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U.S. Department of Energy

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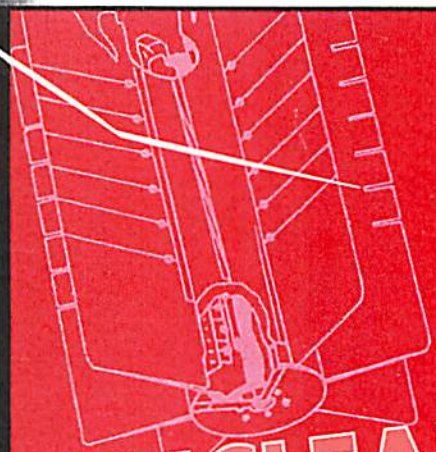
NUCLEAR

Power in Space



NUCLEAR ENERGY

U.S. Department of Energy
Office of Nuclear Energy, Science and Technology

On the cover:
Launch of the Atlantis Space Shuttle carrying Galileo into space (October 1989).

Nuclear Power in Space

Table of Contents

Introduction 1
Contemplating the Heavens 2
Power in Space - The Special Requirements 5
How Does an RTG Work? 5
Pu-238 – The Radioisotope of Choice for RTGs 6
RTGs - The Safety Factor 8
The Missions - An Overview 12
The Apollo Missions 15
The Pioneer Missions 16
The Viking Mission 17
The Voyager Missions 18
The Galileo Mission 19
The Ulysses Mission 21
The Cassini Mission 24
Pluto: New Horizons 25
Heat Without Power 26
The Future of RTGs in Space 27
Future Requirements 28
Conclusion 29

U.S. Department of Energy
Office of Nuclear Energy, Science and Technology
Washington, D.C. 20585

Contemplating the Heavens

Many ancient peoples, including the Aztecs, Egyptians, and the builders of Stonehenge, were intensely interested in astronomy. Their writings and architecture indicate they studied the Moon's phases and movement. They related the position and the perceived movement of the Sun to Earth and its seasons. Some charted the stars, identifying the constellations.

Through the ages, scholars suggested various explanations for the makeup, movement, and relationship to Earth of these heavenly bodies. Like us today, they wanted to know more about those distant objects, but a lack of technology limited their ability to learn.

Over the centuries, scientists like Galileo and Newton described the structure of the solar system and the movement of the planets. Inventions such as the telescope permitted them to see the Moon's craters, the "canals" on Mars, Saturn's rings, and other intriguing details. This knowledge increased their curiosity about the Moon, Sun, and planets, and they longed for more information. They even dreamed of expeditions across space to explore them firsthand.

The Century of Flight

During the 20th century, fantasies about space flight progressed toward reality on the wings of the many aircraft that became commonplace. People from various countries contributed to the beginnings of spacecraft exploration. One of the most important was an American, Robert Goddard, who studied both solid and liquid propellants. In 1916, he launched a test rocket that traveled 184 feet. Two decades later, Werner Von Braun and his team of German scientists were developing powerful new rockets that could fly hundreds of miles.

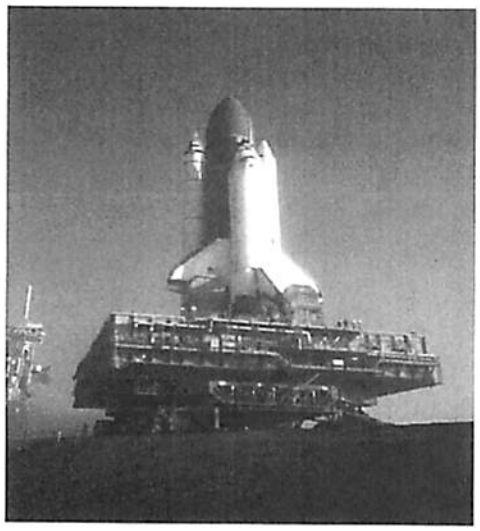
In 1954, the United States began Project Orbiter, the Nation's first major step in developing satellite systems. The United States would soon become a world leader in this emerging technology, with the National Aeronautics and Space Administration (NASA) playing a leading role.

The Quest for Reliable Power

On January 16, 1959, a dramatic photograph appeared in a Washington, D.C., newspaper. The headline proclaimed "President Shows Atom Generator." The photograph, above, pictured President Eisenhower and a group of U.S. Atomic Energy Commission (AEC) officials in the Oval Office at the White House. They were gathered around the President's desk, staring at a strange grapefruit-shaped object. Dubbed the world's first atomic battery, it was actually one of the earliest models of a radioisotope thermoelectric generator (RTG), a nuclear generator specifically developed by AEC to provide electric power during space missions.

The first unmanned vehicle in space was Sputnik, launched by the Soviet Union in 1957. The United States followed three months later with its first unmanned flight, Explorer 1. The number of U.S. and Soviet space missions increased dramatically over the next few years. By the end of 1969, more than 1,000 spacecraft were orbiting Earth. Five years later, the number of these satellites had climbed to nearly 1,700.

Today, the U.S. Space Shuttle Program is the Nation's primary space transportation system. It has launched numerous spacecraft and satellites on research and communications missions.



