American Nuclear Society

Detecting Radiation in our Radioactive World

Teacher Resource Guide

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Mini-Rutherford

With the Mini-Rutherford Activity, students deduce shapes and sizes of unseen objects by tracking the movements of objects they can see, in relation to the unseen object. By extension, this device is a useful analogy to Rutherford's alpha scattering experiments and to atomic particle detection utilizing accelerators. *(Since the particles are too small to be seen, it was necessary to deduce their sizes by other means in both of these instances.)* This experiment is best used by students working in pairs.

Grade Level

5-12

Disciplinary Core Ideas (DCI, NGSS)

5-PS1-1, MS-PS1-1, MS-PS1-4, HS-PS1-8

Time for Teacher Preparation

40-60 minutes – To make the mini-Rutherford Boards
40-60 minutes – To prepare for the classroom

Activity Time:

40-60 minutes (1 Class Period)

Materials

- 5-10 blocks of various shapes 20 cm (8" x 10" x 3/4")
- 5-10 30.5 x 30.5 cm (12" x 12" x 1/8") masonite boards
- Pkg./30-1.9 cm (3/4") or (5/8") marbles
- Paper
- Pen, marker, or pencil
- Ruler

Safety

- Students should use care when handling marbles
- Students should not throw marbles
- Students should avoid stepping on marbles

Science and Engineering Practices (NGSS)

- Ask questions
- Define Problems
- Use Models
- Plan and Carry out investigation
- Analyze and interpret Data
- Construct Explanations
- Communicate Information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models

Objective

Students will try to determine the shape of an unknown object by using the scientific thought process of creating a hypothesis, then testing it through inference. It is based upon the Rutherford Gold Foil Experiment where scientists discovered that the structure of the atom includes the nucleus in the center surrounded by electrons in empty space.

It is a great introduction to the scientific process of deducing, forming scientific theories, and communicating with peers. It is also useful in the mathematics classroom by plotting the angles of incidence and reflection

Background

From 1911 to 1913, British physicists Geiger and Marsden, working in the laboratory of Ernest Rutherford, conducted experiments with beams of positively charged, alpha particles to penetrate gold, silver, and copper atoms. They observed that most of the alpha particles went directly through the foil. However, some particles were deflected and others recoiled back toward the source. Rutherford systematically investigated the results Geiger and Marsden obtained with alpha particles; Rutherford concluded that most of the mass of an atom is concentrated in a small region in its center, now called the nucleus.

Fundamental Particles Detection

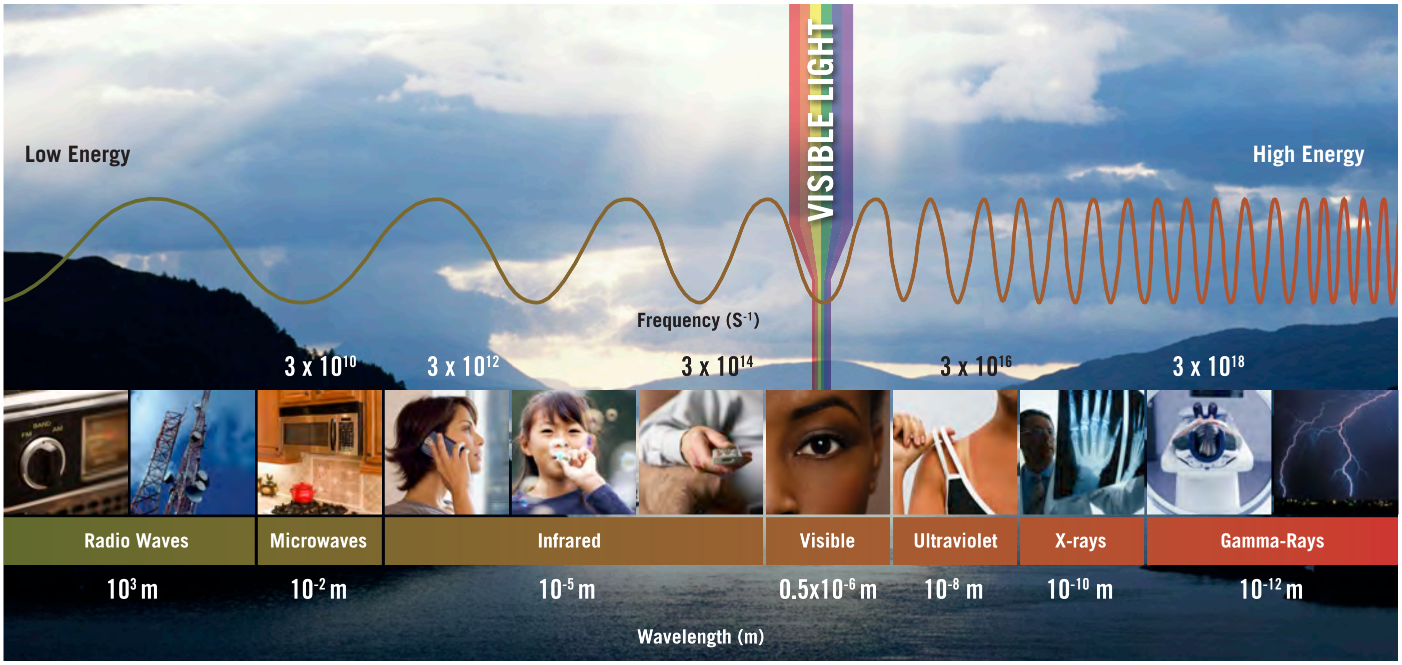
Light has a wavelength of 10^{-7} m. Light microscopes enable us to view parts of a cell as small as 10^{-6} m. Electron microscopes enable us to see an image with a wavelength as small as 10^{-9} m. With the help of scanning electron microscopes, we can see fuzzy images of atoms. To detect a smaller image, such as a fundamental particle, we need to produce particles with greater energy, and thus, a shorter wavelength. The smallest fundamental particle is less than 10^{-18} m in diameter!

Although scientists have not yet been able to actually see fundamental particles, they can infer the presence of these particles by observing events and applying conservation laws of energy, momentum, electric charges, etc.

One way to do this is with a particle accelerator. Essentially, a particle accelerator works by shooting particles at high speed toward a target. When these bullet particles hit a target, a detector records the information about the resulting event.

Necessary Components for Particle Detection

1. **Bullet Particles**. These can be either electrons, positrons (the anti-particle of an electron), or protons. The particles are collected as follows:
   - Electrons are collected the same way a TV picture tube collects them; a metal plate is heated and electrons are emitted.
   - To obtain positrons, a beam of electrons collides with a target, resulting in a photon. From the photon, electrons and positrons may be formed and are separated by their charges in a magnetic field.
   - Protons are obtained by ionizing hydrogen gas. Ionization requires collisions at energy great enough to strip electrons from hydrogen, leaving protons.
2. An **accelerator** increases the speed of bullet particles to greater energy levels. The particles are accelerated with an electric field by riding on traveling electromagnetic (EM) waves. The EM waves are created in devices called klystrons, which are large microwave generators.
3. The **steering device** directs the bullet particles to their target. Magnets are used to steer the particles around a circular accelerator and to focus the particles so they will hit the target. The same magnets make positive and negative particles traveling in the same direction bend in opposite directions.
4. A **target** can be any solid, liquid, or gas, or another beam of particles.
5. A **detector** interprets the paths of the resulting particles once the bullet particles have collided with their target. Modern detectors have several layers, to detect the many particles produced in a collision event. A detector can be up to three stories tall. An advanced computer system is used to reconstruct the many paths of the particles detected in the layers associated with a collision. By viewing particle paths through each layer of the detector, scientists can determine the results of an event. Charged particles leave a track in the inner (tracking) layer of the detector. The positive or negative charge of the resulting particle can be determined by the direction it curves in a magnetic field. A particle with great momentum (speed x mass) will have a less curved path compared to one with less momentum. After a collision, electrons and protons will leave showers of particles in certain detector layers. Photons and neutrons travel a little further through the layers before their collisions create a shower of particles. Muons (one type of a fundamental particle), however, can be detected in the outer layer of a detector. They travel right through the inner layers with little or no interaction.



Modeling Atoms

Teacher Lesson Plan:

Traditional

To make Mini-Rutherford Boards:

Velcro, glue, or nail block shapes underneath the masonite boards. Note: Some hardware stores will cut shapes for you free of charge.

Potential Block Shapes:

Triangle Square Rhombus Isosceles Trapezoid Hexagon

Place the Mini-Rutherford boards on a large table or on the floor, obstructing the shapes from your students' view. Place a piece of paper on top of each Mini-Rutherford board. Beware: your students may be tempted to peek.

The student activity, described in the accompanying worksheet, should take about five minutes to complete. The activity can be repeated several times during a class period, using different shapes and/or marbles each time. Some shapes are more difficult to detect than others.

NGSS Inquiry

Explain Rutherford's experiment. Tell students that they will design their own experiment, using rolling marbles as alpha particles to discover the shape of a hidden geometric shape, which simulates the nucleus.

You might suggest that the students experiment with rolling a marble at different angles at a straight surface and seeing the different ways the marble deflects.

Student Procedure

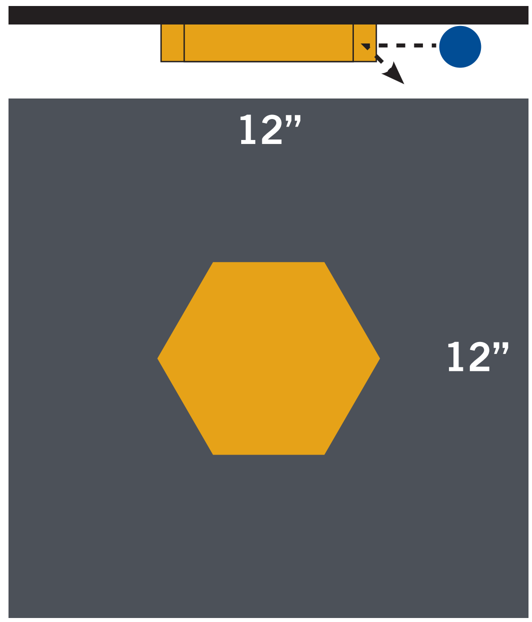
Using the Mini-Rutherford boards:

Middle School

Part 1

1. Working in small groups, roll one of the marbles at the hidden object underneath the Mini-Rutherford board while one student draws the marble's path in, and the deflected path out, on the piece of paper placed on the Mini-Rutherford board. Map the paths of the marbles that do not deflect or deflect slightly, as well. Make sure you roll the marble fast enough so that it makes a clean shot in and out.
2. Repeat **Step 1** as many times as needed to define the outline of the hidden shape, using the same size marble each time. Make sure you roll the marble from many points on each side of the board.

Potential Rutherford Board Set-Up



3. Once you are satisfied that you know the shape of the object under the Mini-Rutherford board, draw the shape onto the piece of paper. (You might want to trace the shape from the paper with the outline formed by the collision paths).
4. Before looking at the actual block shape, show your instructor the shape you have drawn. Then look at the block underneath the Mini-Rutherford board, and discuss any parts of the shape you have drawn that are ill-determined.

Part 2

5. Have the instructor place a different block back under the Mini-Rutherford board (or switch boards if they are permanently attached). Place a clean sheet of paper on the top of the Mini-Rutherford board and repeat the procedure (**Steps 1-4**).

High School

Repeat steps 1-5 as per the Middle School procedure.

Place the Mini-Rutherford board on a large piece of butcher paper, and then have the students record the shapes on the large paper. Do not put the paper on the board so that students must infer the shape from the surrounding angles of incidence/reflection.

Data Collection

Attached Student Data Collection Sheet

Post Discussion/ETS

Questions provided on the Student Data Collection Sheet

Questions

1. Explain the necessity of drawing the pathways of the marbles that miss as well as those that hit.
   a. How can you find where the hits occurred?
2. Describe how varying the block shape can change the outcome of the event.
3. List two ways in which the Mini-Rutherford Activity is analogous to and two ways in which it is different from Rutherford's scattering experiment.

Assessment Ideas

- Question the student about how this experiment is similar to Rutherford's Gold Foil Experiment
- Test the students' ability to determine an unknown geometric shape
- To better represent the presentation of scientific results, explain to the students that every time they guess the shape and get it wrong they will lose 10 points. This will emphasize that scientists do not "guess" at the answers until someone tells them that they are right. Scientists perform multiple experiments using different variables before they announce their results.

Differentiated Learning/Enrichment

Repeat experiment using more complicated shapes and equipment, i.e. mirrored surfaces and inexpensive lasers

Enrichment Questions

1. Compare the Mini-Rutherford Activity components to that of a particle detector. Describe the target, bullet, accelerator, steering device, and detector components of the Mini-Rutherford board.
2. Have students devise an experiment that would more closely simulate the Rutherford experiment using magnetic particles and a charged shape under the board.

Further Resources

For more information on Ernest Rutherford:

http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1908/rutherford-bio.html

http://www.rutherford.org.nz/

http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/atomic-and-nuclear-structure/rutherford.aspx

For similar experiments:

http://www.lepp.cornell.edu/Education/Lessons.html

Adapted from:

- Science Kit & Boreal Laboratories (1992). Mini-Rutherford Laboratory 64712-02.

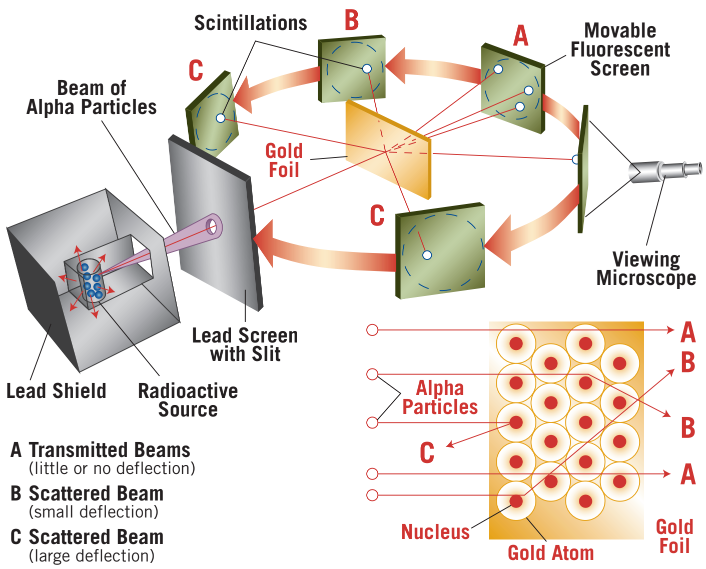
Mini-Rutherford

Student Data Collection ANSWER Sheet

Objective

Students try to determine the shape of an unknown object by using the scientific thought process of creating a hypothesis, then testing it through inference. It is based upon the Rutherford Gold Foil Experiment where scientists discovered that the structure of the atom includes the nucleus in the center surrounded by electrons in empty space.

It is a great introduction to the scientific process of deducing, forming scientific theories, and communicating with peers. It is also useful in the mathematics classroom by plotting the angles of incidence and reflection.



Procedure

Using the Mini-Rutherford Boards:

Part 1

1. Working in small groups, roll one of the marbles at the hidden object underneath the Mini-Rutherford board while one student draws the marble's path in, and the deflected path out, on a piece of paper placed on the Mini-Rutherford board. Map the paths of the marbles that do not deflect or deflect slightly, as well. Make sure you roll the marble fast enough so that it makes a clean shot in and out.

2. Repeat **Step 1** as many times as needed to define the outline of the hidden shape, using the same size marble each time. Make sure you roll the marble from many points on each side of the board.

3. Once you are satisfied that you know the shape of the object under the Mini-Rutherford board, draw the shape onto the provided piece of paper. *(You might want to trace the shape from the paper with the outline formed by the collision paths of the marbles).*

4. Before looking at the actual block shape, show your instructor the shape you have drawn. Then look at the block underneath the Mini-Rutherford board, and discuss any parts of the shape you have drawn that are ill-determined.

Part 2

5. Have the instructor place a different block back under the Mini-Rutherford board (or switch boards if they are permanently attached). Place a clean sheet of paper on the top of the Mini-Rutherford board and repeat the procedure (**Steps 1-4**).

Mini-Rutherford

Student Data Collection ANSWER Sheet

Part 1 - Marble Test Sketch of Hidden Shape

Part 2 - Steel Ball/Different Size Marble Test: Sketch of Hidden Shape

Mini-Rutherford

Student Data Collection ANSWER Sheet

Questions

1. Explain the necessity of drawing the pathways of the marbles that miss as well as those that hit.

   The marbles that miss denote empty space. The marbles that hit show an object.

   a. How can you find where the hits occurred?

      By measuring the angle of incidence and reflection, you can determine where they meet and the point where they hit the shape. The marbles come out at a different angle than where they went in.

2. Describe how varying the block shape can change the outcome of the event.

   If you use a shape that is non-symmetrical and not centered under the board, the students will have to overcome their bias that the outside of the object defines what is underneath.

3. List two ways in which the Mini-Rutherford Activity is analogous to and two ways in which it is different from Rutherford's scattering experiment.

   Similarities: In this experiment we are shooting particles at an object and using angles of incidence and reflection to determine the shape. Another is that we are using the scientific principle of inference to identify an object that we cannot see.

   Differences: The particles and shapes are on a very large scale as compared to Rutherford's experiment which dealt with atoms. The shape used in this laboratory is not magnetic, and does not attract or deflect the particles being directed toward it.

Enrichment Questions

1. Compare the Mini-Rutherford Activity components to that of a particle detector. Describe the target, bullet, accelerator, steering device, and detector components of the Mini-Rutherford board.

   The bullet particle is the marble. The accelerator is the student releasing the marble or shooting the marble under the board. The steering device can be a ruler that the students roll the marble down, or the student as they send it under the board. The target is the shape under the board. The detector is the student data collection sheet.

2. Devise an experiment that would more closely simulate the Rutherford experiment using magnetic particles.

   Using a magnet as the shape under the board and using metal balls or other magnets rather than marbles as the bullets.

Modeling Atoms

Mini-Rutherford

Student Data Collection Sheet

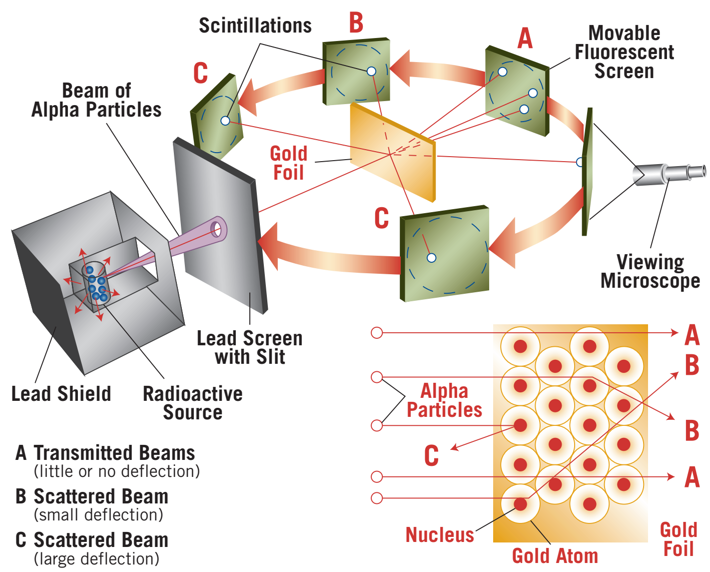
Name: ______________________________

Date: ______________________________

Objective

Students try to determine the shape of an unknown object by using the scientific thought process of creating a hypothesis, then testing it through inference. It is based upon the Rutherford Gold Foil Experiment where scientists discovered that the structure of the atom includes the nucleus in the center surrounded by electrons in empty space.

It is a great introduction to the scientific process of deducing, forming scientific theories, and communicating with peers. It is also useful in the mathematics classroom by plotting the angles of incidence and reflection.



Procedure

Using the Mini-Rutherford Boards:

Part 1

1. Working in small groups, roll one of the marbles at the hidden object underneath the Mini-Rutherford board while one student draws the marble's path in, and the deflected path out, on a piece of paper placed on the Mini-Rutherford board. Map the paths of the marbles that do not deflect or deflect slightly, as well. Make sure you roll the marble fast enough so that it makes a clean shot in and out.

2. Repeat **Step 1** as many times as needed to define the outline of the hidden shape, using the same size marble each time. Make sure you roll the marble from many points on each side of the board.

3. Once you are satisfied that you know the shape of the object under the Rutherford board, draw the shape onto the provided piece of paper. *(You might want to trace the shape from the paper with the outline formed by the collision paths of the marbles).*

4. Before looking at the actual block shape, show your instructor the shape you have drawn. Then look at the block underneath the Mini-Rutherford board, and discuss any parts of the shape you have drawn that are ill-determined.

Part 2

5. Have the instructor place a different block back under the Mini-Rutherford board (or switch boards if they are permanently attached). Place a clean sheet of paper on the top of the Mini-Rutherford board and repeat the procedure (**Steps 1-4**).

Modeling Atoms – Mini-Rutherford
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Part 1 - Marble Test: Sketch of Hidden Shape

Modeling Atoms – Mini-Rutherford
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Part 2 - Different Marble Test: Sketch of Hidden Shape

Modeling Atoms – Mini-Rutherford
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. Explain the necessity of drawing the pathways of the marbles that miss as well as those that hit.
   a. How can you find where the hits occurred?
2. Describe how varying the block shape can change the outcome of the event.
3. List two ways in which the Mini-Rutherford Activity is analogous to and two ways in which it is different from Rutherford's scattering experiment.

Enrichment Questions

1. Compare the Mini-Rutherford Activity components to that of a particle detector. Describe the target, bullet, accelerator, steering device, and detector components of the Mini-Rutherford board.
2. Devise an experiment that would more closely simulate the Rutherford experiment using magnetic particles.

Cloud Chamber

Allow students to visualize and understand ionizing radiation.

Grade Level
5-12

Disciplinary Core Ideas (DCI, NGSS)
5-PS1-1, MS-PS1-1, MS-PS1-4, HS-PS1-8, HS-PS4-2, HS-PS4-5

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Plastic cloud chamber kit, 3 1/4" diameter:
  (Petrie dish with band of black construction paper around the sides and bottom painted black or lined with black construction paper)
  - At least 3 cloud chambers (or as many to allow students to observe different sources)
  - 3 Radioactive Sources: radioisotope disks, Coleman lantern mantle pieces (thoriated), Uranium ore, or orange Fiestaware piece.
  - Dry ice
  - Rubbing alcohol – 95% ethyl
  - Flashlights
  - Styrofoam plates
  - Gloves
  - Magnet (Optional)
- Student Data Collection Sheets

Safety

- Students should use care when handling rubbing alcohol
- Students should not touch dry ice with their bare hands
- Students should not touch radioactive materials

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Use Models
- Plan and Carry out investigation
- Analyze and interpret Data
- Using mathematics, information and computers
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

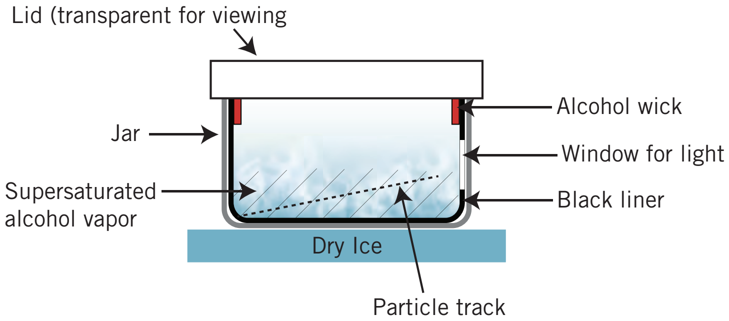
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objective

To visually demonstrate the concepts of ionizing radiation.

Background

Radioactive elements continually undergo a process of radioactive decay during which their nuclei emit high-speed particles and rays. These are much too small to be seen under a microscope. The Cloud Chamber was invented by an English physicist, C. T. R. Wilson, in 1911. It is an instrument designed for the study of the trails of radioactive emissions. The investigation is accomplished in the following way. First, the air must be saturated with water or alcohol vapor. When the high-energy particles flow through the air, electrons are knocked loose from some of the atoms and form ions. Ions act as excellent centers for condensation. This condensation, however, must be stimulated by cooling the air. The water vapor or alcohol condenses on the ions, leaving a vapor tail which clearly reveals the path of the ray.



Cloud chambers detect the paths taken by ionizing radiation. Much like the vapor trail of a jet airplane, the tracks in a cloud chamber mark where ionizing radiation has been traveling. The radiation itself is not visible. Radioactive materials are one source of ionizing radiation. Three types of rays are given off by a radioactive element. They are alpha particles (positive nuclei of helium atoms traveling at high speed), beta particles (high-speed, negative electrons), and gamma rays (electromagnetic waves similar to X-rays). Most of the tracks will be about one-half inch long and quite sharp. These are made by alpha radiation. Beta particles are smaller and are moving faster and are not affected as strongly. Occasionally you will see some twisting, circling tracks that are so faint that they are difficult to see. These are caused by gamma radiation. Note: A gamma particle will not directly produce a track but once it strikes the wall or bottom of the container may knock free an electron which can travel in any direction and create a track.

Teacher Lesson Plan:

Traditional

Cloud Chambers

1. Prepare the cloud chambers as followed:
   a. Open the lid of the cloud chamber and saturate the felt strip inside with alcohol.
   b. Put the radiation source inside the cloud chamber and replace the lid tightly.
   c. Place the palm of your hand firmly on top of the cloud chamber for about 1 minute to evaporate the alcohol.
   d. Place the cloud chamber on a piece of FLAT dry ice that is at least a little larger than the chamber.
   e. Turn off the lights in the room and shine the flashlight through the cloud chamber to make the ion trails easier to see. Trails should begin a few minutes after placement on the dry ice.

NOTE: You can use radioisotope disks in each chamber in lieu of Coleman lantern mantle pieces. By providing alpha, beta, and gamma sources, students will find that only the alpha and beta sources will produce tracks. This is because gamma radiation is electromagnetic radiation not particles, and it's the particles moving through the alcohol cloud that makes the tracks. To create a large supply of alpha sources from one lantern mantel, see **Appendix A**: Making an Alpha Source.

NGSS Guided Inquiry

Give the students radioactive samples and ask them to reduce/block the radiation to normal background levels with things they find in the classroom.

Explain about the different types of radiation and radioactivity. Tell students to design their own experiment, to detect different types of radiation, and then share their results with the class.

Student Procedure

Observe the vapor trails produced within the cloud chamber and answer the questions on the student data sheet.

High School

1. Prepare the cloud chambers as followed:
   a. Open the lid of the cloud chamber and saturate the felt strip inside with alcohol.
   b. Put the radiation source inside the cloud chamber and replace the lid tightly.
   c. Place the palm of your hand firmly on top of the cloud chamber for about 1 minute to evaporate the alcohol.
   d. Place the cloud chamber on a piece of FLAT dry ice that is at least a little larger than the chamber.
   e. Turn off the lights in the room and shine the flashlight through the cloud chamber to make the ion trails easier to see. Trails should begin a few minutes after placement on the dry ice.

NOTE: You can radioisotope disks in each chamber in lieu of Coleman lantern mantle pieces. By providing alpha, beta, and gamma sources , students will find that only the alpha and beta sources will produce tracks. This is because gamma radiation is electromagnetic radiation not particles, and it's the particles moving through the alcohol cloud that makes the tracks.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. What is creating the vapor trails?
2. How is it creating them?
3. How far did each type of radiation travel away from the source? List your answers from furthest travelling to shortest travelling distance.
4. Are any tracks visible when no source of radiation is near the chamber? What kinds of radiation can be found in our environment?

Assessment Ideas

Have students draw a diagram of what is happening at the atomic level when a vapor trail is created.

Differentiated Learning/Enrichment

1. Hold the north end of a strong magnet next to the chamber. How does magnetism affect the radiation tracks?
2. If you have access to a Geiger counter, count the number of tracks that you can see in ten seconds and then compare that number to the number of clicks produced by the Geiger counter in the same amount of time. Which is more accurate?
3. If you shield the source, which types of radiation are still visible?
   a. Materials to experiment with shielding include: aluminum foil, plastic, cloth. Which types of radiation are shielding by each type of material?

Enrichment Question

1. How do you think shielding is useful to the nuclear industry? Give three examples.

Further Resources

CERN Cloud Chamber Workshop: https://teachers.web.cern.ch/teachers/document/cloud-final.pdf

How Cloud Chambers Work: http://science.howstuffworks.com/dictionary/physics-terms/cloud-chamber-info.htm

Making an Alpha Source: **Appendix A, page 2.12**

Cloud Chamber

Student Data Collection ANSWER Sheet

Objectives

- To visually demonstrate the concepts of ionizing radiation.

Directions

1. Watch the demonstration.
2. Draw what you observe.

Questions

1. Explain why the gamma radiation particles did not make tracks in the cloud chamber.

   Gamma particles are not electrostatically charged, so do not cause the alcohol vapor "clouds" to ionize, and thus, no coalescing cloud is created.

2. How do the tracks generated by the radioactive particles in cloud chambers resemble what you can see created by jet airplanes as they pass through the upper atmosphere?

   Both are caused by vapor coalescing around a nucleus to form a dropet.

3. Have the students describe how gravity affects the particles as they are emitted from the source.

   The alpha particles would be drawn down due to the effects of gravity. Beta particles are smaller and are moving faster and are not affected as strongly.

4. Have the students describe the differences in the particle tracks in the cloud chambers.

   The alpha particle path is large. The beta particle path is more erratic and much smaller. A gamma particle will not directly produce a track but once it strikes the wall or bottom of the container may knock free an electron which can travel in any direction and create a track.

Enrichment Question

1. How do you think shielding is useful to the nuclear industry? Give three examples.

   Students need to research power versus beneficial uses in industry.

   Answers may involve shielding for human safety and structural material issues, and to protect electronic devices and photographic film.

Making Atoms Visible

Cloud Chamber

Student Data Collection Sheet

Name: ______________________

Date: ______________________

Objectives

- To visually demonstrate the concepts of ionizing radiation.

Directions

1. Watch the demonstration.
2. Draw what you observe.

Questions

1. Explain why the gamma radiation particles did not make tracks in the cloud chamber.
2. How do the tracks generated by the radioactive particles in cloud chambers resemble what you can see created by jet airplanes as they pass through the upper atmosphere?
3. Have the students describe how gravity affects the particles as they are emitted from the source.
4. Have the students describe the differences in the particle tracks in the cloud chambers.

Enrichment Question

1. How do you think shielding is useful to the nuclear industry? Give three examples.

Autoradiographs

With the Autoradiograph activity, students gain a better understanding of the different types of radiation, alpha, beta, and gamma. This is a way that students can detect invisible emissions.

This experiment is best used by students working in groups.

Grade Level

1-5 (sun paper)
6-8 (demonstration)
9-12 (activity)

Disciplinary Core Ideas (DCI, NGSS)

5-PS1-1, MS-PS1-1, MS-PS1-4, HS-PS1-8, HS-PS4-2, HS-PS4-5

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up
1 Week to develop the autoradiograph

Activity Time:

30-60 minutes (1 Class Period) for set-up
30-60 minutes (1 Class Period) to develop the autoradiograph

Materials

- Pen, Marker, or Pencil
- 1 box-Polaroid Type 57 instant (3000 speed) 4x5 packet film
- Radiation Sources
    - 1 Coleman Lantern Mantle
    - Fiesta®ware plate
    - Radium-dial clock
    - Smoke-detector part (Americium)
    - Uranium ore (sealed in a plastic ziplock to prevent dust contamination)
- Rubber or plexiglass photo developing roller, rolling pin, or sturdy wooden or plastic ruler
- Sheet of aluminum foil, paper (optional)
- Student Data Collection Sheets

Safety

- Students should use care when handling aluminum foil
- Students should not touch chemicals on polaroid film on their bare hands
- Students should use care when touching radioactive materials.
- Students should wash hands after handling radioactive materials.

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Use Models
- Plan and Carry out investigation
- Analyze and interpret data
- Using mathematics, information and computers
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objectives

- To visually demonstrate the concepts of ionizing radiation.

Background

Autoradiographs

Often used to detect radiation by imaging its emissions, an autoradiograph is a representation of where radioactive substances are located. The image can be projected onto a medium such as an x-ray film, nuclear emulsion, or even photographic film. Autoradiography, which can also be digital, is used in many cases for biological and medical applications. In contrast to other methods of detecting radiation, they can show the locations of radioactive materials in a sample. The images can therefore be used with biological specimens labeled with such materials, to track cellular activity for example.

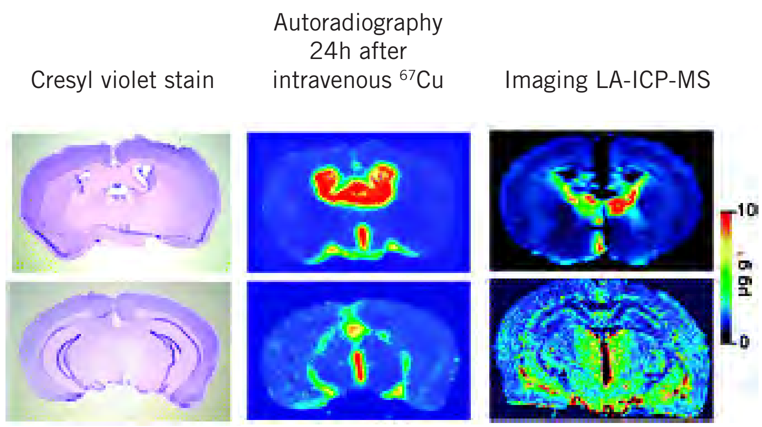
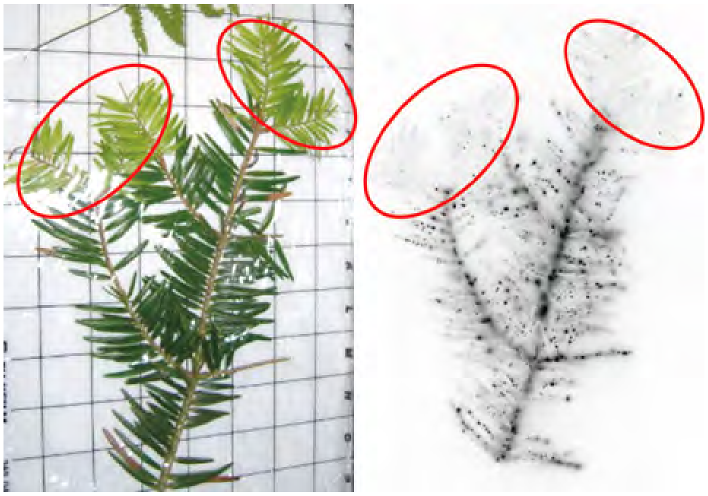


Figure 1: Bioimaging of copper alterations in the aging mouse brain by autoradiography, laser ablation inductively coupled plasma mass spectrometry and immunohistochemistry

Source: http://pubs.rsc.org/en/content/articlelanding/2010/mt/c003875j/unauth#!divAbstract



(a) (b)

Figure 2: (a) Photograoph of Torreya nucifera, (b) autoradiograph image. Black spots in (b) showed the radiation source in branches and leaves, indicating the presence of radioactive Cs. Red circles indicate the leaves (light green colored leaves in (a)) that grew after the accident. Black spots are practically zero within the red circles, indicating that the radioactive samples from the old leaves were rarely transported to the young leaves. See details in the text.

Source: http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/mirai-en/2012/1_17.html

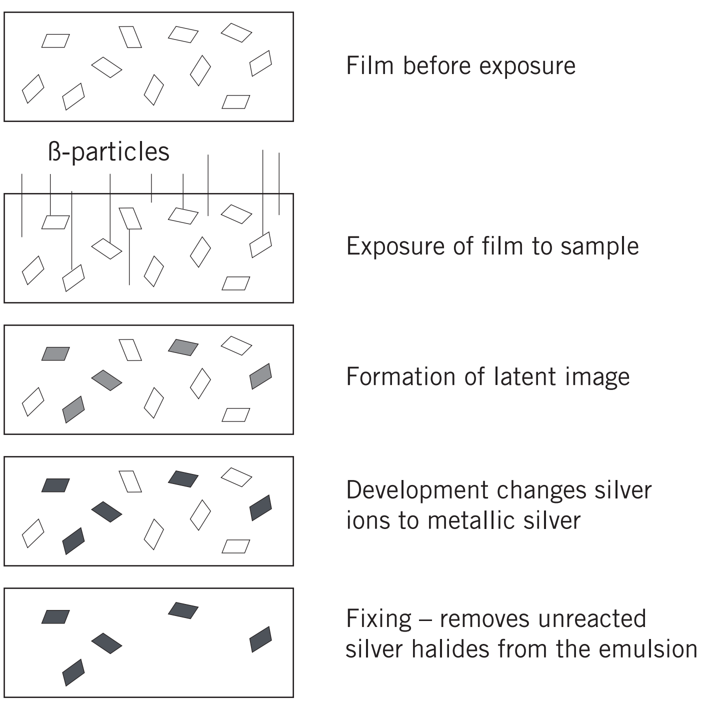


Figure 3: This shows how the beta particles fix the image on the photographic substrate and is used for the autoradiograph section of seeing the invisible.

