NASA SBIR 2019 Phase I Solicitation

Z10.03 Nuclear Thermal Propulsion

Lead Center: MSFC

Participating Center(s): GRC, SSC

Technology Area: TA15 Aeronautics

Reactor and Fuel System

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 is 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 is 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.

Fuels focused on Ceramic-metallic (cermet) 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.
- Best joining and manufacturing processes for thin-walled (0.010”) tungsten, molybdenum, and molybdenum/tungsten alloys.
- Diffusion bonding/other bonding technologies for CERMET materials.
- Machining processes for cooling channel formation in CERMET materials.
- Uranium nitride and uranium dioxide fuel particle production methods and particle coating methods.
- Development of dispersion strengthen molybdenum/tungsten alloys.
- Formation of small diameter (0.100” ID) thin-walled (0.010”) molybdenum, tungsten, and molybdenum/tungsten cylindrical tubes.

Fuels focused on carbide designs:

- 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 (e.g., of 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.

Future mission applications for this technology include Human Missions to Mars, Science Missions to Outer Planets, and Planetary Defense. Some technologies may have applications for fission surface power systems.

Desired Deliverables for this technology would include research that could be conducted to demonstrate technical feasibility during Phase I and show a path toward 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.

Expected TRL for this project is 2 to 5.

Ground Test Technologies

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, and 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.

Future mission applications for this technology include Human Missions to Mars, Science Missions to Outer Planets, and Planetary Defense.

Desired Deliverables for this technology include research that could 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.

Expected TRL for this project is 2 to 5.

Engine System Design

Scope is on a range of modern technologies associated with NTP using solid core nuclear fission reactors. The baseline engines are pump fed with a thrust ~25,000 lbf and 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 Thrust to weight is ~3.5 without the external shield. Specific areas of interest include the following:

- *Subcritical LH_2 Turbopump for NTP Engine* - LH_2 Turbopump design that is capable of operating in a subcritical mode over the full range of turbopump speeds for a NTP Engine. The benefit of a turbopump operating with a subcritical design is that an NTP engine with long transient start-up and shutdown durations can operate over the entire transients without encountering any resonance modes where vibration levels are high. The mass flow rate is less than 28 lbs/sec, pump exit pressure less than 2800 psia and pump inlet pressure 8-30 psia.
- *NTP Engine Instrumentation* - Instrumentation is needed for engine control and health monitoring. Sensors must be designed to withstand a harsh NTP environment such as high temperatures, nuclear radiation composed of neutrons and gamma rays, and high vibration levels, and provide accurate measurements. Non-invasive designs for measuring neutron flux (possibly outside of reactor assembly), chamber temperature, operating pressure, and liquid hydrogen propellant flow rates over a wide range of temperatures are desired. Sensors need to operate for total run times in these harsh environments on the order of a few hours, interspersed over periods of months/years. The radiation environment adjacent to the reactor core assembly may include up to 10^{14} fast (>1MeV) neutrons/cm^2-sec, 10^{15} thermal/epithermal (<1 MeV) neutrons/cm^2-sec, and a gamma ray dose rate up to 10^9 Rad(Si)/hr.

Future mission applications for this technology include Human Missions to Mars, Science Missions to Outer Planets, and Planetary Defense.

Desired Deliverables for this technology include research that could be conducted to demonstrate technical feasibility during Phase I and show a path toward 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.

Expected TRL for this project is 2 to 5.

References:

Reactor and Fuel System

- 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. 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.

Ground Test Technologies

- 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. 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.

Engine System Design

- 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. 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.