The NASA Advanced Exploration Systems Nuclear Thermal Propulsion Project

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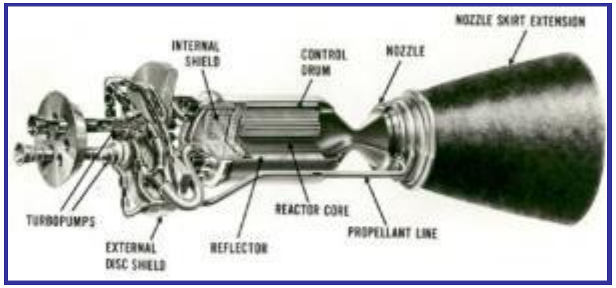
Nuclear Thermal Propulsion (NTP)



- **Nuclear thermal propulsion (NTP) is a fundamentally new capability**
  - Energy comes from fission, not chemical reactions
  - Virtually unlimited energy density
- **Initial systems will have specific impulses roughly twice that of the best chemical systems**
  - Reduced propellant (launch) requirements, reduced trip time
  - Beneficial to near-term/far-term missions currently under consideration
- **Advanced nuclear propulsion systems could have extremely high performance and unique capabilities**
- **The goal of the AES NTP project is to establish adequate confidence in the affordability and viability of NTP such that NTP is seriously considered as a baseline technology for future NASA human exploration missions**

AES NTP Project Recent Activities

Fabrication of 16” coated graphite composite fuel elements (hafnium surrogate in place of uranium)

Fabrication of short (<6”) W/UO_2 cermet fuel element segments (depleted uranium) / testing in Compact Fuel Element Environmental Tester (CFEET)

Completion of Nuclear Thermal Rocket Element Environmental Simulator (NTREES) 1.2 MW upgrade

Preparation for NTREES test of 16” coated graphite composite fuel element (hafnium surrogate) by end of FY15.

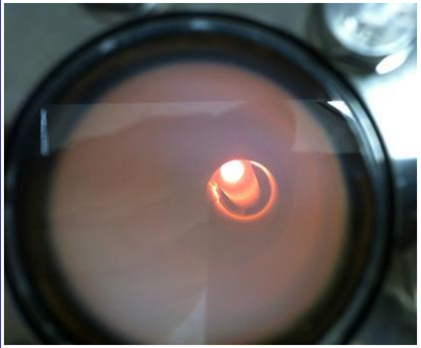
Additional AES NTP project emphasis on potential early flight demonstration engine using highly enriched uranium (HEU) fuel. Coated graphite composite selected as the “lead” fuel for that engine.

Additional work related to early flight (or ground) demonstration includes facility identification, schedule generation, and cost estimation.

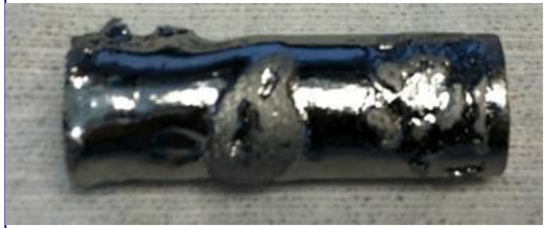
Short, 7 Channel W/UO_2 Element Fabricated and Tested in Compact Fuel Element Environmental Tester (CFEET)

