NASA'S NUCLEAR THERMAL PROPULSION PROJECT

PRESENTED AT

NUCLEAR AND EMERGING TECHNOLOGIES FOR SPACE (NETS) 2015
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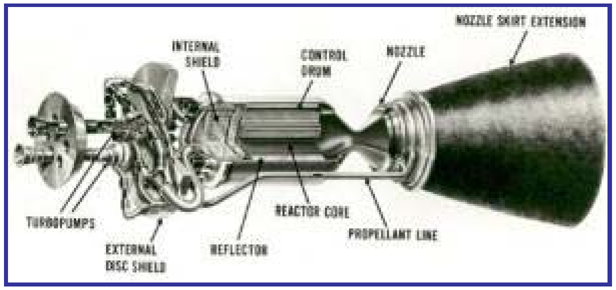
Nuclear Thermal Propulsion (NTP)



- **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 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**

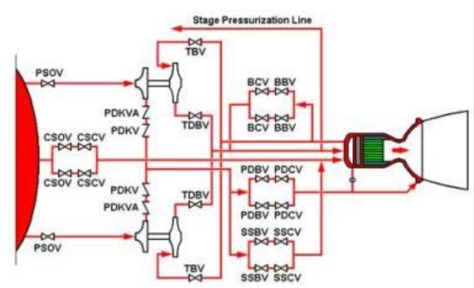
Nuclear Thermal Propulsion (NTP) Organizational Structure

1.0 NCPS Project Management

Project Manager:	Sonny Mitchell (MSFC)
Principal Investigator:	Mike Houts (MSFC)
GRC Lead:	Stan Borowski
JSC Lead:	John Scott
SSC Lead:	Kevin Power
DOE - NE75 Lead:	Anthony Belvin
DOE - NNSA Lead:	Steven Clement

2.0 Pre-conceptual Design of the NCPS & Architecture Integration

Co-Leads: Tony Kim (NASA), Stan Borowski (NASA), David Poston (LANL)

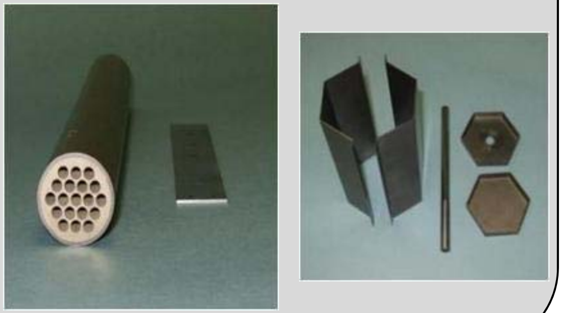


3.0 High Power (≥ 1 MW) Nuclear Thermal Rocket Element Environmental Simulator (NTREES)

Lead: Bill Emrich (NASA)

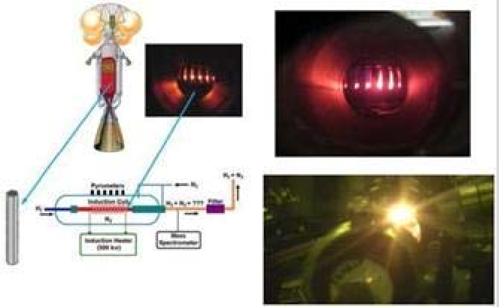
4.0 NCPS Fuel Design / Fabrication

Co-Leads: Robert Hickman (NASA), Lou Qualls (ORNL), Jim Werner (INL)



5.0 NCPS Fuels Testing in NTREES & CFEET

Co-Leads: Bill Emrich (NASA), Robert Hickman (NASA), Lou Qualls (ORNL), Jim Werner (INL)



6.0 Affordable NCPS Development and Qualification Strategy

Co-Leads: Harold Gerrish (NASA), Glen Doughty (NASA), Stan Borowski (NASA), David Coote (NASA), Robert Ross (NASA), Jim Werner (INL), Roy Hardin (NRC)

NTP Project FY 15 Milestones

1. Independent Review Panel provides recommendations on down selection of leader and follower fuel element types (Cermet vs. graphite composite) – Completed 2/15/15
2. Complete initial NTREES testing of ~16" cermet fuel element with prototypic depleted uranium loading (Due 3/15/2015)
3. Complete initial NTREES testing of ~16" coated graphite composite fuel element with prototypic depleted uranium loading (Due 4/28/2015)
4. Independent Review Panel completes initial assessment of ground test facilities and provides recommendations on facilities and test approach (Due 9/15/2015).

