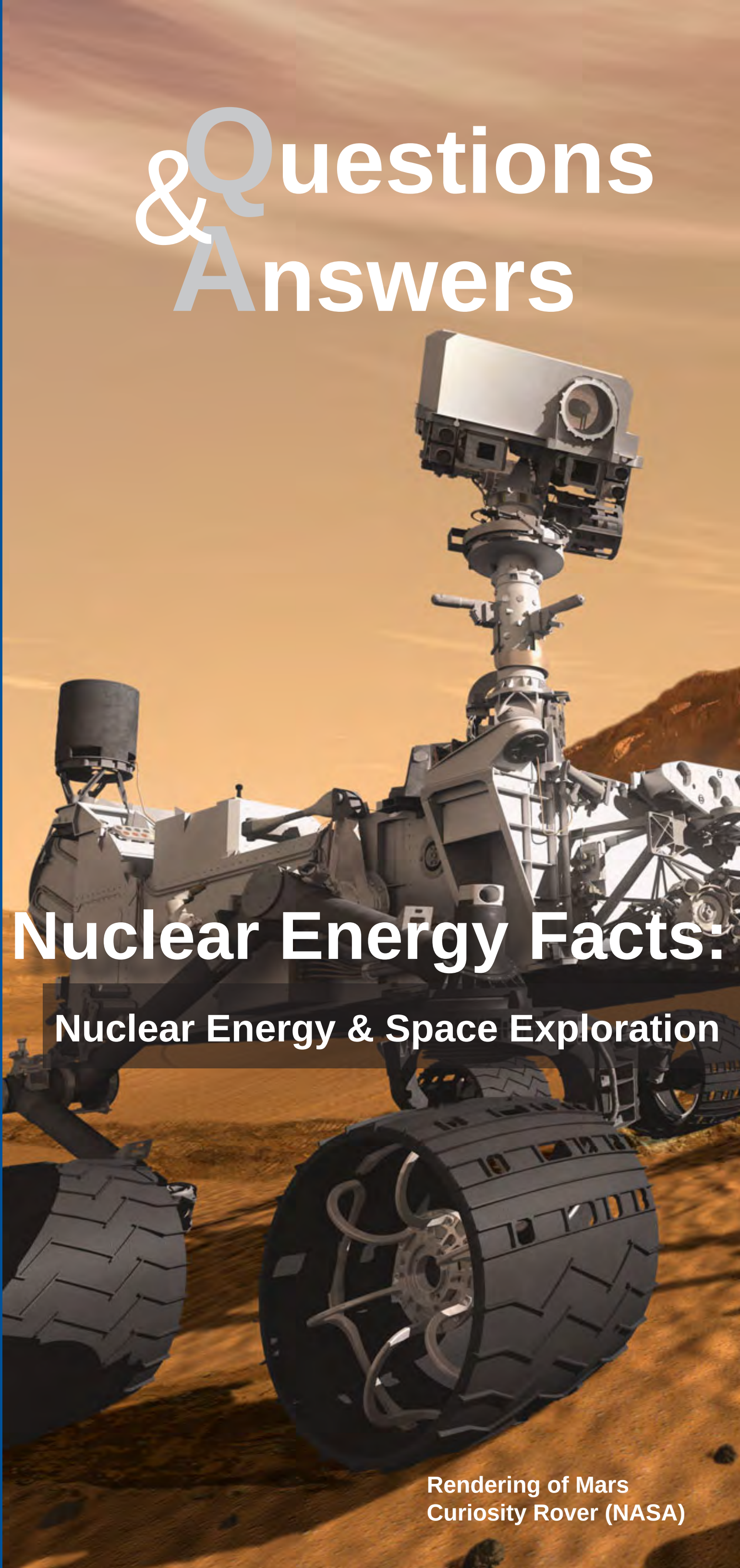
American
Nuclear
Society

# Questions & Answers



# Nuclear Energy Facts:

## Nuclear Energy & Space Exploration

Rendering of Mars
Curiosity Rover (NASA)

ANS order No. 750065
Nuclear Energy Facts:
Q&A Nuclear Energy & Space Exploration
ISBN-0-89448-531-8
First Edition - 2005
Revised 2013

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# American Nuclear Society

## What is the American Nuclear Society?

The American Nuclear Society is a professional organization devoted to advancing science and engineering related to the atomic nucleus. The Society's membership of more than 11,000 professionals represents all sectors of the global economy, including individuals in government, academia, research laboratories, and private industry.