In its basic form, an autoradiograph can require film to be exposed overnight. Radioactivity is detected through bands on an image, which are produced as particles hit crystals of silver halide. The images on the film typically depend on the activation of the crystals and the effects of particles on a gel. If each crystal is insulated by a gelatin capsule, then a permanently developed image can accurately show the sample and where it is radioactive.

An autoradiograph is often taken after biological tissue is exposed to a radioactive substance, left for a certain period of time, and examined under a microscope. Sections can be cut and a photographic image can be developed as a radioisotope decays. Samples are often stained to enhance the detail and to see the grains of silver that react with the substance. The resulting autoradiograph can be recorded and kept on file as part of an experiment or test.

While a solid film was typically used in the past, a liquid emulsion is often used in the 21st century to make an autoradiograph. This technique can take less time to complete. Liquid can flow and make the thickness of the sample uneven, but following the basic steps for coating slides and developing the film can dry the sample appropriately. A phosphor-imager screen can help detect radioactivity in gel quicker than x-ray film. It is typically used with electronic instruments and a computer system that can digitally image the sample.

Autoradiographs can show radioactive particles attached to enzymes or integrated into nucleic acid. Metabolic processes can be tracked in cells when images of radioactive particles are compared. Researchers can track proteins, photosynthesis, and the division and movement of cells. Sequences of deoxyribonucleic acid (DNA) can be tracked. Autoradiography DNA is often used to monitor cell cycles and track the progress of viruses to analyze their behavior.

Teacher Lesson Plan:

Traditional

Paper

1. Prepare **Autoradiographs** in accordance with Autoradiograph instructions:
   a. Place a key, coin, or other metal object onto the face of the film sheet. Place a Coleman lantern mantle, Fiesta®ware plate, or a radium-dial clock completely over the object. Let it sit for at least one week.
   b. Remove the mantle and object from the film sheet. Lay the sheet on a flat table with the side marked "This side toward lens" up. Locate the bulge in the sheet that contains the developer chemicals. Place a ruler, flashlight, or other stiff, heavy object (a roller works best) behind the bulge and, while applying moderate pressure, slowly and evenly drag the object across the film sheet to spread the chemicals. Even distribution of the chemicals is critical for good development. It takes lots of practice to make a good picture.

c. Wait 30 seconds for the film to develop then open the packet.

d. Students will find a dark shadow of the metal object surrounded by a white "fog". The white is due to the radiation given off by the Coleman mantle exposing the film. The dark shadow is because the metal object shielded the radiation from the film.

NOTE: You can use the three radiation sources on one film sheet in lieu of the key and Coleman lantern mantle, Fiesta®ware plate, or a radium-dial clock. Students will find that only the beta and gamma sources will expose the film. This is because the paper surrounding the film shields alpha radiation.

NOTE: Elementary school students could try to perform this experiment using SunSensitive paper rather than Polaroid film. The SunSensitive paper reacts to UV sunlight and would be a good substitution for Polaroid film for this experiment.

NGSS Guided Inquiry

1. Break students up into groups of three
2. Give each group
   - A sheet of film
   - A sheet of paper and some aluminum foil
   - An alpha, beta, and gamma source
3. Have groups design an experiment to discover what kind of radiation each source is emitting.

Student Procedure

1. Place a key, coin, or other metal object onto the face of the film sheet. Place a Coleman lantern mantle, Fiesta®ware plate, or a radium-dial clock completely over the object
2. Allow the photos to develop for a week
3. Develop the film according to your teacher's instructions
4. Observe the resulting image that is developed

Data Collection

- Attached Student Data Collection Sheets
- Students should label sources and type of radiation on film

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. What caused the image to develop on the sheet of film?
2. How did you use shielding principles to identify what kind of radiation each source emits?
3. For sun paper activity, how does placing an object on the sun paper and putting sun screen on skin compare to protecting an area from the sun's radiation?

Assessment Ideas

Have students identify an unknown source by experimenting with shielding, different sources, and different types of film.

Differentiated Learning/Enrichment

- Explore how autoradiography is used in DNA sequencing.
- Have students place various objects between the film and the source (coin, leaf, paperclips, etc.)

Enrichment Question

1. How did scientists use this concept in medicine?
   a. Compare the early usage of 1900's Medicine to today's application.

References

ANS Center for Nuclear Science and Technology Information

http://www.nuclearconnect.org/in-the-classroom/for-teachers/making-radiation-photographs

http://www.nuclearconnect.org/know-nuclear/applications/medical-uses

Autoradiographs Background:

http://www.wisegeek.com/what-is-an-autoradiograph.htm

Image Credits:

Figue 1: http://pubs.rsc.org/en/content/articlelanding/2010/mt/c003875j/unauth#!divAbstract

Figue 2: http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/mirai-en/2012/1_17.html

Making Atoms Visible

Autoradiographs

Student Data Collection ANSWER Sheet

Objectives

- To visually demonstrate the concepts of ionizing radiation.

Directions

1. Place a key, coin, or other metal object onto the face of the film sheet. Place a Coleman lantern mantle, fiesta-ware plate, or a radium-dial clock completely over the object
2. Allow the photos to develop for a week
3. Develop the film according to your teacher's instructions
4. Observe the resulting image that is developed
5. Attach developed film to this sheet and label

Questions

1. What caused the image to develop on the sheet of film?

   The gamma radiation from the lantern mantle.

2. How did you use shielding principles to identify what kind of radiation each source emits?

   By using lead or aluminum foil or other objects, you can determine what kind of radiation that goes through.

3. For sun paper activity, why does placing an object on the sun paper and putting sun screen on skin compare to protecting an area from the Sun's radiation.

   Both physically block the cosmic radiation from the sun.

Enrichment Question

1. How did scientists use this concept in medicine?
   a. Compare the early usage of 1900's medicine to today's application.

   Have student research about the uses of x-ray Radium and Radon and today's medical uses.

Making Atoms Visible

Autoradiographs

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objectives

- To visually demonstrate the concepts of ionizing radiation.

Directions

1. Place a key, coin, or other metal object onto the face of the film sheet. Place a Coleman lantern mantle, fiesta-ware plate, or a radium-dial clock completely over the object
2. Allow the photos to develop for a week
3. Develop the film according to your teacher's instructions
4. Observe the resulting image that is developed
5. Attach developed film to this sheet and label

Questions

1. What caused the image to develop on the sheet of film?
2. How did you use shielding principles to identify what kind of radiation each source emits?
3. For sun paper activity, how does placing an object on the sun paper and putting sun screen on skin compare to protecting an area from the Sun's radiation?

Enrichment Question

1. How did scientists use this concept in medicine?
   a. Compare the early usage of 1900's medicine to today's application.

Electroscope

Easily create an electroscope to detect static electricity and radiation.

Grade Level

5-12

Disciplinary Core Ideas (DCI, NGSS)

5-PS1-1, MS-PS1-1, MS-PS1-4, HS-PS1-8, HS-PS4-2, HS-PS4-5

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Foam plate
- Drinking straw
- Aluminum pie pan
- Aluminum foil
- Wool fabric
- Plastic ruler
- Student Data Collection Sheets
- Balloon
- Foam cup
- Glue
- Thread
- Masking tape
- Comb

Safety

- Students should use care when handling aluminum foil
- Students should use care when handling glue

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Use Models
- Plan and Carry out investigation
- Analyze and interpret data
- Using mathematics, information and computers
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objective

Make a simple instrument to detect static electricity and radiation.

Background

An electroscope is a very simple instrument that is used to detect the presence and magnitude of electric charge on a body such as static electricity. The type of electroscope detailed in this experiment is called a pith-ball electroscope. It was invented in 1754 by John Canton. The ball was originally made out of a spongy plant material called pith. Any lightweight neutrally conductive material, such as aluminum foil, can work as a pith ball. The pith ball is charged by touching it to a charged object. Since the ball is neutrally conductive and the electrons are not free to leave the atoms and move around the ball, when the charged ball is near a positively charged body, or source, the negatively charged electrons are attracted to it and the ball moves towards the source. Conversely, a negatively charged source will repel the electrons, and therefore the ball. Electroscopes can also be used to detect ionizing radiation. In this case, the radiation ionizes the air to be more positively or negatively charged depending on the type of radiation, and the ball will either be attracted or repelled by the source. This is how electroscopes can be used for detecting x-rays, cosmic rays, and radiation from radioactive material.

Teacher Lesson Plan:

Traditional

1. Lecture students on background
2. Provide them with materials and procedure
3. Provide balloons and radiation sources to test the electroscopes with

NGSS Guided Inquiry

1. After students construct electroscopes, have them experiment with charged and neutral sources to experiment.
2. Have students analyze radioactive sources with electroscopes.

Student Procedure

1. Make two holes near the bottom of a foam cup on opposite sides.
2. Push a plastic straw through the holes in the cup.
3. Turn the cup upside down and glue it onto the bottom of an aluminum pie pan. Make sure that the cup is right at the edge so that the straw sticks out over it. If you don't want to wait for the glue to dry, tape the cup to the pan.
4. Cut a piece of thread about 8 inches long and tie a few knots in one end of the thread.
5. Cut a one-inch square of aluminum foil. Use it to make a ball around the knots in the thread. The ball should be about the size of a marble. It should be just tight enough so it doesn't fall off the thread.
6. Tape the end of the thread to the straw so that the ball of foil hangs straight down from the straw, right next to the edge of the pan.
7. Tape the straw to the cup so it doesn't move around when you use the electroscope.
8. To test the electroscope, create some static electricity. An easy way to create static is by rubbing a balloon on a foam plate. When you do this, you "charge" the plate, which means you cause a buildup of electrons on one side. Even though the plate is charged, the electrons don't move because foam doesn't conduct electrons.
9. Once you've created some static electricity, place the electroscope on top of the foam plate. Be sure to hold the electroscope by the foam cup and not the aluminum pan, otherwise it won't work. Electrons move easily through metal, so when you put the pie pan onto the foam plate, the electrons travel into the pan and the foil ball. When the electroscope detects static electricity, the foil ball pushes out from the pan.
10. Try charging different objects, like a comb or ruler, with static electricity. Test them on the electroscope and record your results on the data sheet.

Data Collection

Attached Student Data Collection Sheets

Students should record which objects hold a charge and which do not

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. Which objects hold an electric charge? Which don't?
2. Why is the ball attracted or repelled by different objects?
3. How is using an electroscope similar to testing the charge of a balloon with your hair?
4. How is the electroscope able to detect radioactivity?

Assessment Ideas

Have students use electroscopes to discern between radioactive sources and nonradioactive sources.

Differentiated Learning/Enrichment

Have students compare radioactivity of different sources?

Enrichment Question

1. Why did John Canton invent the first electroscope and what did he use it for?

Further Resources

For additional background information:

Electroscope: http://science.howstuffworks.com/electroscope-info.htm

Electroscope: http://www.gdr.org/radiationdetectors.htm

Reference

ANS: http://www.ans.org/pi/resources/boyscouts/docs/electroscope-activity2013.pdf

Appendix A: Making an Alpha Source

1. A lantern mantel is tied at the bottom. Cut the string that pulls the mantel closed at the bottom and you should have a cylinder like in **Figure A**.

2. Cut up one side of the mantel to give you a flat sheet like in **Figure B**.

3. Grab one thread at the top or bottom of the mantel and pull it free. See **Figure B**.

4. Once the thread has been removed it will be wrinkly like in **Figure C**.

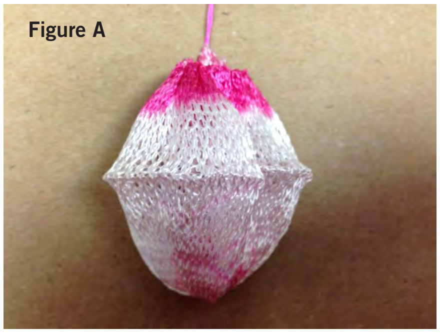
5. **Figure D** shows an electrical ring connector that you can buy at any auto part or electrical supply store. The recommended size is 9/16 inch in diameter with an insulated end. The insulated (vinyl) end works well with students, because they cannot get it frozen to their fingers when they remove it from the freezing cloud chamber.

6. Place a large dab of silicon cement onto the electrical connector and starting from the middle of the dab begin pushing the thread into the silicon cement. Simply spiral around and around with the thread making larger and larger circles. Be sure to leave at least half of the loops sticking above the silicon cement. You may find using tweezers makes this an easier task. **Figure F** shows a top view of what it will look like when finished.

7. Place the completed assembly on a piece of plastic wrap and allow the silicon cement to dry overnight. The silicon cement will not stick to the plastic wrap and can easily be peeled off.

8. After the silicon cement has dried bend the plastic end of the electrical connection up to act as a handle. See **Figure G**.

Figure A



Grab one thread at the top or bottom of the mantel and pull it free.

Figure B

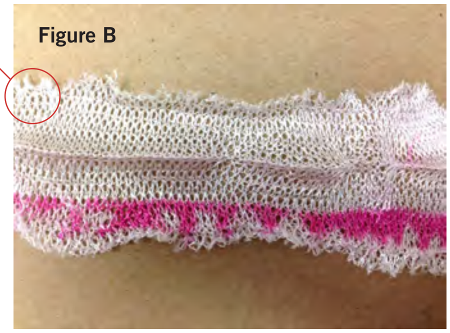


Figure C

Figure D

9/16" diameter & insulated end

Figure E

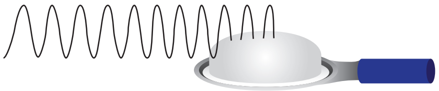


Figure F

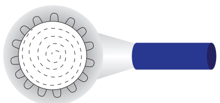
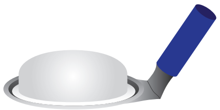


Figure G



Electroscope

Student Data Collection ANSWER Sheet

Objectives

- Make a simple instrument to detect static electrcity and radiation.

Directions

1. Make two holes near the bottom of a foam cup on opposite sides.
2. Push a plastic straw through the holes in the cup.
3. Turn the cup upside down and glue it onto the bottom of an aluminum pie pan. Make sure that the cup is right at the edge so that the straw sticks out over it. If you don't want to wait for the glue to dry, tape the cup to the pan.
4. Cut a piece of thread about 8 inches long and tie a few knots in one end of the thread.
5. Cut a one-inch square of aluminum foil. Use it to make a ball around the knots in the thread. The ball should be about the size of a marble. It should be just tight enough so it doesn't fall off the thread.
6. Tape the end of the thread to the straw so that the ball of foil hangs straight down from the straw, right next to the edge of the pan.
7. Tape the straw to the cup so it doesn't move around when you use the electroscope.
8. To test the electroscope, create some static electricity. An easy way to create static is by rubbing a balloon on a foam plate. When you do this, you "charge" the plate, which means you cause a buildup of electrons on one side. Even though the plate is charged, the electrons don't move because foam doesn't conduct electrons.
9. Once you've created some static electricity, place the electroscope on top of the foam plate. Be sure to hold the electroscope by the foam cup and not the aluminum pan, otherwise it won't work. Electrons move easily through metal, so when you put the pie pan onto the foam plate, the electrons travel into the pan and the foil ball. When the electroscope detects static electricity, the foil ball pushes out from the pan.
10. Try charging different objects, like a comb or ruler, with static electricity. Test them on the electroscope and record your results on your data sheet.

Electroscope

Student Data Collection ANSWER Sheet

Questions

1. Which objects hold an electric charge? Which don't?

   Objects that conduct electricity very well, such as metals and other compounds hold an electric charge. Covalent compounds do not conduct electricity very well, thus not allowing them to hold an electric charge.

2. Why is the ball attracted or repelled by different objects?

   It is electrostatically charged.

3. How is using an electroscope similar to testing the charge of a balloon with your hair?

   Both deal with electrostatic charges to attract or detract objects.

4. How is the electroscope able to detect radioactivity?

   The radioactive particles are charged particles, and are affected by the electrostatic charges of the electroscope.

Enrichment Question

1. Why did John Canton invent the first electroscope and what did he use it for?

   Students need to research background on John Canton.
   Answers may include that he was trying to make magnets without using natural magnets.

Making Atoms Visible

Electroscope

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objectives

- Make a simple instrument to detect static electrcity and radiation.

Directions

1. Make two holes near the bottom of a foam cup on opposite sides.
2. Push a plastic straw through the holes in the cup.
3. Turn the cup upside down and glue it onto the bottom of an aluminum pie pan. Make sure that the cup is right at the edge so that the straw sticks out over it. If you don't want to wait for the glue to dry, tape the cup to the pan.
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5. Cut a one-inch square of aluminum foil. Use it to make a ball around the knots in the thread. The ball should be about the size of a marble. It should be just tight enough so it doesn't fall off the thread.
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7. Tape the straw to the cup so it doesn't move around when you use the electroscope.
8. To test the electroscope, create some static electricity. An easy way to create static is by rubbing a balloon on a foam plate. When you do this, you "charge" the plate, which means you cause a buildup of electrons on one side. Even though the plate is charged, the electrons don't move because foam doesn't conduct electrons.
9. Once you've created some static electricity, place the electroscope on top of the foam plate. Be sure to hold the electroscope by the foam cup and not the aluminum pan, otherwise it won't work. Electrons move easily through metal, so when you put the pie pan onto the foam plate, the electrons travel into the pan and the foil ball. When the electroscope detects static electricity, the foil ball pushes out from the pan.
10. Try charging different objects, like a comb or ruler, with static electricity. Test them on the electroscope and record your results on your data sheet.

Making Visible – Electroscope
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. Which objects hold an electric charge? Which don't?
2. Why is the ball attracted or repelled by different objects?
3. How is using an electroscope similar to testing the charge of a balloon with your hair?
4. How is the electroscope able to detect radioactivity?

Enrichment Question

1. Why did John Canton invent the first electroscope and what did he use it for?

Totally Rad:
Flying Salesman and Twins Compete

Students try to determine radiation dose by reading passages and estimating the personal radiation dose of the people described in the passages. Students use a chart given to them by the instructor to estimate how different types of radiation exposure affect the total personal dose that a person receives.

Grade Level
5-12

Disciplinary Core Ideas (DCI)
5-ESS3-1, 3-5 ETS1-1, MS-PS3-2, HS-PS1-8, HS-PS3-2, HS-PS4-1, HS-PS4-4, HS-PS4-5

Time for Teacher Preparation
20-60 minutes – To gather materials

Activity Time:
20-60 minutes (1/2 to 1 class period)

Materials
- ANS Personal Radiation Dose Chart
- Paper
- Pen, Marker, or Pencil
- Student Data Collection Sheets

Safety
- No precautions required

Science and Engineering Practices (NGSS)
- Ask questions and define problems
- Plan and carry out investigation
- Analyze and interpret data
- Use mathematics and computational thinking
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objectives
Students try to determine radiation dose by reading passages and estimating the personal radiation dose of the people described in the passages. Students use a chart given to them by the instructor to estimate how different types of radiation exposure affect the total personal dose that a person receives. It is a great introduction to the scientific process of deducing, forming scientific theories, and then communicating with peers.

- To define the terms radiation and personal dose
- To determine how people receive different personal doses from different sources
- To determine how much radiation dose comes from nature and how much comes from the uses of radiation in society.
- To compare data

Background
We live in a radioactive world and always have. Radiation is all around us as part of our natural environment. The annual average dose of radiation per person in the United States is about 300 millirems (mrems). National standards allow up to 5,000 mrems/year dose for those who work with and around radioactive materials. A mrem of background radiation is equivalent to absorbing 100 ergs in 1 gram of material, e.g., body tissue.

Teacher Lesson Plan:

Traditional

Give students personal dose charts in the Student Data Worksheet.

Have students research:

1. Locate the Nuclear and Coal Plants in the U.S.
2. Establish altitudes for different parts of the U.S.
3. Locate the Colorado Plateau

Have students read the following scenarios and answer the questions.

Flying Salesman

William is excited that his position as a Health Food Salesperson of some excellent Herbal Products manufactured here in the United States allows him to travel to London, Spain, and South Africa. Bill's home base is in Pittsburgh, Pennsylvania. He lives in a quiet community of brick homes with tree-lined streets. He enjoys taking photographs, especially of nature for about 24 days a year with his telephoto lens.

In the past year, Bill has traveled 300 hours at 39,000 feet altitude to and from these three countries to set up businesses. To satisfy his passport requirements, he had to have a chest x-ray. First, he was given the Tuberculosis Saline Test. It gave a positive reaction. His doctor, a good one, had him take a chest x-ray as a follow-up. The x-ray photos were negative. He was really happy about his news. Bill found out that he has an allergic reaction to the chemicals in the Saline Test. His doctor advised never to let anyone inject him with the chemical again.

Twins Compete

The twins, Gina and George are very sports oriented. They live in a brick mansion in Salt Lake City, Utah. Gina is on the girls' basketball team and George is on the boys' team. In fact, they are good competitors on the swim and baseball teams during the spring and summer.

In the winter, things change a bit. George and Mom love to ski. It is not unusual for the two of them to spend at least five long weekends during the winter months on the slopes in Colorado. Oh! I forgot to tell you the family is very rich. However, Gina is not too keen on heights, so she does not ski. When her brother and mom go off to ski, she becomes a couch potato and watches television, then plays with her IPad non-stop until her twin returns home. One these skiing trips and other flights, George spends 20 hours at 39,000 feet each year, while Gina does not fly at all.

Dad provides well for his family. He makes certain that there is a check for radon in the basement so that it does not exceed about 200 mrem/yr. and checks to see that the smoke detectors are in good operating condition. He made sure that Gina kept her appointment with the dentist after she complained of pain from her lower braces. The dentist did an x-ray to make sure the braces were not cutting into her gums. It was the second one she had during that year. George did not have this problem with his braces. The family is exposed to what any average family is exposed to in background radiation.

NGSS Guided Inquiry

Explain about radiation and personal dose. Tell students to design their own experiment, using aspects of their own lives or to make up reasonable scenarios to estimate their personal dose.

You might suggest that the students experiment with sharing their results and scenarios.

Student Procedure

You were given personal dose charts.

Research:

1. Locate the Nuclear and Coal Plants in the U.S.
2. Establish altitudes for different parts of the U.S.
3. Locate the Colorado Plateau

Read the following scenarios and answer the questions.

Scenario 1 – The Flying Salesman

William is excited that his position as a Health Food Salesperson of some excellent Herbal Products manufactured here in the United States allows him to travel to London, Spain, and South Africa. Bill's home base is in Pittsburgh, Pennsylvania. He lives in a quiet community of brick homes with tree-lined streets. He enjoys taking photographs, especially of nature for about 24 days a year with his telephoto lens.

In the past year, Bill has traveled 300 hours at 39,000 feet altitude to and from these three countries to set up businesses. To satisfy his passport requirements, he had to have a chest x-ray. First, he was given the Tuberculosis Saline Test. It gave a positive reaction. His doctor, a good one, had him take a chest x-ray as a follow-up. The x-ray photos were negative. He was really happy about his news. Bill found out that he has an allergic reaction to the chemicals in the Saline Test. His doctor advised never to let anyone inject him with the chemical again.

Scenario 2 – The Twins Compete

The twins, Gina and George are very sports oriented. They live in a brick mansion in Salt Lake City, Utah. Gina is on the girls' basketball team and George is on the boys' team. In fact, they are good competitors on the swim and baseball teams during the spring and summer.

In the winter, things change a bit. George and Mom love to ski. It is not unusual for the two of them to spend at least five long weekends during the winter months on the slopes in Colorado. Oh! I forgot to tell you the family is very rich. However, Gina is not too keen on heights, so she does not ski. When her brother and mom go off to ski, she becomes a couch potato and watches

television, then plays with her iPad non-stop until her twin returns home. One these skiing trips and other flights, George spends 20 hours at 39,000 feet each year, while Gina does not fly at all.

Dad provides well for his family. He makes certain that there is a check for radon in the basement so that it does not exceed about 200 mrem/yr. and checks to see that the smoke detectors are in good operating condition. He made sure that Gina kept her appointment with the dentist after she complained of pain from her lower braces. The dentist did an x-ray to make sure the braces were not cutting into her gums. It was the second one she had during that year. George did not have this problem with his braces. The family is exposed to what any average family is exposed to in background radiation.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. What dose of radiation has Bill been exposed to this past year?
2. How does the twin's exposure to radiation compare for the year?
3. How does Bill's personal radiation dose compare to the twins?
4. What is your personal radiation dose for this year?
   a. How does your personal radiation dose compare to that of your classmates?
5. Is smoking a pack of cigarettes per day more dangerous than working with and around radioactive materials?

Assessment Ideas

- Have the students discuss if where you live affects the annual radiation dose
- Have the students describe three things that affect the amount of radiation dose a person receives

Differentiated Learning/Enrichment

Repeat experiment using more complicated sources of radiation exposure, i.e. transportation of radioactive materials in your area, etc.

Enrichment Questions

1. How many packs of cigarettes could you smoke in a year to fall within the maximum exposure that radiation workers are allowed to receive?
2. How far would a pilot have to fly every year to receive more than 5,000 mrems of radiation?

Further Resources

ANS Personal Radiation Dose Chart (print)

http://www.nuclearconnect.org/wp-content/uploads/2014/04/Radiation-Dose-Chart-web.pdf

ANS Personal Radiation Dose Chart (on-line)

http://www.ans.org/pi/resources/dosechart/

The ANS Center for Nuclear Science and Technology Information
http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

For locations of the Nuclear and Coal Plants in the U.S.:
http://www.energyjustice.net/map/searchobject.php?gsTable=facility&gsSearchtype=themap

Personal Dose

Further Resources:

Radiation From:	Average Dose (mrems)	
Where You Live		
Cosmic Radiation from Outer Space at 5,000 feet		+47
Terrestrial Radiation from the land:		
States bordering Gulf or Atlantic Coasts	+23	
New Mexico, Utah, Colorado, or Wyoming	+90	
All other states	+46	
If you live in a stone, brick, concrete or adobe building.	+7	
What You Eat, Drink, and Breathe		
Internal radiation from food and water and your body	+40	
From the radon in the air we breathe	+228	
How You Live and Choices You Make		
Jet plane travel for each 1,000 miles	+1	
The following are man-made sources or radiation exposure		
Fallout from weapons testing (actually less than 1)		+1
Use a computer monitor	+1	
For smoke detectors in your home (0.008)	+0	
Transportation of radioactive materials (0.1)	+0	
Low Level Radioactive Waste Burial Site	+1	
Live within 50 miles of coal-fired power plant (0.03)	+0	
Enhanced sources (natural radiation increased by human activity)		
Consumer products and enhanced sources such as radon in water and second hand smoke		+10
Smoking 1 pack of cigarettes per day	+8000	
Live within 50 miles of a nuclear reactor (0.009)	+0	
Medical Exposures		
Diagnostic X-rays (dental, broken arms, legs, etc.) Average	+40	
Nuclear medical procedures (thyroid scan)	+14	
Cancer Treatments (range from 40,000 to 70,000 mrem)		
TOTAL ANNUAL DOSE		

- Personal dose chart to estimate average annual dose in mrems.
- New Mexico's "Radiation Education and Awareness Program (REAP)"

Totally Rad: Flying Salesman and Twins Compete

Student Data Collection ANSWER Sheet

Objectives

- To define the terms radiation and personal dose
- To determine how people receive different personal doses from different sources
- To determine how much radiation dose comes from nature and how much comes from the uses of radiation in society.
- To compare data

Directions

You were given personal dose charts.

Research:

1. Locate the Nuclear and Coal Plants in the U.S.
2. Establish altitudes for different parts of the U.S.
3. Locate the Colorado Plateau

Read the following scenarios and answer the questions.

Scenario 1 – The Flying Salesman

Bill is excited that his position as a Health Food Salesperson of some excellent Herbal Products manufactured here in the United States allows him to travel to London, Spain, and South Africa. Bill's home base is in Pittsburgh, Pennsylvania. He lives in a quiet community of brick homes with tree-lined streets. He enjoys taking photographs, especially of nature for about 24 days a year with his telephoto lens.

In the past year, Bill has traveled 300 hours at 39,000 feet altitude to and from these three countries to set up businesses. To satisfy his passport requirements, he had to have a chest x-ray. First, he was given the Tuberculosis Saline Test. It gave a positive reaction. His doctor, a good one, had him take a chest x-ray as a follow-up. The x-ray photos were negative. He was really happy about his news. Bill found out that he has an allergic reaction to the chemicals in the Saline Test. His doctor advised never to let anyone inject him with the chemical again.

Scenario 2 – The Twins Compete

The twins, Gina and George are very sports oriented. They live in a brick mansion in Salt Lake City, Utah. Gina is on the girls' basketball team and George is on the boys' team. In fact, they are good competitors on the swim and baseball teams during the spring and summer.

In the winter, things change a bit. George and Mom love to ski. It is not unusual for the two of them to spend at least five long weekends during the winter months on the slopes in Colorado. Oh! I forgot to tell you the family is very rich. However, Gina is not too keen on heights, so she does not ski. When her brother and mom go off to ski, she becomes a couch potato and watches television, then plays with her iPad non-stop until her twin returns home. One these skiing trips and other flights, George spends 20 hours at 39,000 feet each year, while Gina does not fly at all.

Dad provides well for his family. He makes certain that there is a check for radon in the basement so that it does not exceed about 200 mrem/yr. and checks to see that the smoke detectors are in good operating condition. He made sure that Gina kept her appointment with the dentist after she complained of pain from her lower braces. The dentist did an e-ray to make sure the braces were not cutting into her gums. It was the second one she had during that year. George did not have this problem with his braces. The family is exposed to what any average family is exposed to in background radiation.

Questions:

1. How does Bill's personal radiation dose compare to the twins?

   ~476 as compared to ~387-395

2. What is your personal radiation dose for this year?

   Varies depending on altitude, air travel, and medical dosages. Will be no less than 310 mrem, which is living at sea level, in a state that borders the Gulf or Atlantic Coasts, and your house is not made of stone, adobe, brick or concrete.

   a. How does your personal radiation dose compare to that of your classmates?

      Varies depending on house construction, travel, and medical diagnostic tests. Will be no less than 310 mrem.

      Standards allow exposure to as much as 5,000 mrems per year for those who work with and around radioactive material.

3. Is smoking a pack of cigarettes per day more dangerous than working with and around radioactive materials?

   Yes! It adds 18 mrem because the tobacco leaves used in making cigarettes contain radioactive material, particularly lead-210 and polonium-210. The radionuclide content of tobacco leaves depends heavily on soil conditions and fertilizer use.

   Soils that contain elevated radium lead to high radon gas emanations rising into the growing tobacco crop. Radon rapidly decays into a series of solid, highly radioactive metals (radon decay products). These metals cling to dust particles which in turn are collected by the sticky tobacco leaves. The sticky compound that seeps from the trichomes is not water soluble, so the particles do not wash off in the rain. There they stay, through curing process, cutting, and manufacture into cigarettes. Lead-210 and Polonium-210 can be absorbed into tobacco leaves directly from the soil. But more importantly, fine, sticky hairs (called trichomes) on both sides of tobacco leaves grab airborne radioactive particles.

   For example, phosphate fertilizers, favored by the tobacco industry, contain radium and its decay products (including lead-210 and polonium-210). When phosphate fertilizer is spread on tobacco fields year after year, the concentration of lead-210 and polonium-210 in the soil rises.

Totally Rad: Flying Salesman and Twins Compete

Student Data Collection ANSWER Sheet

Factors	Common Sources of Radiation	Bill's Annual Dose (mrems)	Gina's Annual Dose (mrems)	George's Annual Dose (mrems)	Your Annual Dose (mrems)
Where You Live	**Cosmic Radiation** (from outer space) Exposure depends on your elevation (how much air is above you to block radiation). Amounts are listed in mrem (per year). At sea level.....26 mrem; 0-1000 ft........28; 1-2000 ft........31; 2-3000 ft........35; 3-4000 ft........41; 4-5000 ft .....47 mrem; 5-6000 ft .....52; 6-7000 ft .....66; 7-8000 ft .....79; 8-9000 ft .....96 (Elevation of cities (in feet): Atlanta 1050; Chicago 595; Dallas 435; Denver 5280; las Vegas 2000; Minneapolis 815; Pittsburg 1200; St.louis 455; Salt lake City 4400; Spokane 1890.)	28 mrem	47 mrem	47 mrem	mrem
	Terrestrial (from the ground) If you live in a state that borders the Gulf or Atlantic Coasts, add 16 mrem If you live in the Colorado Plateau area, add 63 mrem If you live anywhere else in the continental US, add 30 mrem	30 mrem	63 mrem	63 mrem	mrem
	House Construction If you live in a stone, adobe, brick or concrete building, add 7 mrem	7 mrem	7 mrem	7 mrem	mrem
	Power Plants If you live within 50 miles of a nuclear power plant, add 0.01 mrem If you live within 50 miles of a coal-fired power plant, add 0.03 mrem	0.01 mrem	0.03 mrem	0.03 mrem	mrem
Food, Water, Air	**Internal Radiation**[2] From food (Carbon-14 and Potassium-40) & from water (radon dissolved in water)	40 mrem	40 mrem	40 mrem	40 mrem
	From air (radon)	228 mrem	228 mrem	228 mrem	228 mrem
How You Live	Jet Plane Travel ....0.5 mrem per hour in the air	150 mrem	mrem	10 mrem	mrem
	If you have porcelain crowns or false teeth[3] .... 0.07 mrem	mrem	mrem	mrem	mrem
	If you go past luggage x-ray inspection at airport....... 0.002 mrem	(~6) 0.012 mrem	mrem	(~10) 0.020 mrem	mrem
	If you view a TV or computer screen which uses CRT technology[4] .... 1 mrem	1 mrem	1 mrem	mrem	mrem
	If you smoke 1/2 pack of cigarettes every day of the year.. add 18 mrem	mrem	mrem	mrem	mrem
	If you have a smoke detector...................................... 0.008 mrem	0.008 mrem	0.008 mrem	0.008 mrem	mrem
Medical Tests	**Medical Diagnostic Tests –** Number of millirems per procedure[5] X-Rays: Chest-10 mrem, Mammography (2 views)-72, Skull-10, Cervical Spine-20, Lumbar Spine-600, Upper GI-600, Abdomen (kidney/bladder)-700, Barium Enema-800, Pelvis-60, Hip-70, Dental Bitewing/Image-0.5, Extremity (hand/foot)-0.5	20 mrem	1.0 mrem	mrem	mrem
	CT Scans: Head-200 mrem, Chest-700, Abdomen/Pelvis-1000, Extremity-10, Angiography (heart)-2000, Angiography (head)-500, Spine-1000, Whole Body-1000, Cardiac-2000	mrem	mrem	mrem	mrem
	Your Estimated Annual Radiation Dose	476.03 mrem	387.038 mrem	395.058 mrem	mrem

Totally Rad: Flying Salesman and Twins Compete

Student Data Collection ANSWER Sheet

Factors	Common Sources of Radiation	Your Annual Dose (mrems)
Where You Live	**Cosmic Radiation** (from outer space) Exposure depends on your elevation (how much air is above you to block radiation). Amounts are listed in mrem (per year). At sea level........26 mrem; 0-1000 ft...........28; 1-2000 ft...........31; 2-3000 ft ....35 mrem; 3-4000 ft ....41; 4-5000 ft ....47; 5-6000 ft ....52; 6-7000 ft ....66 mrem; 7-8000 ft ....79; 8-9000 ft ....96 (Elevation of cities (in feet): Atlanta 1050; Chicago 595; Dallas 435; Denver 5280; las Vegas 2000; Minneapolis 815; Pittsburg 1200; St.louis 455; Salt lake City 4400; Spokane 1890.)	______ mrem
	Terrestrial (from the ground) If you live in a state that borders the Gulf or Atlantic Coasts, add 16 mrem If you live in the Colorado Plateau area, add 63 mrem If you live anywhere else in the continental US, add 30 mrem	______ mrem
	House Construction If you live in a stone, adobe, brick or concrete building, add 7 mrem	______ mrem
	Power Plants If you live within 50 miles of a nuclear power plant, add 0.01 mrem If you live within 50 miles of a coal-fired power plant, add 0.03 mrem	______ mrem
Food, Water, Air	**Internal Radiation**[2] From food (Carbon-14 and Potassium-40) & from water (radon dissolved in water)	40 mrem
	From air (radon)	228 mrem
How You Live	Jet Plane Travel ....0.5 mrem per hour in the air	______ mrem
	If you have porcelain crowns or false teeth[3] ....0.07 mrem	______ mrem
	If you go past luggage x-ray inspection at airport........0.002 mrem	______ mrem
	If you view a TV or computer screen which uses CRT technology[4]........1 mrem	______ mrem
	If you smoke 1/2 pack of cigarettes every day of the year ....add 18 mrem	______ mrem
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Medical Tests	**Medical Diagnostic Tests** – Number of millirems per procedure[5] X-Rays: Chest-10 mrem, Mammography (2 views)-72, Skull-10, Cervical Spine-20, Lumbar Spine-600, Upper GI-600, Abdomen (kidney/bladder)-700, Barium Enema-800, Pelvis-60, Hip-70, Dental Bitewing/Image-0.5, Extremity (hand/foot)-0.5	______ mrem
	CT Scans: Head-200 mrem, Chest-700, Abdomen/Pelvis-1000, Extremity-10, Angiography (heart)-2000, Angiography (head)-500, Spine-1000, Whole Body-1000, Cardiac-2000	______ mrem
	Your Estimated Annual Radiation Dose	______ mrem

We live in a radioactive world - humans always have. Radiation is part of our natural environment. We are exposed to radiation from materials in the earth itself, from naturally occurring radon in the air, from outer space, and from inside our own bodies (as a result of the food and water we consume). This radiation is measured in units called millirems (mrems). The average dose per person from all sources is about 620 mrems per year. It is not, however, uncommon for any of us to receive less or more than that in a given year (largely due to medical procedures we may undergo). Standards allow exposure to as much as 5,000 mrems a year for those who work with and around radioactive material.[1]

1. See http://www.nrc.gov/about-nrc/radiation/health-effects/info.html
2. Average values.
3. Some of the radiation sources listed in this chart result in an exposure to only part of the body. For example, false teeth or crowns result in a radiation dose to the mouth. The annual dose numbers given here represent the "effective dose" to the whole body.
4. The value is less than 1, but adding a value of 1 would be reasonable.
5. Exposures for medical tests vary depending upon equipment and the patient. The doses listed are an average for an actual exposure.