Power in Space -- The Special Requirements

Scientific instruments and electronic, photographic, and communication equipment are the heart of exploratory missions because they collect the data and transmit it back to Earth. Without the technology to reliably power these instruments in space, our knowledge of the solar system would be only a fraction of what it is today. RTG technology was developed to provide that electric power.

Requirements for power in space are highly specialized. The weight and volume of hardware launched into space are carefully considered including power sources. The generator must meet mission power requirements as well as weight and space limitations. Safety is also a prime consideration because of hazards associated with launch, reentry, and other mission activities.

How Does an RTG Work?

An RTG has no moving parts. It produces electric energy through the interaction of its two main components: the radioactive heat source (fuel and containment) and the thermoelectric generator.

Radioactive material can be used for fuel because it is unstable and decays, or spontaneously disintegrates to form a different atom. As the material naturally decays, it produces heat. The other main component of the RTG is the thermoelectric converter, it changes heat into electricity.

This heat-to-electricity conversion occurs through the thermoelectric principle discovered early in the 19th century. This principle is a way of producing electric current without using a device that has moving parts. It involves two leads; each made of a different metal that conducts electricity. Joining these two leads to form a closed electrical circuit and keeping the two junctions at different temperatures produces an electric current. These pairs are called thermocouples. In an RTG, the radioisotopic fuel heats one end of these thermocouples while the other end remains unheated and is cooled by radiating the unconverted heat to space.

RTGs are reliable because they produce electricity without moving parts that can fail or wear out. This high degree of reliability is especially important in space applications where the investment is great and repair or replacement of equipment is not feasible.

Pu-238 -- The Radioisotope of Choice for RTGs

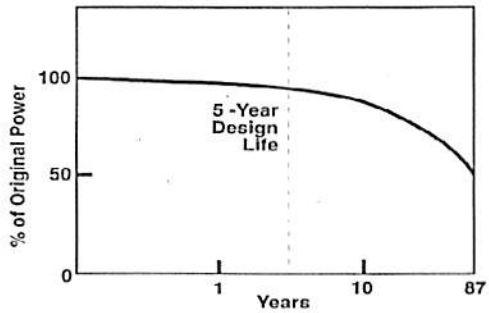
Fuel

Many radioactive fuels have been considered for RTGs. Of them, plutonium-238 (Pu-238) has been the most widely used. Pu-238 is a radioactive isotope -- a form of plutonium that gives off energy mostly as alpha particles, has a relatively long half-life, and does not support a chain reaction.

The early SNAP 3 RTG used polonium-210 as a fuel. It has a half-life of 138.4 days. At the end of that time, the amount of radioactive material remaining is half of the original amount. This means there is only half the heat available for conversion into electric energy.

Longer space missions require a radioisotope with a longer half-life. Pu-238, with its half-life of 87.7 years, fills the need. For example, after 5 years, approximately 96 percent of the original heat output of Pu-238 is still available. It continues to be the radioactive fuel of choice today and in planned future missions.

The 87-year half-life of Pu-238 results in 96% of the original heat output even after five years

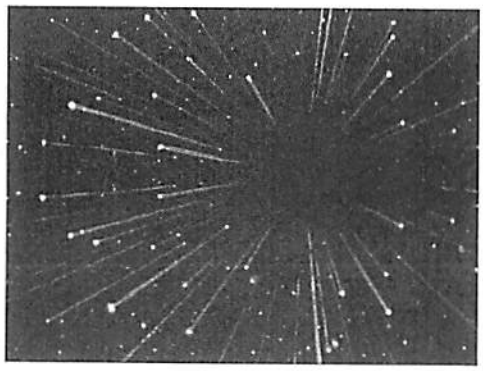


Radiation Safety

Because the nuclear fuel in RTGs is radioactive, safety is a critical issue. As it decays, Pu-238 emits radiation mainly in the form of alpha particles, which have a very low penetrating power. Only lightweight shielding is necessary because alpha particles cannot penetrate a sheet of paper. Other radioisotopes can produce more penetrating radiation such as beta particles or gamma rays. These would be more difficult to handle safely and would require heavier shielding, a distinct drawback on space missions.

Smaller and Lighter

The weight and size of solar panels can cause problems on some space missions. With RTGs, weight and size are far less of a concern. Pu-238 has a relatively high power density and a given volume or weight of Pu-238 can produce a relatively high number of watts of power for long periods of time. These qualities lead to smaller and lighter heat sources than comparable power levels from other sources. This makes Pu-238 fuel an efficient power producer for the space it occupies and the weight it adds to a mission.



RTGs -- The Safety Factor

Radiation that escapes a radioisotope heat source is of potential concern. RTG safety efforts revolve around containing the radioactive fuel in case of accident during a critical time in the mission, such as launch or reentry. Multiple layers of special material enclose the Pu-238 fuel to contain it under both normal and accident conditions. Extensive testing and analysis are used to demonstrate that safety design criteria are met. Today we design to have the fuel capsule remain intact even after Earth reentry and impact. The Apollo 13 accident and subsequent reentry of the RTG, without any material release, provided further proof of this safety principle.

General Purpose Heat Source

The General-Purpose Heat Source (GPHS) is the radioactive fuel package being used in RTGs of current and planned space missions. GPHSs use Pu-238 fuel just as earlier model RTGs did, but the unique fuel containment is designed to maximize safety in an accident. The basic heat source unit is the GPHS module. Each GPHS-RTG contains 18 modules.

