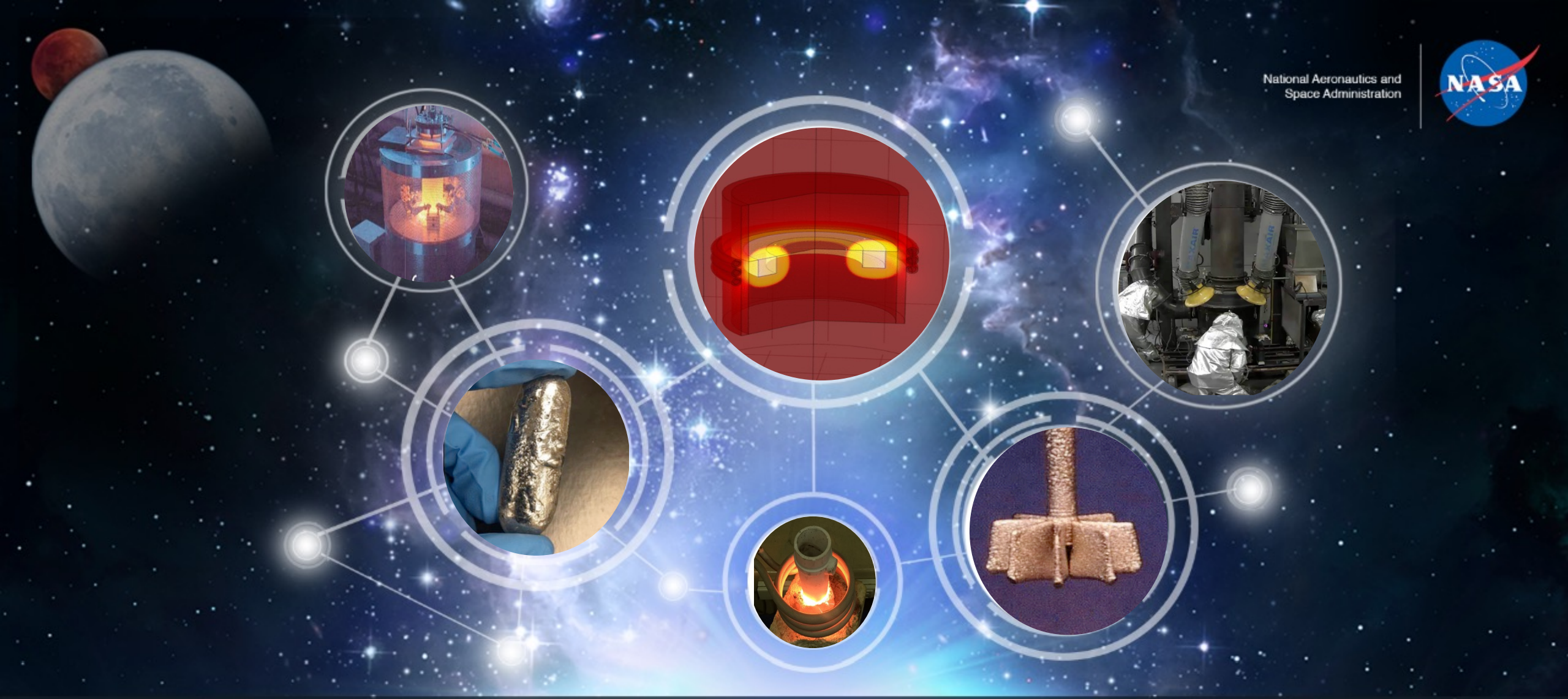


National Aeronautics and Space Administration

NASA

GALORE (Gaseous Lunar Oxygen from Regolith Electrolysis): Successful Demonstration of a Cold-Walled Molten Regolith Electrolysis Reactor Design in a Vacuum Environment

NASA: Kevin D. Grossman, Elspeth Petersen, Evan Bell, Jaime Toro-Medina,
SURA: Laurent Sibille Honeybee Robotics: Hunter Williams, Timothy Newbold, Kris Zacny RDO Induction: Iain Bates

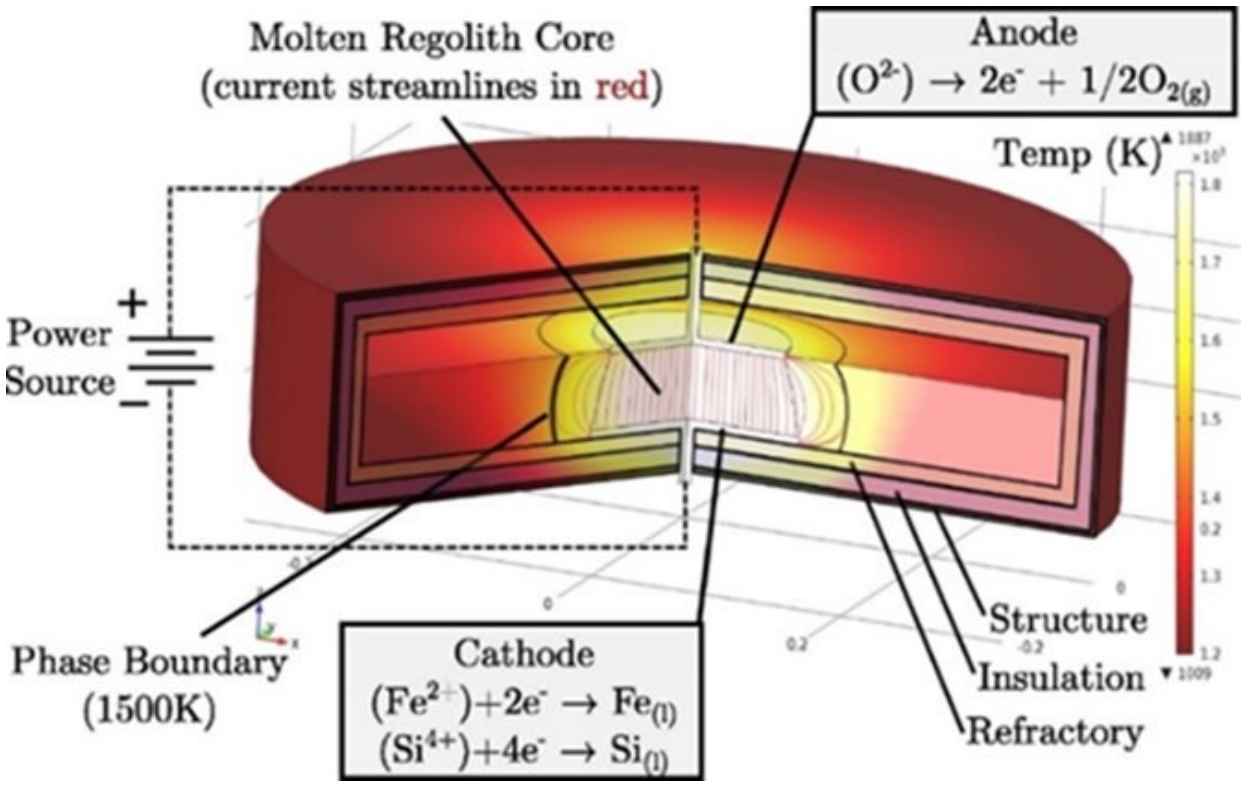
MRE Technology Overview

The MRE reactor design enables **one-step electrolysis of regolith into metal and oxygen** without the need for fluxing agent, and without catalyst or consumable reagents.

$$Regolith + e^{-} \rightarrow Metal + O_2$$

Produces oxygen and a ferrosilicon alloy, with other inclusions, that can be further processed.