Primary sources for this information are National Council on Radiation Protection and Measurements Reports: #92 Public Radiation Exposure from Nuclear Power Generation in the United States (1987); #93 Ionizing Radiation Exposure of the Population of the United States (1987); #94 Exposure of the Population in the United States and Canada from Natural Background Radiation (1987); #95 Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources (1987); #100 Exposure of the U.S. Population from Diagnostic Medical Radiation (1989); and #160 Ionizing Radiation Exposure of the Population of the United States (2009).

Personal Dose

Name: ______________________________

Date: ______________________________

Totally Rad:

Flying Salesman and Twins Compete

Student Data Collection Sheet

Objectives

- To define the terms radiation and personal dose
- To determine how people receive different personal doses from different sources
- To determine how much radiation dose comes from nature and how much comes from the uses of radiation in society.
- To compare data

Directions

You were given personal dose charts.

Research:

1. Locate the Nuclear and Coal Plants in the U.S.
2. Establish altitudes for different parts of the U.S.
3. Locate the Colorado Plateau

Read the following scenarios and answer the questions.

Personal Dose – Totally Rad: Flying Salesman and Twins Compete

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Scenario 1 – The Flying Salesman

Bill is excited that his position as a Health Food Salesperson of some excellent Herbal Products manufactured here in the United States allows him to travel to London, Spain, and South Africa. Bill's home base is in Pittsburgh, Pennsylvania. He lives in a quiet community of brick homes with tree-lined streets. He enjoys taking photographs, especially of nature for about 24 days a year with his telephoto lens.

In the past year, Bill has traveled 300 hours at 39,000 feet altitude to and from these three countries to set up businesses. To satisfy his passport requirements, he had to have a chest x-ray. First, he was given the Tuberculosis Saline Test. It gave a positive reaction. His doctor, a good one, had him take a chest x-ray as a follow-up. The x-ray photos were negative. He was really happy about his news. Bill found out that he has an allergic reaction to the chemicals in the Saline Test. His doctor advised never to let anyone inject him with the chemical again.

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The twins, Gina and George are very sports oriented. They live in a brick mansion in Salt Lake City, Utah. Gina is on the girls' basketball team and George is on the boys' team. In fact, they are good competitors on the swim and baseball teams during the spring and summer.

In the winter, things change a bit. George and Mom love to ski. It is not unusual for the two of them to spend at least five long weekends during the winter months on the slopes in Colorado. Oh! I forgot to tell you the family is very rich. However, Gina is not too keen on heights, so she does not ski. When her brother and mom go off to ski, she becomes a couch potato and watches television, then plays with her iPad non-stop until her twin returns home. One these skiing trips and other flights, George spends 20 hours at 39,000 feet each year, while Gina does not fly at all.

Dad provides well for his family. He makes certain that there is a check for radon in the basement so that it does not exceed about 200 mrem/yr. and checks to see that the smoke detectors are in good operating condition. He made sure that Gina kept her appointment with the dentist after she complained of pain from her lower braces. The dentist did an e-ray to make sure the braces were not cutting into her gums. It was the second one she had during that year. George did not have this problem with his braces. The family is exposed to what any average family is exposed to in background radiation.

Personal Dose – Totally Rad:
Flying Salesman and Twins Compete
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions:

1. How does Bill's personal radiation dose compare to the twins?

2. What is your personal radiation dose for this year?

    a. How does your personal radiation dose compare to that of your classmates?

3. Is smoking a pack of cigarettes per day more dangerous than working with and around radioactive materials?

Personal Dose – Totally Rad: Flying Salesman and Twins Compete

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Factors	Common Sources of Radiation	Bill's Annual Dose (mrems)	Gina's Annual Dose (mrems)	George's Annual Dose (mrems)	Your Annual Dose (mrems)
Where You Live	**Cosmic Radiation** (from outer space) Exposure depends on your elevation (how much air is above you to block radiation). Amounts are listed in mrem (per year). At sea level.....26 mrem 0-1000 ft........28 1-2000 ft........31 2-3000 ft........35 3-4000 ft........41 4-5000 ft .....47 mrem 5-6000 ft .....52 6-7000 ft .....66 7-8000 ft .....79 8-9000 ft .....96 (Elevation of cities (in feet): Atlanta 1050; Chicago 595; Dallas 435; Denver 5280; las Vegas 2000; Minneapolis 815; Pittsburg 1200; St.louis 455; Salt lake City 4400; Spokane 1890.)	____ mrem	____ mrem	____ mrem	____ mrem
	Terrestrial (from the ground) If you live in a state that borders the Gulf or Atlantic Coasts, add 16 mrem If you live in the Colorado Plateau area, add 63 mrem If you live anywhere else in the continental US, add 30 mrem	____ mrem	____ mrem	____ mrem	____ mrem
	House Construction If you live in a stone, adobe, brick or concrete building, add 7 mrem	____ mrem	____ mrem	____ mrem	____ mrem
	Power Plants If you live within 50 miles of a nuclear power plant, add 0.01 mrem If you live within 50 miles of a coal-fired power plant, add 0.03 mrem	____ mrem	____ mrem	____ mrem	____ mrem
Food, Water, Air	**Internal Radiation**[2] From food (Carbon-14 and Potassium-40) & from water (radon dissolved in water)	40 mrem	40 mrem	40 mrem	40 mrem
	From air (radon)	228 mrem	228 mrem	228 mrem	228 mrem
How You Live	Jet Plane Travel ....0.5 mrem per hour in the air	____ mrem	____ mrem	____ mrem	____ mrem
	If you have porcelain crowns or false teeth[3] .... 0.07 mrem	____ mrem	____ mrem	____ mrem	____ mrem
	If you go past luggage x-ray inspection at airport....... 0.002 mrem	____ mrem	____ mrem	____ mrem	____ mrem
	If you view a TV or computer screen which uses CRT technology[4] .... 1 mrem	____ mrem	____ mrem	____ mrem	____ mrem
	If you smoke 1/2 pack of cigarettes every day of the year.. add 18 mrem	____ mrem	____ mrem	____ mrem	____ mrem
	If you have a smoke detector..................................... 0.008 mrem	____ mrem	____ mrem	____ mrem	____ mrem
Medical Tests	**Medical Diagnostic Tests –** Number of millirems per procedure[5] X-Rays: Chest-10 mrem, Mammography (2 views)-72, Skull-10, Cervical Spine-20, Lumbar Spine-600, Upper GI-600, Abdomen (kidney/bladder)-700, Barium Enema-800, Pelvis-60, Hip-70, Dental Bitewing/Image-0.5, Extremity (hand/foot)-0.5	____ mrem	____ mrem	____ mrem	____ mrem
	CT Scans: Head-200 mrem, Chest-700, Abdomen/Pelvis-1000, Extremity-10, Angiography (heart)-2000, Angiography (head)-500, Spine-1000, Whole Body-1000, Cardiac-2000	____ mrem	____ mrem	____ mrem	____ mrem
	Your Estimated Annual Radiation Dose	____ mrem	____ mrem	____ mrem	____ mrem

Personal Dose – Totally Rad: Flying Salesman and Twins Compete

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Factors	Common Sources of Radiation	Your Annual Dose (mrems)
Where You Live	**Cosmic Radiation** (from outer space) Exposure depends on your elevation (how much air is above you to block radiation). Amounts are listed in mrem (per year). At sea level........26 mrem; 0-1000 ft...........28; 1-2000 ft...........31 2-3000 ft ....35 mrem; 3-4000 ft ....41; 4-5000 ft ....47; 5-6000 ft ....52 6-7000 ft ....66 mrem; 7-8000 ft ....79; 8-9000 ft ....96 (Elevation of cities (in feet): Atlanta 1050; Chicago 595; Dallas 435; Denver 5280; las Vegas 2000; Minneapolis 815; Pittsburg 1200; St.louis 455; Salt lake City 4400; Spokane 1890.)	________ mrem
	Terrestrial (from the ground) If you live in a state that borders the Gulf or Atlantic Coasts, add 16 mrem If you live in the Colorado Plateau area, add 63 mrem If you live anywhere else in the continental US, add 30 mrem	________ mrem
	House Construction If you live in a stone, adobe, brick or concrete building, add 7 mrem	________ mrem
	Power Plants If you live within 50 miles of a nuclear power plant, add 0.01 mrem If you live within 50 miles of a coal-fired power plant, add 0.03 mrem	________ mrem
Food, Water, Air	**Internal Radiation**[2] From food (Carbon-14 and Potassium-40) & from water (radon dissolved in water)	________ mrem
	From air (radon)	40 mrem
How You Live	Jet Plane Travel ....0.5 mrem per hour in the air	228 mrem
	If you have porcelain crowns or false teeth[3] ....0.07 mrem	________ mrem
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	If you view a TV or computer screen which uses CRT technology[4]..............1 mrem	________ mrem
	If you smoke 1/2 pack of cigarettes every day of the year ....add 18 mrem	________ mrem
	If you have a smoke detector....................0.008 mrem	________ mrem
Medical Tests	**Medical Diagnostic Tests** – Number of millirems per procedure[5] X-Rays: Chest-10 mrem, Mammography (2 views)-72, Skull-10, Cervical Spine-20, Lumbar Spine-600, Upper GI-600, Abdomen (kidney/bladder)-700, Barium Enema-800, Pelvis-60, Hip-70, Dental Bitewing/Image-0.5, Extremity (hand/foot)-0.5	________ mrem
	CT Scans: Head-200 mrem, Chest-700, Abdomen/Pelvis-1000, Extremity-10, Angiography (heart)-2000, Angiography (head)-500, Spine-1000, Whole Body-1000, Cardiac-2000	________ mrem
	Your Estimated Annual Radiation Dose	________ mrem

We live in a radioactive world - humans always have. Radiation is part of our natural environment. We are exposed to radiation from materials in the earth itself, from naturally occurring radon in the air, from outer space, and from inside our own bodies (as a result of the food and water we consume). This radiation is measured in units called millirems (mrems). The average dose per person from all sources is about 620 mrems per year. It is not, however, uncommon for any of us to receive less or more than that in a given year (largely due to medical procedures we may undergo). Standards allow exposure to as much as 5,000 mrems a year for those who work with and around radioactive material.[1]

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Growing Irradiated Bean Seeds

What happens to seeds that are exposed to very high levels of radiation? Will they grow normally?

Grade Level
5-12

Disciplinary Core Ideas (DCI, NGSS)
5-PS1-3, 5-ESS3-1, 3-5 ETS1-1, MS-ETS1-2, MS-ETS1-3, HS-PS4-4, HS-ESS2-3

Time for Teacher Preparation
30-60 minutes – To gather materials and set-up

Activity Time:
1-2 Weeks Minimum. Passive observations as beans grow.

Materials
- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Mung bean seed
- Irradiated Mung bean seeds (50,000; 100,000; 150,000 rad exposure)
- Potting soil
- Pots (2" to 3" pots)
- Small metric rulers

Safety
- Students should not put bean seeds, soil, pots, or metric rulers in their mouths due to choking hazard.
- Students should not try eating bean seeds or irradiated bean seeds.

Science and Engineering Practices (NGSS)
- Ask questions and define problems
- Plan and carry out investigation
- Analyze and interpret data
- Use mathematics and computational thinking
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objectives
The students develop a procedure to study the effects of radiation on mung bean seeds and other irradiated seeds. Students will observe and record data on the germination and development of the plants. Student data, results, and conclusions will be presented, supported, and defended by the students to the class.

- To define the terms radiation and irradiation
- To determine how irradiation affects the growth of bean seeds
- To determine how much radiation dose comes from nature and how much comes from the uses of radiation in society.
- To compare data

Background
Irradiation is becoming increasingly more popular in the treatment of foods to kill bacteria, diseases and pests. A fear of radiation causes some people to believe that food that is irradiated becomes radioactive. The irradiated bean seeds in this experiment have been exposed to various levels of gamma radiation, but are not radioactive and are completely safe to handle.

You cannot tell how much radiation the seeds were given by looking at them. These seeds were harvested and irradiated after the plants were mature. However, you will be able to observe differences in the plants growing from these seeds. Each seed contains an embryo plant. When the gamma radiation passed through these seeds, it damaged some of the cells in the embryo. The greater the radiation, the more cells were damaged. Therefore, the resulting plants grown from seeds with greater exposures will show more abnormalities than those with lower exposures.

Teacher Lesson Plan:

Traditional

Split students into groups of four and give each group four sets of bean seeds (control; 50,000; 100,000; 150,000 rad). Have each group plant their seeds in separate pots and set up a table to chart and graph the growth of the seeds over the next couple of weeks. Students should record height and observations of their beans at least twice a week. Remind students to water their beans as frequently as needed in order to take care of their plants.

It might be helpful to stress that the beans have been irradiated, but are not radioactive.

Students may also grow the seeds in test tubes of water and plant them once they have germinated.

NGSS Guided Inquiry

Have students design an experiment to discover about how much radiation each of their seeds was exposed to.

Student Procedure

1. Plant seeds into separate pots and water until the soil is moist.
   - Alternatively, grow the seeds submerged in water inside of test tubes until they germinate and then pot them.
2. Set up a data table to record height and observations of the bean seedlings. Observations should be made at least twice per week.
3. Take care of your plants by watering them as frequently as needed.
4. Graph data from your data table and deduce which seeds received which dose of radiation (control; 50,000; 100,000; 150,000 rad)
5. Add a step to include listing the variables which must be controlled in this experiment.

   Examples of this include:
   - exposure to sun or artificial light
   - temperature of the surroundings
   - whether seed is grown in soil or in water
   - the amount of water added to the soil (students should measure the added water in milliliters).

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. What happened? Why do you think the things you observed occurred? Were your observations and conclusions different from other students? Why? Who's "right?"
2. 100,000 rads or 150,000 rads is enough to kill a human. Did it kill all the plants? What do you think are some possible explanations?

Assessment Ideas

- Test the student's observations against the actual irradiated exposure of each plant.

Differentiated Learning/Enrichment

- Have students make slides of each of the beans for viewing under a microscope.
- Try getting a couple more generations from the plants to observe successive generations.

Enrichment Questions

1. If radiation increases on earth, what effects do you think it will that have on plant growth? On other organisms? On humans?
2. What do you think happened to the cells of the irradiated Mung bean plants?
3. Why do we use irradiation to prevent food from spoiling?

Further Resources

The ANS Center for Nuclear Science and Technology Information

http://www.nuclearconnect.org/know-nuclear/applications/food

Purchase Irradiated Mung Seeds through Ward's Science (#6730926)

https://www.wardsci.com

For similar experiments:

http://www.hometrainingtools.com/images/art/science-fair-guide.pdf

Citations for Reference:

- Los Alamos National Laboratory (1992). **Detecting the Invisible: The SWOOPE Radiation and Radon Discovery Unit**. Los Alamos National Laboratory.

Growing Irradiated Bean Seeds

Student Data Collection ANSWER Sheet

Objectives

- To define the terms radiation and irradiation
- To determine how irradiation affects the growth of bean seeds
- To determine how much radiation dose comes from nature and how much comes from the uses of radiation in society.
- To compare data

Instructions

1. Plant seeds into separate pots and water until the soil is moist.
   - Alternatively, grow the seeds submerged in water inside of test tubes until they germinate and then pot them.
2. Set up a data table to record height and observations of the bean seedlings. Observations should be made at least twice per week.
3. Take care of your plants by watering them as frequently as needed.
4. Graph data from your data table and deduce which seeds received which dose of radiation (control; 50,000; 100,000; 150,000 rad)
5. List the variables you will control in this experiment.
6. Record the source of light, temperature of surroundings, amount of soil, amount of water, amount of radiation for each seed planted.

Growing Irradiated Bean Seeds

Student Data Collection ANSWER Sheet

Seed 1 - Control			Seed 2 - 50,000 rad		
Height	Observation	Drawing	Height	Observation	Drawing

Seed 3 - 100,000 rad			Seed 4 - 150,000 rad		
Height	Observation	Drawing	Height	Observation	Drawing

Growing Irradiated Bean Seeds

Student Data Collection ANSWER Sheet

Questions

1. What happened? Why do you think the thing you observed occurred? Were your observations and conclusions different from other students? Why? Who's "right"?

   Results will vary.

2. 100,000 rads or 150,000 rads is enough to kill a human. Did it kill all the plants? What do you think are some possible explanations?

   No, it should not have killed all the plants. Possible explanations could include either size of the seed or complexity of the DNA contained in the seed. The seed is non-living and cannot repair DNA whereas humans are alive and can potentially repair DNA.

3. If radiation increases on earth, what effects do you think it will that have on plant growth? On other organisms? On humans?

   What was seen in this experiment is that the greater the radiation, the more plant cells were damaged. Therefore, the resulting plants grown from seeds with greater exposures will show more abnormalities than those with lower exposures.

   Radiation hormesis is the hypothesis that low doses of ionizing radiation (within the region of and just above natural background levels) are beneficial, stimulating the activation of repair mechanisms that protect against disease, that are not activated in absence of ionizing radiation.

Questions

4. What do you think happened to the cells of the irradiated mung bean plants?

   Gamma radiation passed through the seeds, and either had no effect, damaged the cells in the embryo or the actual DNA structure itself.

5. List the controls in this experiment. What is the variable in this experiment?

   The controls are the non-irradiated seed and the amount of water and sunlight supplied to each seed. The variables in the experiment are the amount of irradiation that the seeds were exposed to.

6. What is the general rule about the number of variables which can change when testing the effect in an experiment?

   An experiment is typically carried out by manipulating a variable, called the independent variable, affecting the experimental group. The effect that the researcher is interested in, the dependent variable(s), is measured.

   Identifying and controlling non-experimental factors which the researcher does not want to influence the effects, is crucial to drawing a valid conclusion. This is often done by controlling variables, if possible, or randomizing variables to minimize effects that can be traced back to third variables. Researchers only want to measure the effect of the independent variable(s) when conducting an experiment, allowing them to conclude that this was the reason for the effect.

Growing Irradiated Bean Seeds

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objectives

- To define the terms radiation and irradiation
- To determine how irradiation affects the growth of bean seeds
- To determine how much radiation dose comes from nature and how much comes from the uses of radiation in society.
- To compare data

Instructions

1. Plant seeds into separate pots and water until the soil is moist.
   - Alternatively, grow the seeds submerged in water inside of test tubes until they germinate and then pot them.
2. Set up a data table to record height and observations of the bean seedlings. Observations should be made at least twice per week.
3. Take care of your plants by watering them as frequently as needed.
4. Graph data from your data table and deduce which seeds received which dose of radiation (control; 50,000; 100,000; 150,000 rad)
5. List the variables you will control in this experiment.
6. Record the source of light, temperature of surroundings, amount of soil, amount of water, amount of radiation for each seed planted.

Irradiation and Benefits – Growing Irradiated Bean Seeds

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Seed 1 - Control			Seed 2 - 50,000 rad		
Height	**Observation**	**Drawing**	**Height**	**Observation**	**Drawing**

Seed 3 - 100,000 rad			Seed 4 - 150,000 rad		
Height	**Observation**	**Drawing**	**Height**	**Observation**	**Drawing**

Irradiation and Benefits – Growing Irradiated Bean Seeds

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. What happened? Why do you think the things you observed occurred? Were your observations and conclusions different from other students? Why? Who's "right"?

2. 100,000 rads or 150,000 rads is enough to kill a human. Did it kill all the plants? What do you think are some possible explanations?

3. If radiation increases on earth, what effects do you think it will that have on plant growth? On other organisms? On humans?

Irradiation and Benefits – Growing Irradiated Bean Seeds
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

4. What do you think happened to the cells of the irradiated mung bean plants?

5. List the controls in this experiment. What is the variable in this experiment?

6. What is the general rule about the number of variables which can change when testing the effect in an experiment?

Radioisotopes in Industry

Demonstrate to students how radioisotopes can be useful in industry for gauging and measuring.

Grade Level
5-12

Disciplinary Core Ideas (DCI)
5-PS1-1, MS-PS1-1, MS-PS1-4, HS-PS1-8

Time for Teacher Preparation
30-60 minutes – To gather materials and set-up

Activity Time:
30-60 minutes (1 Class Period)

Materials
- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Flashlight
- Six sheets of paper – 8.5 x 11
- Transparent glass bottle or jar
- Milk, coffee, or colored water to fill the bottle of jar with

Safety
- Students should not drink liquid
- Students should handle liquids with care

Science and Engineering Practices
- Ask questions and define problems
- Plan and carry out investigation
- Analyze and interpret data
- Use mathematics and technology
- Construct explanations
- Argue from Evidence
- Evaluate and communicate information

Cross Cutting Concepts
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objective
To help students understand how radioisotopes can be used in industry for gauging and measuring. Students will observe and record data on the demonstration.

Background
Radiation is very useful to practically every industry. Radiation can pass through material, but it loses a little bit of energy as it does. By comparing the amount of radiation that passes through the material and the original amount of radiation it was exposed to, we can figure out how thick or how dense a material is. Examples of such materials are welding seams on gas pipelines and aluminum metal sheets used to make soda cans. Alpha particles don't penetrate materials very well so beta and gamma radiation are much more practical for the purpose of industry. Gauging with radiation can be very helpful for inspecting finished products that have just been manufactured to ensure that they are quality products.

Teacher Lesson Plan:

Traditional
To demonstrate how radioisotopes can be used as a thickness gauge, turn off the lights and turn on the flashlight. Hold one (1) piece of paper about one (1) foot away from the flashlight and ask the students to draw what they observe. Then, hold five (5) pieces of paper, at the same distance, and ask students to draw what they observe. By adding successive sheets to the first one, the light will grow dimmer and dimmer until it cannot pass through the paper.

To demonstrate how radioisotopes can be used as a level gauge, fill the jar or bottle up with the fluid of choice. Then place a piece of paper behind the jar or bottle and shine the flashlight through the jar towards the paper. You will notice that you can tell the level of the liquid by the silhouette on the paper. It may be helpful to place the paper towards the students so that they cannot see the jar or bottle from their perspective and have them guess the level of the liquid solely from the silhouette.

NGSS Guided Inquiry
Split students into small groups and give each group a flashlight. Have students design an experiment to guess how many pages are resting on top of the instructor's flashlight without counting them. Then place the jar or bottle inside a paper box and have students shine the light into the box to discover the level of the liquid.

Student Procedure

This is a teacher demonstration. The students should draw the results that they observe onto the Student Data Collection Sheet that was provided.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. Can you explain how the thickness gauge technique might be used to gauge the thickness of a material such as metal, plastic, or paper coming from a manufacturing plant?

Assessment Ideas

- Use the paper box to test the student's proficiency in gauging the level of an unseen liquid.
- Use a paper box thicker than a single sheet of paper and have students gauge the thickness (accounting for the light passing through two sides of the box during the test).

Differentiated Learning/Enrichment

- Place any object inside the paper box and have students deduce what is inside the box with their flashlights. (ex: stapler, action figure, marble, etc.)
- Have students research examples of radioactive materials that are currently being used in industry.
- Have students determine the thickness of an Aluminum sheet or multiple sheets using a pure beta source.
- Have students determine the thickness of a Lead sheet or multiple sheets using a pure gamma source.

Enrichment Question

1. Can you describe how radiation might be used to operate an automatic shut-off valve for a tank being filled with liquid, or how it might be used to measure the liquid height in a can of soda?

Further Resources

ANS Center for Nuclear Science and Technology Information

http://www.nuclearconnect.org/know-nuclear/applications/industrial-applications

Radioisotopes Commonly Used Industry

http://www.epa.gov/rpdweb00/source-reduction-management/radionuclides.html

http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Radioisotopes/Radioisotopes-in-Industry/

Citations for Reference:

Adapted from BROMM, B. (1992). ***Easy to Perform Classroom Experiments in Nuclear Science***. American Nuclear Society.

Irradiation and Benefits Student Data Collection ANSWER Sheet

Drawings

Students should draw what they observe from the demonstration in the boxes below, then answer the attached questions.

Flashlight through 1 piece of paper

Flashlight through 5 pieces of paper

Level of liquid in jar through paper

Student Data Collection ANSWER Sheet

Irradiation and Benefits

Questions

1. Can you explain how the thickness gauge technique might be used to gauge the thickness of a material such as metal, plastic, or paper coming from a manufacturing plant?

   The example of beta attenuation: The shielding of the metal, plastic, or paper can be determined by comparing Beta emissions through the same thickness of air to see how much is stopped.

2. Can you describe how radiation might be used to operate an automatic shut-off valve for a tank being filled with liquid, or how it might be used to measure the liquid height in a can of soda?

   The liquid will interfere with the beam emission, so a switch would be shut off if the beam is disturbed. Very similar to what happens in motion detectors and smoke alarms.

Irradiation and Benefits

Radioisotopes in Industry

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Drawings

Students should draw what they observe from the demonstration in the boxes below, then answer the attached questions.

Flashlight through 1 piece of paper

Flashlight through 5 pieces of paper

Level of liquid in jar through paper

Irradiation and Benefits –
Growing Irradiated Bean Seeds
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. Can you explain how the thickness gauge technique might be used to gauge the thickness of a material such as metal, plastic, or paper coming from a manufacturing plant?

2. Can you describe how radiation might be used to operate an automatic shut-off valve for a tank being filled with liquid, or how it might be used to measure the liquid height in a can of soda?

Radioactive vs. Irradiated Salt

Students will understand the effects of irradiation and how it differs from radioactivity. They will also learn about thermo-luminescence and how it is used in the nuclear industry.

Grade Level

5-12

Disciplinary Core Ideas (DCI)

5-PS1-1, MS-PS1-1, MS-PS1-4, HS-PS1-8

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Colored pencils or crayons
- Student Data Collection Sheets
- Irradiated Salt (Table salt that has been exposed to at least 180,000 rads of gamma radiation) *Keep the salt in a dark container or covered with aluminum foil*
- A frying pan or any other flat metal surface capable of withstanding heat
- A hot plate

Safety

- Students should not eat salt (Not because it is irradiated, but because it has not been handled or stored in an FDA approved fashion.)
- Students should handle irradiated materials with care
- Student should use care when dealing with hot materials/objects

Science and Engineering Practices

- Ask questions and define problems
- Plan and carry out investigation
- Analyze and interpret data
- Use mathematics and technology
- Construct explanations
- Argue from Evidence
- Evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objective

To teach students how irradiation of a material may change it physically, but does not make it radioactive; how energy changes occur when electrons move to different energy states; and how a Thermoluminescent Dosimeter (TLD) works to measure the radiation dose a radiation worker might receive. TLD badges are worn by personnel, such as x-ray technicians. Sodium chloride (NaCl) will be used in the experiment to simulate the crystals in the TLD badges.

Background

After table salt, NaCl, has been exposed to a high level of ionizing radiation its color changes due to the way the energy is stored in the salt crystal. When the gamma rays pass through the salt, the energy deposited excites electrons and causes them to move to a higher energy state. Due to the nature of salt crystal, the electrons become trapped in that higher energy state. The reason the salt looks a different color (brownish) is because these electrons affect the way that light is reflected by the crystal. We can create artificial sapphires, emeralds, and rubies by irradiating quartz.

In order to release the energy trapped by the electron in the crystal, the salt needs to be heated. When the salt is heated, the electrons have the ability to return to the original positions and in the process release their stored energy. The energy released is in the form of visible light - not gamma rays. In addition, after heating and releasing all of its energy, the salt will return to its original white color.

Teacher Lesson Plan:

Traditional

Preheat the hot plate and frying pan on its highest setting and once it is hot, turn off the lights and pour some irradiated salt into the frying pan. The students will see a demonstration of thermo-luminescence.

NGSS Guided Inquiry

Split students into small groups and explain the difference between radioactive and irradiation. Have students design an experiment to determine how to tell the difference between irradiated salt and regular salt using a hot plate.

Student Procedure

This is a teacher demonstration. The students should draw the results that they observe onto the Student Data Collection Sheet that was provided.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. After the salt has been exposed to ionizing radiation, is it radioactive?
2. What happens to the salt when it is heated?
3. Why does the salt change color?
4. Is it safe to eat the irradiated salt - either before it was heated or after?

Assessment Ideas

- Have the students research to find other irradiated food items and discuss the positive aspects of irradiating food

Differentiated Learning/Enrichment

- Have students model how the electrons become trapped in table salts structure.
- Have students use a Geiger counter to validate that the salt is not actually radioactive.

Enrichment Question

1. How does this demonstration show how a radiation worker's Thermoluminescent Dosimeter (TLD) dosimeter measures their radiation exposure?

Further Resources

ANS Center for Nuclear Science and Technology Information:

http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

VIDEO: FlinnScientific. ***Salt with a Sparkle***.

https://www.youtube.com/watch?v=k3EWN4y3oTE

Purchase irradited salt through Flinn Scientific, Inc. (#16450)

http://www.flinnsci.com

Radioactive vs. Irradiated Salt

Student Data Collection ANSWER Sheet

Drawings

Students should draw what they observe from the demonstration in the boxes below, and then answer the attached questions. Use colored pencils for all drawings.

Initial Irradiated Salt	After Heating the Irradiated Salt

Radioactive vs. Irradiated Salt

Student Data Collection ANSWER Sheet

Questions

1. After the salt has been exposed to ionizing radiation, is it radioactive?

   No, it has been irradiated.

2. What happens to the salt when it is heated?

   It gives off light.

3. Why does the salt change color?

   The electrons move out of their artificial orbits back to stable, so they reflect light differently.

4. Is it safe to eat the irradiated salt - either before it was heated or after?

   It is just salt, but no because the salt is not produced to health standards.

5. How does this demonstration show how a radiation workers TLD dosimeter measures their radiation exposure?

   Thermo Luminescent Devices absorb radiation in their crystal structure. As they are heated, light is given off and that can be accurately measured to determine how much radiation was "captured."

Radioactive vs. Irradiated Salt

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Drawings

Students should draw what they observe from the demonstration in the boxes below, and then answer the attached questions. Use colored pencils for all drawings.

Initial Irradiated Salt	After Heating the Irradiated Salt

Irradiation and Benefits –
Growing Irradiated Bean Seeds
Student Data Collection Sheet

Name: ____________________

Date: ____________________

Questions

1. After the salt has been exposed to ionizing radiation, is it radioactive?

2. What happens to the salt when it is heated?

3. Why does the salt change color?

4. Is it safe to eat the irradiated salt - either before it was heated or after?

5. How does this demonstration show how a radiation workers TLD dosimeter measures their radiation exposure?

Half-Life of Paper, M&M's, Pennies, Puzzle Pieces & Licorice

With the Half-Life Laboratory, students gain a better understanding of radioactive dating and half-lives. Students are able to visualize and model what is meant by the half-life of a reaction. By extension, this experiment is a useful analogy to radioactive decay and carbon dating. Students use M&M's, Licorice, Puzzle Pieces or paper to demonstrate the idea of radioactive decay. This experiment is best used by students working in pairs.

Grade Level

5-12

Disciplinary Core Ideas (DCI)

3-5ETS1-2, MS-ESS1-4, HS-ESS1-6

Time for Teacher Preparation

40-60 minutes – To gather materials

Activity Time:

40-60 minutes (1 Class Period)

Materials

- Bag of (choose one): M&M's® , pennies, puzzle pieces, or licorice
- Paper – 8.5″ x 11″
- Graph Paper
- Zip-Lock Bags
- Pen, Marker, or Pencil
- Rulers
- Student Data Collection Sheets

Safety

- Students should not eat M&M's®, Licorice, Pennies or Puzzle Pieces

Science and Engineering Practices

- Ask questions and define problems
- Use models
- Analyze and interpret data
- Use mathematics and computational thinking
- Construct explanations
- Argue from evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation

Objectives

Students try to model radioactive decay by using the scientific thought process of creating a hypothesis, then testing it through inference. It is a great introduction to the scientific process of deducing, forming scientific theories, and communicating with peers. It is also useful in the mathematics classroom by the process of graphing the data.

Students should begin to see the pattern that each time they "take a half-life," about half of the surrogate radioactive material becomes stable. Students then should be able to see the connection between the M&M's, Puzzle Pieces, or Licorice and radioactive elements in archaeological samples. Seeing this connection will help students to understand how scientists can determine the age of a sample by looking at the amount of radioactive material in the sample.

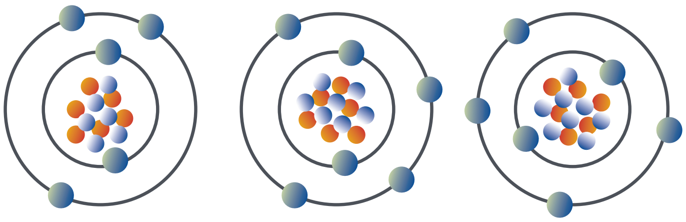
- To define the terms half-life and radioactive decay
- To model the rate of radioactive decay
- To create line graphs from collected data
- To compare data
- To understand how radioactive decay is used to date archaeological artifacts

Background

Half-Life

If two nuclei have different masses, but the same atomic number, those nuclei are considered to be isotopes. Isotopes have the same chemical properties, but different physical properties. An example of isotopes is carbon, which has three main isotopes: carbon-12, carbon-13 and carbon-14. All three isotopes have the same atomic number of 6, but have different numbers of neutrons. Carbon-14 has 2 more neutrons than carbon-12 and 1 more than carbon-13, both of which are stable. Carbon-14 is radioactive and undergoes radioactive decay.

Half-Life



Carbon
6 Protons
6 Neutrons

Nuclear number
= 6 + 6
= 12

Carbon-13
6 Protons
7 Neutrons

Nuclear number
= 6 + 7
= 13

Carbon-14
6 Protons
8 Neutrons

Nuclear number
= 6 + 8
= 14

Radioactive materials contain some nuclei that are stable and other nuclei that are unstable. Not all of the atoms of a radioactive isotope (radioisotope) decay at the same time. Rather, the atoms decay at a rate that is characteristic to the isotope. The rate of decay is a fixed rate called a half-life.

The half-life of a radioactive isotope refers to the amount of time required for half of a quantity of a radioactive isotope to decay. Carbon-14 has a half-life of 5,730 years, which means that if you take one gram of carbon-14, half of it will decay in 5,730 years. Different isotopes have different half-lives.

The ratio of the amounts of carbon-12 to carbon-14 in a human is the same as in every other living thing. After death, the carbon-14 decays and is not replaced. The carbon-14 decays, with its half-life of 5,730 years, while the amount of carbon-12 remains constant in the sample. By looking at the ratio of carbon-12 to carbon-14 in the sample and comparing it to the ratio in a living organism, it is possible to determine the age of a formerly living thing. Radiocarbon dates do not tell archaeologists exactly how old an artifact is, but they can date the sample within a few hundred years of the age.