A not-for-profit scientific and educational organization, ANS integrates many disciplines as its members explore nuclear applications in agriculture, aerospace, energy, industry, and medicine.

The American Nuclear Society, founded in 1954, upholds its mission to "serve its members in their efforts to develop and safely apply nuclear science and technology for public benefit through knowledge exchange, professional development, and enhanced public understanding."

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# Introduction

Nuclear energy plays a vital role in the exploration of space. Whether we need a satellite to track hurricanes on Earth, a probe to explore the moons of Jupiter, or a spaceship to send people to Mars, these missions require knowledge in the key areas of radiation shielding, power, and propulsion technologies to launch objects and people safely into orbit.

Studying and applying the principles of nuclear science will be a key factor in the coming decades of space exploration. The development and use of radioisotopic and fission-based nuclear systems will enable future exploration of space by humans and robots.

With the goal of increasing public understanding of nuclear science and technology, professionally qualified members of the American Nuclear Society have prepared the information in this book. The "Q&A Nuclear Energy Facts" series is published by ANS as a public service. Each booklet answers some of the most-asked questions about nuclear energy and its beneficial uses. Topics are addressed briefly but as factually as possible in a short format. Lists of references and texts for further reading are included in the back for readers interested in learning more.

# What is space nuclear power?

Space nuclear power refers to the use of nuclear technology to power or propel space vehicles. These generators provide the electrical power to operate instruments and electronics inside a craft. Chemical batteries and solar power can also provide electricity needed; however, both have limited effectiveness in longer, deep space missions.

Nuclear technology offers other solutions in space. Radioisotopic heater units are compact and long-lasting heat sources that maintain the function of a craft's sensitive instrumentation. In the cold vacuum of outer space, temperatures can reach –400°F.[1]

Fission-based nuclear reactors have been designed and tested for larger-scale, fission-based power production on space missions. Scientists in the United States and the former Soviet Union launched space vehicles with reactors on board. These reactors provided power for electrical systems. Also, nuclear rocket technology has been developed and tested, even though it has not been used. A nuclear rocket provides heat directly to a propellant to provide propulsion. Fission systems can also be used to provide propulsion indirectly by first converting the energy into electrical power which is then used to drive electric thrusters, as proposed for the Jupiter Icy Moons Orbiter mission.

# How long have we used nuclear energy in space?

The United States has been designing and launching thermal and electric generators that use radioactive elements (radioisotopes) for over forty years.

Initially, low power nuclear devices were designed to supplement a craft's primary power source. In 1961, the United States launched its first 2.7-watt nuclear-powered generator called the Space Nuclear Auxiliary Power (SNAP-3). It was launched aboard a U.S. Navy Transit navigation satellite and provided energy for 15 years.[2]

When Albert Einstein developed his famous formula $E=mc^2$, he laid out the foundation for future scientists to fully explore the power residing in the tiny atom. Since then, scientists and engineers have discovered new ways to use this power.

To support space exploration, the energy within the nucleus of an atom can be used passively or actively. Scientists use radioactive elements passively by using the heat given off through radioactive decay. The atom's energy can also be used actively, through controlled nuclear fission, the process of splitting an atom and harnessing the energy released.

Today, space programs rely on nuclear technologies for power systems, propulsion, and more. The constraints of power and mass limit the amount of science that can be done in space. Nuclear technologies provide compact, lightweight solutions that perform safely and efficiently, allowing us to explore our solar system and beyond.

# What is radiation?

Radiation and radioactivity are natural processes as old as the earth. Materials that are radioactive are made up of atoms that contain excess energy. These radioactive atoms give off their excess energy as radiation in the form of waves or sub-atomic particles.

"Ionizing" radiation is high-frequency radiation that gives off enough energy that it can cause observable chemical changes in the surrounding atoms.

The three basic kinds of radiation that come from radioactive materials are alpha, beta, and gamma radiation. All three types are present in nature. Naturally occurring radiation from soil, water, the atmosphere, and cosmic radiation (from space) is called "background radiation."

**Alpha particles** are clusters of two protons and two neutrons, equivalent to the nuclei (centers) of helium atoms. They can be blocked by a sheet of paper.

**Beta particles** are high-speed electrons. A thin sheet of aluminum can block them.

**Gamma radiation**, like medical X-rays, consists of photons (electromagnetic radiation), except that gamma radiation comes from the atomic nucleus. Gamma rays can be blocked by several inches of lead, several feet of concrete, or a large amount of water.

