Radioactivity Powers Curiosity Rover on Mars

Since August 2012, Americans have seen and heard reports about the exploits and scientific promise of NASA’s Mars Rover Curiosity. Some people followed the excitement of Curiosity’s landing. Some were amused or intrigued by the images of NASA’s “Mohawk Guy” who received attention for his unique haircut. Some people are still following the news and scouring web sites for information about scientific discoveries that may be made on the so-called red planet.

The Curiosity mission has the potential to satisfy human desire for knowledge. We surely want to know whether there has been life on Mars and whether the planet might have life now. Could the Gale Crater have supported microbial life? So, Curiosity is equipped with a laser, many cameras, rock sampling equipment, and a host of other devices (see page 2) to collect scientific information about Mars.

Setting the Mood
Before you read further, just for fun, you can set the mood with music from Gustav Holst’s best known composition, The Planets. This selection conveys the composer’s sense of Mars as the “bringer of war.” Go to [http://www.youtube.com/watch?v=9KYJOLM8SUE](http://www.youtube.com/watch?v=9KYJOLM8SUE)

Previous Rovers
NASA has sent rovers to Mars before. Smaller than Curiosity, the earlier rovers (Sojourner, Spirit and Opportunity) were powered by solar panels. Dust accumulations on the solar panels and variations in solar exposure during the Martian winter reduced their efficiency and limited the electrical power available to the rovers.

Plutonium as Power Source
For Curiosity, a rover significantly larger (the size of a small car) and heavier than its predecessors, NASA chose a different power source – the multi-mission radioisotopic thermoelectric generator (MMRTG). The MMRTG utilizes plutonium-238, a non-fissile* plutonium isotope with a half-life of 87.7 years. Plutonium-238 does not fission or split apart; rather, plutonium-238 undergoes radioactive decay and releases heat as it does so, along with alpha particles. (Alpha particles are a relatively heavy and bulky combination of two protons and two neutrons, which can be stopped by your skin or a sheet of paper). The MMRTG uses this heat to produce electricity without the aid of any moving parts.

The MMRTG is capable of providing electricity for more than a decade even though the Curiosity mission is scheduled to cruise the Martian surface for only 23 months. Radioisotopic thermoelectric generators (RTG) have been used on a number of previous space missions. Plutonium-238 used in the MMRTG was a byproduct of efforts to create plutonium-239 which was used for nuclear warheads during the Cold War era. Plutonium-239, found in nuclear weapons, is fissile.

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*Fissile — Material that will fission, i.e. split into two or more lighter materials, upon absorbing a neutron.
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The reasons for using plutonium in space missions are often unclear to those outside the mission planning community. Observers may see or hear only that the space mission is nuclear related, and that the power source uses plutonium. Plutonium is a word that in some communities has very negative connotations. Plutonium was needed to create the atomic weapons of the Cold War, is highly regulated by proponents of nuclear nonproliferation, and is one of the causes of the environmental woes at the Hanford site in Washington State. On the other hand, it is also the element that has been used to safely power many space missions, including the Voyager, Galileo, Cassini, New Horizons, and the most recent Mars rover, Curiosity.

So, why is plutonium still used if it has issues associated with it?

The answer is that plutonium exists in multiple nuclear forms, or isotopes. Isotopes occur in elements naturally due to differing number of neutrons in the nucleus. While relatively unimportant on the chemical level, on the nuclear level isotopes of a single element can behave very differently. Plutonium-239, the isotope of plutonium with 94 protons and 145 neutrons, is a fissile isotope, meaning that after the absorption of a non-energetic neutron it has a possibility of splitting, or fissioning. Because of this capability, plutonium-239 can be used in nuclear reactors and weapons. Plutonium samples with a large fraction of the plutonium-239 isotope are referred to as weapons-grade plutonium.

However, devices that use plutonium to produce power use the plutonium-238 isotope, which has 94 protons and 144 neutrons. It is not fissile, and cannot be used in atomic bombs or nuclear reactors. Plutonium-238 is useful for radioisotope heat sources, and radioisotope power systems, because it decays radioactively, releasing a particularly useful form of radiation called alpha radiation.

Alpha radiation is simply energized and completely ionized helium atoms, which lose their energy in the form of heat when interacting with other matter. This energy loss mechanism is similar to how friction generates heat on a surface. Alpha radiation is generally not harmful to humans, provided its emitters are not inhaled or ingested; alpha particles can be stopped by the outermost layer of skin.

Pu-238 is safe and can produce heat, but why is it preferred over other power sources?

Radioisotope power systems are useful for space applications for two main reasons:

First, they are very versatile. Unlike solar power sources, radioisotope power systems do not rely on correct orientation toward the sun, nor do they depend on proximity to the sun.

Second, the power from plutonium-238 lasts a long time. The half-life of plutonium-238, or the amount of time it takes for the power produced by the isotope to decrease by half, is 87.7 years.