Finding Half-Life

The basic equation for calculating the amount of radioactive material remaining is: $$y = \frac{1}{2^{t_{1/2}}}$$

Where,

y = the fraction of the original material remaining

$t_{1/2}$ = the number of half-lives

To find the age of an object using half-life, the following equations are used:

$$t_{age} = (\text{half-life}) * \log_2\left(\frac{1}{y}\right) = t_{age} = \left(\frac{\text{half-life}}{0.693}\right) * \ln\left({}^{1}/_{y}\right) = t_{age} = \frac{(-1)}{K} * \ln\left(\frac{n_\circ}{n_t}\right)$$

Where,

$$K = \frac{0.693}{\text{half-life}} = \frac{\ln(2)}{\text{half-life}}$$

and $$y = \left(\frac{n_\circ}{n_t}\right)$$

y = fraction of original material

$n_\circ$ = amount of parent material left

n_t = total amount of material = parent + daughter

Teacher Lesson Plan:

Traditional

Paper

1. Give each student a blank piece of paper. This represents the amount of radioactive material when first formed.
2. Tell the students to take the **Day of the Month** on which they were born and multiply that number by 2,000 (x2000). For example, if you were born on the 23rd day of a month, you would multiply 23 x 2000 and your answer would be 46,000.
3. Have the students calculate their number and fill it into the box labeled **Beginning Amount** in Table 1 of the data collection sheet. This number represents the initial number of Radioactive Atoms in their sheet of paper.
4. Call "Half-Life" at 30 second intervals (until the students have completed their 7th Half-Life). The students will take their number of radioactive atoms and divide by 2 (in half) and write the new number into the box labeled 1st Half-Life.
5. Then, have the students tear the provided sheet of paper in half. They should place the top half of paper onto their desks in front of them. These atoms are now stable and are no longer radioactive.
6. Repeat Steps 1-4 until after the 7th half-life.

M&M's® (or Pennies or Puzzle Pieces)

1. Give each student 10 M&M's® candies of any color and a zip lock bag. All of M&M's® candies are considered radioactive.
2. Have the student put the M&M's® into the zip lock bag and shake the bag. Have the students spill out the candies onto a flat surface.
3. Instruct the students to pick up ONLY the candies with the "m" showing - these are still radioactive. The students should count the "m" candies as they return them to the bag.
4. Have the students record the number of candies they returned to the bag under the next Trial.
5. The students should move the candies that are blank on the top to the side – these have now decayed to a stable state.
6. The students should repeat steps 2 through 5 until all the candies have decayed or until they have completed Trial 7.
7. Set up a place on the board where all students or groups can record their data.
8. The students will record the results for 9 other groups in their data tables and total all the Trials for the 100 candies.

Licorice

1. Instruct the students to label the horizontal axis of the graph paper "Time (seconds)" and the vertical axis "Radioactive Licorice (%)". Show them how to calibrate the horizontal axes so that one block equals 5 seconds and two blocks equal 10 seconds. Instruct them to mark the horizontal axis at 10-second intervals.
2. Give each student one piece of licorice to place onto the graph paper. Tell them to stretch the full length of the licorice vertically over the time "zero" mark and to make a mark on the paper at the top of the licorice. This mark represents 100% of the radioactive material at time zero.
3. Call out "GO" or "HALF-LIFE" at 10-second intervals for up to 90 seconds. When you say "GO" or "HALF-LIFE," the students will have ten seconds to remove one-half of their licorice and set it aside. They place the remaining piece of licorice on the 10 seconds line and mark its current height. At 20 seconds, they should again remove half of the licorice and set it aside, then mark the height of the remaining portion on their graphs at the 20 second line. Repeat this process until 90 seconds have gone by.
4. Now, the students should connect all the height marks with a "best fit" line, completing a graph of the "Half-Life of Licorice."

NOTE: The original strip of licorice represents radioactive material; the portion which is "set aside" during the activity represents the material that has "decayed" and is no longer radioactive.

NGSS Guided Inquiry

Explain about radiation and half-lives of isotopes. Tell students to design their own experiment, using paper, M&M's®, Pennies, other 2 sided material or Licorice as a radioactive material undergoing decay to discover the nature of the half-life of that material.

You might suggest that the students experiment with their graphing results to see if trends begin to form.

Student Procedure

Paper

1. Take the **Day of the Month** on which you were born and multiply that number by 2,000 (x2000). For example, if you were born on the 23rd day of a month, you would multiply 23 x 2000 and your answer would be 46,000.
2. Calculate your number and fill it into the box labeled **Beginning Amount** in Table 1. This number represents the initial number of Radioactive Atoms in your sheet of paper.
3. When your teacher calls "Half-Life," divide your number of radioactive atoms by 2 (in half) and write the new number in the box labeled 1st Half-Life in Table 1.
4. Then, tear the provided sheet of paper in half. Place the top half of paper onto your desk in front of you. These atoms are now stable and are no longer radioactive.
5. Repeat Steps 1-4 until after the 7th half-life.

M&M's® (or pennies or puzzle pieces)

1. Put 10 M&M's® candies of any color into a zip lock bag. Each group is starting with 10 M&M's® candies, which is recorded as Trial 0 in the data table. *All of the M&M's® candies are considered to be radioactive at the beginning.*
2. Shake the bag and spill out the candies onto a flat surface.
3. Pick up **ONLY** the candies with the "**m**" showing – *these are still radioactive*. Count the "**m**" candies as you return them to the bag.
4. Record the number of candies you returned to the bag under the next Trial.
5. Move the candies that are blank on the top to the side – these have now decayed to a stable state.
6. Repeat steps 2 through 5 until all the candies have decayed or until you have completed Trial 7.
7. Record the results for 9 other groups and total all the Trials for the 100 candies.

Licorice

1. Label the horizontal axis of the graph paper "Time (seconds)" and the vertical axis "Radioactive Licorice (%)". Calibrate the horizontal axes so that one block equals 5 seconds and two blocks equal 10 seconds. Mark the axis at 10-second intervals.
2. Start with one piece of licorice to place onto the graph paper. Stretch the full length of the licorice vertically over the time "zero" mark, which is the same as the vertical axis. Make a mark on the graph paper at the top of the licorice. This mark represents 100% of the radioactive material at time zero.
3. Your teacher will call out "GO" or "HALF-LIFE" at 10-second intervals up to 90 seconds. When your teacher says "GO" or "HALF-LIFE" you will have ten seconds to remove one-half of your licorice and set it aside. Place the remaining piece of licorice on the 10 seconds line and mark its current height. At 20 seconds, you should again remove half of the licorice and set it aside, then mark the height of the remaining portion on your graph at the 20-second line. Repeat this process until 90 seconds have gone by.
4. Now, connect all the height marks with a "best fit" line, completing a graph of the "Half-Life of Licorice."

NOTE: The original strip of licorice represents radioactive material. The portion which is "set aside" during the activity represents the material that has "decayed" and is no longer radioactive.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

Paper

1. Define the term **half-life**.
2. What does it mean when we say an atom has "**decayed**"?
3. Based on the numbers in **Table 1**, approximately what percentage of the atoms decay in each half-life?
4. List two things that stayed the same during this activity and list two things that are different during this activity.
5. Do the number of atoms you start with affect the outcome? Explain.
6. How do scientists use radioactive decay to date fossils and artifacts?

M&M's® (or Pennies or Puzzle Pieces)

1. Define the term **half-life**.
2. What does it mean when we say an atom has "**decayed**"?
3. Do the number of atoms you start with affect the outcome? Explain.
4. Did each group get the same results?
5. Did any group still have candies remaining after Trial 7?
6. Why do the totals for the 10 groups better show what happens during half-life rather than any other group's results?
7. What happens to the total number of candies with each trial (half-life)?
8. Plot the total results on a graph with number of candies on the vertical axis and trial number on the horizontal axis. Is the result a straight or a curved line? What does the line indicate about the nature of decay of radionuclides?
9. How do scientists use radioactive decay to date fossils and artifacts?

Licorice

1. Did the licorice ever completely disappear or just get so small that you couldn't tear it into halves?
2. If the entire earth could be divided in half, and then in half again over and over like the piece of licorice for as long as you could, what would be the smallest piece you would end up with?
3. If you had started with twice as long a piece of licorice, would it have made any difference in the graph line you would have obtained?

   ** To try this, move back to a time minus (-) 10 seconds and imagine how tall the licorice would have been then. What really does change when you use more?

4. Let's go the other direction for a change. Let us suppose the tiny bit of licorice at 90 seconds was your starting place. Then suppose you would double it in size every 10 seconds as you moved left on your graph towards 0 seconds. At 0, of course, you would have reached the size of one piece of licorice. However, what would be the size of the piece of licorice MINUS (-) 40 seconds?
5. Using the same method as in questions 4, continue doubling your licorice until you would reach MINUS (-) 100 seconds. How large a piece would you have then?
6. Does it really matter how large a sample you start with for this graph? WHY or WHY NOT?
7. Describe how the graph would be different if you took another piece of licorice exactly the same size as the first piece but you bit it in half and marked it on the graph every 30 seconds instead of every 10 seconds?

Assessment Ideas

- Question the student about how this experiment is similar to Carbon Dating.

Differentiated Learning/Enrichment

- Have the students calculate the age of objects when given the half-life, original amount, and current amount of that material.

Enrichment Question

1. The population of the earth is doubling every 40 years. If the population of the earth is now 7 billion people, how many people will be here when you are 95 years old?

Further Resources

For similar experiments:

http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

http://www.idahogeology.org/FieldWorkshops/Island_Park_2007b/Cash_Activities/Half-life_activity.pdf

http://hps.org/sciencesupport/documents/half_life.pdf

For more information on Carbon Dating:

http://www.c14dating.com/

http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/cardat.html

http://www.101science.com/Carbon14.htm

References:

Equations for Half-Life
http://lpc1.clpccd.cc.ca.us/lpc/hanna/HistoricalGeology/HalfLifeEquations.pdf

Table on Radiation Measurements
http://orise.orau.gov/reacts/guide/measure.htm

Student Data Collection ANSWER Sheet

Half-Life of Paper

Objectives

- To define the terms half-life and radioactive decay
- To compare data
- To understand how radioactive decay is used to date archaeological artifacts

Procedure

1. Take the **Day of the Month** on which you were born and multiply that number by 2,000 (x2000). Fo r example, if you were born on the 23rd day of a month, you would multiply 23 x 2000 and your answer would be 46,000.
2. Calculate your number and fill it into the box labeled **Beginning Amount** in Table 1. This number represents the initial number of radioactive atoms in your sheet of paper.
3. When your teacher calls "Half-Life," divide your number of radioactive atoms by 2 (in half) and write the new number in the box labeled 1st Half-Life in Table 1.
4. Then, tear the provided sheet of paper in half. Place the top half of paper onto your desk in front of you. These atoms are now stable and are no longer radioactive.
5. Repeat Steps 1-4 until after the 7th half-life.

Data Collection

Table 1

Beginning Amount	1st Half-Life	2nd Half-Life	3rd Half-Life	4th Half-Life	5th Half-Life	6th Half-Life	7th Half-Life
% Decayed							

Half-Life of Paper

Student Data Collection ANSWER Sheet

Questions

1. Define the term **half-life**.

   The time it takes for half of the atoms to decay to a stable state.

2. What does it mean when we say an atom has "**decayed**"?

   The atom has fissioned into 2-3 smaller particles, releasing energy in the form of alpha, beta, or gamma rays, and is now at a stable state. When an atom has fully decayed, all the electrons are at the lowest energy shell available, the atom is not releasing alpha, beta or gamma rays.

3. For **Table 1**, at the end of **each** half-life, at approximately what percentage are the atoms decaying?

   50%

4. List two things that stayed the same during this activity and list two things that are different during this activity.

   The things that stay the same: Total number of atoms, time of half-life
   The things that change: number of radioactive atoms, % of radioactive atoms

5. Do the number of atoms you start with affect the outcome? Explain.

   No, the half-life defines the ratio and the number of stable atoms. The percent of decrease is the same no matter how many atoms you start with.

6. How do scientists use radioactive decay to date fossils and artifacts?

   By looking at the ratio of carbon-12 to carbon-14, they can calculate back to the amount of original carbon-14 using the carbon-14 half-life of 5,730 years.

Enrichment Question

1. The population of the earth is doubling every 40 years. If the population of the earth is now 6 billion people, how many people will be here when you are 95 years old?

Age of Student	Number of people when student is 95	Age of Student	Number of people when student is 95
10	30.53 billion	15	28 billion
11	30.01 billion	16	27.52 billion
12	29.49 billion	17	27.05 billion
13	28.99 billion	18	26.58 billion
14	28.49 billion		

Half-Life of Paper

Name: ______________________________

Date: ______________________________

Student Data Collection Sheet

Objectives

- To define the terms half-life and radioactive decay
- To compare data
- To understand how radioactive decay is used to date archaeological artifacts

Procedure

1. Take the **Day of the Month** on which you were born and multiply that number by 2,000 (x2000). For example, if you were born on the 23rd day of a month, you would multiply 23 x 2000 and your answer would be 46,000.
2. Calculate your number and fill it into the box labeled **Beginning Amount** in Table 1. This number represents the initial number of radioactive atoms in your sheet of paper.
3. When your teacher calls "Half-Life," divide your number of radioactive atoms by 2 (in half) and write the new number in the box labeled 1st Half-Life in Table 1.
4. Then, tear the provided sheet of paper in half. Place the top half of paper onto your desk in front of you. These atoms are now stable and are no longer radioactive.
5. Repeat Steps 1-4 until after the 7th half-life.

Half-Life – Half-Life of Paper
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Data Collection

Table 1

Beginning Amount	1st Half-Life	2nd Half-Life	3rd Half-Life	4th Half-Life	5th Half-Life	6th Half-Life	7th Half-Life
% Decayed							

Half-Life – Half-Life of Paper

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. Define the term **half-life**.

2. What does it mean when we say an atom has "**decayed**"?

3. For **Table 1**, at the end of **each** half-life, at approximately what percentage are the atoms decaying?

4. List two things that stayed the same during this activity and list two things that are different during this activity.

5. Do the number of atoms you start with affect the outcome? Explain.

6. How do scientists use radioactive decay to date fossils and artifacts?

Enrichment Question

1. The population of the earth is doubling every 40 years. If the population of the earth is now 6 billion people, how many people will be here when you are 95 years old?

Half-Life of M&M's®

Student Data Collection ANSWER Sheet

Objectives

- To define the terms half-life and radioactive decay
- To observe the exponential nature of radioactive decay
- To create line graphs from collected data
- To compare data
- To understand how radioactive decay is used to date archaeological artifacts

Procedure

1. Put 10 M&M's® candies of any color into a zip lock bag. Each group is starting with 10 M&M's® candies, which is recorded as Trial 0 in the data table. *All of the* M&M's® *candies are radioactive*.
2. Shake the bag and spill out the candies onto a flat surface.
3. Pick up **ONLY** the candies with the "**m**" showing - *these are still radioactive*. Count the "**m**" candies as you return them to the bag.
4. Record the number of candies you returned to the bag under the next Trial.
5. Move the candies that are blank on the top to the side - *these have now decayed to a stable state*.
6. Repeat steps 2 through 5 until all the candies have decayed or until you have completed Trial 7.
7. Record the results for 9 other groups and total all the Trials for the 100 candies.

Toss Results	Trial 0	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Ours	10							
Group 2	10							
Group 3	10							
Group 4	10							
Group 5	10							
Group 6	10							
Group 7	10							
Group 8	10							
Group 9	10							
Group 10	10							
Totals	100							

Student Data Collection ANSWER Sheet

Half-Life of M&M's®

Questions

1. Define the term **half-life**.

   The time it takes for half of the atoms to decay to a stable state.

2. What does it mean when we say an atom has "**decayed**"?

   The atom has fissioned into 2-3 smaller particles, generally giving off gamma energy, and is now at a stable state.

3. Do the number of atoms you start with affect the outcome? Explain.

   Generally no; however, the larger the number of atoms, the better your data will be. If you start with a very small number of atoms it is difficult to get a good data chart.

4. Did each group get the same results?

   No. They should not be the same.

5. Did any group still have candies remaining after Trial 7?

   Yes, perhaps. Sometimes it takes more than 7 half-lives for all to decay.

6. Why do the totals for the 10 groups better show what happens during half-life rather than any one group's results?

   The higher the total number of atoms, the better the data.

7. What happens to the total number of candies with each trial (half-life)?

   It should be about half of what you started with for each trial.

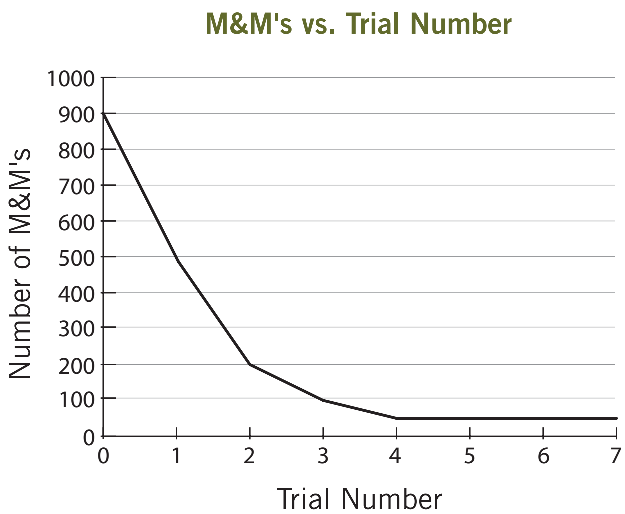
Half-Life of M&M's®

Student Data Collection ANSWER Sheet

Questions

8. Plot the total results on a graph with number of candies on the vertical axis and trial number on the horizontal axis. Is the result a straight or a curved line? What does the line indicate about the nature of decay of radionuclides?

The first 3 to 4 half-lives are where the majority of radioactive decay occurs.



9. How do scientists use radioactive decay to date fossils and artifacts?

By looking at the ratio of carbon-12 to carbon-14, they can calculate back to the amount of original carbon-14 using the half-life of carbon-14 = 5,730 years.

Enrichment Question

1. The population of the earth is doubling every 40 years. If the population of the earth is now 6 billion people, how many people will be here when you are 95 years old?

Age of Student	Number of people when student is 95	Age of Student	Number of people when student is 95
10	30.53 billion	15	28 billion
11	30.01 billion	16	27.52 billion
12	29.49 billion	17	27.05 billion
13	28.99 billion	18	26.58 billion
14	28.49 billion		

Half-Life of M&M's®

Name: ______________________________

Date: ______________________________

Student Data Collection Sheet

Objectives

- To define the terms half-life and radioactive decay
- To observe the exponential nature of radioactive decay
- To create line graphs from collected data
- To compare data
- To understand how radioactive decay is used to date archaeological artifacts

Procedure

1. Put 10 M&M's® candies of any color into a zip lock bag. Each group is starting with 10 M&M's® candies, which is recorded as Trial 0 in the data table. *All of the* M&M's® *candies are radioactive*.
2. Shake the bag and spill out the candies onto a flat surface.
3. Pick up **ONLY** the candies with the "**m**" showing - *these are still radioactive*. Count the "**m**" candies as you return them to the bag.
4. Record the number of candies you returned to the bag under the next Trial.
5. Move the candies that are blank on the top to the side - *these have now decayed to a stable state*.
6. Repeat steps 2 through 5 until all the candies have decayed or until you have completed Trial 7.
7. Record the results for 9 other groups and total all the Trials for the 100 candies.

Toss Results	Trial 0	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Ours	10							
Group 2	10							
Group 3	10							
Group 4	10							
Group 5	10							
Group 6	10							
Group 7	10							
Group 8	10							
Group 9	10							
Group 10	10							
Totals	100							

Half-Life – Half-Life of M&M's®

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. Define the term **half-life**.

2. What does it mean when we say an atom has "**decayed**"?

3. Do the number of atoms you start with affect the outcome? Explain.

4. Did each group get the same results?

5. Did any group still have candies remaining after Trial 7?

6. Why do the totals for the 10 groups better show what happens during half-life rather than any one group's results?

7. What happens to the total number of candies with each trial (half-life)?

Half-Life – Half-Life of M&M's®

Student Data Collection Sheet

Name: ____________________

Date: ____________________

Questions

8. Plot the total results on a graph with number of candies on the vertical axis and trial number on the horizontal axis. Is the result a straight or a curved line? What does the line indicate about the nature of decay of radionuclides?

9. How do scientists use radioactive decay to date fossils and artifacts?

Enrichment Question

1. The population of the earth is doubling every 40 years. If the population of the earth is now 6 billion people, how many people will be here when you are 95 years old?

Half-Life of Licorice

Student Data Collection ANSWER Sheet

Objectives

- To define the terms half-life and radioactive decay
- To observe the exponential nature of radioactive decay
- To create line graphs from collected data
- To compare data
- To understand how radioactive decay is used to date archaeological artifacts

Procedure

1. Label the horizontal axis of the graph paper “Time (seconds)” and the vertical axis “Radioactive Licorice (%)”. Calibrate the horizontal axes so that one block equals 5 seconds and two blocks equal 10 seconds. Mark the axis at 10-second intervals.
2. Start with one piece of licorice to place onto the graph paper. Stretch the full length of the licorice vertically over the time “zero” mark, which is the same as the vertical axis. Make a mark on the graph paper at the top of the licorice. This mark represents 100% of the radioactive material at time zero.
3. Your teacher will call out “GO” or “HALF-LIFE” at 10-second intervals up to 90 seconds. When your teacher says “GO” or “HALF-LIFE,” you will have ten seconds to remove one-half of your licorice and set it aside. Place the remaining piece of licorice on the 10 seconds line and mark its current height. At 20 seconds, you should again remove half of the licorice and set it aside, then mark the height of the remaining portion on your graph at the 20-second line. Repeat this process until 90 seconds have gone by.
4. Now, connect all the height marks with a “best fit” line, completing a graph of the “Half-Life of Licorice.”

NOTE: The original strip of licorice represents radioactive material; the portion which is “set aside” during the activity represents the material that has “decayed” and is no longer radioactive.

Student Data Collection ANSWER Sheet

Half-Life of Licorice

Questions

1. Did the licorice ever completely disappear or just get so small that you couldn't tear it into halves?

   Got too small.

2. If the entire earth could be divided in half, and then in half again over and over like the piece of licorice for as long as you could, what would be the smallest piece you would end up with?

   Answers will vary. A grain of sand. An atom.

3. If you had started with twice as long a piece of licorice, would it have made any difference in the graph line you would have obtained?

   * *To try this, move back to a time minus (-) 10 seconds and imagine how tall the licorice would have been then. What really does change when you use more?*

   It would have been taller at the beginning, but still ends up very small in just a few half-lives.

4. Let's go the other direction for a change. Let us suppose the tiny bit of licorice at 90 seconds was your starting place. Then suppose you would double it in size every 10 seconds as you moved left on your graph towards 0 seconds. At 0, of course, you would have reached the size of one piece of licorice. However, what would be the size of the piece of licorice MINUS (-) 40 seconds?

   The piece of licorice would be 16 times larger than the original piece.

5. Using the same method as in question 4, continue doubling your licorice until you would reach MINUS (-) 100 seconds. How large a piece would you have then?

   The piece of licorice would be 1024 times larger than the original piece at 0 seconds.

6. Does it really matter how large a sample you start with for this graph? WHY or WHY NOT?

   No, there would be more decays that occur, but the number of half-lives would remain the same.

Half-Life of Licorice

Student Data Collection ANSWER Sheet

Questions

7. Describe how the graph would be different if you took another piece of licorice exactly the same size as the first piece but you bit it in half and marked it on the graph every 30 seconds instead of every 10 seconds?

   It would take three times as long to completely decay.

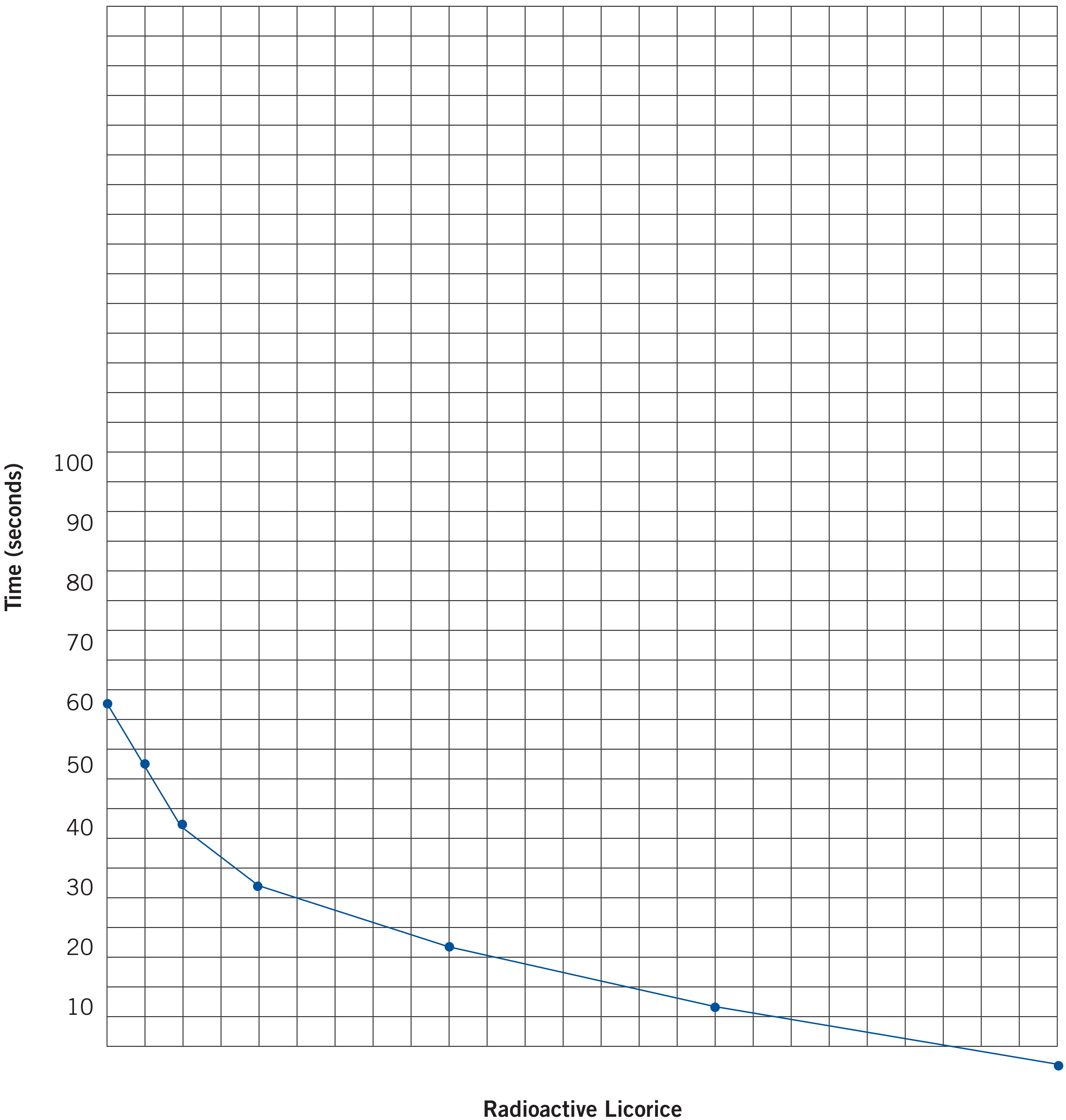
Enrichment Question

1. The population of the earth is doubling every 40 years. If the population of the earth is now 6 billion people, how many people will be here when you are 95 years old?

Age of Student	Number of people when student is 95	Age of Student	Number of people when student is 95
10	30.53 billion	15	28 billion
11	30.01 billion	16	27.52 billion
12	29.49 billion	17	27.05 billion
13	28.99 billion	18	26.58 billion
14	28.49 billion		

Half-Life of Licorice

Student Data Collection ANSWER Sheet



Half-Life of Licorice

Name: ______________________________

Date: ______________________________

Student Data Collection Sheet

Objectives

- To define the terms half-life and radioactive decay
- To observe the exponential nature of radioactive decay
- To create line graphs from collected data
- To compare data
- To understand how radioactive decay is used to date archaeological artifacts

Procedure

1. Label the horizontal axis of the graph paper "Time (seconds)" and the vertical axis "Radioactive Licorice (%)". Calibrate the horizontal axes so that one block equals 5 seconds and two blocks equal 10 seconds. Mark the axis at 10-second intervals.
2. Start with one piece of licorice to place onto the graph paper. Stretch the full length of the licorice vertically over the time "zero" mark, which is the same as the vertical axis. Make a mark on the graph paper at the top of the licorice. This mark represents 100% of the radioactive material at time zero.
3. Your teacher will call out "GO" or "HALF-LIFE" at 10-second intervals up to 90 seconds. When your teacher says "GO" or "HALF-LIFE," you will have ten seconds to remove one-half of your licorice and set it aside. Place the remaining piece of licorice on the 10 seconds line and mark its current height. At 20 seconds, you should again remove half of the licorice and set it aside, then mark the height of the remaining portion on your graph at the 20-second line. Repeat this process until 90 seconds have gone by.
4. Now, connect all the height marks with a "best fit" line, completing a graph of the "Half-Life of Licorice."

NOTE: The original strip of licorice represents radioactive material; the portion which is "set aside" during the activity represents the material that has "decayed" and is no longer radioactive.

Half-Life – Half-Life of Licorice
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. Did the licorice ever completely disappear or just get so small that you couldn't tear it into halves?

2. If the entire earth could be divided in half, and then in half again over and over like the piece of licorice for as long as you could, what would be the smallest piece you would end up with?

3. If you had started with twice as long a piece of licorice, would it have made any difference in the graph line you would have obtained?

** To try this, move back to a time minus (-) 10 seconds and imagine how tall the licorice would have been then. What really does change when you use more?*

4. Let's go the other direction for a change. Let us suppose the tiny bit of licorice at 90 seconds was your starting place. Then suppose you would double it in size every 10 seconds as you moved left on your graph towards 0 seconds. At 0, of course, you would have reached the size of one piece of licorice. However, what would be the size of the piece of licorice MINUS (-) 40 seconds?

5. Using the same method as in question 4, continue doubling your licorice until you would reach MINUS (-) 100 seconds. How large a piece would you have then?

6. Does it really matter how large a sample you start with for this graph? WHY or WHY NOT?

Half-Life – Half-Life of Licorice
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

7. Describe how the graph would be different if you took another piece of licorice exactly the same size as the first piece but you bit it in half and marked it on the graph every 30 seconds instead of every 10 seconds?

Enrichment Question

1. The population of the earth is doubling every 40 years. If the population of the earth is now 6 billion people, how many people will be here when you are 95 years old?

Half-Life – Half-Life of Licorice

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Is It Radioactive?

With the Measuring Laboratory, students gain a better understanding of radioactivity and radiation. Students are able to visualize what is meant by radiation and background radiation.

Grade Level

5-12

Disciplinary Core Ideas (DCI, NGSS)

5-PS1-1, 3-5ETS1-2, MS-PS1-1, MS-PS1-4, MS-PS3-2, MS-ETS1-1, MS-ETS1-3, HS-PS1-8, HS-PS3-2, HS-PS4-1, HS-PS4-4, HS-ESS1-2, HS-ESS2-3, HS-ESS3-6

Time for Teacher Preparation

30-60 minutes – Clear the room of any unnatural radioactive sources.

Create identifiable "locations" within the room – to correspond to the number of lab groups you will have. Code each of these locations in some way for easy reference.

Activity Time:

30-60 minutes (1 Class Period)

Materials

Use as many Geiger counters as you have available. *We will assume for this experiment that you are using Geiger counters which are **not** calibrated* (they may not provide the same readings under the same circumstances). So, you may want to label each Geiger counter with a code number or letter; then, each group can record the code of the Geiger counter being used and use it for future activities.

- Geiger counters

  NOTE: digital read-out Geiger Counters give easier readouts for classroom use and more accurate measurements

- An assortment of objects with varying radioactivity, including some in each of three categories:
  - Not detectably radioactive
  - Just barely radioactive ("Vaseline glass", thoriated welding rods, "depression green" glass, some fossils)
  - Unambiguously radioactive (orange/red Fiestaware, certain lantern mantles, some uranium ore and minerals)

Number each sample and record which category they fall into in a spreadsheet.

The students love testing the "hotter" items, but having the three categories of objects assures that everyone tests at least two each of clearly radioactive, marginally radioactive (would really need more counting time than available during lab to be sure), and essentially non-radioactive. The point is to have the students struggle with and face the uncertainty concerning whether or not items are radioactive.

Safety

- Students should use care when dealing with radioactive materials
- Students should wash their hands after this experiment

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Plan and Carry out investigation
- Analyze and interpret Data
- Use mathematics and computational thinking
- Construct Explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objectives

- Familiarize students with the concept of background radiation.
- Determine the amount of background radiation present at a specific location.
- To define the terms radiation
- To become familiar with the different types of radiation
- To become familiar with operating a Geiger-Mueller counter

The **key ideas** for students to understand upon completing this lab are:

- There is background radiation wherever they are.
- Levels of background radiation vary somewhat from one location to another and from one moment to the next.
- Background radiation must be taken into account when measuring the radiation from an object.
- Uncalibrated Geiger counters may give *slightly* different counts in identical situations; however, they are useful for:
  - determining that radiation is present.
  - comparing radiation levels for locations or objects.

Measuring and Units

Background

Introductory Information

We live in a radioactive world, as did our earliest ancestors. The radiation in our world comes from many sources – cosmic radiation (outer space), terrestrial sources (the earth), radon in the air, etc. In addition, we live and work in buildings made from materials (stone, adobe, brick, concrete) which contain elements that are naturally radioactive. The amount of naturally occurring background radiation we experience varies, depending upon location.

Background Radiation

Geiger counters will register the presence of some radiation even if you have not placed them near a known radiation source. This is a measure of the background radiation that is always present at a given location.

In order to make meaningful measurements of the radioactive nature of specific objects or materials, we will need to know how much radiation is naturally present in the environment. The difference between background radiation and the radiation measured near a specific object will give us the level of radiation due to the object.

Although background radiation is quite steady on average, you would never conclude that by listening to or watching a Geiger counter. The amount of radiation will appear to vary, depending upon the specific time at which you take a measurement.

The covert theme of this lab is dealing with ambiguity. Because there is background radiation always giving a background signal, and a non-constant signal at that, measuring a sample for a minute or two (with ordinary Geiger counters) just cannot determine with certainty if the sample is weakly radioactive or not.

Because of the randomness of radiation, if the true long-term average background count rate were 16 counts per minute, then by chance alone, a single one-minute measurement of background has about a 17% chance of being more than 20[1]. Similarly there is about a 1% chance of getting a one-minute count rate of 25 or higher[2].

Repeating the measurement and again getting 25 or higher increases the chance the object is really radioactive, as opposed to background just happening to be very high twice.

[1] $16 \pm \sqrt{16}$ = range of 12-20

[2] $16 \pm 2\sqrt{16}$ = range of 8-24

An Analogy

Suppose that someone sets up a water sprinkler and maintains a steady flow of water to the sprinkler. If one quantifies the rate at which the sprinkler puts water on the ground by how many drops of water fall on a sheet of notebook paper in a short time, one will not get the same result every time or in every location under the sprinkler. This is because the water falls onto the ground in discrete units (drops). Similarly, radiation (alpha and beta particles, gamma photons, etc.) strikes a given location in discrete units or amounts.

If the *average* number of water drops that fall on a piece of paper in one minute is 25 drops, you may **not** get exactly 25 drops in a one-minute measurement. Results ranging between 20 and 30 drops are likely, and counts as low as 15 and as high as 35 might occur, though that is less likely.

This same variation in measurements may occur with radiation.

Fundamental Particles Detection

Light has a wavelength of 10^{-7} m. Light microscopes enable us to view parts of a cell as small as 10^{-6} m. Electron microscopes enable us to see an image with a wavelength as small as 10^{-9} m. With the help of scanning electron microscopes, we can see fuzzy images of atoms. To detect a smaller image, such as a fundamental particle, we need to produce particles with greater energy, and thus, a shorter wavelength. The smallest fundamental particle is less than 10^{-18} m in diameter!

Although scientists have not yet been able to actually see fundamental particles, they can infer the presence of these particles by observing events and applying conservation laws of energy, momentum, electric charges, etc.

One way to do this is with a particle accelerator. Essentially, a particle accelerator works by shooting particles at high speed toward a target. When these bullet particles hit a target, a detector records the information about the resulting event.

Radiation Measurements

	Radioactivity	Absorbed	Dose Equivalent	Exposure
Common Units	curie (Ci)	rad	rem	roentgen (R)
SI Units	becquerel (Bq)	gray (Gy)	sievert (Sv)	coulomb/ kilogram (C/kg)

Teacher Lesson Plan:

Traditional

Before beginning, make sure students have some familiarity with the Geiger counter and how it will be used. Predetermine whether measurements are to be made with the "window" on the Geiger tube open or closed. Give students an overview of how and where to set the sensitivity level, etc.