CFEET System 50 kW Buildup & Checkout

Completed CFEET system

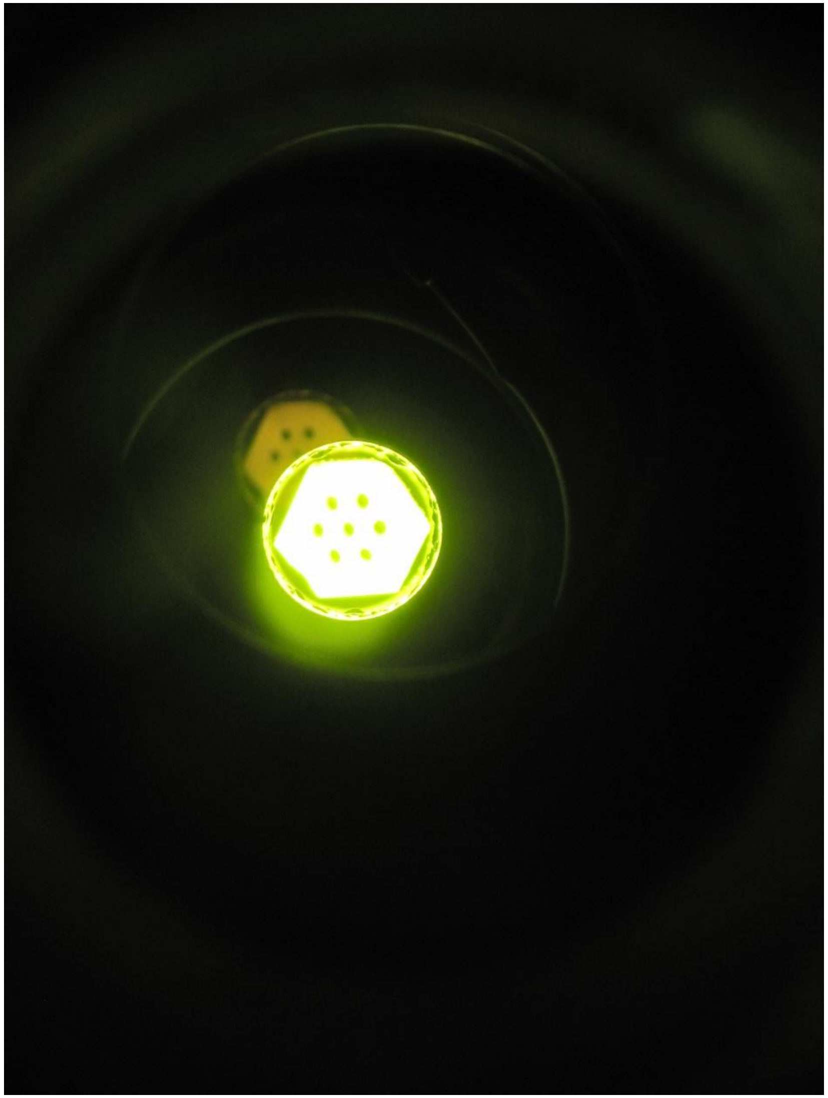


Left: View looking down into the CFEET chamber during shakeout run 1. BN insulator and bright orange sample inside

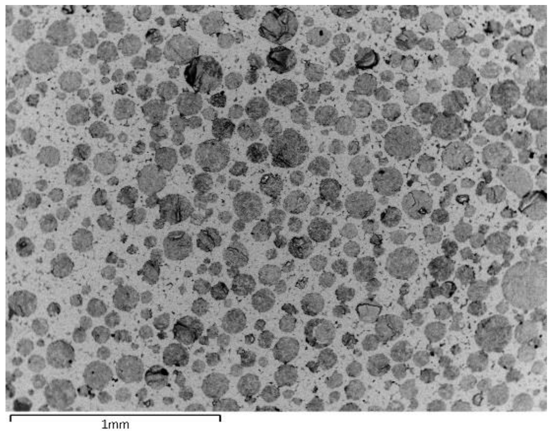


Above/left: Pure W sample post shakeout run 2. Sample reached melting point (3695K) and was held in place by the BN insulator.

