

NUCLEAR CRYOGENIC PROPULSION STAGE. M. G. Houts¹, S. K. Borowski², J. A. George³, T. Kim¹, W. J. Emrich¹, R. R. Hickman¹, J. W. Broadway¹, H. P. Gerrish¹, R. B. Adams¹. ¹NASA Marshall Space Flight Center, MSFC, AL 35812, ²NASA Glenn Research Center, Cleveland, OH, 44135, ³NASA Johnson Space Center, Houston, TX, 77058

Introduction: The fundamental capability of Nuclear Thermal Propulsion (NTP) is game changing for space exploration. A first generation Nuclear Cryogenic Propulsion Stage (NCPS) based on NTP could provide high thrust at a specific impulse above 900 s, roughly double that of state of the art chemical engines. Characteristics of fission and NTP indicate that useful first generation systems will provide a foundation for future systems with extremely high performance. The role of the NCPS in the development of advanced nuclear propulsion systems could be analogous to the role of the DC-3 in the development of advanced aviation. Progress made under the NCPS project could help enable both advanced NTP and advanced NEP.

The Nuclear Cryogenic Propulsion Stage Project: The Nuclear Cryogenic Propulsion Stage (NCPS) project was initiated in October, 2011, with the goal of assessing the affordability and viability of an NCPS. Key elements of the project include 1) Pre-conceptual design of the NCPS and architecture integration; 2) Development of a High Power (~1 MW input) Nuclear Thermal Rocket Element Environmental Simulator (NTREES); 3) NCPS Fuel Design and Testing; 4) NCPS Fuels Testing in NTREES; 5) Affordable NCPS Development and Qualification Strategy; and 6) Second Generation NCPS Concepts. The NCPS project involves a large (~50 person) NASA/DOE team supplemented by a small amount of procurement funding for hardware and experiments. In addition to evaluating fundamental technologies, the team will be assessing many aspects of the integrated NCPS, and its applicability to NASA architectures of interest.

Pre-Conceptual Design of the NCPS and Architecture Integration: The NCPS will be designed to integrate with the Space Launch System (SLS), and to leverage technologies and configurations being developed for the SLS. The NCPS design will focus on ensuring maximum benefit to human Mars mission, although the stage will have numerous other applications as well. Two leading fuel candidates for the NCPS are tungsten cermet and composite fuels, both with an extensive development history. The sensitivity of stage performance to specific impulse and engine thrust-to-weight ratio will also be assessed under this element. Both propulsion only and “bimodal” (propulsion and power) systems will be assessed under the NCPS.

Development of a High Power (~1 MW input) Nuclear Thermal Rocket Element Environmental Simulator: The development of a stable fuel form is a key risk for an NCPS. Fuel life and performance is largely limited by mass loss in a hot gas/cyclic environment. Hence a major milestone of the NCPS project is the completion of the 1-MW Nuclear Thermal Rocket Element Environmental Simulator (NTREES) test chamber at MSFC. The purpose of the NTREES facility (which also includes an arc heater and a compact hot hydrogen test chamber) is 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. Once fully operational, the 1-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 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; however the focus of FY 2012 activities will be on hydrogen propellants.

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. Using propellant fed from gas storage trailers located external to the facility, NTREES is configured to allow continuous, uninterrupted testing of fuel elements for any desired length of time. The NTREES facility also includes an operational arc heater that is capable of flowing hot hydrogen over a material or fuel sample at a hydrogen gas temperature of up to 3160 K for approximately 30 minutes, which is particularly useful for the preliminary vetting of material samples. A compact test chamber capable of high temperature fuel sample testing is also available at the NTREES facility.

The project will also develop a detailed understanding of the energy deposition and heat transfer processes

in NTREES, along with effects on material mechanics and fluid/material interaction, to better improve future test conditions and obtain as much information as possible to accurately extrapolate non-nuclear test data to real reactor conditions. A picture of the most recent operational NTREES primary chamber configuration is shown in Figure 1.

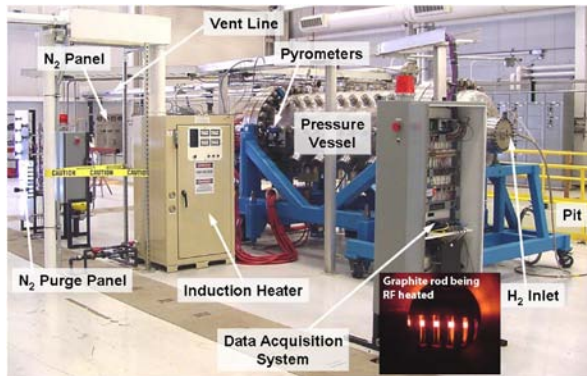


Figure 1. Nuclear Thermal Rocket Element Environmental Simulator (NTREES)

NCPS Fuel Design / Fabrication: Early fuel materials development is critical to help validate requirements and minimize technical, cost, and schedule risks for future exploration programs. NASA and DOE have demonstrated the ability to collaborate on a number of nuclear power and propulsion technology projects, and this collaboration will continue on the NCPS project.

This element will focus on tungsten cermet and composite fuels. Modern fabrication techniques (Hot Isostatic Pressing and Pulsed Electric Current) will be used to demonstrate fabrication of cermet elements with good performance potential. Composite fuel elements will also be fabricated, with emphasis on coatings to help prevent fuel loss in the hot flowing hydrogen environment and to potentially increase maximum allowable operating temperature. Other fuels developed and tested during the Rover/NERVA program [1] may also be evaluated, including carbide fuels and bead-loaded graphite fuels.

NCPS Fuels Testing in NTREES: Testing in NTREES will range from fuel sample testing (using the small chamber) to the testing of near-prototypic fuel elements. A primary goal of the testing is to demonstrate adequate fuel performance and to increase confidence in fuel system designs (e.g. materials, coatings, geometries) prior to potential nuclear testing.

Affordable NCPS Development and Qualification Strategy: This element will focus on ensuring the overall affordability of the NCPS. Development and qualification testing of the NCPS is one potential cost

driver, and at least two potential strategies will be emphasized. The first will be to utilize existing boreholes at the Nevada test site to enable flexible and affordable testing of nuclear thermal rocket engines. The second would be to utilize highly instrumented demonstration flights, including the potential for significant post-operation examination of the NCPS engine. Both strategies appear to show promise

Second Generation NCPS Concepts: Potential second generation NCPS concepts will be devised and evaluated. Modern materials and fabrication techniques may enable an NCPS capable of providing Isp in excess of 1000 s with high thrust-to-weight ratio. Radically different design approaches could yield even higher performance. The work performed under this task will devise new concepts and re-evaluate existing concepts taking into account recent advancement in materials and technologies. Concepts with high performance potential and moderate technology risk (such as ternary carbide encapsulated UC₂) will receive particular attention. Novel approaches for capitalizing on the unique attributes of fission systems will also be investigated. Such approaches include the direct use of volatiles available in space for NTP propellant. This task will also include system concepts for very high performance BNTEP.

Conclusion: The fundamental capability of Nuclear Thermal Propulsion (NTP) is game changing for space exploration. A first generation Nuclear Cryogenic Propulsion Stage (NCPS) based on NTP could provide high thrust at a specific impulse above 900 s, roughly double that of state of the art chemical engines. Near-term NCPS systems would provide a foundation for the development of significantly more advanced, higher performance systems.

References:

- [1] Koenig D. R. (1986) Experience Gained from the Space Nuclear Rocket Program (Rover), LA-10062-H, Los Alamos National Laboratory, Los Alamos, NM