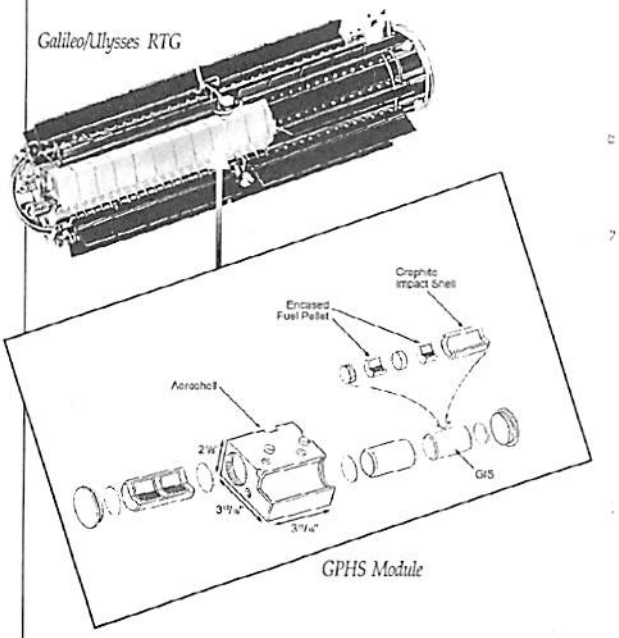
Design features include:

- Fuel pellets made of hard, ceramic Pu-238 oxide that does not dissolve in water. The pellets are also highly resistant to vaporizing or fracturing into inhalable or respirable particles following impact on hard surfaces. Each of the GPHS's 18 modules contains four fuel pellets, for a total of 72 pellets per GPHS RTG.

- Iridium, a very stable metal with elastic properties, encapsulates each fuel pellet. These capsules (about the size and shape of a marshmallow) would tend to stretch or flatten instead of ripping open if the GPHS module struck the ground at high speed. This would help keep the capsules intact and contain the fuel.

- A high-strength graphite cylinder called a graphite impact shell that holds a pair of fuel capsules. The graphite impact shell is designed to limit damage to the iridium fuel capsules from free-fall or explosion fragments.

- An "aeroshell" enclosing a pair of graphite impact shells. It serves as a shield designed to withstand the heat of reentering Earth's atmosphere in case of an unplanned event.



Each of the RTG's 18 modules contains four Pu-238 fuel pellets enclosed in three layers of protection -- the metal encasing the pellets, the graphite shell, and the aeroshell.

Testing the Possibilities

The nuclear fuel in the GPHS faces a variety of possible accidents during a space mission. Launch and reentry pose many types of risks to the spacecraft and its components.

As a result, rigorous testing is conducted to ensure the RTG's nuclear heat sources will survive a launch accident or other mishap by remaining intact and containing the fuel. The battery of tests that the GPHS's fuel modules have undergone included the effects of:

Fire - Direct exposure to solid propellant fires, such as the GPHS might encounter in a launch accient, could produce some fuel release, but the probability of such events is low.

Blast - Blast waves greater than those predicted from a shuttle fuel explosion were simulated with explosives; no fuel was released during the tests.

Reentry - The modules survived the high temperatures of simulated atmospheric orbital decay entry as tested in an arc-jet furnace; no fuel was released.

Earth Impact - Impact at 120 miles per hour (approximate top speed for an aeroshell falling to Earth) on sand, water, or soil produced no release of heat source module fuel. Impact on rock and concrete sometimes produced a release, but the surrounding graphite module retained most of the fuel. This left only small amounts of radioactive material that could enter the localized environment.

Immersion in Water - Long-term exposure to the corrosive effects of seawater showed the iridium clad is corrosion resistant, and the fuel itself is highly insoluble.

Shrapnel - Researchers used aluminum and titanium bullets to simulate the small fragments that might be present in a launch vehicle explosion. Speeds of test fragments exceeded those predicted for an actual explosion. Results indicated that shrapnel would not lead to a release of much nuclear fuel.

Large Fragments - In tests representing solid rocket booster failures, steel plates were fired at simulated RTGs. Some unlikely events, such as impact with the edges of steel plates, caused some releases from a few fuel capsules. More likely events, such as impacts with the faces of steel plates, did not produce a release.