Initial Testing of Short W/UO_2 Element

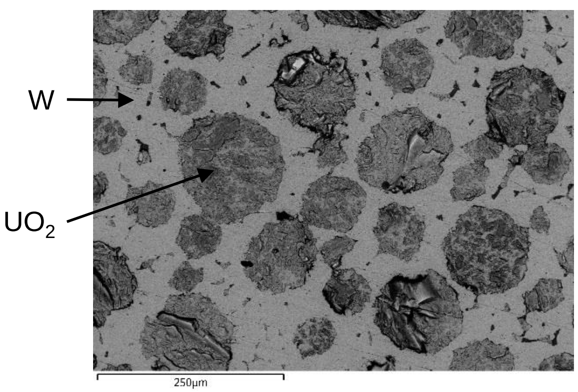


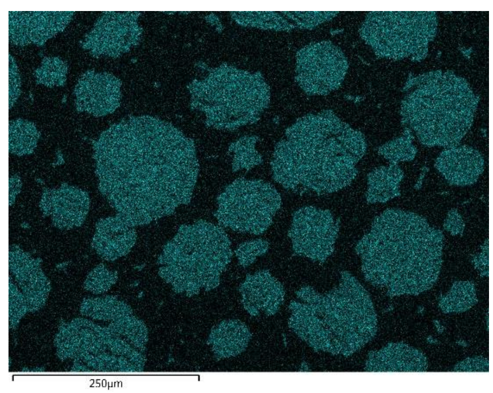
CERMET W Powder Coated UO_2 HIP Sample



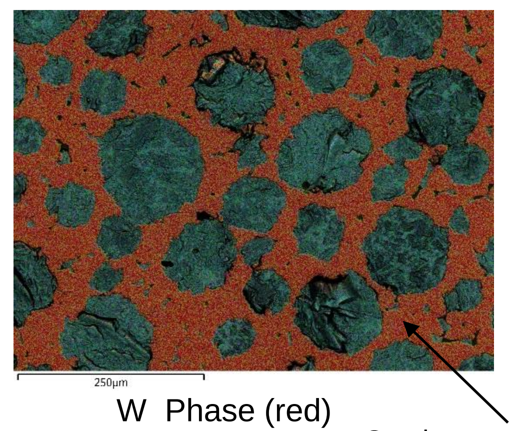
Micrograph of W powder coated UO_2 HIP sample showing improved distribution of UO_2 (dark phase) spheres in the W (light phase)matrix.

Crimp and sealing of W powder coated UO_2 sample in glovebox





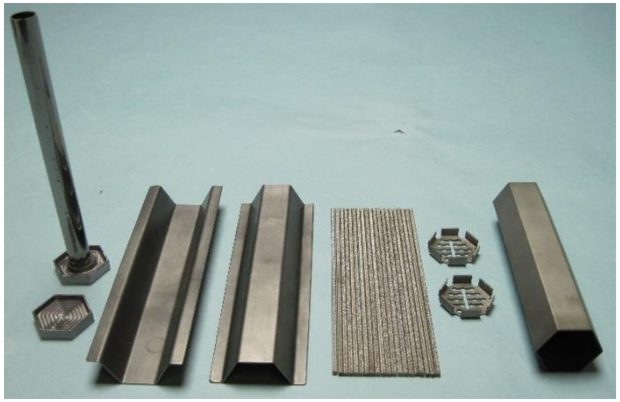
Uranium Phase (blue)

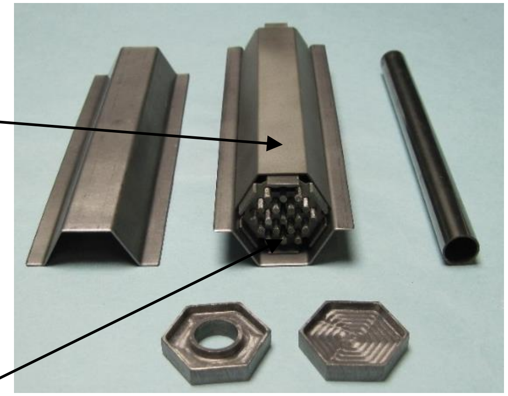


W Phase (red)

SEM phase map of W powder coated UO_2 HIP sample showing improved distribution of UO_2 (blue phase) spheres in the W (red phase) matrix.

CERMET W-UO_2 6” 19-Hole Fuel Sample





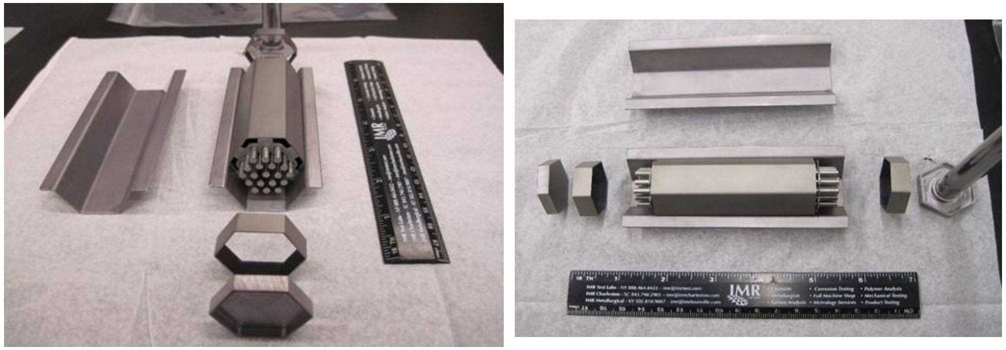
HIP Tooling

Images showing the 6” long 19-hole W-UO_2 HIP can assembly prior to, during, and after welding