A power system fueled by plutonium-238 can last for a very long time. This is, of course, dependent upon the reliability of the heat-to-electricity conversion components. The most common power conversion method—a static system known as thermoelectric conversion—is very reliable and can last for decades.

Future radioisotope power systems will adopt a new method for power conversion called the Stirling cycle—a dynamic (moving) cycle—which will allow for higher efficiency and lower mass systems. The new generators will be termed Advanced Stirling Radioisotope Generators. For more information on radioisotope power systems, see this [website](http://www.nuclear.energy.gov/space/neSpace20d.html).

Where do we get plutonium-238? Can it be found naturally?

Unfortunately, plutonium-238 cannot be found naturally. This is because it is radioactive and will have almost completely decayed into a different element after a geologically short period of 1000 years. Thus, plutonium-238 must be produced using nuclear reactors.

During the Cold War, when weapons-grade plutonium production was at full scale, plutonium-238 was a byproduct that could be saved and used for space power production. Since the 1990s, however, the United States has stopped production of weapons-grade plutonium, yet we continue to plan space missions that require the use of plutonium-238. NASA and the DOE have discussed plans to use national laboratory reactors to produce plutonium-238 for general purpose applications, but it is questionable if they will be able to supply a sufficient amount to meet national needs.

Another concept, proposed by the Center for Space Nuclear Research (CSNR), uses flexible TRIGA research reactors to produce a higher quantity of Pu-238 per year at lower cost. For more information on low cost plutonium-238 production, contact the CSNR at [http://csnr.usra.edu/](http://csnr.usra.edu/).

Regardless of its source, Pu-238 remains an important tool for scientific research. Many space missions have been powered by plutonium-238, and future missions will continue to be enabled by it. Its long lasting heat generation—coupled with a dependable power conversion system—allows it to be used in many environments and configurations. The use of plutonium-238 can be expected to become even more important as space exploration pushes further outward to Mars, Jupiter, their moons, and beyond!
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AMERICAN NUCLEAR SOCIETY
Project #68 — Modeling Activity

Modeling Radioactive & Stable Atoms

Use this as a demonstration or as a hands-on activity for students.

Introduction:
A zip-close plastic bag represents the nucleus of an atom and holds representation for protons and neutrons. If the atom is stable, zip the bag closed. If atom is radioactive, bag is left open to emit ionizing radiation (alpha particles, beta particles and/or gamma rays).

Materials:  
- large marshmallows  
- fine point permanent marker  
- toothpicks  
- quart size zip-close plastic bags  
- Chart of the nuclides (optional)

Directions:  
1) Mark 7 large marshmallows with a positive (+) sign. They represent protons.  
2) Select 7 unmarked large marshmallows to represent neutrons.  
3) From the group above, select 2 “protons” and 2 “neutrons”; use toothpicks and glue to join these into a group of four. This represents an alpha particle.  
4) Mark the sides of a mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, a toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of a “proton” (so the positive sign is partially covered). This now represents a neutron.  
5) Put the alpha particle from step #3 into an empty zip-close bag. Add 4 “protons” and 4 unmarked marshmallows (neutrons). Zip bag closed. The closed bag represents the nucleus of a stable atom. The binding energy can contain all the protons and neutrons within the nucleus; atom is stable.

Q1. How many positively charged marshmallows (protons) are in the bag? (Do not count the one whose positive sign is partially covered by the mini-marshmallow!) This is the atomic number of the atom.  
Q2. What element is represented by this model?  
Q3. How many neutral particles are in the bag? (You do count the particle where positive and negative charges cancel each other out!)  
Q4. What is the atomic mass of this atom? (Each large marshmallow equals 1 atomic mass unit, regardless of charge.)  
Q6. What is the atomic number of the atom now?  
Q7. What element does the atomic model represent now?  
Q8. What is the atomic mass of the atom now?

Summary:  
- Radioactive atoms emitting beta particles will change into the element which is one atomic number higher, but they will have the same atomic mass as before.  
- To show another radioactive atom that emits an alpha particle to become stable, place an alpha particle in an empty zip bag. Add 2 protons and 2 neutrons. This represents the nucleus of Beryllium-8. The atom “emits” an alpha particle, which will pick up two electrons to become a stable atom of Helium-4. The result is two atoms of Helium-4.  
- Represent a Gamma ray emission by shining a flashlight through the bag. Although gamma rays are really not visible, you can use this to model the fact that gamma rays are not particles; they are a form of electromagnetic radiation. All three types of radiation (alpha, beta, gamma) are ionizing radiation; they have enough energy to remove electrons from ordinary atoms. These ions allow us to detect radiation using a Geiger counter, photographic film, or an electroscope.

If desired, you can add pipe cleaners onto the bag to represent the orbits or shells where electrons would be present; mini-marshmallows with a negative (-) sign on them can be attached to the pipe cleaners to represent orbital electrons.

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