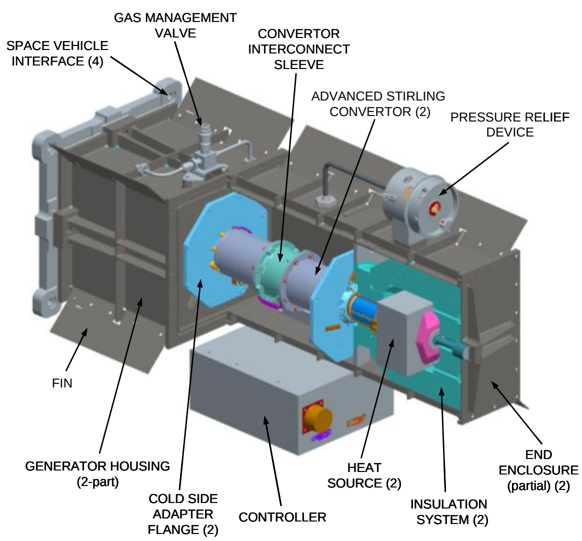
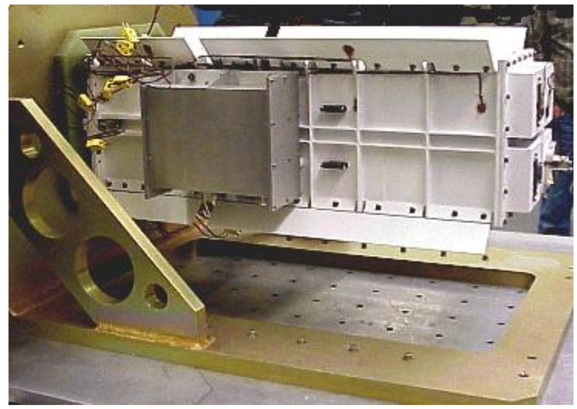
Space Radioisotope Power Systems
Advanced Stirling Radioisotope Generator
January 2011

For nearly fifty years, Radioisotope Thermoelectric Generators (RTGs) have provided safe, reliable electric power for NASA missions where solar power is not feasible. Although RTGs have performed with exceptional reliability over very long mission durations, they are limited by the low conversion efficiency of thermoelectric materials, with system efficiencies typically ranging from about 5-7%. Because Plutonium-238 (Pu-238) is an extremely limited resource, for which the United States currently has no production capacity, DOE and NASA are pursuing higher-efficiency systems such as the Advanced Stirling Radioisotope Generator (ASRG) that would reduce the amount of Pu-238 required for a given electric power output. Each ASRG is projected to produce 130-140 Watts of power using less than 1 kg of Pu-238 fuel. This is less than 25% of the Pu-238 that would be required for a comparable RTG.

ASRG ENGINEERING UNIT



The ASRGs advancements are made possible by the use of highly efficient Stirling engines coupled with linear alternators (together known as Advanced Stirling Convertors, or ASCs) to convert the natural radioactive decay heat of Pu-238 into electricity. Although Stirling engines have been in use since the early 1800s, they have never been used to generate electricity for spacecraft. This is because the benefits they offer also bring some challenges that must first be overcome. Unlike RTGs, the ASRG is a complex thermodynamic system with moving parts. Like any dynamic system, it requires a controller to maintain optimum performance, to prevent piston overstroke and to convert the AC output of its alternators to DC suitable for a spacecraft bus. This level of complexity is manageable and will be worth accepting to gain the benefits offered by the ASRG, once it has been proven to offer the high reliability demanded of spacecraft power systems. Cryocoolers using similar technology have been used on NASA missions, but no dynamic system has yet been used in space for power production. Before the ASRG can be considered as an alternative to RTGs for NASA missions, a flight-like system must be built and demonstrated, and its reliability must be well understood. These are the primary near-term goals of the ASRG project.



ASRG EU ON THERMAL VACUUM FIXTURE

The ASRG builds on years of Stirling convertor technology development and reliability testing conducted by the NASA Glenn Research Center (GRC) and on an earlier system design. A flight-like engineering unit ASRG was tested during the first part of 2008. The generator underwent a series of tests to characterize its performance in a variety of environments, including vibration, shock and thermal vacuum tests that simulate the environments the system must survive during launch and in space. The next step toward use of ASRG on a mission is qualification. This phase involves building, fueling and testing an ASRG that is of the same design and rigorous quality requirements as one that would be used for flight. After qualification, a flight generator could be available for NASA mission use as early as 2015.

