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Development of a kg-Scale Oxide Reduction Module for Spent Light Water Reactor Fuel

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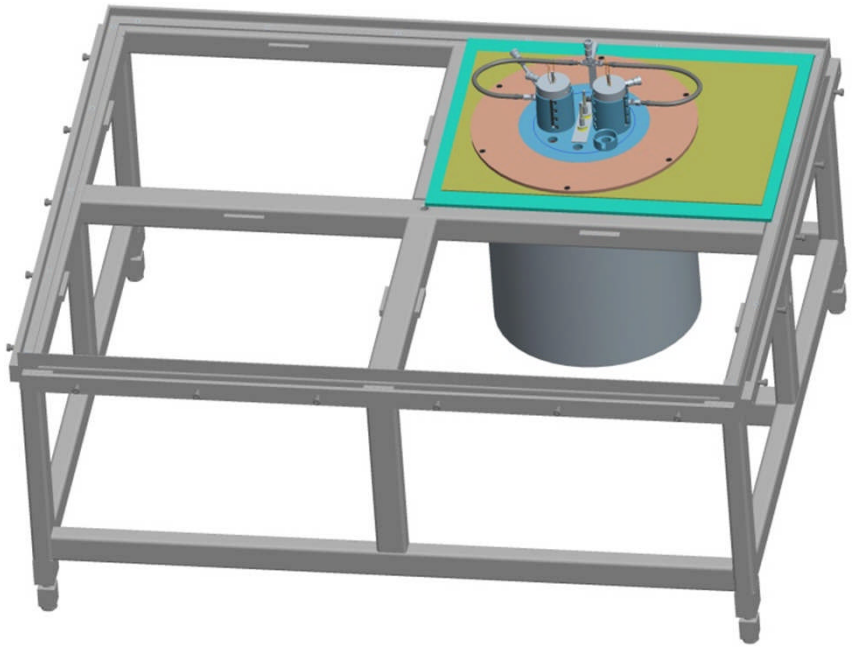
Overview

- **Background / Motivation**
- **Challenges Faced**
  - Design
  - Operating Environment
- **Major System Features**
- **Design Details of Subassemblies**
- **Thermal Analysis Results**



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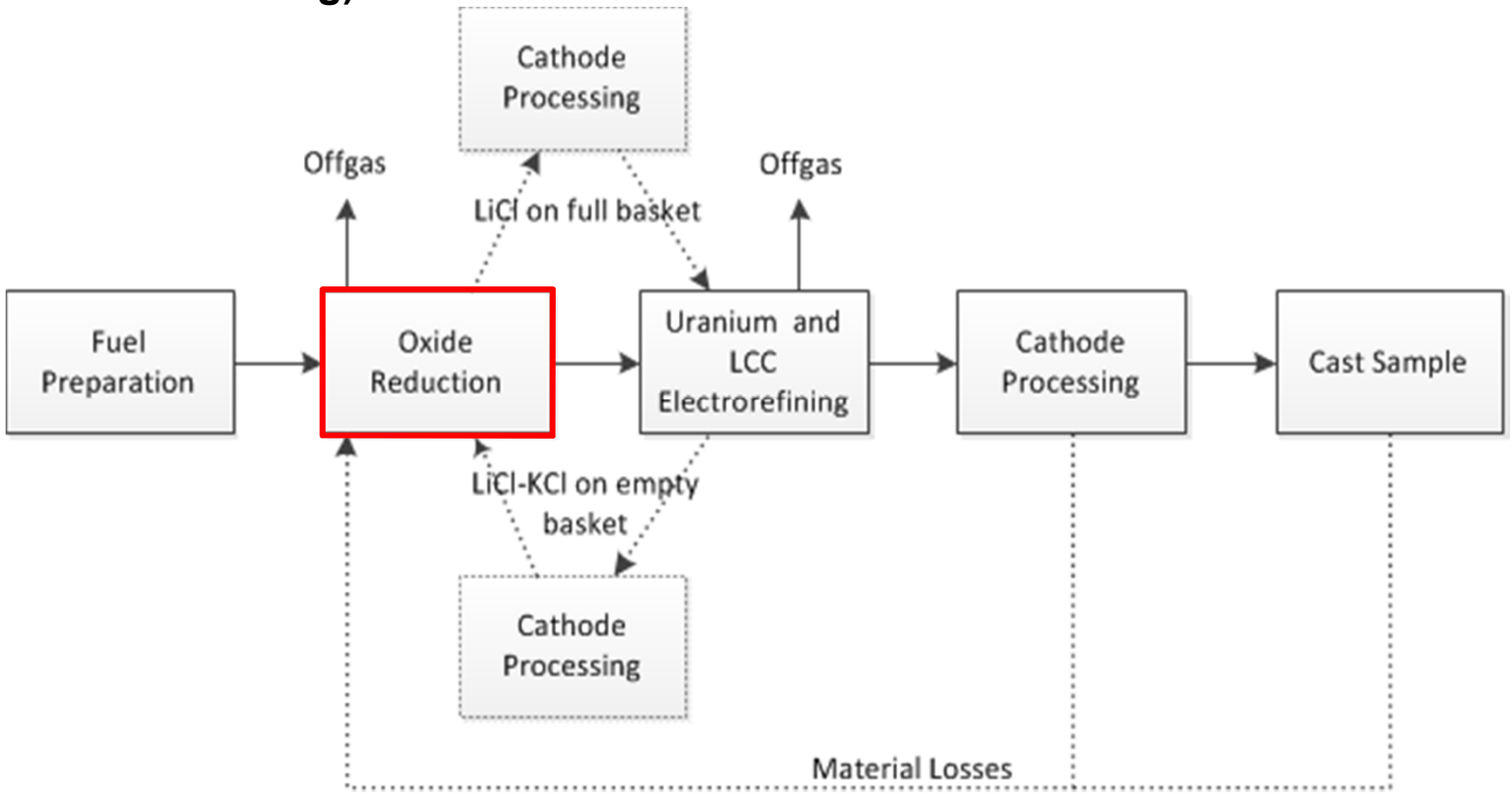
Background / Motivation

- Evaluate the recycling of used LWR oxide fuels via electrochemical technologies
- Produce metallic fuel from used oxide fuel (to enable subsequent electrorefining)