Operating temperature for MRE is set at (or above) 1600°C to keep regolith and metal products (ferrous alloys) in molten state.



2

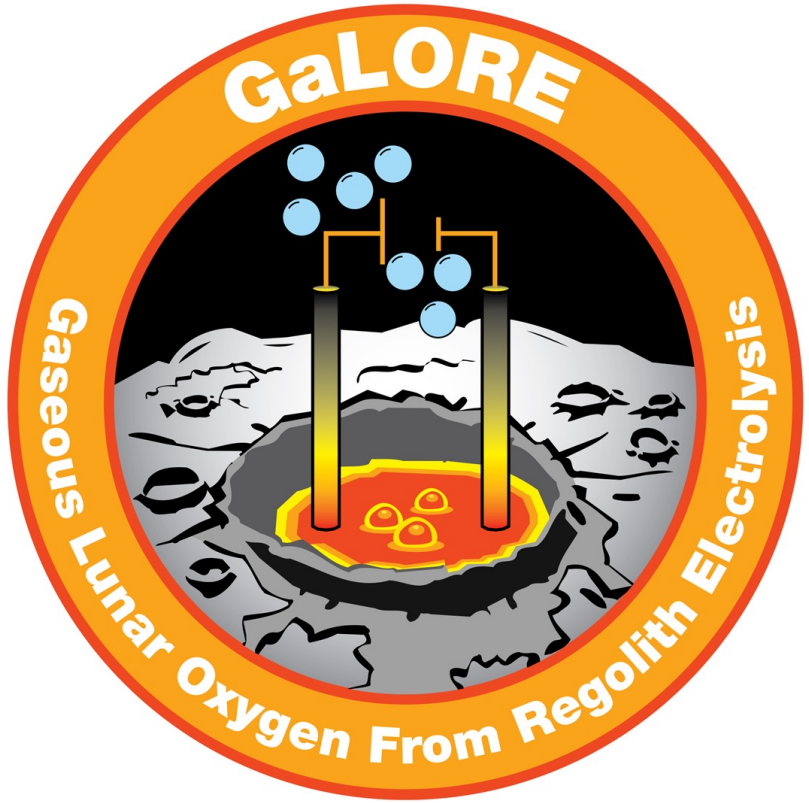
Challenge: Containment materials fail in corrosive environment of molten metals, regolith and high temperature oxygen

Project Objectives

- The Gaseous Lunar Oxygen from Regolith Electrolysis (GaLORE) project aims to build a prototype molten regolith electrolysis (MRE) reactor that can produce oxygen and metals from any regolith found on the moon.

- **Phase I (year 1):** Design, build and test heater devices to melt regolith in a localized region between electrodes.

- **Phase II (year 2):** Integrate heater device(s) into reactor prototype to melt regolith and then electrolyze the produced melt.



- **Produced Materials:** Metals and oxygen produced from this technology will be analyzed to determine production rates, production energy requirements, purity, in-situ behavior, etc.

Induction Heating
- Atmospheric testing -

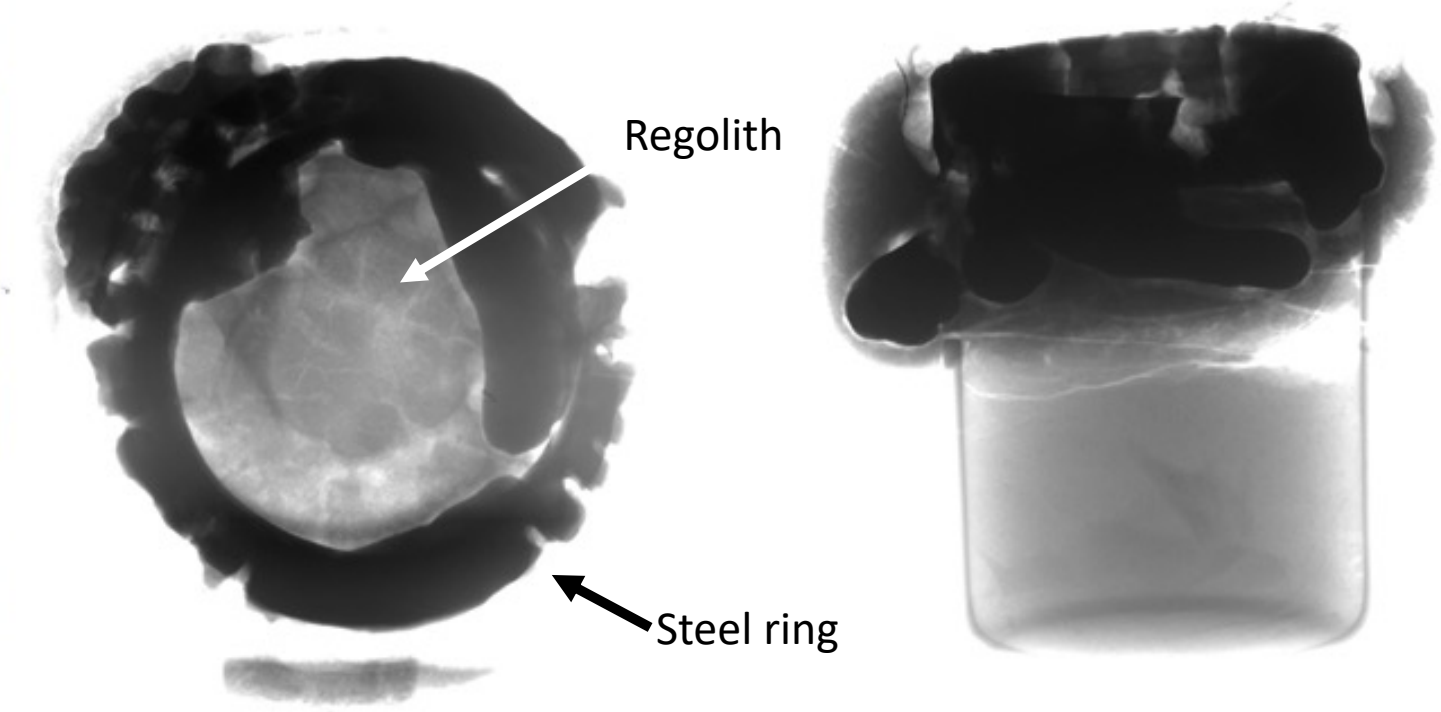
Induction heating using 17.7 cm coil

- Up to 8 kW of power
- Steel ring susceptor (10cm OD, 7.5 cm ID and 3 cm height
- Buried 1 cm deep in LHS-1 (Exolith labs, UCF)