1. Have the students measure background counts for one minute.
   a. This is done by counting the number of "clicks" from the Geiger counter. It is **not** practical to make this measurement by reading the counts/min scale on the Geiger counter.
2. Have each lab group enter the results of all the groups into the proper space on the table you provide.
   a. Ask students to examine the results. Do the results vary? If so, what is the lowest value and the highest value? What is the "range" of results? What are some possible reasons why the results might be different?
      i. Results **will** vary. Possible reasons include: inaccurate counting, inaccurate timing, slight variations in background radiation from location to location within the room, and/or differences between Geiger counters. There may be other suggestions from students -- which you must evaluate.
   b. Ask students how they could try to eliminate some sources of error. They may suggest repeating the measurements to rule out inaccurate timing and counting. They may suggest removing any jewelry, etc.
3. Have students run a second and third trial and *enter **only** the data **for their own group** into the table.*
   a. Ask the class: Do the results **for your lab group** vary from one trial to another? If so, why? What is the range for your own measurements?
      i. At this stage, students may have discovered that the results for their own group vary slightly in each trial. Discuss this variation. Consider the possibility that errors were made during every measurement and discuss whether this is likely.
      ii. Also, discuss the idea that the amount of background radiation present may actually be slightly different from one moment to the next -- even though it has an "average" value. Refer to the water sprinkler analogy mentioned in the introduction.
         1. Have each group enter the "range" for their own measurements in the bottom row of the table.
   b. Regarding the counts they took, ask "Were the clicks always evenly spaced? OR, did the clicks sometimes cluster together with pauses between them?"
      i. Clicks are usually NOT evenly spaced. There are usually some "clusters" of clicks and some pauses.
      ii. Discuss the possibility that this variation or "clustering" of clicks may have some impact on how long a time period we use for measuring radioactivity levels. For example, using a really short time period might make measurements more prone to error than a longer time, especially if you did the "short period" measurement during a "pause" or during a "cluster" of clicks.
         1. To illustrate, draw a clock face and let it represent a 60 second measurement. Then, make marks around the perimeter to represent when clicks are heard. This will give you clusters of marks and some empty spaces. If someone takes a measurement in a specific period of 5 seconds, it can easily affect the count they get.
4. Then, have the students enter the data for all of the groups into the table.
   a. Ask the students: Are there variations from group to group? If so, what are some possible reasons?
      i. Discuss possibilities: variations in Geiger counters, variations due to "location" in the room, etc.
   b. How could we determine if these differences are due to our Geiger counters being different or to differences within the room?
      i. You should realize when you begin this activity that these "uncalibrated" instruments are likely to give slightly different results under identical conditions and at the same time. However, it IS possible for there to be slight variations within the room. Proximity to a particular building material or exposure to some other radiation source, for example, may produce higher "background" readings in a specific location.
   c. There are several experimental approaches you and your students could use in resolving this issue.
      i. You could have each group make measurements at the same location and compare them. OR, each group could move to each of the identified locations and make readings for comparison purposes. Students may come up with other suggested solutions. Depending upon the time you want to allow and the sophistication level of your students, you can structure another set of measurements to provide an answer to the question above.

NOTE: If you are doing this activity in a one-period time slot, it is difficult to include measurement of background. Thus, most teachers use an average value for background, measured on a previous day. (Background varies little over time.) (Refer to Geiger Counter Resource for further instruction on attaching speakers or head phones to CPV700: www3.ans.org/pi/teachers/reactions/2001-04-02.html)

NOTE: If your Geiger counters have analog as opposed to digital (total counts) meters, fear not, you have many options. With earphones or an amplifier/speaker connected to the counter, your students can still count the number of clicks in a minute.

NOTE: A reasonably accurate count can also be obtained for low count rates by counting every time the needle jumps up a little (and counting as two if the needle jumps up significantly more than average). All of this will keep your class very busy and quiet.

NGSS Guided Inquiry

Have students design an experiment to discover about how much radiation can be found in different objects using Geiger-Mueller counters.

Student Procedure

1. Measure background counts for 1 minute. This is done by counting the number of "clicks" from the Geiger counter. Note that it is NOT practical to make this measurement by reading the counts/min scale on the Geiger counter.
2. Enter your results in the results table and share with the rest of the class.
3. Repeat the background measurement twice more and enter the results into the results table
4. Discuss with your group the results for your group and for the entire class

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. What is background radiation? What are its sources?
2. Can you eliminate background radiation?
3. Why would we take a measurement of background radiation levels before starting a radiation experiment?

Assessment Ideas

- Have the students use their Geiger counters to identify which of three unknown sources are radioactive using the same methodology they used to find background.

Differentiated Learning/Enrichment

- Students could measure levels of background radiation in other areas of the school (indoors, outdoors, on a higher floor, in the basement, etc.). Each group could prepare a table to summarize its findings for use in comparing them to the results of other groups. They could compare to see if there are differences between clear, sunny days and cloudy days, etc.
- Use known radioactive sources so that students can experiment with different types of shielding (metal, paper, etc.)

Enrichment Questions

1. In measuring background radiation, would it be better to take a 5 second reading or a 1 minute reading? Why would this time period be a better choice?
2. When making measurements of radiation, would it be better to make one measurement or three measurements? Why?

Further Resources

Center for Nuclear Science and Technology Information
http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

Geiger Counter Resource for instructions on attaching speakers or head phones to CD-V 700:
http://www.nuclearconnect.org/in-the-classroom/connecting-a-speaker-to-your-geiger-counter

For more information on how to store and dispose of radioactive waste:

http://blink.ucsd.edu/safety/research-lab/hazardous-waste/radioactive.html

Citations for Reference

http://orise.orau.gov/reacts/guide/measure.htm

Is It Radioactive?

Student Data Collection ANSWER Sheet

Objectives

- Become familiar with the concept of background radiation
- Determine the amount of background radiation present at a specific location
- Define the term radiation
- Become familiar with the different types of radiation
- Become familiar with operating a Geiger-Mueller Counter

The **key ideas** for students to understand upon completing this lab are:

- There is background radiation wherever they are
- The level of background radiation varies somewhat from one location to another
- There are some small variations in the level of background radiation from one moment to the next
- When measuring the radiation from an object, we must take into account the contribution made by background radiation
- Although un-calibrated Geiger counters may give *slightly* different counts in identical situations; however, they are useful for
- We can compare radiation levels for locations or objects

** *Refer to Geiger Counter Resource for instructions on attaching speakers or head phones to CD-V 700: http://www.nuclearconnect.org/in-the-classroom/connecting-a-speaker-to-your-geiger-counter*

Procedure

1. Measure Background counts for 1 minute. This is done by counting the number of "clicks" from the Geiger counter. Note that it is NOT practical to make this measurement by reading the counts/min scale on the Geiger counter.
2. Enter your results in the results table and share with the rest of the class.
3. Repeat the background measurement twice more and enter the results into the results table
4. Discuss with your group the results for your group and for the entire class

Results:

Measurement time (sec)	**Count Rate** (expressed in "counts per minute")					
	Lab Group or Student Name and "location" code					**Range** (Lowest Count to highest count ratio)
60 (1st trial)						
60 (2nd trial)						
60 (3rd trial)						
Range for group (Lowest count, Highest Count in a trial)						**Class Average** ↓
Mean (Average)						

Student Data Collection ANSWER Sheet

Is It Radioactive?

Questions

1. What is background radiation? What are its sources?

   Natural background radiation comes from the following three sources:

   Cosmic Radiation
   Terrestrial Radiation
   Internal Radiation

   Cosmic Radiation

   The sun and stars send a constant stream of cosmic radiation to Earth, much like a steady drizzle of rain. Differences in elevation, atmospheric conditions, and the Earth's magnetic field can change the amount (or dose) of cosmic radiation that we receive.

   Terrestrial Radiation

   The Earth itself is a source of terrestrial radiation. Radioactive materials (including uranium, thorium, and radium) exist naturally in soil and rock. Essentially all air contains radon, which is responsible for most of the dose that Americans receive each year from natural background sources. In addition, water contains small amounts of dissolved uranium and thorium, and all organic matter (both plant and animal) contains radioactive carbon and potassium. Some of these materials are ingested with food and water, while others (such as radon) are inhaled. The dose from terrestrial sources varies in different parts of the world, but locations with higher soil concentrations of uranium and thorium generally have higher doses.

   Internal Radiation

   All people have internal radiation, mainly from radioactive potassium-40 and carbon-14 inside their bodies from birth and, therefore, are sources of exposure to others. The variation in dose from one person to another is not as great as that associated with cosmic and terrestrial sources.

   (Information taken from the NRC Website: http://www.nrc.gov/about-nrc/radiation/around-us/sources/nat-bg-sources.html)

2. Can you eliminate background radiation?

   No.

Is It Radioactive?

Student Data Collection ANSWER Sheet

Questions

3. Why would we take a measurement of background radiation levels before starting a radiation experiment?

   The amount of background radiation is measured before starting a radiation experiment in order to get a more accurate reading that is not impacted by any radiation sources that could be present due to the experiment.

Enrichment Questions

1. In measuring background radiation, would it be better to take a 5 second reading or a 1 minute reading? Why would this time period be a better choice?

   It is better to take a 1 minute reading. It is often suggested to take 10 minute readings, but that is impractical in a 60 minute class period. Background radiation levels vary widely, so the longer you measure background, the more statistically accurate your background reading will be.

2. When making measurements of radiation, would it be better to make one measurement or three measurements? Why?

   Three measurements. Background radiation levels vary widely, so the longer you measure background, the more statistically accurate your background reading will be.

Measuring and Units

Is It Radioactive?

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objectives

- Become familiar with the concept of background radiation
- Determine the amount of background radiation present at a specific location
- Define the term radiation
- Become familiar with the different types of radiation
- Become familiar with operating a Geiger-Mueller Counter

The **key ideas** for students to understand upon completing this lab are:

- There is background radiation wherever they are
- The level of background radiation varies somewhat from one location to another
- There are some small variations in the level of background radiation from one moment to the next
- When measuring the radiation from an object, we must take into account the contribution made by background radiation
- Although un-calibrated Geiger counters may give *slightly* different counts in identical situations; however, they are useful for
- We can compare radiation levels for locations or objects

** *Refer to Geiger Counter Resource for instructions on attaching speakers or head phones to CD-V7 00: http://www.nuclearconnect.org/in-the-classroom/connecting-a-speaker-to-your-geiger-counter*

Procedure

1. Measure Background counts for 1 minute. This is done by counting the number of "clicks" from the Geiger counter. Note that it is NOT practical to make this measurement by reading the counts/min scale on the Geiger counter.
2. Enter your results in the results table and share with the rest of the class.
3. Repeat the background measurement twice more and enter the results into the results table
4. Discuss with your group the results for your group and for the entire class

Results:

Measurement time (sec)	**Count Rate** (expressed in "counts per minute")					
	Lab Group or Student Name and "location" code					**Range** (Lowest Count to highest count ratio)
60 (1st trial)						
60 (2nd trial)						
60 (3rd trial)						
Range for group (Lowest count, Highest Count in a trial)						**Class Average** ↓
Mean (Average)						

Measuring and Units – Is It Radioactive?

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. What is background radiation? What are its sources?

2. Can you eliminate background radiation?

Measuring and Units –
Is It Radioactive?
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

3. Why would we take a measurement of background radiation levels before starting a radiation experiment?

Enrichment Questions

1. In measuring background radiation, would it be better to take a 5 second reading or a 1 minute reading? Why would this time period be a better choice?

2. When making measurements of radiation, would it be better to make one measurement or three measurements? Why?

Fission Demonstration

With the Fission Demonstration, students gain a better understanding of nuclear fission and fusion. Students are able to visualize and model what is meant by nuclear fission. By extension, this experiment is a useful analogy to the generation of electricity via nuclear reactors. This experiment is best performed by students working in groups.

Grade Level
5-12

Disciplinary Core Ideas (DCI, NGSS)
5-PS1-1, 5-PS1-3, 5-ESS3-1, 3-5 ETS1-1, MS-PS1-4, MS-PS1-5, MS-PS3-1, MS-PS3-2, MS-PS3-4, MS-PS3-5, HS-PS1-1, HS-PS1-8

Time for Teacher Preparation
30-60 minutes – To gather materials and set-up

Activity Time:
30-60 minutes (1 Class Period)

Materials
- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Twisting balloons
- Scissors

Safety
- Student should use care when handling scissors

Science and Engineering Practices (NGSS)
- Ask questions and define problems
- Use models
- Plan and carry out investigation
- Analyze and interpret data
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change of Systems

Objective
Learn the concepts of nuclear fission and fusion and investigate how these reactions are used to generate energy.

Background
Fission is the release of energy by splitting heavy nuclei such as uranium-235 and plutonium-239. Each fission releases 2 or 3 neutrons. These neutrons are slowed down with a moderator, so they can initiate more fission events. Control rods absorb neutrons to keep the chain reaction in check. These fast-moving fission fragments are knocked into a water molecule, which causes the water molecules to move a little bit faster. This increased amount of motion is measured as an increase in temperature. The energy from the reaction drives a steam cycle to produce electricity. Nuclear power produces no greenhouse gas emissions; each year U.S. nuclear plants prevent atmospheric emissions totaling[1]:

- 5.1 million tons of sulfur dioxide
- 2.4 million tons of nitrogen oxide
- 164 million tons of carbon

Fusion is the opposite of fission. Fusion is the release of energy by combining two light nuclei such as deuterium and tritium. The goal of fusion research is to confine fusion ions at high enough temperatures and pressures, and for a long enough time, to fuse. There are two main confinement approaches:

- Magnetic confinement uses strong magnetic fields to confine the plasma.
- Inertial confinement uses powerful lasers or ion beams to compress a pellet of fusion fuel to the right temperatures and pressures.

Teacher Lesson Plan:

Traditional

This experiment can be performed as either a demonstration or by the students themselves. Regardless, the procedure remains the same.

Explain that the balloon is like a heavy nucleus, such as uranium-235 or plutonium-239. Once they have twisted the balloon into two sections, cut the twisted section to cause the "nuclei" to undergo fission. When the two smaller balloons are released, explain that the balloons flying off represent the energy given off by the reaction and how these fragments knock water molecules, speeding them up, and thus increasing their temperature. Afterwards, collect the balloon fragments to throw away and explain that nuclear waste needs to be disposed of properly and not dumped into the environment (just as you would not leave pieces of balloons lying around the classroom).

NGSS Guided Inquiry

Split students into small groups and give each group a balloon. Have students design an experiment to model nuclear fission with the balloon acting as a heavy nucleus, such as uranium-235 or plutonium-239. Have each group discuss ways to dispose of the waste products.

Student Procedure

The students should draw the results that they observe onto the Student Data Collection Sheet that was provided.

1. Blow up the twisting balloon and tie off the end.
2. Twist the balloon in the center, creating two separate, but equal sections.
3. While holding both ends of each inflated section, have a partner cut the twisted portion of the balloon in the middle.
4. Hold onto the ends of both of the resulting smaller balloons.
5. Release the balloons allowing them to fly off.
6. Collect the balloon fragments to throw away.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. How was this activity similar to nuclear fission?
2. What would need to happen to model nuclear fusion?
3. Why is it important to dispose of radioactive waste properly?

Assessment Ideas

- Question the student as to the similarities and differences of nuclear fission and fusion.

Differentiated Learning/Enrichment

- Have students model fusion
- Have students research contamination by waste products of fission.

Enrichment Questions

1. How could fission be used to generate electricity in a nuclear power plant?
2. Instead of scissors, what is actually used to make an atom undergo fission?

Further Resources

ANS Center for Nuclear Science and Technology Information:

http://www.nuclearconnect.org/know-nuclear/applications/electricity

http://www.nuclearconnect.org/know-nuclear/science/nuclear-fission

Nuclear Fission Animation:

http://www.atomicarchive.com/Movies/Movie4.shtml

Citations for Reference

Adapted from ***Easy to Perform Classroom Experiments in Nuclear Science***. (1992), BROMM, B, American Nuclear Society.

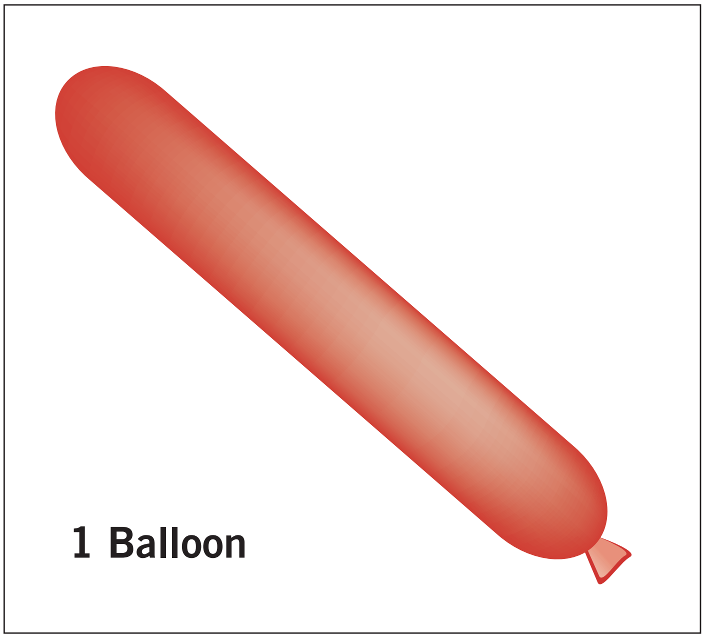
1. Fission vs. Fusion, American Nuclear Society (2013)

Fission Demonstration

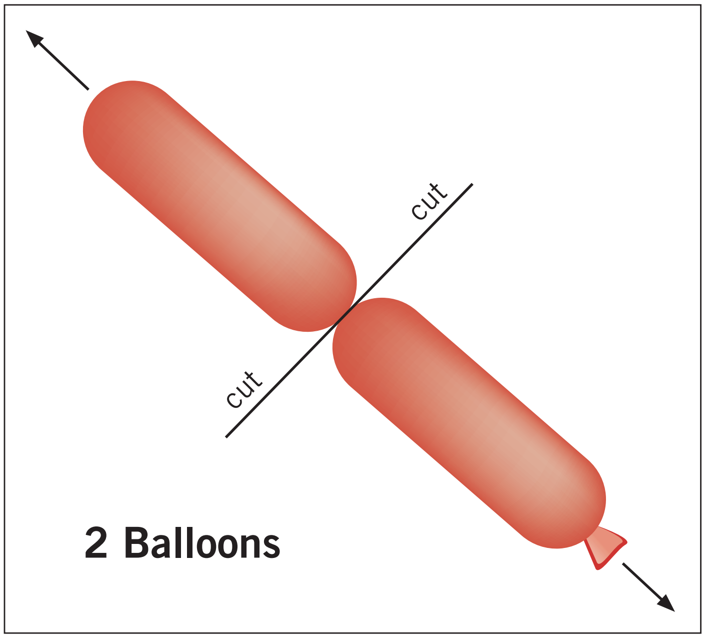
Student Data Collection ANSWER Sheet

Drawings

Student should draw what they observe from the demonstration in the boxes below, and then answer the attached questions. Use arrows to indicate size and direction of motion.



Before Fission



After Fission

Student Data Collection ANSWER Sheet

Fission Demonstration

Questions

1. How was this activity similar to nuclear fission?

   Nuclear Fission starts with a large nucleus that splits into 2 smaller ones.

2. What would need to happen to better model nuclear fusion?

   Some nuclei fission into three parts, not two. The balloon fragments could hit another balloon which would then fission into smaller parts. Inserting a marshmallow inside the balloon could show a different kind of particle emission.

3. Why is it important to dispose of radioactive waste properly?

   As with all types of waste, disposal is regulated and so fragments should not be left in the environment. That could contaminate the area.

Enrichment Questions

1. How could fission be used to generate electricity in a nuclear power plant?

   Fissioning atoms release heat, and so are used to heat water, to make steam, which spins a turbine. This process is almost identical to using fossil fuels such as coal or natural gas to boil the water.

2. Instead of scissors, what is actually used to make an atom undergo fission?

   The atom either divides naturally or other fissionable materials are added to it. Neutron particle bombardment from the natural isotopes can set off the reaction.

Fission Demonstration

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Drawings

Student should draw what they observe from the demonstration in the boxes below, and then answer the attached questions. Use arrows to indicate size and direction of motion.

Before Fission	After Fission

Fission – Fission Demonstration

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. How was this activity similar to nuclear fission?

2. What would need to happen to better model nuclear fusion?

3. Why is it important to dispose of radioactive waste properly?

Enrichment Questions

1. How could fission be used to generate electricity in a nuclear power plant?

2. Instead of scissors, what is actually used to make an atom undergo fission?

Radioactive Decay Series Activity

With the Radioactive Decay Series Activity, students gain a better understanding of radioactive decay chains and the changes that occur in the nucleus of the atom as they decay into more stable atoms. Students will understand that the radioactive decay chains define the number and type of particles emitted by the differing isotopes of atoms. This activity ialso relates to half-life and radioactive decay activities.

Grade Level
5-12

Disciplinary Core Ideas (DCI, NGSS)
5-PS1-1, 5-PS1-2, 5-PS1-3, MS-PS1-5, MS-PS2-5, MS-PS3-1, MS-PS3-4, MS-PS3-5, HS-PS1-1, HS-PS1-8, HS-PS3-3, HS-PS4-5, HS-ESS1-6

Time for Teacher Preparation
30-60 minutes – To gather materials and set-up

For NGSS Guided Inquiry
10-20 minutes – Print flashcards. Laminating is recommended, but not required.

Activity Time:
30-60 minutes (1 Class Period)

Materials
- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Flashcards with all of the isotopes and radiation types for the U-238 decay series
- Appendix II : Abbreviated Chart of the Nuclides

Safety
- No precautions required

Science and Engineering Practices (NGSS)
- Ask questions and define problems
- Use models
- Plan and carry out investigation
- Analyze and interpret data
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change of Systems

Objectives
- Investigate the concept of radioactive decay series
- Define alpha and beta particles

Background
Radioactive atoms do not behave the same as stable atoms. Stable atoms, such as ordinary copper will stay the same, whereas radioactive atoms are unstable, meaning they suddenly change by flinging out a particle such as an alpha particle, becoming an atom of a different element.

Most radioactive nuclei change or decay by the emission of electrons (betas) or alphas. Each of these decays changes the number of neutrons and protons in the nucleus, thus creating a new element. The nucleus resulting from the decay of a 'parent' is often called the 'progeny'. Using simple mathematics (addition and subtraction) the identity of the progeny nucleus can easily be determined.

Alpha Particles, (2 neutrons, 2 protons): ${}_{2}^{4}He$

Beta Particles, (1 electron): ${}_{-1}^{0}e$

So if bismuth-214 undergoes beta decay and then the progeny undergoes alpha decay, the equations would look like:

$${}_{83}^{214}Bi \dashrightarrow {}_{-1}^{0}e + {}_{84}^{214}Po \dashrightarrow {}_{2}^{4}He + {}_{82}^{210}Pb$$

The progeny of bismuth-214 by beta decay has an atomic number of 84 which is polonium (Po) and the progeny of polonium-214 by alpha decay has an atomic number (Z) of 82, which is lead (Pb). Thus, we can write an equation that identifies the progeny in a long decay chain.

Another example of creating a new element through radioactive decay is found with radium which has the chemical behavior of a heavy metal, until it suddenly hurls out this alpha particle. The resulting atom is no longer a heavy metal, but a quite different element. This progeny of radium is an atom of a heavy inert gas, which is at the end of the noble gas series, called radon. The atomic masses have been measured directly, by separating the isotopes of radium-226 and radon-222. Separate measurements confirm that there is a difference of 4 suggesting that the lost alpha particle is a helium nucleus.

When you have a mixture of a parent element and a progeny element that have different chemical properties, they can be

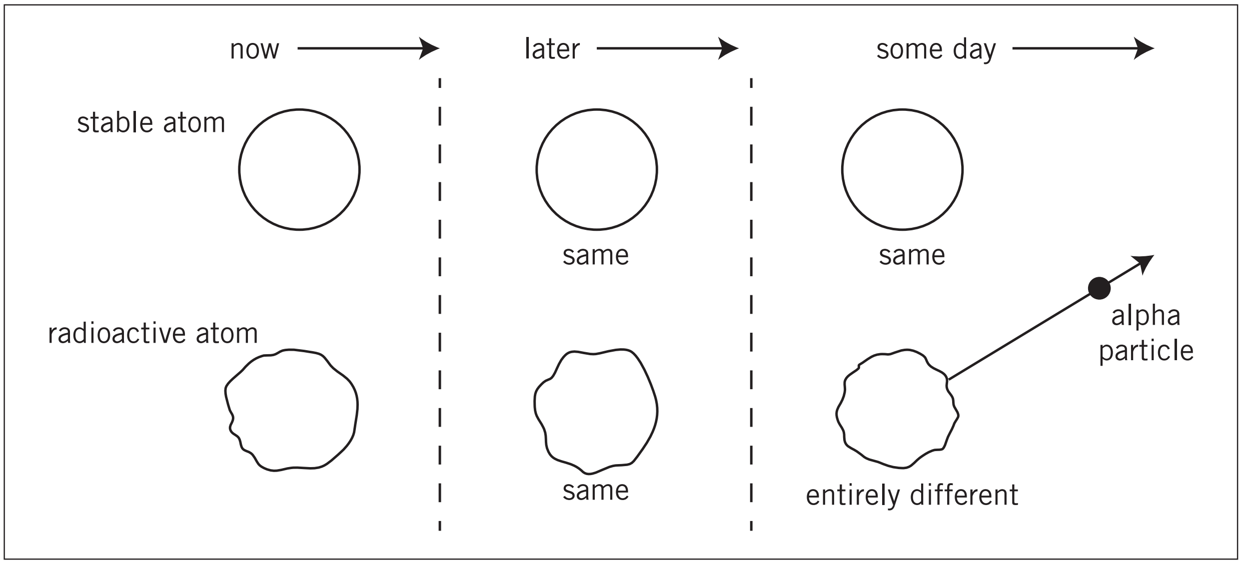


Figure 1

Radon gas is itself unstable and radioactive. Each of its atoms suddenly, at an unpredictable moment, hurls out an alpha particle. The remainder is a new atom, very unstable, which is called polonium, the 'progeny' of radon and the 'grand-progeny' of radium. The series continues through several more radioactive elements and stops at a stable form of lead. The series does not begin with radium: it begins with uranium several stages earlier. Radioactive uranium (Z=92) turns into lead (Z=82).

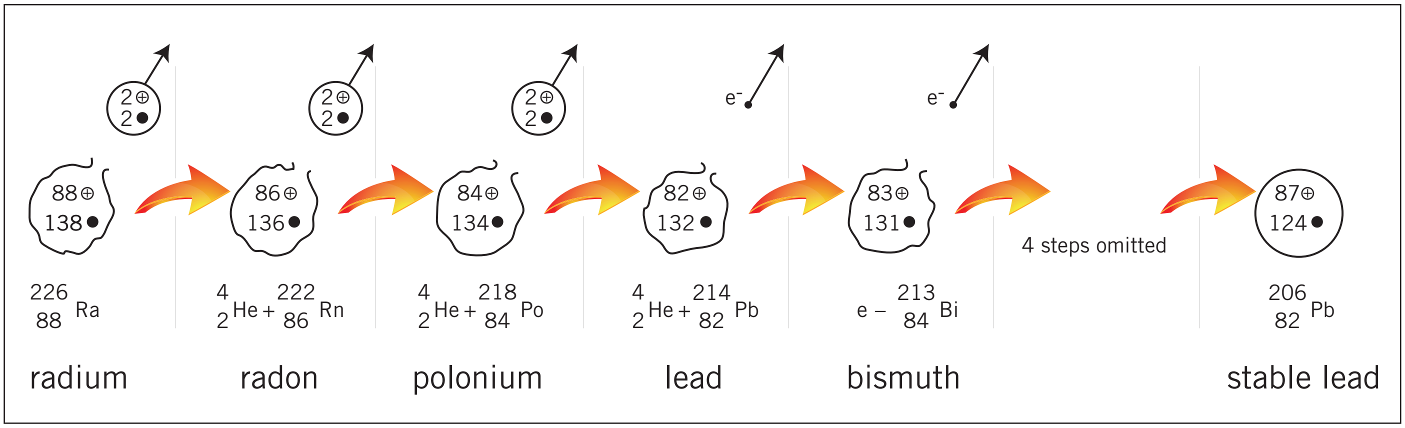


Figure 2

For heavy nuclei like radium, it often occurs that the progeny nuclei (which have been formed by radioactive decay) undergo radioactive decay again to form new progeny nuclei and so on, until finally, after many decay processes, a stable nucleus is left. This process is referred to as a decay series or decay chain.

There are 3 natural radioactive decay series that have been identified for the elements uranium, thorium, and actinium. A fourth series, the Transuranic decay series, begins with plutonium, which is a man-made element. All of the series begin with a long half-life radioisotope and end with a stable isotope. All of the members in each series decay by either alpha or beta decay (generally accompanied by gamma emission). Some members decay by both alpha and beta decay which creates two different decay chains, but by following all paths, the chains will always end in the same final isotope. Listed below are the names of the four known decay series as well as their first radioactive member and their final stable member.

	Radioactive	**Stable**
Series Name	**First Member**	**Last Member**
Uranium	U-238	Pb-206
Thorium	Th-232	Pb-208
Actinium	U-235	Pb-207
Transuranic	Pu-241	Bi-209

Decay Chains

A century ago, radioactivity was a peculiarity of a few mostly heavy elements: the last few at the end of the Periodic Table. Today, scientists can bombard samples of lighter elements with high speed, high energy protons or neutrons, provided directly or indirectly by an accelerator. They can make unstable isotopes of every element in the periodic table. This has opened up the field of nuclear chemistry. Radioactive isotopes behave chemically like their stable isotopes and can be mixed with them. Their progress as radioactive tags can be traced, like luggage labels, following the progress of a 'labelled' isotope through the human body or an industrial process.

Teacher Lesson Plan:

Traditional

1. Divide the class into working groups or pairs.
2. Have each pair fill out the worksheet for the decay series.

NGSS Guided Inquiry

Give each student a flashcard with the isotope information on it. Have students use their flashcard to identify the U-238 decay series.

Student Procedure

Fill out the worksheet given to you by your instructor.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. Describe how a decay chain can transform a radioactive nucleus into a stable nucleus.
2. Using Appendix I: Abbreviated Chart of the Nuclides, have the students choose any nuclei (such as uranium-235, thorium-232, and neptunium-237), and write the decay chain for the nuclei.

Assessment Ideas

1. How could understanding decay chains be useful in medical treatments?

Differentiated Learning/Enrichment

- Have students discuss how the different decay chains are affected by their method of decay, either alpha or beta.
- Have students research half-life and how it relates to the decay chain.

Enrichment Questions

1. Have students discuss the significance of radon gas in the uranium-238 decay series.
2. Have students research the decay series of the isotopes involved in medicine and industry.

Further Resources

For similar activites:

American Nuclear Society (2013). **Isotope Discovery Kit.**

http://www.nuclearconnect.org/in-the-classroom/for-teachers/isotope-discovery-kit

Radon

Environmental Protection Agency

http://www.epa.gov/radiation/radionuclides/radon.html

Radioistopes in Industry and Medicine

World Nuclear Organization

http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Radioisotopes/Radioisotopes-in-Industry/

http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Radioisotopes/Radioisotopes-in-Medicine/

P*hoto credits*

Figure 1 and 2: http://www.nuffieldfoundation.org/practical-physics/developing-model-atom-radioactive-atoms

α 238 U Uranium 92 4.5×10^9 years	ß 234 Th Thorium 90 24.1 days	ß 234 Pa Proactinium 91 1.17 minutes
α 234 U Uranium 92 2.5×10^5 years	α 230 Th Thorium 90 8.0×10^4 years	α 226 Ra Radium 88 1,620 years
α 222 Rn Radon 86 3.82 days	α 218 Po Polonium 84 3.05 minutes	ß 214 Pb Lead 82 26.8 minutes

RADIOACTIVE DECAY OF URANIUM-238

ß

214

Bi

Bismuth

83

19.7 minutes

α

214

Po

Polonium

84

1.6 x 10^{-4} seconds

ß

210

Pb

Lead

82

19.4 years

ß

210

Bi

Bismuth

83

5.0 days

α

210

Po

Polonium

84

138 days

none

206

Pb

Lead

82

STABLE

RADIOACTIVE DECAY OF URANIUM-238

Objectives

- Investigate the concept of radioactive decay series
- Define alpha and beta particles

Directions

Fill out the worksheet given to you by your instructor.

Questions

1. Describe how a decay chain can transform a radioactive nucleus into a stable element.

   As the unstable nucleus emits radiation (disintegrates), the radionuclide transforms to different nuclides. The process is called radioactive decay. It will continue until the forces in the nucleus are balanced. For example, as a radionuclide decays, it will become a different isotope of the same element if the number of neutrons changes and a different element altogether if the number of protons changes.

   Often, when a radionuclide decays, the decay product (the new nuclide) is also radioactive. This is true for most naturally occurring radioactive materials and for some fission products. In order to become stable, these materials must go through many steps, becoming a series of different nuclides and giving off energy as particles or rays at each step. The series of transformations that a given radionuclide will undergo, as well as the kind of radiation it emits, are characteristic of the radionuclide

2. Using Appendix I, choose any nuclei (such as uranium-235, thorium-232, and neptunium-237), and write the decay chain for the nuclei.

   Answers will vary.

Enrichment Questions

1. Discuss the significance of radon gas in the uranium-238 decay series.

   Radon-222 is the decay product of radium-226. Radon-222 and its parent, radium-226, are part of the long decay chain for uranium-238. Since uranium is essentially ubiquitous in the earth's crust, radium-226 and radon-222 are present in almost all rock and all soil and water

2. Research the decay series of the isotopes involved in medicine and industry.

   Answers will vary. Example: Strontium-82, Used as the parent in a generator to produce Rubidium-82, which is used as a Convenient PET agent in myocardial perfusion imaging.

Uranium-238 Decay Series

Complete the following table. You will have to use the Appendix on the reverse side to determine the names for the elements. Each element is identified through its atomic number which is the number of protons the nucleus contains. The atomic weight of each isotope is determined by adding the number of protons and neutrons together. Recall that by expelling an alpha particle, the nucleus of a particular isotope loses 2 protons and 2 neutrons. As a result the isotope is changed the nucleus of an element with an atomic number lower by 2 and an atomic weight lower by 4. During beta particle emission, a neutron is converted into a proton when the negative electron is expelled. This increases the number of protons in the nucleus by one and coverts the atom to another element with an atomic number higher than one.

Name of the Element	Atomic Weight	Type of Radiation Emitted	Number of Protons	Number of Neutrons	Half-Life
uranium	238	Alpha particle	92	146	4.5 x 10^9 years
			- 2	- 2	
thorium	234	Beta particle	90	144	24.10 days
			+ 1	- 1	
protactinium	234	Beta particle	91	143	6.70 hours
			+ 1	- 1	
uranium	234	Alpha particle	92	142	2.5 x 10^5 years
			- 2	- 2	
thorium	230	Alpha particle	90	140	7.5 x 10^4 years
			- 2	- 2	
radium	226	Alpha particle	88	138	1,620 years
			- 2	- 2	
radon	222	Alpha particle	86	136	3.82 days
			- 2	- 2	
polonium	218	Alpha particle	84	134	3.10 minutes
			- 2	- 2	
lead	214	Beta particle	82	132	26.8 minutes
			+ 1	- 1	
bismuth	214	Beta particle	83	131	19.9 minutes
			+ 1	- 1	
polonium	214	Alpha particle	84	130	1.6 x 10^{-4} seconds
			- 2	- 2	
lead	210	Beta particle	82	128	22.30 years
			+ 1	- 1	
bismuth	210	Beta particle	83	127	5.0 days
			+ 1	- 1	
polonium	210	Alpha particle	84	126	138.38 days
			- 2	- 2	
lead	206	Stable Atom	82	124	Stable

Note that when lead-206 is stable and not radioactive. We have reached the end of the line.

Decay Chains

Radioactive Decay Series Activity

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objectives

- Investigate the concept of radioactive decay series
- Define alpha and beta particles

Directions

Fill out the worksheet given to you by your instructor.

Questions

1. Describe how a decay chain can transform a radioactive nucleus into a stable nucleus.

2. Using Appendix I, choose any nuclei (such as uranium-235, thorium-232, and neptunium-237), and write the decay chain for the nuclei.

Enrichment Questions

1. Discuss the significance of radon gas in the uranium-238 decay series.

2. Research the decay series of the isotopes involved in medicine and industry.

Decay Chains – Radioactive Decay Series Activity
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Uranium-238 Decay Series

Complete the following table. You will have to use the Appendix on the reverse side to determine the names for the elements. Each element is identified through its atomic number which is the number of protons the nucleus contains. The atomic weight of each isotope is determined by adding the number of protons and neutrons together. Recall that by expelling an alpha particle, the nucleus of a particular isotope loses 2 protons and 2 neutrons. As a result the isotope is changed the nucleus of an element with an atomic number lower by 2 and an atomic weight lower by 4. During beta particle emission, a neutron is converted into a proton when the negative electron is expelled. This increases the number of protons in the nucleus by one and coverts the atom to another element with an atomic number higher than one.

