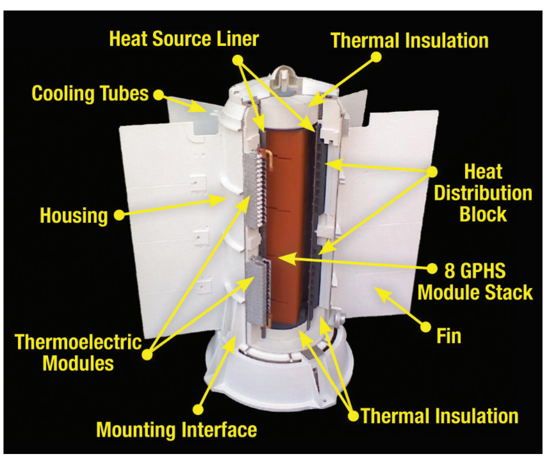
# Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)



Space exploration missions require safe, reliable, long-lived power systems to provide electricity and heat to spacecraft and their science instruments. One flight-proven source of dependable power is Radioisotope Power Systems (RPS). A type of RPS is a Radioisotope Thermoelectric Generator (RTG) — a space nuclear power system that converts heat into electricity using no moving parts.

The Department of Energy (DOE), in support of NASA, has developed several generations of such space nuclear power systems that can be used to supply electricity — and useful excess heat — for a variety of space exploration missions. The current RPS, called a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), was designed with the flexibility to operate on planetary bodies with atmospheres, such as at Mars, as well as in the vacuum of space. An MMRTG generates about 110 watts of electrical power at launch, an increment of power that can be matched with a variety of potential mission needs. As with prior RPS, ensuring a high degree of safety is also a fundamental consideration.




*Model of an MMRTG, including its internal General Purpose Heat Source (GPHS) modules*

## History of RPS in Space

First launched into Earth orbit in 1961, RPS have flown on 31 U.S. space missions. RPS have enabled NASA to explore the Solar System for five decades and counting. The Apollo missions to the moon, the Viking missions to Mars, and the Pioneer, Voyager, Ulysses, Galileo, Cassini and New Horizons mission to Pluto and the Kuiper Belt all used RPS. The spectacular Voyager 1 and 2 missions, operating on RPS power since their launches in 1977, continue to function and return scientific data, with both having now reached the void of interstellar space.

## How RTGs Work

RTGs work by converting heat from the natural decay of radioisotope materials into electricity. RTGs consist of two major elements: a heat source that contains the radioisotope fuel (mostly plutonium-238), and solid-state thermocouples that convert the plutonium's decay heat energy to electricity.

Conversion of heat directly into electricity is a scientific principle discovered two centuries ago. German scientist Thomas Johann Seebeck observed that an electric voltage is produced when two dissimilar, electrically conductive materials are joined in a closed circuit and the two junctions are kept at different temperatures. Such pairs of junctions are called thermoelectric couples (or thermocouples).

The power output from such thermocouples is a function of the temperature of each junction and the properties of the thermoelectric materials. The thermocouples in RTGs use heat from the natural decay of the radioisotope fuel to heat the hot-side junction of the thermocouple, and the cold of space to produce a low temperature at the cold-side junction.

## Safety and Design of RPS

Several layers of safety features in an MMRTG help minimize the release and dispersal of nuclear material under a wide range of possible accident conditions. These safety features include the ceramic form of the plutonium dioxide heat source material, iridium metal cladding, graphite sleeves that protect the fuel clads, and the rugged carbon-fiber material that forms the aeroshell "box" of the eight General Purpose Heat Source (GPHS) modules inside an MMRTG as shown in Figure 1. The GPHS module provides protection for potential ground impact and accidental reentry scenarios.

While RPS have never been the cause of a spacecraft accident, they have been on board three U.S. space missions that failed for other reasons. In all three cases, the RPS performed precisely as designed. For example, an RPS was aboard a NASA weather satellite that suffered a launch abort in 1968 — the radioisotope fuel was fully contained, the generator was recovered from the ocean floor, and the fuel was re-used on a future mission.