Temperature set point: 1400°C

Total Test runtime: 1 hour, roughly 30 minutes until melt

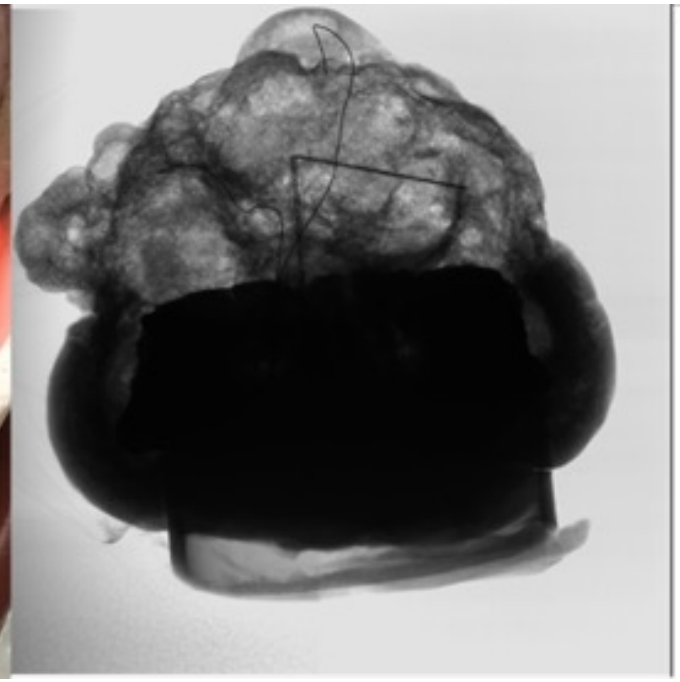
X-ray images (below)

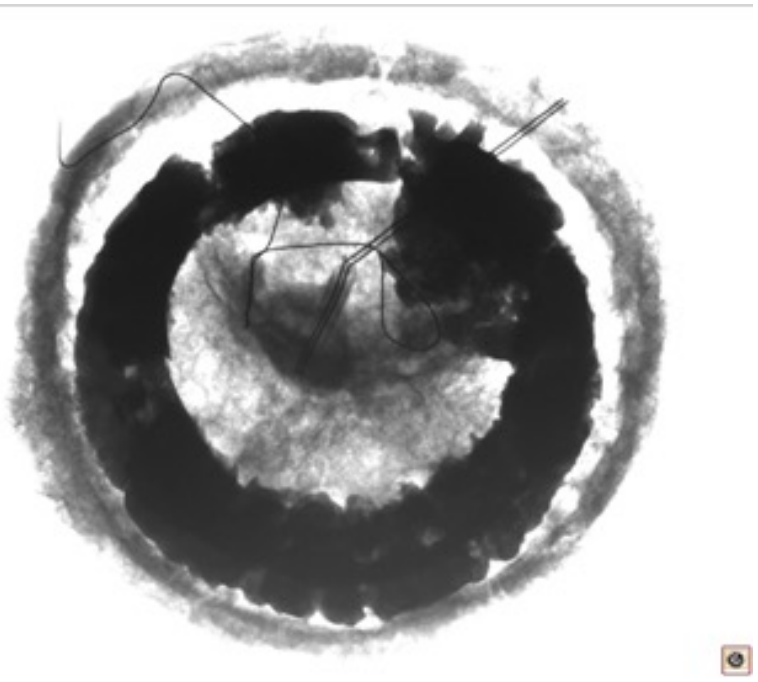


Ambient Induction Melting Test

Induction Heating
- Atmospheric testing -

Steel ring susceptor was reheated to 1400 °C
Trapped gases expanded and were unable to escape