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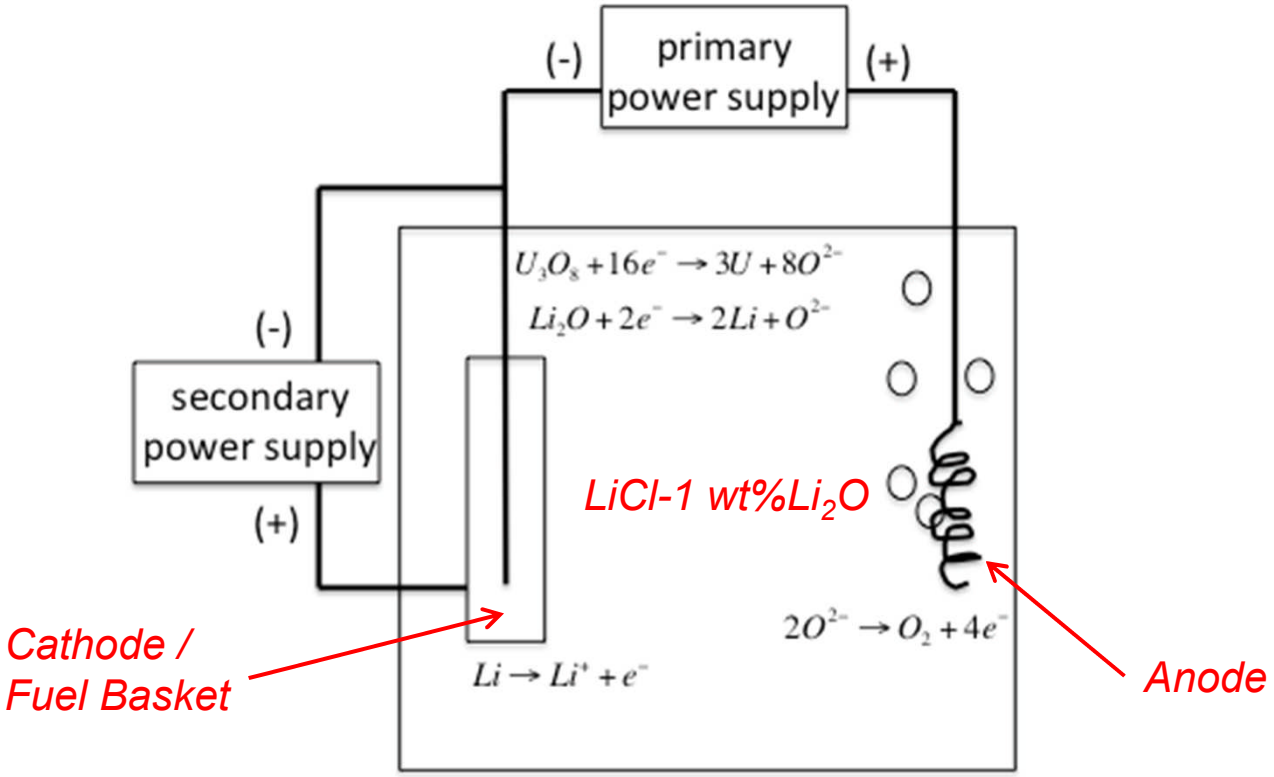
Electrolytic Oxide Reduction

- **Oxide fuel dipped into molten salt bath, voltage applied across cathode/anode**
  - Oxide reduced to metallic product at cathode
  - Oxygen gas liberated at inert anode



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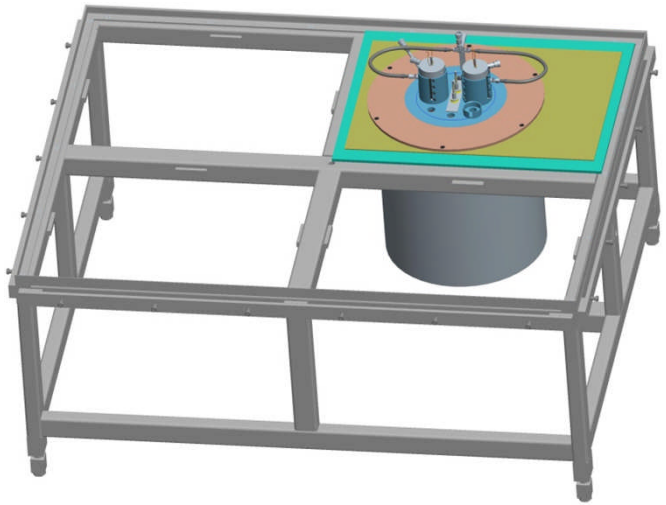
Challenging Design Requirements

- **1 kg heavy metal batch size**
- **Interface with existing worktable quadrant**
- **Molten salt bath (LiCl-1wt% Li_2O) at 650°C; design temp = 800°C**
- **≤150°C outer surface temperature**
- **Sufficient gas space above salt to drain & preheat components**
- **Preheated, clean argon cover gas (≈650°C)**
- **Heating elements (furnace) shall have at least two independent vertical zones**
- **Complex fuel basket**
  - Utilized with other process equipment (universal design)
  - Electrically isolated cathode
  - Fuel basket separable from upper portion
- **Two inert anodes**



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Challenging Design Requirements

- **Presence of oxygen gas creates an extremely corrosive environment**
  - Oxygen removal & monitoring system
  - Salt vapor trap & reflux system
- **Mitigations for general migration and condensation of salt vapor**

- **Reference electrodes to monitor cell voltage**
- **Thermocouple probe to measure electrolyte temperature at multiple depths**
- **Ports dedicated for additions, stirring (variable speed), sampling, and safeguards instrumentation**

- **Controlled at an Operator Control Station (OCS) in the passageway of the facility adjacent to the hot cell**
- **OCS shall accommodate data acquisition requirements**

