Nuclear Thermal Rocket Element Environmental Simulator (NTREES) Upgrade Activities

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To support the on-going nuclear thermal propulsion effort, a state-of-the-art non nuclear experimental test setup has been constructed to evaluate the performance characteristics of candidate fuel element materials and geometries in representative environments. The facility to perform this testing is referred to as the Nuclear Thermal Rocket Element Environment Simulator (NTREES). This device can simulate the environmental conditions (minus the radiation) to which nuclear rocket fuel components will be subjected during reactor operation. Test articles mounted in the simulator are inductively heated in such a manner so as to accurately reproduce the temperatures and heat fluxes which would normally occur as a result of nuclear fission and would be exposed to flowing hydrogen. Initial testing of a somewhat prototypical fuel element has been successfully performed in NTREES and the facility has now been shutdown to allow for an extensive reconfiguration of the facility which will result in a significant upgrade in its capabilities.

I. Introduction

Over the past year the Nuclear Thermal Rocket Element Environmental Simulator (NTREES) has been undergoing a significant upgrade beyond its initial configuration[1]. The NTREES facility is designed to perform realistic non-nuclear testing of nuclear thermal rocket (NTR) fuel elements and fuel materials. Although the NTREES facility cannot mimic the neutron and gamma environment of an operating NTR, it can simulate the thermal hydraulic environment within an NTR fuel element to provide critical information on material performance and compatibility.

The first phase of the upgrade activities has been now been completed. This upgrade in part consisted of an extensive modification to the hydrogen system to permit computer controlled operations outside the building through the use of pneumatically operated variable position valves. The new setup also allows the hydrogen flow rate to be increased to over 200 gm/sec. Other aspects of the upgrade included reworking NTREES to reduce the operational complexity of the system. To this end, many of the controls were consolidating on fewer panels. Additionally, the purge system was modified so as to permit simplified purging operations. As part of this upgrade activity, the Safety Assessment (SA) and the Standard Operating Procedures (SOPs) for NTREES were extensively rewritten.

In the second stage of modifications to NTREES, which is currently underway, the capabilities of the facility will be increased significantly. In particular, the current 50 kW induction power supply will be replaced with a 1.2 MW unit which will allow more prototypical fuel element temperatures to be reached. To support this power upgrade, the water cooling system will also be upgraded to so as to be capable of removing 100% of the heat generated during testing and the nitrogen system will be upgraded to increase the nitrogen flow rate from its current 1.2 lb/sec to at least 4.5 lb/sec. The new setup will require that the NTREES vessel be raised onto a platform along with most of its associated gas and vent lines. The induction heater and water systems will be located underneath the platform. The new design will also allow for additional upgrades which could raise the power level of NTREES to 5 MW. Once fully operational, the 1.2 MW NTREES test chamber will be capable of testing fuel elements and fuel materials in flowing hydrogen at pressures up to 1000 psi at temperatures up to and beyond 3000 K and at near-prototypic reactor channel power densities. NTREES will also be capable of testing potential fuel elements with a variety of

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propellants, including hydrogen with additives to inhibit corrosion of certain potential NTR fuel forms. Additional diagnostic upgrades planned for NTREES include the addition of a gamma ray spectrometer located near the vent filter to detect uranium fuel particles exiting the fuel element in the propellant exhaust stream to provide additional information any material loss occurring during testing.

II. NTREES Facility Description

The NTREES test facility is designed to simulate the environmental conditions (minus the radiation) to which nuclear rocket fuel components will be subjected during reactor operation. Test articles are mounted in the simulator and inductively heated in such a manner so as to accurately reproduce the temperatures and heat flux distributions which would normally occur as a result of nuclear fission while simultaneously undergoing operation with flowing hydrogen. The basic laboratory setup for NTREES is illustrated in Figure 1.