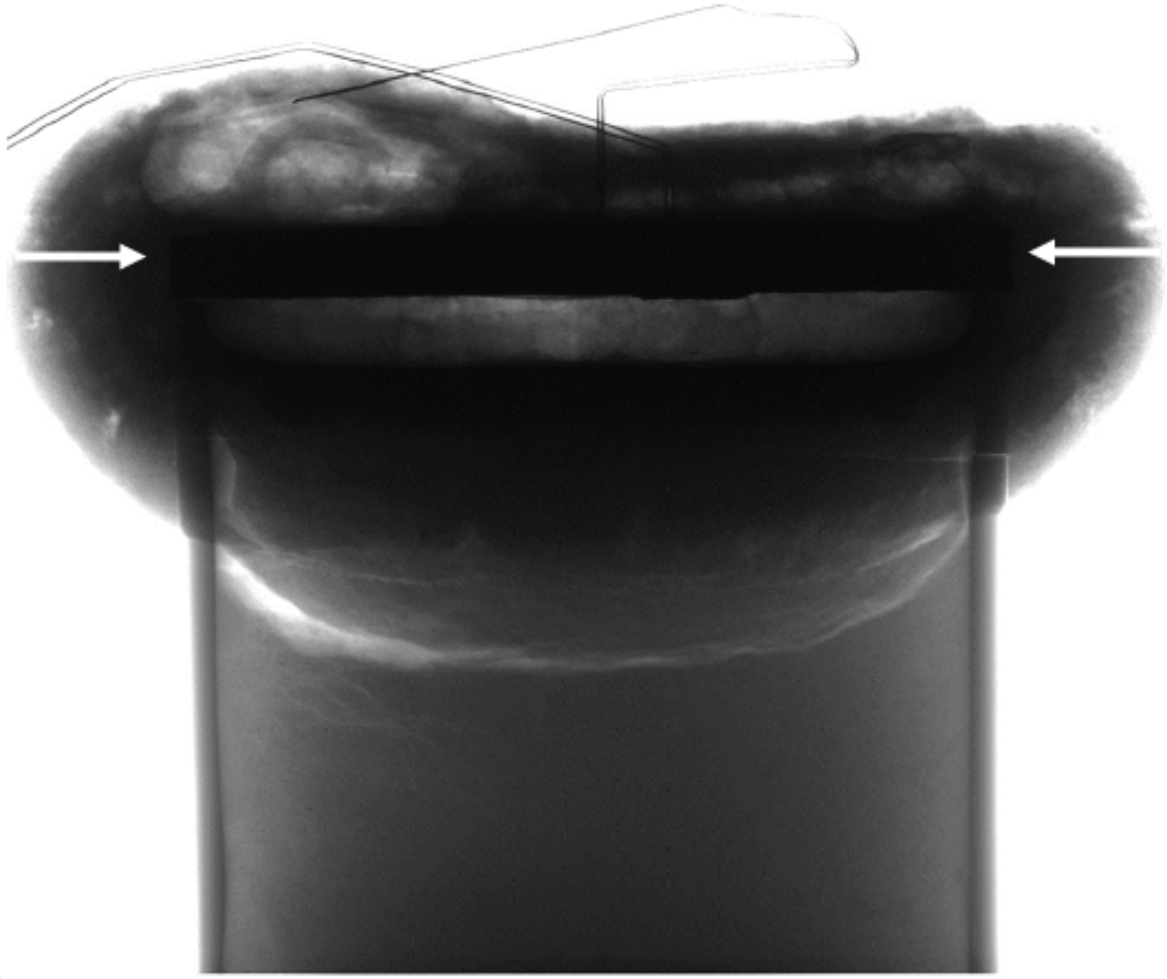




Induction Heating
- Atmospheric testing -

Repeated the same induction heating test with a tantalum disk instead of a ring.

Tantalum withstood the melting process much better.

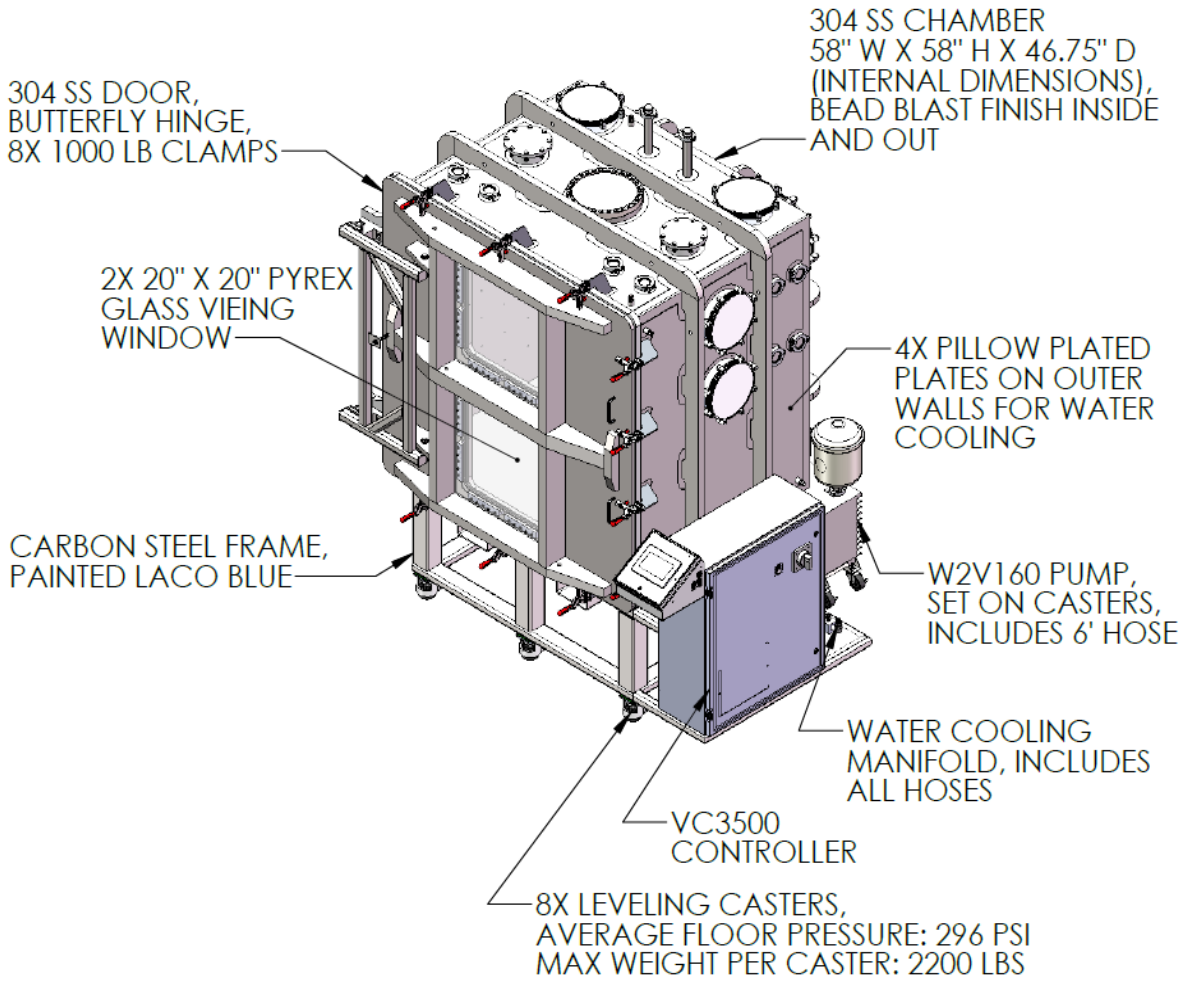


Test Facility

Atmospherically Sealed Simulator for In-situ System Testing (ASSIST)

- Features
  - Large Internal Dimensions (5ft w x 4ft d x 5ft t)
  - 10^{-3} Torr to 1 Atm Pressure Range
  - External Cooling for Chamber Walls
  - 10” Diameter Quartz Viewport
  - Dedicated dirty chamber

