OFFICE OF SPACE & DEFENSE POWER SYSTEMS

Radioisotope Power Systems

Description

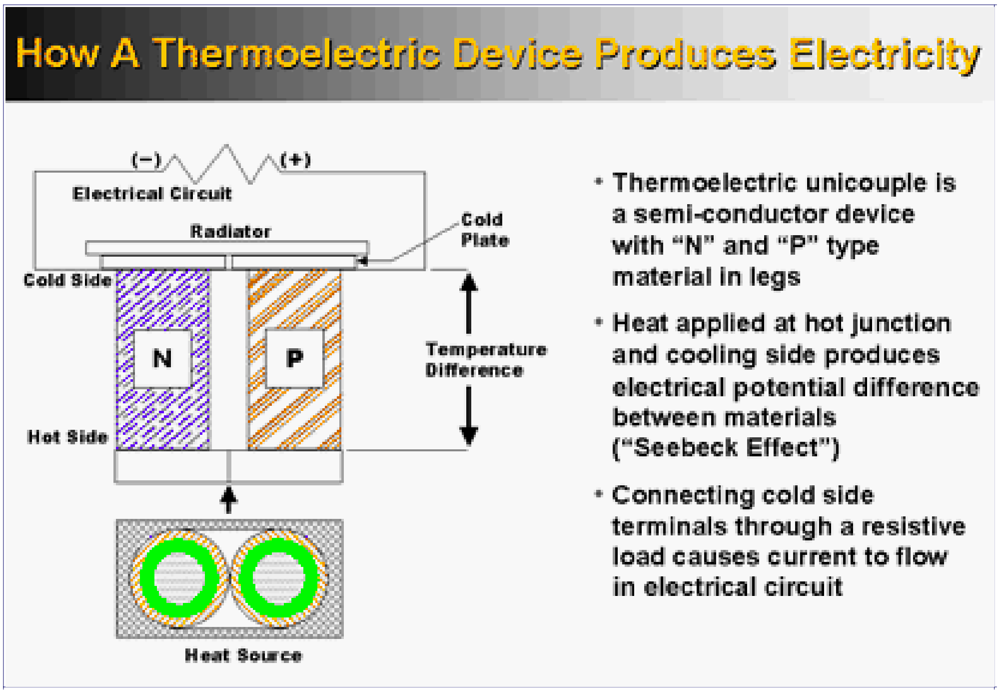
The Space and Defense Radioisotope Thermoelectric Generator (RTG) Program provides support for radioisotope power source development, demonstration, testing, and delivery. Radioisotope power sources are the enabling technology for space applications requiring proven, reliable, and maintenance-free power supplies capable of producing up to several kilowatts of power and operating under severe environmental conditions for many years. Previous space missions that have used radioisotope power sources include the Apollo lunar surface scientific packages and Pioneer, Viking, Voyager, Galileo, and Ulysses spacecrafts.


Cassini Spacecraft

The program will develop new, state-of-the-art power supplies required to support the National Aeronautics and Space Administration (NASA) space missions. The outyear planning for these missions reflects arrangements with NASA and the U.S. Department of Energy (DOE) that ensure the capabilities of the facility infrastructure to produce RTGs. This infrastructure represents the sole national capability to produce radioisotope power systems. Without these systems, NASA missions to explore deep space and the surfaces of neighboring planets would not occur. In accordance with arrangements with our customer agencies, NASA will provide funds to DOE to pay for mission-specific development and hardware fabrication costs.

DOE and its predecessor agencies have provided nuclear power systems for use in space applications for over 35 years. These systems are safe, proven, reliable, maintenance free, and capable of producing either heat or electricity for decades under remote harsh environment such as in deep space exploration. The unique characteristics of these systems make them especially suited for applications where large arrays of solar cells are not practical. To date, DOE has provided 44 RTGs for use on a total of 24 missions to provide some or all of the onboard electric power.

Radioisotope power generators convert the heat (thermal energy) generated from the decay of radioisotopes into electricity. The systems previously built by DOE consisted of plutonium-238 (Pu-238) oxide fuel and static electrical converter systems that use thermoelectric elements to convert the heat to electricity without moving parts. The major advantage of the static process is the simplicity. They are highly reliable because there are no moving parts.