# What types of radiation are found in space?

Three types of radiation exist in space:

**Trapped Radiation** The rotation of Earth's metallic core causes the formation of doughnut-shaped magnetic rings around the planet. These are called the Van Allen radiation belts. The sun releases a constant stream of ionized particles, mostly electrons and protons, into space. Earth's magnetic field deflects these particles and protects the surface. The few particles not deflected are trapped in the Van Allen belt. Most manned missions stay well below these rings, letting Earth's magnetic field protect them.

**Galactic Cosmic Radiation (GCR)** GCR consists of ionized atoms that travel very close to the speed of light and can produce intense ionization when they pass through matter. This comes from outside the solar system. Earth's magnetic field protects us from most cosmic radiation.

**Solar Particle Events** Energetic electrons, protons, alpha particles, and heavier particles can be shot into space by stars. These particles cause a temporary rise in radiation levels in the area of space around Earth that is controlled by Earth's magnetic field, called the magnetosphere. They also may penetrate to low altitudes in the polar regions, causing displays of light in the atmosphere known as the Northern (and Southern) Lights.

# How is radiation measured?

"Rem" is the standard unit used to measure a dose from radiation energy absorbed in human tissue. It stands for "roentgen equivalent in man."

Standard radiation measures are relatively large numbers, so fractional units often are used in actual measurements of radiation. Radiation measurements may be expressed in rem or millirem, which equals 1/1,000th of a rem. The international unit for measuring radiation exposure is the sievert (Sv), and 1 Sv equals 100 rems.

Different units are used to measure radiation in different ways. Other measurements of radiation include curies, roentgens, and rads. Curies are used to measure the quantity of radioactivity in a material. Roentgens measure radiation exposure in the air. Rad stands for "radiation absorbed dose" and measures the amount of alpha, beta, neutron, gamma, and "X" energy deposited in a material.

# Are we exposed to radiation on Earth?

We are constantly surrounded by small amounts of radiation. Unstable isotopes that give off ionizing radiation (radiation capable of knocking electrons off of atoms) are found everywhere. Much of Earth's natural background radiation is in the form of gamma radiation, which comes from outer space. We are also exposed to radiation that comes from such elements as potassium, thorium, uranium, and radium.

Deposits of radioactive material in rocks and minerals vary in concentration and location. In places where certain elements are concentrated, there are also higher amounts of radiation. For example, living near a granite rock formation can increase an individual's background radiation by as much as 100 millirems per year.[3] Living in Denver, Colorado, or flying in an airplane also increases a person's exposure to radiation.

Living things are made of radioactive elements such as carbon and potassium; therefore, they are made of naturally radioactive materials. About half of the radioactivity in our bodies comes from potassium-40. Most of the rest of our bodies' radioactivity is from carbon-14 and tritium, a radioactive form of hydrogen.

Americans get about 25 millirems of radiation from the food and water they eat and drink each year. For example, bananas and Brazil nuts have high concentrations of potassium.

We receive man-made radiation from medical sources, building materials, coal-fired plants, and historic nuclear weapons testing from the 1950s.

# How much radiation do I receive?

Individuals receive an average exposure from all sources of about 620 millirems per year. This includes natural sources, such as rocks and cosmic radiation, and man-made sources such as X-rays. The dose depends on where you live, how much time you spend on an airplane, your number of medical -rays, and your occupational dose.

Naturally occurring background radiation is not regulated. The Nuclear Regulatory Commission, which regulates the nuclear industry in the United States, imposes annual limits for radiation doses from the licensed use of radioactive sources. These regulations limit radiation workers' total effective dose equivalent to no more than 5 rems from regulated sources of radioactivity. The regulations also protect members of the public.[4]

| Common sources of radiation[5] | |
|---|---|
| Cosmic Radiation | 26 mrem |
| Rocks and Soil | 28 mrem |
| Naturally occurring radioactive material in the human body | 40 mrem |
| Radon | 228 mrem |
| Medical X-rays | 39 mrem |
| Nuclear medicine | 14 mrem |
| Consumer products | 10 mrem |

# What are the health effects of radiation?

Conclusive scientific evidence regarding the health effects of radiation doses less than 1 rem (1,000 millirems) is not available. Radiation doses above 5 rems but less than 25 rems (25,000 millirems) cause minor blood changes detectable only by laboratory examination. No other clinically observable effects are seen until a dose of more than 50 rems (50,000 millirems) is received.[6]

The health effects of very high doses of radiation are serious, while effects of normal background radiation can only be estimated.

