COMPACT FUEL ELEMENT ENVIRONMENT TESTER 2.0. D. P. Cavender[1] , C. F. Gomez[2], and D. E. Bradley[3], [1]NASA MSFC ER24 Huntsville, AL 35812, [2]NASA MSFC ER24 Huntsville, AL 35812, [3]Yetispace. Inc. 3701 Lakewood Dr. NW, Huntsville, AL 35811

Introduction:

New and advanced aerospace technologies must be taken to test early to ".. separate the real from the imagined, and to make known the overlooked and the unexpected problems…" Hugh Dryden's aphorism embodies the purpose of CFEET, a "table top" version of NTREES that allows candidate fissile fuels to be tested early and quickly before committing to full scale fuel element fabrication and testing. The first 7-hole surrogate W-ZrO_2 cermet sample was tested in September 2013. The sample was unclad spherical ZrO_2 powder mixed with 40% weight tungsten powders. The test marked the completion of FY13 milestones for in-house fabrication & testing of a surrogate fuel cermet sample.

Operational Details:

The CFEET chamber (Figure 1) is 2 cubic foot hot hydrogen test cell powered by a 50kW induction heater, and is capable heating candidate cermet fuel samples to temperatures above 2800K.

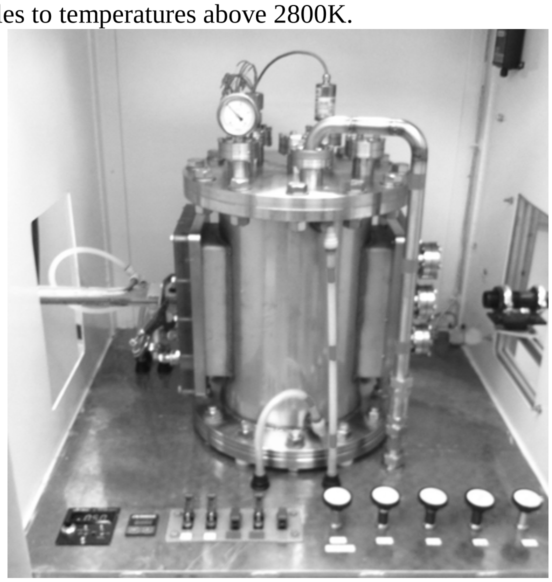

Figure 1: CFEET chamber

The flow control system (Figure 2) applies a combination of T/C controlled solenoid valves, check valves, relief valves, and mass flow controllers to evacuate and purge the chamber of oxygen, and flow a measured quantity of hydrogen into the chamber. Hydrogen gas enters CFEET at 16 slpm through the sample pedestal and flows around the sample. Normal chamber operating pressure is 1 atm. Exhausted gas is scrubbed through a nuclear grade HEPA filter then passed out an H_2 burn stack.

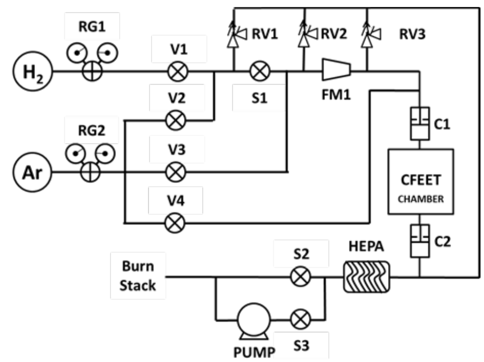

Figure 2: CFEET flow system schematic

The cermet sample is loaded into CFEET by a boron nitride (BN) pedestal loader under the chamber. The pedestal serves to hold and thermally insulate the sample. Multilayer molybdenum sheeting heat shielding further insulates the sample. The CFEET chamber's water jacket removed heat radiated to the chamber walls improving extended run time safety and unit performance.

Power from the induction power supply is applied to the heater coils by a thick water cooled copper bus. The heater coils is a spiral wound copper tube brazed to thick-walled brass tubes. Cooling water is pumped through the heater coil at a rate of >8 slpm.

Pyrometry readings are taken through a sight hole in the moly shield and BN insulator. Proper calibration of the pyrometer with portholes and sample range from collimator is necessary for accurate sample temperature measurements.

Induction Load Matching "Tuning"

Matching the inductance of the heater coil with the power supply is paramount if high efficiency and performance are to be achieved. Tuning the SP16 power supply (Figure 3) involves tapping the optimal number of available capacitors to adjust the systems natural frequency to within 60% - 90% accounting for all inductive sources and losses.

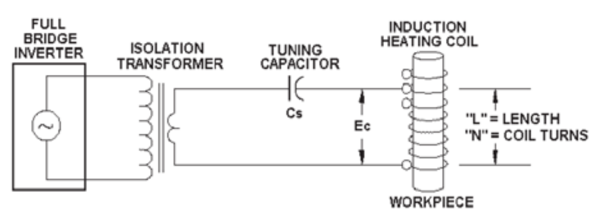

Figure 3: Simple induction circuit illustration

The heater coil's inductance can be calculated with Equation 1[1]

$$L_{coil} = \frac{1}{l}\mu_0 K N^2 A \qquad \text{[Equation 1]}$$

where μ_0 is the permeability of free space, K is the Nagaoka coefficient ($0 < K \leq 1$), N is the number of coil turns, and A is cross sectional area of a coil turn (m^2). Inductive losses in the bus and chamber feedthroughs are estimated in a similar manner.