The Missions

An Overview

Power Source	Spacecraft	Mission Type	Launch Date	Status
SNAP-3B7	Transit 4A	Navigational	June 29, 1961	RTG operated for 15 years. Satellite now shut down but operational.
SNAP-3B8	Transit 4B	Navigational	Nov. 15, 1961	RTG operated for 9 years. Satellite operated periodically after 1962 high altitude test. Last reported signal in 1971.
SNAP-9A	Transit 5-BN-1	Navigational	Sept. 28, 1963	RTG operated as planned. Non-RTG electrical problems on satellite caused satellite to fail after 9 months.
SNAP-9A	Transit 5-BN-2	Navigational	Dec. 5, 1963	RTG operated for over 6 years. Satellite lost ability to navigate after 1.5 years.
SNAP-9A	Transit 5-BN-3	Navigational	April 21, 1964	Mission was aborted because of launch vehicle failure. RTG burned up on re-entry as designed.
SNAP 19B2	Nimbus-B-1	Meteorological	May 18, 1968	Mission was aborted because of range safety destruct. RTG heat sources recovered and recycled.
SNAP 19B3	Nimbus III	Meteorological	April 14, 1969	RTGs operated for over 2.5 years.
ALRH	Apollo 11	Lunar surface	July 14, 1969	Radioisotope heater units for seismic experimental package. Station was shut down August 3, 1969.
SNAP-27	Apollo 12	Lunar surface	Nov. 14, 1969	RTG operated for about 8 years until station was shut down.
SNAP-27	Apollo 13	Lunar surface	April 11, 1970	Mission aborted on the way to the moon. RTG re-entered earth's atmosphere and landed in South Pacific Ocean. No radiation was released.
SNAP-27	Apollo 14	Lunar surface	Jan. 31, 1971	RTG operated for over 6.5 years until station was shut down.
SNAP-27	Apollo 15	Lunar surface	July 26, 1971	RTG operated for over 6 years until station was shut down.
SNAP-19	Pioneer 10	Planetary	March 2, 1972	RTGs still operating. Spacecraft successfully operated to Jupiter and is now beyond orbit of Pluto.
SNAP-27	Apollo 16	Lunar surface	April 16, 1972	RTG operated for about 5.5 years until station was shut down.
Transit-RTG	"Transit" (Triad-01-1X)	Navigational	Sept. 2, 1972	RTG still operating.
SNAP-27	Apollo 17	Lunar surface	Dec. 7, 1972	RTG operated for almost 5 years until station was shut down.
SNAP-19	Pioneer 11	Planetary	April 5, 1973	RTGs still operating. Spacecraft successfully operated to Jupiter, Saturn, and beyond.
SNAP-19	Viking 1	Mars surface	Aug. 20, 1975	RTGs still operating for over 6 years until lander system was shut down.
SNAP-19	Viking 2	Mars surface	Sept. 9, 1975	RTGs still operating for over 4 years until relay link system was lost.
MHW-RTG	LES 8*	Communications	March 14, 1976	RTGs still operating.
MHW-RTG	LES 9*	Communications	March 14, 1976	RTGs still operating.
MHW-RTG	Voyager 2	Planetary	Aug. 20, 1977	RTGs still operating. Spacecraft successfully operated to Jupiter, Saturn, Uranus, Neptune, and beyond.
MHW-RTG	Voyager 1	Planetary	Sept. 5, 1977	RTGs still operating. Spacecraft successfully operated to Jupiter, Saturn, and beyond.
GPHS-RTG	Galileo	Planetary	Oct. 18, 1989	RTGs still operating. Spacecraft successully operating in Jupiter orbit.
GPHS-RTG	Ulysses	Planetary/Solar	Oct. 6, 1990	RTG still operating. Spacecraft successfully operating in solar polar orbit
GPHS-RTG	Cassini	Planetary	Oct. 17, 1997	RTGs still operating. Spacecraft en route to orbit Saturn.

The safety tests demonstrated that the RTGs are extremely rugged and capable of meeting the design objective *to prevent or minimize any fuel release.*

The Missions

In 1961, the first RTG used in a space mission was launched aboard a U.S. Navy transit navigation satellite. The electrical power output of this RTG, which was called Systems for Nuclear Auxiliary Power (SNAP-3), was a mere 2.7 watts. The importance of the story is that it continued to perform for 15 years after launch.

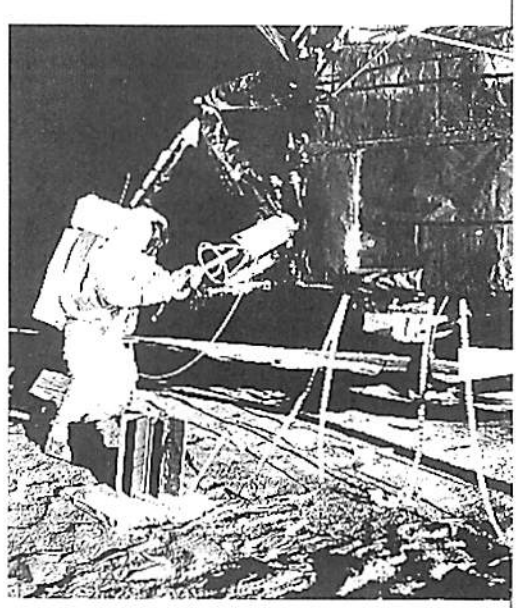
Since that initial SNAP-3 mission, RTGs have been an indispensable part of America's space program. They have been involved in more than 25 missions (22 successful and 3 aborted), orbiting Earth and traveling to planets and their moons, both nearby and in deep space. (Astronauts on five Apollo missions left RTG units on the lunar surface to power the Apollo Lunar Surface Experiment Packages.)

In addition to contributing to numerous navigational, meteorological, and communications flights, RTG power sources have provided all the electrical power required on the Pioneer, Viking Landers, Voyager, Galileo, Ulysses, and Cassini missions. This series of unmanned flights has helped us study the Sun and outer planets of the solar system. RTG technology has evolved steadily and dramatically since the groundbreaking, low-power units of the 1950s. The first RTGs, which produced only a few watts, have evolved into today's generation of RTGs, which produce power in the hundreds of watts. RTGs will continue to play an enabling role in major space missions in the 21st century.