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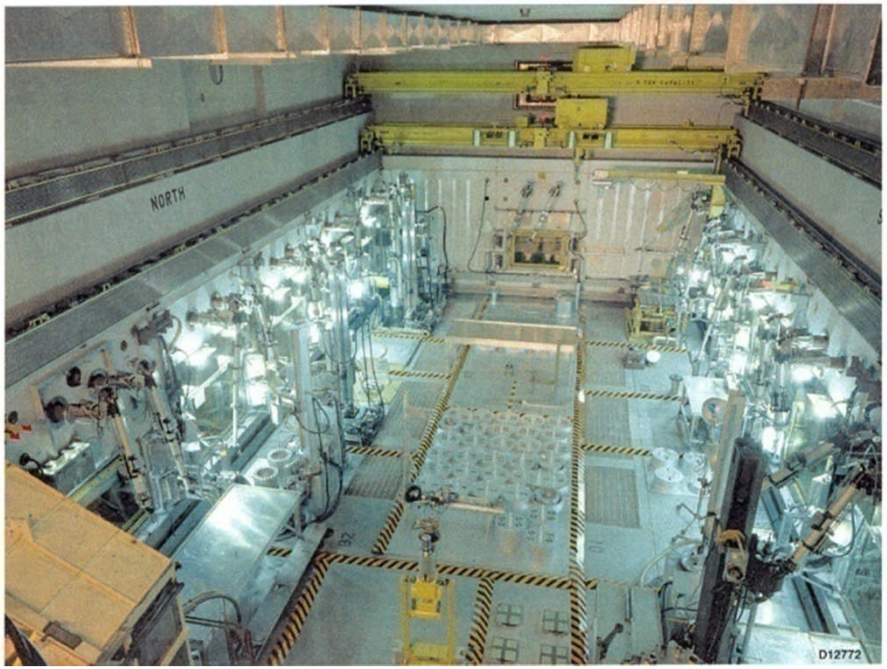
A Challenging Operational Environment

- High radiation fields (design for 10^8 R when possible)
- Dry argon atmosphere (60 ± 40 ppm O_2, 60 ± 40 ppm H_2O)
- Operate in temperature range of argon cell atmosphere (typically ≈35°)
- Consider heat load imposed on adjacent equipment and hot cell atmosphere



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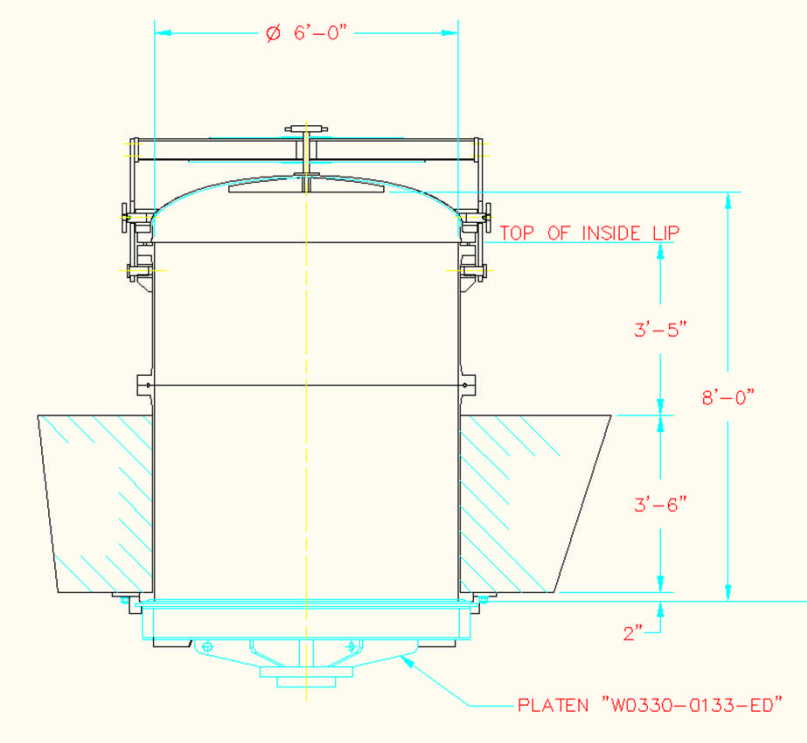
Remote Equipment Installation

- Size limitations based on existing transfer paths
- Large transfer lock for equipment installation into hot cell
- Small transfer lock for transfer between adjacent cells (argon/air atmospheres)
- Modular design philosophy facilitates transfer and remote installation

Small Transfer Lock Between Cells



Large Transfer Lock

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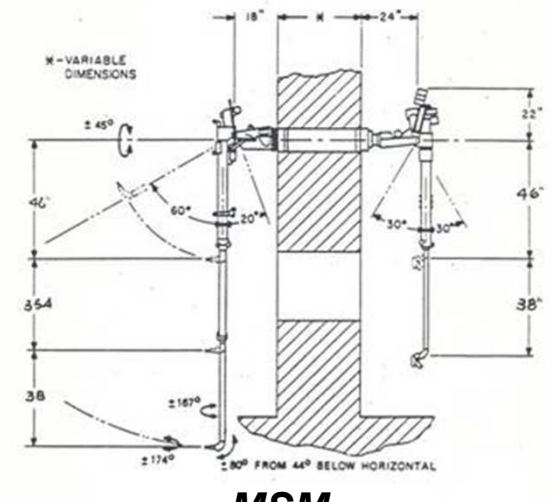
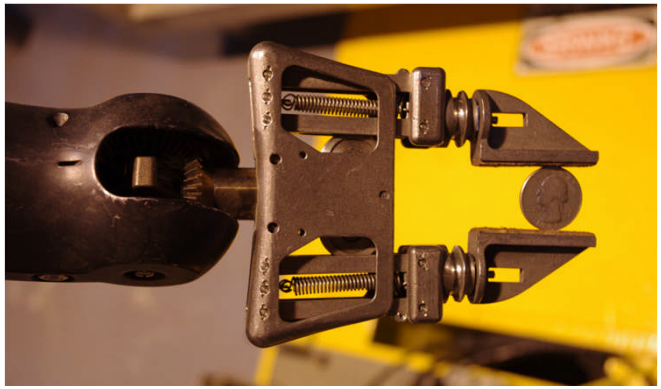
Typical Hot Cell Handling Systems

- **In-cell handling systems used to remotely operate and maintain equipment include:**
  - Telescoping master-slave-manipulators (MSM) with varying operating load capabilities
  - Electromechanical manipulators (EM) straight boom configuration, 750 lb capacity
  - Overhead cranes, capacities up to 5 tons
- **OR will be operated primarily with master-slave-manipulators**



MSM



MSM – Slave Gripper Fingers

EM

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Remote Equipment Operation & Maintenance

- **"Simplicity is the ultimate sophistication" – Leonardo da Vinci**
- **Modular design also improves repair and replacement activities**
- **Maintenance methods of remote equipment include:**
  - Repair in-cell by remote replacement of component (modular design required)
  - Remote decontamination followed by maintenance in glovebox or through glovewall
  - Remote decontamination followed by hands-on maintenance in contaminated maintenance suited repair area