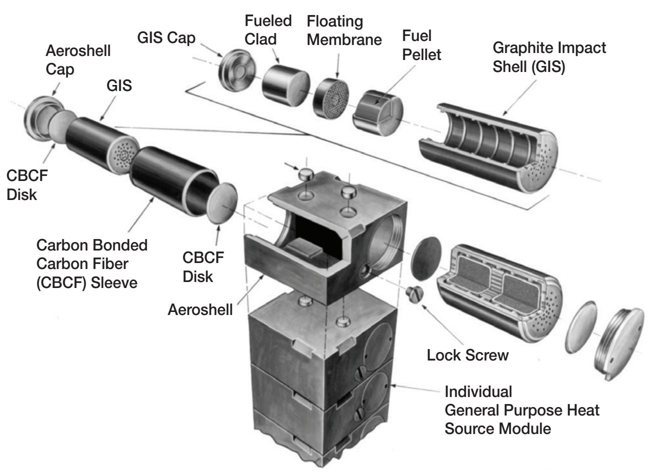



*Figure 1: GPHS Module illustration  Credit: Department of Energy*

Essentially a nuclear battery, the MMRTG contains a total of 10.6 pounds (4.8 kilograms) of plutonium dioxide fuel that initially provides approximately 2,000 watts of thermal power when exposed to deep space environments. The thermoelectric materials in an MMRTG are similar to those used for the two Viking spacecraft that landed on Mars in 1976. The MMRTG generator is about 25 inches (64 centimeters) in diameter (fin-tip to fin-tip) by 26 inches (66 centimeters) tall, and weighs about 94 pounds (45 kilograms).

## Delivering the Power to Explore

The first NASA mission to carry an MMRTG was the Curiosity Mars rover, which was launched in the Mars Science Laboratory mission in November 2011 and landed successfully on the Red Planet on August 6, 2012, and is now well into an extended mission. Curiosity, the largest and most capable rover ever sent to another planet, has operated for more than 2,700 days and already achieved its main goal of determining that its landing site, Gale Crater, could have supported microbial life in the ancient past.

| MMRTG Technical Specifications | |
|---|---|
| Number of GPHS modules | 8 |
| Thermoelectric Materials | Lead telluride (PbTe)//Germanium telluride/Silver Antimony telluride (TAGS) |
| Number of Thermocouples | 768 |
| Beginning of Life Power (Watts) | 110 |
| Est. End-of-Design-Life power (Watts) at 17 years* | 72 |
| Beginning-of-Life (BOL) System Efficiency | 6% |
| Beginning-of-Life Specific Power (Watts/kilogram) | 2.8 |
| Load Voltage (Volts) | 30 |
| Fin-root temperature (degrees C/F) | 157/315 |
| Mission Usage | Multi-mission: space vacuum and planetary atmospheres |

* Design life includes three years of fueled storage before launch

An MMRTG also powers NASA's Mars 2020 rover, Perseverance, which is designed to explore a habitable site on Mars, collect samples of Mars that could be returned to Earth by a future mission, and test technology that could be useful for future robotic and human exploration. The MMRTG for Perseverance includes a small amount of newly produced domestic Pu-238, demonstrating the full supply chain to support further space exploration missions. Looking further ahead, an MMRTG is the baseline space nuclear power system for NASA's Dragonfly mission, an aerial rotorcraft designed to explore the surface and thick atmosphere of Saturn's intriguing moon Titan.

*The Curiosity rover took this self portrait on Mars that includes its MMRTG electrical power source (the white cylinder with radiator fins, at the rear of the rover).*

For more information about NASA's use of Radioisotope Power Systems, see **https://rps.nasa.gov** or email *NASA-RPS@mail.nasa.gov*