The functional requirements for the RTGs usually included a 5-year operational life. In all of the prior missions, the RTGs have continued to operate far beyond their design life with a predictable decrease in power over time due to the decay of the Pu-238 fuel. With the advances in communication (receiving) capabilities, even with the reduced power levels, communication with spacecraft such as Pioneer 10 have been maintained for over 20 years. The Voyager 1 and 2 spacecrafts, having already operated for 21 years, are expected to continue to send signals for another 15 to 20 years. No failures of spacecraft have been attributed to the RTGs.


RTGs Ready to be Shipped to Cape Canaveral

The first RTGs produced about 2.7 watts of electric power. The most recently designed system, the General Purpose Heat Source RTG (GPHS-RTG), generates about 290 watts of electric power. The first system launched, a SNAP-3B unit (SNAP, systems for nuclear auxiliary power) provided only partial power for the Navy Transit 4 satellite. DOE provided three RTGs for NASA's Cassini mission to Saturn. The Cassini spacecraft, launched to Saturn on October 15, 1997, required three GPHS-RTGs (approximately 870 watts electric). The RTGs are the only source of onboard electric power.

Many design changes have been made over the 37 years that RTGs have been used in space missions. In addition to designing larger systems capable of higher power output, DOE has funded research in thermoelectrics and other conversion technologies in order to increase the conversion efficiency. DOE has also conducted extensive safety testing to assure the power systems would be safe under all accident conditions, including accidents that occur on or near the launch pad, and reentry accidents. The fuel form has been changed from a Pu-238 metal to a more stable pressed oxide. During the three mission accidents that did occur, the RTGs performed as predicted. The Transit 5-BN-3 mission was aborted because of launch vehicle failure. The RTG burned up on reentry as designed with the plutonium dispersed in the upper atmosphere. The RTG design was changed shortly after that to accommodate intact reentry. The next accident was with the Nimbus-B-1 that was aborted shortly after launch by a range safety destruct. The RTG was recovered, with no release of plutonium, and the heat sources were reused in later missions. The Apollo 13 spacecraft carried an RTG to be used on the moon to power a seismic station. The Apollo 13 mission was aborted and the spacecraft returned to Earth. The RTG was attached to the lunar module that broke up on reentry. The RTG heat source reentered the Earth atmosphere intact, with no release of plutonium, and currently is located deep in the Tonga trench in the Pacific Ocean. Extensive testing of RTGs in sea water has been conducted, and there will be no release of plutonium over time from this unit.

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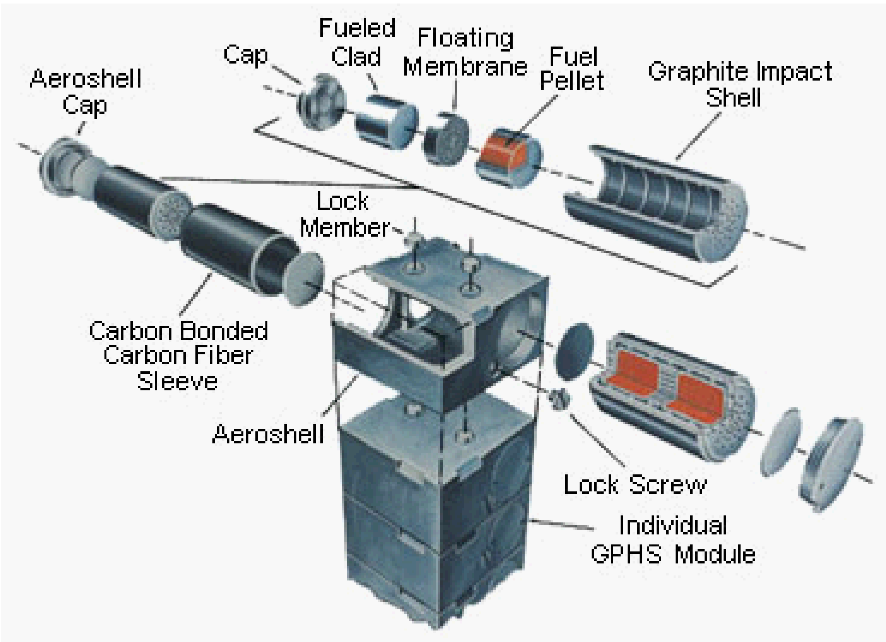
General Purpose Heat Source