Milestones for FY16 and FY17 will be defined later in FY15

Recommendations from Independent Review Panel (IRP)

Given four key assumptions, the Independent Review Panel (IRP) recommended Graphite Composite fuel as the leader technology and Cermet fuel as the follower technology.

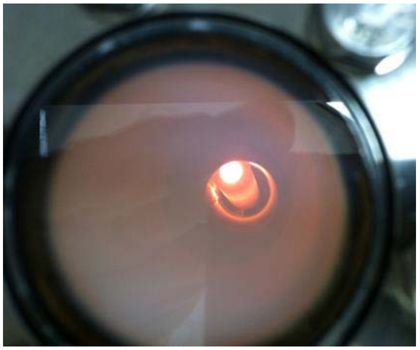
Under “Better Approaches and Alternatives,” the IRP suggested that the need and timing for an early flight demonstration should be reassessed. In addition, fully developed DDT&E plans should be generated.

Under “Better Approaches and Alternatives” the IRP also noted the need to evaluate the safety and mission performance achievable for both graphite composite and cermet fuel using low-enriched uranium (LEU).

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

CFEET System 50 kW Buildup & Checkout

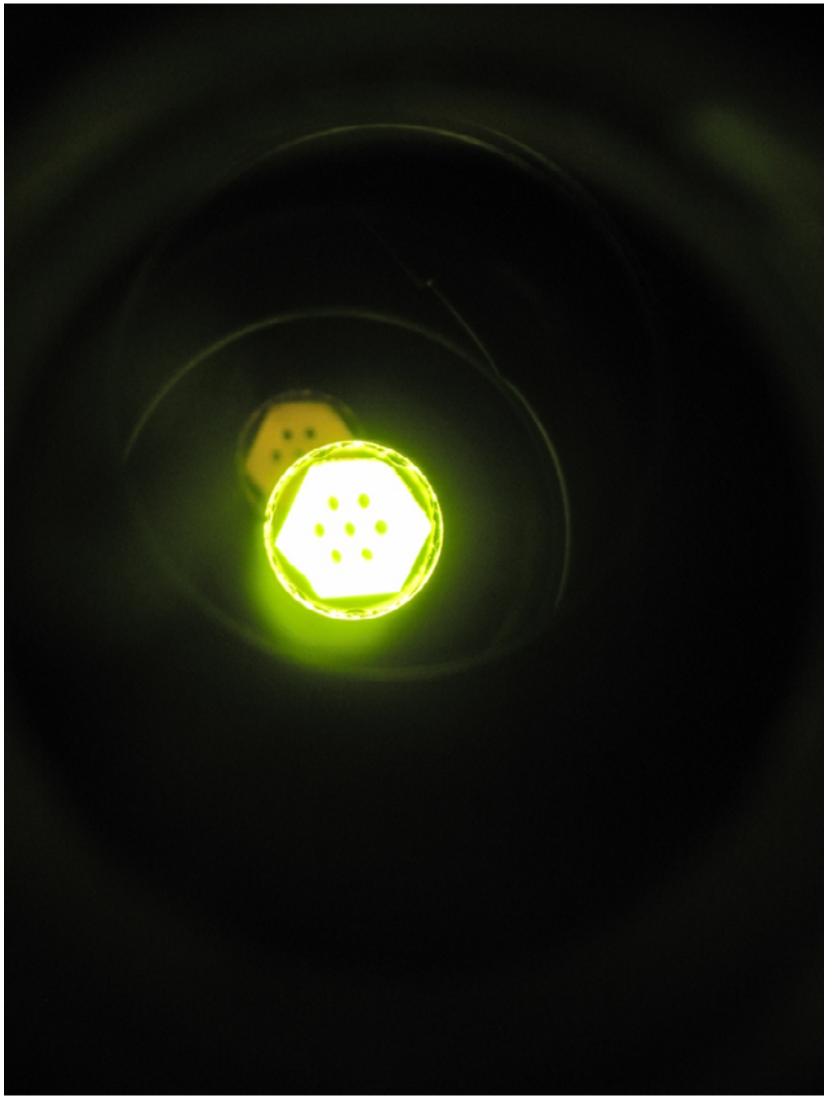
Completed CFEET system



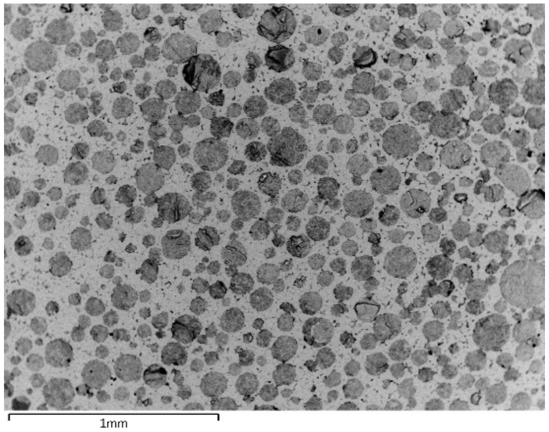
Left: View looking down into the CFEET chamber during shakeout run 1. BN insulator and bright orange sample inside

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

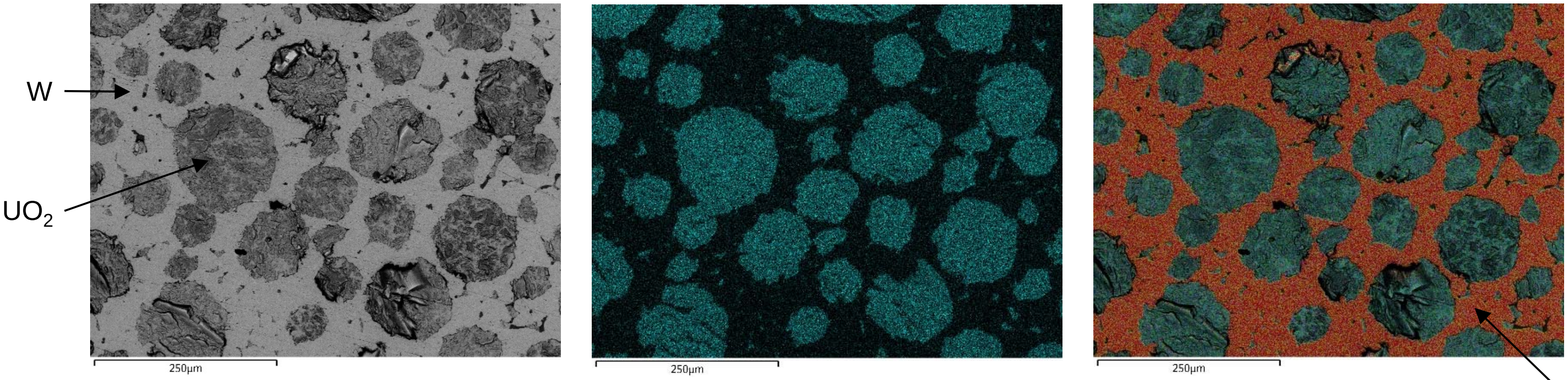


CERMET W Powder Coated UO_2 HIP Sample



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



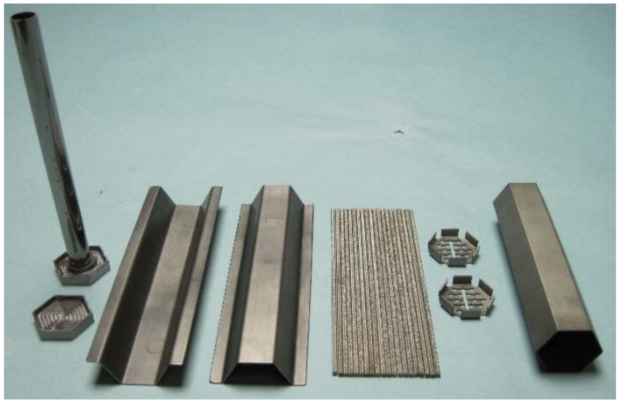
Uranium Phase (blue)

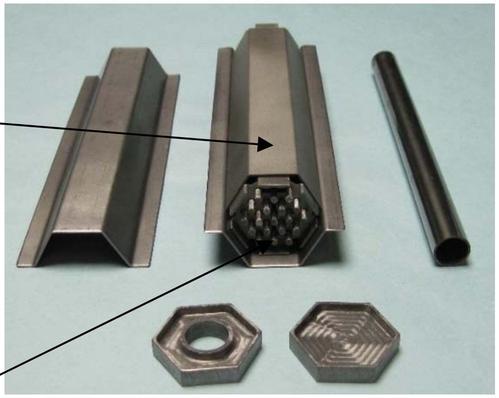
W Phase (red)