Some studies explore a theory called “hormesis”. This research shows that low doses of radiation may be beneficial to health. Like a vaccine, small amounts of radiation may stimulate the immune system and promote health.

Medical doses of 5,000 rems to specific organs or parts of the human body are common cancer treatments. Much smaller doses of radioactive materials are used as diagnostic tools. The use of radioactive materials in medicine for both diagnostic and therapeutic purposes helps millions of people every year.[7]

# How much radiation are astronauts exposed to?

Ionizing radiation from the sun and other celestial objects penetrates a space craft and exposes astronauts to radiation. In many cases, the dose an astronaut receives is similar to what a person would receive during an airline flight at 35,000 feet. Nonetheless, protection of astronauts from radiation in space is a major concern, especially on long duration flights.

The amount of radiation in a normal mission is not as extensive as some people believe. Within the International Space Station, the metal of the hull and the various instruments mounted on the walls provide shielding against soft X-rays and similar radiation. Also, the duration of the flights is sufficiently short that there is little danger of receiving too much radiation.[8]

Orbiting near Earth, a spacecraft and the astronauts inside are shielded from some radiation by the planet’s magnetic field. Deep space exploration will present new challenges. For longer flights to Mars or extended stays on the moon, more advanced materials and technologies will be needed to minimize radiation exposure.

# Is it dangerous to send humans into space?

The National Council on Radiation Protection and Measurements (NCRP) has evaluated the potential health-related effects for more than thirty years. Scientists have tried to come up with worst-case scenarios, as well as more probable scenarios of radiation exposure.

When proper precautions are taken, humans can spend extended periods of time in space without serious risk. High-speed nuclear propulsion can keep a crew of astronauts safer by lessening their exposure to radiation during space travel. Nonetheless, increased exposure to the types of radiation found in outer space can lead to an increased chance of health effects.

The NCRP estimated one worst-case scenario involving a major solar particle event, known as a solar flare. If such an event occurred during a visit to the moon, it could give the astronauts doses to their skin. Without an additional shielded structure for refuge during a solar storm, radiation skin doses could reach 600 rem and bone marrow doses could be close to 90 rem. While this exposure would not be life threatening, it may lead to visible reddening of the skin and temporary hair loss, with increased cancer risk in later years.[9]

To reduce longer-term health effects, astronauts monitor their radiation exposure to ensure they remain under a maximum dose.

# How do radiation doses in space compare to everyday doses on Earth?

Radiation is part of our natural environment. The average dose per person is about 620 millirems per year. Air provides shielding from cosmic radiation, so the higher in altitude you live, the more radiation you receive. For example, at sea level, coast dwellers are exposed to 26 mrem/year. For residents of Denver, Colorado, towering a mile above sea level, cosmic radiation exposure averages at 52 mrem/year.

As astronauts reach new heights, their exposure levels rise too. The average skin dose for astronauts on shuttle missions is approximately 433 mrem per mission.[10]

# How are spacecrafts and satellites powered?

Since Chinese alchemists discovered gunpowder, rockets have relied on fire. Chemical combustion propels objects into the air by throwing a stream of particles backward.

Currently, chemical rockets provide the thrust to lift a spacecraft into orbit. Once in orbit, spacecrafts and satellites may be powered by any of these power systems:

- Chemical rockets and batteries
- Solar panels
- Radioisotope Thermoelectric Generators (RTG)
- Fission systems (nuclear reactors)

Once off the ground, early space missions relied on lightweight batteries, fuel cells, and solar modules to provide electric power. Today, new in-space technologies exist that provide the electricity and heat to keep the instruments aboard functioning. New inventions also supply power to propel objects in space or on the surface of moons and planets. Efficient and long-lasting, nuclear power sources offer more electricity for weight of the equipment needed than existing alternatives.

# Why not use solar power on spacecrafts?

Solar power works well for satellites that stay near the sun. However, at distances far from the sun, solar panels must be quite large to produce the required power output. For this reason, alternative technologies have been sought for missions that travel farther from the sun for longer periods of time.

