



## NASA SBIR 2020 Phase I Solicitation

### Z10.03 Nuclear Thermal Propulsion

Lead Center: MSFC

Participating Center(s): GRC, SSC

Technology Area: TA2 In-Space Propulsion Technologies

#### Scope Title

Reactor and Fuel System

#### Scope Description

The focus is on highly stable materials for nuclear fuels and non-fuel reactor components (i.e., moderator tie tubes, etc.) that can heat hydrogen to temperatures greater than 2600K without undergoing significant dimensional deformation, cracking, or hydrogen reactions. Current technology hurdles related to ceramic metal fuels center around refractory metal processing and manufacturing (i.e., welding of refractories, refractory metal coatings, etc.). The development of refractory alloys with enhanced/targeted material properties are of key interest (i.e., tungsten or molybdenum with increased ductility, or dispersion strengthen Mo/W alloys). Current technology hurdles with carbide fuels include embedding carbide kernels with coatings in a carbide matrix with potential for total fission product containment and high fuel burn-up. Manufacturing and testing of the insulator and reflector materials are also critical to the success of a Nuclear Thermal Propulsion (NTP) reactor.

Technologies being sought include:

- Low Enriched Uranium reactor fuel element designs with high temperature (> 2600K), high power density (>5 MW/L) to optimize hydrogen propellant heating.
- New advanced 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.
- High temperature fuels that build on experience from AGR (Advanced Gas Reactor) TRISO (Tristructural-isotropic) design and testing. Potentially enable NTP with Isp > 900 seconds.

Fuels focused on Ceramic-metallic (cermet) designs:

- Fabrication technique for full length W/UN or W/UNO<sub>2</sub> fuel elements with greater than 60% volume ceramic loading

Fuels focused on carbide designs:

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- Compatibility with high temperature hydrogen.
  - High thermal conductivity and other properties (e.g., ductility) needed for high power density operation (~5MW/l).
  - Kernel diameters, including coatings for fission product containment, which allow the fuel element to be fabricated with adequate strength for high temperature and high-power density operation.

Insulator design (one application is for tie tubes and the other is for interface with the pressure vessel) which has very low thermal conductivity and neutron absorption, withstands high temperatures, compatible with hot hydrogen and radiation environment, and light weight.

**Expected TRL or TRL range at completion of the project: 2 to 5**

### **Desired Deliverables of Phase II**

Prototype hardware is desired.

### **Desired Deliverables Description**

Desired deliverables for this technology would include research that can be conducted to determine technical feasibility of the proposed concept during Phase I and show a path toward a Phase II hardware demonstration. Testing the technology in a simulated (as close as possible) NTP environment as part of Phase II is preferred. Delivery of a prototype test unit at the completion of Phase II allows for follow-up testing by NASA.

Phase I Deliverables - Feasibility analysis and/or small-scale experiments proving the proposed technology to develop a given product (TRL 2-3). The final report includes a Phase II plan to raise the TRL. The Phase II plan includes a 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 - A full report of component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Also delivered is a prototype of the proposed technology for NASA to do further testing if Phase II results show promise for NTP application. Opportunities and plans should also be identified and summarized for potential commercialization of the proposed technology.

### **State of the Art and Critical Gaps**

The SOA (State-Of-the-Art) is reactor fuel developed for the Rover/NERVA program in the 1960's and early 1970's. The fuel was carbon based and had what is known as "mid-ban" corrosion, which effected the fuel endurance. Switching over to cermet (metal and ceramics) or advance carbide fuels shows promise, but has fabrication challenges.

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS (Space Launch System) launches than other propulsion concepts for human missions to Mars over a variety of mission years. 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.

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 ~25,000 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.

### **Relevance / Science Traceability**

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STMD (Space Technology Mission Directorate) is supporting the NTP project.

Future mission applications:

- Human Missions to Mars
- Science Missions to Outer Planets
- Planetary Defense

Some technologies may have applications for fission surface power systems.

### **Scope Title**

Ground Test Technologies

### **Scope Description**

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:

- 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.

**Expected TRL or TRL range at completion of the project:** 2 to 5

### **Desired Deliverables of Phase II**

Prototype hardware is desired

### **Desired Deliverables Description**

Desired deliverables for this technology would include research to determine the technical feasibility during Phase I and show a path toward a Phase II hardware demonstration. Determine a prototype instrument arrangement which can be strategically positioned to monitor NTP operation as good as possible. To monitor fuel degradation in the exhaust stream, the optimum position of the sensors must account for anomalies near an operating reactor core and have the ability to withstand the radiation and heat environment. Testing the technology in a simulated (as close as possible) NTP environment as part of phase II is preferred. Delivery of a prototype test unit at the completion of phase II allows for follow-up testing by NASA.

Phase I Deliverables - Feasibility analysis and/or small-scale experiments proving the proposed technology to develop a given product (TRL 2-3). The final report includes a Phase II plan to raise the TRL. The Phase II plan includes a 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 - A full report of component and/or breadboard validation of sensor measurements, including populated verification matrix from Phase I (TRL 4-5). Also delivered is a prototype of the proposed technology for NASA to do further testing if phase II results show promise for NTP application. Opportunities and plans must also be identified and summarized for potential commercialization of the proposed technology.

### **State of the Art and Critical Gaps**

The SOA NTP ground testing involved open air testing in the 1960's and early 1970's. The current regulations require an exhaust treatment system to avoid release of significant quantities of fission products into the air.

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Validating various exhaust treatment concepts requires a subscale simulation of NTP hot hydrogen, the cooling system, filtering, and special instrumentation to monitor what is coming out in the hydrogen exhaust, which could lead to shutdown.

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