Continuous W Matrix

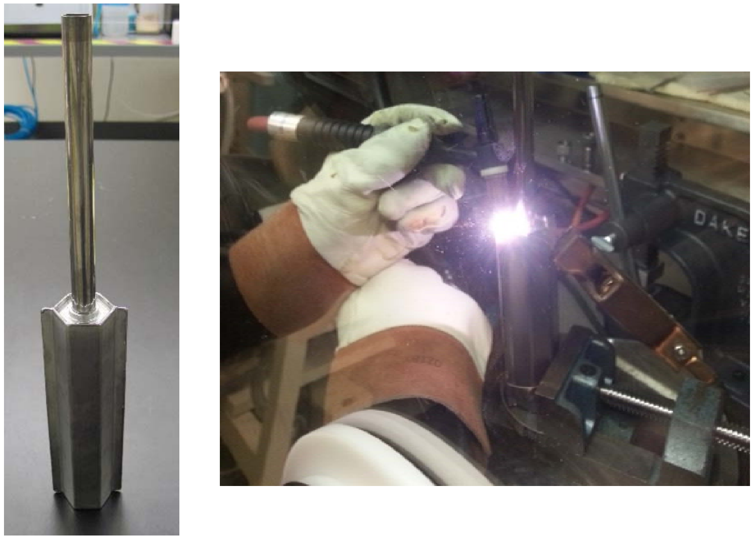
SEM phase map of W powder coated UO_2 HIP sample showing improved distribution of UO_2 (blue phase) spheres in the W (red phase) matrix.

CERMET W-UO_2 6” 19-Hole Fuel Sample





HIP Tooling

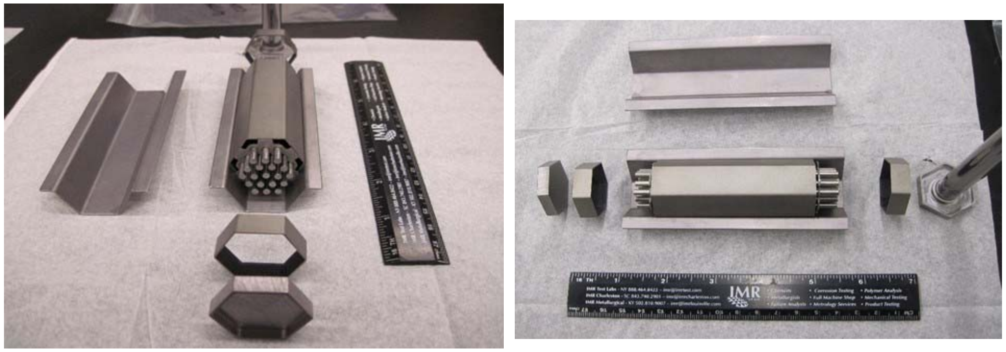


Images showing the 6” long 19-hole W-UO_2 HIP can assembly prior to, during, and after welding

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
- Fabricating full length HIP can for pure W sample prior to fab/HIP of full length UO_2 FE
- Will follow with NTREES sample fabrication



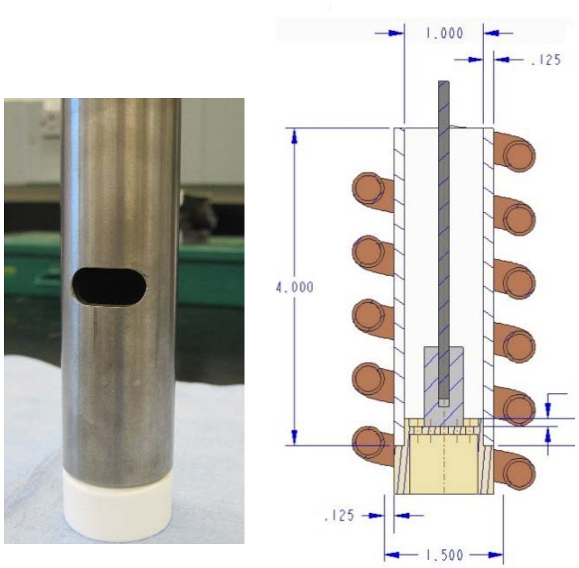
HIP can assembly for pure W samples prior to welding