19 Hole HIP can W-UO_2 powder fill in glovebox

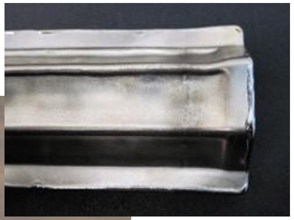
NTP CERMET Fuel Element Development

- Completed fabrication, assembly, welding of two 4.5” HIP cans for pure W samples (one with internal cladding/one without)
  - Change to 4.5” from 6” was due to availability of the W cladding
- Filled two HIP cans with pure W powder
  - Achieved ~65% packing density in each can
- Completed HIP cycle for the pure W sample with internal cladding
  - Sample appears to be near full consolidation without can failure
  - Pure W samples will be used to evaluate shrinkage, etching, and machining
- Full length HIP can for pure W sample has been fabricated
- March, 2015 AES NTP project decision to defer additional cermet fuel work until FY16 or beyond.



HIP can assembly for pure W samples prior to welding

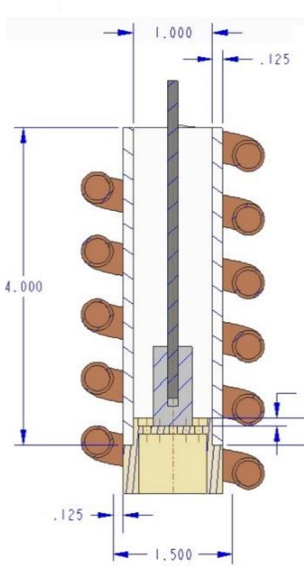
Welded HIP can assemblies for pure W samples



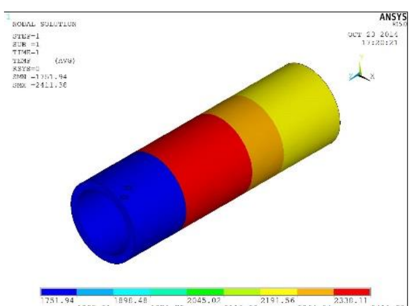
Pure W sample with internal cladding after HIP consolidation

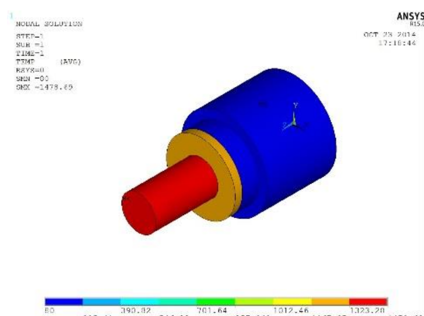
Pure W sample being loaded into HIP vessel for consolidation. Sample is buried in Al2O3 grit; Provides structural support

