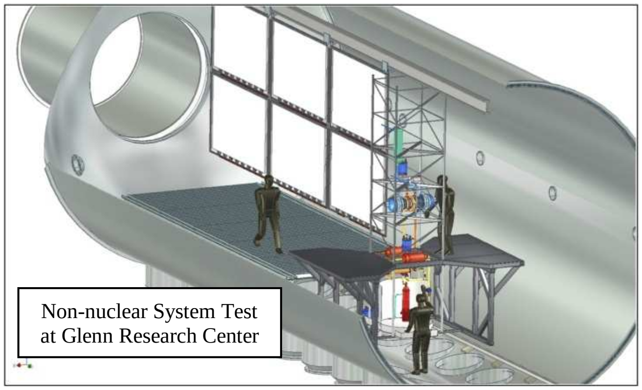
Fission Power System Technology for NASA Exploration Missions



Non-nuclear System Test at Glenn Research Center

Under the NASA Exploration Technology Development Program, and in partnership with the Department of Energy (DOE), NASA is conducting a project to mature Fission Power System (FPS) technology. A primary project goal is to develop viable system options to support future NASA mission needs for nuclear power. The main FPS project objectives are as follows:

1) Develop FPS concepts that meet expected NASA mission power requirements at reasonable cost with added benefits over other options.
2) Establish a hardware-based technical foundation for FPS design concepts and reduce overall development risk.
3) Reduce the cost uncertainties for FPS and establish greater credibility for flight system cost estimates.
4) Generate the key products to allow NASA decision-makers to consider FPS as a preferred option for flight development.

In order to achieve these goals, the FPS project has two main thrusts: concept definition and risk reduction. Under concept definition, NASA and DOE are performing trade studies, defining requirements, developing analytical tools, and formulating system concepts. A typical FPS consists of the reactor, shield, power conversion, heat rejection, and power management and distribution (PMAD). Studies are performed to identify the desired design parameters for each subsystem that allow the system to meet the requirements with reasonable cost and development risk. Risk reduction provides the means to evaluate technologies in a laboratory test environment. Non-nuclear hardware prototypes are built and tested to verify performance expectations, gain operating experience, and resolve design uncertainties.

The concept definition and risk reduction activities are highly coupled and the products are staggered so that the results of one can influence the other. For example, data from an electromagnetic pump test could be used to anchor a reactor thermal-hydraulic analysis code. The code could then be used to design a flight-like primary heat transport circuit. The resulting heat transport design could provide the basis for a higher fidelity ground test loop to validate the code.

The NASA/DOE Team

The FPS Project is managed by Glenn Research Center (GRC) in Cleveland, OH. GRC is also responsible for power conversion, heat rejection, and PMAD development, referred to as the balance-of-plant. Marshall Space Flight Center (MSFC) in Huntsville, AL provides expertise in reactor simulation, primary heat transport, and non-nuclear testing. The DOE is represented by four National Laboratories: Idaho, Los Alamos, Oak Ridge and Sandia. Each brings unique capabilities to the team. Some of the key contributions of the DOE Labs are in the areas of reactor and shield design, modeling and tools, fuel development, instrumentation and control, materials and irradiation testing, heat exchangers, and pumps. Various industry partners and university participants also play key roles in the technology development.

Why Nuclear Fission?

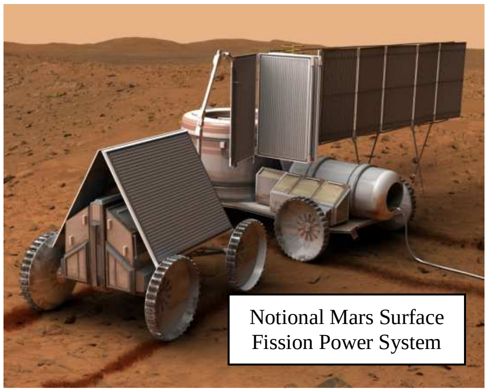
Nuclear power systems are best suited for NASA missions requiring high power in harsh environments where sunlight is limited and reliability is paramount. These are the conditions that are anticipated for future human missions beyond low earth orbit. The electric power to sustain a crew of four on the moon or Mars is estimated to be in the 10's of kilowatts. The moon's 29.5 day rotational period results in a long, cold, lunar night of 354 hours. On Mars, the night period is only 12 hours but sunlight at the surface is reduced to about 20% that of the moon. Martian dust storms and missions to the higher latitudes further diminish the availability of sunlight for solar power. On either surface, crew members would be highly dependent on the power system to achieve mission objectives and assure human safety.

