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`Lessons Learned from Recent Testing in the Nuclear Thermal Rocket Element Environmental Simulator

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The Nuclear Thermal Rocket Element Environmental Simulator (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 reproduce 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 NTREES facility is currently being reconfigured with an all new suite of pyrometers, a new coil and feedthrough design along with a new gas sampling system for the mass spectrometer. Also new is the ability to perform chamber purges using argon. All of these modifications are the result of experiences gained through several years of testing various NTR components under a wide range of operating conditions. The testing details and the lessons learned from those tests are discussed in this presentation.

I. NTREES FACILITY DESCRIPTION

The NTREES facility is designed to perform realistic non-nuclear testing of nuclear thermal rocket (NTR) fuel elements and fuel materials in representative environments and is licensed by the Nuclear Regulatory Commission to handle fuel elements containing depleted uranium. Although the NTREES facility cannot reproduce 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 NTREES simulates the fission process through the use of induction heaters and has the ability to simultaneously flow hydrogen through the test articles. It is also licensed by the Nuclear Regulator Commission to test uranium bearing fuel elements. Over the past several years, testing activities in NTREES have been quite varied and as a result have pointed up several areas where modifications to the facility would greatly enhance its usefulness.

II. NTREES TESTING OF A COMPOSITE FUEL ELEMENT

In one these tests (Ref. 1) a test article was received from Oakridge consisting of a fuel element composed of a graphite composite material about 16 inches long containing 4 coolant channels. In this test, the primary objective was to run the fuel element for around five minutes at a temperature of at least 2000 K with flowing hydrogen to meet a milestone for the Nuclear Cryogenic Propulsion Stage (NCPS) project. This objective was met successfully.

The second objective was to test the fuel element under harsher conditions that would likely lead to the destruction of the fuel element. During this test, the fuel element temperature was increased to over 2800 K for several minutes. Figure 1 shows the fuel element under test at these harsher conditions and the state of the test element before and after the test.

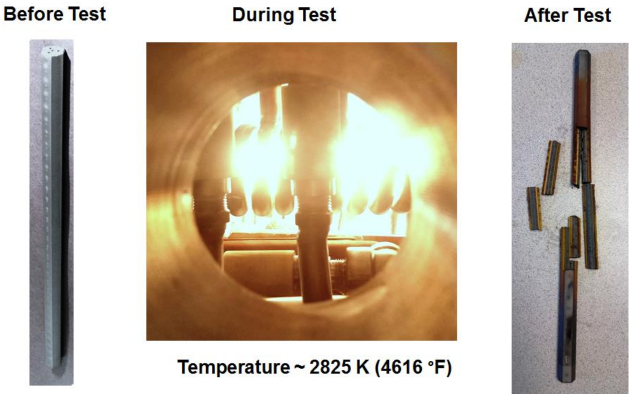

Fig. 1. Fuel Element at Maximum Power

Figure 2 illustrates the test profile. Note that near the end of the 4.5 minute interval over which the fuel element was at 2800 K, that the temperature in the fuel element began to rapidly fluctuate over a several hundred degree range and to generally decrease in magnitude. Simultaneously, the power in the induction heating unit began to increase slightly. This erratic behavior indicated that fuel element damage was probably occurring. The decision was then made to slowly decrease the induction power in the NTREES induction heater so as to gradually drop the temperature in the fuel element. After about 11 minutes, the temperature in the fuel element had dropped to roughly 1000 K whereupon the hydrogen concentration level in the chamber spiked significantly resulting in an automatic shutdown. This hydrogen spike was due to the catastrophic failure of the fuel element and resulted in the hydrogen normally flowing through the fuel element to discharge directly into the NTREES chamber.

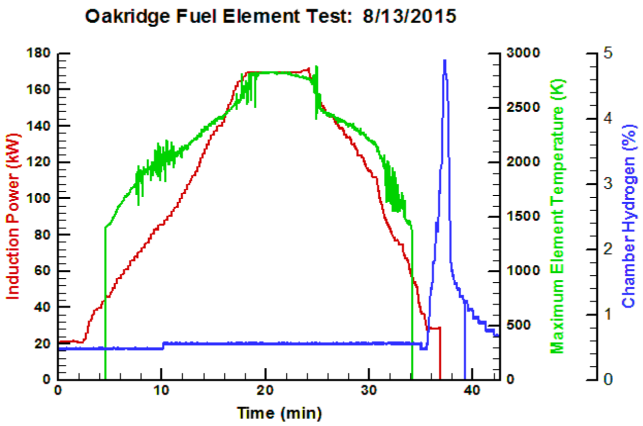

Fig. 2. Test Conditions Profile

Posttest examination of the fuel element showed that in addition to the expected hydrogen interactions there was also evidence of some unwanted nitrogen interactions on the outside of the fuel element. These interactions can be seen in Figure 1 from the brownish color on portions of the fuel element. Although these high temperature nitrogen interactions were not entirely unexpected, they were, nevertheless, quite unwelcome.

