



## NASA SBIR 2020 Phase I Solicitation

### Z1.03 Kilowatt-Class Energy Conversion for Small Fission Reactors

Lead Center: GRC

Participating Center(s): JPL

Technology Area: TA3 Space Power and Energy Storage

#### Scope Title

Kilowatt-Class Fission Energy Conversion

#### Scope Description

NASA is considering the use of kilowatt class Fission Power Systems for surface missions to the moon and Mars. This technology directly aligns with the Space Technology Mission Directorate (STMD) roadmap for space power and energy storage. Prior work in fission power systems had focused on a 1kWe ground demonstration, however, NASA desires to scale-up the system and components for a flight demo mission to the lunar surface, so component technologies that support a 10kWe-class fission power system are sought that address the following technical challenges:

- Robust, efficient, highly reliable, and long-life thermal-to-electric power conversion in the range of 1-10kWe. Stirling, Brayton, and thermoelectric converters that can be coupled to Kilowatt reactors are of interest.
- Freeze tolerant heat pipe radiators that can operate through lunar night (-173 Å°C) and day (127 Å°C) temperature swings. Heat pipes must start-up from lunar night temperature and begin transferring heat within several thermal cycles.
- Radiation shield materials selection, design, and fabrication for mixed neutron and gamma environments, with consideration for mass effectiveness, manufacturability, and cost.
- Radiation tolerant generator control electronics designed to withstand an induced radiation environment in addition to the ambient environment in space. These electronics can include: source control and generation, high voltage outputs with dynamic response needed to meet power quality standards, short term heating prior to startup, shunt control to manage excess power production, and source monitoring for power management. Target dose tolerance ranges for fission power system electronics are between 1E11 to 1E13 n/cm<sup>2</sup> total neutron fluence, and between 100 kRad (Si) and 1000kRad (Si) total ionizing gamma dose. Natural space environment should also be considered, with specific attention to Single Event Effect susceptibility.

The desired deliverables are primarily prototype hardware, research, and analysis to demonstrate concept feasibility and a TRL range of 3 to 5. The prototype hardware may include one (or more) of the following:

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- Power convertor (hot-end temperature = 800 Å°C, cold-end temperature = 100 to 200 Å°C)
  - Heat pipe radiator (for up to 30 kW heat rejection)
  - Radiation shield (reduce radiation down to 1E11 to 1E13 n/cm<sup>2</sup> neutron fluence and 100 to 1000 kRad TID at minimum mass)
  - Control electronics (capable of surviving the radiation environment that passes through the radiation shield)

NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: <https://www.nasa.gov/content/commercial-lunar-payload-services>. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2020 and flight opportunities are expected to continue well into the future. In future years it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

## References

Kilopower (<https://www.nasa.gov/directorates/spacetech/kilopower>).

Gibson, M.A., et al., "The Kilopower Reactor Using Stirling Technology (KRUSTY) Nuclear Ground Test Results and Lessons Learned," AIAA P&E 2018, AIAA-2018-4973.

Mason, Lee S., "A Comparison of Energy Conversion Technologies for Space Nuclear Power Systems," AIAA P&E 2018, AIAA-2018-4977.

Chaiken, M.F., et al., "Radiation Tolerance Testing of Electronics for Space Fission Power Systems," Nuclear and Emerging Technologies for Space 2018, Paper No. 24146.

Gibson, M.A., et al., "NASA's Kilopower Reactor Development and the Path to Higher Power Missions," 2017 IEEE Aerospace Conference, 4-11 March 2017, Big Sky, MT.

Mason, Lee S., et al., "A Small Fission Power System for NASA Planetary Science Missions," NASA/TM--2011-217099.

**Expected TRL or TRL range at completion of the project: 3 to 5**

## Desired Deliverables of Phase II

Hardware, Analysis, and Research

## Desired Deliverables Description

We are primarily looking for component and/or breadboard hardware to demonstrate concept feasibility in a lab or relevant environment. The appropriate research and analysis required to develop the hardware are also desired.

## State of the Art and Critical Gaps

Kilowatt-class fission power generation is an enabling technology for lunar and Mars surface missions that require day and night power for long-duration surface operations, and may be the only viable power option to achieve a sustained human presence. The surface assets that could benefit from a continuous and reliable fission power supply include landers, rover recharge stations, science platforms, mining equipment, ISRU (In-Situ Resource Utilization) propellant production, and crew habitats. Compared to solar arrays with energy storage, nuclear fission offers considerable mass savings, greater simplicity of deployment, improved environmental tolerance, and superior growth potential for increasing power demands. Fission power is also one of very few technologies that can be used on either the moon or Mars with the same basic design. A first-use on the moon provides an excellent proving ground for future Mars systems, on which the crew will be highly dependent for their survival and return

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propellant. The technology is also extensible to outer planet science missions with power requirements that exceed the capacity of radioisotope generators, including nuclear electric propulsion spacecraft that could enable certain science missions that might otherwise be impossible.

Current work on fission power systems has focused on a 1kWe design using a highly enriched Uranium-Molybdenum reactor core with a Beryllium oxide reflector. Depleted uranium, tungsten, and lithium hydride provide shielding of gamma rays and neutrons to the power conversion system, control electronics, payload, and habitat. Heat is removed from the core at approximately 800Å° C using sodium heat pipes and delivered to the power conversion system. Waste heat is removed from the power conversion system at approximately 100 to 200Å° C using water heat pipes coupled to aluminum or composite radiator panels.

Reliable, robust, and long life power conversion is highly desirable in fission systems. There are currently not enough vendors or enough long duration reliability data for power conversion technologies under these operating conditions and environments. More work is needed in this area to expand the supplier base, and to increase the TRL of power conversion technology. The reactor core must be isolated from the Martian environment to prevent oxidation. However, simply canning the core may not be an option since increased distance between the core and reflector can have large negative effects on system mass. Canning the reflector and core together is the simplest option; however, the increased temperature of the reflector results in reduced reactivity and increased mass. Innovations are necessary to provide isolation while reducing the negative effect due to the neutronics.

Total Ionizing Dose (TID) effects, Displacement Damage Dose (DDD) effects, and Single Event Effect (SEE) transients are well studied for the standard space radiation environment composed of charged particles and electromagnetic radiation of either solar or galactic origin. Aerospace electronics vendors offer high reliability product lines that have been qualified using standard irradiation testing procedures. These procedures do not typically cover the neutron environment of a nuclear fission reactor. Further qualification in a reactor radiation environment is needed for components and systems that will be used in a space fission power system.

#### **Relevance / Science Traceability**

This technology directly aligns with the STMD roadmap for space power and energy storage. This technology could be infused into the Kilopower Project to enhance performance or reliability.