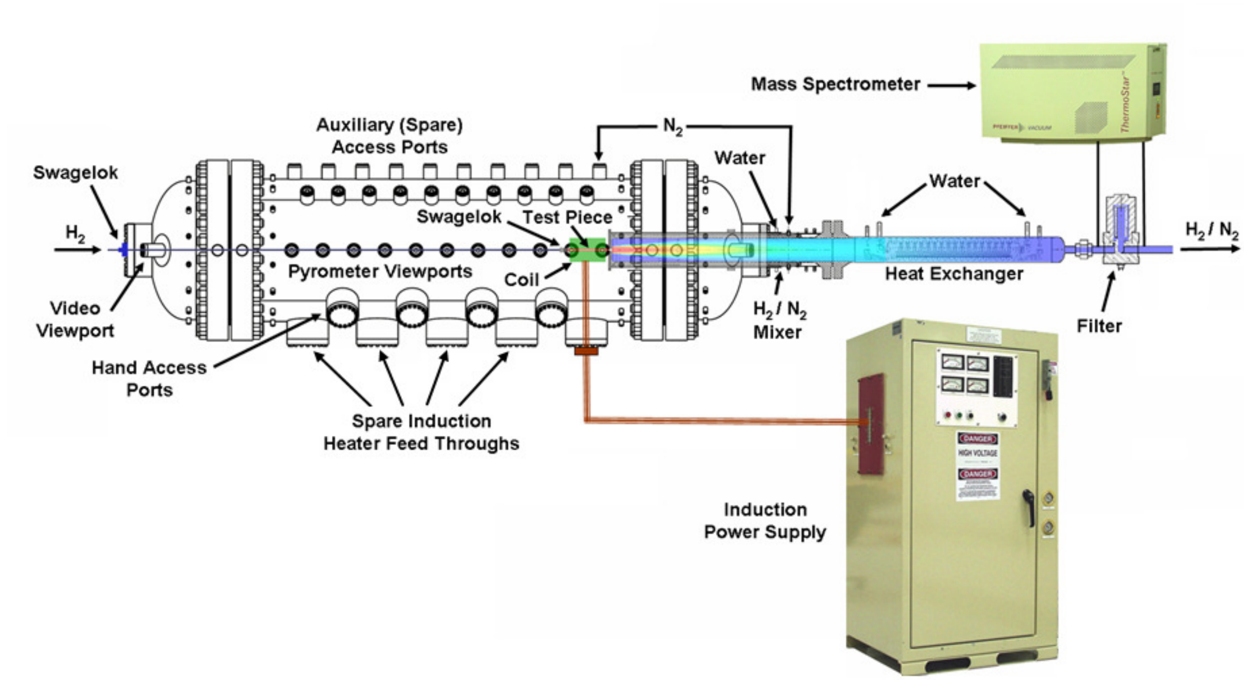


Figure 1. NTREES System Diagram.

The NTREES device is currently located in the building 4205 laboratory 101 high-bay. The laboratory has access to the cross country nitrogen supply system at the Marshall Space Flight Center (MSFC) plus a high capacity building cooling water system. Gaseous hydrogen used for testing is supplied by a trailer that is connected only during operations.

Several major systems comprise the NTREES facility. These systems include the main pressure vessel, the induction heating system, the hydrogen/nitrogen mixer system, the water system, and the data acquisition system.

A. Chamber

The chamber houses the test article which is mounted to fixtures which allow hydrogen to flow into and out of the test article. Normally the chamber is pressurized with nitrogen such that the nitrogen pressure is slightly higher than the hydrogen pressure flowing through the test article. This arrangement minimizes hoop stresses on the test article during operation and provides a stressenvironment sililar to what the a fuel element would experience during operation in a nuclear engine.

Physically, the chamber consists of a water cooled ASME code stamped vessel and its associated support stand. The vessel has a maximum operating pressure of 7.0 MPa and a design pressure of 7.6 MPa. Much effort was spent designing flexibility into the vessel so that it would be capable of testing a wide variety of test elements by including numerous ports of various sizes for visual access, power and instrumentation feedthrus, arm holes to allow for hand access, nitrogen flow, etc.

B. Hydrogen/Nitrogen Mixer Assembly

The NTREES mixer assembly is used to support the test articles during testing while they are being heated and exposed to flowing hydrogen. In addition to supporting the test pieces, the mixer assembly dilutes and cools the hot hydrogen as it leaves the NTREES with large quantities of high pressure, room temperature nitrogen. The nitrogen is injected into the mixer assembly through taps on the outside of the chamber and is distributed within the mixer such that the hot hydrogen is prevented from touching the sides of the mixer until it has been well diluted and cooled by the nitrogen. To provide additional temperature margins, the entire mixer assembly is internally cooled with water.