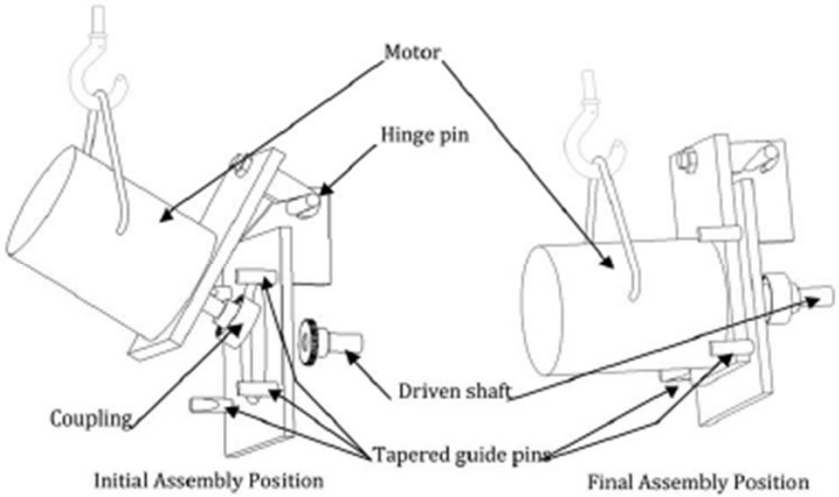

FIG. 21 Gravity Secured Motor Mount

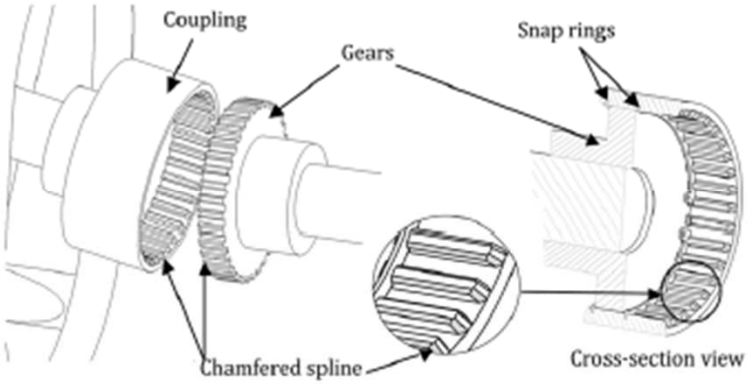

FIG. 22 Drive Coupling Details

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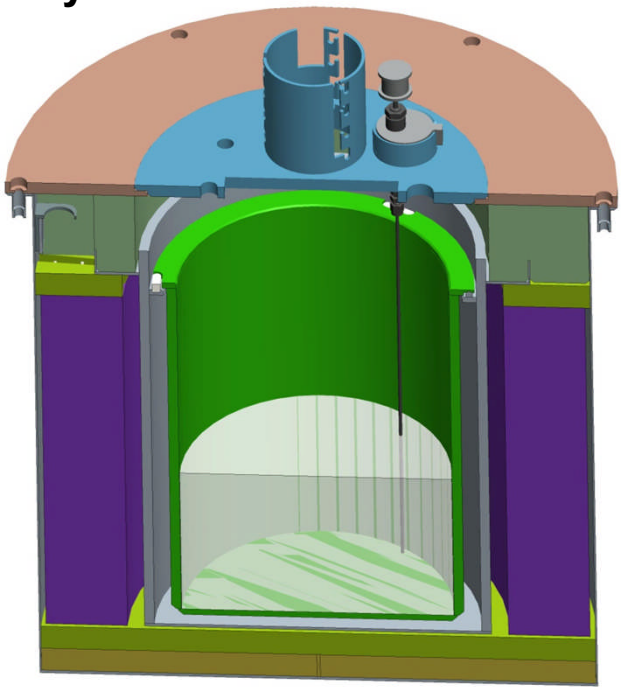
Oxide Reduction Module

- **Crucible to contain molten salt**
- **Centrally located universal fuel basket / cathode assembly**
- **Anode assemblies**
  - Inert materials
  - Shrouds to contain oxygen
  - Active oxygen removal system
  - Salt vapor trap and reflux system
- **Ancillary probes**
  - Reference electrodes
  - Thermocouple probe
  - Stirring probe with integrated motor
  - Salt addition & removal probe
  - Salt level indicator
- **Secondary containment vessel**
- **OEM two-zone high temperature ceramic fiber heater**
- **Insulating materials to control heat transmission pathways**
- **Cover gas preheater**



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Universal Fuel Basket & Cathode Assembly

- 1 kg heavy metal capacity
- Isolated leads for primary & secondary power supplies
- High current capacity
- Integrated heat shielding
- Fuel basket separable from leads and heat shielding
- Features to facilitate separation following salt condensation

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Oxygen Removal & Monitoring System

- **Presence of oxygen and salt at high temperature leads to an extremely corrosive environment**
- **Oxygen removal beneficial for two reasons:**
  - Reduce potential for corrosion
  - Measuring liberated oxygen enables process monitoring and system diagnostics
- **Contain & direct oxygen out of the equipment with shrouds**
- **Active oxygen removal via vacuum pump (either venturi or "traditional" pump)**
- **Still require ultra corrosion-resistant materials**

