SE MAPS PROJECT

Nuclear Science Activity #2

(Southeastern Coastal Plain Region)

Radiation Shielding

The SE MAPS Project is a NSF-funded project that evolved from a South Carolina model for inquiry-based classroom instructional modules proposed by South Carolina K-12 teachers participating in a series of Professional Development Courses designed to help educators better understand and appreciate the natural environment of their state. Each activity was reviewed by content specialists at Clemson University before final publication. Funding support for the 'Nuclear Science' series of activities was provided by the NEESRWM Center at Clemson University (The Center for Nuclear Environmental Engineering Sciences and Radioactive Waste Management).

Investigating Radiation Shielding

Steven Pruitt and John Wagner [based on an activity written by Sarah Disario, Nick Hill, and Alexandra McIntyre]

INSTRUCTIONAL FOCUS: Students will investigate the amount of shielding needed to block the passage of various types of ionizing radiation produced by the decay of radioactive isotopes. Students will use the results of these studies to analyze the effectiveness of various engineering attempts to contain such radiation and the risks of radiation escaping into the environment.

SUGGESTED TARGET AUDIENCE: high school chemistry classes

PRIMARY CORRELATION TO S.C. ACADEMIC SCIENCE STANDARDS (2014):

CHEMISTRY – ATOMIC STRUCTURE AND NUCLEAR PROCESSES

Standard H.C.2: The student will demonstrate an understanding of atomic structure and nuclear processes.

H.C.2B.1 Obtain and communicate information to compare alpha, beta, and gamma radiation in terms of mass, charge, penetrating power, and their practical applications (including medical benefits and associated risks).

Other Curriculum Connections [middle school physical and environmental science]

"SC MAPS (South Carolina Maps and Aerial Photographic Systems) – Study Sites #5A and #2B"

PRIOR SKILLS REQUIRED: The students should have a basic understanding of atomic structure and have been introduced to the concepts of radioactivity, nuclear fission, and the electromagnetic spectrum. Also, students should be familiar with accessing different websites and using search engines (Google™, etc.) to search for information.

LOGISTICS: The basic activity could fit within a 50-minute class, but more time is recommended, especially if supplemental materials or optional activities are used – a flat work area is needed and internet access is required. Students should work in cooperative groups.

KEY VOCABULARY AND CONCEPTS:

- alpha particle
- beta particle
- density
- gamma radiation
- ionizing radiation
- shielding
- spent nuclear reaction fuel

CONTENT OVERVIEW: [more detail is provided in the "Teacher Answer Key."]

1. Most nuclear waste emits ionizing radiation in the form of alpha, beta, and gamma radiation.
   - *Nuclear waste is composed of various radioactive materials produced as a result of nuclear fission.*
   - *Alpha and Beta decay eject lower-energy sub-atomic particles from the nucleus of the radioactive isotope.*
   - *Gamma decay is a form of highly energetic electromagnetic radiation released when certain isotopes decay.*
2. Radiation has a negative impact on humans and the environment.
   - *Even small amounts of exposure to ionizing radiation can cause severe health problems in humans.*
   - *Higher energy forms of ionizing radiation have greater potential to cause harm to humans.*
   - *If released into the environment, radiation can spread through air and water and affect entire populations.*
3. Appropriate shielding must be used to protect workers and prevent any radiation leakage into the environment. Nuclear waste disposal sites need to be monitored to detect any escaping radiation.
   - *Common shielding materials include concrete, steel, lead, water, and glass.*
   - *Different forms of radiation have different energies and therefore different abilities to penetrate shielding.*
   - *Both the thickness and density of the shielding material determine its effectiveness at blocking radiation.*

MATERIALS: 6 standard flashlights; 6 rolls one-ply white toilet paper; 24 sheets of 8.5" x 11" white copy paper (20-pound); 48 3" x 5" white index cards (65 pound standard card stock); 12 pieces (~3" x 5") standard-grade aluminum foil; 6 scissors; 6 rulers; internet access.

PROCEDURES:

1. Review vocabulary words, nuclear fission (in particular how gamma radiation and alpha and beta particles are produced during radioactive decay), and the electromagnetic spectrum. The website <http://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html> gives a good summary of nuclear processes. The website <https://www.youtube.com/watch?v=HPcAWNlVl-8> has an extended tour of the electromagnetic spectrum and its uses (first 4 minutes are most helpful).
2. Ask groups to follow the instructions on the Student Work Sheet, Part I, discuss the questions/answers within their group, and be ready to share their results in a whole-class discussion.
3. Have groups present their answers to the questions on Student Work Sheet, Part I, A and discuss how frequently each type of radiation is encountered in daily life. Emphasize that for certain types of radiation, there are many different sources of exposure. Additional information about health effects can be accessed at the website: <http://www.epa.gov/radiation/understand/health_effects.html>.
4. Discuss types of shielding (Student Work Sheet, Part I, B) and explain that higher energy particles or waves require more shielding to protect people from exposure. Use the diagram in the Teacher Answer Key (pg. 6) to show that gamma radiation poses the most severe threat to human health.
5. Explain to the class that they will be performing a simulation experiment in which light emitted from a flashlight represents gamma radiation and various types of paper and foil represent the shielding material that will attempt to absorb that radiation. Pass out the necessary materials to each group and ask them to follow the instructions on the Student Work Sheet, Part II. If the different grades of paper and the foil have not been pre-cut to optimum size (3-4" tall x 4-5" wide), ask groups to cut all materials into similar sized pieces before beginning the experiment.
6. Review conclusions from Student Work Sheet, Part II. Be sure students know the difference between 'density' and 'thickness' of shielding materials and understand the effect of each factor.
7. [optional] Ask students to research three sites where nuclear waste and/or spent nuclear reaction fuel is stored and determine how these sites provide shielding from the harmful radiation.