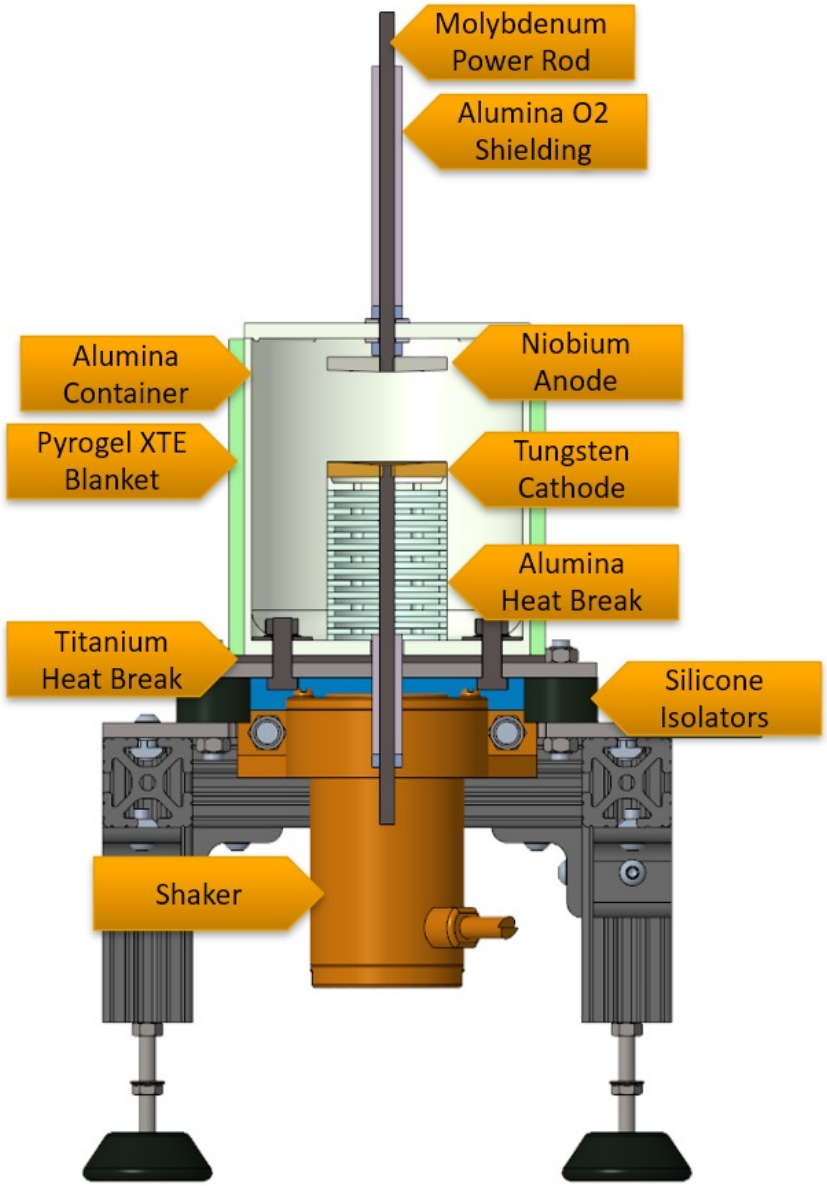
GMRO Facility Mod in place to supply 15kW of electrical power to ASSIST Chamber area



Electrolysis Test Cell

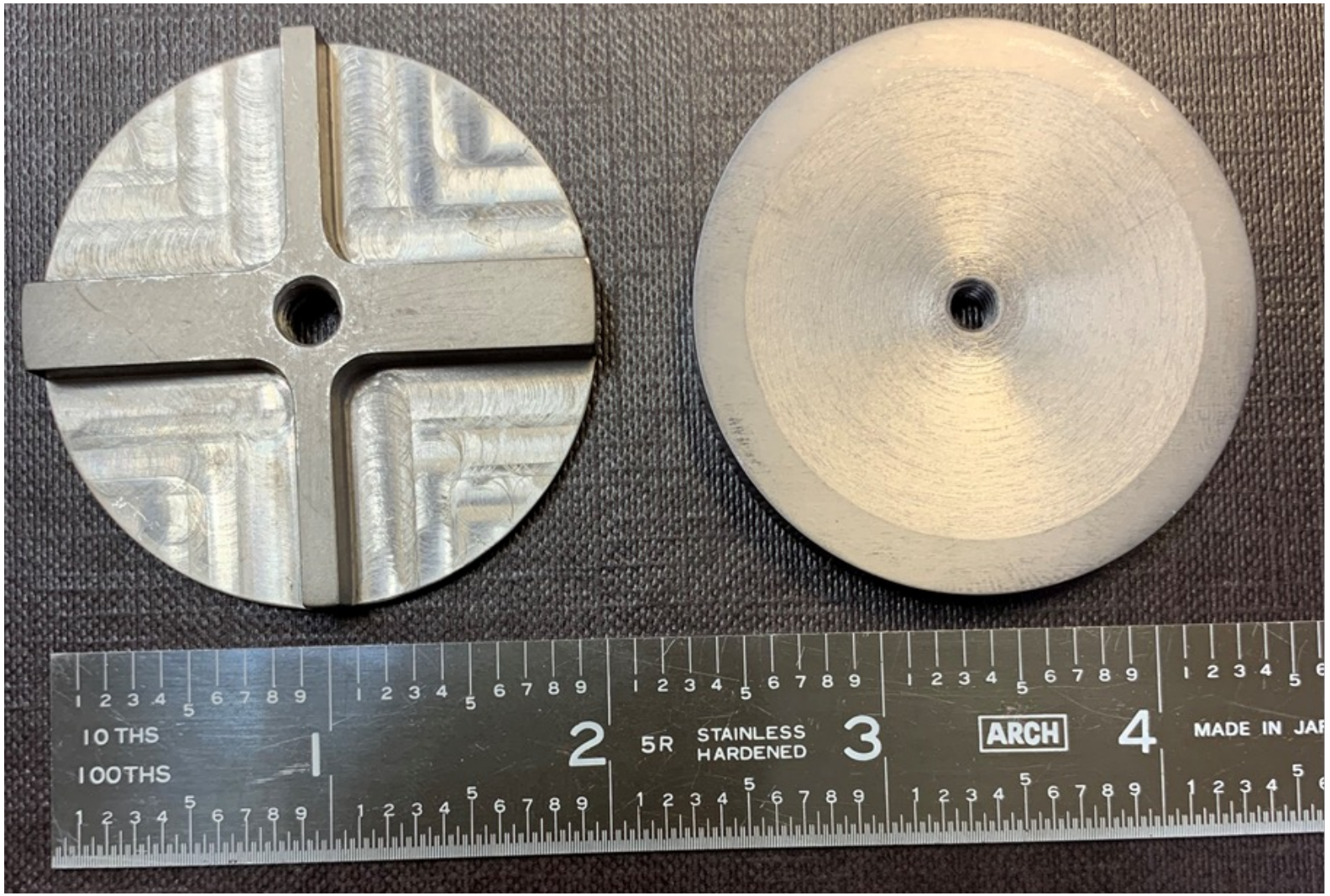
A test cell has been developed at KSC for a cold-walled reactor concept demonstration using an induction heating system directly on a 4 cm diameter electrode.

