Development of NASA's Small Fission Power System for Science and Human Exploration M.A. Gibson[1], L. Mason[1], C. Bowman[1], D.I. Poston[2], P.R. McClure[2]. J. Creasy[3], C. Robinson[3]; [1]NASA Glenn Research Center, marc.a.gibson@nasa.gov. [2]Los Alamos National Laboratory, pmcclure@lanl.gov. [3]Oak Ridge Y-12, robinsonrc@Y12.doe.gov

Introduction: Exploration of our solar system and beyond has brought many exciting challenges to our nation's scientific and engineering community. As we expand our visions to explore new, more challenging destinations, we must also expand our technology base to support these new missions. NASA's Space Technology and Mission Directorate (STMD) is tasked with defining and developing these technologies for future mission infusion and continues to seek answers to many existing technology gaps. One such technology gap is related to compact power systems (> 1 kWe) that do not rely on solar energy and can provide abundant power for several years if not decades. Below 1 kWe, Radioisotope Power Systems (RPS) have been the workhorse for NASA and will continue to be used for lower power applications similar to prior missions like Voyager, Ulysses, New Horizons, Cassini, and Curiosity. Above 1 kWe, Fission Power Systems (FPS) become the base technology with multiple options for reactor design, power conversion, and heat rejection which are driven by specific power needs and mission requirements. Near term emphasis has been placed in the 1-10kWe range that would enable both science and human exploration missions that could not be accomplished with current power systems. History has shown that development of space reactors is technically, politically, and financially challenging and requires a new approach to their design and development. A small team of NASA and DOE experts are providing a solution to these enabling FPS technologies starting with the lowest power and most cost effective reactor series named "Kilopower" that is scalable from approximately 1-10 kWe.

Kilopower Design: The Kilopower FPS is being designed for long life missions that could last more than 15 years in harsh environments. These missions could include exploration of deep space objects in the Kuiper belt or beyond, planetary orbiters, landers, and submersibles, or surface power for human outposts and robotic precursors [1]. In order to accomplish these challenging missions the design has focused on a passive compact system capable of long term operation while being compatible with a wide variety of spacecraft architectures. The team has engineered a design that consists of a sodium heat pipe cooled cast uranium core, Stirling power conversion, and titanium/water heat pipes for heat rejection. Figure 1 shows the current 1 kWe and 10 kWe kilopower designs.

Reactor Design. Unique to this reactor is a solid cast uranium core, which provides the most compact geometry and lowest possible mass with proven reactor technology. The solid core works well with lower power reactors because of negligible fuel burnup and volume swelling issues that can challenge higher power reactors typically incorporating pin type fuel [2]. This small solid core design reduces the fuel, radial reflector and shadow shield mass giving the total system a higher specific power (W/kg) than other fuel forms. The baseline material for the core has been chosen to be 93% highly enriched U^{235} alloyed with 7% Mo by weight, and is expected to produce an optimum balance between neutronic, thermal, and metallurgical properties [3]. The sodium heat pipes cool the reactor core by transporting the thermal energy, via the sodium vapor, from the uranium to the power conversion system. Alloy 230 is the baseline material for the heat pipes because of its known compatibility and prior experience with sodium as well as its high temperature strength and creep resistance. The radial reflector is made from BeO for its high neutron reflectance throughout the required temperature and energy spectrum as well as the mechanical strength, density, and stability. Criticality safety and reactor startup are provided by insertion or removal of a B_4C control rod. This system design requires very little power for reactor startup as all the heat transfer is provided by the passive thermal control of the heat pipes. This is an important design feature needed for missions that may require the reactor to startup under minimum power at a location where sunlight is not available.

Power Conversion. High efficiency free piston Stirling convertors have been baselined for initial development to increase system performance. Their use benefits from existing flight development of the 80 We Advanced Stirling Convertor (ASC) as well as recent successful technology demonstrations of both 1 and 6 kWe by NASA. The Stirling convertors in both the 1 and 10 kWe designs are arranged in the vertical dual opposed configuration that allows easy power scaling and decreases the shield half angle and mass. Thermoelectric conversion has been studied as an alternate power conversion technology that offers simplicity and additional redundancy but requires significantly more thermal power from the reactor thus increasing size and mass. Specific mission requirements will help determine which conversion technology will be integrated into future flight systems.