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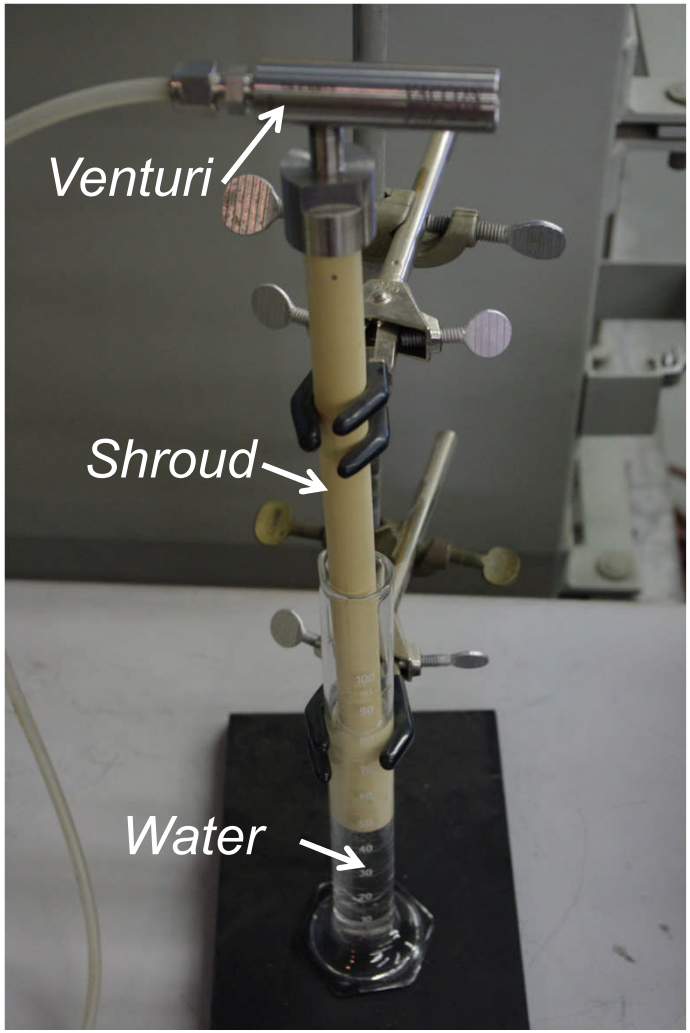
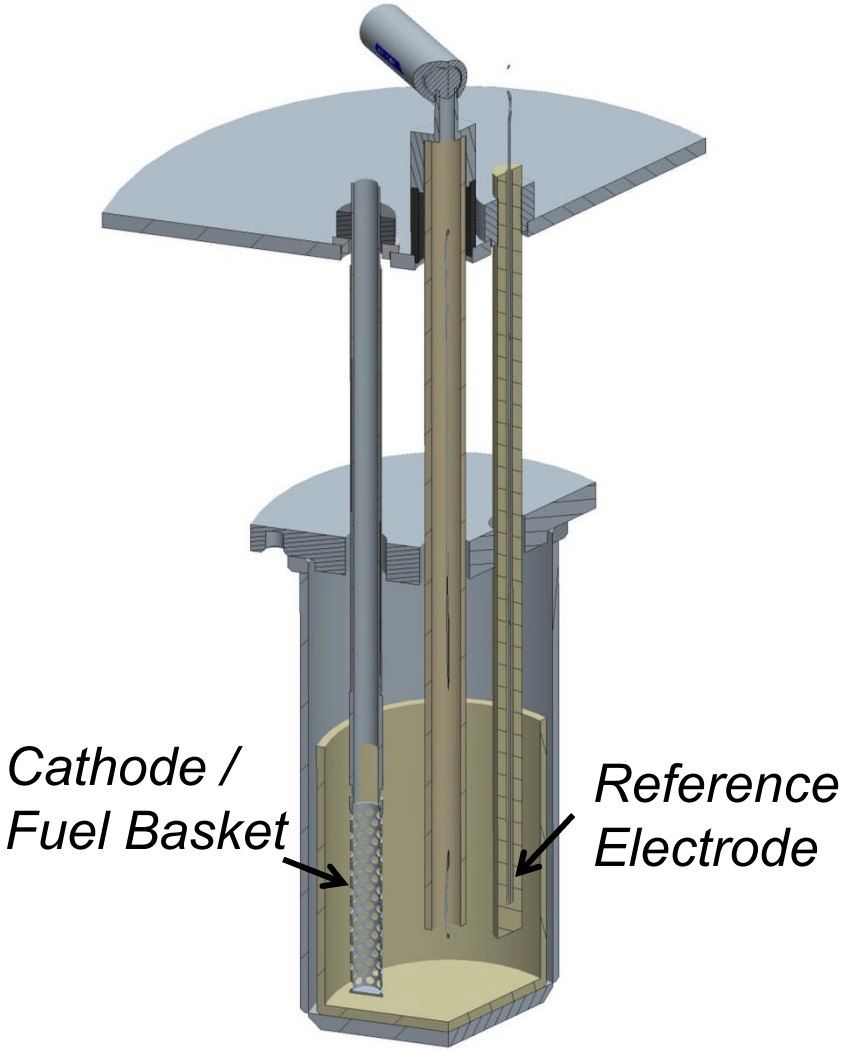
Oxygen Removal System – Subscale Demo





