NEAR TERM, LOW COST OPTIONS FOR MARS FISSION POWER. L. S. Mason[1] and D. I. Poston[2], [1]NASA Glenn Research Center, Cleveland OH 44135, lee.s.mason@nasa.gov, [2]Los Alamos National Laboratory, Los Alamos NM 87545, poston@lanl.gov.

Introduction: Nuclear power provides an enabling capability for exploration missions which might otherwise be constrained by power availability, mission duration, or operational robustness. NASA and the Department of Energy (DOE) are developing fission power technology to serve a wide range of future space uses. Advantages include lower mass, longer life, and greater mission flexibility than competing options. This paper examines several near term fission power concepts that could be used to support robotic and human Mars missions.

Fission Technology Development: The fission technology development project is a collaboration between NASA Glenn, NASA Marshall, and the DOE National Laboratories at Idaho, Los Alamos, Oak Ridge, and Sandia. The work effort currently resides under the Office of Chief Technologist, Game Changing Development Program as the Nuclear Systems Project. The team has been in place since the end of the Prometheus Program performing analysis and hardware testing to establish technology readiness. The current focus is a non-nuclear Technology Demonstration Unit (TDU) that will be tested in thermal-vacuum to demonstrate system performance [1].

Through the course of the technology development process, the team has identified several viable concepts that could be inserted into near term Mars missions. Kilowatt-class systems, designated Kilopower, were developed to address the need for low power reactor systems to fill the gap above current Radioisotope Power Systems (RPS). Larger Fission Surface Power (FSP) systems, in the 10 to 100 kWe range, were developed to address the needs of crewed surface bases on the moon and Mars.

Kilopower: The Kilopower concept was initially conceived through a study performed for the National Research Council Planetary Science Decadal Survey. The purpose was to evaluate the feasibility of fission power systems for kilowatt-class science missions as an alternative to RPS, given the limited availability of the plutonium-238 heat source. The goal was to minimize development risk and cost, with system mass that was comparable to multi-unit RPS. The selected reactor concept uses 93% enriched block UMo fuel surrounded by a beryllium reflector with a single, centered boron-carbide control rod. The compact, fast-spectrum core is 12.9 cm diameter by 30 cm long and is cooled by eighteen sodium heat pipes. With an average fuel temperature of 1200 K and a heat pipe condenser temperature of 1100 K, the reactor can generate about 13 kWt. A conical LiH/W shadow shield provides electronics-rated radiation protection at the science payload, assumed to be 10 m from the core.

The reactor can be combined with thermoelectric (TE) power conversion, as shown in Figure 1, to produce 1 kWe. The concept utilizes segmented TE materials with a combination of Zintl, $La_{3-x}Te_4$, and Skutterudites that provide 8% system efficiency at 1050 K hot-end and 525 K cold-end temperature. The TE elements are distributed along the heat pipe condensor sections and coupled directly to aluminum radiator fins, with a total radiating surface area of 5 m^2. The total system mass is about 600 kg, or 2 W/kg [2].

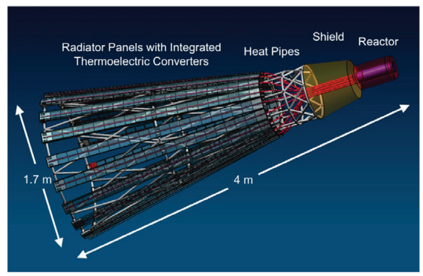

Figure 1. Kilopower System with TE (1 kWe)

The same 13 kWt reactor can be combined with Stirling power conversion, as shown in Figure 2, to produce 3 kWe. This concept uses eight, 400-watt Stirling convertors that provide 23% system efficiency at 950 K hot-end and 475 K cold-end. The Stirling option uses water heat pipes on the cold-end coupled to a cylindrical aluminum radiator, with a total radiating surface area of 9.6 m^2. The total system mass is about 750 kg, or 4 W/kg [3].

