NUCLEAR THERMAL ROCKET (NTR) PROPULSION: *"BEFORE THE DECADE IS OUT".*

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Introduction: The NTR represents the next evolutionary step in cryogenic liquid rocket engines. Unlike chemical rockets that produce their energy through combustion, the NTR derives its energy from fission of Uranium-235 atoms contained within fuel elements that comprise the engine's reactor core. Using an "expander" cycle for turbopump drive power, hydrogen propellant is raised to a high pressure and pumped through coolant channels in the fuel elements where it is superheated then expanded out a supersonic nozzle to generate high thrust at a specific impulse of ~900 seconds or more – twice that of today's best chemical rockets. *During his now famous Moon-landing speech in May 1961, President John F. Kennedy also called for accelerated development of the NTR saying this technology "gives promise of some day providing a means for even more exciting and ambitious explorations of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself."*

From 1955 – 1972, twenty rocket reactors were designed, built and ground tested in the Rover and NERVA (Nuclear Engine for Rocket Vehicle Applications) nuclear rocket programs. These programs demonstrated: (1) high temperature carbide-based nuclear fuels; (2) a wide range of thrust levels; (3) sustained engine operation; (4) accumulated lifetime at full power; and (5) restart capability – all the requirements needed for a human Mars mission. Ceramic metal "cermet" fuel was also pursued as a backup. In NASA's recent Mars Design Reference Architecture (DRA) 5.0 study [1,2], the NTR was selected as the preferred propulsion option because of its proven technology, higher performance, lower launch mass, simple assembly, and growth potential (e.g., "bimodal" operation). Furthermore, in contrast to other advanced propulsion options, Nuclear Thermal Propulsion (NTP) requires no large technology scale-ups. In fact, the smallest engine tested during the Rover program – the 25 klb_f "Pewee" engine is sufficient for a human Mars mission when used in a clustered engine arrangement.

Key Task Activities: In FY'11, NASA restarted a NTP technology development and demonstration effort under the Advanced In-Space Propulsion (AISP) component of its Exploration Technology Development and Demonstration (ETDD) program. The NTP effort included two key tracks – "Foundational Technology Development" followed by "Technology Demonstration" projects (shown in Figure. 1). Near-term NTP activities initiated under Foundational Technology Development, which are now part of NASA's new Nuclear Cryogenic Propulsion Stage (NCPS) project [3], included five key tasks and objectives:

Task 1. *Mission Analysis, Engine/Stage Characterization and Requirements Definition* to help guide initial foundational technology work, and the subsequent development of small ground and flight technology demonstration engines that are scalable to the full size engines needed for future human precursor asteroid and Mars exploration missions;

Task 2. *NTP Fuels and Coatings Assessment and Technology Development* aimed at recapturing fabrication techniques, maturing and testing fuel, then selecting between the two primary fuel forms previously identified by DOE and NASA – NERVA "composite" and UO_2 in tungsten "cermet" fuel. Samples and candidate coatings will be produced initially followed by partial-length, then full-length fuel elements. The NTR Element Environmental Simulator (NTREES) [3] at the MSFC will provide up to ~1.2 MW of RF heating to simulate the NTP thermal environment that includes exposure to hot H_2. NTREES will be used to screen candidate fuels and fuel element designs prior to irradiation testing and final selections;

Task 3. *Engine Conceptual Design, Analysis, and Modeling* aimed at developing conceptual designs of small demonstration engines and the full size 25 klb_f-class engines utilizing the candidate fuels mentioned above. State-of-the-art numerical models will be used to determine reactor core criticality, detailed energy deposition and control rod worth within the reactor subsystem, provide thermal, fluid and stress analysis of fuel element geometries, and predict engine operating characteristics and overall mass;

Task 4. *Demonstration of Affordable Ground Testing* focused on "proof-of-concept" validation of the SAFE (Subsurface Active Filtration of Exhaust) or "bore-hole" test option at the Nevada Test Site (NTS). Non-nuclear, subscale hot gas injection tests, some with a radioactive tracer gas (Krypton-85), will be conducted in existing vertical bore-holes to obtain valuable test data on the effectiveness of the porous rock (alluvium) to capture, holdup and filter the engine exhaust. The data will also help calibrate design codes needed by DOE to design the SAFE test facility and support infrastructure needed for the small ground and flight technology demonstration engine tests and the larger 25 klb_f-class engine tests to follow; and

Task 5. *Formulation of Affordable and Sustainable NTP Development Strategy* which outlines a plan that utilizes separate effects tests (e.g., NTREES and irradiation tests), innovative SAFE ground testing at the NTS, plus the use of a small scalable engine for ground then flight technology demonstrations.