The Apollo Missions

The Apollo Program included a large number of uncrewed test missions and 11 crewed missions. The 11 crewed missions included two Earth orbiting missions, two lunar orbiting missions, a lunar swingby, and six Moon landing missions.

Apollo 7, which tested the Command Module, and Apollo 9, which tested both the Command Module and Lunar Module, were Earth-orbiting missions. Apollo 8 and 10 tested various components while orbiting the Moon and returned photography of the lunar surface. Apollo 13 did not land on the lunar surface due to a malfunction, but during the brief orbit around the Moon, the crew was able to collect photographs.



On the moon, Apollo-12 astronaut Gordon Bean prepares to load the plutonium-238 heat source into the SNAP-27 thermoelectric generator (arrow). The generator produced 73 watts of power for the Apollo Lunar Surface Experiment Package for nearly eight years.

The Apollo Program was designed to land humans on the Moon and bring them safely back to Earth. Six of the missions -- Apollo 11, 12, 14, 15, 16 and 17 -- achieved this goal. Lunar surface experiments included soil mechanics, meteoroids, seismic, heat flow, lunar ranging, magnetic fields, and solar wind experiments. These experiment packages were each powered by a 70-watt RTG.

The Pioneer Missions

The Pioneer 10 and Pioneer 11 missions launched in 1972 and 1973 were spectacular successes in the long-range strategy to explore the outer planets. Pioneer 10 and its RTG demonstrated that spacecraft could survive the asteroid belt and the intense radiation field around Jupiter, and continued to perform experiments perfectly. Pioneer 10 was the first spacecraft to contact and explore Jupiter. It continued its journey and finally left the solar system -- the first manmade object ever to do so. Pioneer 11 flew by Jupiter, going through the peak radiation zone in even better shape than the earlier Pioneer 10. It also visited Saturn -- our first close direct encounter with the ringed planet. Both Pioneer spacecraft continued to send back data to Earth for over 27 years, even as they passed beyond the solar system, because the RTGs provide long-lived, reliable power. Four SNAP-19 RTGs producing about 120 watts of electricity powered each Pioneer mission.

On January 23, 2003, NASA's Deep Space Network (DSN) received its final broadcast from Pioneer 10. After more than 30 years of operation, the fuel of the RTG has decayed to the point where the power generated is insufficient to transmit a signal.

The Viking Mission

The Viking missions represent key milestones in the history of NASA space program. Viking was the first spacecraft to operate on the surface of another planet.

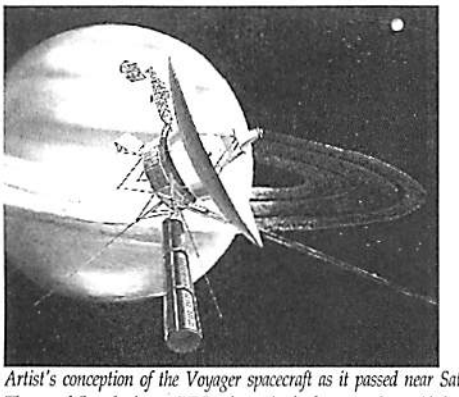
On August 20, 1975, the Viking 1 spacecraft was launched on a more than 200 million-mile journey to Mars. The second spacecraft, Viking 2, was launched on September 9, 1975, and followed Viking 1 on a similar mission. After achieving Mars orbit, each spacecraft, consisting of an orbiter and lander, examined the Martian terrain at the selected landing sites. Following the evaluation of the sites, the lander of each spacecraft separated from the orbiter and descended to a soft landing on the Martian surface -- Viking 1 in July 1976 and Viking 2 in September 1976. Each lander carried sophisticated equipment that would allow it to analyze the atmosphere and the surface. Part of the experiments conducted by the spacecraft was to search for signs of life. However, no signs of life or any of the organic compounds that are abundant on Earth were found. Two 30-watt RTGs supplied continuous power for each Lander, and rechargeable batteries were available during cycles of peak demand.

Both landers far exceeded their 90-day surface operational requirement. Lander 2 operated until February 1980 when there was a shutdown of the scientific instrumentation power bus. Signals from the lander indicated that RTG power was still available. Lander 1 provided data until November 1982 when an earth command to change the battery charging cycle resulted in loss of contact with the lander.

The Voyager Missions

Voyager 1 and Voyager 2 were launched within a few weeks of each other in 1977. Though they used different routes and trajectories (curved paths of flight), both spacecraft visited Jupiter and Saturn. They took spectacular photographs of Saturn's rings and observed 11 of its moons close up. Voyager 2 then continued to Uranus and Neptune. The Voyager spacecraft's power supply was provided by three RTGs generating 470 watts of electricity. The RTGs powered versatile and complex instruments including computers and communications equipment that made it possible for the Voyagers to transmit 115,200 bits of data per second from Jupiter.