Notional NEP Space Vehicle

Fission systems could also serve as the power source for spacecraft utilizing nuclear electric propulsion (NEP) technology. NEP space vehicles have the potential to deliver more payload on cargo missions, or achieve faster trip times on piloted missions than conventional chemically-propelled spacecraft. The key to good mission performance is low power system specific mass. NEP power systems can range in size from kilowatts to megawatts. Specific mass values of 10 kg/kWe, or less, would be desirable for the large megawatt-class systems.

The FPS would be designed to be safe during all mission phases. It could be launched cold (with no fission products from nuclear operations) to keep radiation at negligible levels. The reactor would be designed to remain sub-critical during all postulated mission events prior to startup. During operation, shielding would reduce radiation to safe levels for humans and cargo. After shutdown, the radiation from the reactor would drop to relatively low residual levels.

Nuclear system designs can be highly flexible and operationally robust. On planetary surfaces, the reactor could be buried or shielded with local materials to allow its use near crew habitation areas. The FPS could even provide process heat for in situ resource utilization (ISRU) plants and habitats. For NEP applications, the FPS could be operated continuously during thrusting, and throttled during coast periods to conserve life. After arrival, the same power system could provide abundant power for crew operations, scientific measurements, and high data-rate communications. The high energy density inherent with nuclear systems permits generous design and performance margins. Operational robustness would be achieved through multi-fault tolerant architectures and long-life components, requiring no maintenance.

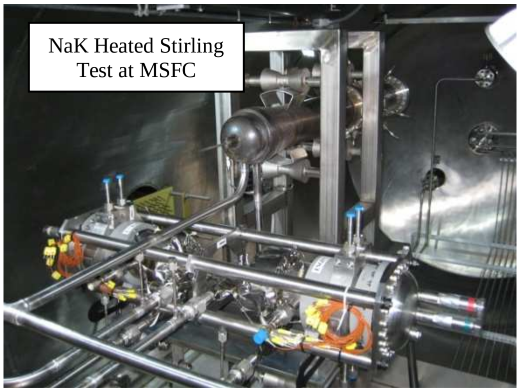


Notional Mars Surface Fission Power System

Concept Definition Studies

While a flight FPS would be the ultimate goal, technology development must proceed first. To identify key technologies, suitable concepts must be defined. Concept design activities are focusing on affordable approaches to FPS. The main emphasis is on mature reactor technologies that have terrestrial design basis. Current plans presume the use of stainless steel clad, uranium dioxide (UO_2) fuel pins. This limits heat delivery temperatures to about 900 K. The preferred heat transport medium is liquid metal, either sodium (Na) or a sodium-potassium (NaK) mixture. The relatively low reactor temperature and the desire to minimize reactor thermal power require efficient power conversion techniques. Stirling and Brayton cycle heat engines offer high efficiency at cold-end temperatures that are compatible with space and planetary surface thermal environments. The present heat rejection approach includes pumped-water heat transport and composite radiator panels with embedded heat pipes operating at about 400 K. The current PMAD implementation assumes that AC alternator power is delivered to a power distribution node where it is converted to DC for the loads.

In order to satisfy a multitude of possible missions, NASA and DOE have developed a modular design concept. A single FPS unit could provide a net power of 40 kWe with a design life of 8 years, for either lunar or Mars surface missions. That design could be adapted for an initial 100 kWe-class fission system for NEP robotic precursor missions. As experience is gained in developing and flying nuclear systems, the technology could evolve to the higher power, lower specific mass systems needed for piloted NEP.



NaK Heated Stirling Test at MSFC

Risk Reduction Activities

Early risk reduction efforts are focused on demonstrating component technologies under expected FPS conditions, using prototype “pathfinder” test articles. At MSFC, testing was completed on a NaK-heated Stirling power conversion system using commercial engines from Sunpower, Inc and a GRC-developed NaK heat exchanger. Testing was also completed at MSFC on a NaK annular linear induction pump (ALIP), developed by Idaho National Lab, that uses magnetic fields to pump the fluid with no moving parts. At GRC, testing was completed on a full-scale radiator demonstration unit (RDU), that was approximately 2 m tall by 3 m wide and used titanium-water heat pipes embedded in a lightweight, high thermal-conductivity composite structure.

The centerpiece of the risk reduction activities is the non-nuclear Technology Demonstration Unit (TDU). The goal of the TDU is to assemble the major components of the FPS (heat source, power conversion, heat rejection, and PMAD) and conduct non-nuclear integrated system testing in thermal-vacuum to evaluate overall performance. Plans are to develop full-scale components and assemble a 1/4th power (10 to 12 kWe) system in GRC’s Vacuum Facility #6. DOE and MSFC will jointly develop the reactor simulator. GRC and its industrial partners will develop the balance-of-plant. The testing will help to verify performance projections, develop safe and reliable control methods, and gain valuable system operating experience to advance the technology readiness of FPS for future flight applications.

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