The general purpose heat source (GPHS) module is the building block for both the GPHS-Radioisotope Thermoelectric Generator. These modules contain the radioisotope plutonium-238 (Pu-238) used to produce heat that is subsequently converted into electricity by thermoelectrics. Pu-238 is fabricated into pellets and encapsulated in an iridium cladding forming a fueled clad. Fueled clads are encased within nested layers of carbon based material and placed within an aeroshell housing to comprise the complete GPHS-module.



GPHS modules stand approximately two inches tall and have a base that is almost square with sides less than four inches in length. Each GPHS module is designed to weigh no more than 1.44 kilograms and produces a nominal thermal power of 250 watts at beginning of mission. A total of 18 modules are stacked together to provide the heat source for each of the radioisotope thermoelectric generators used on the Cassini mission.

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Need For RHUs

Most spacecraft can use solar energy to provide heat to keep their structure, systems, and instruments warm enough to operate effectively. However, when solar or other heat source technologies are not feasible, an alternate heat source is required for the spacecraft.

By using RHUs, the spacecraft designer can allocate scarce spacecraft electrical power to operate the spacecraft systems and instruments. RHUs also provide the added benefit of reducing the potential for electromagnetic interference generated by electrical heating systems.

Characteristics of RHUs include:

- Highly reliable, continuous, and predictable output of heat.
- No moving parts.
- Compact structure.
- Resistance to radiation and meteorite damage.
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RHUs provide proven and reliable continuous heat to sensitive spacecraft instruments and scientific experiments enabling their successful operation throughout the mission.

How RHUs Work

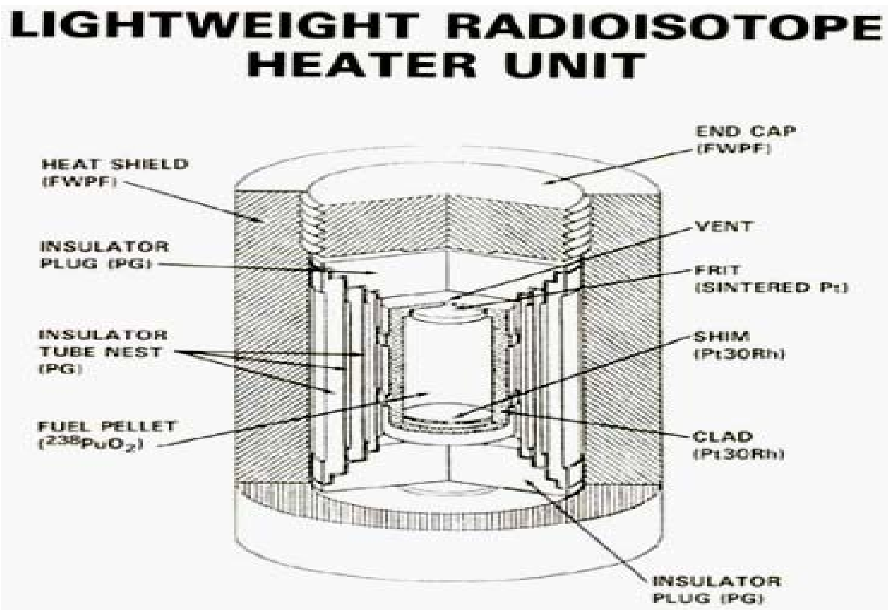
RHUs generate heat from the natural radioactive decay of a small pellet of plutonium dioxide (mostly plutonium-238). This heat is transferred to spacecraft structures, systems, and instruments directly without moving parts or intervening electronic components.

RHUs are very compact, 3.2 centimeters (1.3 inches) long and 2.6 centimeters (1 inch) in diameter. The fuel pellet is about the size and shape of a pencil eraser weighing approximately 2.7 grams (0.1 ounces). All together each RHU weighs about 40 grams (1.4 ounces).