Welded HIP can assemblies for pure W samples

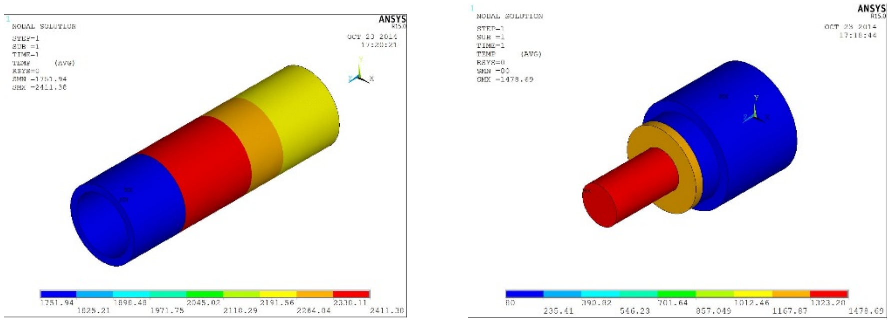
Pure W sample with internal cladding after HIP consolidation

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

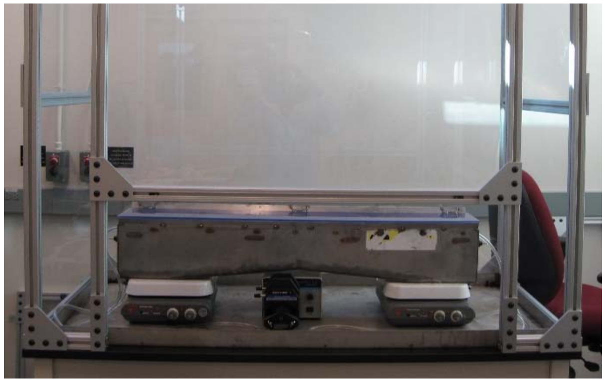
Compact Fuel Element Environmental Test (CFEET) System and Etch System Upgrades



W susceptor and BN Pedestal



Thermal Model of W susceptor and BN Pedestal



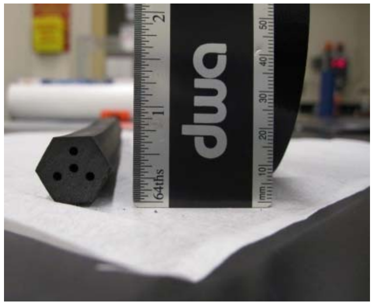
Full Length Fuel Element Etch System

Other Milestones: ORNL Graphite Composite 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

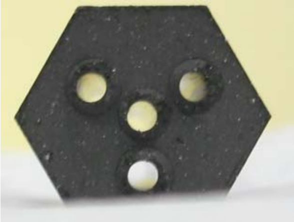


Above and left: Graphite sample prior to heat treatment

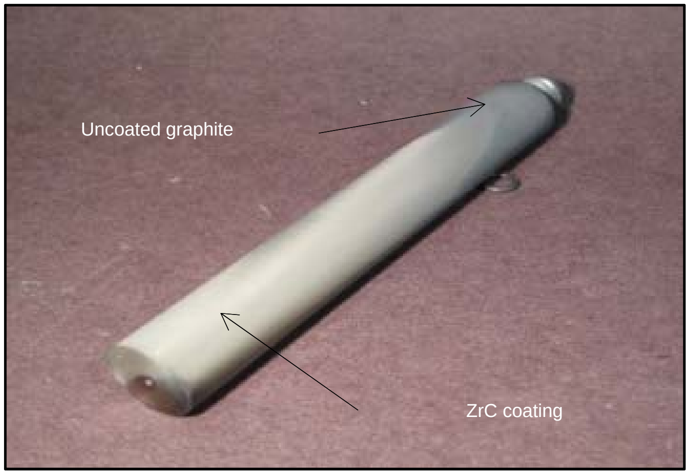
ORNL graphite composite samples after the final heat treatment to 2700 C. Long sample is a section from an extrusion run. Short one is run out material left over from extrusion run. (Heat treated to have some extra material)

Coated Graphite Composite Development (ORNL)

