2201
LOW COST NUCLEAR THERMAL ROCKET CERMET FUEL ELEMENT ENVIRONMENT TESTING (CFEET)

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Purpose of Test Hardware

• Low-Cost, small scale testing of NTR fuel element samples to obtain non-fissile materials data.

• Concentrated heating of fuel sample to near-prototypical temperatures (and expose to Hydrogen) to identify material failure modes.

• Allow for rapid turnaround testing of fuel elements manufactured using variety of materials and techniques.
Test Setup Dimensions

- Width: 12.0”
- Height: 16.9”
- Depth: 10.0”

Dimensions: 26.9”
RF Coil, Fuel Element, Pyrometer Detail
Fuel Sample Pedestal Details

Fuel Elements may be swapped in and out via removal of the 2.75” conflat blank (six bolts/one Cu gasket)

¼” SS Tube Acts as Position Adjuster (can easily be bent by hand) so that fuel element may be centered in RF Coil
Vacuum Chamber Setup – front view

- Chamber Relief Valve
- Vacuum Chamber
- RF Coil Feedthrough
- Analog Vacuum Gauge – since replaced by digital sender.
- Pyrometer Sight Glass
View Inside Vac Chamber Showing RF Coil
Non-Contact Pyrometers

- Vacuum Chamber
- Sight Glass
- Mikron M770S Pyrometer
- FAR Pyrometer Lens and Optical Fiber
View Into Sight Glass During Heating Test

Temperature Scale Shown for Reference – NOT ACTUAL ELEMENT TEMPERATURE

* http://www.blksmth.com/heat_colors.htm
Data Plot from 1.5kW Non-Melt Test of 308 stainless steel sample

Mikron Pyrometer (Orange)
FAR Pyrometer (Green)
RF Power
Pyrometer Viewport During Melt Test
Melt Test Videos

- melt test view 1.mp4
- melt test view 2.mp4
304 Fuel Element in RF Coil Before and After Melt
Estimated RF Heating Efficiency during Melt Test, no shielding

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>duration of applied RF, (seconds)</td>
<td>50</td>
</tr>
<tr>
<td>Power output level indicated on Flexitune, (kW)</td>
<td>9.3</td>
</tr>
<tr>
<td>total energy input, (kJ)</td>
<td>465</td>
</tr>
<tr>
<td>fuel element start temperature, (°C)</td>
<td>25</td>
</tr>
<tr>
<td>fuel element end temperature, (°C)</td>
<td>1500</td>
</tr>
<tr>
<td>specific heat of fuel element, Cp, (kJ/kg·K)</td>
<td>0.5</td>
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<tr>
<td>fuel element density, ρ, (g/cm³)</td>
<td>8.03</td>
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<tr>
<td>fuel element volume, V, (cm³)</td>
<td>6.44</td>
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<tr>
<td>mass of fuel element, m, (g)</td>
<td>51.67</td>
</tr>
<tr>
<td>total energy added to fuel element (kJ)</td>
<td>38.11</td>
</tr>
<tr>
<td>overall efficiency of RF heating (%)</td>
<td>8.2%</td>
</tr>
</tbody>
</table>
Thermodynamic Modeling

• Using simple equations for conduction and thermal radiation heat transfer, heat loss rates were predicted.
• Conduction heat loss is proportional to the element temperature.
• Thermal radiation heat loss is proportional to the fourth power of element temperature.
• At higher operating temperatures, thermal radiation dominates.
Shielding Techniques

• Reducing thermal radiation heat loss from the fuel element to the vacuum chamber requires a shield of some kind.

• An Alumina ceramic insulator was fabricated to fit between the fuel element and the RF coil.
Alumina Sleeve Insulator as Installed
Alumina Sleeve Insulator during Test
Low Power Heating Tests,
Element Temp During Heating

- No insulation, vacuum pumps isolated.
- With insulation, vacuum pumps isolated.
- With insulation, vacuum pumps operating.
- No insulation, vacuum pumps operating.
Low Power Heating Test,
Element Temp During Cool Down

- No insulation, vacuum pumps isolated.
- With insulation, vacuum pumps isolated.
- With insulation, vacuum pumps operating.
- No insulation, vacuum pumps operating.
High Power Heating Tests

• Some estimate of maximum system performance was desired.
• An in-coil ceramic insulator provided potential gains in heating efficiency.
• A heavier wall Zirconia ceramic insulator was cast and installed around a high-melting point cermet surrogate fuel element for this testing.
Cermet Surrogate Fuel Element Specifications

• W: Tungsten, 63% by weight, Cp=132 J/Kg·K, MP=3422 °C
• Rh: Rhenium, 5% by weight, Cp=136 J/Kg·K, MP=3186 °C
• HfN: Hafnium Nitride, 32% by weight, Cp≈249 J/Kg·K, MP=3305 °C
• Sample Mass: 92.881 g
• Estimated properties (based on mass percentages): Cp=169.8 J/Kg·K, MP=3373 °C
• Dimensions: ½ in. in diameter x 1.5 in. in length
• Sample Density: 19.2 g/cm³
RF Coil, Fuel Element and Insulator Setup for High Power Test

Note hole in ceramic insulator for pyrometer temperature measurement.
Time Lapse Photos of High Power Test
High Power Test Video

• high power test with W-Rh-HfN.mp4
High Power Heating
Fuel Element Temperature Plot
High Power Testing Results and Discussion

• RF Power supply tripped off on high water temperature limit (40°C).
• Water temperature dropped sufficiently to resume heating after about 60 seconds.
• Maximum fuel element temperature achieved: 1931°C
• Heating was limited by a cooling water limit and not insufficient heating power.
The hardware was observed post-test and physical contact between the in-coil insulator and the water-cooled RF coil was detected. Excessive conduction of heat from ceramic insulator to cooling water most likely cause of high water temperature trip. Eliminating physical contact and increasing cooling water flow rate should preclude further high temperature water trip.
System Upgrades –
New Ceramic Insulator with Clearance Fit to Coil

New Two-Piece Ceramic Casting: Improves Stress Relief Due to Thermal Expansion

Pyrometer Sight Lines

New RF Coil with 3/8” diameter Copper Tubing
Upcoming Future Work

• Integrate new and upgraded components into system.
• Install thermocouples on vacuum chamber outer wall.
• Run system check-out and ceramic bake-out tests using stainless steel sample.
• Run identical heating power profiles with all available combinations of insulation/shielding.
• Install Tungsten/Rhenium/Hafnium sample in chamber.
• Bake-out ceramics pulling active vacuum.
• Hard bolt chamber top flange, pull deepest possible vacuum and isolate pumps (observe vacuum decay).
• Test to highest possible fuel sample temperature or to system failure whichever comes first.
BACKUP CHARTS
RF Power Supply Specs

- Radyne Flexitune +15 2-255750-001
- 15kW, 150 VAC, 2400A, 20-60kHz
FAR Full Spectrum Pyrometer Specs

• Temperature range
  – FMP2: 800 - 2500°C nominal; lower limit is dependent upon the absorption of the optical path and emissivity of the target.

• Resolution: 0.1°C

• Repeatability: 0.015%

• Accuracy: 0.15% on gray targets; typically better than 0.75% on targets with nongray or changing emissivity or with absorbing atmospheres

• Wavelength range
  – 500 - 1000 nanometers
Mikron M770S Pyrometer Specs

- Temperature Range, 600 – 1400°C
- Accuracy: ±0.5% of full scale span
- Repeatability: 0.1% of full scale span
- Temperature Resolution: 1 °C/°F
- Spectral Response: One or two narrow bands near infrared