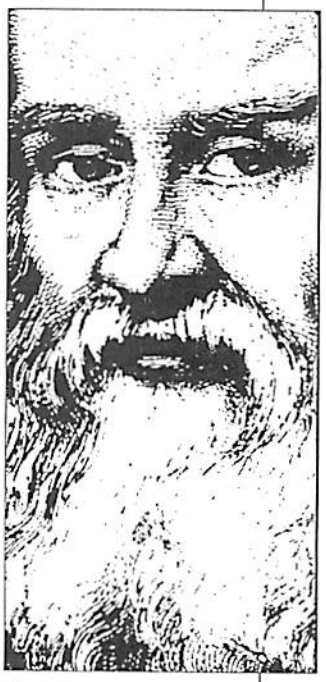
Voyager 1 and 2 can easily be described as one of the great scientific achievements in history. Both spacecraft are entering their 26th year of operation, and their mission has been redefined. Both craft are approaching the heliopause and the beginning of interstellar space. The heliopause is the point considered to be the boundary of the Sun's magnetic sphere of influence. It is now the mission of Voyager 1 and 2 to characterize the environments that they have ventured. It is estimated that the Voyagers have enough fuel and power to continue operation until 2020.



Artist's conception of the Voyager spacecraft as it passed near Saturn. Three multihundred-watt RTGs, shown in the foreground, provided power for the spacecraft.

The Galileo Mission

Galileo lifted into space in October 1989 aboard the space shuttle Atlantis. Its mission involved a scheduled eight-year, deep space voyage to the solar system's largest planet, Jupiter, and its four major moons. Galileo used a technique called "gravity assist" to make the journey to Jupiter, which is nearly 500 million miles from Earth. This technique uses the gravity of another planet to increase the velocity of spacecraft allowing it to arrive at the destination.



The Galileo spacecraft was named after the 17th-century scientist who discovered Jupiter's moons.

Throughout the voyage to Jupiter, Galileo's instruments have examined the celestial bodies it passed, and cameras have relayed photos back to an international team of scientists on Earth. Galileo provided the first closeup photographs of an asteroid, Gaspra, in 1993. It also provided the only direct photos of the impacts on Jupiter of the comet Shoemaker-Levy 9 in July 1994.

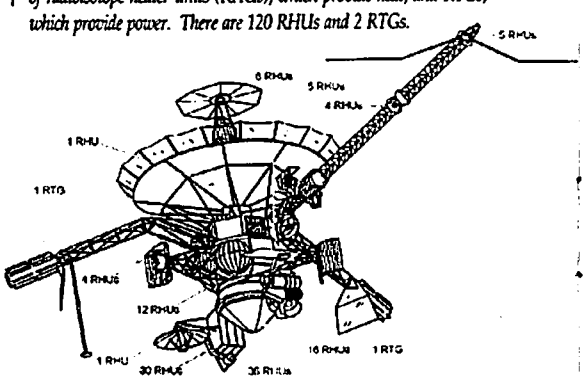
The Galileo mission is built around two distinct pieces of spacecraft, an orbiter and a separate atmospheric probe. About 150 days before arriving at Jupiter, the atmospheric probe separated from the orbiter and entered the planet's atmosphere. For a short 60 to 75 minutes, its instruments took atmospheric measurements and relayed the data to the orbiter for transmission to Earth. The probe de-

scended farther and farther until the increasing temperature and pressure of Jupiter's atmosphere crushed and eventually vaporized it.

The orbiter was scheduled to make 10 orbits of Jupiter over a 22-month mission life. The spacecraft's two RTGs generate 570 watts of power for mission operations. The orbiter's mission was to study the planet, its magnetosphere, and four of the Jovian satellites—Io, Europa, Calisto, and Ganymede. Galileo's mission was originally scheduled to end in 1997. However, the spacecraft has performed so well that its mission has been extended twice and is currently in orbit around Jupiter continuing to conduct detailed investigations of the planetary system. Scientists are intensely interested in Jupiter. Unlike Earth and other planets, Jupiter has kept much of its original composition and can enhance our understanding of the solar system's origins.

Galileo will see the end of its historic service in September 2003 when it is expected that the gravity of Jupiter will pull it into the planet.

This drawing of the Galileo spacecraft shows locations and quantities of radioisotope heater units (RHUs), which provide heat, and RTGs, which provide power. There are 120 RHUs and 2 RTGs.



The effectiveness of Galileo's instruments depends not only on RTG power but also on heat from radioisotope heater units (RHU). Because the journey is far from the Sun, these compact, light, and long-lasting RTG and RHU units are the only effective power and heat sources for the Galileo mission.

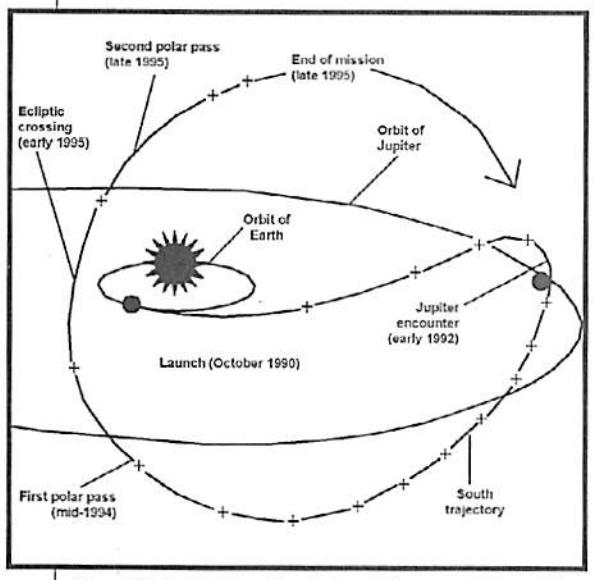
One hundred and twenty small RHUs protect the craft's sensitive instruments from damage in the cold vacuum of outer space. They are small, barrel-shaped devices that contain a Pu-238 dioxide ceramic pellet much like the fuel pellets used in RTGs. The heater units are designed and tested to contain their radioactive fuel during all normal and accident conditions. Eighty-four of these units are placed at various locations on the orbiter to heat its instruments, and 36 are located on the atmospheric probe. Each heater unit produces about 1 watt of heat -- about as much as a miniature Christmas tree bulb. It is enough to protect the instruments from the cold, which can reach -400 degrees Fahrenheit.

