Abstract.

Nuclear Thermal Rockets or NTR’s have been suggested as a propulsion system option for vehicles traveling to the moon or Mars. These engines are capable of providing high thrust at specific impulses at least twice that of today’s best chemical engines. The performance constraints on these engines are mainly the result of temperature limitations on the fuel coupled with a limited ability to withstand chemical attack by the hot hydrogen propellant. To operate at maximum efficiency, fuel forms are desired which can withstand the extremely hot, hostile environment characteristic of NTR operation for at least several hours. The simulation of such an environment would require an experimental device which could simultaneously approximate the power, flow, and temperature conditions which a nuclear fuel element (or partial element) would encounter during NTR operation. Such a simulation would allow detailed studies of the fuel behavior and hydrogen flow characteristics under reactor like conditions to be performed. Currently, the construction of such a simulator has been completed at the Marshall Space Flight Center, and will be used in the future to evaluate a wide variety of fuel element designs and the materials of which they are fabricated. This present work addresses the operational status of the Nuclear Thermal Rocket Element Environmental Simulator or NTREES and some of the design considerations which were considered prior to and during its construction.
NTREES Testing and Operations Status

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A key technology element in Nuclear Thermal Propulsion is the development of fuel materials and components which can withstand extremely high temperatures while being exposed to flowing hydrogen. NTREES provides a cost effective method for rapidly screening of candidate fuel components with regard to their viability for use in NTR systems.

- 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.

Numerous laboratory upgrades in 4205/110 have been required to support the operation of NTREES. These modifications include the installation of a cooling water system, a power distribution system consisting of switch panels and transformers, and a propellant gas feed/exhaust system.
The NTREES system has been reviewed and approved by the MSFC Radiation Safety Officer (RSO) and has been licensed by the NRC to handle Depleted Uranium

- The Operating Procedures have been approved by the RSO
- Filters have been installed on all vent lines (0.3 μm) to capture DU particles which escape the test element
- A mass spectrometer on the vent line monitors the exhaust for traces of U^{238} (DU)

<table>
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<tr>
<th>MSFC License Application For Use of Depleted Uranium</th>
<th>MSFC License Application Authorizing use of Depleted Uranium in 4205/110</th>
<th>NRC License allowing MSFC To Possess Up to 27.3 kg of Depleted Uranium</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Image of MSFC License Application For Use of Depleted Uranium" /></td>
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Use of Depleted Uranium (DU) in NTREES
General Description:

- Water cooled ASME coded test vessel rated for 1050 psi
- GN$_2$ (facility) and GH$_2$ (trailer) gas supply systems
- Vent system (combined GN$_2$/GH$_2$ flow)
- 50kW RF power supply with induction coil
- Water cooling system (test chamber, exhaust mixer and RF system)
- Control & Data Acquisition implemented via LabView program
- Extensive H$_2$ leak detection system
- Data acquisition system consists of a pyrometer suite for axial temperature measurements and a mass spectrometer
- "Fail Safe" design
Key components on test chamber setup:

- 50 kW RF power supply (NTREES is sized to accommodate up to 4 MW of RF power)
- Exhaust mixer system and heat exchanger to cool and dilute hot hydrogen flow
- Backpressure control instrumentation, valves, and filters
- Mass spectrometer on vent gas system
- Pyrometers to measure test specimen surface temperatures
NTrees Facility in the PRDL

- Water Recirculation System
- Vent Line
- H₂ / N₂ Mixer
- Pressure Vessel
- Heat Exchanger (dummy)
- Mass Spectrometer
- Hydrogen Panel
- N₂ Purge Panel
- Pit
NTREES Facility in the PRDL

- Vent Line
- Pyrometers
- Pressure Vessel
- N₂ Panel
- Induction Heater
- Data Acquisition System
- N₂ Purge Panel
- Pit
- H₂ Inlet
Includes **Nitrogen**, **Hydrogen**, and **Vent** systems

- All components and layout are ASME certified
- Main chamber is ASME code stamped
Primary hardware items placed on laboratory floor:

- **Hazardous Classification of areas around GH$_2$ panels and external vent**
- **Hydrogen supply from trailer (external); only hooked up during tests**
- **H$_2$ detectors strategically located**

All electrical components are explosion proof in these zones
NTREES Induction Coil Mounted in Chamber with $H_2/N_2$ Mixer Assembly

H$_2$ Inlet

$H_2/N_2$ Mixer

Coil Assembly
NTREES Data Acquisition and Control

ER24/Nuclear Systems Branch

Provides the following

- System monitoring with 7 RTD’s, 8 pressure transducers, & 3 flowmeters
- Active system to monitor and control test operations
- Automatically shuts down the system when anomalous conditions or redline cuts are detected (e.g. pressure too high or too low, over temperature, high H₂ concentration, low N₂ flow, etc.)

**Key:**
- O Sensor
- E E-Stop

P - Pressure Measurement
T - Temperature Measurement
F - Flow Measurement
H - Hydrogen sensor
A number of power system panels are located in room 110

- Some power system panels feed the NTREES system (e.g. water, DAQ, etc.)
- All other panels will be locked out during testing (e.g. lights, crane, etc.)
Lab has capability of providing up to 5 MW of power for induction heating

- Two 2.5MW Transformers
- High power switch gear
- High power conduit going to opposite side of room
NTrees Operation – Safety Controls

Fail-Safe Components
- Relief valves on pressurized equipment
- High pressure gas supply lines with fail-closed valves (loss of power/pneumatics)
- Back pressure control valves (vent)
  1. Proportional control for chamber and test article pressure
  2. Fail open
  3. Pneumatically controlled, safer for GH$_2$ environment

Emergency Shutdown
- Actively set to safe condition by real-time controllers
- Real-time controllers operation includes:
  1. Termination of RF Power
  2. Closing of GH$_2$ supply valve
  3. Opening of outlet vent valves to relieve chamber and test article pressure

Emergency Shutdown Criteria include:
- Any room/chamber GH$_2$ sensor exceeding limit
- Loss of cooling water flow
- Any E-Stop button activated (pressed)
- Watchdog timeout (both controllers monitor each other)
- Chamber pressure or delta pressure (too high or erratic behavior)
- Pressure (too low) in chamber sampling stream (GH$_2$ sensor location)
Conclusions

• The NTR Element Environmental Simulator is complete and will allow fuel elements or other components to be tested in a hot hydrogen environment with or without internal heat generation and enables:

  - High temperature (> 3000 K) operation in flowing hydrogen
  - A wide range of instrumentation for monitoring test article behavior under extreme conditions
  - High pressure operation up to 1050 psi
  - Close personnel access during operation resulting from forced cooling of the chamber

• Due to a lack of funding, the NTREES facility is currently sitting in a standby condition pending future authorization to proceed to testing
The NTR Element Environmental Simulator is operational at MSFC and is available to begin testing fuel materials and other components under prototypical NTR operating conditions.