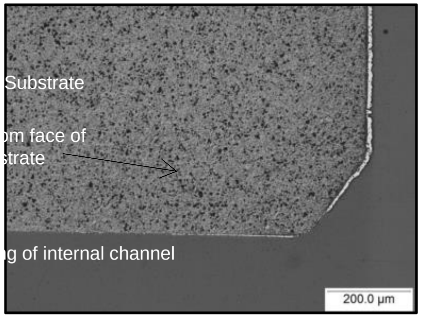
Above: Members of Oak Ridge National Laboratory fuels team with the graphite extruder; Left: Graphite extruder with vent lines installed for DU capability



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



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

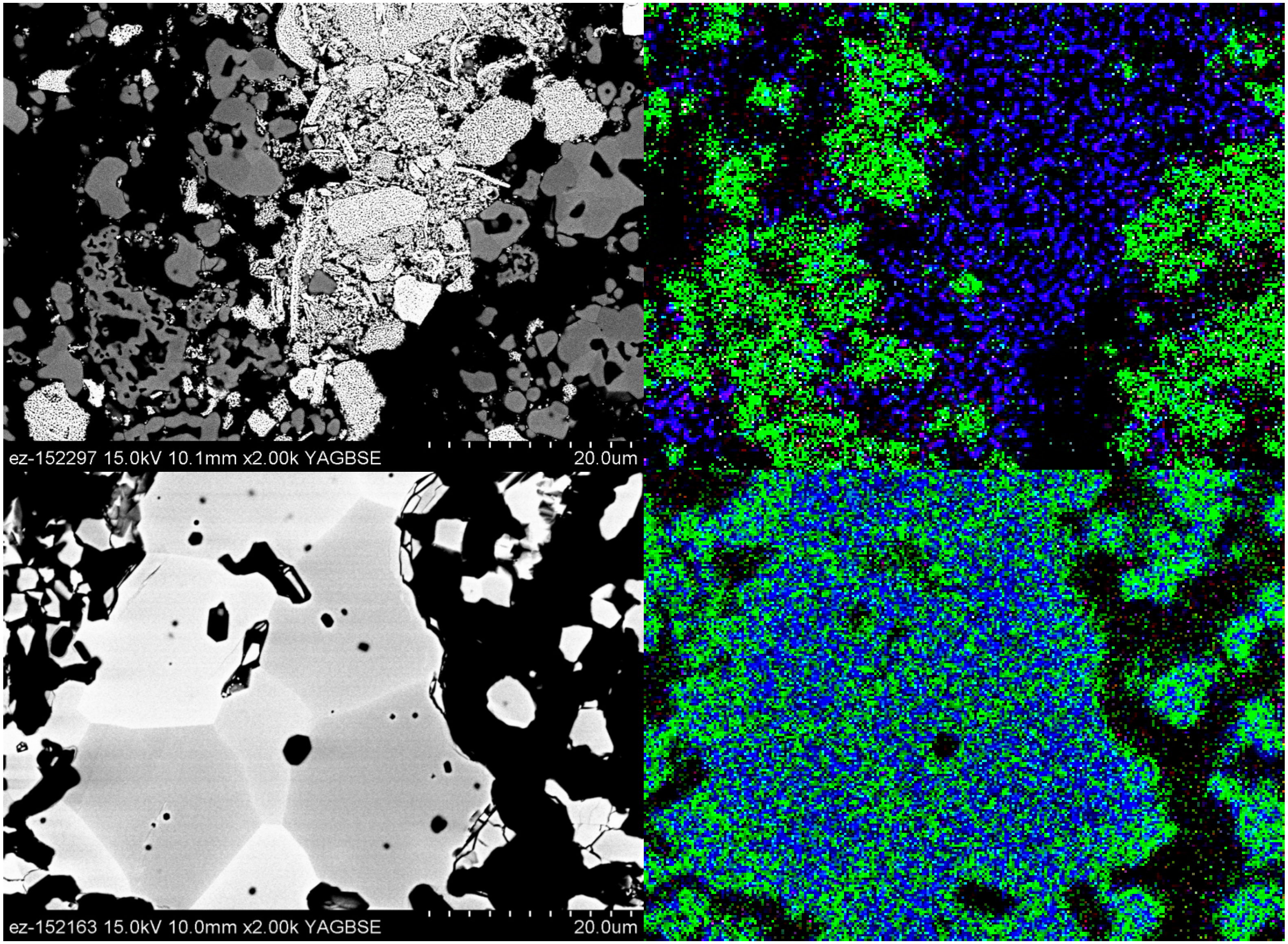


Right: Layoff base / Graphite insert

ORNL Graphite Composite Development

Backscattered SEM

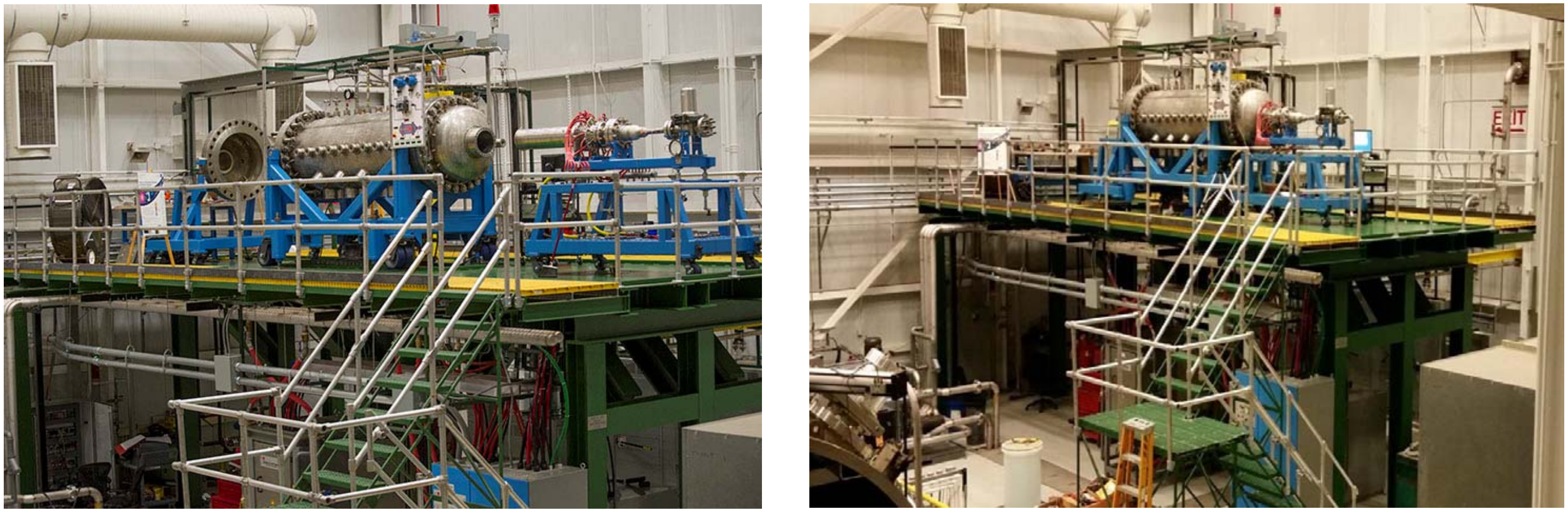