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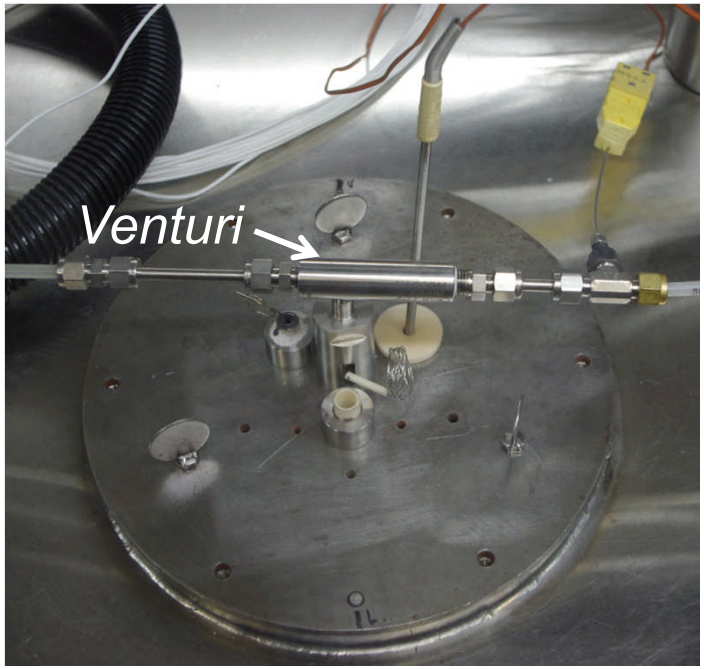
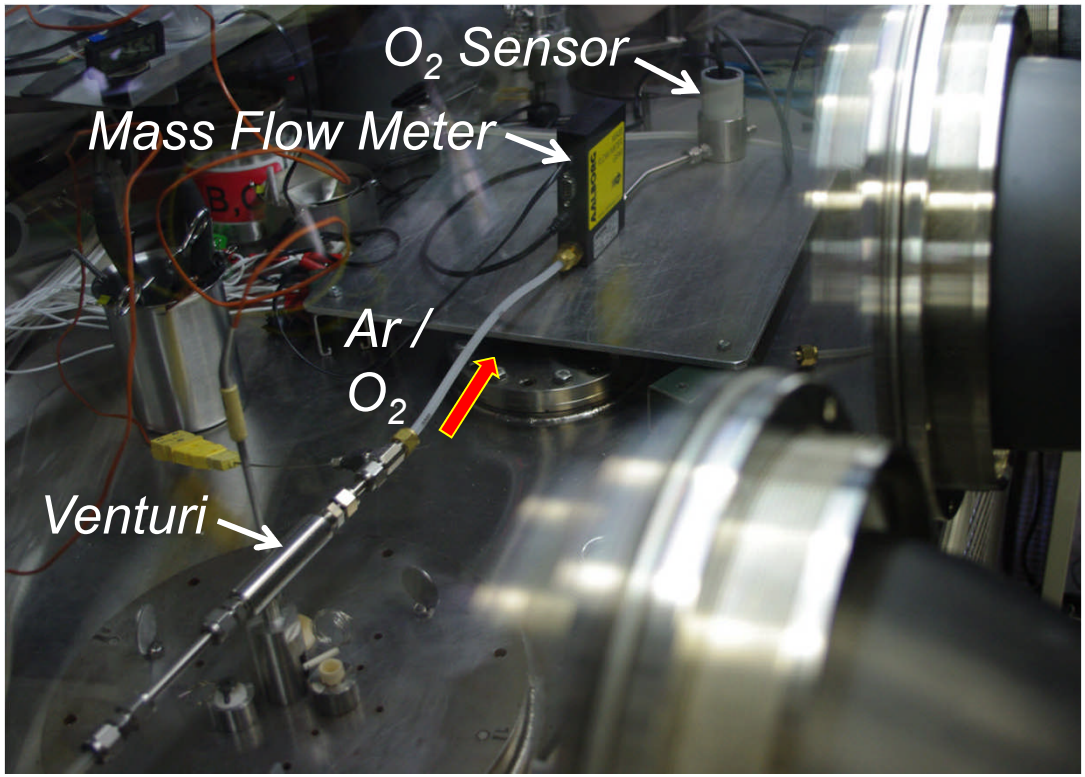
Oxygen Removal System – Subscale Demo





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Salt Vapor Trap & Reflux System

- Oxygen removal system will entrain salt vapors, must remove vapors to prevent plugging and protect downstream equipment
- Provide a trap within the gas stream (inside the anode shroud) to condense salt vapors on cooled surfaces in a controlled process
- Following a complete reduction, internal heaters will melt condensed salt and gravity drain back into crucible

- Actively cooled surfaces to promote condensation while reducing oxide fuel
- Actively heated surfaces to clean surfaces in preparation for next reduction

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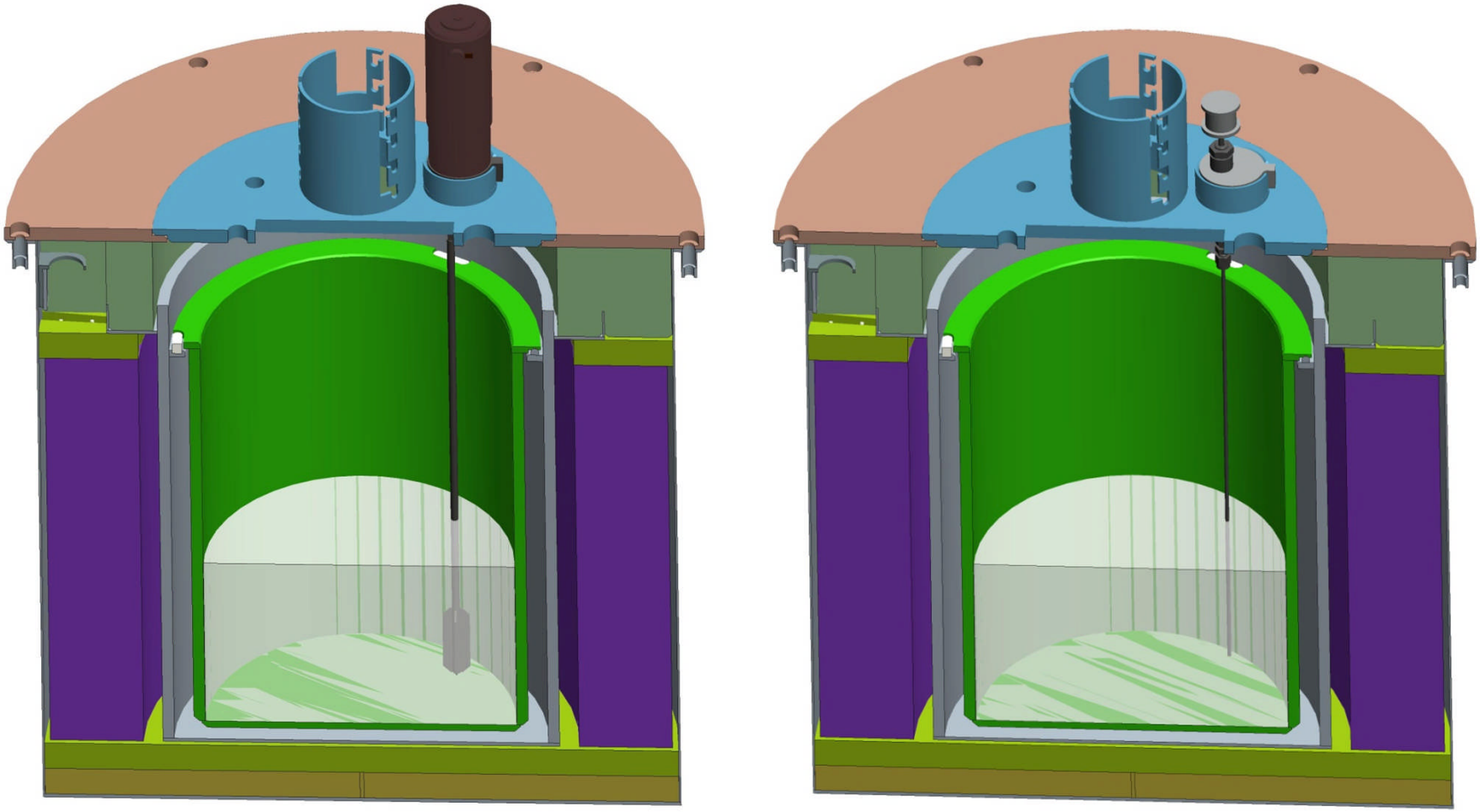
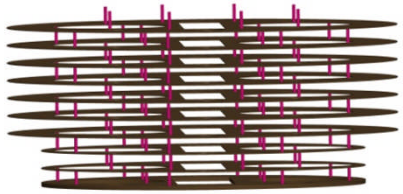
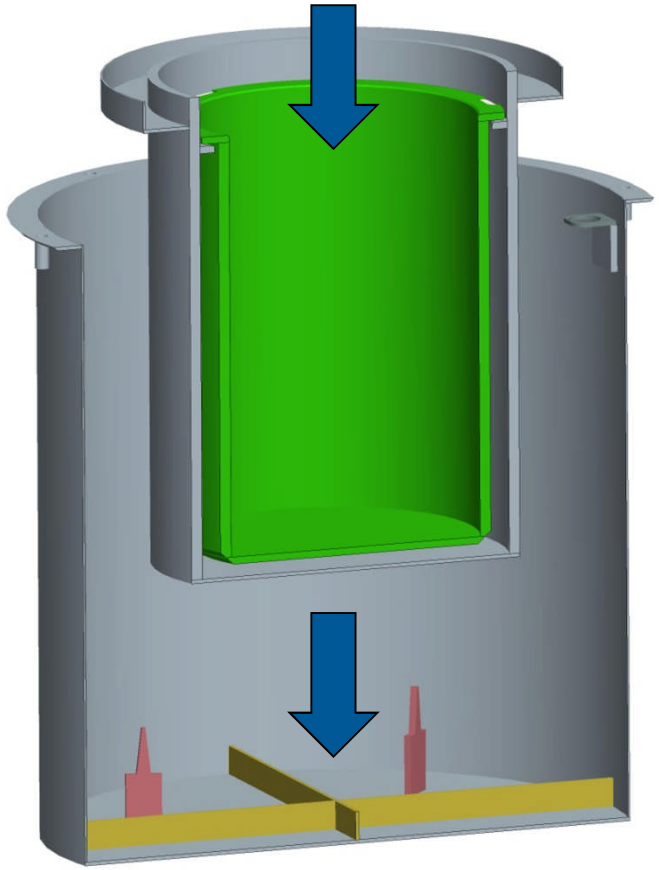
Molten Salt Stirring and Sampling