Name of the Element	Atomic Weight	Type of Radiation Emitted	Number of Protons	Number of Neutrons	Half-Life
uranium	238	Alpha particle	92	146	4.5×10^9 years
________	____	Beta particle	____	____	24.10 days
________	____	Beta particle	____	____	6.70 hours
________	____	Alpha particle	____	____	2.5×10^5 years
________	____	Alpha particle	____	____	7.5×10^4 years
________	____	Alpha particle	____	____	1,620 years
radon	222	Alpha particle	____	____	3.82 days
________	____	Alpha particle	____	____	3.10 minutes
________	____	Beta particle	____	____	26.8 minutes
________	____	Beta particle	____	____	19.9 minutes
________	____	Alpha particle	____	____	1.6×10^{-4} seconds
________	____	Beta particle	____	____	22.30 years
________	____	Beta particle	____	____	5.0 days
________	____	Alpha particle	____	____	138.38 days
lead (Pb)	206	Stable Atom	82	124	Stable

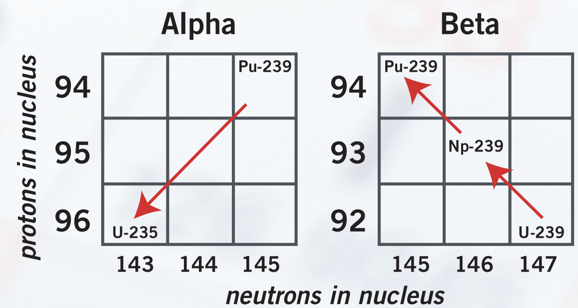
Note that when lead-206 is stable and not radioactive. We have reached the end of the line.

Appendix I – Abbreviated Chart of the Nuclides

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
American	Am	95
Plutonium	Pu	94
Neptunium	Np	93
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81

Protons	Element	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	Symbol
94	Americium																							241		Am
94	Plutonium																					238	239	240	241	Pu
93	Neptunium																					237		239		Np
92	Uranium																		233	234	235			238	239	U
91	Protactinium																	231		233	234					Pa
90	Thorium															228	229	230	231	232		234				Th
89	Actinium													225		227	228									Ac
88	Radium												223	224	225	226		228								Ra
87	Francium											221		223												Fr
86	Radon										219	220		222												Rn
85	Astatine							215		217	218															At
84	Polonium			210		212	213	214	215	216		218														Po
83	Bismuth			209	210	211	212	213	214																	Bi
82	Lead	206	207	208	209	210	211	212		214																Pb
81	Thallium		206	207	208	209																				Tl

Examples of Decay Transitions



Types of Radiation

With the *Types of Radiation* activity, students gain a better understanding of the different types of radiation, alpha, beta, and gamma. This is a way that students can detect invisible emissions.

This experiment is best used by students working in groups.

Grade Level
5-12

Disciplinary Core Ideas (DCI)
5-ESS3-1, 3-5 ETS1-1, MS-PS3-2, HS-PS1-8, HS-PS3-2, HS-PS4-1, HS-PS4-4, HS-PS4-5

Time for Teacher Preparation
1 week – To gather materials and set-up

Activity Time:
30-60 minutes (1 Class Period) per activity

Materials
- Pen, Marker, or Pencil
- Student Data Collection Sheets
- 1 set -Three radiation sources, each emitting one of the three types of radiation, such as:
    - Thoriated Coleman Lantern Mantle
    - Antique orange glaze Fiesta®ware plate
    - Radium-dial clock
    - For more sources ideas see: http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-resources/radiation-sources-for-teachers
- Autoradiographs
    - 1 box-Polaroid Type 57 instant film
    - Radiation Source
    - Wooden or linoleum roller
- Cloud Chambers
    - Pre-assembled Cloud Chambers, 1 per 3-4 students or
        - small transparent container with transparent lid (i.e. petri dish)
    - Radiation Source, 1 per cloud chamber
    - Dry ice, 5 lbs is generally enough for 1 class
    - Ethyl Rubbing alcohol, 50 mL
    - Flashlights, 1 per cloud chamber
    - Styrofoam plates, 1 per cloud chamber
    - Insulated Gloves, 1 pair
- Shielding
    - 1 each - Geiger Counter
    - 1 piece - Paper
    - 1 piece - Aluminum foil or thin baking sheet
    - 1 piece - 1/4" thick steel (a cast iron frying pan works)

Safety
- Students should use care when handling aluminum foil
- Students should use care when dealing with Geiger counters
- Students should use care when handling steel/cast iron
- Students should use care when handling rubbing alcohol
- Students should not touch dry ice with their bare hands
- Students should not touch chemicals on polaroid film on their bare hands
- Students should not touch radioactive materials

Science and Engineering Practices (NGSS)
- Ask questions and define problems
- Plan and carry out investigation
- Analyze and interpret data
- Use mathematics and computational thinking
- Construct explanations
- Argue from evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objectives
- Define alpha radiation
- Define beta radiation
- Define gamma radiation

Background

The Discovery of Radioactivity

Henri Becquerel, the discoverer of radioactivity, was born in Paris on December 15, 1852. He was descended from a family of distinguished physicists. He was the direct successor to his father in both of his professional appointments, as a professor at the Museum of Natural History in Paris in 1892 (in which position Henri's grandfather also served! and Henri in turn was succeeded by his own son!) and as a professor at the École Polytechnique in 1895.

The discovery of x-rays by Wilhelm Roentgen in 1895 created a stir throughout the world as unprecedented pictures of bones in living hands were published in the popular press; it prompted a slew of scientific investigation. Henri had continued the line of study of his father and grandfather on phosphorescence and fluorescence. When it was suggested that the recently discovered x-rays might be connected to this phenomenon, Henri investigated the possibility with some phosphorescent minerals that had been chemically prepared by his grandfather. He hoped that they might be a powerful source of x-rays and leave a clear imprint on photographic plates.

On February 26, 1896, Becquerel prepared his experiments with a phosphorescent uranium salt (potassium uranyl sulfate). Clouds shut out the sun, so he put everything away in a drawer just as it was: plate wrapped in black paper, a metal cut-out pattern on top, placed between the paper and the uranium to produce a shadow and leave no doubt as to the cause of the photographic image; and finally the all- important uranium salt--impotent without sunlight to stimulate it into action, or so Becquerel thought!

The sun did not come out for three days. On March 1, Becquerel decided to develop the plate anyways presumably to prove that without the sun, there was very little effect. He was astonished to find instead a very clear image; the uranium salt evidently gave out invisible rays even without first absorbing energy from the sun.

Becquerel soon found that the rays emanate from the uranium in the salts. He found that the intensity of the images on photographic plates depended only on the amount of uranium present, in whatever chemical form. He found the rays to be similar to X-rays in some respects -- they were invisible and would act on photographic plates and would ionize air, splitting it into positive and negative components that would conduct electricity. He also showed that these rays, like x-rays, could penetrate thin sheets of aluminum and copper and could still cause the darkening of the photographic plate. What he had discovered were called "Becquerel rays" or "uranic rays" until 1898 when the emission of these rays was named radioactivity by Marie Curie, who had discovered other chemical elements, radium and polonium that also displayed this property.

The rays from uranium were different from X-rays in two crucial ways. First, the uranium rays did not penetrate materials as readily. Second, uranium and its compounds emitted the rays spontaneously. Day and night, for weeks on end - and, as we now know for millennia - uranium gives off invisible rays. X-rays, on the other hand, are produced only when cathode rays or high-energy electrons are slowed down by a material such as the glass at the end of a vacuum tube.

Often used to detect radiation by imaging its emissions, an autoradiograph is a representation of where radioactive substances are located. The image can be projected onto a medium such as an x-ray film, nuclear emulsion, or even photographic film. Autoradiography, which can also be digital, is used in many cases for biological and medical applications. In contrast to other methods of detecting radiation, they can show the locations of radioactive materials in a sample. The images can therefore be used with biological specimens labeled with such materials, to track cellular activity for example.

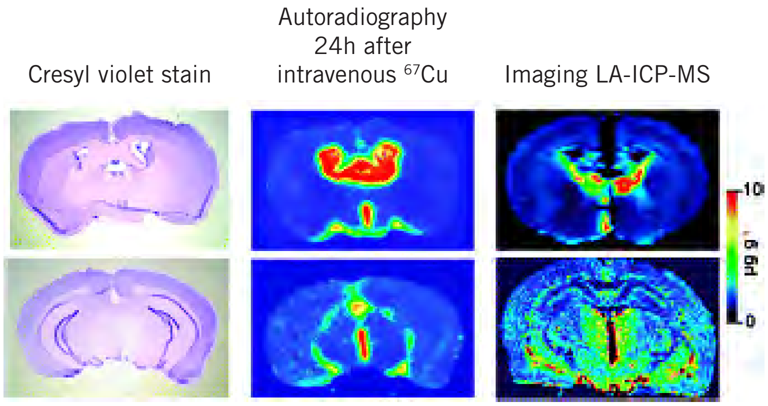


Figure 1: These images compare the active Copper (Cu) uptake in the brains of mice.

Source: http://pubs.rsc.org/en/content/articlelanding/2010/mt/c003875j/unauth#!divAbstract

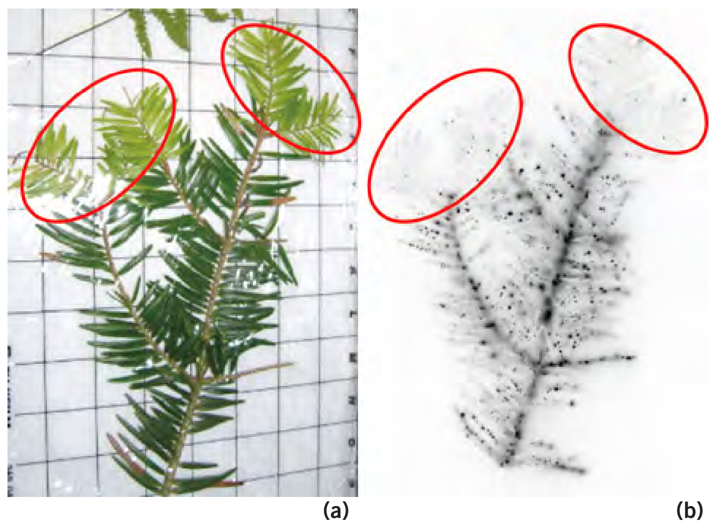


Figure 2: Visualization of distribution of fallout radioactive Cesium (Cs) in plants near Fukushima

Source: http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/mirai-en/2012/1_17.html

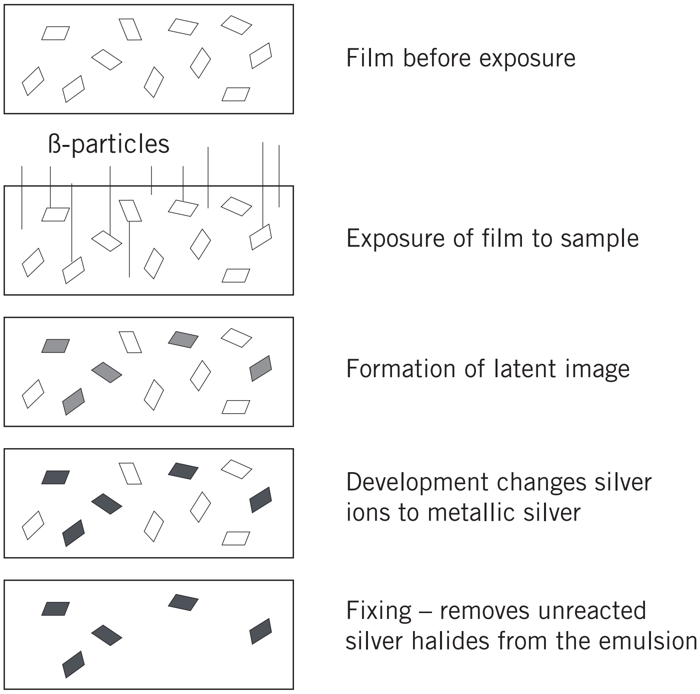


Figure 3: Exposure of film to radioactive sample. Source: http://isites.harvard.edu/fs/docs/icb.topic1050994.files/CH156_Lecture5%20Autoradiography.pdf

A very basic form of autoradiograph production may require the film to be exposed to the radioactive material overnight. Radiation emanates from the material placed on the film and interacts with silver in the film to change it chemically. An image of the radioactive sample will result as some areas of the film will be changed and others won't, according to where the radiation interacts.

An autoradiograph is often taken after biological tissue is exposed to a radioactive substance, left for a certain period of time, and examined under a microscope. Sections can be cut and a photographic image can be developed as a radioisotope decays. Samples are often stained to enhance the detail and to see the grains of silver that react with the substance. The resulting autoradiograph can be recorded and kept on file as part of an experiment or test.

While a solid film was typically used in the past, a liquid emulsion is often used in the 21st century to make an autoradiograph. This technique can take less time to complete. Liquid can flow and make the thickness of the sample uneven, but following the basic steps for coating slides and developing the film can dry the sample appropriately. A phosphor-imager screen can help detect radioactivity in gel quicker than x-ray film. It is typically used with electronic instruments and a computer system that can digitally image the sample.

Autoradiographs can show radioactive particles attached to enzymes or integrated into nucleic acid. Metabolic processes can be tracked in cells when images of radioactive particles are compared. Researchers can track proteins, photosynthesis, and the division and movement of cells. Sequences of deoxyribonucleic acid (DNA) can be tracked. Autoradiography DNA is often used to monitor cell cycles and track the progress of viruses to analyze their behavior.

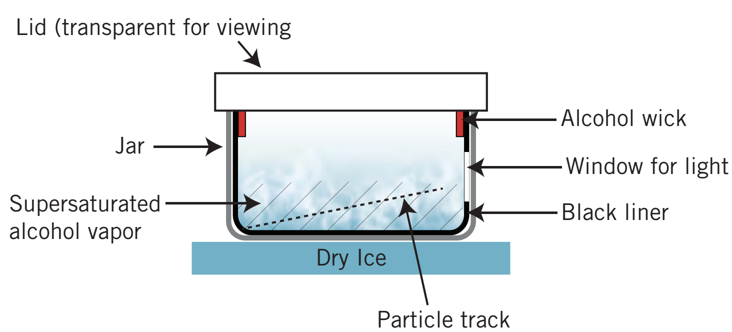
Cloud Chambers

Elements occurring in nature that are radioactive emit alpha,beta, and gamma radiation. Alpha particles are actually the nuclei of helium atoms containing two neutrons and two protons. They usually travel only a few centimeters through air before losing their kinetic energy and gaining electrons to become helium atoms Moving at relatively slow speeds (about 1/10 the speed of light), they ionize the air as they pass through it--but can be stopped by a single sheet of paper or deflected by a magnet.

Beta particles are electrons. Because of their negative charge, they also can be deflected by magnets. They move at very close to the speed of light and have a greater penetrating power than alpha particles, but they do not readily ionize air. They can be stopped by a thin sheet of aluminum.

Gamma radiation is similar to x-rays but with greater penetrating power than x-rays, alpha particles, or beta particles. Gamma rays can be stopped by several centimeters of lead. Since they are not charged, they are not deflected by magnets.

A cloud chamber allows us to see the trail (or track) made as radiation leaves a radioactive source and travels through the surrounding environment. The tracks that form are actually tiny droplets of alcohol that condense on the ionized particles created by the radiation. A cloud chamber is designed to encourage alcohol condensation. As the dry ice underneath the chamber sublimes, it absorbs heat from the air in the chamber, creating a very cool environment. This reduces the amount of alcohol vapor that can "dissolve" in air, so the alcohol vapor already present forms a supersaturated gaseous solution.



The major evidence of radiation in a cloud chamber is due to the presence of alpha particles, although beta particles are undoubtedly present. Alpha particles (helium nuclei) make more intense tracks due primarily to the larger mass and, hence, lower speed than beta particles (electrons). Differences in direction and length of the tracks can also be due to variations in temperature and degree of saturation with alcohol vapor.

Teacher Lesson Plan:

Traditional

Autoradiograph

1. Prepare **Autoradiographs** as followed:

   a. Place a key, coin, or other metal object onto the face of the film sheet. Place a Coleman lantern mantle, Fiesta®ware plate, or a radium-dial clock completely over the object. Let it sit for at least one week.

   b. Remove the mantle and object from the film sheet. Lay the sheet on a flat table with the side marked "This side toward lens" up. Locate the bulge in the sheet that contains the developer chemicals. Place a ruler, flashlight, or other stiff, heavy object (a linoleum roller works best) behind the bulge and, while applying moderate pressure, slowly and evenly drag the object across the film sheet to spread the chemicals. Even distribution of the chemicals is critical for good development. It takes lots of practice to make a good picture.

   c. Wait 30 seconds for the film to develop then open the packet. Do not get the chemicals on your hands.

   d. Students will find a dark shadow of the metal object surrounded by a white "fog". The white is due to the radiation given off by the Coleman mantle or other radioactive item exposing the film. The dark shadow is caused by the metal object shielding the film from the radiation.

NOTE: You can use the three radiation sources on one film sheet in lieu of the key and Coleman lantern mantle, Fiesta®ware plate, or a radium-dial clock. Students will find that only the beta and gamma sources will expose the film. This is because the paper surrounding the film shields alpha radiation.

NOTE: Elementary school students could try to perform this experiment using SunSensitive paper rather than Polaroid film. The SunSensitive paper reacts to sunlight and would be a good substitution for Polaroid film for this experiment. SunSensitive Paper can be found at your local art supply store (i.e. Hobby Lobby or Michaels)

Cloud Chambers

2. Prepare the cloud chambers as followed:

   a. Open the lid of the cloud chamber and saturate the felt strip inside with alcohol.

   b. Put the radiation source inside the cloud chamber and replace the lid tightly.

   c. Place the palm of your hand firmly on top of the cloud chamber for about 1 minute to evaporate the alcohol.

   d. Place the cloud chamber on a piece of FLAT dry ice that is at least a little larger than the chamber.

   e. Turn off the lights in the room and shine the flashlight through the cloud chamber to make the ion trails easier to see. Trails should begin a few minutes after placement on the dry ice.

NOTE: You can use one of the radiation disks in each chamber in lieu of Coleman lantern mantle pieces. Students will find that only the alpha and beta sources will produce tracks. This is because gamma radiation is electromagnetic radiation not particles, and it's the particles moving through the alcohol cloud that makes the tracks.

NOTE: Due to variations in the amount of alcohol, the temperature, contact with dry ice, and atmospheric pressure, some cloud chambers will work and some will not. The bottom of the cloud chamber will freeze up so after a short time take it off of the dry ice and warm it up in your hands before placing it back on the dry ice. Have students view the cloud chambers that work and explain the variability of conditions.

Shielding

3. Place the three radiation sources on a table about 5 or 6 inches apart. Place a sheet of paper over all three, place the aluminum foil over the paper, and place the steel over the aluminum foil. Measure the radiation above the three sources. Students will find that radiation is at background level because of the shielding. Remove the steel and re-measure the radiation. Students will find that the gamma source is now detectable. Remove the aluminum foil and re-measure the radiation. Students will find that both the gamma and beta sources are now detectable. Finally, remove the paper and re-measure the radiation. Students will find that all three sources are now detectable. This experiment demonstrates the penetrating power of the three types of radiation.

NOTE: The Geiger counter must be held the same distance away from the source to eliminate the shielding effects of air.

NGSS Guided Inquiry

Give the students radioactive samples and ask them to completely block the radiation with things they find in the classroom.

Explain about the different types of radiation and radioactivity. Tell students to design their own experiment, to detect different types of radiation, and then share their results with the class.

Student Procedure

The cloud chambers and autoradiographs should be performed as demonstrations for Elementary and Middle School students. High school students can perform the experiments.

Radiation Types

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. Explain why only beta and gamma radiation affected the film and not the alpha radiation.
2. Explain why the gamma radiation did not make tracks in the cloud chamber.
3. How do the tracks generated by the radioactive particles in Cloud Chambers resemble what you can see created by jet airplanes as they pass through the upper atmosphere?
4. Have the students describe how gravity affects the particles as they are emitted from the source.
5. Have the students describe the differences in the particle tracks in the cloud chambers.

Assessment Ideas

- Have students discuss the differences between alpha, beta, and gamma radiation and how different types of shielding are used to block each type of radiation.
- The teacher can divide the students into alpha, beta, and gamma "expert" groups. Each group is given time and materials to make observations and carry on other research. The team then makes an presentation on the characteristics of alpha, beta, and gamma radiation the entire class.
- Ask each student to draw an alpha, beta, and gamma cartoon character that describes their characteristics.

Differentiated Learning/Enrichment

- Have students discuss how the autoradiograph works
- Have students examine the effect of static electricity on the cloud chamber tracks by moving a charged comb over the chamber.
- After completing the basic tests, the students are free to test other possible barrier materials they find in the classroom. Encourage students to test other items: textbooks, windows, walls, water, etc., as barriers. Remind students not to use their bodies as shields. Why?

Enrichment Question

1. How do you think shielding is useful to the nuclear industry? Give three examples.

References

BROMM, B, Easy to Perform Classroom Experiments in Nuclear Science (1992), Los Angeles Section American Nuclear Society

Background adapted from:

Activities For Teaching Fundamental Concepts of Nuclear Energy and Related Topics (1996), West Texas A&M University

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCkQFjAA&url=http%3A%2F%2Fwww.uraweb.org%2Freports%2Fskoog.pdf&ei=6shdU_2uJenWyQHFx4CICQ&usg=AFQjCNEOTg83F7BvFQ6wUIMWV_LA26TK-w&sig2=exkwB3XrK_ywXtFmUxsdkA&bvm=bv.65397613,d.aWc

Autoradiographs background adapted from: Wise Geek, What Is an Autoradiograph?

http://www.wisegeek.com/what-is-an-autoradiograph.htm

Radiation background adapted from:

Students Watching Over Our Planet Earth (SWOOPE)

Photo Sources:

Figure 1: http://pubs.rsc.org/en/content/articlelanding/2010/mt/c003875j/unauth#!divAbstract

Figure 2: http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/mirai-en/2012/1_17.html

Figure 3: http://isites.harvard.edu/fs/docs/icb.topic1050994.files/CH156_Lecture5%20Autoradiography.pdf

Types of Radiation

Student Data Collection ANSWER Sheet

Objectives

- Define alpha radiation
- Define beta radiation
- Define gamma radiation

Procedure

1. Watch the demonstration.
2. Draw what you observe.

For High School Students

Autoradiograph

Prepare **Autoradiographs** as followed:

- Place a key, coin, or other metal object onto the face of the film sheet.
- Place a Coleman lantern mantle, Fiesta®ware plate, or a radium-dial clock completely over the object. Let it sit for at least one week.
- Remove the mantle and object from the film sheet.
- Lay the sheet on a flat table with the side marked "This side toward lens" up.
- Locate the bulge in the sheet that contains the developer chemicals.
- Place a ruler, flashlight, or other stiff, heavy object (a linoleum roller works best) behind the bulge and, while applying moderate pressure, slowly and evenly drag the object across the film sheet to spread the chemicals.
- Even distribution of the chemicals is critical for good development. It takes lots of practice to make a good picture.
- Wait 30 seconds for the film to develop then open the packet. Do not get the chemicals on your hands. Rinse your skin with water for 5 minutes if chemicals get on your skin.

Cloud Chambers

Prepare three cloud chambers in accordance with the cloud chambers instructions:

- Open the lid of the cloud chamber and saturate the felt strip inside with alcohol.
- Put the radiation source inside the cloud chamber and replace the lid tightly.
- Place the palm of your hand firmly on top of the cloud chamber for about 1 minute to evaporate the alcohol.
- Place the cloud chamber on a piece of FLAT dry ice that is at least a little larger than the chamber.
- Turn off the lights in the room and shine the flashlight through the cloud chamber to make the ion trails easier to see. Trails should begin a few minutes after placement on the dry ice.

Types of Radiation

Student Data Collection ANSWER Sheet

Shielding

- Place the three radiation sources on a table about 5 or 6 inches apart.
- Place a sheet of paper over all three, place the aluminum foil over the paper, and place the steel over the aluminum foil.
- Measure the radiation above the three sources.
- Remove the aluminum foil and re-measure the radiation.
- Finally, remove the paper and re-measure the radiation.

NOTE: The Geiger-counter must be held the same distance away from the source to eliminate the shielding effects of air.

Questions

1. Explain why only beta and gamma radiation affected the film and not the alpha radiation.

   Alpha radiation cannot penetrate the paper covering the film.

2. Explain why the gamma radiation did not make tracks in the cloud chamber.

   The reason gamma tracks aren't seen is because gamma has such a low rate of Linear Energy Transfer (LET). It's still ionizing radiation, but it is very unlikely to interact in the small volume of the cloud chamber.

3. How do the tracks generated by the radioactive particles in cloud chambers resemble what you can see created by jet airplanes as they pass through the upper atmosphere?

   The jet contrails are created by the particles emitted by the exhaust of the airplane engines. The moisture in the upper atmosphere coalesces and condenses on the exhaust particles in the same way the alcohol vapor condenses on the charged particles in the cloud chamber.

4. Have the students describe how gravity affects the particles as they are emitted from the source.

   Gravity affects the particles depending on their mass. The heavier particle, alpha, is more affected by gravity than lighter particles, beta.

5. Have the students describe the differences in the particle tracks in the cloud chambers.

   The alpha particle tracks will be more visible and wider. They also arc toward the bottom of the cloud chamber. Beta particles will be more erratic and smaller.

Enrichment Question

1. How do you think shielding is useful to the nuclear industry? Give three examples.

   Worker protection, containment of the nuclear fuel, and protection of the instruments, among other potential answers.

Radiation Types

Types of Radiation

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objectives

- Define alpha radiation
- Define beta radiation
- Define gamma radiation

Procedure

1. Draw what you observe.

Radiation Types – Types of Radiation
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

For High School Students

Autoradiograph

Prepare **Autoradiographs** as followed:

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- Remove the mantle and object from the film sheet.
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- Locate the bulge in the sheet that contains the developer chemicals.
- Place a ruler, flashlight, or other stiff, heavy object (a linoleum roller works best) behind the bulge and, while applying moderate pressure, slowly and evenly drag the object across the film sheet to spread the chemicals.
- Even distribution of the chemicals is critical for good development. It takes lots of practice to make a good picture.
- Wait 30 seconds for the film to develop then open the packet. Do not get the chemicals on your hands. Rinse your skin with water for 5 minutes if chemicals get on your skin.

Cloud Chambers

Prepare the cloud chambers as followed:

- Open the lid of the cloud chamber and saturate the felt strip inside with alcohol.
- Put the radiation source inside the cloud chamber and replace the lid tightly.
- Place the palm of your hand firmly on top of the cloud chamber for about 1 minute to evaporate the alcohol.
- Place the cloud chamber on a piece of FLAT dry ice that is at least a little larger than the chamber.
- Turn off the lights in the room and shine the flashlight through the cloud chamber to make the ion trails easier to see. Trails should begin a few minutes after placement on the dry ice.

Shielding

- Place the three radiation sources on a table about 5 or 6 inches apart.
- Place a sheet of paper over all three, place the aluminum foil over the paper, and place the steel over the aluminum foil.
- Measure the radiation above the three sources.
- Remove the aluminum foil and re-measure the radiation.
- Finally, remove the paper and re-measure the radiation.

NOTE: The Geiger counter must be held the same distance away from the source to eliminate the shielding effects of air.

Radiation Types – Types of Radiation

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. Explain why only beta and gamma radiation affected the film and not the alpha radiation.

2. Explain why the gamma radiation did not make tracks in the cloud chamber.

3. How do the tracks generated by the radioactive particles in cloud chambers resemble what you can see created by jet airplanes as they pass through the upper atmosphere?

4. Have the students describe how gravity affects the particles as they are emitted from the source.

5. Have the students describe the differences in the particle tracks in the cloud chambers.

Enrichment Question

1. How do you think shielding is useful to the nuclear industry? Give three examples.

Modeling Radioactive and Stable Atoms

With the Modeling Radioactive and Stable Atoms activity, students gain a better understanding of the differences between radioactive atoms and stable atoms. Students gain a better understanding of protons, neutrons, and electrons. Students are able to visualize what is meant by proton, neutron, and electron particles. By extension, this experiment is a useful analogy to radioactive decay. This experiment is best used by students working in groups.

A zip-close plastic bag represents the nucleus of an atom. 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).

Grade Level
5-9

Disciplinary Core Ideas (DCI)
5-ESS3-1, 3-5 ETS1-1, MS-PS3-2, HS-PS1-8, HS-PS3-2, HS-PS4-1, HS-PS4-4, HS-PS4-5

Time for Teacher Preparation
30-60 minutes – To gather materials and set-up

Activity Time:
30-60 minutes (1 Class Period)

Materials
- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Water, 1 cup
- Food coloring, 1/2 to 1 bottle
  - Pink and yellow
- Toothpicks, round, undyed
- Zipper-type plastic bags
- Marshmallows Large and Mini- air-dried (sticky-free), as many as you need
- Styrofoam tray
- Glue
- Flashlight
- Pipe cleaners

Safety
- Students should not eat marshmallows
- Students should not throw marshmallows at fellow students
- Students should use care when handling toothpicks

Science and Engineering Practices (NGSS)
- Ask questions and define problems
- Plan and carry out investigation
- Analyze and interpret data
- Use mathematics and computational thinking
- Construct explanations
- Argue from evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objectives
- Define Atomic Number
- Define Atomic Mass
- Define Radiation
- Define Radioactive Decay
- Discuss the differences between radioactive and stable atoms

Background
An **atom** is made up of three subatomic particles -- **protons**, **neutrons** and **electrons**. The center of an atom, called the **nucleus**, is composed of protons and neutrons. Protons are positively charged, neutrons have no charge at all and electrons are negatively charged. The proton-to-electron ratio is generally one to one, so the atom as a whole has a neutral charge. For example, a carbon atom has six protons and six electrons. Generally, if the proton to neutron ratio is larger than 1 to 1.5, the nuclear binding energy cannot hold the nucleus together and the nucleus will emit radiation and decay.

It's not that simple though. An atom's properties can change considerably based upon how many of each subatomic particles it has. If you change the number of protons, you wind up with a different element altogether. If you alter the number of neutrons in an atom, you wind up with an **isotope**. For example, carbon has three isotopes:

- carbon-12 (six protons + six neutrons), a stable and commonly occurring form of the element,
- carbon-13 (six protons + seven neutrons), which is stable but rare, and

- carbon-14 (six protons + eight neutrons), which is rare and unstable (or radioactive).

As we see with carbon, some atomic nuclei are stable and some are unstable. Unstable nuclei spontaneously emit particles and waves that scientists refer to as radiation. A nucleus that emits radiation is, of course, radioactive, and the process of emitting radiation is known as radioactive decay. Three types of radioactive decay will be studied:

- **Alpha decay**: A nucleus ejects two protons and two neutrons bound together, known as an **alpha particle**. **The atomic number will decrease by 2**, **and the mass will decrease by 4**.
- **Beta decay**: A neutron becomes a proton, an electron and an antineutrino. The ejected electron is a beta particle and it is accompanied by the antineutrino (a massless, chargeless particle). **The atomic number will increase by 1, and the mass will remain the same.**
- **Spontaneous fission:** A nucleus splits into two pieces. In the process, it can eject neutrons, which can become neutron rays.

In all three types of decay, the nucleus can also emit a burst of electromagnetic energy known as a gamma ray. Gamma rays are the only type of nuclear radiation that is wave energy instead of a fast-moving particle.

Teacher Lesson Plan:

Traditional

Demonstration:

Preparation for Student activity:

1. Remove the marshmallows from the packaging and let them “air” for a day.
2. Mix the water and food coloring in a cup.
3. Insert a toothpick into a marshmallow.
4. Dip the marshmallow “fondue style” into the colored water for about 2-3 seconds.

One suggestion - make the protons PINK and make neutrons YELLOW. There should be 7 protons and 7 neutrons and 1 mini-marshmallow electron per group.

5. Remove from colored water and stick in a Styrofoam tray to dry.
6. Let dry for several days or until not sticky to the touch.
7. Use marker to indicate protons with a “+” (plus sign).
8. Put in plastic bags, i.e., 7 neutrons (yellow) and 7 protons (pink) and 1 mini-marshmallow.

NOTE: If you keep the marshmallows in a cool, dry place your “particles” will last for several years.

9. Mark 7 large (pink) marshmallows with a positive (+) sign. They represent protons.
10. Select 7 unmarked large (yellow) marshmallows to represent neutrons.
11 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.
12. Mark the sides of 1 mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, 1 toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of 1 “proton” (so the positive sign is partially covered). This now represents a neutron.
13. Put the alpha particle from step #3 into an empty zip-close bag. Add 4 “protons” (pink) and 4 unmarked neutrons (yellow). Zip bag closed. The closed bag represents the nucleus of a stable atom. If the binding energy can contain all the protons and neutrons within the nucleus, the atom is stable.
14. Open the bag. Add one “neutron” (yellow) and one “neutron” that was made in step #4. Leave the bag unzipped; excess neutrons have now made it unstable because the proton-neutron ratio is greater than 1:1.5.
15. 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’s nucleus has changed and is stable again.

To show a different radioactive atom that emits an alpha particle to become stable, place an alpha particle in an empty zip bag.

Radiation Types

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 and shaking the contents, showing nuclear re-arrangement. 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.

If desired, you can add pipe cleaners around 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.

NGSS Guided Inquiry

Split students into small groups and give each student marshmallows. Have students design an experiment to model the differences between radioactive and stable atoms.

Student Procedure

1. Mark 7 large (pink) marshmallows with a positive (+) sign. They represent protons.
2. Select 7 unmarked large (yellow) 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 1 mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, 1 toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of 1 "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" (pink) and 4 unmarked neutrons (yellow). Zip bag closed. The closed bag represents the nucleus of a stable atom. If the binding energy can contain all the protons and neutrons within the nucleus, the atom is stable.
6. Open the bag. Add one "neutron" (yellow) and one "neutron" that was made in step #4. Leave the bag unzipped; excess neutrons have now made it unstable because the proton-neutron ratio is greater than 1:1.5.
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's nucleus has changed and is stable again.
8. Draw your atoms on the Student Data Collection Sheet

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

After Step 5:

1. 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.
2. What element is represented by this model?
3. How many neutral particles are in the bag? (You **do count** the particle where positive and negative charges cancel each other out!)
4. What is the atomic mass of this atom? (Each large marshmallow equals 1 atomic mass unit, regardless of charge.)

Assessment Ideas

- Have students discuss the differences between radioactive and stable atoms
- Have the students discuss the difference between radiation and radioactive decay

Differentiated Learning/Enrichment

- Have students discuss how the different arrangements of protons, neutrons, or electrons affect the radioactivity of an atom

Enrichment Questions

1. What is the atomic number of the atom at the end of the experiment?
2. What element does the atomic model represent at the end of the experiment?
3. What is the atomic mass of the atom at the end of the experiment?

Further Resources

ANS Center for Nuclear Science and Technology Information
http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

Modeling Radioactive and Stable Atoms

Student Data Collection ANSWER Sheet

Objectives

- Define Atomic Number
- Define Atomic Mass
- Define Radiation
- Define Radioactive Decay
- Discuss the differences between radioactive and stable atoms

Procedure

1. Mark 7 large (pink) marshmallows with a positive (+) sign. They represent protons.
2. Select 7 unmarked large (yellow) 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 1 mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, 1 toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of 1 "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" (pink) and 4 unmarked neutrons (yellow). Zip bag closed. The closed bag represents the nucleus of a stable atom. If the binding energy can contain all the protons and neutrons within the nucleus, the atom is stable.
6. Open the bag. Add one "neutron" (yellow) and one "neutron" that was made in step #4. Leave the bag unzipped; excess neutrons have now made it unstable because the proton-neutron ratio is greater than 1:1.5.
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's nucleus has changed and is stable again.
8. Draw your atoms below.

Modeling Radioactive and Stable Atoms

Student Data Collection ANSWER Sheet

Questions

1. 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.

   There are 6 protons in the bag (2 in the alpha particle and the 4 that were added).

2. What element is represented by this model?

   Carbon-12

3. How many neutral particles are in the bag? (You do count the particle where positive and negative charges cancel each other out!)

   There are 6 neutrons in the bag (2 in the alpha particle and the 4 that were added: 3 neutrons and a proton-electron pair).

4. What is the atomic mass of this atom? (Each large marshmallow equals 1 atomic mass unit, regardless of charge.)

   The atomic mass is 12.

Enrichment Questions

1. What is the atomic number of the atom at the end of the experiment?

   The atomic number is 7, because the neutron decayed to a proton and electron which added 1 to the atomic number.

2. What element does the atomic model represent at the end of the experiment?

   It is nitrogen-14.

