NASA SBIR 2017 Phase I Solicitation

Z10.03 Nuclear Thermal Propulsion (NTP)

Lead Center: MSFC

Participating Center(s): GRC, SSC

Technology Area: TA2 In-Space Propulsion Technologies

Nuclear Thermal Propulsion (NTP)

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology needed for future human exploration of Mars. NTP had major technical work done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. A few other NTP programs followed including the Space Nuclear Thermal Propulsion (SNTP) program in the early 1990's. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber and exposes the engine components and surrounding structures to a radiation environment.

Engine System Design

Focus is on a range of modern technologies associated with NTP using solid core nuclear fission reactors and technologies needed to ground test the engine system and components. The engines are pump fed ~15,000-35,000 lbf with a specific impulse goal of 900 seconds (using hydrogen), and are used individually or in clusters for the spacecraft's primary propulsion system. The NTP can have multiple start-ups (>4) with cumulative run time >100 minutes in a single mission, which can last a few years. The Rover/NERVA program ground tested a variety of engine sizes, for a variety of burn durations and start-ups with the engine exhaust released to the open air. Current regulations require exhaust filtering of any radioactive noble gases and particulates. The NTP primary test requirements can have multiple start-ups (>8) with the longest single burn time ~50 minutes.

Technologies being sought include:

- Reactor fuel element designs with high temperature (> 2600K), high power density (>5 MW/L) to optimize hydrogen propellant heating.
- New additive manufacturing processes to quickly manufacture the fuel with uniform channel coatings and/or claddings that reduce fission product gas release and reactor particulates into the engines exhaust stream. Fuel can made of Ceramic-metallic (cermet) or composite/carbide designs:
    - New fuel element geometries which are easy to manufacture and coat, and better performing than the traditional prismatic fuel geometries with small through holes with coatings.
    - Insulator design (one application is for tie tubes) which has very low thermal conductivity and neutron absorption, withstands high temperatures, compatible with hot hydrogen and radiation

environment, and light weight.

Operations and Safety

Engine operation involves start-up, full thrust operation, shutdown, coast, and restart. Technologies being sought include advanced instrumentation and special reactor safety design features which prevent uncontrolled reactor criticality accidents. Also needed are radiation shielding technologies that minimize exposure to other stage components and reduce total crew radiation dose. Specific areas of interest include:

- Concepts to cool down the reactor decay heat after shutdown to minimize the amount of open cycle propellant used in each engine shutdown. (Depending on the engine run time for a single burn, cool down time can take many hours.)
- Low risk reactor design features which allow more criticality control flexibility during burns beyond the reactor circumferential rotating control drums, and/or provide nuclear safety for ground processing, launch, and possible launch aborts:
  - Control of criticality with water submersion and compaction accidents.
  - Concept for quick restart of reactor (2-6 hours) after 30-40 minute burns and accounting for Xe135 buildup.
- Radiation shielding concepts that protect the crew and minimize heating of store propellant and the stage. Strategies that minimize radiation shielding system mass, such as utilization of the payload and consumables for shielding (when practical) that may provide an additional bonus of shielding galactic cosmic radiation as well as radiation from the NTP engines.

Ground Test Technologies

Environmental regulations require NTP engine exhaust filtering of radioactive noble gases and particulates to maintain safe environmental levels. NTP engine ground testing will require the development of large scale engine exhaust scrubber technologies and options for integrating it to the NTP engine for ground tests (reference 51st AIAA/SAE/ASEE Joint Propulsion Conference paper AIAA 2015-3773, 'Review of Nuclear Thermal Propulsion Ground Test Options', D. Coote, et al). Included in this area of technology development needs are identification and application of robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature, pressure and radiation environments. Specific areas of interest include:

- Advanced high-temperature and hydrogen embrittlement resistant materials for use in a hot hydrogen environment (<5500°F) and possibly exposed to neutrons and gamma rays.
- Efficient generation of high temperature, high flow rate hydrogen (<30 lb/sec).
- Devices for measurement of radiation, pressure, temperature and strain in a high temperature and radiation environment:
  - Non-intrusive diagnostic technology to monitor engine exhaust for fuel element erosion/failure and release of radioactive particulates.
- Effluent scrubber technologies for efficient filtering and management of high temperature, high flow hydrogen exhausts. Specific interests include:
  - Filtering of radioactive particles and debris from exhaust stream having an efficiency rating greater than 99.5%.
  - Removal of radioactive halogens, noble gases and vapor phase contaminants from a high flow exhaust stream with an efficiency rating greater than 99.5%.
- Applicable Integrated System Health Monitoring and autonomous test operations control systems.
- Modern robotics which can be used to inspect the ground test system exposed to a radiation environment.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 2-3). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables - Working engineering model of proposed product, along with full report of component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.