The mixer assembly is designed to eliminate the need for a high temperature seal at the test article / mixer assembly interface. This is accomplished by keeping the chamber nitrogen pressure slightly above the hydrogen pressure in the test piece. In-leakage of nitrogen through a small gap in the test article support cap mounted on the mixer cools the interface where the cap supports the test piece and prevents significant quantities of hydrogen from escaping into the chamber.

Once the hydrogen/nitrogen effluent leaves the mixer assembly, it is directed into a filter prior to entering the vent piping to prevent any particles whch may have eroded off the test article from being discharged to the environment.

C. Data Acquisition System

The NTREES facility is equipped with a variety of hardware for instrumentation, control, and data acquisition. The hardware is distributed around the test chamber and support equipment, but integrated and controlled from one piece of software running on one computer located in the control room.

The instrumentation on NTREES includes:

- Pressure sensors for GH_2 and GN_2
- Temperature sensors for GH_2 and GN_2
- Flow sensors for GH_2 and GN_2
- Thermocouples for general temperature measurements
- Hydrogen detection for the test chamber and room 101
- Pyrometers for high temperature measurement of test pieces
- Mass spectrometer to measure gas composition

D. Induction Heating System

The induction heater used to simulate fission processes in the test articles by providing a noncontact means of heating the test article. During operation, the induction heater supplies an alternating to a coil within which the test article resides. Eddy currents induced into the test article through the alternating currents in the coil can heat the test article to extremely high temperatures. Through proper coil design, almost any desired power distribution may be imposed on the test article to very closely simulate the power distribution which would be present in an operating nuclear rocket reactor.

Connections to the coil from the induction heater are made via large feedthroughs mounted underneath the chamber. Cooling for the induction heater is accomplished with a dedicated cooling water and heat exchanger system which is connected to the building service water system

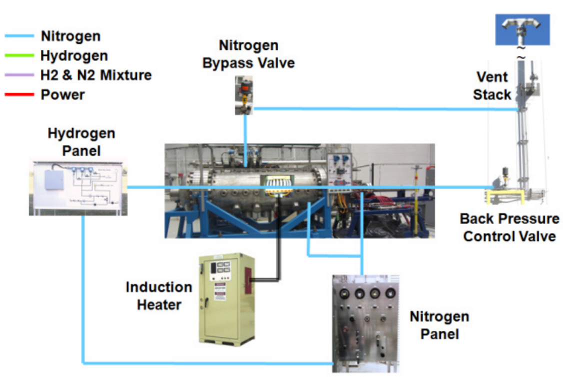
III. NTREES Test Operations

Over the past year the Nuclear Thermal Rocket Element Environmental Simulator (NTREES) has been undergoing a significant upgrade. Currently, the first phase of the upgrade activities has been completed. This upgrade in part consisted of an extensive modification to the hydrogen system to permit computer controlled operations outside the building through the use of pneumatically operated variable position valves. The new setup also allows the hydrogen flow rate to be increased to over 200 gm/sec. Other aspects of the upgrade included reworking NTREES to reduce the operational complexity of the system. To this end, many of the controls were consolidating on fewer panels. Additionally, the purge system was modified so as to permit simplified purging operations. As part of this upgrade activity, the Safety Assessment (SA) and the Standard Operating Procedures (SOPs) for NTREES were extensively rewritten.

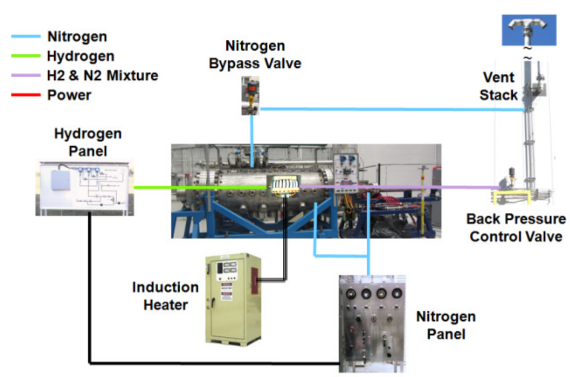
The NTREES facility is licensed to test fuels containing depleted uranium. It includes a pyrometer suite to measure fuel temperature profiles and a mass spectrometer to help assess fuel performance and evaluate potential material loss from the fuel element during testing. After completion of this initial buildup, test operations were performed to check out the system. In these tests dummy fuel elements were heated to approximately 1500 ^{o}C in the presence of flowing hydrogen. The tests indicated that the NTREES could be operated safely and that it behaved in the expected manner. A picture of this initial NTREES setup configuration is shown in Figure 2.