The Ulysses Mission

The Ulysses mission is a joint enterprise of the European Space Agency and NASA, with the Jet Propulsion Laboratory in California providing major support. The craft was launched in October 1990 aboard the space shuttle Discovery and was powered by an RTG supplying 283 watts of electricity. The primary mission of the Ulysses spacecraft was focused on gaining a better understanding of the velocity and density of the solar wind and the shape of the Sun's magnetic field

Previous craft launched to study the Sun have always orbited the Sun's equator—the plane in which Earth orbits the Sun. Ulysses is the first craft to orbit the sun's poles, giving scientists an entirely new perspective and important new data.

The mission trajectory directed the craft toward Jupiter after launch. It called for Jupiter's immense gravity to push the spacecraft out of the ecliptic plane into a polar orbit of the Sun. This novel orbit produced original data from areas of the Sun not previously studied. It also created a more complete understanding of the Sun and its effects on Earth.



Ulysses Mission Trajectory. The mission, which was extended beyond the original five-year period, has provided original data on the sun's poles.

In June 1994, mission scientists received the first scientific data on the south pole of the Sun. In June 1995, they received data on the north pole as well. Because the RTGs have a long life, mission planners extended the mission to a second orbit cycle, vastly increasing mission data return.

New objectives evolving since launch are to combine Ulysses in situ measurements of solar wind fields and particles, cosmic rays, and radio waves with remote observations of the Sun and solar corona from ongoing and upcoming missions. This combination will be used to analyze properties and dynamics of coronal mass ejections and of sources of the solar wind in order to enhance the ability of those missions to meet their own science objectives and to construct models of the 3D Sun and heliosphere

Why Ulysses Doesn't Use Solar Energy

Ulysses orbits the Sun; why not use solar energy instead of an RTG to power it?

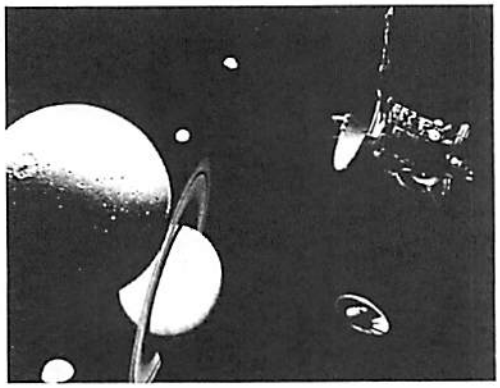
The spacecraft Ulysses was named for the Greek warrior king who went on a strange, exotic 10-year journey returning from the Trojan War.

The closest that Ulysses ever is to the Sun is at launch. As the spacecraft traveled to Jupiter, the Sun grew more distant and the rays much weaker. A solar panel system large enough to catch the required amount of light would add 1,200 pounds, nearly doubling the weight of the spacecraft. No current rocket booster could have sent Ulysses on its mission. Instead a single RTG provides all the power for instruments and other equipment aboard Ulysses. It is the only available power source capable of meeting the mission's requirements. Furthermore, the RTG provides power for many years. This has enabled mission scientists and program managers to extend the life of the spacecraft and reap more scientific benefits.

The Cassini-Huygens Mission

The Cassini-Huygens mission was launched on October 15, 1997, on a Titan IV launch vehicle. The mission is a joint U.S.-European venture to explore Saturn in detail, a journey that will take nearly seven years. Like Galileo, Cassini has used gravity assists from other planets to achieve the necessary speed to reach Saturn. Cassini has employed four flybys: two by Venus, one by Earth, and one by Jupiter, to reach its destination in deep space.

Cassini-Huygens is one of the most ambitious missions ever launched into space. Some of the main scientific goals of the mission include measuring Saturn's huge magnetosphere, analyzing from up close those stunning rings, and studying Saturn's composition and atmosphere. Cassini consists of an orbiter and a probe. The orbiter has 12 instruments, and the probe has six. The probe, named Huygens after the Dutch scientist who discovered Titan in 1659, will descend by parachute to the surface of Titan late in 2004. It will beam data to the orbiter during descent and after landing. Once there, it will examine the surface of Titan with three dozen sensors.



After releasing the Huygens probe for descent to Titan, the Cassini orbiter will explore the Saturnian system for nearly four years, flying more that 70 orbits around the giant planet during that time. The Cassini spacecraft is loaded with an array of sophisticated instruments and cameras. The instruments often have multiple functions, equipped to thoroughly investigate all the important elements that the Saturn system may reveal. The electrical energy to power the mission equipment will come from three RTG units that provide a total of 850 watts of power. The mission also utilizes 117 RHUs to control the temperature of on-board equipment and science instruments. Cassini will be sending home several gigabytes of data daily. The data will then be analyzed by more than 200 scientists worldwide.