Temperature Management

- **Large temperature gradient**
  - Molten salt temperature = 650°C
  - Worktable surface temperature ≤ 150°C





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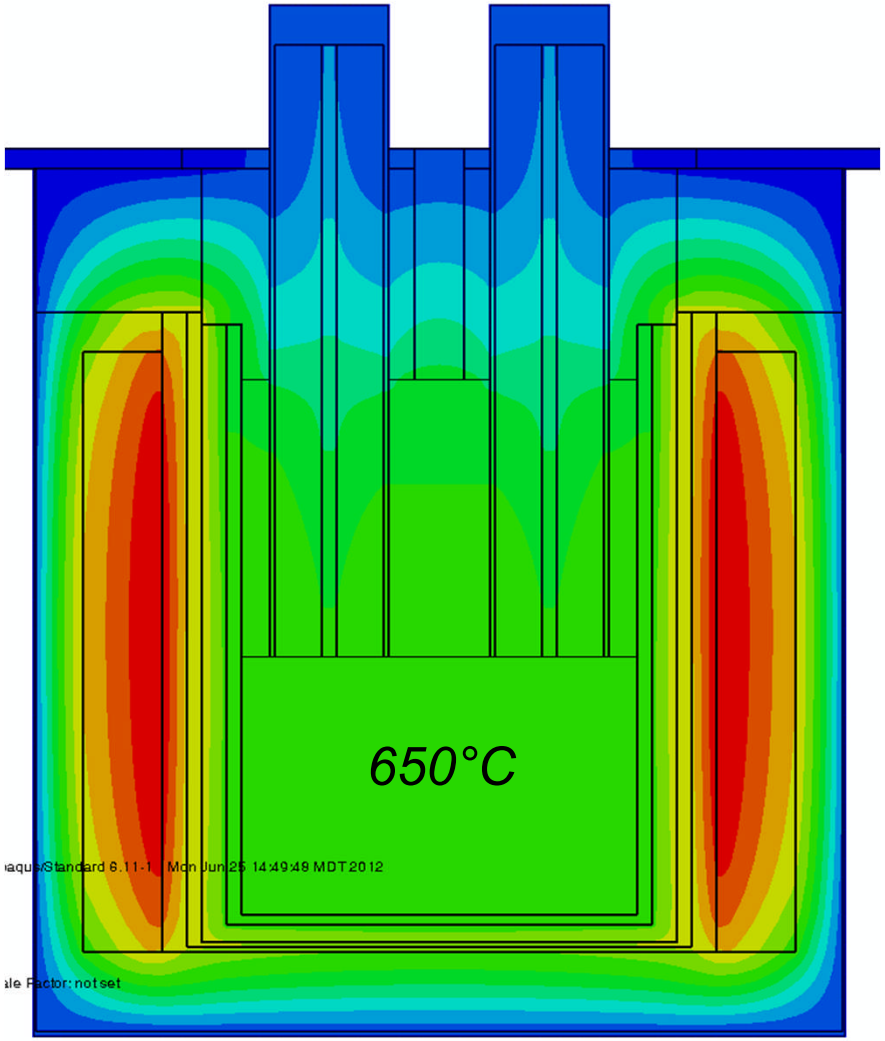
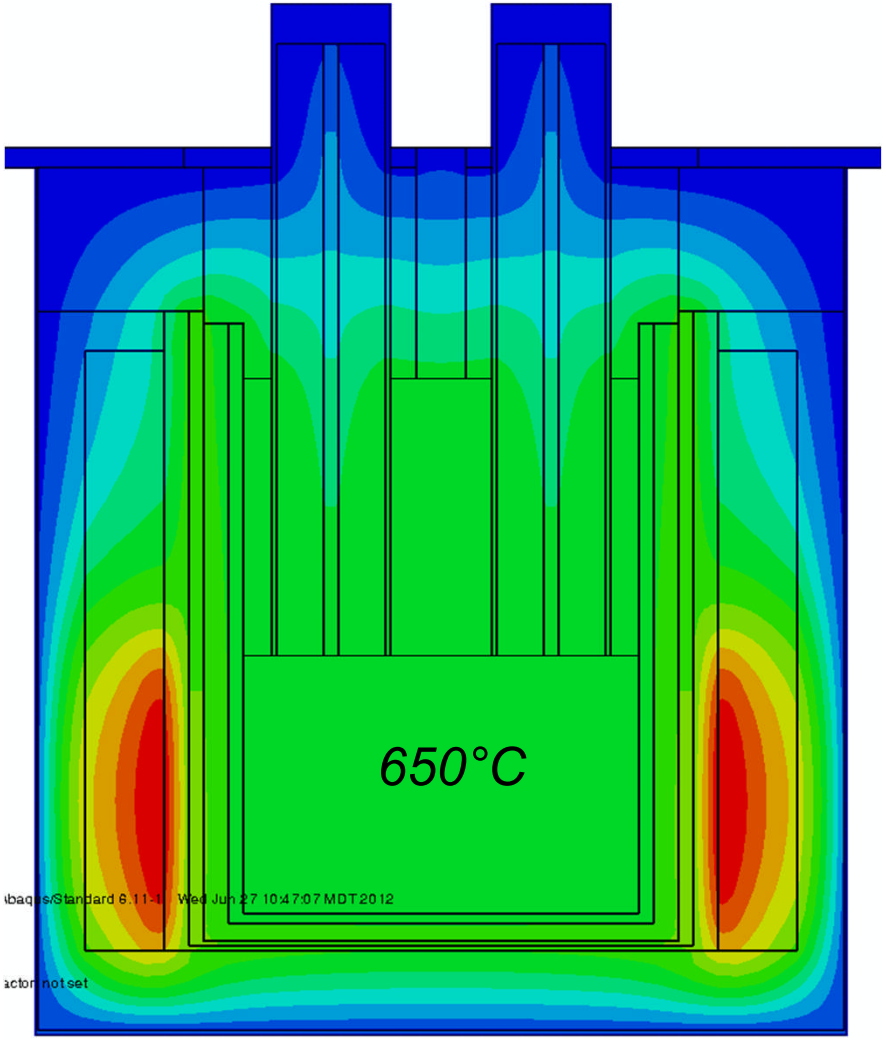
Thermal Analysis