Compact Fuel Element Environmental Test (CFEET) System and Etch System Upgrades

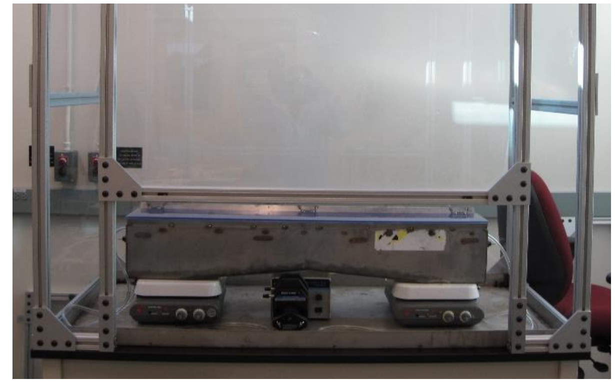


W susceptor and BN Pedestal





Thermal Model of W susceptor and BN Pedestal



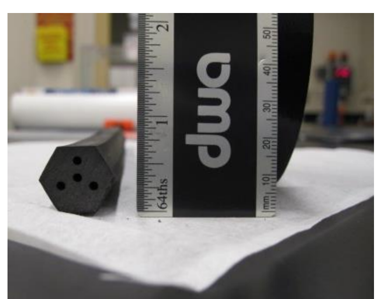
Full Length Fuel Element Etch System

ORNL Graphite Composite Fuel Element Development

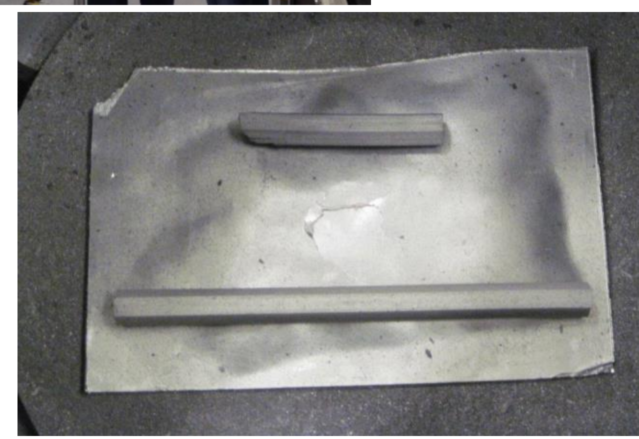
MSFC High Temperature Furnace

ORNL Fuels Dev. Team from left to right: Jim Miller, Brian Jolly, Mike Trammel. ORNL multi-zone coating furnace shown in background.

MSFC High Temperature Furnace. Licensed for depleted uranium



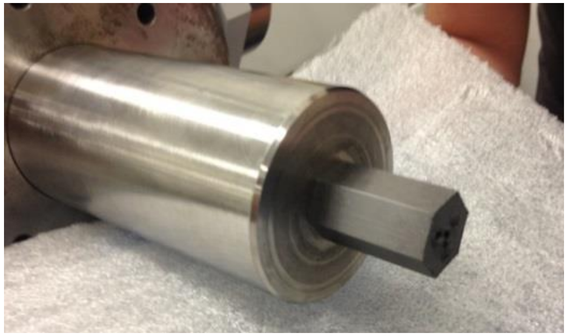
Above and left: Graphite sample prior to heat treatment

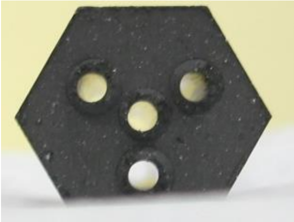


Initial ORNL graphite composite samples after the final heat treatment to 2700 C. Long sample is a section from an extrusion run. Short one is run out material left over from extrusion run. (Heat treated to have some extra material)

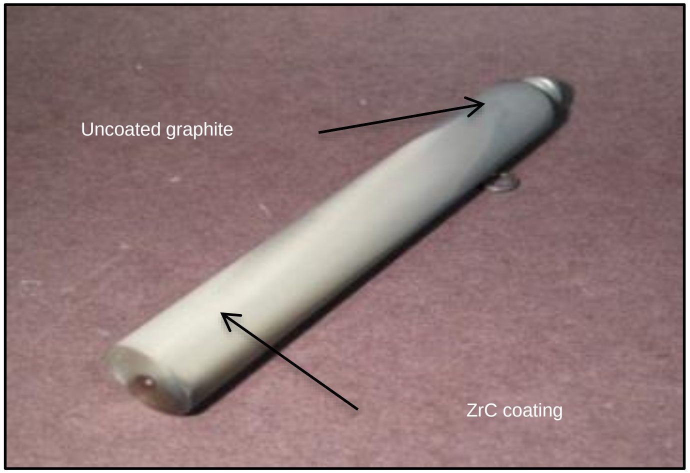
Coated Graphite Composite Development (ORNL)

Above: Members of Oak Ridge National Laboratory fuels team with the graphite extruder; Left: Graphite extruder with vent lines installed for DU capability