Safety Design

RHUs have a very rugged containment system to prevent or minimize the release of plutonium dioxide fuel even when subjected to severe accident conditions. Containment is achieved through multiple layers that are resistant to the heat and impact that might be encountered during a spacecraft accident. An external graphite aeroshell (a reentry shield) and a graphite insulator protect the fuel from impacts, fires, and atmospheric reentry conditions. Internally, the fuel is encapsulated in a high-strength, platinum-rhodium metal shell (or "clad") that further contains and protects the fuel during any potential accident.

In addition to this containment, the plutonium dioxide fuel is used in a ceramic form of the material that tends to break into large pieces rather than dispersing as fine particles. This minimizes interaction of the fuel with the environment and the potential for human exposure in the extreme unlikely event the multiple fuel containment barriers are breached. Since each RHU fuel pellet is individually encapsulated in its own aeroshell and fuel clad, the potential for a single event to affect more than one pellet is reduced.



Safety Testing

RHUs have been subjected to a rigorous series of laboratory and field tests. Those tests were more severe than anticipated for credible accident scenarios. No releases occurred for those events that were within the limits of anticipated accident scenarios.

In summary, the RHUs are extremely rugged and reliable devices that have been designed and tested to contain their fuel in a wide range of mission accidents.

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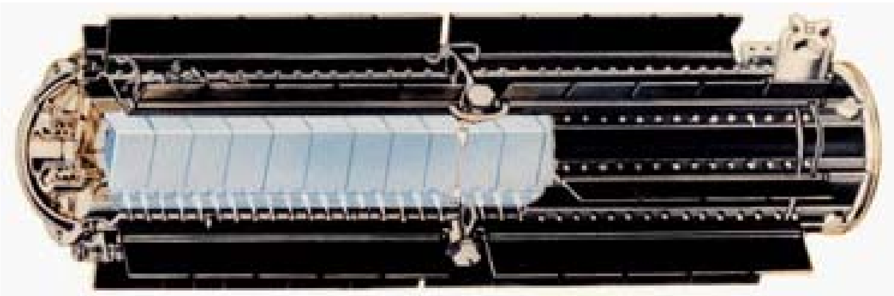
The U.S. Department of Energy (DOE) has provided radioisotope thermoelectric generators for space applications since 1961. These generators provide electrical power for spacecraft by direct conversion of the heat generated by the decay of plutonium-238 (Pu-238) oxide to electrical energy. The first generator was used on the Navy Transit 4A spacecraft launched on June 29, 1961. Between 1961 and 1972, DOE provided power systems for six Navy navigational satellites. In addition, DOE provided power systems for two Air Force communications satellites, LES 8 and LES 9, both launched together on March 14, 1976.



Radioisotope Thermoelectric Generator (RTG)

DOE first supported the use of radioisotope power systems on National Aeronautics and Space Administration (NASA) spacecraft

meteorological satellite on May 10, 1968. This was followed by the Nimbus III satellite on April 14, 1969. DOE radioisotope generators were used on six missions to the Moon, Apollo 12 through 17, to power the seismic stations on the lunar surface (1969 to 1972). Our involvement with NASA continued as NASA moved out into the solar system with the Pioneer, Voyager, Galileo, and Ulysses missions (six missions beginning in 1972). These solar system exploration missions have continued far beyond their design life of about 5 years each, with the Voyager spacecraft now having traveled through the solar system and beyond, providing data over the last 20 years. The Voyager spacecraft is expected to provide data for another 25 years.

Cassini Spacecraft

DOE has also played a key role in the support of exploration of Mars. The Viking landers, launched in 1975, were both electrically powered by radioisotope power systems. The Mars Pathfinder spacecraft and rover were launched in December 1996 and landed on Mars July 4, 1997. The Rover had three Pu-238 oxide heater units that provided heat to the Rover electronics. The heater units are small, contained, radioisotope units that are placed next to spacecraft instruments to provide heat only (not electricity). The Rover would probably not have remained operational after the first Martian night without the heater units.

In all, DOE has provided a total of 44 RTGs and more than 240 heater units for 26 missions since 1961. DOE continues to maintain the capability to provide power and heater systems to NASA for further missions.

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