



## NASA SBIR 2016 Phase I Solicitation

### H2.02 Nuclear Thermal Propulsion (NTP)

Lead Center: MSFC

Participating Center(s): GRC, SSC

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 (SNTTP) 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. In addition, the engine components and surrounding structures are exposed to a radiation environment formed by the reactor during operation.

This solicitation will examine 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.

Specific technologies of interest to meet the proposed requirements include:

- Reactor fuel element designs with high temperature (> 2600K), high power density (>5 MW/L) to maximize hydrogen propellant heating. New additive manufacturing processes to quickly manufacture the fuel with uniform channel coatings and/or claddings to reduce fission product gas release and particulates into the engine's exhaust stream.
  - Composite or carbide designs with low burn-up coating technology.
  - Ceramic-metallic (cermet) based nuclear fuels need improved methods to apply W coatings on small UO<sub>2</sub> spheres and the best way to bond W-UO<sub>2</sub> wafers with integral claddings.
- 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 flexible criticality control during burns beyond the reactor circumferential rotating control drums, and/or provide nuclear safety for ground processing, launch, and possible launch aborts.

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- 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.
  - Ground test engine effluent processing technologies for efficient containment and/or filtering of radioactive particles and noble gases, and management of high temperature, high flow hydrogen exhausts (16-39 lbs/sec). In particular, to produce large quantities of hot hydrogen, and develop robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature and radiation environments.
    - Advanced materials to resist high-temperature (<4400° F), hydrogen embrittlement and radiation environment.
    - Efficient non-nuclear generation of high temperature (<5000° F), high flow rate hydrogen (<39 lb/sec).
    - Effluent processing 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 99.9%.
      - 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 that provide diagnostic capability to detect reactor fuel degradation in the engine exhaust.
    - Technologies providing an affordable low power (<20 MW) nuclear furnace to ground test a variety of fuel elements at conditions replicating a full scale NTP engine.

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.