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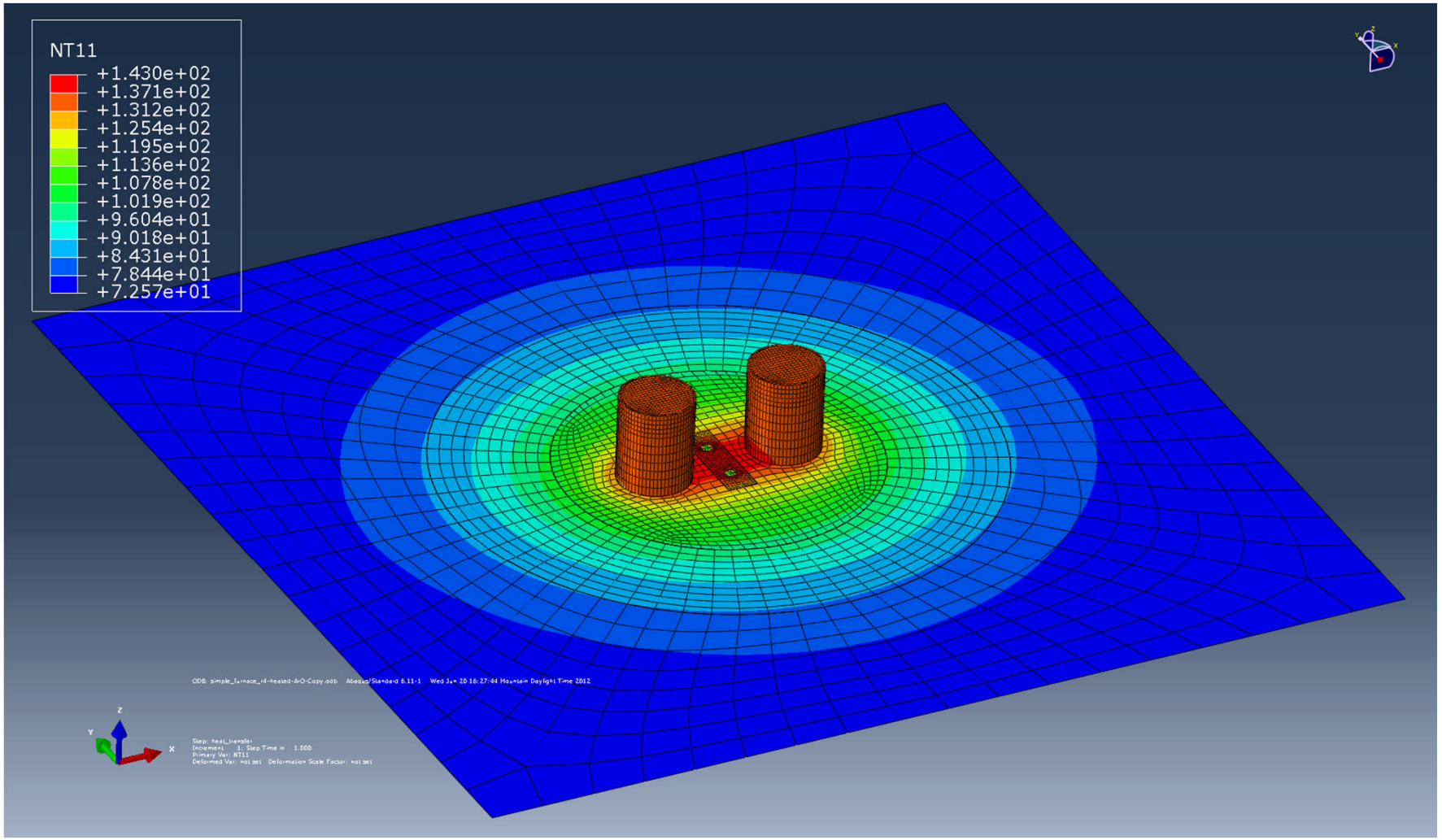
Thermal Analysis



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Discussion

Thank you

Questions?

KAERI Korea Atomic Energy Research Institute

INL Idaho National Laboratory

Argonne NATIONAL LABORATORY