Pluto: New Horizons

Pluto is the only planet that has not been visited by a spacecraft. It is under great debate as to its classification as a planet, or as a large object such as an asteroid or comet. Our only information about the planet and its moon has come mostly from ground-based observations. Tentatively scheduled for a 2006 launch date, the Pluto: New Horizons Mission is NASA's first attempt to explore our distant neighbor. The spacecraft will use a remote sensing package that includes imaging a radio science instrument as well as spectroscopic and other experiments to characterize the geology and morphology of Pluto and its moon Charon, map their surface, and characterize Pluto's atmosphere. The spacecraft's RTG is intended to supply 228 watts when it arrives at Pluto. The mission also plans for a fly-by of the Kuiper Belt by 2026.

Heat without Power

The RHUs used to keep equipment warm on the Galileo have spread in their use to new missions that do not use RTGs for power supplies. Light Weight Radioisotope Heater Units (LWRHU) are used to keep electrical equipment warm and operational. This is vital in the vacuum of space or for surface applications where the temperatures are cold enough to damage the equipment.

The Mars Pathfinder Mission

The Pathfinder mission launched on December 4th began its long trek to Mars with the objective of exploring the Martian surface. Three LWRHUs kept the scientific equipment aboard the robot "Sojourner" within operating temperatures. Without the LWRHUs, Sojourner would have only been able to operate for one day, instead it lasted past its mission life of 30 days.

The Mars Exploration Rover (MER) Missions

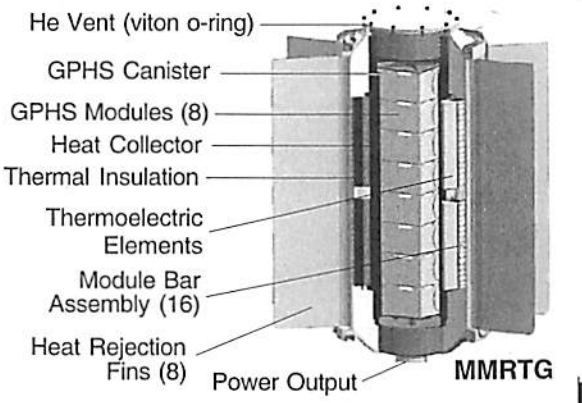
In a further attempt to understand the surface of Mars, NASA lunched two rovers to the planet, Spirit and Opportunity. Similar to the successful Pathfinder, mission's scientific goals are to search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars. The spacecraft will be sent to sites that may have had liquid water in the past. Spirit was launched on June 10, 2003, and Opportunity followed on July 10. In order to accomplish their missions, the electrical equipment will be kept within operating temperatures using eight LWRHUs per rover.

The Future of Radioisotope Power Systems in Space

The Technology

The future of RTG power sources is dependent upon the needs and requirements expressed by the mission designers. Systems that are lighter, generate more power, and use less radioactive material are highly desirable. New nuclear generator technologies for space applications have been under investigation. These technologies involve more efficient conversion of heat into electricity. Safe and reliable operation are key factors in determining the possible value of each technology for space missions. Currently two alternative systems are under development.

The first is a dynamic power system, which is much more efficient in converting heat into electricity than the RTGs used on recent missions. Dynamic systems have moving parts that transform heat into mechanical energy, which is used to generate electricity. One such engine, the Stirling engine, contains helium that expands by absorbing heat on the hot side of the engine and rejecting it on the cold side. The rapidly changing pressure cycles cause a piston to move back and forth, driving an alternator that produces the electricity.



The second is a new generation of the RTG and is known as the MMRTG or Multi-Mission Radioisotope Thermoelectric Generator. The MMRTG relies on current RTG technology; the difference is that its purpose is to supply a wider range of missions. Most RTGs provided to NASA are made for in-space use and cannot be landed on the surfaces of planets with atmospheres. The atmosphere interacts with the RTG and begins to degrade the performance. The MMRTG will be developed to fit both applications.

The higher efficiencies and increased range of use of these new technologies mean that future spacecraft may require less Pu-238 and be used in more environments. This makes these new space power technologies highly attractive.

Future Requirements

NASA has identified a number of potential missions that can best or only be undertaken using radioisotope power and/or heat sources. These future missions depend upon two important conditions.

First, there must be a reliable and continuing supply of Pu-238 fuel from the U.S. Department of Energy. U.S. facilities that could supply Pu-238 are being considered, as are some foreign sources.

Second, smaller and more efficient power systems will have to be developed consistent with NASA's needs.

Conclusion

For many missions on which RTGs were used, there was no other viable option for providing power. These missions included Apollo, Viking, Pioneer, Voyager, Galileo, Ulysses, and Cassini, which have provided scientists with critical information about the origins of the solar system.

Nuclear fuel has proven to be an ideal source of energy in space because of its high power, long life, acceptable weight and volume, and excellent reliability and safety when used in RTGs.

RTGs have made vital contributions to the U.S. space program from its earliest days to the present. Because of its many advantages, it is likely that nuclear energy will continue to provide power on space missions in the futuer, whether in RTGs or other advanced generators, as we further our knowledge of the solar system in which we live.