Thermal Desktop & COMSOL Simulations:

Quantifying losses within the CFEET system has been challenging, which drove the development of a Thermal Desktop and COMSOL simulations (Figure 4) to visualize and understand the "coupling" between the ceramic-metallic (cermet) sample and the heater coil, and how that drives the design.[2] The purpose of the simulations was to predict the total power being induced to the sample and evaluate design changes.

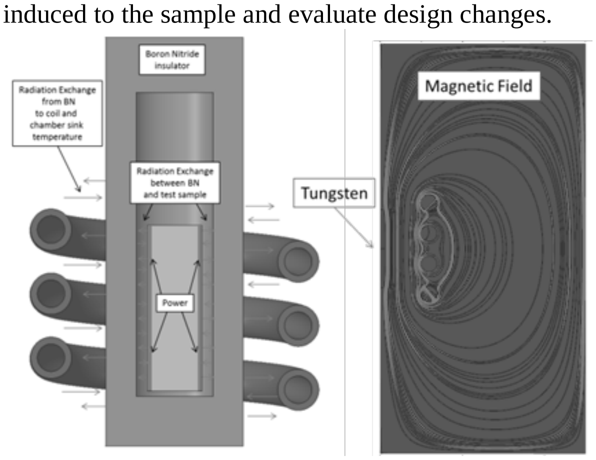

Figure 4: Thermal Desktop & COMSOL model illustration

The Thermal Desktop and COMSOL simulations and other parallel effort have led to several evolutions of the heater coils (Figure 5) to increase magnetic flux density, and improve or extend overall operations of the CFEET.

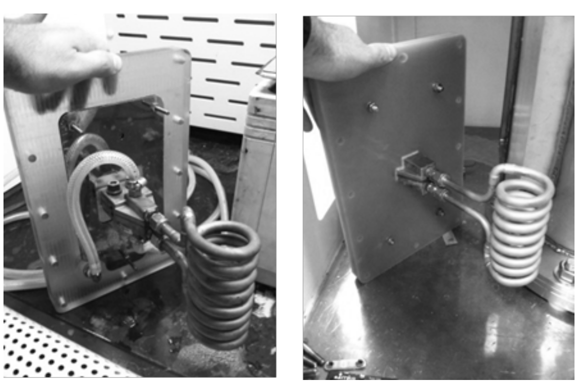

Figure 5: Coil design #4 (left), coil design #6 (right)

Testing & Results:

The first CFEET runs were powered by the more versatile but smaller 15kW flexitune power supply. The 15kW flexitune reports real-time operating and self-health monitoring data. Each run increased in duration or temperature. Argon gas replaced hydrogen for the first three shakedown tests. The first shakedown test was run at 5kW power for 2 hours with no anomalies. The second shakedown test was run at 15 kW power, and the test was terminated at 7 minutes when the tungsten sample melted (Figure 6).

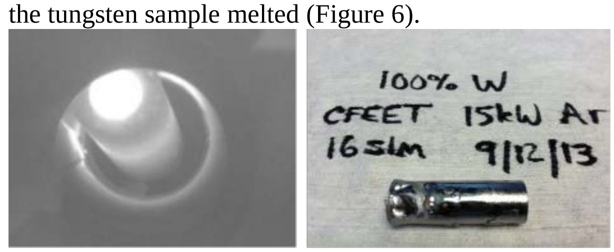

Figure 6: Molten tungsten sample (left), once removed (right).

Hydrogen gas replaced argon, and hafnium carbide replaced tungsten for all subsequent testing leading up to the W-ZrO_2 testing.

The first 7-hole W-ZrO_2 surrogate sample test ran 90 minutes with no anomalies. The sample was unclad spherical ZrO_2 powder mixed with 40% weight tungsten powders. The low tungsten content greatly affected the coupling with the induction coil and reduced the temperatures previously achieve with the 100% W samples. The test marked the completion of FY13 milestones for in-house fabrication & testing of a surrogate fuel cermet sample, but more power was required to reach the target temperature of 3000K. The 50kW SP16 replaced the 15kW flexitune, and the first SP16 test run was conducted in late December 2013. The W-ZrO_2 sample exhibited localized melting and oxidation to the sample. The sample is now being analyzed in the materials lab at MSFC.

References:

[1] Nagaoka, Hantaro (1909-05-06). The Inductance Coefficients of Solenoids 27. Journal of the College of Science, Imperial University, Tokyo, Japan. p. 18. Retrieved 2011-11-10.
[2] Carlos, G., Cavender, D., (2013, July) Induction heating model of cermet fuel element environmental test: Thermal & Fluids Analysis Workshop (TFWAS) conference, Daytona Beach, FL.