While it is not known whether these nitrogen interactions contributed to the fuel failure or were whether they were simply an inconsequential surface effect, they were, nevertheless, unrepresentative of what would actually occur to the fuel in an operating NTR and as a result cast doubt on the ultimate legitimacy of NTREES testing.

The use of a relatively inert gas such as nitrogen in the NTREES test chamber is required because of the need to provide a backpressure on the fuel elements during testing. If this gaseous backpressure were not present, unwanted (and unrealistic) hoop stresses would develop in the fuel elements because of the high internal pressure of the hydrogen flowing through the fuel element cooling channels. Because of the legitimate concerns about the possible negative effects of nitrogen interactions at high temperatures, the decision was made to modify the NTREES system to allow for the use of pressurant gases, other than nitrogen. An obvious choice for an alternate pressurant gas is argon, since it should be considerably less reactive than nitrogen at high temperatures. Downstream of the chamber the use of nitrogen as a means of cooling and inerting the hydrogen outlet stream is still acceptable since it does not contact with test article in the chamber. Figure 3 illustrates the NTREES modifications which were made to incorporate the use of argon as the backpressure gas in the NTREES chamber.

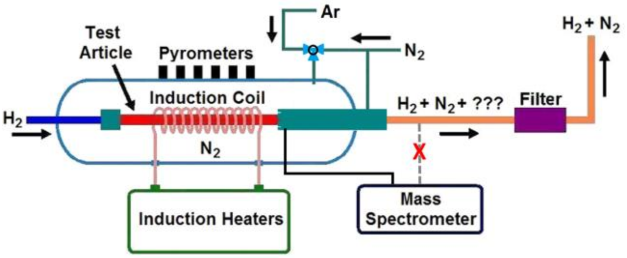

Fig. 3. Current NTREES Configuration

As currently configured, the argon for the tests is delivered as needed to the NTREES facility in racks containing either 12 or 16 “K” bottles. These “K” bottles will be set up just outside the building housing NTREES where they will be connected to an argon inlet port that has been installed for that purpose.

As part of the modifications to allow the use of argon in the chamber, it was decided to also move the mass spectrometer sampling tube to a location inside the chamber where test articles are attached to the hydrogen/nitrogen mixer. Moving the sampling tube to this location in the chamber allows for more efficient gas sampling to detect degradation in the test articles. This configuration change will especially enhance the ability to evaluate the performance of uranium nitride test articles where fuel degradation is characterized by the release of nitrogen gas.

Also during this high power testing, thermal imaging cameras, detected parasitic heating in the power feedthrough. This heating was due to stray induction coupling between the feedthrough assembly and the flange bolts attaching the feedthrough assembly to the chamber as illustrated in Figure 4.

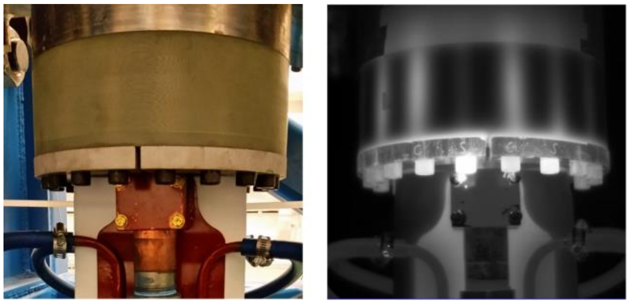

Fig. 4. Parasitic Heating in the NTREES Feedthrough

Inefficiencies in the original design of the feedthrough was determined to be the cause of the parasitic heating and as a result, the entire feedthrough assembly has been redesigned. This redesign is now complete and the new assembly fabricated. Currently, the new feedthrough is awaiting installation in the NTREES chamber. The new feedthrough system is illustrated in Figure 5.