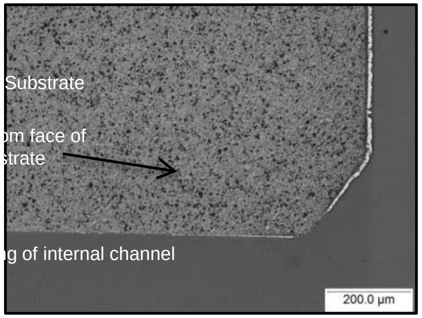




Above and Left: Extrusion samples using carbon-matrix/Hf blend .75” across flats, .125” coolant channels



Above: Test Piece highlighting ZrC Coating
Right: Coating primarily on external surface



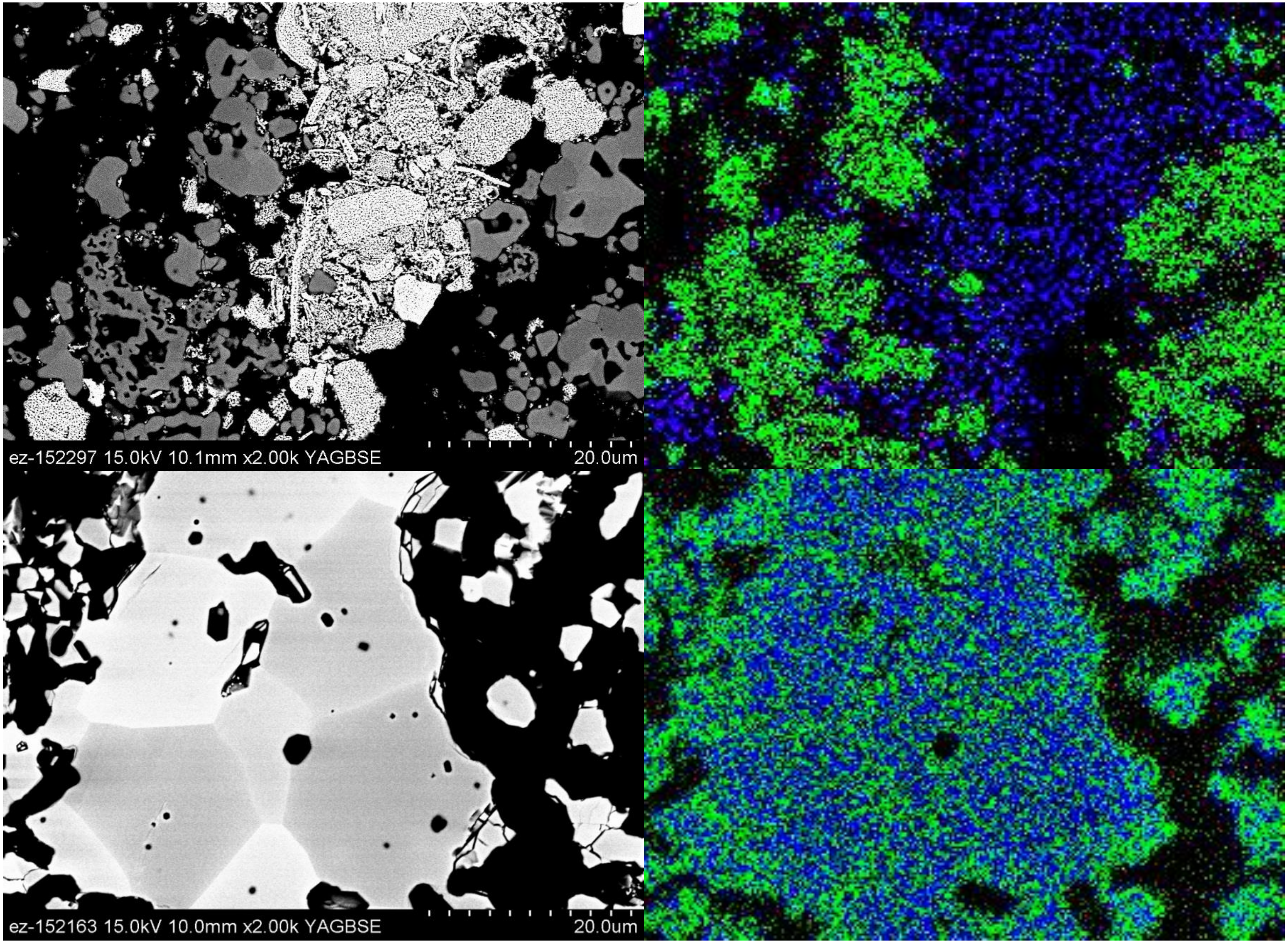
Right: Layoff base / Graphite insert

ORNL Graphite Composite Development

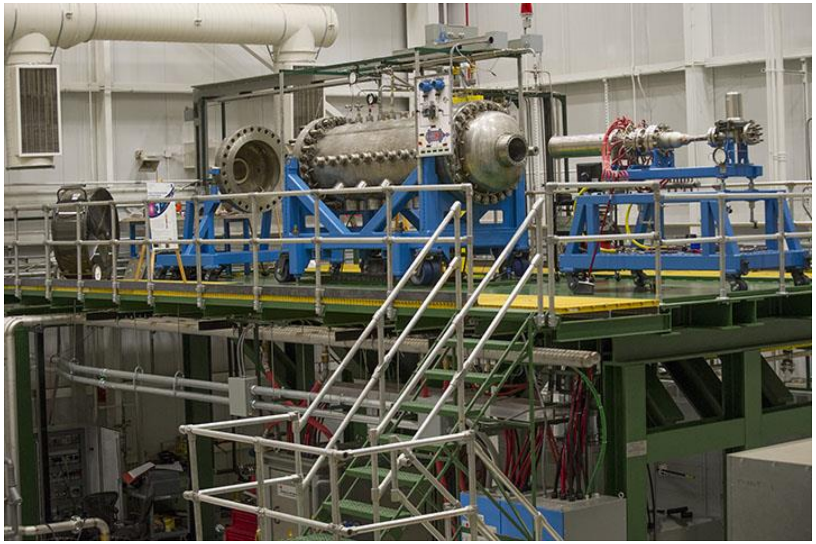
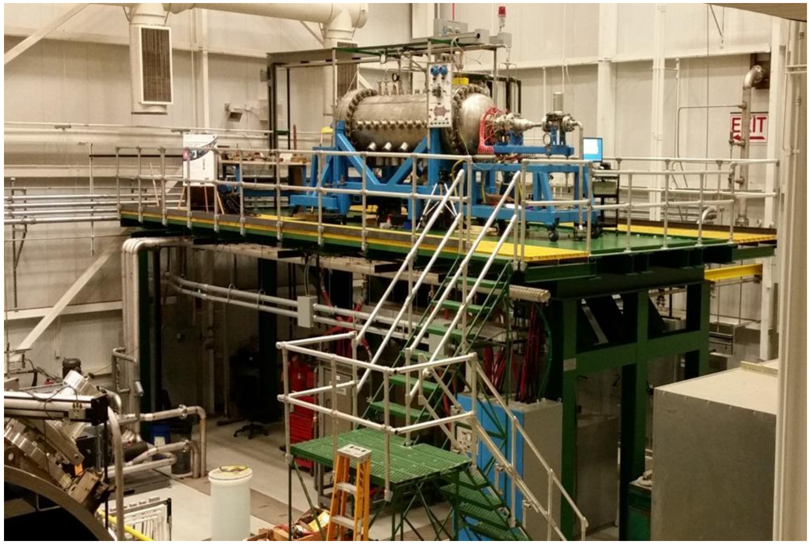
Backscattered SEM | EDS analysis - Zr (green), Hf (blue)