Plans for Ground and Flight Demonstrations: *Results from the above tasks will provide the basis for "authority to proceed" (ATP) in ~2015 with ground technology demonstration (GTD) tests at the NTS in late 2019, followed by a flight technology demonstration (FTD) mission in 2023.* In order to reduce development costs, the GTD and FTD tests will use a smaller, lower thrust (~5 – 7.5 klb_f) engine that is based on a "common" fuel element design that is scalable to the desired higher thrust engines by increasing the number of elements in a larger diameter core that can produce greater thermal power output. The GTD project will build and test two ground test articles (GTA1, GTA2) and one flight test article (FTA) that provides system technology demonstration and design validation for a follow-on FTD mission. The small engine can be used individually for small robotic science missions, or arranged in a 2 – 3 engine cluster for higher payload missions. The FTD will provide the technical foundation for an "accelerated approach" to design, fabrication, ground then flight-testing of the larger 25 klb_f-class engine. The Rover program used a common fuel element design and similar approach to test the 50 klb_f Kiwi-B4E, the 75 klb_f Phoebus-1B, the 250 klb_f Phoebus-2A, and 25 klb_f Pewee engines, in that order, between 1964 and 1968. Flight testing a NTR propulsion stage with clustered 25 klb_f engines would follow next in time to support 1-year round trip human asteroid missions in the late 2020's and short round trip / short orbital stay Mars missions using a "split cargo and crew" mission approach in the early 2030's.

References:

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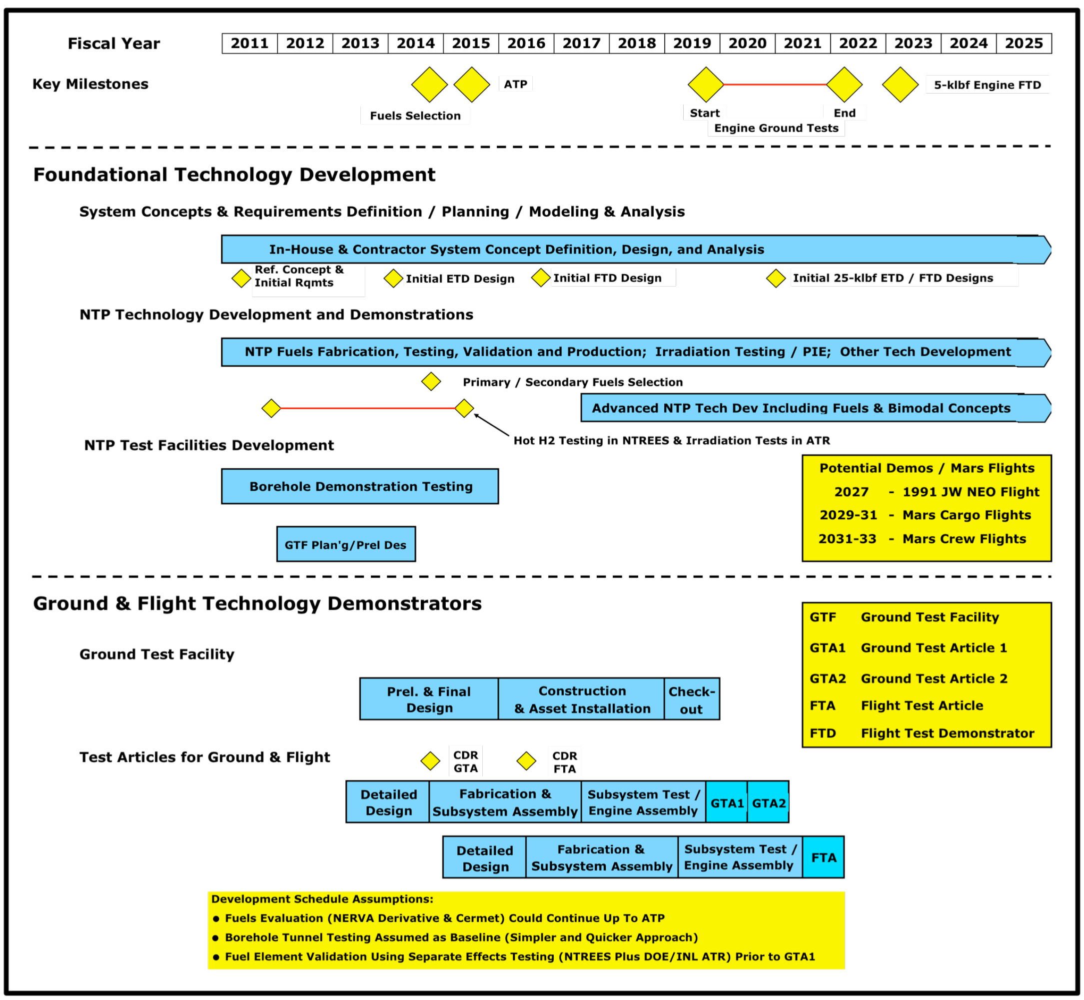

Figure 1. NTP Development Plan includes Foundational, Ground and Flight Technology Demonstration