Solar power is ineffective on deep space missions because the intensity of sunlight decreases as the distance from the sun increases. To make deep space missions possible, NASA has been using RTGs to power deep-space probes and satellites because they generate low-levels of power and are long-lived and reliable. A fission power system, such as the one proposed for the Jupiter Icy Moons Orbiter Mission, could produce tens to hundreds of kilowatts of power.[11]

# What is an RTG?

RTG stands for Radioisotope Thermoelectric Generator. This technology operates without moving parts for long periods of time without human intervention. The first RTG was used in 1961.

An RTG uses the heat emitted from radioisotopes such as plutonium. The isotopes decay by emitting an alpha particle, which is easily stopped, and the heat is recovered. The heat from the radioactive plutonium is converted to electricity.

Just as coal and wood are different forms of carbon-based fuels, there are different kinds of plutonium. Most RTGs rely on Plutonium-238 (Pu-238), a man-made radioactive element with a half-life of about 88 years. Pu-238 is not weapons-grade material. The weapons-grade isotope, Plutonium-239, is more radioactive and has a half life of 24,000 years.[12]

Power from RTGs is strongest at the beginning of a mission and the amount of energy it can produce decreases over time as the radioisotope inside becomes less radioactive. This technology has been applied in terrestrial pursuits as well. Tiny amounts of Pu-238 have been used to provide power to heart pacemakers. [13]

# Could RTGs reenter the atmosphere and spread plutonium throughout the atmosphere?

RTGs are designed to reenter Earth’s atmosphere without releasing radioactive material. The material is encased in high-temperature ceramics which will contain the Pu-238 fuel under both normal and extreme accident conditions. Extensive testing and analysis are used to demonstrate that safety criteria are satisfied.

Several modern RTGs have reentered Earth's atmosphere, including the Apollo 13 Lunar Module and the Nimbus-B satellite. Neither released any radioactivity, and the radioactive material from Nimbus-B was recovered and reused in future missions. These examples of incidents without material release provide evidence of the success of current safety practices.

# What if an accident does occur during reentry?

Historic examples of nuclear power sources reentering Earth's atmosphere demonstrate the potential health and environmental impacts. In 1964, the Transit 5BN navigational satellite reentered the atmosphere and the satellite, along with the RTG providing its electricity, burned up in the atmosphere.

This RTG was designed by the U.S. Navy before the philosophy of containing the radioactive material upon reentry was adopted; instead, the RTG was designed to burn up in the upper atmosphere about 75 miles up. There was a small amount of material that was spread over a large area, so the satellite's reentry did not have any environmental impact.

The Soviets had several vessels with small nuclear reactors on board during reentry to the atmosphere which did burn up in the atmosphere. Radioactivity was released during these events, but it was released high in the atmosphere and spread over a large area.

One incident did leave contamination on the ground. The reentry of the Kosmos 954 left an affected area in Canada which was cleaned up. Currently, there is no detectable radioactivity there.

# What other uses are there for nuclear energy?

From the orange-flavored beverage Tang to Velcro adhesives, the U.S. space program is known for its contributions to new products and technologies that become commonplace in our daily lives. Similarly, expansion of our understanding of radiation and radioactive elements has made our lives easier and more productive in many ways. From industrial applications to medical uses, nuclear science has provided the foundation for many time- and life-saving applications.

For example, the transparent plastic wrap used to package fruits and other foods depends on a radiation process for its strength and clinging ability. Radioactive elements are also used to protect the environment by detecting pathways for pollutants to get into water supplies.

In the medical field, the radioactive isotope Cobalt-60 helps to stop the body's immune reaction to transplanted human organs. Also, tests using nuclear materials in hospital laboratories can detect thyroid under-activity in newborn babies. This makes prompt treatment possible, saving many children from mental retardation.

There are uses for small reactors to produce hydrogen, to power remote mining operations, and to desalinate seawater.

# What is our responsibility concerning nuclear energy?

It is our responsibility to become informed and make decisions based on reliable information. The scientific community takes responsibility for collecting knowledge about energy technologies, evaluating technologies, and inventing new applications.

Nuclear power sources are also a safe and proven technology. Working together, researchers, community members, and policymakers can make decisions based on scientific facts. We have a responsibility to ensure that future generations have an adequate supply of energy and a healthy ecosystem.

By studying the nuclear sciences, we have accomplished missions and science experiments now reaching beyond Pluto's orbit. With future research and development, we will overcome existing technology limits and seek ways to sustain human life in space to enable us to go to Mars and beyond.

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