Before heat treatment, 2000x

After heat treatment, 2000x

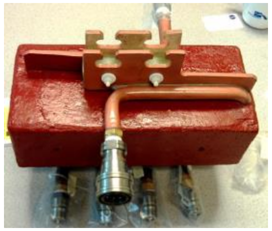


Testing in NTREES

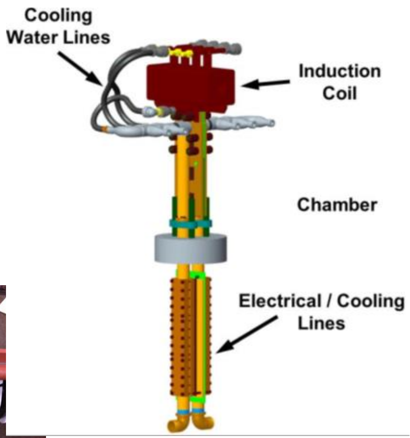



Above left & right: NTREES in preparation for graphite FE testing

1.2 MW induction heater and DAQ system

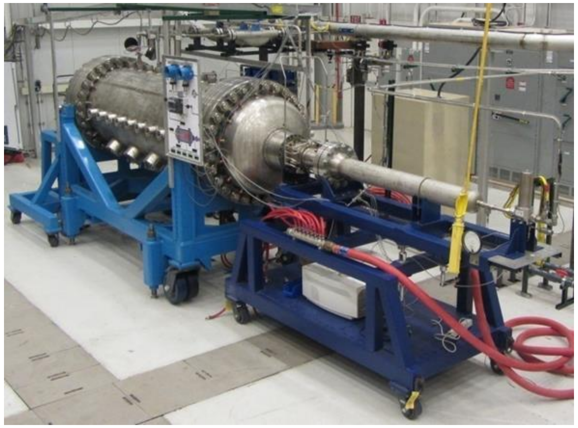



Induction coil with and without insulation



- NTREES has been modified to allow much higher power operation – achieved > 200kW
- Check out testing uncovered design deficiencies which limited the power that could be applied to test elements
- Design deficiencies have been corrected
- Modifications to coils needed prior to very high power testing – pursuing designs to allow greater test fidelity
- NTREES fully operational for testing fuel elements with prototypic surrogate or depleted uranium loading

Nuclear Thermal Rocket Element Environmental Simulator (NTREES)



NTREES Phase 1 50kW (2011)

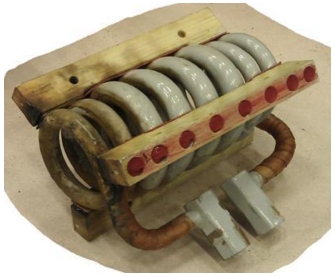
NTREES Phase 2 – 1MW Upgrade (2015)

New Cooling Water System now provides 2 separate systems that cool induction coil and power feedthrough, induction heater and H_2N_2 mixer respectively

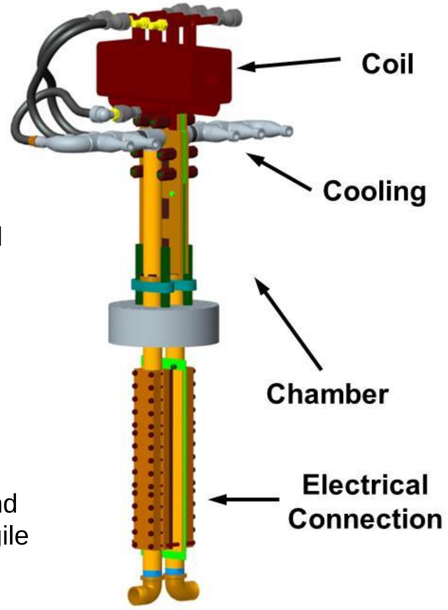
General Description:

- Water cooled ASME coded test vessel rated for 1100 psi
- GN_2 (facility) and GH_2 (trailer) gas supply systems
- Vent system (combined GN_2/GH_2 flow)
- 1.2 MW RF power supply with new inductive coil
- Water cooling system (test chamber, exhaust mixer and RF system)
- Control & Data Acquisition implemented via LabVIEW program
- Extensive H_2 leak detection system and O_2 monitoring system
- Data acquisition system consists of a pyrometer suite for axial temperature measurements and a mass spectrometer
- “Fail Safe” design

New Coil is Heavily Insulated and Rugged



Old Coil was Uninsulated and Somewhat Fragile



Coil and Feedthrough Assembly

Observations / Summary

Since FY 2012, the NASA AES NTP project has made progress in certain key areas.

Safety is the highest priority for NTP (as with other space systems). After safety comes affordability.

No centralized capability for developing, qualifying, and utilizing an NTP system. Will require a strong, closely integrated team.

Tremendous potential benefits from NTP and other space fission systems. No fundamental reason these systems cannot be developed and utilized in a safe, affordable fashion.