EDS analysis - Zr (green), Hf (blue)



Before heat treatment, 2000x

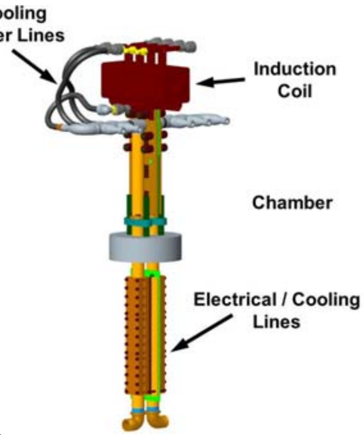
After heat treatment, 2000x

Other Milestones: Testing in NTREES



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

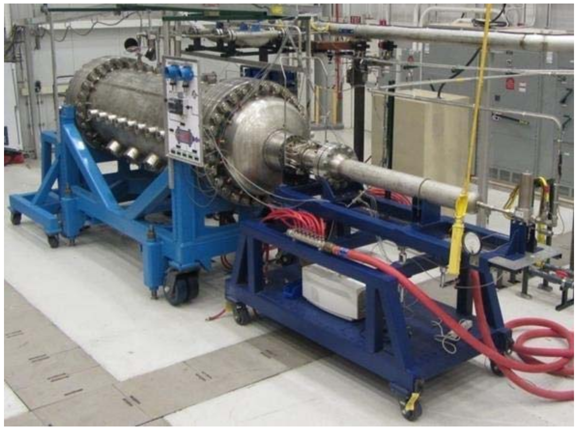
1.2 MW induction heater and DAQ system



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 on track to be ready for testing fuel elements with prototypic depleted uranium loading in March, 2015