Figure 2. NTREES Test Facility and Hydrogen Setup.

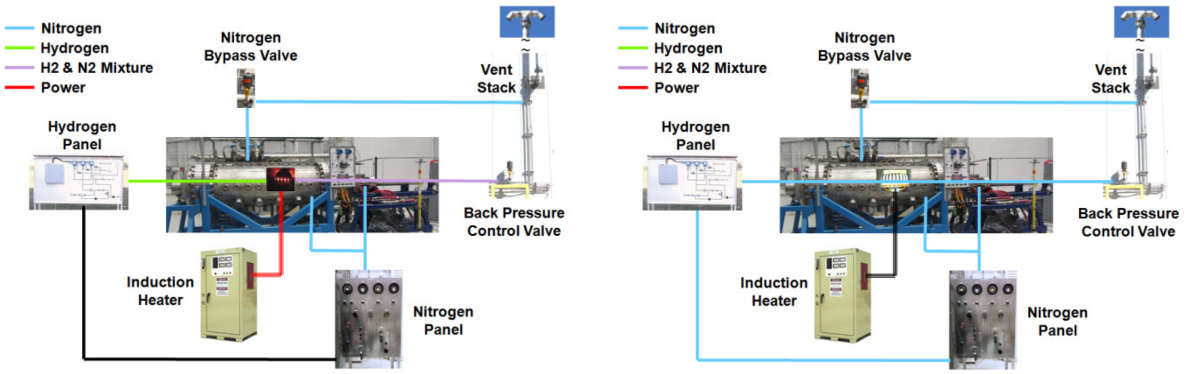
A typical test sequence involves several operations. Initially, NTREES is purged of all oxygen so that should hydrogen be introduced into the gas line or pressure vessel due to fuel failure or for some other reason, there will be no possibility of an ignition. Once the system has been purged, the nitrogen flow through the propellant line is terminated and a hydrogen flow through the line is established at the appropriate pressure and flow rate. After the hydrogen flow has been established, the induction heater is started and the test article is brought up to its required temperature. The actual test is then considered "in progress" and the power and hydrogen flow are ramped, started and stopped, etc. following the desired operational sequence. Once the test is completed, the power is shutdown, the hydrogen flow is stopped, and the system is purged with nitrogen. Figure 3 illustrates this test sequence.



Step 1 -Nitrogen Purge



Step 2 - Establish Hydrogen Flow



Step 3 - Powered Operation **Step 4 - Nitrogen Purge**

Figure 3. NTREES Test Operations.

Once all the initial checkouts of NTREES were completed a semi prototypical type fuel element was mounted into NTREES for testing. This test article consisted of a 5/8" diameter specimen comprized of pure tungsten with 40 volume % hafnium nitride particles. A 0.030" niobium can surrounded the hafnium nitride. Seven flow channels were incorporated along the length of the specimen. The test sequence for this fuel specimen consisted of several start /stop sequences for durations equivalent to over two Mars missions. The total powered time of the test was over four hours with ten minutes of cooldown time between power sequences. Figure 4 illustrates the fuel specimen under test and its condition afterward. Note that at some point during the test the fuel failed, though in such a way that the fuel element remained largely intact even to the extent that the test sequence was able to be completed without problem.

Figure 4. Test Article During and After Testing.