- Capable of producing a melt by applying induction heating directly on cathode
- Capable of applying up to 510 A to regolith melt to produce oxygen at a rate of up to 0.0012 mol/s of gaseous oxygen.
- Capable of sustaining melt size throughout electrolysis without the use of induction heater due to joule-heating of regolith

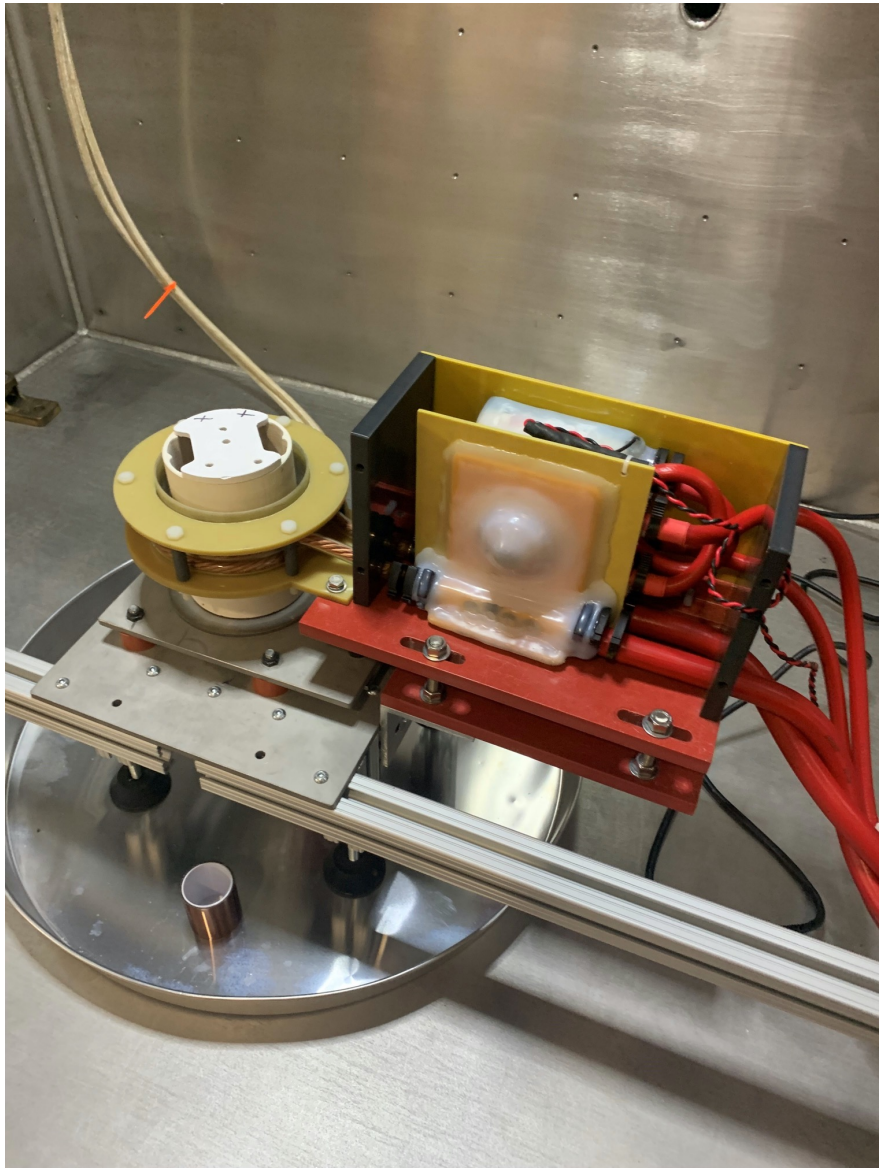


Electrodes

- 10 sets of electrodes.
- Electrodes cut by University of Arizona
- Anodes were coated in platinum by Honeybee Robotics
- U of A using broken electrodes for materials research
  - Melted regolith on material held at temperature for 100 hours.
  - Compare corrosion rates

