Nuclear Cryogenic Propulsion Stage (NCPS) Fuel Element Testing in the Nuclear Thermal Rocket Element Environmental Simulator (NTREES)

To satisfy the Nuclear Cryogenic Propulsion Stage (NCPS) testing milestone, a graphite composite fuel element using a uranium simulant was received from the Oakridge National Lab and tested in the Nuclear Thermal Rocket Element Environmental Simulator (NTREES) at various operating conditions. The nominal operating conditions required to satisfy the milestone consisted of running the fuel element for a few minutes at a temperature of at least 2000 K with flowing hydrogen. This milestone test was successfully accomplished without incident. An illustration of the fuel element tested is illustrated in Figure 1.

Figure 1 Oakridge Fuel Element Tested in NTREES to Meet the NCPS Milestone

The testing began by loading the fuel element into NTREES and subjecting it to an axial loading of approximately 35 pounds. The NTREES chamber was then closed and the atmosphere was inerted with nitrogen gas and pressurized to approximately 200 psig. A hydrogen flow through the fuel element was then established at approximately 1 gm/sec. The induction heater was then energized and power was applied to the fuel element. The power and maximum temperature profiles which the fuel element encountered during the test are illustrated in Figure 2. A view of the fuel element at approximately 2000 K is illustrated in Figure 3. The 2000 K temperature in the fuel element was achieved at an induction power level of approximately 65 kW or at just over 5% of the power available from the 1.2 MW induction heating unit.

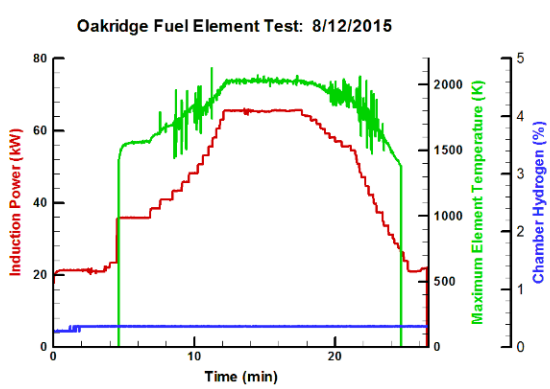

Figure 2 Nominal Test Conditions

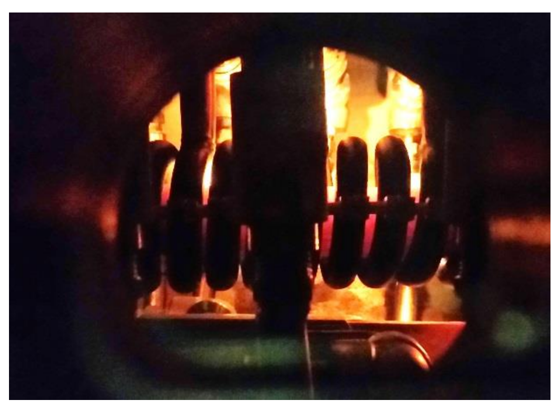

Figure 3 Fuel Element at Nominal Power

During the testing, the fuel element behaved as expected indicating that it likely survived the nominal testing conditions intact thus meeting all the predetermined project objectives. After the test concluded, the NTREES test chamber was depressurized and the fuel element allowed to cool to room temperature. The NTREES test chamber was then opened up and the fuel element removed. A visual inspection of the fuel element confirmed that no damage had occurred to the fuel element thus satisfying testing milestone required by the NCPS project. Figure 4 illustrates the condition of the fuel element after the test was completed. Note that the surface shows no obvious signs of damage.

Figure 4 Testing Shows No Visible Damage

Having met the project milestones, it was decided to reinsert the fuel element into and perform additional testing. This additional testing was designed to be much more severe than that which was performed during the initial testing, and was intended to test the fuel element to the point of failure. As before, the fuel element was loaded into NTREES and subjecting to an axial loading of approximately 35 pounds. The NTREES chamber was then closed and the chamber inerted with nitrogen gas and pressurized to approximately 250 psig. For this test the hydrogen flow rate within the fuel element was established at approximately 2 gm/sec. The induction heater was energized once again and power applied to the fuel element. The power and maximum temperature profiles which the fuel element encountered during this test are illustrated in Figure 4. A view of the fuel element at approximately 2800 K is illustrated in Figure 5. Note especially the increase in brightness of the fuel element in Figure 5 as compared to Figure 3 indicating the much higher fuel element temperatures achieved during this more aggressive testing sequence.

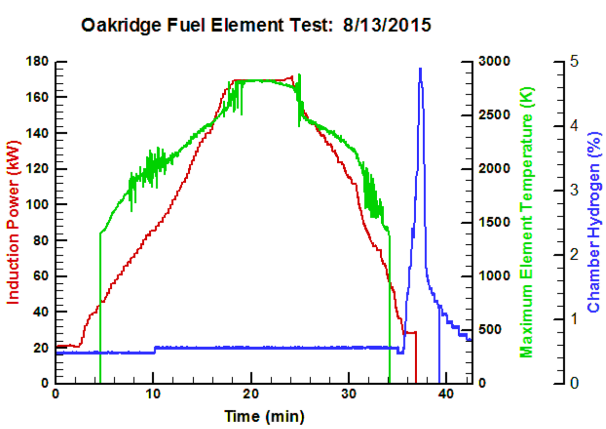

Figure 4 Aggressive Test Conditions

Figure 5 Fuel Element at Maximum Power

During this testing, the fuel element was above 2800 K for almost 4.5 minutes and was above 2500 K for over 8.5 minutes. The 2800 K temperature in the fuel element was achieved at an induction power level of approximately 169 kW or at just over 14% of the power available from the 1.2 MW induction heating unit. It was noticed near the end of the 4.5 minutes the fuel element was at 2800 K, that the temperature in the fuel element was starting rapidly fluctuate over a several hundred degree range and generally decrease in magnitude. Simultaneously, the induction power in the induction heating unit started to increase slightly. This type of behavior indicated that fuel element damage was probably beginning to occur. The decision was then made to slowly decrease the induction power in the NTREES induction heater so as to slowly drop the temperature in the fuel element. After about 11 minutes, the induction power level had been reduced to approximately 30 kW and the temperature in the fuel element had been reduced to roughly 1000 K. At this point, the hydrogen concentration level in the chamber spiked significantly resulting in an automatic system shutdown wherein the induction power was cutoff and the main hydrogen inlet valves were closed. System purging with nitrogen was also initiated as a result of the shutdown. The cause of the hydrogen concentration spike was thought to almost certainly be due to the catastrophic failure of the fuel element. Such a failure would cause the hydrogen normally flowing through the fuel element to discharge directly into the NTREES chamber rather than into the hydrogen/nitrogen mixer assembly as would be the case if the fuel element were still intact. Upon removal of the fuel element from the chamber, it was indeed confirmed that the fuel element had failed catastrophically as shown in the post test photograph illustrated in Figure 6. It should be emphasized that the conditions under which the fuel element failed were well in excess of those at which fuel failure was expected to occur and demonstrated considerable robustness in a very preliminary fuel element configuration.

Figure 6. Failed Fuel Element from NTREES Test at 2800 K

NTREES itself apparently suffered no damage as a result of the fuel failure. The induction coil showed no degradation from the fuel failure and even the insulating sleeve which surrounded the fuel element during the test survived intact. There was a noticeable smell near the chamber after the test which was probably due to heating in the G10 feedthru flange as a result of the high current going through the conductor plates. Other than the smell, however, there did not appear to be any damage to the flange.