National Aeronautics and Space Administration

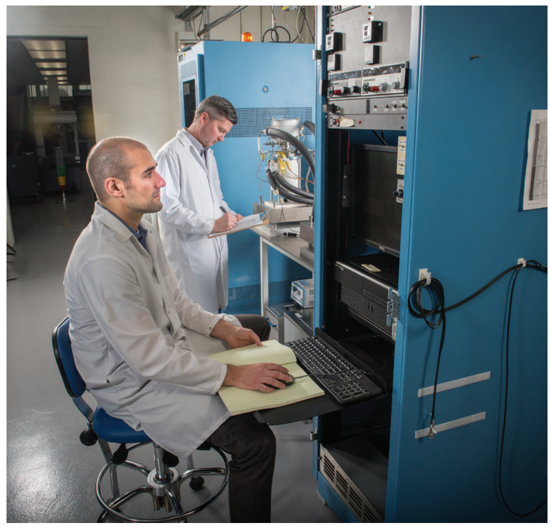
Dynamic Radioisotope Power Systems

For more than five decades, Radioisotope Power Systems (RPS) have been a steady source of electrical power for NASA space missions to some of the most distant, darkest, dustiest locations in our solar system. Radioisotope Thermoelectric Generators (RTGs) convert heat from the natural decay of plutonium-238 into useful electrical power by means of the thermoelectric effects between carefully chosen dissimilar materials. With no moving parts, RTGs are a robust and reliable power source over long mission durations.

Why does NASA need a Dynamic RPS?

Another means of converting heat from plutonium decay to electrical power is to harness the work produced in certain thermodynamic cycles using engines with moving parts to generate a current. NASA and the Department of Energy (DOE) are working together to enable more space missions through the development of Dynamic Radioisotope Power Systems (DRPS) that utilize such engines. NASA is working to achieve efficiencies in DRPS on the order of 3-4 times greater than the current state of the art RTG. This increase in efficiency provides more power per kilogram of generator mass. This means that a mission could have more power and potentially use less of the radioisotope fuel, limiting the amount of radiation and waste heat that they produce. These options make a DRPS ideal for certain human exploration missions and a viable option for specialized science missions.

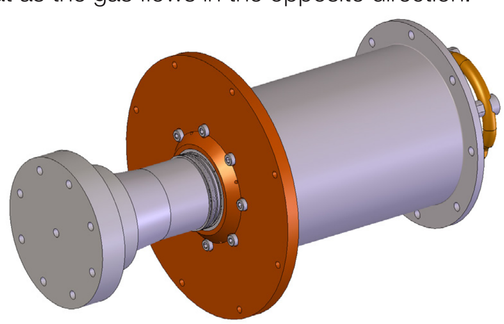
NASA is developing the conversion technologies that would be the core element of a DRPS. Various engine heat cycles can be employed to convert heat from the decay of plutonium into electricity. Such heat cycles include Brayton, and Stirling engines. The Stirling cycle generator was invented two hundred years ago during the Industrial Revolution. By November 2018 several Stirling convertors operating at the NASA Glenn Research Center will have passed 12 years of operation, with multiple units each breaking the previous world record for longest-running heat engine in history.



NASA engineers have tested Stirling Convertors over 110,000 hours of operation.

How does a DRPS generate electricity?

A free-piston Stirling cycle DRPS works by transforming the thermal energy from the hot radioisotope fuel into the high-speed oscillating kinetic motion of a small piston and its companion displacer. In turn, a magnet fixed to the piston moves back and forth more than 100 times per second through a coil of wire, thereby generating a flow of alternating electric current (using a property of physics known as Faraday's Law). The addition of a regenerator heat exchanger greatly improves the efficiency of the cycle by conserving energy as it extracts heat as the gas moves from the hot end to the cold end and then gives up that heat as the gas flows in the opposite direction.



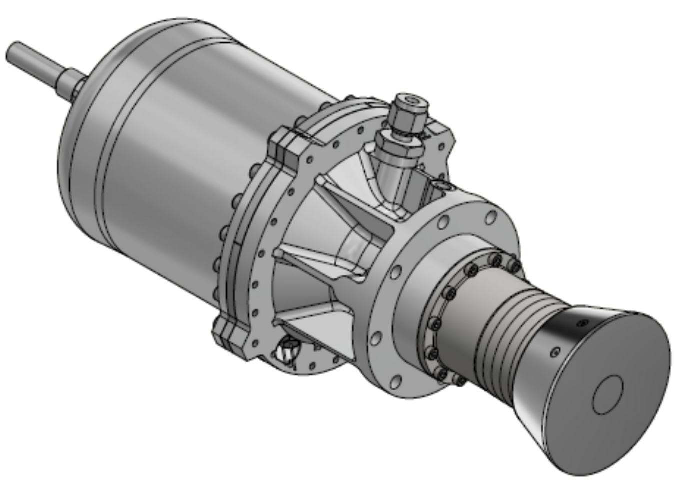
Sunpower Robust Stirling Convertor: Sunpower, Inc.