In the second stage of modifications to NTREES, which is currently underway, the capabilities of the facility will be increased significantly. In particular, the current 50 kW induction power supply will be replaced with a 1.2 MW unit which will allow more prototypical fuel element temperatures to be reached. To support this power upgrade, the water cooling system will also be upgraded to so as to be capable of removing 100% of the heat generated during testing and the nitrogen system will be upgraded to increase the nitrogen flow rate from its current 1.2 lb/sec to at least 4.5 lb/sec. The new setup will require that the NTREES vessel be raised onto a platform along with most of its associated gas and vent lines. The induction heater and water systems will be located underneath the platform. The new design will also allow for additional upgrades which could raise the power level of NTREES to 5 MW. Once fully operational, the 1.2 MW NTREES test chamber will be capable of testing fuel elements and fuel materials in flowing hydrogen at pressures up to 1000 psi at temperatures up to and beyond 3000 K and at near-prototypic reactor channel power densities. NTREES will also be capable of testing potential fuel elements with a variety of propellants, including hydrogen with additives to inhibit corrosion of certain potential NTR fuel forms. Additional diagnostic upgrades planned for NTREES include the addition of a gamma ray spectrometer located near the vent filter to detect uranium fuel particles exiting the fuel element in the propellant exhaust stream to provide additional information any material loss occurring during testing. A rendering of NTREES as it might appear if it is upgraded to 5 MW is illustrated in Figure 5.

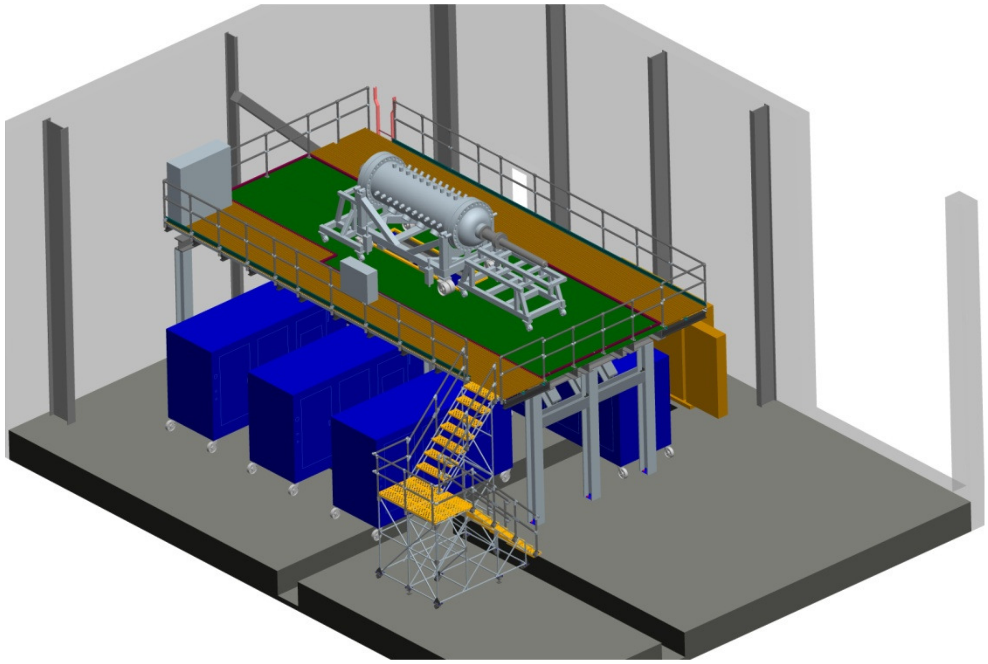


Figure 5. NTREES Fully Configured Layout.

IV. Conclusion

The upgrade of NTREES facility is due to be completed early in 2013. At that time it is expected that fuel elements will be available which will more closely resemble, both in material composition and geometry, those which will be used in actual nuclear thermal rockets. NTREES will provide a means to realistically test these fuel elements, even to the point of failure for extremely little cost. Such testing will allow the best fuel designs to quickly move forward to more highly realistic testing in nuclear test facilities with high confidence in their ultimate performance capabilities.

Acknowledgments

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References

[1]Emrich, W. J., "Nuclear Thermal Rocket Element Environmental Simulator (NTREES)," *Space Technology and Applications International Forum: 25th Symposium on Space Nuclear Power and Propulsion*, Albuquerque, NM, Ed. Mohamed S. El-Genk, 2008, pp. 541-548.