ASRG DESCRIPTION

The ASRG is being developed by Lockheed Martin Space Systems Company, under contract to DOE. It has been designed to meet a generic "multi-mission" requirements set that includes both deep space and Mars surface environments.

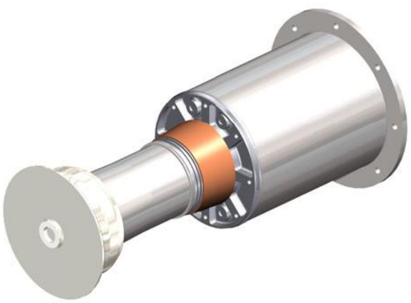
It is designed as a modular, self-contained unit. The heat input to the ASRG is provided by two General-Purpose Heat Source (GPHS) modules, which generate heat through the radioactive decay of Pu-238. The GPHS is a standard heat source design, which is also used in RTGs and has a long flight heritage. Each GPHS module will produce roughly 250 thermal watts at launch, decaying to approximately 224 watts by the end of a 14-year mission. This heat is converted to electricity by the ASC, developed by Sunpower, Inc. under a NASA Research Announcement award with GRC. Sunpower and GRC are also implementing improvements to the ASC that allow it to operate at a higher temperature. Higher temperature operation will increase the power output for the same amount of radioisotope fuel. The current ASRG performance estimate is shown in the following table:

ASRG ESTIMATED PERFORMANCE

Power at Launch	~130-140 We
Power Degradation	~ 0.8 %/yr (power decays with fuel)
Mass	<32 kg
System Efficiency (electric power out/ heat produced by fuel)	>27 %
Maximum Overall Dimensions (excluding separately mounted controller)	50 cm x 50 cm x 80 cm
Controller	Single fault tolerant
Environments	Deep space and Martian surface
Lifetime	3 yrs storage + 14 yrs operating

ADVANCED STIRLING CONVERTOR (ASC)

The ASC consists of a free-piston Stirling engine and an integral linear alternator that converts the piston reciprocating motion to electrical output. The internal moving components are supported by hydrostatic gas bearings, which allow movement without contact or rubbing. Two ASCs are used in each ASRG, mounted opposite each other and electrically synchronized so that their pistons move in opposite directions, eliminating most of the vibration.

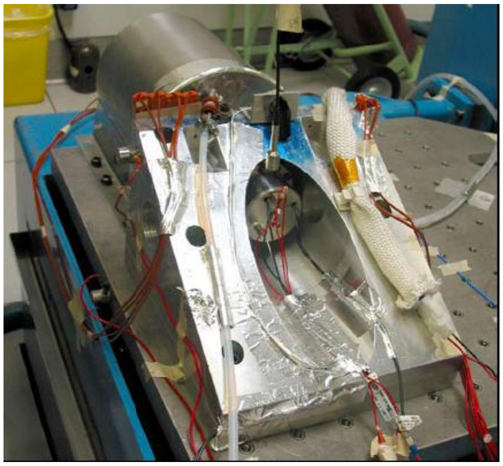


ADVANCED STIRLING CONVERTOR

RELIABILITY

Extensive efforts are underway to evaluate, improve, and verify the ASC and ASRG reliability. Lockheed Martin Space Systems Company is leading a reliability team that also includes GRC, DOE, Sunpower and the NASA Jet Propulsion laboratory (JPL). Traditional analyses include failure modes, effects, and criticality analysis (FMECA) and fault tree analysis for the convertor, controller, and system. Physics-based modeling of the convertor with probabilistic analysis is being done by GRC. The reliability efforts draw on supporting technology work in various areas, including convertor testing, hot-end material and heater head creep testing, heater head life analysis, regenerators, magnet aging, linear alternator analysis and testing, gas bearing analysis, organics testing, and system dynamic modeling.

A key element of the ASRG reliability program is long-term life testing of the ASCs. GRC has unique facilities and expertise that allow continuous long-term operation of Stirling convertors, alone or in pairs to simulate their configuration in generators. This facility has already been used to gather many thousands of hours of life test information on ASCs, and the testing is ongoing. A set of ASCs is currently being manufactured to the final flight design. Although the changes from prior models are minor, these will also be subjected to testing at GRC, so that this information can be added to the already extensive ASRG reliability test database.



ASC LAUNCH VIBRATION TESTING

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