Volume 25 • September/October 2012

REACTIONS

FROM THE AMERICAN NUCLEAR SOCIETY TO TEACHERS INTERESTED IN THE NUCLEAR SCIENCES

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.

Image: NASA/JPL-Caltech

Curiosity at Work on Mars ***(Artist's Concept)***

This artist's concept depicts the rover Curiosity, of NASA's Mars Science Laboratory mission, as it uses its Chemistry and Camera (ChemCam) instrument to investigate the composition of a rock surface. ChemCam fires laser pulses at a target and views the resulting spark with a telescope and spectrometers to identify chemical elements. The laser is actually in an invisible infrared wavelength, but is shown here as visible red light for purposes of illustration.

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**

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.

Image: NASA/JPL-Caltech

Three Generations of Rovers with Standing Engineers

Two spacecraft engineers stand with a group of vehicles providing a comparison of three generations of Mars rovers developed at NASA's Jet Propulsion Laboratory, Pasadena, Calif. The setting is JPL's Mars Yard testing area.

Front and center is the flight spare for the first Mars rover, Sojourner, which landed on Mars in 1997 as part of the Mars Pathfinder Project. On the left is a Mars Exploration Rover Project test rover that is a working sibling to Spirit and Opportunity, which landed on Mars in 2004. On the right is a Mars Science Laboratory test rover the size of that project's Mars rover, Curiosity.

The engineers are JPL's Matt Robinson, left, and Wesley Kuykendall. The California Institute of Technology, in Pasadena, operates JPL for NASA.

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.

*Fissile —
Material that will fission, i.e. split into two or more lighter materials, upon absorbing a neutron.

Continued next page

Plutonium in Space Missions *by Wes Deason*

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 **http://www.nuclear.energy.gov/space/neSpace2d.html** maintained by the Department of Energy.

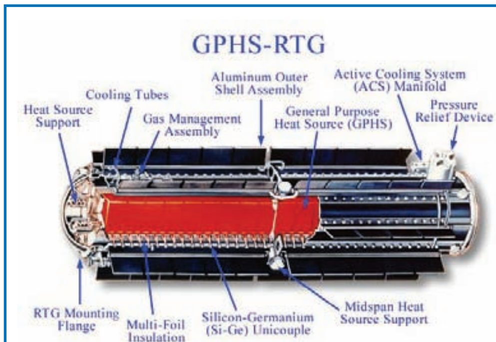

Image: NASA

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/**.

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! ■

Wes Deason is a graduate research assistant in Nuclear Engineering at Oregon State University, Corvallis, Oregon, and a member of the Aerospace Nuclear Science and Technology Division of the American Nuclear Society.

Radioactivity Powers Curiosity – Continued from p.1

The advantage of an RTG?

The MMRTG provides a steady supply of energy regardless of the conditions on the surface of Mars – where temperatures can vary widely and the intensity of sunlight can vary, too.

In addition, excess heat from radioactive decay is used to maintain suitable operating temperatures for Curiosity's scientific equipment and computers on planet Mars' surface which can be extremely frigid (as low as -225 Fahrenheit at the poles at night). ■

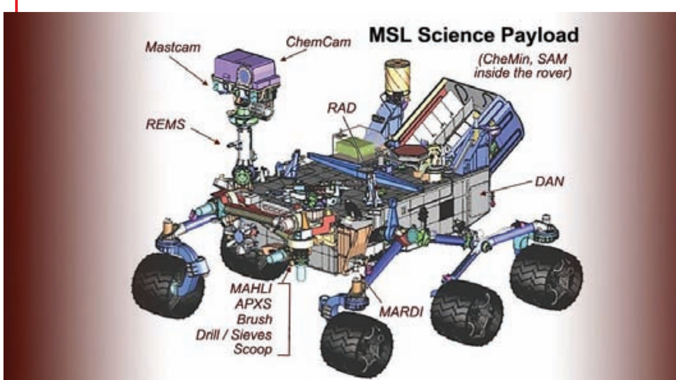

Image: NASA/JPL-Caltech

Diverse Science Payload on Mars Rover Curiosity

This drawing of the Mars Science Laboratory mission's rover, Curiosity, indicates the location of science instruments and some other tools on the car-size rover.

Clockwise from upper left:

- **Mastcam is the Mast Camera instrument.**
- **ChemCam is the Chemistry and Camera instrument.**
- **RAD is the Radiation Assessment Detector instrument.**
- **CheMin is the Chemistry and Mineralogy instrument.**
- **SAM is the Sample Analysis at Mars instrument.**
- **DAN is the Dynamic Albedo of Neutrons instrument.**
- **MARDI is the Mars Descent Imager instrument.**
- **MAHLI is the Mars Hand Lens Imager instrument.**
- **APXS is the Alpha Particle X-ray Spectrometer instrument.**
- **The brush, drill, sieves and scoop are tools on the rover's robotic arm.**
- **REMS is the Rover Environmental Monitoring Station.**