Heat Rejection. The Stirling engines must reject their waste heat to space at the optimum temperature in order to establish a balance between the conversion efficiency and radiator mass. This optimum temperature is not equal for the 1 and 10 kWe systems but does fit well within the operating range for water based heat pipes. NASA Glenn Research Center has been developing titanium water heat pipes for nuclear applications over the past decade and has brought the Technology Readiness Level (TRL) to 6 through many ground and parabolic aircraft flight tests.

Technology Demonstration: Demonstrating this small reactor technology will be a crucial step in gaining acceptance and support for a future flight unit. The goal is to perform a full scale nuclear ground test of the 1kWe flight prototypic reactor core, reflector, sodium heat pipes, and power conversion system in 3 years. This Kilopower Reactor Using Stirling TechnologY KRUSTY test would use existing infrastructure and control systems at the Device Assembly Facility (DAF) at the Nevada Test Site to verify criticality, thermal performance, and power conversion of the prototypic assembly. The Demonstration using Flattop Fissions (DUFF) experiment in 2011 [4] showed that nuclear testing of space reactors and their subcomponents can be affordably tested. The KRUSTY test would incorporate the core, reflector, sodium heat pipes, and power convertors but would not include the control rod, shield, and heat rejection radiators. Most of the non-nuclear components of the 1 kWe design are already at or above a TRL 6 from prior flight and technology programs, leaving the overall system and nuclear components to be successfully demonstrated.

Starting with the lower 1kWe power system for the first nuclear demonstration is extremely important to keeping development costs at an affordable level. Nuclear testing costs are directly proportional to reactor thermal power and the 1kWe system requires only 4 kWt from the reactor. By design, the lower power demonstration offers a subscale test of a 10 kWe capability, adding considerable value to both science and human exploration needs and paving the way for future higher power needs. Successful nuclear testing of the Kilopower reactor will help fill the existing technology gap of compact power systems in the 1-10 kWe range enabling new higher power NASA science and human exploration missions.

References:

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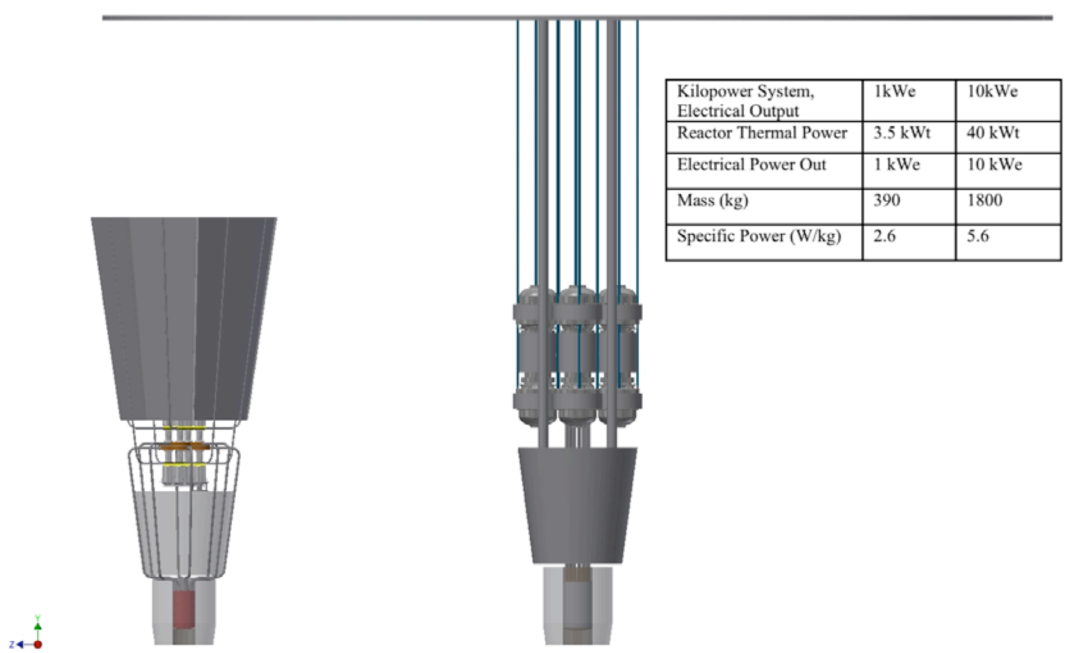

Kilopower System, Electrical Output	1kWe	10kWe
Reactor Thermal Power	3.5 kWt	40 kWt
Electrical Power Out	1 kWe	10 kWe
Mass (kg)	390	1800
Specific Power (W/kg)	2.6	5.6

Figure 1. left, 1kWe In-Space Kilopower system. Right, 10 kWe Mars Mobile Kilopower system with deployable radiator.