

VERSATILE STIRLING TECHNOLOGY FOR RADIOISOTOPE AND FISSION POWER SYSTEMS. L. S. Mason¹, J. F. Zakrajsek¹, and D.T. Palac¹, ¹NASA Glenn Research Center, 21000 Brookpark Road, Cleveland OH 44135, lee.s.mason@nasa.gov, june.f.zakrajsek@nasa.gov, donald.t.palac@nasa.gov.

Introduction: Free-piston Stirling technology has been under development at NASA Glenn Research Center (GRC) since the 1970s. The current focus is on 100-watt class convertor technology for Radioisotope Power Systems (RPS) and multi-kilowatt convertor technology for Fission Power Systems (FPS).

The NASA Science Mission Directorate (SMD) has sponsored the RPS Stirling development. The technology is at a high Technology Readiness Level (TRL) based on the Advanced Stirling Convertor (ASC) from Sunpower Inc. The ASC, shown in Fig. 1, is designed to produce 80 We AC at 32% thermal-to-electric efficiency. The high efficiency allows a four-fold reduction in the amount of Pu-238 fuel as compared to Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) technology.



Figure 1. 80 We Advanced Stirling Convertor

Over 25 ASCs have been built and tested, with over 629,000 hours of cumulative operation in GRC's Stirling Research Lab [1,2]. Testing has included performance mapping, launch vibration exposure, and extended 24/7 operations. The final engineering model ASC-E3 units, built to flight specifications using flight quality processes, are under test and ready for assembly as a dual opposed pair in a Stirling Radioisotope Generator (SRG) Engineering Unit, shown in Fig. 2.



Figure 2. SRG Engineering Unit

The FPS Stirling development has been sponsored by the Space Technology Mission Directorate (STMD) under the Nuclear Systems Project. A 12 kWe AC Power Conversion Unit (PCU) with two dual opposed and thermodynamically-coupled Stirling engines, shown in Fig. 3, is in the final stages of development at Sunpower with delivery to GRC expected in Spring 2014 [3].



Figure 3. 12 kWe PCU

The PCU will be integrated into a fission Technology Demonstration Unit (TDU) that includes an electrically-heated reactor simulator with a pumped sodium-potassium (NaK) heat transfer loop that couples directly to the Stirlings [4]. The TDU test configuration, shown in Fig. 4, is designed to represent a 40 kWe-class lunar or Mars fission surface power system, and thermal-vacuum system testing of this unit will begin at GRC in FY14.



Figure 4. Technology Demonstration Unit

Mission Needs: The RPS Stirling units are well suited for planetary science missions with power requirements below a kilowatt. The 140 We Advanced Stirling Radioisotope Generator (ASRG), using two ASCs, was ear-marked for use in NASA Discovery class missions such as Titan Mare Explorer (TiME) and Comet Hopper (CHopper). The limited Pu-238 fuel supply constrains the number of science missions that can be performed with the less efficient MMRTGs. If NASA proceeds with one MMRTG for

the planned Mars 2020 rover and five MMRTGs for the proposed Europa Clipper mission, the present Pu-238 inventory will be largely exhausted. Future missions such as Saturn Ring Observer, Chiron Orbiter, and Trojan Tour and Rendezvous will be impossible without a switch to a more efficient technology.

A significant number of future planetary missions have projected power requirements of a kilowatt and above [5]. These missions may include orbiters, landers, multiple science targets, expanded instrument suites, in-situ data analysis, high-rate communications, and/or electric propulsion. To better accommodate the higher power missions, a large SRG, shown in Fig. 5, has been proposed that could generate 500 We using the same number of Pu-238 fuel modules required for the 110 We MMRTG.

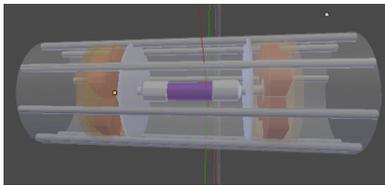


Figure 5. 500 We-class SRG

Human outpost missions to the moon and Mars have generally required tens of kilowatts to accommodate landers, habitats, in-situ resource utilization (ISRU) plants, rover recharging, communication relays, and science packages. Until recently, the preferred approach was to deliver a large, centralized fission power plant that could meet the mission requirements with margin for growth. The drawback was the large landed mass, complex installation, and lack of system-level redundancy.

A new fission design option, designated KiloPower, has been developed that bridges the gap between RPS and large FPS power plants [6]. The technology is readily scalable from 500 We to 10 kWe or more using the same basic building blocks. A small KiloPower system, as shown in Fig. 6, can be used on planetary missions that exceed the RPS power capabilities or require too much Pu-238 fuel. Larger versions could serve on human precursor missions to demonstrate ISRU production or on human outpost missions where compact packaging, modularity, and redundancy are favored for over growth capacity.

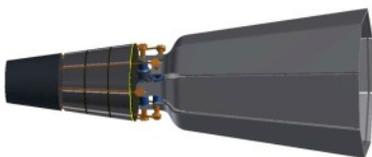


Figure 6. 1 kWe-class KiloPower System

KiloPower systems utilize a solid, cast uranium-molybdenum (UMo) core and sodium heat pipes to transfer the fission heat to Stirling engines that are cooled by water heat pipe radiators. The highly-enriched UMo fuel is abundantly available and currently produced at DOE's Y12 facility. The Stirling engines are derivatives of the flight-ready ASCs. The water heat pipe radiators have been under development since the Prometheus Program (circa 2003), with considerable thermal-vacuum and microgravity testing already completed. A key benefit is that the KiloPower systems are small enough to be fully tested in current DOE nuclear facilities.

Stirling Technology Roadmap: Key next steps for Stirling technology are the SRG Engineering Unit test under SMD and the TDU test under STMD. Additional component and subsystem technology development is being pursued under the RPS Technology Advancement Project (TAP). TAP has on-going Stirling-related tasks on multi-layer thermal insulation, heat source back-up cooling, high temperature alternators, cold-end heat pipes, mechanical balancers, and advanced controllers. The overall objective is to improve Stirling performance and reliability while extending its mission use. A proposed new area of development is a higher power, scaled version of the ASC (perhaps 300 to 400 We per unit) that could be used in larger SRGs or KiloPower systems.

Following the TDU test, a proposed STMD focus for the Nuclear Systems Project is KiloPower development. The primary objective is to conduct a reactor prototype test at the Nevada National Security Site's Device Assembly Facility. The test would use a highly-enriched UMo reactor core, beryllium reflector, and sodium heat pipes coupled to two ASCs for a full-scale, one-quarter power TRL5 system demonstration. The test would demonstrate the basic building blocks for KiloPower systems up to about 10 kWe while leveraging Stirling technology development from SMD and nuclear materials and testing assets from DOE's National Nuclear Security Administration (NNSA).

References: [1] Wong, et al, "Continuing Development of the Advanced Stirling Converter For NASA RPS," NETS-2014. [2] Schifer, et al, "Summary of ASC Testing at NASA GRC," NETS-2014. [3] Geng, et al, "Development of a 12 kWe Stirling Power Conversion Unit for Fission Power Systems - Status Update," NETS-2014. [4] Briggs, et al, "Status Update for the Fission Surface Power Technology Demonstration Unit," NETS-2014. [5]

http://sites.nationalacademies.org/SSB/SSB_059331. [6] Gibson, et al, "Development of NASA's Small Fission Power System for Science and Human Exploration," NETS-2014.