3. What is the atomic mass of the atom at the end of the experiment?

   The atomic mass is 14.

Radiation Types

Modeling Radioactive and Stable Atoms

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objectives

- Define Atomic Number
- Define Atomic Mass
- Define Radiation
- Define Radioactive Decay
- Discuss the differences between radioactive and stable atoms

Procedure

1. Mark 7 large (pink) marshmallows with a positive (+) sign. They represent protons.
2. Select 7 unmarked large (yellow) 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 1 mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, 1 toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of 1 "proton" (so the positive sign is partially covered). This now represents a neutron.
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6. Open the bag. Add one "neutron" (yellow) and one "neutron" that was made in step #4. Leave the bag unzipped; excess neutrons have now made it unstable because the proton-neutron ratio is greater than 1:1.5.
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's nucleus has changed and is stable again.
8. Draw your atoms below.

Radiation Types – Modeling Radioactive and Stable Atoms
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

1. 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.

2. What element is represented by this model?

3. How many neutral particles are in the bag? (You do count the particle where positive and negative charges cancel each other out!)

4. What is the atomic mass of this atom? (Each large marshmallow equals 1 atomic mass unit, regardless of charge.)

Enrichment Questions

1. What is the atomic number of the atom at the end of the experiment?

2. What element does the atomic model represent at the end of the experiment?

3. What is the atomic mass of the atom at the end of the experiment?

Radioactive Ping-Pong

Students will explore practices and concepts about nuclear waste disposal as well as the importance of teamwork among engineers in order to achieve a mutual goal.

Grade Level

5-12

Disciplinary Core Ideas (DCI, NGSS)

4-ESS3-1, 5-ESS3-1, 3-5 ETS1-1, MS-ESS3-3, MS-ESS3-4, MS-ESS3-5, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, HS-PS1-8, HS-PS4-4, HS-ESS3-3, HS-ESS3-4

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Student Data Collection Sheets
- 1 Stopwatch per group
- 1 box of latex free vinyl gloves
- Fluorescent chalk
- Black light
- Paper Towels
- 2 brown paper lunch bags per group:
  - Place in Bag #1
    - 6 "radioactive" brightly colored ping-pong balls to model radioactivity
  - Place in Bag # 2
    - 2 paper clips
    - 3 straws
    - 4 3" x 3" pieces of paper
    - 5 rubber bands
    - 6 craft sticks
    - 7 push pins
    - 8 plastic spoons
    - 9 pieces of 6" string
    - 10 pieces of 6 inches long scotch tape

Safety

- Students should not throw ping-pong balls

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Use models
- Plan and carry out investigation
- Analyze and interpret data
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change of Systems

Objective

Explore how engineers must work together to dispose of nuclear waste.

Background

Types of Radioactive Waste

Exempt waste & very low level waste

Exempt waste and very low level waste (VLLW) contains radioactive materials at a level which is not considered harmful to people or the surrounding environment. It consists mainly of demolished material (such as concrete, plaster, bricks, metal, valves, piping etc.) produced during rehabilitation or dismantling operations on nuclear industrial sites. Other industries, such as food processing, chemical, steel etc. also produce VLLW as a result of the concentration of natural radioactivity present in certain minerals used in their manufacturing processes. The waste is therefore disposed of with domestic refuse, although countries such as France are currently developing facilities to store VLLW in specifically designed VLLW disposal facilities.

Low-level waste

Low-level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters etc., which contain small amounts of mostly short-lived radioactivity. It does not require shielding during handling and transport and is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. It comprises some 90% of the volume but only 1% of the radioactivity of all radioactive waste.

Intermediate-level waste

Intermediate-level waste (ILW) contains higher amounts of radioactivity and some requires shielding. It typically comprises resins, chemical sludges and metal fuel cladding, as well as contaminated materials from reactor decommissioning. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal. It makes up some 7% of the volume and has 4% of the radioactivity of all radwaste.

High-level waste

High-level waste (HLW) arises from the 'burning' of uranium fuel in a nuclear reactor. HLW contains the fission products and transuranic elements generated in the reactor core. It is highly radioactive and hot, so requires cooling and shielding. It can be considered as the 'ash' from 'burning' uranium. HLW accounts for over 95% of the total radioactivity produced in the process of electricity generation. There are two distinct kinds of HLW:

- Used fuel itself.
- Separated waste from reprocessing the used.

HLW has both long-lived and short-lived components, depending on the length of time it will take for the radioactivity of particular radionuclides to decrease to levels that are considered no longer hazardous for people and the surrounding environment. If generally short-lived fission products can be separated from long-lived actinides, this distinction becomes important in management and disposal of HLW.

What are nuclear wastes and how are they managed?

The most significant high-level waste from a nuclear reactor is the used nuclear fuel left after it has spent about three years in the reactor generating heat for electricity. Low-level waste is made up of lightly-contaminated items like tools and work clothing from power plant operation and makes up the bulk of radioactive wastes. Items disposed of as intermediate-level wastes might include used filters, steel components from within the reactor and some effluents from reprocessing.

	By Volume	By Radioactive Content
High Level Waste	3%	95%
Intermediate Level Waste	7%	4%
Low Level Waste	90%	1%

Generating enough electricity for one person produces just 30 grams of used fuel each year.

High level wastes make just 3% of the total volume of waste arising from nuclear generation, but they contain 95% of the radioactivity arising from nuclear power. Low level wastes represent 90% of the total volume of radioactive wastes, but contain only 1% of the radioactivity.

Electricity generation

In terms of radioactivity, high-level waste (HLW) is the major issue arising from the use of nuclear reactors to generate electricity. Highly radioactive fission products and also transuranic elements are produced from uranium and plutonium during reactor operations and are contained within the used fuel. Where countries have adopted a closed cycle and utilized reprocessing to recycle material from used fuel, the fission products and minor actinides are separated from uranium and plutonium and treated as HLW (uranium and plutonium is then re-used as fuel in reactors). In countries where used fuel is not reprocessed, the used fuel itself is considered a waste and therefore classified as HLW.

Low- and intermediate-level waste is produced as a result of operations, such as the cleaning of reactor cooling systems and fuel storage ponds, the decontamination of equipment, filters and metal components that have become radioactive as a result of their use in or near the reactor.

How much waste is produced?

As already noted, the volume of nuclear waste produced by the nuclear industry is very small compared with other wastes generated. Each year, nuclear power generation facilities worldwide produce about 200,000 m^3 of low- and intermediate-level radioactive waste, and about 10,000 m^3 of high-level waste including used fuel designated as waste.

In the OECD countries, some 300 million tons of toxic wastes are produced each year, but conditioned radioactive wastes amount to only 81,000 m^3 per year.

In the UK, for example, the total amount of radioactive waste (including radioactive waste expected to arise from existing nuclear facilities) is about 4.7 million m^3, or around 5 million tons. A further 1 million m^3 has already been disposed. Of the UK's total radioactive waste, about 94% (i.e. about 4.4 million m^3) falls into the low-level radioactive waste (LLW) category. About 6% (290,000 m^3) is in the intermediate-level radioactive waste (ILW) category, and less than 0.1% (1000 m^3) is classed as high-level waste (HLW). Although the volume of HLW is relatively small, it contains about 95% of the total inventory of radioactivity.

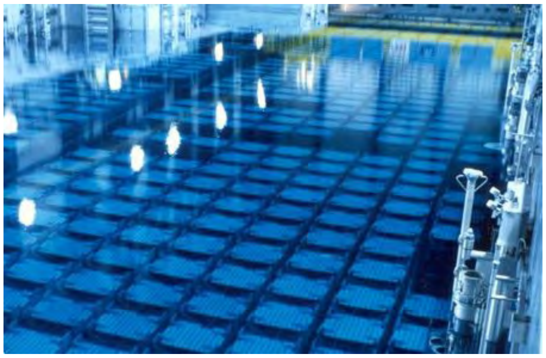
A typical 1000 MWe light water reactor will generate (directly and indirectly) 200-350 m^3 low- and intermediate-level waste per year. It will also discharge about 20 m^3 (27 tons) of used fuel per year, which corresponds to a 75 m^3 disposal volume following encapsulation if it is treated as waste. Where that used fuel is reprocessed, only 3 m^3 of vitrified waste (glass) is produced, which is equivalent to a 28 m^3 disposal volume following placement in a disposal canister.

This compares with an average 400,000 tons of ash produced from a coal-fired plant of the same power capacity. Today, volume reduction techniques and abatement technologies as well as continuing good practice within the work force all contribute to continuing minimization of waste produced, a key principle of waste management policy in the nuclear industry. Whilst the volumes of nuclear wastes produced are very small, the most important issue for the nuclear industry is managing their toxic nature in a way that is environmentally sound and presents no hazard to both workers and the general public.

Managing used fuel

Used nuclear fuel is very hot and radioactive. Handling and storing it safely can be done as long as it is cooled and plant workers are shielded from the radiation it produces by a dense material like concrete or steel, or by a few meters of water.

Water can conveniently provide both cooling and shielding, so a typical reactor will have its fuel removed underwater and transferred to a storage pool. After about five years it can be transferred into dry ventilated concrete containers, but otherwise it can safely remain in the pool indefinitely - usually for up to 50 years.



Nuclear fuel storage pool

Currently, the majority of used fuel is not recycled; but reprocessing used fuel to recover uranium (as reprocessed uranium, or RepU) and plutonium (Pu) avoids the wastage of a valuable resource. Most of the used fuel– about 96% – is uranium, and up to 1% is plutonium, with the remaining 3% being high-level waste. Both reprocessed uranium and plutonium have been recycled into new fuel. Plutonium mixed with uranium in their oxide forms is known as mixed oxide fuel (MOX).

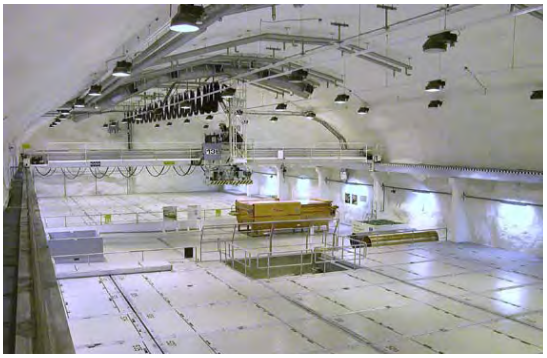
The high-level wastes (whether as used fuel after 50 years cooling, or the separated 3% of reprocessed fuel) will be disposed of deep underground in geological repositories.

Intermediate and low-level wastes

Intermediate- and low-level wastes are disposed of closer to the surface, in many established repositories. Low-level waste disposal sites are purpose built, but are not much different from normal municipal waste sites.

Nuclear power is not the only industry that creates radioactive wastes. Other industries include medicine, particle and space research, oil and gas, and mining - to name just a few. Some of these materials are not produced inside a reactor, but rather are concentrated forms of naturally occurring radioactive material.

Civil nuclear wastes from nuclear power plants have never caused any harm, nor posed an environmental hazard, in over 50 years of the nuclear power industry. Their management and eventual disposal is straightforward.



Low-level and Intermediary-level waste (LLW/ILW) repository at TVO's Olkiluoto site in Finland.

One characteristic of all radioactive wastes which distinguishes them from the very much larger amount of other toxic industrial wastes is that their radioactivity progressively decays and diminishes. For instance, after 40 years, the used fuel removed from a reactor has only one thousandth of its initial radioactivity remaining, making it very much easier to handle and dispose of.

Disposal

The categorization - high, intermediate, low - helps determine how wastes are treated and where they end up. High-level wastes require shielding and cooling, low-level wastes can be handled easily without shielding.

All radioactive waste facilities are designed with numerous layers of protection to make sure that people remain protected for as long as it takes for radioactivity to reduce to background levels. Low-level and intermediate wastes are buried close to the surface. For low-level wastes disposal is not much different from a normal municipal landfill. High-level wastes can remain highly radioactive for thousands of years. They need to be disposed of deep underground in engineered facilities built in stable geological formations. While no such facilities for high-level wastes currently operate, their feasibility has been demonstrated and there are several countries now in the process of designing and constructing them.

Teacher Lesson Plan:

Traditional/NGSS Guided Inquiry

- Coat ping pong balls in fluorescent chalk. Place ping pong balls into Bag #1
- Split students up into groups of 4-6
- Have the students time how long it takes their group to move all of the ping pong balls from Bag #1 to Bag #2.
- Empty the supplies from Bag #2 and place Bag #1 and Bag #2 on the floor approximately 8 feet apart from each other. The bags are to sit on the ground with the opening toward the ceiling, and they may not be moved, slid, tipped, etc..

- The balls need to be transported from Bag #1 to Bag #2 using only the supplies provided. No part of the body or clothes may touch the balls – ONLY the supplies. The team may alter the supplies in any way necessary, but once a supply item has been used to move a ball, it is contaminated and must be dropped into Bag #2 with the transported balls.
- If a person touches a ball or if a ball gets dropped, there is a contamination leak! The leader of the group may put on protective gear (rubber gloves) and return the ball to Bag #1 and place the glove in Bag #2. The ball still must be transported to Bag #2, and the team gets a15-second addition.
- Use blacklight to check for contamination, and then use paper towels to clean up. (If any of the fluorescent chalk is anywhere outside of Bag # 2, there has been a contamination leak for a 15-second addition.)

Student Procedure

- Work together as a team to transport the radioactive ping pong balls to bag #2 as quickly as possible using the supplies provided.
- No part of the body or clothes may touch the balls, only the supplies provided. Once a supply has been used to move a ball, it is contaminated and must also be disposed of in bag #2.
    - If a person touches a ball or if a ball gets dropped, there is a contamination leak! The leader of the group may put on protective gear (rubber gloves) and return the ball to Bag #1 and place the glove in Bag #2. The ball still must be transported to Bag #2, and the team gets a15-second addition
- Students should record how long it takes for them to complete the activity.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. Do you think you could have completed this activity just as quickly individually?
2. How did having a team affect the outcome of this activity?
3. I think that disposing nuclear waste is ________?
4. What was the biggest challenge in disposing the waste?

Assessment Ideas

Have the students race each other to see who can complete the task the fastest, most creatively, or with the best teamwork.

Differentiated Learning/Enrichment

- Give students more difficult supplies and a harder object to transport.
- Give each team a budget and have them research the amount of money needed to purchase supplies to complete the task. See which team can complete the task fastest as well as see which team can complete the task with the least amount of money.

Enrichment Question

1. Have the students research the costs associated with the transportation of radioactive waste from a National Laboratory to the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

Further Resources

For similar experiments:

http://www.nrc.gov/waste.html

http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/

Background *Citations:*

http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/

http://www.world-nuclear.org/nuclear-basics/what-are-nuclear-wastes-/

Student Data Collection ANSWER Sheet

Radioactive Ping-Pong

Objective

- Explore how engineers must work together to dispose of nuclear waste.

Procedure

- Work together as a team to transport the radioactive ping pong balls to bag #2 as quickly as possible using the supplies provided.
- No part of the body or clothes may touch the balls, only the supplies provided. Once a supply has been used to move a ball, it is contaminated and must also be disposed of in bag #2.
  - If a person touches a ball or if a ball gets dropped, there is a contamination leak! The leader of the group may put on protective gear (rubber gloves) and return the ball to Bag #1 and place the glove in Bag #2. The ball still must be transported to Bag #2, and the team gets a 15-second addition
- Students should record how long it takes for them to complete the activity.

Questions

1. Do you think you could have completed this activity just as quickly individually?

   No. It takes a team to properly and effectively move the waste without dropping it.

2. How did having a team affect the outcome of this activity?

   It would have been tremendously difficult and time consuming to do this activity alone.

3. I think that disposing nuclear waste is ____?

   Answers will vary.

4. What was the biggest challenge in disposing the waste?

   Contamination can occur very easily. For all intents and purposes, waste will remain radioactive for a long period of time.

Enrichment Question

1. Research the costs associated and the regulations involved with the transportation of radioactive waste from a National Laboratory to the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

   Students need to research background on WIPP.

   Answers may include regulations involving the Department of Transportation, the Nuclear Regulatory Commission, the Environmental Protection Agency, and the individual states that the material travels through.

Waste

Radioactive Ping-Pong

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objective

- Explore how engineers must work together to dispose of nuclear waste.

Procedure

- Work together as a team to transport the radioactive ping pong balls to bag #2 as quickly as possible using the supplies provided.
- No part of the body or clothes may touch the balls, only the supplies provided. Once a supply has been used to move a ball, it is contaminated and must also be disposed of in bag #2.
  - If a person touches a ball or if a ball gets dropped, there is a contamination leak! The leader of the group may put on protective gear (rubber gloves) and return the ball to Bag #1 and place the glove in Bag #2. The ball still must be transported to Bag #2, and the team gets a15-second addition
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Questions

1. Do you think you could have completed this activity just as quickly individually?

2. How did having a team affect the outcome of this activity?

3. I think that disposing nuclear waste is ______________________________?

4. What was the biggest challenge in disposing the waste?

Enrichment Question

1. Research the costs associated and the regulations involved with the transportation of radioactive waste from a National Laboratory to the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

Transporting Nuclear Waste

Students participate in and learn principles of transporting nuclear waste.

Grade Level

6-12

Disciplinary Core Ideas (DCI, NGSS)

4-ESS3-1, 5-ESS3-1, 3-5 ETS1-1, MS-ESS3-3, MS-ESS3-4, MS-ESS3-5, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, HS-PS1-8, HS-PS4-4, HS-ESS3-3, HS-ESS3-4

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Brown paper lunch bags
- Radiation Source(s)

NOTE: Radioactive Source not mandatory, there just needs to be something in the paper bag.

- Construction Paper or Butcher Paper

Safety

- Students should not throw ping-pong balls

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Use models
- Plan and carry out investigation
- Analyze and interpret data
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change of Systems

Objective

The transportation of radioactive wastes to a disposal or storage facility is often perceived as a dangerous undertaking when considering that highway and railway accidents do occur. By modeling the moving of a radioactive material within your school, students will be able to better visualize the issues addressed in actual rad-waste shipments to insure safe transportation of these materials.

Background

Types of Radioactive Waste

Exempt waste & very low level waste

Exempt waste and very low level waste (VLLW) contains radioactive materials at a level which is not considered harmful to people or the surrounding environment. It consists mainly of demolished material (such as concrete, plaster, bricks, metal, valves, piping etc.) produced during rehabilitation or dismantling operations on nuclear industrial sites. Other industries, such as food processing, chemical, steel etc. also produce VLLW as a result of the concentration of natural radioactivity present in certain minerals used in their manufacturing processes. The waste is therefore disposed of with domestic refuse, although countries such as France are currently developing facilities to store VLLW in specifically designed VLLW disposal facilities.

Low-level waste

Low-level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters etc., which contain small amounts of mostly short-lived radioactivity. It does not require shielding during handling and transport and is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. It comprises some 90% of the volume but only 1% of the radioactivity of all radioactive waste.

Intermediate-level waste

Intermediate-level waste (ILW) contains higher amounts of radioactivity and some requires shielding. It typically comprises resins, chemical sludges and metal fuel cladding, as well as contaminated materials from reactor decommissioning. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal. It makes up some 7% of the volume and has 4% of the radioactivity of all radwaste.

High-level waste

High-level waste (HLW) arises from the 'burning' of uranium fuel in a nuclear reactor. HLW contains the fission products and transuranic elements generated in the reactor core. It is highly radioactive and hot, so requires cooling and shielding. It can be considered as the 'ash' from 'burning' uranium. HLW accounts for over 95% of the total radioactivity produced in the process of electricity generation. There are two distinct kinds of HLW:

- Used fuel itself.
- Separated waste from reprocessing the used.

HLW has both long-lived and short-lived components, depending on the length of time it will take for the radioactivity of particular radionuclides to decrease to levels that are considered no longer hazardous for people and the surrounding environment. If generally short-lived fission products can be separated from long-lived actinides, this distinction becomes important in management and disposal of HLW.

What are nuclear wastes and how are they managed?

The most significant high-level waste from a nuclear reactor is the used nuclear fuel left after it has spent about three years in the reactor generating heat for electricity. Low-level waste is made up of lightly-contaminated items like tools and work clothing from power plant operation and makes up the bulk of radioactive wastes. Items disposed of as intermediate-level wastes might include used filters, steel components from within the reactor and some effluents from reprocessing.

	By Volume	By Radioactive Content
High Level Waste	3%	95%
Intermediate Level Waste	7%	4%
Low Level Waste	90%	1%

Generating enough electricity for one person produces just 30 grams of used fuel each year.

High level wastes make just 3% of the total volume of waste arising from nuclear generation, but they contain 95% of the radioactivity arising from nuclear power. Low level wastes represent 90% of the total volume of radioactive wastes, but contain only 1% of the radioactivity.

Electricity generation

In terms of radioactivity, high-level waste (HLW) is the major issue arising from the use of nuclear reactors to generate electricity. Highly radioactive fission products and also transuranic elements are produced from uranium and plutonium during reactor operations and are contained within the used fuel. Where countries have adopted a closed cycle and utilized reprocessing to recycle material from used fuel, the fission products and minor actinides are separated from uranium and plutonium and treated as HLW (uranium and plutonium is then re-used as fuel in reactors). In countries where used fuel is not reprocessed, the used fuel itself is considered a waste and therefore classified as HLW.

Low- and intermediate-level waste is produced as a result of operations, such as the cleaning of reactor cooling systems and fuel storage ponds, the decontamination of equipment, filters and metal components that have become radioactive as a result of their use in or near the reactor.

How much waste is produced?

Waste generated by nuclear power plants is significantly less in volume than most other forms of energy production. However, the waste is incredibly toxic the recycling, reprocessing, and disposal of nuclear waste are the biggest hurdles to the nuclear energy industry. High level nuclear waste is often vitrified, or turned into glass, and encapsulated into a secure container and then entombed deep into the earth.

As already noted, the volume of nuclear waste produced by the nuclear industry is very small compared with other wastes generated. Each year, nuclear power generation facilities worldwide produce about 200,000 m^3 of low- and intermediate-level radioactive waste, and about 10,000 m^3 of high-level waste including used fuel designated as waste.

In the OECD countries, some 300 million tons of toxic wastes are produced each year, but conditioned radioactive wastes amount to only 81,000 m^3 per year.

In the UK, for example, the total amount of radioactive waste (including radioactive waste expected to arise from existing nuclear facilities) is about 4.7 million m^3, or around 5 million tons. A further 1 million m^3 has already been disposed. Of the UK's total radioactive waste, about 94% (i.e. about 4.4 million m^3) falls into the low-level radioactive waste (LLW) category. About 6% (290,000 m^3) is in the intermediate-level radioactive waste (ILW) category, and less than 0.1% (1000 m^3) is classed as high-level waste (HLW). Although the volume of HLW is relatively small, it contains about 95% of the total inventory of radioactivity.

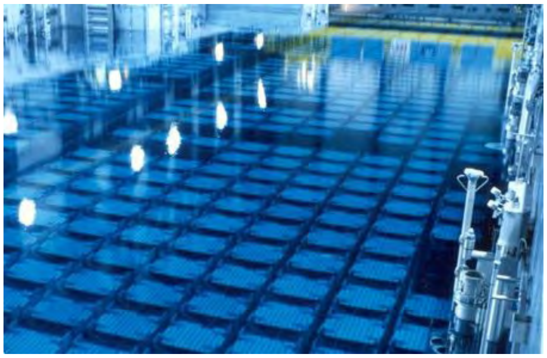
A typical 1000 MWe light water reactor will generate (directly and indirectly) 200-350 m^3 low- and intermediate-level waste per year. It will also discharge about 20 m^3 (27 tons) of used fuel per year, which corresponds to a 75 m^3 disposal volume following encapsulation if it is treated as waste. Where that used fuel is reprocessed, only 3 m^3 of vitrified waste (glass) is produced, which is equivalent to a 28 m^3 disposal volume following placement in a disposal canister.

This compares with an average 400,000 tons of ash produced from a coal-fired plant of the same power capacity. Today, volume reduction techniques and abatement technologies as well as continuing good practice within the work force all contribute to continuing minimisation of waste produced, a key principle of waste management policy in the nuclear industry. Whilst the volumes of nuclear wastes produced are very small, the most important issue for the nuclear industry is managing their toxic nature in a way that is environmentally sound and presents no hazard to both workers and the general public.

Managing used fuel

Used nuclear fuel is very hot and radioactive. Handling and storing it safely can be done as long as it is cooled and plant workers are shielded from the radiation it produces by a dense material like concrete or steel, or by a few meters of water.

Water can conveniently provide both cooling and shielding, so a typical reactor will have its fuel removed underwater and transferred to a storage pool. After about five years it can be transferred into dry ventilated concrete containers, but otherwise it can safely remain in the pool indefinitely - usually for up to 50 years.



Nuclear fuel storage pool

Currently, the majority of used fuel is not recycled; but reprocessing used fuel to recover uranium (as reprocessed uranium, or RepU) and plutonium (Pu) avoids the wastage of a valuable resource. Most of the used fuel– about 96% – is uranium, and up to 1% is plutonium, with the remaining 3% being high-level waste. Both reprocessed uranium and plutonium have been recycled into new fuel. Plutonium mixed with uranium in their oxide forms is known as mixed oxide fuel (MOX).

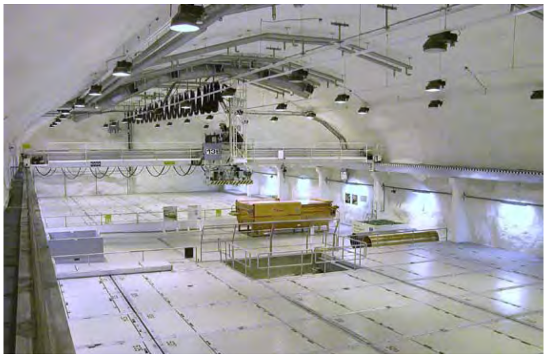
The high-level wastes (whether as used fuel after 50 years cooling, or the separated 3% of reprocessed fuel) will be disposed of deep underground in geological repositories.

Intermediate and low-level wastes

Intermediate- and low-level wastes are disposed of closer to the surface, in many established repositories. Low-level waste disposal sites are purpose built, but are not much different from normal municipal waste sites.

Nuclear power is not the only industry that creates radioactive wastes. Other industries include medicine, particle and space research, oil and gas, and mining - to name just a few. Some of these materials are not produced inside a reactor, but rather are concentrated forms of naturally occurring radioactive material.

Civil nuclear wastes from nuclear power plants have never caused any harm, nor posed an environmental hazard, in over 50 years of the nuclear power industry. Their management and eventual disposal is straightforward.



Low-level and Intermediary-level waste (LLW/ILW) repository at TVO's Olkiluoto site in Finland.

One characteristic of all radioactive wastes which distinguishes them from the very much larger amount of other toxic industrial wastes is that their radioactivity progressively decays and diminishes. For instance, after 40 years, the used fuel removed from a reactor has only one thousandth of its initial radioactivity remaining, making it very much easier to handle and dispose of.

Transportation[1]

Radioactive materials must be shipped from one location to another. Shipments of radioactive materials have been made with an excellent record of public safety -- because of the care taken by the companies involved and the government agencies which regulate them.

Regulations to control the transport of radioactive material were initiated by the Postal Service in 1935. Over the years, the Interstate Commerce Commission (ICC), now the Surface Transportation Board, became involved. Today, there are at least five groups that make rules governing the transport of radioactive material.

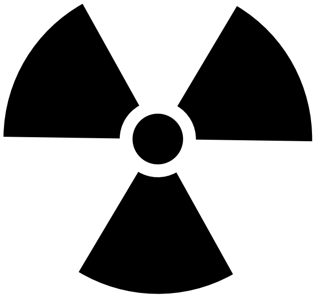
These groups are the Department of Transportation (DOT), the Nuclear Regulatory Commission (NRC), the Postal Service, the Department of Energy (DOE), and the States. Of these agencies, the Department of Transportation and the Nuclear Regulatory Commission are the primary ones issuing regulations based on the standards developed by the International Atomic Energy Agency.

The Nuclear Regulatory Commission and the Department of Transportation share responsibility for the control of radioactive material transport. Department of Transportation regulations are detailed and cover all aspects of transportation, including packaging, shipper and carrier responsibilities, documentation, and all levels of radioactive material from exempt quantities to very high levels.

NRC regulations, however, are primarily concerned with special packaging requirements for higher level quantities.

For transportation purposes, radioactive material is defined as any material which has a specific activity greater than 0.002 microcurie per gram. This definition does not specify a quantity, only a concentration.

1. Information comes from NRC, http://www.nrc.gov/reading-rm/basic-ref/teachers/unit5.html



Since transport accidents cannot be prevented, the regulations are primarily designed to insure safety in routine handling situations for minimally hazardous material and insure integrity under all circumstances for highly dangerous materials.

These goals are accomplished by focusing on the package and its ability to

- contain the material (prevent leaks)
- prevent unusual occurrences (such as criticality)
- reduce external radiation to safe levels (provide shielding)

When shipping used fuel from nuclear power plants, special care is taken to prevent any release of radioactivity to the environment even under the worst imaginable accident conditions.

Spent fuel is shipped in heavy casks that weigh from 20 to 100 tons. Different casks are used for different carriers (truck, barge, train), but all must pass a series of severe tests, such as

- a collision with an immovable object (like being dropped from 30 feet onto reinforced concrete)
- being dropped from 40 inches onto a steel spike
- being burned in a hot (gasoline) fire for 30 minutes
- submersion in water for eight hours

These tests are carefully monitored and measured with high-speed cameras. This help engineers and scientists study these containers under conditions that simulate an accident.

To make doubly sure that nothing can go wrong, spent fuel casks have been tested under real and possibly extreme accident conditions. For example, in one test a truck carrying a cask crashed into an unyielding cement wall at 85 miles per hour and in another test a cask was broadsided at 100 miles per hour by a 140-ton locomotive pulling three railroad cars. In both instances, the casks did not leak any radioactive waste.

There is a process to prepare the spent fuel is prepared for shipment. First, the spent fuel assembly from the reactor is placed inside its cask and the cask is sealed. Second, the outside of the cask is cleaned and then measured or surveyed for radioactivity. Third, the cask is loaded onto the truck or train car that will carry it.

However, before shipping can begin the cask must be inspected a second time to make sure that it is properly installed on the vehicle. Finally, the spent fuel cask and the vehicle carrying it must both be labeled.

In addition to all the requirements that casks must meet to be shipped by truck, the truck driver must be trained in the hazards of radioactive materials, transportation regulations, and emergency procedures. The route the truck carrying the cask takes is also given careful consideration to avoid large cities and undesirable road conditions.

Whether high- or low-level wastes are being shipped, how they are packaged is the most important consideration. The three basic types of packages are strong tight containers (STCs), Type A containers, and Type B containers. While the characteristics of STCs are not specified by regulation, types A and B have very specific requirements listed in the Department of Transportation regulations.

An STC is designed to survive normal transportation handling. In essence, if the contained material makes it from point A to point B without being released, the package is classified as being a strong tight container.

A Type A container, on the other hand, is designed to survive normal transportation handling and minor accidents. Type B containers must be able to survive severe accidents.

Fissile materials (spent fuel) that could be involved in a criticality accident also have additional packaging requirements.

Markings on packages, labeling, and placarding on transportation vehicles are also important aspects of the transport of radioactive materials. Markings are designed to provide an explanation of the contents of a package by using standard terms and codes.

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Labels are used to visually indicate the type of hazard and the level of hazard contained in a package. Labels rely principally on symbols to indicate the hazard. Although the package required for transporting radioactive material is based on the activity **INSIDE** the package, the label required on the package is based on the radiation hazard **OUTSIDE** the package.

Radioactive material is the only hazardous material which has three possible labels, depending on the relative radiation levels external to the package. Also, labels for radioactive material are the only ones which require the shipper to write some information on the label. The information is a number called the Transport Index (TI), which, in reality, is the highest radiation level at one meter from the surface of the package.

The three labels are commonly called White I, Yellow II, and Yellow III, referring to the color of the label and the roman numeral prominently displayed. A specific label is required if the surface radiation limit and the limit at one meter satisfy the requirements shown on the "Labeling" transparency.

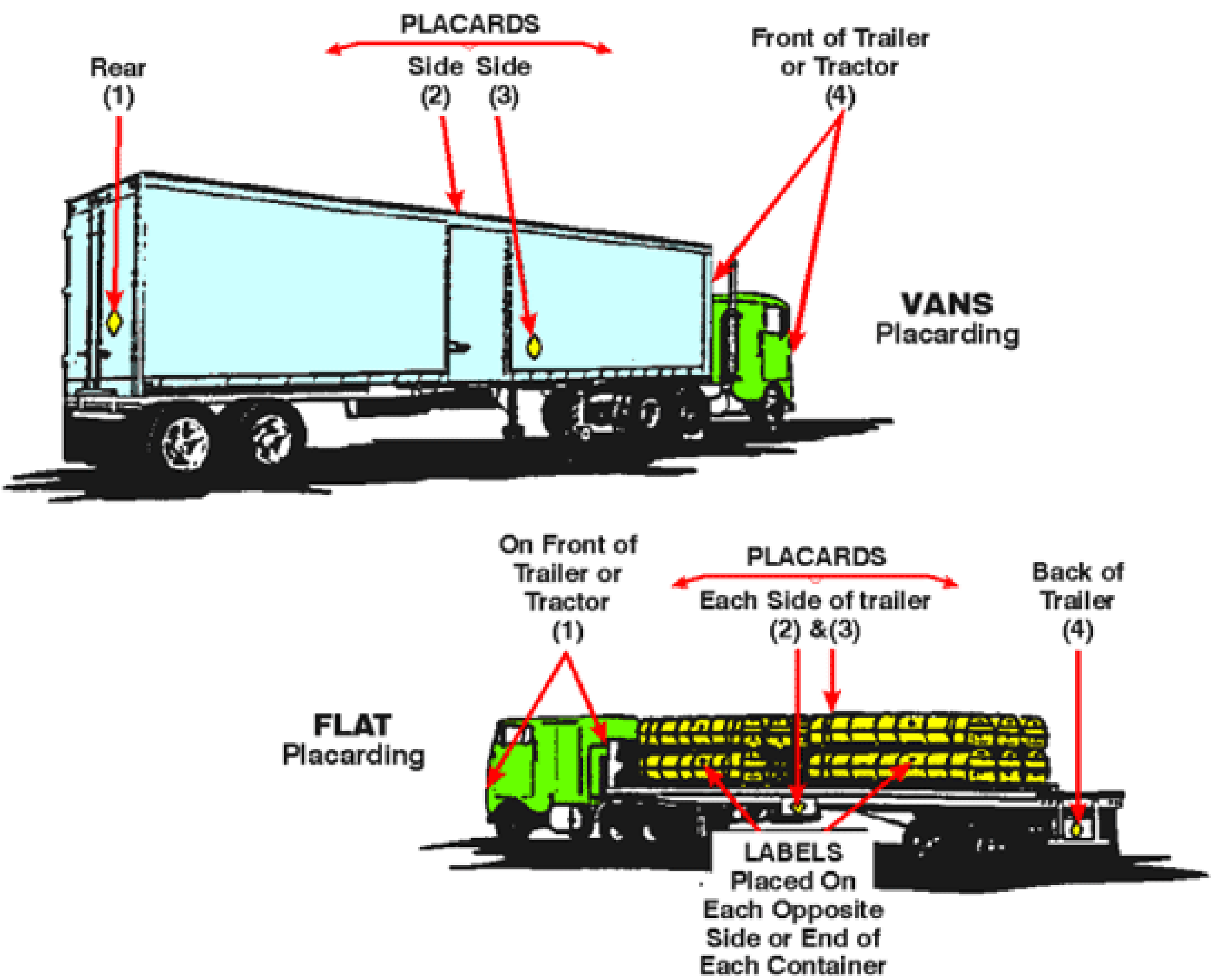
Placards are just bigger labels that are placed on the outside of the vehicle. Unlike labels, there is only one placard and no information need be written on it. Placards on a vehicle are only required if the vehicle is carrying a package bearing a Yellow III label or is carrying low specific radioactive material.

The outstanding safety record of storing and shipping used fuel is no accident. It is the result of a philosophy that places public safety and environmental protection first, and a practice of controlled handling and packaging of the used fuel so that it cannot harm the workers, the public, or the environment.

Disposal

The categorization - high, intermediate, low - helps determine how wastes are treated and where they end up. High-level wastes require shielding and cooling, low-level wastes can be handled easily without shielding.

All radioactive waste facilities are designed with numerous layers of protection to make sure that people remain protected for as long as it takes for radioactivity to reduce to background levels. Low-level and intermediate wastes are buried close to the surface. For low-level wastes disposal is not much different from a normal municipal landfill. High-level wastes can remain highly radioactive for thousands of years. They need to be disposed of deep underground in engineered facilities built in stable geological formations. While



Placards are just bigger labels which are placed on the outside of the vehicle. Unlike labels, there is only one placard and no information need be written on it (i.e. no TI). In fact, a placard on a vehicle is only required if the vehicle is carrying a package bearing a Yellow 3 label or LSA material. If the amount of the material being transported constitutes a highway route controlled quantity, the diamond shaped placard has a black square border surrounding it.

no such facilities for high-level wastes currently operate, their feasibility has been demonstrated and there are several countries now in the process of designing and constructing them.

