NASA SBIR 2021 Phase I Solicitation

Z10.03 Space Nuclear Propulsion

Lead Center: MSFC

Participating Center(s): GRC, SSC

Scope Title:

Reactor and Fuel System for Nuclear Thermal Propulsion (NTP) and Nuclear Electric Propulsion (NEP)

Scope Description:

The focus is on highly stable materials for nuclear fuels and nonfuel reactor components (insulator, moderator, etc.) that can heat the working fluid to high temperatures, be compatible with the working fluid, minimize dimensional deformation during operation, and be easy to manufacture to meet the design requirements.

NEPÂ relies on reactor systems capable of achieving 5-yr life with a working fluid exit temperature of at least 927 Â°C and a thermal power of at least 5 MW.Â Innovative concepts for enhancing reactor reliability, fabricability, and testability while still enabling an acceptable power system specific mass (typically <15 kg/kWe) are sought. Projected use for human missions to Mars will require continuous run times ~2 yr.

NTPÂ uses hydrogen as the working fluid (propellant). Fuel temperatures required to achieve a specific impulse (Isp) of 900 sec can exceed 2,600 Â°C. Projected use for human missions to Mars will require cumulative run times ~3.5 hrÂ and 5 to 6 restarts. Current technology hurdleswith ceramic and carbide fuels include embedding nitride or carbide kernels with coatings in a carbide matrix with potential for total fission product containment and high fuel burnup, and simple modern manufacturing of complex geometries with high uniform density.

Specific technologies being sought include:

- Innovative ultrahigh-temperature material property testing and performance evaluation above 2,000 Â°C in a vacuum and hot hydrogen environment. The materials used in the reactor core will reach temperatures up to 2,700Â Â°C. No current material property data and performance characteristics above 2,000 Â°C exist, and the subtopic wishes to solicit innovations in this area to start filling those data gaps, thus reducing technical risk of material choices within the reactor, and begin optimization of material choices. The key materials to be evaluated are the fuel element matrix materials, such asÂ refractory ceramics. These materials are highly sensitive to oxygen and must be tested in a vacuum, inert atmosphere, or reducing (hydrogen) atmosphere. Some of the key parameters to gather at 2,000+ Â°C temperatures include (but are not limited to) static modulus, modulus of rupture, tension and compression flow curves, tension and compression creep, fatigue and hardness with measurement absolute accuracies *Â*±0.5%. In addition to those key parameters, contact and noncontact strain measurement techniques with absolute accuracies of *Â*±0.5% at these ultrahigh temperatures are also sought.Â

- Innovative fuel element designs and propellant flow configurations that facilitate achieving propellant exit temperatures in excess of 2,500 Â°C.

Expected TRL or TRL Range at completion of the Project: 2 to 5
Primary Technology Taxonomy:
Level 1: TX 01 Propulsion Systems
Level 2: TX 01.4 Advanced Propulsion
Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Research

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 followup testing by NASA.

Phase I Deliverables: Feasibility analysis and/or small-scale experiments proving the proposed technology to develop a given product (Technology Readiness Level (TRL) 2 to 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 3 to 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. Unique government facilities can be used as part of Phase II.

State of the Art and Critical Gaps:

The state of the artÂ is reactor fuel developed for the Rover/NERVA program in the 1960s and early 1970s. The fuel was carbon based and had what is known as "midband" corrosion, which affected the fuel endurance. Switching over to cermet (metal and ceramics) or advance carbide fuels shows promise but has fabrication challenges. Limited property data for most materials at ultrahigh temperatures considered makes the material performance analysis to meet the engine operating requirements riskier.

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 an Isp goal of 900 sec (using hydrogen) and are used individually or in clusters for the spacecraft's primary propulsion system. The NTP can have multiple startups (>5) with cumulative run time >200Â minÂ in a single mission, which can be no more than 2-yrÂ round trip, according to a recentÂ NASA study. The Rover/NERVA program ground tested a variety of engine sizes for a variety of burn durations and startups.

Relevance / Science Traceability:

By closing these ultrahigh-temperature data gaps, the Space Nuclear Propulsion (SNP) project intends to infuse the results into design considerations/optimizations for risk reduction. In addition to directly benefiting SNP by closing the current material data gaps, the technology improvements in high-temperature materials would also benefit the following:

- Department of Defense (DOD) Defense Advanced Research Projects AgencyÂ (DARPA) NTP program.
- Wing leading-edge systems, due to their use of refractory alloy base structures to 2,000 Â°C.
- Fission surface power, due to the use of materials in long-term high-temperature environments.
- Refractory reaction control systems (RCSs) that reach up to 2,000 Â°C temperatures.

- Refractory rocket nozzles for upper stages and landers that reach ~2,200+ Â°C.

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

Â Future mission applications:

- Human missions to Mars.
- Science missions to the outer planets.
- Planetary defense.

Some technologies may have applications for fission surface power systems.

References:

Solid-core NTP has been identified as an advanced propulsion concept that could provide the fastest trip timesÂ for human missions to Mars over a variety of mission years. NTP had major technical work done between 1955 and 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 1990s. The NTP concept is like 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.

1. Durham, F. P., â€œNuclear Engine Definition Study Preliminary Reportâ€, LA-5044-MS Vol I, Informal Los Alamos Report, 1972.
2. Altseimer, J. H., Mader, G. F., Stewart, J. J., â€œOperating Characteristics and Requirements for the NERVA Flight Engine,â€ Paper 70-676, AIAA 6th Propulsion Joint Specialist Conference, June 1970.
3. Angelo, J. A., Buden, D., â€œSpace Nuclear Powerâ€, OrbitBook Company 1985.
4. Koenig, D. R., â€œExperience Gained from the Space Nuclear Rocket Program (Rover)â€, LA-10062-H, Los Alamos Document, 1986.
5. Walton, J. T., â€œAn Overview of Tested and Analyzed NTP Conceptsâ€, AIAA-91-3503.
6. Finseth, J. L., â€œOverview of Rover Engine Tests- Final Reportâ€, NAS 8-37814, 1991.
7. Bhattacharyya, S.K. et al, â€œSpace Exploration Initiative Fuels, Materials and Related Technologies â€“ Nuclear Propulsion Technology Panel Final Reportâ€, NASA Technical Memorandum 105706, September 1993.
8. Haslett, R. A., â€œSpace Nuclear Thermal Propulsion Program Final Reportâ€, PL-TR-95-1064, Phillips Laboratory Air Force Report, 1995.