Initial Operation and Shakedown of the Nuclear Thermal Rocket Element Environmental Simulator (NTREES)

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A key technology element in Nuclear Thermal Propulsion is stability of the fuel material and high temperatures when exposed to hydrogen. NTREES provides a cost effective method for rapidly screening of candidate material and examining thermal hydraulic performance.

- The NTREES is designed to mimic the conditions (minus the radiation) to which nuclear rocket fuel elements and other components would be subjected to during reactor operation.

- The NTREES consists of a water cooled ASME code stamped pressure vessel and its associated instrumentation coupled with inductive heaters to simulate the heat provided by the fission process.

- The NTREES has been designed to allow hydrogen gas to be injected into internal flow passages of a test article mounted in the chamber.

Various modifications to NTREES have been performed on the facility over the last year. These modifications greatly increase the power level of NTREES, add new diagnostics, and simplify the facility operation.
Nuclear Thermal Rocket Element
Environmental Simulator (NTREES)
Test Element Layout in NTREES

ER24/Nuclear Systems Branch

Test Article
Support

Test Article

Test Article

Support

Test Article

N2

H2 / N2 Mixer

Water

N2

Chamber

Induction Coil

Feedthru

Water

H2 + N2

Filter

H2

H2 + N2

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NASA

Engineered to Excel—Driven to Explore

ER Propulsion Systems Department
Coil Damage Occurred During High Temperature Checkouts
Coil Damage Required Procuring of a New Replacement Coil

Old Coil Prior to Damage

Replacement Coil

Old Coil Damaged
Generalized Test Sequence

- Load test element into the NTREES chamber
- Verify/perform calibrations as required by the SOP
- Purge and pressurize the chamber with nitrogen
- Startup water system
- Initiate hydrogen flow
- Power on induction heater and run test sequence
- Shutdown power system at end of test
- Stop hydrogen flow
- Purge the chamber with nitrogen and depressurize
- Survey the area. Remove test element from the NTREES chamber and decontaminate as necessary
Cover those parts of NTREES where there is a potential for contamination with a material such as herculite. Rope off area with rad rope/tape. Post area as Radioactive Material Area. May be changed to Contaminated Area depending upon what is found after opening the chamber after the test.
Open the side access flange and position the test article mounting cart near the rear of NTREES
Receive the test article from the RSO and mount the test article in the cold clamp assembly on the mounting cart.
Close side access flange and reposition the mounting cart to its forward location making sure the test article passes through the induction cart and into the hot clamp assembly.
NTREES System Operation - Purging

- Nitrogen
- Hydrogen
- H2 & N2 Mixture
- Power

Hydrogen Panel

Nitrogen Bypass Valve

Induction Heater

Nitrogen Panel

Back Pressure Control Valve

Vent Stack
NTREES System Operation – Hydrogen Startup

- Nitrogen
- Hydrogen
- H2 & N2 Mixture
- Power

Diagram:
- Nitrogen Bypass Valve
- Induction Heater
- Nitrogen Panel
- Hydrogen Panel
- Back Pressure Control Valve
- Vent Stack
NTREES System Operation - Purging

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- Nitrogen Bypass Valve
- Hydrogen Panel
- Induction Heater
- Nitrogen Panel
- Back Pressure Control Valve
- Vent Stack
Remove side access flange, wipe down with Masslin cloth and survey, decontaminate as directed by the RSO. Place contaminated materials in rad waste container.
Under the direction of the RSO, remove the test article from the mounting cart cold clamp assembly and examine the test article as necessary on the table behind the NTREES chamber. Prepare test article for removal from site or reinsertion into NTREES for further tests.
Reattach the side access flange to the chamber and survey and decontaminate the area as directed by the RSO. Place contaminated materials in rad waste container. Leave everything up until decontamination of the chamber internals is complete.
The NTREES Test Readiness Review was held on February 23, 2015. No significant constraints to test were found by the review panel.

Specifics for the TRR included:

- Test objectives, goals, and success criteria
- Test element description
- Test matrix with objectives
- Layout of the test element within facility
- NTREES system description
- Test element handling (insertion & removal)
- Personnel & certifications
The objective of the anticipated test series is to subject a section of a graphite composite or cermet based fuel element containing depleted uranium to an increasingly severe temperature and hydrogen flow environment.

Post test evaluations will quantify any changes to the fuel which occurred as a result of the NTREES testing.

This initial test is designed to meet a major milestone required by the NCPS project.
• Fission heating in a reactor typically involves conditions in which the fuel element has a roughly flat power distribution with adiabatic walls. The cross sectional temperature distribution is therefore, fairly flat.

• Induction heating of a single fuel element yields a power distribution in which the power is deposited preferentially on the outer portions of the fuel element. With adiabatic walls conditions, the cross sectional temperature distribution will also be skewed toward the outer portions of the fuel element.
Power & Temperature Profiles in an ANL-200 Fuel Element with an Adiabatic Wall

Power Profile

Temperature Profile with Adiabatic Wall

Temperature T (K)

3500
3450
3400
3350
3300
3250
3200
3150
3100
3050
3000
Question …

• How can one make a single inductively heated fuel element yield a temperature distribution which is comparable to the temperature distribution which would be found in a typical fissioning fuel element in a nuclear rocket engine?

• Perhaps by using incorrect boundary conditions with the incorrect power distribution generated by induction heating, it would be possible to obtain a temperature distribution which is close to that found in the fissioning fuel element.

• What if it were possible to vary the amount of thermal radiation being radiated or convected from the fuel element by varying the view factor from the fuel element?
Power & Temperature Profiles in an ANL-200 Fuel Element with Optimal Wall Cooling

Power Profile

Temperature Profile with Optimal Wall Cooling

[Temperature scale: 3000 to 3300 K]
Temperature Profiles in an ANL-200 Fuel Element with Varying View Factor/Emissivities

\[ F_{12} = 0.1 \]

\[ F_{12} = 0.2 \]

\[ F_{12} = 0.3 \]

\[ F_{12} = 0.4 \]

\[ F_{12} = 0.5 \]

\[ F_{12} = 0.6 \]

\[ F_{12} = 0.7 \]

\[ F_{12} = 0.8 \]

\[ F_{12} = 0.9 \]
Summary

- NTREES has been modified to allow much higher power operation
- Check out tests uncovered design deficiencies which limited the temperature test elements could reach
- All design deficiencies uncovered to date have been corrected
- Alternate coil designs are being pursued to allow even greater fidelity in tests
- First test element is expected to occur later this year