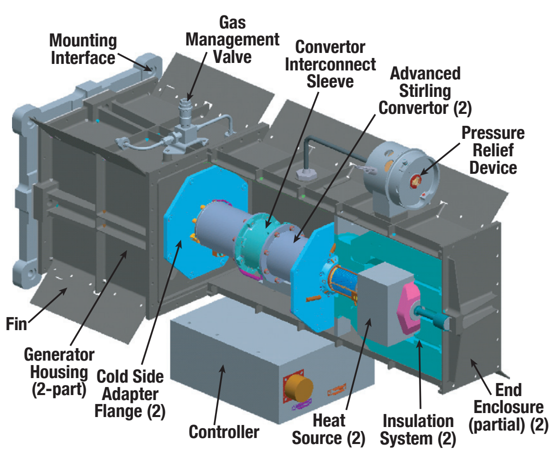
Advanced Stirling Radioisotope Generator

For more than forty years, Radioisotope Thermoelectric Generators (RTGs) have provided safe, reliable electric power for National Aeronautics and Space Administration (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 percent. Since Plutonium-238 (Pu-238) is a limited resource, the Department of Energy (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 approximately 140 watts of power using less than 1 kg of Pu-238 fuel. This is less than 25 percent of the Pu-238 that would be required for a comparable power RTG. The specific power, or power produced per unit mass of the generator, is also improved over current RTG designs. The ASRG Engineering Unit (ASRG-EU) system is about 75 cm (30 in) long and 30 cm (12 in) in cross-section, and weighs about 25 kg (55 lb).



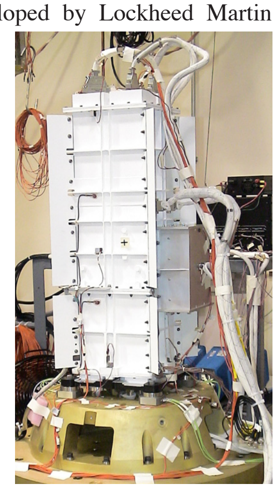
ASRG-Engineering Unit (ASRG-EU)

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 somewhat complex thermodynamic system with moving parts. Like any dynamic system, it requires a controller to control piston stroke 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 investing in to gain the benefits offered by the ASRG. A final challenge to address is to provide the high reliability demanded of spacecraft power systems. While cryocoolers using similar technology have been used on NASA missions, no dynamic system has yet been used in space for power production. Before the ASRG could 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.

The ASRG builds on years of Stirling convertor technology development and reliability testing conducted by the NASA Glenn Research Center (GRC). An ASRG-EU was assembled and tested during the first part of 2008. The generator completed 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 would be exposed to during launch and in space. With engineering unit tests successfully completed, the next step is ASRG qualification. This phase would involve 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.



ASRG-EU undergoing launch vibration simulation

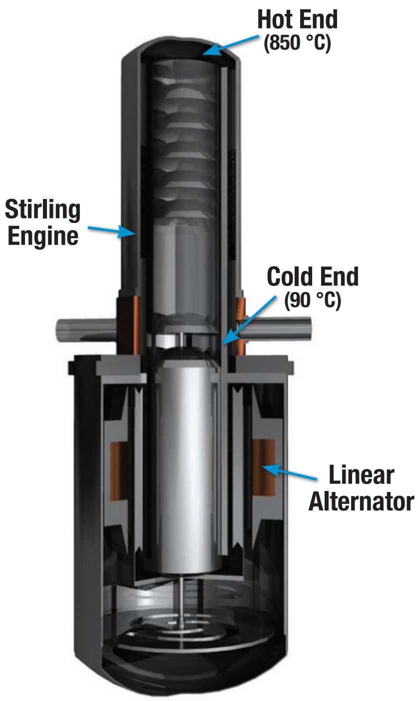
It is designed as a modular, self-contained unit. The heat input to the ASRG is provided by two General-Purpose Heat Source (GPHS) modules, which generate heat through the radioactive decay of Pu-238. The GPHS is a standard heat source design, which is also used in RTGs and has a long, safe, and sucessful flight heritage. Each GPHS module in the ASRG will produce roughly 250 thermal watts at launch. This heat is converted to electricity by the ASC, developed by Sunpower, Inc. under contract to NASA. The electricity is converted to use-

ASRG**facts**

able power for the spacecraft in the controller. The system is being designed for a 14-year mission life.

Advanced Stirling Convertor (ASC)

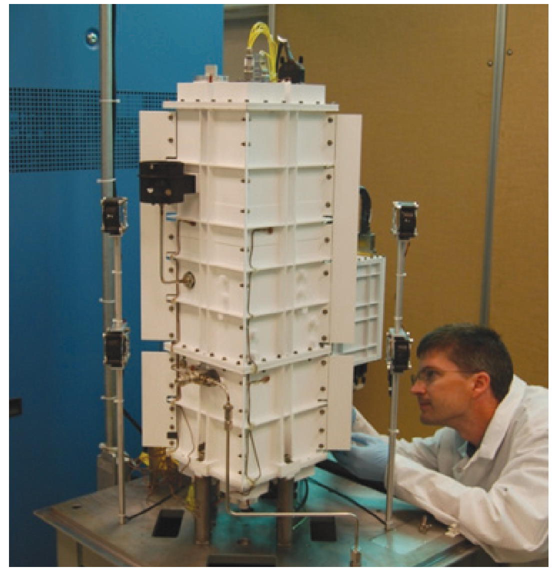
The ASC consists of a free-piston Stirling engine and an integral linear alternator that converts the piston reciprocating motion to electrical output. The ASC weighs only about 1.3 kg, has demonstrated a convertor efficiency of 38 percent at 850 °C hot-end temperature and 90 °C cold-end temperature. 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 model

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. JPL used a Defect Detection and Prevention (DDP) risk management tool to support the ASC/ASRG effort. Physics-based modeling of the convertor with probabilistic analysis is being done by GRC. The reliability efforts draw on supporting technology work at GRC 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.



ASRG-EU being prepared for extended operation testing at GRC

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. GRC's test facility includes multiple test stations for 24-hour unattended operation in air and a thermal vacuum chamber, as well as other test stations for performance and controller testing. Two pairs of ASCs operating at 650 °C hot-end temperature, have completed thermal vacuum testing. As of January 2009, one hermetically sealed pair completed over 16,000 hours of testing. Two ASCs capable of 850 °C operation were received from Sunpower and are currently running in-air extended operation. GRC also has two pairs of convertors from Infinia Corporation on extended testing. These convertors were also designed to produce power from the heat of one GPHS module but use flexural bearings to allow movement of internal components with minimal contact. As of February 2010, one convertor pair has achieved over 51,600 hours of testing (each convertor), while the other pair has completed over 37,890 hours. While demonatration of ASCs longevity is critical, demonstration of the integrated system is just as importatnt. GRC has begun extended operation testing of the ASRG-EU and have completed nearly 9,000 hours.

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