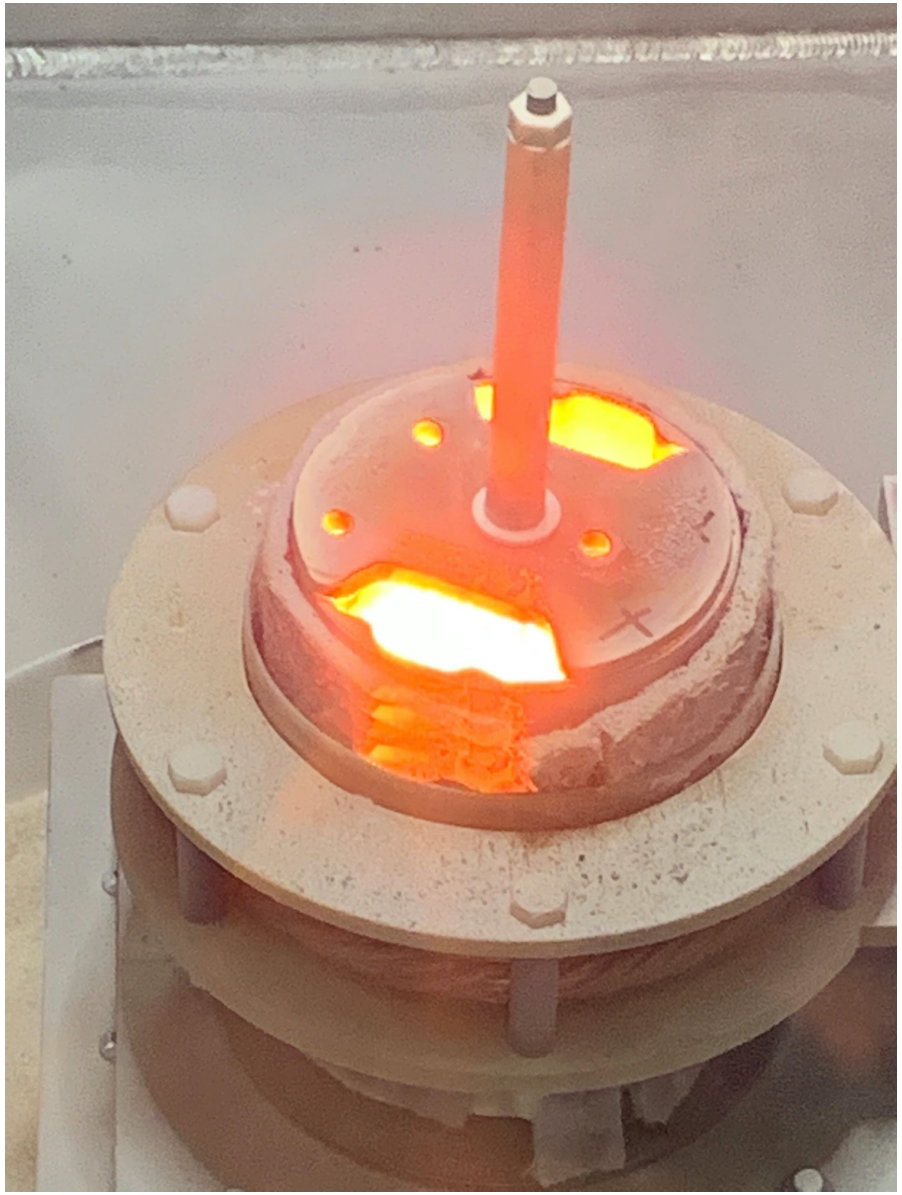


Melt Testing in ASSIST

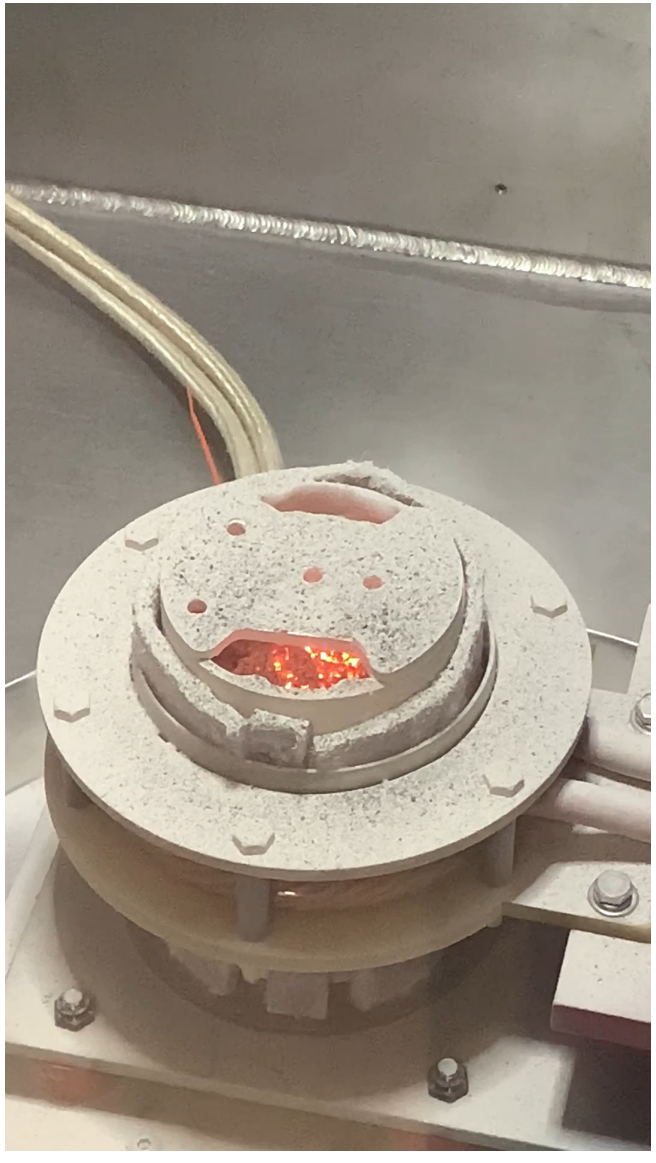


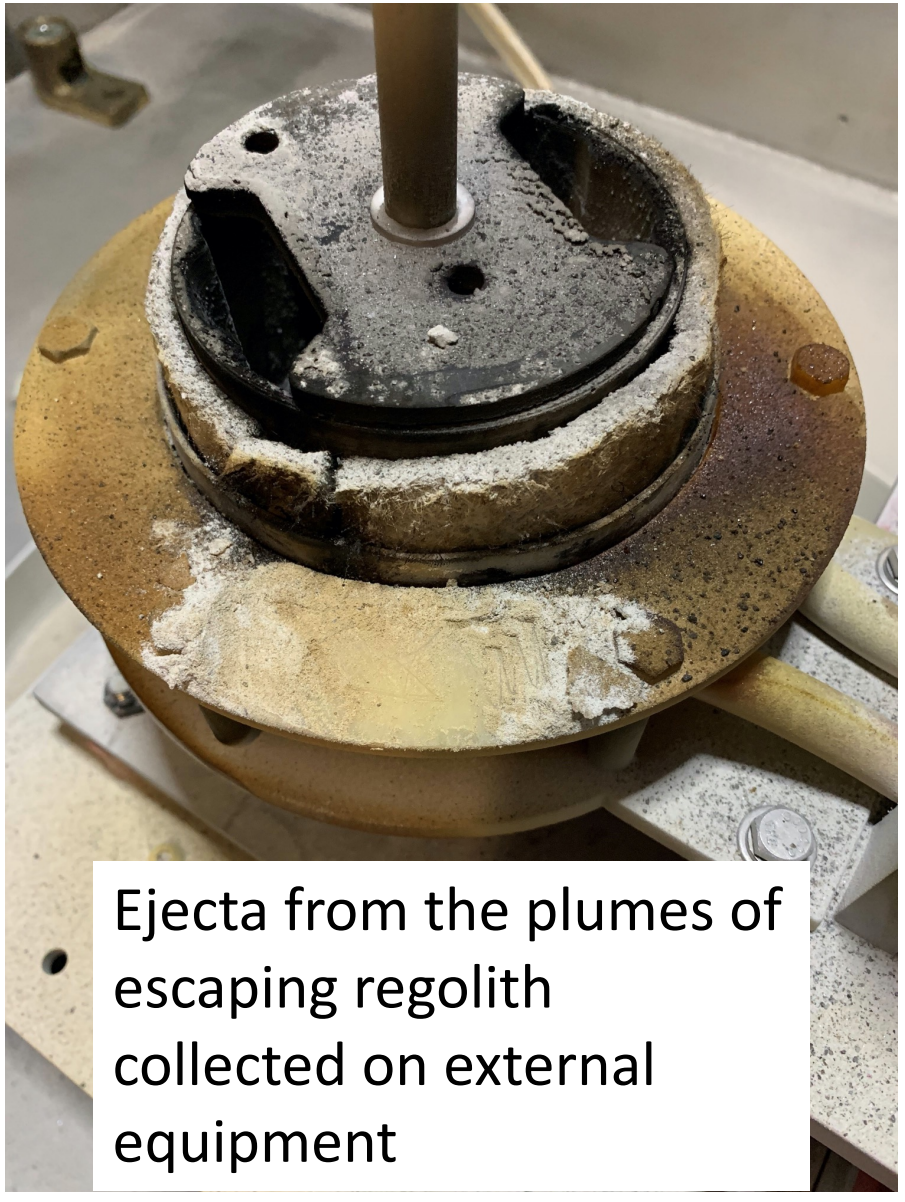
Melting tests were done in 0.5 Torr vacuum using 3kW of power from induction heater.

Melting lasted 30 minutes.