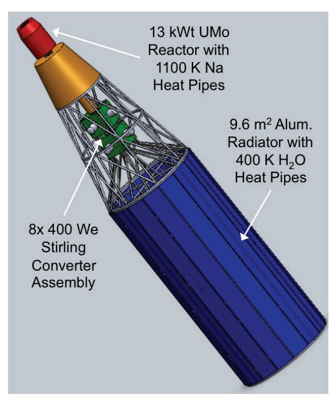

Figure 2. Kilopower System with Stirling (3 kWe)

The Kilopower systems could be utilized on Mars orbiters or pre-crew surface stations on Mars or its moons, Phobos and Deimos. The compact size and constant power output make it ideal for precursor in-situ resource utilization (ISRU) experiments. An early technology demonstration mission combining fission power and ISRU to demonstrate local propellant production would validate methods that could be scaled to support subsequent human missions.

Fission Surface Power: The Kilopower concepts are applicable for power levels up to about 10 kWe. At higher power levels, an alternative reactor approach is recommended. The FSP reactor design leverages terrestrial technology with fast-spectrum UO_2 pin-type fuel, stainless steel construction, and NaK coolant. The reactor approach allows for operating temperatures up to 900 K. The power system would utilize multiple redundant Stirling convertors with 400 VAC power distribution and a 120 VDC power bus. Heat rejection is provided by pumped water coolant coupled to composite radiator panels with titanium-water heat pipes at approximately 400 K [4].

A Mars-based FSP concept is shown in Figure 3. The mission architecture assumes an initial cargo lander that delivers the FSP system and an ISRU plant to produce the return propellant before the crew ever leaves Earth. A nuclear power system allows the propellant production to be completed faster and more efficiently through continuous day-night operations. The reactor is mounted on a mobile cart that is robotically deployed from the lander. A circumferential shield provides human-rated radiation protection for crew located 1 km away. The 40 kWe system is approximately 7000 kg, or 6 W/kg.

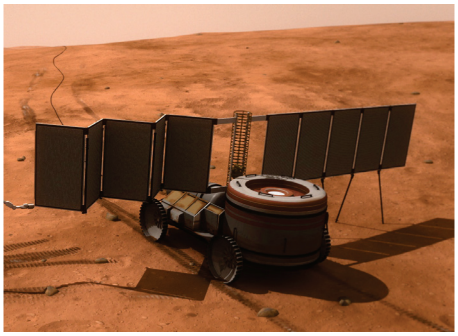

Figure 3. Large, Deployable FSP System (40 kWe)

A smaller, simpler variant of the 40 kWe system is shown in Figure 4. This 10 kWe system was developed to support lunar architectures where surface assets would be robotically repositioned to accommodate different crew landing sites. The concept is optimized for easy deployment and can be shut down and relocated if needed. It uses the same reactor from the 40 kWe system, to maximize extensibility, but only one Stirling power unit (instead of 4) and two radiator panels (instead of 10). A water shield and regolith berm provides human-rated radiation protection at the 200 m power hub. The total system mass is about 3300 kg, or 3 W/kg [5].

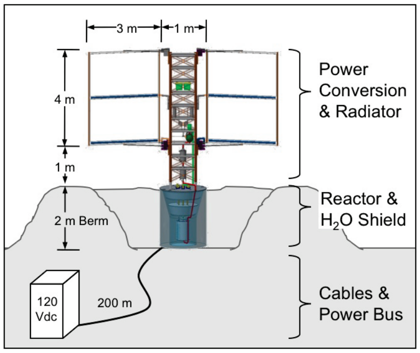

Figure 4. Simple, Deployable FSP System (10 kWe)

Conclusion: The concepts described in this paper provide near term options to meet future Mars mission power needs utilizing robust and scalable fission power technology. The proposed fission systems minimize risk and cost by employing mature technologies and leveraging past/current development efforts. The diverse system configurations illustrate the flexibility of fission power to serve a wide range of mission architectures. The concepts were intentionally developed to simplify mission integration and minimize operational complexity.

References:

[1] NASA TM-2011-217100, [2] NASA TM-2011-217099, [3] NASA TM-2011-217204, [4] NASA TM-2010-216772, [5] NASA TM-2011-216819.