Additional Resources for Information

Mars Rover Curiosity

http://mars.jpl.nasa.gov/msl/
This web page from NASA's Jet Propulsion Laboratory provides access to a wealth of information about Mars Rover Curiosity. There are options for news, photos, and more.

http://decodedscience.com/nuclear-powered-curiosity-on-mars/16864
Getting Around Mars with Nuclear Power

http://www.digitaltrends.com/cool-tech/curiosity-mars-rover-5-surprising-facts/
Five surprising facts about Curiosity rover

Info about planet Mars

http://www.astronomytoday.com/astronomy/mars.html
An information page about planet Mars from Astronomy Today.

http://solarsystem.nasa.gov/planets/profile.cfm?Object=Mars
Background information about planet Mars from NASA.

http://www.space.com/47-mars-the-red-planet-fourth-planet-from-the-sun.html
Space.com provides information about Mars.

http://www.jpl.nasa.gov/news/news.php?release=2012-290
Mars Rover Opportunity reveals mystifying geological formations on the planet.

http://history.nasa.gov/marschro.htm
A Chronology of Mars exploration as prepared by NASA

Mohawk Guy

http://www.space.com/17423-what-s-behind-mohawk-guy-s-morse-code-shave-curiosity-update-video.html
Video update about Curiosity by "Mohawk Guy"

http://www.youtube.com/watch?v=ZlsaLs5DqCo
An interview with Bobak Ferdowsi, NASA's "Mohawk Guy"

Music

http://www.youtube.com/watch?v=9KYJOLM8SUE
Mars from "Planets" by Gustav Holst. Classical mood music for Mars the "bringer of war."

Radioisotope Power Systems

http://nuclear.gov/pdfFiles/MMRTG.pdf
What is a Multi-Mission Thermoelectric Generator? Info from NASA

http://ansnuclearcafe.org/2012/08/07/converting-heat-into-electricity-without-moving-parts/
This article, which appears on the ANS Nuclear Cafe blog, provides one engineer's recollections about his enthusiasm for the process of converting heat into electricity without moving parts.

http://www.nuclear.energy.gov/space/neSpace2d.html
Info about radioisotope power systems from U.S. Department of Energy

http://www.osti.gov/ostiblog/powering-curiosity-exploring-new-horizons-does-mmrtg
About the DOE's MMRTG on the OSTI blog

http://mars.jpl.nasa.gov/msl/mission/technology/technologiesofbroadbenefit/power/
Info from NASA's Jet Propulsion Laboratory in regard to power for Curiosity rover ■

Upcoming ANS Workshops & Exhibits

October 18-20, 2012, Louisville, KY

NSTA Regional Conference
ANS will be an exhibitor at the NSTA regional and will hold a workshop
Friday, October 19, 2012, 10 a.m. - 11:15 a.m.
No charge for workshop;
must register for NSTA conference.
For information about the NSTA conference in Louisville, KY, go to
http://www.nsta.org/conferences/2012lou/

November 1-3, 2012, Atlanta, GA

NSTA Regional Conference
ANS will be an exhibitor at the NSTA regional and will hold a workshop
Friday, November 2, 2012, 10 a.m. - 11:15 a.m.
No charge for workshop;
must register for NSTA conference.
For information about the NSTA conference in Atlanta, GA, go to
http://www.nsta.org/conferences/2012ata/

November 10, 2012, San Diego, CA

ANS will hold a full-day workshop for teachers, ***Detecting Radiation in our Radioactive World.***
Early registration deadline ($60) is 11:59 p.m. CT, Thursday, October 11, 2012
Regular and final registration deadline ($95) is 11:59 p.m. CT, Thursday, October 25, 2012
Complete workshop information is available at
http://www.new.ans.org/pi/edu/teachers/workshops/

December 6-8, 2012, Phoenix, AZ

NSTA Regional Conference
ANS will be an exhibitor at the NSTA regional and will hold a workshop
(date and time TBA). No charge for workshop;
must register for NSTA conference.
For information about the NSTA conference in Phoenix, AZ, go to
http://www.nsta.org/conferences/2012pho/

Sunday, February 24, 2013, Phoenix, AZ

ANS will hold a full-day workshop for teachers, ***Detecting Radiation in our Radioactive World*** during the **2013 Waste Management Conference (WM 2013)**
Location and time TBA.
Complete workshop information will be available at
http://www.new.ans.org/pi/edu/teachers/workshops/

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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, mini-marshmallows, fine point permanent marker, Periodic Table of the elements, toothpicks, white school glue, quart size zip-close plastic bags, pipe cleaners (optional), 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.)

6) Open the bag. Add two "neutrons." Leave the bag unzipped; excess neutrons have now made it unstable.

7) To become stable, the nucleus will emit a beta particle. Find the "neutron"you made in step #4. Pull off the mini-marshmallow (now it is a beta particle) and toss it about 1-2 feet from you. Leave the remaining proton in the bag and zip it closed. The atom has changed and is stable again.

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. ■

"Back Issues" of ***ReActions*** are available online at ***ReActions*.ans.org**

The Future is in the Atom

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