

# Nuclear Thermal Rocket Element Environmental Simulator (NTREES) Phase II Upgrade Activities

William J Emrich, Jr , Robert P. Moran, and J. Boise Pearson

*NASA Marshall Space Flight Center, Huntsville, AL, 35812*

**Abstract.** 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.

**Keywords:** Nuclear Thermal Propulsion, Simulator

## INTRODUCTION

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. Over the past year the Nuclear Thermal Rocket Element Environmental Simulator (NTREES) has been undergoing an upgrade which will significantly expand its capabilities.

The first phase of the upgrade<sup>1</sup> beyond its initial configuration<sup>2</sup> 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 previous 50 kW induction power supply is being 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. In the new setup the NTREES vessel was raised onto a platform along with most of its associated gas and vent lines. The induction heater and water systems are located underneath the platform. The new design also allows 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.

## 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.

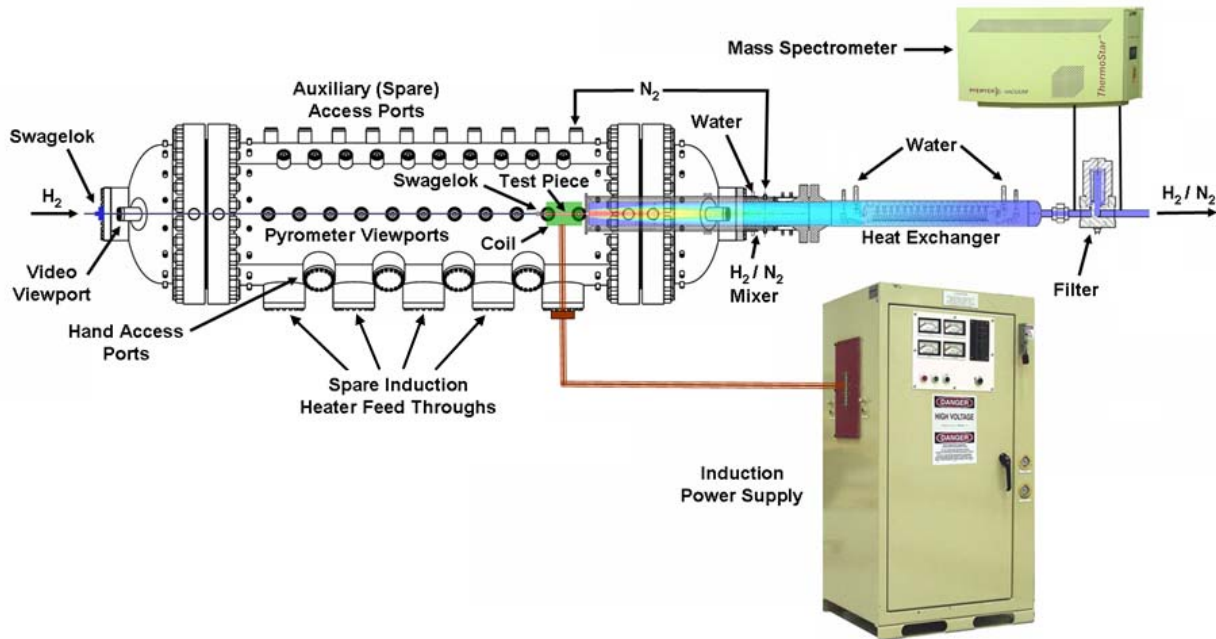


FIGURE 1. NTREES System Diagram.

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.

## 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 stress environment similar to what 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.

## **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 which may have eroded off the test article from being discharged to the environment.

## **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:

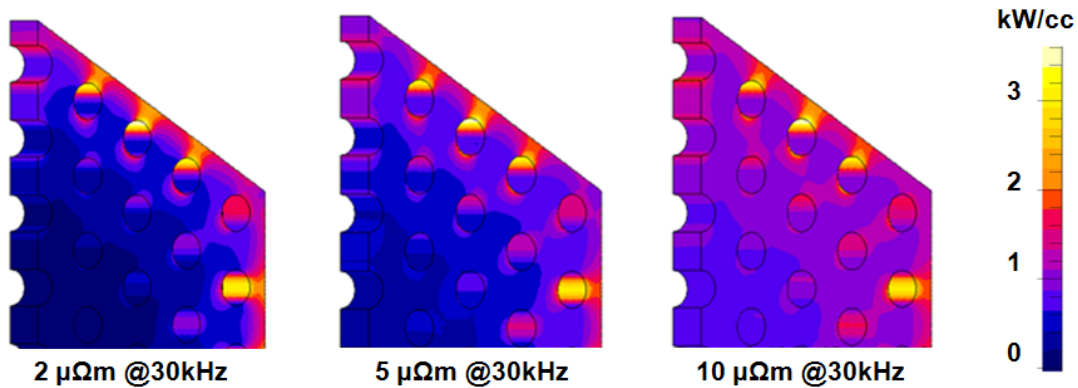
- Pressure sensors for  $\text{GH}_2$  and  $\text{GN}_2$
- Temperature sensors for  $\text{GH}_2$  and  $\text{GN}_2$
- Flow sensors for  $\text{GH}_2$  and  $\text{GN}_2$
- Thermocouples for general temperature measurements
- Hydrogen detection for the test chamber and room 101
- Pyrometers for high temperature measurement of test pieces
- Mass spectrometer to measure gas composition

## **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.

The induction heating unit was designed to operate over a fairly wide range of frequencies. This feature of the induction heating unit enables test operators to generate power distributions in the fuel test articles which closely match the power distributions which would be expected if the power was being generated from fission reactions. Figure 2 illustrates the calculated power distributions within NERVA type fuel elements which would be expected from induction heating.



**FIGURE 2.** Power Distributions in NERVA Fuel Elements from Induction Heating.

### NTREES TEST OPERATIONS

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 second phase upgrade to NTREES, tests on prototypical fuel elements will be performed wherein temperatures in excess of 3100 K in the presence of flowing hydrogen should be achievable. A picture of the current state of the NTREES upgrade is shown in Figure 2.



**FIGURE 3.** NTREES Test Facility and Hydrogen Setup.

## CONCLUSION

This 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

The NTREES facility upgrade and test activities are funded through Science & Technology Office at the Marshall Space Flight Center under the Nuclear Cryogenic Propulsion Stage program. The author greatly appreciates the support, both technical and financial, given by that office.

## REFERENCES

<sup>1</sup>Emrich, W. J., Moran R. P., and Pearson, J. B., "Nuclear Thermal Rocket Element Environmental Simulator (NTREES) Upgrade Activities," *Joint Propulsion Conference* (2012), Paper # AIAA 2012-4307.

<sup>2</sup>Emrich, W. J., "Nuclear Thermal Rocket Element Environmental Simulator (NTREES)," *Space Technology and Applications International Forum: 25<sup>th</sup> Symposium on Space Nuclear Power and Propulsion*, Albuquerque, NM, Ed. Mohamed S. El-Genk, 2008, pp. 541-548.