NASAfacts

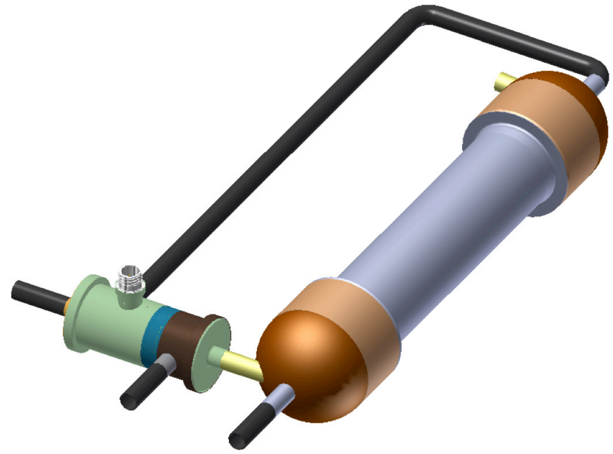
A Brayton cycle DRPS works in a different way. The thermal energy from the radioisotope fuel heats a gas that flows through a turbine, causing it to turn over 100,000 revolutions per minute (rpm). The gas loses some of its thermal energy as it transfers thermal energy into rotational kinetic energy. More energy is taken out of the gas as it passes through a recuperative heat exchanger. Additional excess heat is rejected through radiator panels. This cooler gas is then flowed through a compressor that is on the same rotational shaft as the turbine. This increases the pressure and heats up the gas, which then gains more heat as it is counter-flowed through the recuperator. The gas is then flowed past the RPS heat source and back through the turbine to repeat the cycle.

This continual movement of the working gas in the Brayton system provides constant rotational energy on the shaft that connects the turbine and compressor. At the center of the shaft, a magnet spins at high speed within a coil of wire. Faraday's law is again demonstrated wherein a moving magnetic field causes the motion of electrons within a wire, generating alternating current. For both the Stirling and Brayton systems, the alternating current is converted into direct current by a controller unit, which provides power to spacecraft operations and science instrumentation.

Both types of convertors have their advantages. Stirling-type DRPS engines have been in development for several decades, the most recent being the Advanced Stirling Radioisotope Generator (ASRG). Two companies, Sunpower Inc. and American Superconductor (AMSC), are currently developing free-piston Stirling convertors with different non-contacting piston bearing techniques for testing at NASA GRC. Sunpower's system uses gas bearings to prevent the moving piston from rubbing, thus eliminating wear, which could shorten the lifetime of the convertor. AMSC's system uses a thin metallic spring called a flexure that prevents side motion and rubbing of the piston. Both bearing techniques have been demonstrated successfully in the laboratory on earlier designs and have the potential to allow a DRPS generator to last for 20 years, the amount of time necessary for long transit times to outer planets and their moons. While Stirling engines have yet to be flown in space, Stirling cryocoolers paired with similar technologies have been used successfully on space missions, such as the 16-year RHESSI solar flare observatory.



Flexure Isotope Stirling Convertor: American Superconductor, Inc.



Turbo-Brayton Convertor: Creare, LLC.

Creare LLC is developing a system for NASA based on cryogenic coolers using closed-loop turbo-Brayton Convertors for power generation. Cryocoolers have been used successfully in many space applications since the mid-1990's, including the NICMOS (Near Infrared Camera and Multi-Object Spectrometer) installed in the Hubble Space Telescope. Turbo-Brayton Convertors use hydrodynamic journal bearings to keep the turbine and compressor shaft aligned and free from friction, also enabling a long mission life. AMSC, Creare, and Sunpower will provide prototype DRPS conversion units to NASA GRC by the beginning of 2020.

DRPS Generator Goals

Design lifetime: At least 20 years in space

Electrical power output: 200 to 500 Watts

RPS thermal to electric efficiency: > 20%

Fuel: Plutonium dioxide in General Purpose Heat Source (GPHS) modules

Capability: Operating on Earth, in the vacuum of deep space, in the atmospheres of Mars and Titan, and on distant icy moons, such as Enceladus

For more information about radioisotope power systems, visit **rps.nasa.gov**