Teacher Lesson Plan:

Traditional/NGSS Guided Inquiry

- Split students up into groups of three
- Give each student a piece of butcher or construction paper
- Tell students that the contents of the brown paper bag are radioactive and must be disposed of and stored safely somewhere on the school grounds.
    - Be sure to tell students what kind of radiation the waste emits as it will impact what kind of container they choose to store it in.
- Ask them to work with their team to devise a plan to safely transport the radioactive waste to the location and how to safely store it there.
- Have students include the following details in their plan with an explanation for each decision.
    - Where to store it.
    - What kind of container to transport it in.
    - How to transport it.
    - When to transport it, what time of the day.
    - What route to take to get there.
    - How to make sure the waste is monitored and guarded.
    - How to make sure the material is protected while it is being transported.

Student Procedure

- Get together with your team to make a plan of how to dispose of the radioactive waste and be sure to include the following details.
    - Where to store it.
    - What kind of container to transport it in.
    - How to transport it.
    - When to transport it, what time of the day.
    - What route to take to get there.
    - How to make sure the waste is monitored and guarded.
    - How to make sure the material is protected while it is being transported.
- Draw your plan on the construction paper.

Data Collection

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Construction paper

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. Explain why you made each decision on how to transport the waste.
2. Why have some States formed coalitions to support a single nuclear waste site that would serve several States?
3. Are special packaging containers built to protect the contents or keep the contents from getting in contact with the environment?
4. How would this activity differ if your waste was liquid?

Assessment Ideas

Have each group present their plan and then hold a vote for which plan should be executed.

Differentiated Learning/Enrichment

- Have groups research and choose a long-term location to store a supply of nuclear waste within their state as well as within their country and support why they chose that site as well as how to transport the waste there.

Enrichment Question

1. Have the students research where high-level waste, low-level waste, and transuranic waste are currently being stored.
    a. How is the waste transported to the sites?
    b. How is the waste being stored on the site?

Further Resources

For similar experiments:

http://www.nrc.gov/waste.html

http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/

Background *Citations:*

http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/

http://www.world-nuclear.org/nuclear-basics/what-are-nuclear-wastes-/

Student Data Collection ANSWER Sheet

Objective

- The transportation of radioactive wastes to a disposal or storage facility is often perceived as a dangerous undertaking when considering that highway and railway accidents do occur. By modeling the moving of a radioactive material within your school, you will be able to better visualize the issues addressed in actual rad-waste shipments to insure safe transportation of these materials.

Procedure

- Get together with your team to make a plan of how to dispose of the radioactive waste and be sure to include the following details.
  - Where to store it.
  - What kind of container to transport it in.
  - How to transport it.
  - When to transport it, what time of the day.
  - What route to take to get there.
  - How to make sure the waste is monitored and guarded.
  - How to make sure the material is protected while it is being transported.

Draw your plan on the construction paper.

Questions

1. Explain why you made each decision on how to transport the waste.

   Answers will vary.

2. Why have some States formed coalitions to support a single nuclear waste site that would serve several States?

   The Low-Level Radioactive Waste Policy Act passed by the U.S. Congress in 1980 requires each State to provide for disposal of the low-level waste produced within its borders.

3. Are special packaging containers built to protect the contents or keep the contents from getting in contact with the environment?

   They are designed to keep the contents from getting in contact with the environment.

4. How would this activity differ if your waste was liquid?

The liquids would need to be processed to remove radioactive impurities. This can include

- Filtering
- routing through demineralizers
- boiling off the water and leaving the solid impurities to be processed as solid waste
- storing the liquid to allow the radioactive material to decay

Enrichment Question

1. Have the students research where high-level waste, low-level waste, and transuranic waste are currently being stored.
   a. How is the waste transported to the sites?
   b. How is the waste being stored on the site?

Students need to research background on where high-level waste, low-level waste, and transuranic waste are currently being stored.

Answers may include regulations involving the Department of Transportation, the Nuclear Regulatory Commission, the Environmental Protection Agency, and the individual states that the material travels through.

Transporting Nuclear Waste

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objective

- The transportation of radioactive wastes to a disposal or storage facility is often perceived as a dangerous undertaking when considering that highway and railway accidents do occur. By modeling the moving of a radioactive material within your school, you will be able to better visualize the issues addressed in actual rad-waste shipments to insure safe transportation of these materials.

Procedure

- Get together with your team to make a plan of how to dispose of the radioactive waste and be sure to include the following details.
    - Where to store it.
    - What kind of container to transport it in.
    - How to transport it.
    - When to transport it, what time of the day.
    - What route to take to get there.
    - How to make sure the waste is monitored and guarded.
    - How to make sure the material is protected while it is being transported.

Draw your plan on the construction paper.

Questions

1. Explain why you made each decision on how to transport the waste.

2. Why have some States formed coalitions to support a single nuclear waste site that would serve several States?

3. Are special packaging containers built to protect the contents or keep the contents from getting in contact with the environment?

Name: ______________________________

Date: ______________________________

4. How would this activity differ if your waste was liquid?

Enrichment Question

1. Have the students research where high-level waste, low-level waste, and transuranic waste are currently being stored.
   a. How is the waste transported to the sites?
   b. How is the waste being stored on the site?

Radioactive Waste Disposal

Students work to reduce, recycle, and reuse nuclear waste in the safest manner while evaluating the practices of their peers.

Grade Level
6-12

Disciplinary Core Ideas (DCI, NGSS)

4-ESS3-1, 5-ESS3-1, 3-5 ETS1-1, MS-ESS3-3, MS-ESS3-4, MS-ESS3-5, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, HS-PS1-8, HS-PS4-4, HS-ESS3-3, HS-ESS3-4

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Plastic gloves (2)
- Glass slide
- Salt pellet
- Sponge
- Metal pipe
- Paper towels or rags
- Piece of orange ceramic: Fiesta Ware
- Bent paper clips (5)
- Package of lantern mantles
- Cloth squares (2)
- Plastic/glass vial
- Mechanics tool
- Aluminum foil

Safety

- Students should not open the plastic bag surrounding the lantern mantle
- Students should use care when handling radioactive materials
- Students should use care when dealing with glass or ceramic materials

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Use models
- Plan and carry out investigation
- Analyze and interpret data
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change of Systems

Objective

To follow good disposal practices in the disposal of a simulated sample of low level radioactive waste (LLRW). The disposal practices of "reduce, recycle, and reuse" should be applied to all wastes generated by our technological society. An additional consideration in dealing with LLRW is to reduce the possibility of having radioactive materials and their radiations from entering into the ecosystem.

Background

Types of Radioactive Waste

Exempt waste & very low level waste

Exempt waste and very low level waste (VLLW) contains radioactive materials at a level which is not considered harmful to people or the surrounding environment. It consists mainly of demolished material (such as concrete, plaster, bricks, metal, valves, piping etc.) produced during rehabilitation or dismantling operations on nuclear industrial sites. Other industries, such as food processing, chemical, steel etc. also produce VLLW as a result of the concentration of natural radioactivity present in certain minerals used in their manufacturing processes. The waste is therefore disposed of with domestic refuse, although countries such as France are currently developing facilities to store VLLW in specifically designed VLLW disposal facilities.

Low-level waste

Low-level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters etc., which contain small amounts of mostly short-lived radioactivity. It does not require shielding during handling and transport and is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. It comprises some 90% of the volume but only 1% of the radioactivity of all radioactive waste.

Intermediate-level waste

Intermediate-level waste (ILW) contains higher amounts of radioactivity and some requires shielding. It typically comprises resins, chemical sludges and metal fuel cladding, as well as contaminated materials from reactor decommissioning. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal. It makes up some 7% of the volume and has 4% of the radioactivity of all radwaste.

High-level waste

High-level waste (HLW) arises from the 'burning' of uranium fuel in a nuclear reactor. HLW contains the fission products and transuranic elements generated in the reactor core. It is highly radioactive and hot, so requires cooling and shielding. It can be considered as the 'ash' from 'burning' uranium. HLW accounts for over 95% of the total radioactivity produced in the process of electricity generation. There are two distinct kinds of HLW:

- Used fuel itself.
- Separated waste from reprocessing the used.

HLW has both long-lived and short-lived components, depending on the length of time it will take for the radioactivity of particular radionuclides to decrease to levels that are considered no longer hazardous for people and the surrounding environment. If generally short-lived fission products can be separated from long-lived actinides, this distinction becomes important in management and disposal of HLW.

What are nuclear wastes and how are they managed?

The most significant high-level waste from a nuclear reactor is the used nuclear fuel left after it has spent about three years in the reactor generating heat for electricity. Low-level waste is made up of lightly-contaminated items like tools and work clothing from power plant operation and makes up the bulk of radioactive wastes. Items disposed of as intermediate-level wastes might include used filters, steel components from within the reactor and some effluents from reprocessing.

	By Volume	By Radioactive Content
High Level Waste	3%	95%
Intermediate Level Waste	7%	4%
Low Level Waste	90%	1%

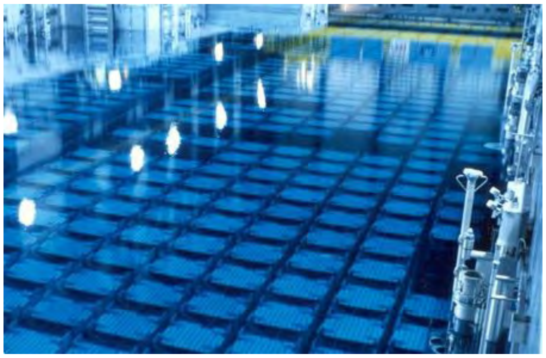
Generating enough electricity for one person produces just 30 grams of used fuel each year.

High level wastes make just 3% of the total volume of waste arising from nuclear generation, but they contain 95% of the radioactivity arising from nuclear power. Low level wastes represent 90% of the total volume of radioactive wastes, but contain only 1% of the radioactivity.

Managing used fuel

Used nuclear fuel is very hot and radioactive. Handling and storing it safely can be done as long as it is cooled and plant workers are shielded from the radiation it produces by a dense material like concrete or steel, or by a few meters of water.

Water can conveniently provide both cooling and shielding, so a typical reactor will have its fuel removed underwater and transferred to a storage pool. After about five years it can be transferred into dry ventilated concrete containers, but otherwise it can safely remain in the pool indefinitely - usually for up to 50 years.



Nuclear fuel storage pool

Currently, the majority of used fuel is not recycled; but reprocessing used fuel to recover uranium (as reprocessed uranium, or RepU) and plutonium (Pu) avoids the wastage of a valuable resource. Most of the used fuel– about 96% – is uranium, and up to 1% is plutonium, with the remaining 3% being high-level waste. Both reprocessed uranium and plutonium have been recycled into new fuel. Plutonium mixed with uranium in their oxide forms is known as mixed oxide fuel (MOX).

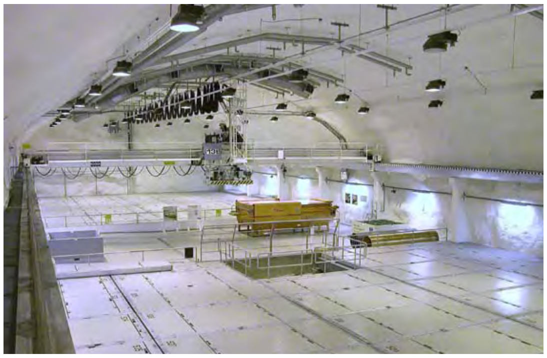
The high-level wastes (whether as used fuel after 50 years cooling, or the separated 3% of reprocessed fuel) will be disposed of deep underground in geological repositories.

Intermediate and low-level wastes

Intermediate- and low-level wastes are disposed of closer to the surface, in many established repositories. Low-level waste disposal sites are purpose built, but are not much different from normal municipal waste sites.

Nuclear power is not the only industry that creates radioactive wastes. Other industries include medicine, particle and space research, oil and gas, and mining - to name just a few. Some of these materials are not produced inside a reactor, but rather are concentrated forms of naturally occurring radioactive material.

Civil nuclear wastes from nuclear power plants have never caused any harm, nor posed an environmental hazard, in over 50 years of the nuclear power industry. Their management and eventual disposal is straightforward.



Low-level and Intermediary-level waste (LLW/ILW) repository at TVO's Olkiluoto site in Finland.

One characteristic of all radioactive wastes which distinguishes them from the very much larger amount of other toxic industrial wastes is that their radioactivity progressively decays and diminishes. For instance, after 40 years, the used fuel removed from a reactor has only one thousandth of its initial radioactivity remaining, making it very much easier to handle and dispose of.

Transportation[1]

Radioactive materials must be shipped from one location to another. Shipments of radioactive materials have been made with an excellent record of public safety -- because of the care taken by the companies involved and the government agencies which regulate them.

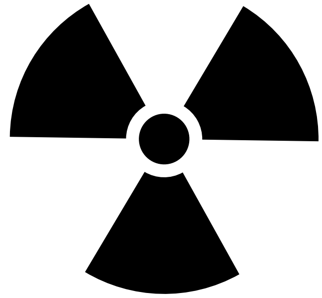
Regulations to control the transport of radioactive material were initiated by the Postal Service in 1935. Over the years, the Interstate Commerce Commission (ICC), now the Surface Transportation Board, became involved. Today, there are at least five groups that make rules governing the transport of radioactive material.

These groups are the Department of Transportation (DOT), the Nuclear Regulatory Commission (NRC), the Postal Service, the Department of Energy (DOE), and the States. Of these agencies, the Department of Transportation and the Nuclear Regulatory Commission are the primary ones issuing regulations based on the standards developed by the International Atomic Energy Agency.

The Nuclear Regulatory Commission and the Department of Transportation share responsibility for the control of radioactive material transport. Department of Transportation regulations are detailed and cover all aspects of transportation, including packaging, shipper and carrier responsibilities, documentation, and all levels of radioactive material from exempt quantities to very high levels.

NRC regulations, however, are primarily concerned with special packaging requirements for higher level quantities.

For transportation purposes, radioactive material is defined as any material which has a specific activity greater than 0.002 microcurie per gram. This definition does not specify a quantity, only a concentration.



Since transport accidents cannot be prevented, the regulations are primarily designed to insure safety in routine handling situations for minimally hazardous material and insure integrity under all circumstances for highly dangerous materials.

These goals are accomplished by focusing on the package and its ability to

- contain the material (prevent leaks)
- prevent unusual occurrences (such as criticality)
- reduce external radiation to safe levels (provide shielding)

When shipping used fuel from nuclear power plants, special care is taken to prevent any release of radioactivity to the environment even under the worst imaginable accident conditions.

Spent fuel is shipped in heavy casks that weigh from 20 to 100 tons. Different casks are used for different carriers (truck, barge, train), but all must pass a series of severe tests, such as

- a collision with an immovable object (like being dropped from 30 feet onto reinforced concrete)
- being dropped from 40 inches onto a steel spike
- being burned in a hot (gasoline) fire for 30 minutes
- submersion in water for eight hours

These tests are carefully monitored and measured with high-speed cameras. This help engineers and scientists study these containers under conditions that simulate an accident.

To make doubly sure that nothing can go wrong, spent fuel casks have been tested under real and possibly extreme accident conditions. For example, in one test a truck carrying a cask crashed into an unyielding cement wall at 85 miles per hour and in another test a cask was broadsided at 100 miles per hour by a 140-ton locomotive pulling three railroad cars. In both instances, the casks did not leak any radioactive waste.

There is a process to prepare the spent fuel is prepared for shipment. First, the spent fuel assembly from the reactor is placed inside its cask and the cask is sealed. Second, the outside of the cask is cleaned and then measured or surveyed for radioactivity. Third, the cask is loaded onto the truck or train car that will carry it.

However, before shipping can begin the cask must be inspected a second time to make sure that it is properly installed on the vehicle. Finally, the spent fuel cask and the vehicle carrying it must both be labeled.

2. Information comes from NRC, http://www.nrc.gov/reading-rm/basic-ref/teachers/unit5.html

In addition to all the requirements that casks must meet to be shipped by truck, the truck driver must be trained in the hazards of radioactive materials, transportation regulations, and emergency procedures. The route the truck carrying the cask takes is also given careful consideration to avoid large cities and undesirable road conditions.

Whether high- or low-level wastes are being shipped, how they are packaged is the most important consideration. The three basic types of packages are strong tight containers (STCs), Type A containers, and Type B containers. While the characteristics of STCs are not specified by regulation, types A and B have very specific requirements listed in the Department of Transportation regulations.

An STC is designed to survive normal transportation handling. In essence, if the contained material makes it from point A to point B without being released, the package is classified as being a strong tight container.

A Type A container, on the other hand, is designed to survive normal transportation handling and minor accidents. Type B containers must be able to survive severe accidents.

Fissile materials (spent fuel) that could be involved in a criticality accident also have additional packaging requirements.

Markings on packages, labeling, and placarding on transportation vehicles are also important aspects of the transport of radioactive materials. Markings are designed to provide an explanation of the contents of a package by using standard terms and codes.

Markings are designed to provide an explanation of the contents of a package by using standard terms and codes.

Labels are used to visually indicate the type of hazard and the level of hazard contained in a package. Labels rely principally on symbols to indicate the hazard. Although the package required for transporting radioactive material is based on the activity **INSIDE** the package, the label required on the package is based on the radiation hazard **OUTSIDE** the package.

Radioactive material is the only hazardous material which has three possible labels, depending on the relative radiation levels external to the package. Also, labels for radioactive material are the only ones which require the shipper to write some information on the label. The information is a number called the Transport Index (TI), which, in reality, is the highest radiation level at one meter from the surface of the package.

The three labels are commonly called White I, Yellow II, and Yellow III, referring to the color of the label and the roman numeral prominently displayed. A specific label is required if the surface radiation limit and the limit at one meter satisfy the requirements shown on the "Labeling" transparency.

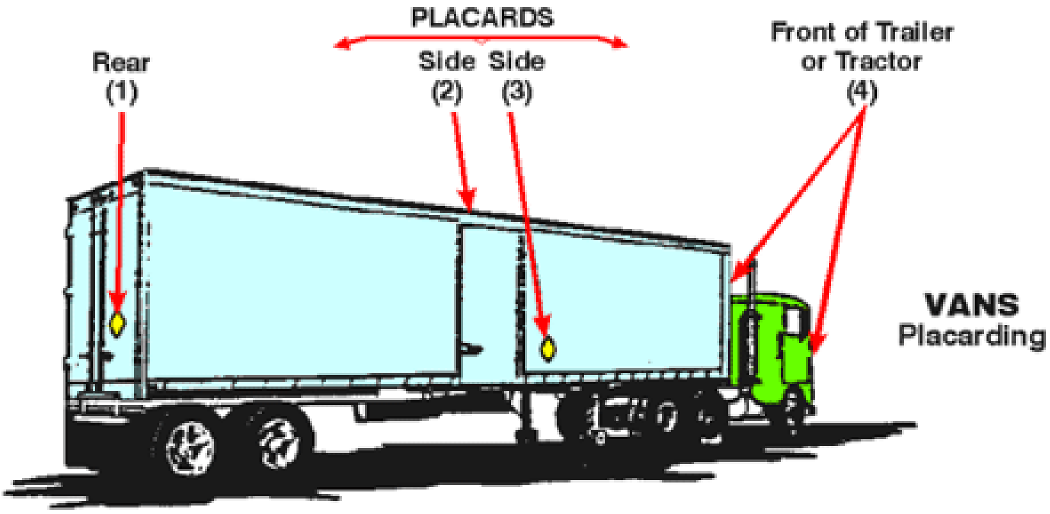
Placards are just bigger labels that are placed on the outside of the vehicle. Unlike labels, there is only one placard and no information need be written on it. Placards on a vehicle are only required if the vehicle is carrying a package bearing a Yellow III label or is carrying low specific radioactive material.

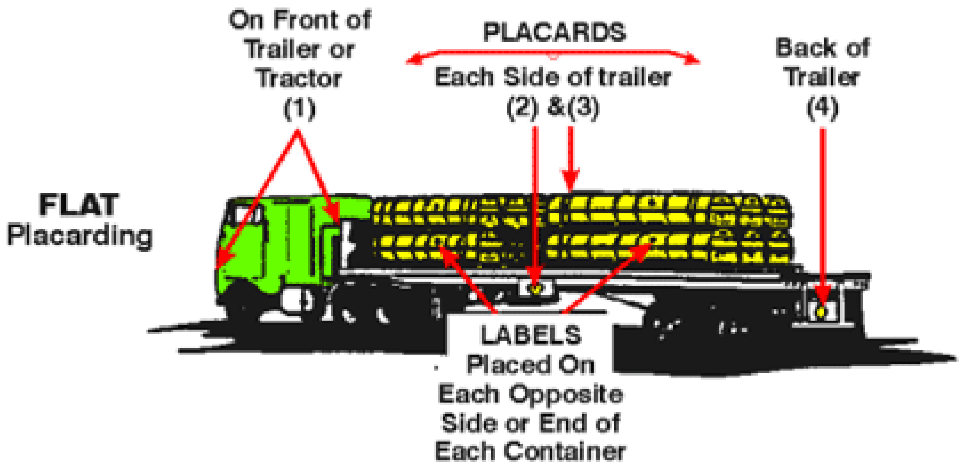
The outstanding safety record of storing and shipping used fuel is no accident. It is the result of a philosophy that places public safety and environmental protection first, and a practice of controlled handling and packaging of the used fuel so that it cannot harm the workers, the public, or the environment.

Disposal

The categorization - high, intermediate, low - helps determine how wastes are treated and where they end up. High-level wastes require shielding and cooling, low-level wastes can be handled easily without shielding.

All radioactive waste facilities are designed with numerous layers of protection to make sure that people remain protected for as long as it takes for radioactivity to reduce to background levels. Low-level and intermediate wastes are buried close to the surface. For low-level wastes disposal is not much different from a normal municipal landfill. High-level wastes can remain highly radioactive for thousands of years. They need to be disposed of deep underground in engineered facilities built in stable geological formations. While no such facilities for high-level wastes currently operate, their feasibility has been demonstrated and there are several countries now in the process of designing and constructing them.





Placards are just bigger labels which are placed on the outside of the vehicle. Unlike labels, there is only one placard and no information need be written on it (i.e. no TI). In fact, a placard on a vehicle is only required if the vehicle is carrying a package bearing a Yellow 3 label or LSA material. If the amount of the material being transported constitutes a highway route controlled quantity, the diamond shaped placard has a black square border surrounding it.

Teacher Lesson Plan:

Traditional

- Split students up into groups of three
- Give each student their activity handout and materials
- Tell students to treat their waste as outlined in the handout and then to trade with another team and evaluate their practices.

NGSS Guided Inquiry

Have the students design an experiment in which they determine how to reuse, recycle, or properly store different types of waste including radioactive waste.

Student Procedure

- To properly treat your team's nuclear waste, sort the wastes by placing them into one of the 3 bags as described below..
    - Wastes to be disposed of in a LLW facility should be placed into the waste bag with the “CAUTION: RADIOACTIVE (waste) MATERIALS” sticker on it.
    - Wastes to be disposed of in a regular municipal landfill should be placed into the waste bag marked “M.W.” (for municipal wastes).
    - Wastes not placed into either bag MUST be itemized on the “REUSE/RECYCLE MATERIALS LIST” below with a **detailed** explanation of how they should be handled or treated before they are recycled or reused.
- Once you have completed treatment, trade materials with another group and evaluate their practices.

Waste

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. List the items the other team placed into the LLW bag that were different from what your team placed there. Why do you think this happened?
2. List the items the other team placed into the MW bag that were different from what your team placed there. Why do you think this happended?
3. Why do real nuclear facilities - hospitals, nuclear power plants, and industries - not have discrepancies in their disposal of wastes?
4. Why are there special sites for disposal of low-level wastes?
5. Why is there a controversy over the selection of a high-level nuclear waste disposal site?

Assessment Ideas

The groups with the highest scores win.

Differentiated Learning/Enrichment

Enrichment Questions

1. What kinds of materials are considered Low-Level Radioactive Waste?
2. What kind of material is considered High-Level Radioactive Waste?
3. What insures that Rad Wastes (either high or low) will be disposed of properly and will not harm us now or in the future?

Further Resources

Adapted from:

"Radioactive Waste Disposal Activity", by Tim DeVries

Citations for Background:

http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/

http://www.world-nuclear.org/nuclear-basics/what-are-nuclear-wastes-/

Radioactive Waste Disposal

Student Data Collection ANSWER Sheet

Objective

- To follow good disposal practices in the disposal of a simulated sample of low level radioactive waste (LLRW). The disposal practices of "reduce, recycle, and reuse" should be applied to all wastes generated by our technological society. An additional consideration in dealing with LLRW is to reduce the possibility of having radioactive materials and their radiations from entering into the ecosystem.

Procedure

- To properly treat your team's nuclear waste, sort the wastes by placing them into one of the 3 bags as described below.
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REUSE/RECYCLE MATERIALS LIST

MATERIAL	TREATMENT PRIOR TO REUSE OR RECYCLING
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

- Once you have completed treatment, trade materials with another group and evaluate their practices.

Questions

1. List the items the other team placed into the LLW bag that were different from what your team placed there. Why do you think this happended?

   Answers will vary

2. List the items the other team placed into the MW bag that were different from what your team placed there. Why do you think this happended?

   Answers will vary

Questions

3. Why do real nuclear facilities - hospitals, nuclear power plants, and industries - not have discrepancies in their disposal of wastes?

   All nuclear facilities monitor wastes and follow strict government regulations that determine where and how wastes are disposed.

4. Why are there special sites for disposal of low-level wastes?

   Low-level waste sites are situated regionally to minimize the amount of transportation needed, and because it must be isolated from the environment.

5. Why is there a controversy over the selection of a high-level nuclear waste disposal site?

   The controversy depends upon the transportation of the waste to the site and all of the regulations involved, final disposal, mitigation of environmental issues, eternal monitoring of the site for leaks and sufficient funding to provide all of these.

   The waste that will be stored in these sites is highly radioactive and will remain so for thousands of years, many people don't want it located near them. They are worried that some of the radioactive material may somehow get (leak) into the environment.

Enrichment Questions

1. What kinds of materials are considered Low-Level Radioactive Waste?

   Low-level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters etc., which contain small amounts of mostly short-lived radioactivity. It does not require shielding during handling and transport and is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. It comprises some 90% of the volume but only 1% of the radioactivity of all radioactive waste.

2. What kind of material is considered High-Level Radioactive Waste?

   High-level waste (HLW) arises from the 'burning' of uranium fuel in a nuclear reactor. HLW contains the fission products and transuranic elements generated in the reactor core. It is highly radioactive and hot, so requires cooling and shielding. It can be considered as the 'ash' from 'burning' uranium. HLW accounts for over 95% of the total radioactivity produced in the process of electricity generation. There are two distinct kinds of HLW:

   - Used fuel itself.
   - Separated waste from reprocessing the used.

   HLW has both long-lived and short-lived components, depending on the length of time it will take for the radioactivity of particular radionuclides to decrease to levels that are considered no longer hazardous for people and the surrounding environment. If generally short-lived fission products can be separated from long-lived actinides, this distinction becomes important in management and disposal of HLW.

3. What insures that Rad Wastes (either high or low) will be disposed of properly and will not harm us now or in the future?

   The categorization - high, intermediate, low - helps determine how wastes are treated and where they end up. High-level wastes require shielding and cooling, low-level wastes can be handled easily without shielding.

   All radioactive waste facilities are designed with numerous layers of protection to make sure that people remain protected for as long as it takes for radioactivity to reduce to background levels. Low-level and intermediate wastes are buried close to the surface. For low-level wastes disposal is not much different from a normal municipal landfill. High-level wastes can remain highly radioactive for thousands of years. They need to be disposed of deep underground in engineered facilities built in stable geological formations. While no such facilities for high-level wastes currently operate, their feasibility has been demonstrated and there are several countries now in the process of designing and constructing them.

Waste

Radioactive Waste Disposal

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Objective

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Procedure

- To properly treat your team's nuclear waste, sort the wastes by placing them into one of the 3 bags as described below.
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  - Wastes not placed into either bag MUST be itemized on the "REUSE/RECYCLE MATERIALS LIST" below with a **detailed** explanation of how they should be handled or treated before they are recycled or reused.

REUSE/RECYCLE MATERIALS LIST

MATERIAL	TREATMENT PRIOR TO REUSE OR RECYCLING
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Questions

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Waste – Radioactive Waste Disposal
Student Data Collection Sheet

Name: ____________________

Date: ____________________

Questions

3. Why do real nuclear facilities - hospitals, nuclear power plants, and industries - not have discrepancies in their disposal of wastes?

4. Why are there special sites for disposal of low-level wastes?

5. Why is there a controversy over the selection of a high-level nuclear waste disposal site?

Enrichment Questions

1. What kinds of materials are considered Low-Level Radioactive Waste?

Waste – Radioactive Waste Disposal
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Enrichment Questions

2. What kind of material is considered High-Level Radioactive Waste?

3. What insures that Rad Wastes (either high or low) will be disposed of properly and will not harm us now or in the future?

Critical Mass

With the Critical Mass Demonstration, students gain a better understanding of critical mass and how a chain reaction can become uncontrolled. Students are able to visualize what is meant by subcritical, critical, and supercritical mass. By extension, this experiment is a useful analogy to nuclear fission. This experiment is best used by students working in groups.

Grade Level

5-12

Disciplinary Core Ideas (DCI)

5-ESS3-1, 3-5 ETS1-1, 3-5ETS1-2, MS-PS1-4, MS-PS3-4, MS-ESS3-1, MS-ESS3-3, MS-ESS3-4, MS-ESS3-5, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, HS-PS1-1, HS-PS1-8, HS-PS3-3, HS-PS3-4, HS-ESS2-4, HS-ESS2-6, HS-ESS3-2, HS-ESS3-3, HS-ESS3-4, HS-ESS3-6

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Student Data Collection Sheets
- 1 Stopwatch per group of students
- Balloons, light weight balls, ping pong balls, marshmallows, etc. (# of students * 2)
    - Alternatively, the activity can be demonstrated with mousetraps

Safety

- It is important that students throw their balls straight up into the air and not aim directly for their fellow students.

Science and Engineering Practices

- Ask questions and define problems
- Use models
- Plan and carry out investigation
- Analyze and interpret data
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change of Systems

Objectives

- Learn the concept of critical mass and how a chain reaction can become uncontrolled
- Define Critical Mass

Background

The splitting of a massive nucleus into two fragments, each with a smaller mass than the original, is known as nuclear fission. A typical example of nuclear fission is the splitting of a uranium-235 nucleus. This is a reaction that is used in nuclear reactors to generate heat by which steam is produced and used to turn turbines that generate electricity. The fission of uranium-235 begins when the uranium-235 nucleus captures a slow moving neutron and forms an unstable "compound nucleus". The compound nucleus quickly disintegrates into two smaller nuclei, such as barium-141 and krypton-92, two or three neutrons (2.5 average), and a tremendous amount of energy (~200MeV per fission).

Because the uranium-235 fission reaction produces 2 or 3 neutrons, it is possible for those neutrons to initiate a series of subsequent fission reactions. Each neutron released can initiate another fission event, resulting in the emission of more neutrons, followed by more fission events, and so on. This is a chain reaction - one event triggers several others, which in turn trigger more events, and so on. In a nuclear power plant the chain reaction is controlled by restricting the number of neutrons available to collide with the uranium. This is accomplished by absorbing some of the released neutrons with various materials. In an uncontrolled chain reaction (such as an atom bomb explosion) there is nothing to control the number of neutrons being released, so the rate of the chain reaction increases dramatically.

There are two parameters needed to create a critical mass, the number of atoms and the spacing of the atoms. In this demonstration each student represents a uranium atom inside of a nuclear reactor. Each uranium atom releases two neutrons when it fissions. For this demonstration, the larger the number of student participants, the better the results.

Energy Production

Teacher Lesson Plan:

Traditional

Arrange the students in a square array approximately 3 feet apart and give each student two balloons. Take a balloon for yourself and to begin the activity, throw your ball up into the air or at a student. Any student that is hit with this balloon throws their two balloons straight up into the air. Any student hit by these balloons then throws their balls into the air. The reaction continues until there are no more balloons in the air. The first time, the reaction will probably die out quickly, this is called **subcritical**.

Repeat the process, but place the students only 1 foot apart this time and carry out the activity. This time, the reaction should be self-sustaining. This is called **critical** and a critical reactor is running at a steady state.

Repeat the process a final time, but place the students in a tight array without any space between them. This time, there should be lots of balloons in the air at one time. This represents a **supercritical mass**, or when a reactor is increasing its power level.

Variation

Replace the students with mousetraps and place them in an array. Set the traps and place a ping pong ball on each one. Be careful not to get your fingers caught in the traps, as sometimes they will go off when you set the ball on them. Then drop a ball on the array and watch the ball bounce around, setting off more traps. View demo at http://www.nuclearconnect.org/in-the-classroom/for-teachers/mouse-trap-reactor

Optional Exercise

In a nuclear reactor, the reaction is controlled by control rods. These are special rods that go in between groups of fuel rods (which have fuel pellets stacked in them) inside the reactor. The control rods help to start (when they are removed), stop (when they are fully inserted), increase or decrease (when they are partially removed or inserted) the fission process.

Explain that students will now demonstrate a controlled reaction. Use the same students to be atoms or select a new group. Choose one (or more) additional student(s) to be a control rod. Their job is to stand inside the “atoms” group and try to grab or bat away the falling balloons before they hit a student. Since there are now control rods in your demonstration, the first balloon may have to be thrown several times before it hits a student. After all the balloons are thrown, discuss what happened. Fewer students should have been hit because the control rods intercepted some of the “neutrons.” Students can see how the rods slow down and can even stop a chain reaction. When that happens, the fission process will stop very quickly.

NGSS Guided Inquiry

Split students into small groups and give each student two balls. Have students design an experiment to model nuclear fission and critical mass with the balls acting as neutrons in a reactor.

Student Procedure

1. Hold a ball in each hand.
2. If you are hit by a ball, throw your balls straight up into the air without aiming directly at your fellow students.
3. Time and record how long each reaction lasts which is when the last ball is thrown in the air.

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

1. What happened during each trial and why?

Assessment Ideas

Have students discuss the differences between how subcritical, critical, and supercritical masses.

Differentiated Learning/Enrichment

Have students discuss how the different arrangements of students affect the reactor reaching subcritical, critical, or supercritical masses.

Enrichment Question

1. How do you think nuclear power plants use this concept to power up or power down?

Further Resources

For additional information:

http://www.atomicarchive.com/Fission/Fission3.shtml

http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/moder.html

ANS Center for Nuclear Science and Technology Information

http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

Critical Mass

Student Data Collection ANSWER Sheet

Objectives

- Investigate the concept of critical mass and how a chain reaction can become uncontrolled
- Define Critical Mass

Critical Mass is the point where the chain reaction can become self-sustaining.

Procedure

Hold a ballooon in each hand.

If you are hit by a balloon, throw your balls straight up into the air without aiming directly at your fellow students.

Time and record how long each reaction lasts which is when the last ball is thrown in the air.

Questions

1. What happened during each trial and why?

They should describe how one ball caused another to be thrown to demonstrate a simple chain reaction.

2. Be specific about the difference in the number of 'reactions' which occur during the trial.

The difference in the number of reactions should explain how about half the students were hit by balls each reaction.

Enrichment Question

1. How do you think nuclear power plants use this concept to power up or power down?

Answers should include the concept of shielding yourself from the ball hitting you which slows down the reaction.

Answers could also talk of having the students have one ball or every other student having two balls. That way the students in-between can act as moderators.

Critical Mass

Student Data Collection Sheet

Name: ____________________

Date: ____________________

Objectives

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- Define Critical Mass

Procedure

Hold a ball in each hand.

If you are hit by a ball, throw your balls straight up into the air without aiming directly at your fellow students.

Time and record how long each reaction lasts which is when the last ball is thrown in the air.

Questions

1. What happened during each trial and why?

2. Be specific about the difference in the number of 'reactions' which occur during the trial.

Enrichment Question

1. How do you think nuclear power plants use this concept to power up or power down?

ANS

The American Nuclear Society would like to acknowledge the following for their involvement in the development of this Detecting Radiation in Our Radioactive World Teacher Resource Guide.

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THANK YOU!

In addition to all of those named above, ANS would like to extend a special thank you to the Center for Nuclear Science and Technology Information corporate and individual donors, as well as to the countless volunteers who work tirelessly to implement ANS programs in their communities.

Without your support, this would not be possible!

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