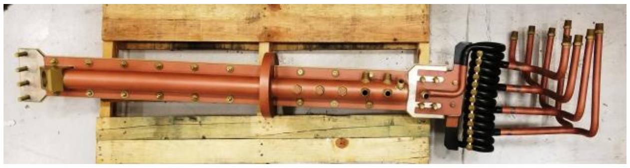

Fig. 5. New NTREES Feedthrough

III. NTREES TESTING OF AN INNOVATIVE SUPPORT ELEMENT DESIGN

In this test, several prototypical support elements were received from Ultra Safe Nuclear Corporation that were fabricated from a material called Borgalloy. Borgalloy is basically Inconel to which small amounts of gadolinium has been added. The gadolinium in the material is designed to burnout quickly during operation so as to counteract the loss of reactivity resulting from the production of xenon-135 during operation. In essence, the Borgalloy acts as a fast acting burnable poison whose purpose is to minimize the amount of control drum movement required during reactor operation.

Fig. 6. Borgalloy Test Article

Figure 6 illustrates condition of the test article after testing in NTREES. In many ways this particular test was the exact opposite of the Oakridge test in that instead of operating for a short time at high temperatures, these tests were designed to operate for extended periods at fairly low temperatures. The temperatures were so low, in fact, that the maximum temperatures specified for the tests were below the temperature range that could be accommodated by the current pyrometer suite. Figure 7 illustrates a view of the borgalloy support element under test in NTREES.

Fig. 7. Borgalloy Test Article in NTREES

This low temperature limitation in the current pyrometer suite has proven to be a problem in the past since some test element failures have occurred at low temperatures as noted above in the Oakridge tests. These failures were due to the build-in of thermal stresses at high temperatures that were subsequently locked into the test element as it cooled. As the temperature in the test element dropped, the increasing brittleness of the test piece was eventually no longer able to resist the high internal stresses, and the test element shattered. In these tests, the fuel element failed at a temperature below the range of the pyrometers, so it was impossible to get a precise reading as to what temperature resulted in the failure.

Due to the inability of the present pyrometer suite to measure test conditions at low temperatures, it was decided to replace the current instruments with pyrometers which could measure temperatures over a much wider range.

Temperatures in NTREES are currently measured through two different types of pyrometers. One type of pyrometer is a multispectral pyrometer that measures the temperature at a large number of wavelengths. The advantages to measuring temperatures in this manner is that it is possible simultaneously to get a measurement for the emissivity of the test article and a determination of the standard deviation of the temperature measurement error.

The fact that the multispectral pyrometer also measures emissivities is quite important in that these values are used to calibrate the single color pyrometers. The single color pyrometers require emissivity data for the material under test in order to obtain accurate values for the temperature. Large discrepancies in the temperature measurements could result if the emissivities are not precisely known. The current multispectral pyrometer will soon be replaced by a more advanced version that will be able to take measurements over a much wider range of temperatures. Figure 8 illustrates the multispectral pyrometer.

Fig. 8. Multispectral Pyrometer

Along with the deficiencies in the multispectral pyrometer, the testing often required the use of two different types of single color pyrometers. One type of pyrometer covered a low temperature range and the other type of pyrometer covered a high temperature range. This arrangement required an a priori knowledge of the temperature distribution along the length of the test element in order to position the different pyrometers appropriately. Also complicating the determination of the appropriate placement of the different pyrometers was the fact that the temperature distribution along the length of the test element changes as the operating conditions change. This situation has proved to be impossible to accomodate during parts of the testing and has resulted in gaps in the temperature measurements.

Due to the problems associated with the use of two different kinds of pyrometers covering different temperature ranges, the decision was made to locate pyrometers with the capability to measure wider temperature ranges. Such single color pyrometers were eventually found and procured. These new pyrometers have a range of 350 °C to 3000 °C which should largely eliminate the problems associated with having to use different pyrometers covering different temperature ranges. Figure 9 illustrates the new single color pyrometers.

Fig. 9. Single Color Pyrometer

IV. CONCLUSIONS

In anticipation of new testing in NTREES during the coming year, the facility is currently undergoing modest configuration changes based upon experience gleaned from earlier tests. These configuration changes are evolutionary as opposed to revolutionary, and should result in a marked improvement in the quantity and quality of the data gathered.

ACKNOWLEDGMENTS

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