Nuclear Thermal Rocket Element Environmental Simulator (NTREES)



NTREES Phase 1 50kW (2011)

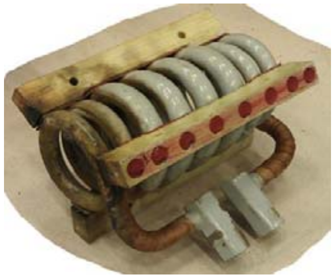
NTREES Phase 2 – 1MW Upgrade (2015)

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

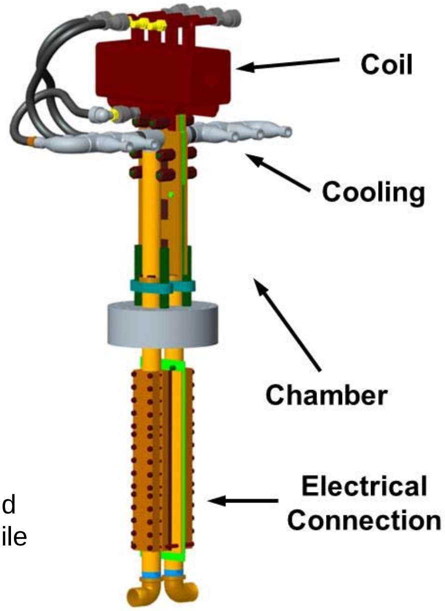
General Description:

- 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

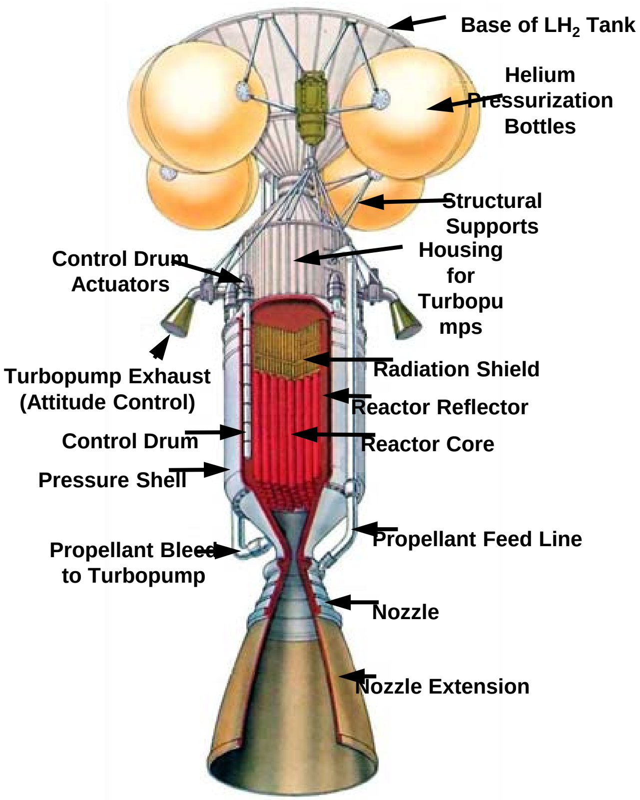
Other Considerations

60 years since the start of the Rover / NERVA program

NTP programs typically cancelled because mission is cancelled, not because of insurmountable technical or programmatic issues

Programmatic constraints, technical capabilities, available facilities, mission needs, etc. all continually change

Need to devise an optimal approach to developing a 21st century NTP system



Other Considerations

Options Have Changed Since 1955

Tremendous advances in computational capabilities (nuclear and non-nuclear).

Increased regulation and cost associated with nuclear operations and safeguards.

Extensive development of non-nuclear engine components. Extensive experience with various types of nuclear reactors.

Recent successes in “space nuclear” public outreach (Mars Science Lab).

Other Considerations

Many Decisions will Affect Long-Term Affordability and Viability of any Potential NTP Development Program

- Balance between computational and experimental work.
- Flight qualification strategy / human rating.
- Low-enriched uranium vs highly-enriched uranium.
- Unscrubbed, scrubbed, or fully contained exhaust during ground testing.
- Choice of facility for any required testing (i.e. NCERC, NASA center, industry, etc.)
- Numerous others!

Observations / Summary

HEOMD’s AES Nuclear Thermal Propulsion (NTP) project is making significant progress. First of four FY 2015 milestones achieved this month.

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.