Melt Testing in ASSIST



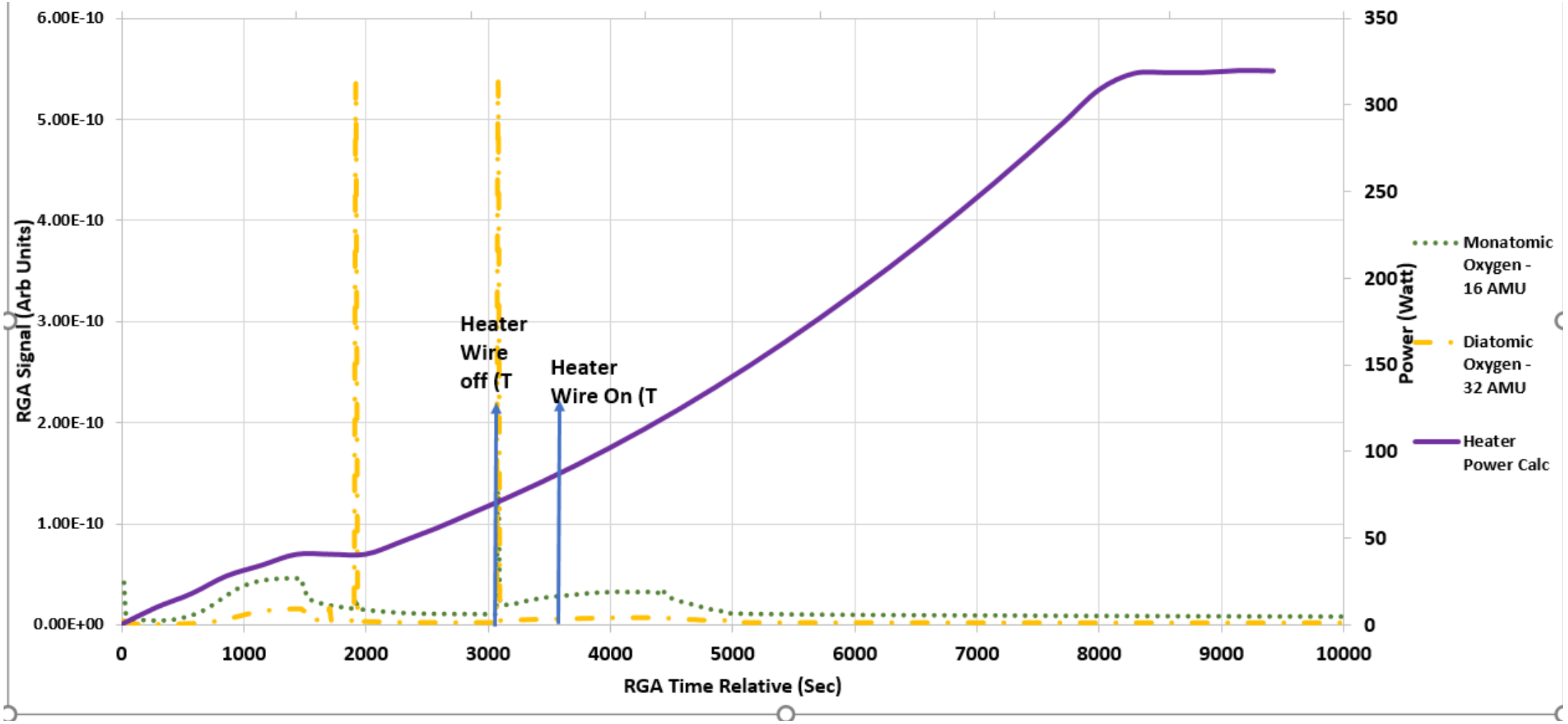


Ejecta from the plumes of escaping regolith collected on external equipment

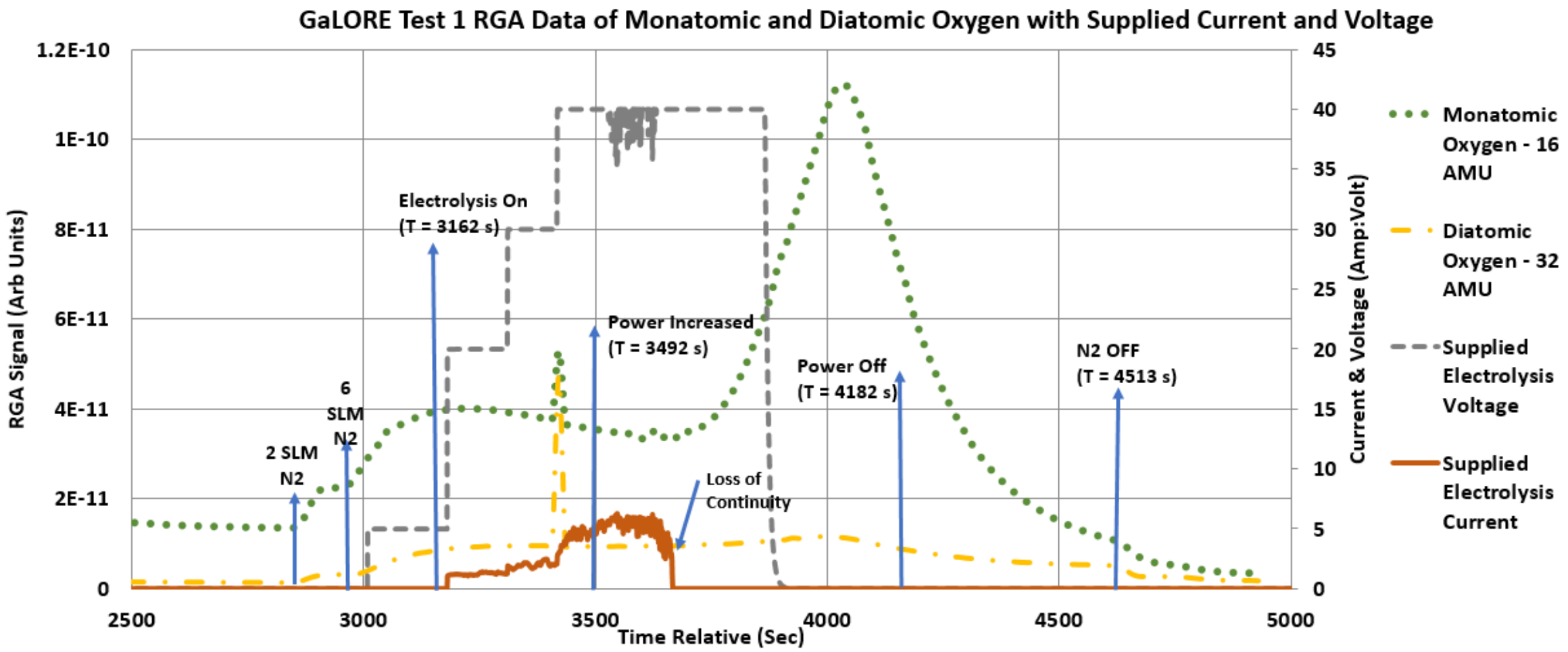
Melt Testing in ASSIST

Cold Wall During Electrolysis

RGA Data on Melted Regolith



RGA Data with Electrolysis



CT Scans of Crucible