SAMPLE CULMINATING ASSESSMENT:

- MULTIPLE-CHOICE QUESTIONS ON EXAM:

Which type of nuclear emission would penetrate farthest into a concrete wall?

a. alpha particle *c. gamma radiation*
b. beta particle *d. all three would travel the same distance*

Which six inch thick wall would provide the greatest protection from gamma radiation exposure?

a. wall made of solid rock *c. wall made of cardboard*
b. wall made of steel *d. wall made of glass*

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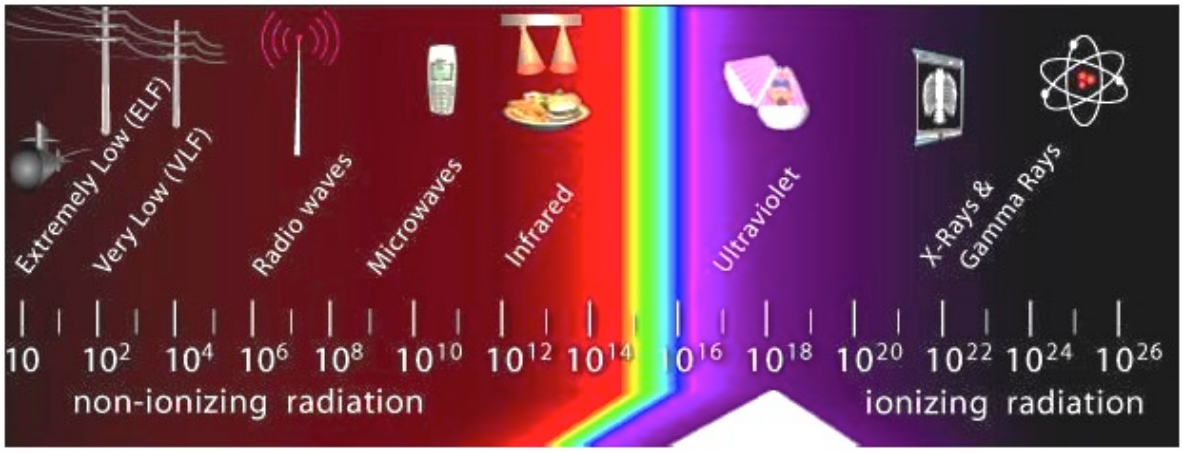
STUDENT WORK SHEET – Part I

Part I – Impact of Ionizing Radiation on Human Health

A. Use the chart (showing complete electromagnetic spectrum) as a guide and discuss in your group how you think each energy level of radiation affects humans and give one example (try to pick an example other than the one shown on the chart) of how you think we might get exposed to that particular portion of the electromagnetic spectrum.



http://chemwiki.ucdavis.edu/Physical_Chemistry/Nuclear_Chemistry/Radioactivity/The_Effects_of_Radiation_on_Matter

	HOW IT AFFECTS HUMANS	HOW WE GET EXPOSED
1. ELF and VLF	_____	_____
2. radio waves	_____	_____
3. microwaves	_____	_____
4. infrared waves	_____	_____
5. visible light	_____	_____
6. ultraviolet	_____	_____
7. 'x' rays	_____	_____
8. gamma rays	_____	_____

B. Discuss in your group which types of electromagnetic waves would require shielding to avoid harming humans that are exposed to those waves. List the type of shielding that could be used in each case. Make notes below and be prepared to share your results with the rest of the class.

STUDENT WORK SHEET – Part II

Part II – Simulating a Mechanism for Shielding from Gamma Radiation

MATERIALS LIST

Each group should have the following items: 1 flashlight 1 roll of one-ply toilet paper
4 pieces of 8.5 x 11 white copy paper 8 white index cards (or pieces of cardstock paper)
2 pieces of aluminum foil 1 ruler 1 scissors

A. Comparing Light-Shielding Capacity of Different Grades of Paper.

1. If the different grades of paper and foil have not been pre-cut by the teacher, use scissors to cut the foil, copy paper and cardstock paper into pieces approximately 3-4 " tall by 4-5 " wide.
2. Turn on the flashlight and hold it vertically on a table so the beam projects upwards. Place sheets of toilet paper (one at a time) over the lens of the flashlight until the light penetration has been completely extinguished. How many sheets did you have to use? _____
3. Remove all the toilet paper from the flashlight and place pieces of copy paper (one at a time) over the lens of the flashlight until the light penetration has been completely extinguished. How many pieces did you have to use? _____
4. Remove all the copy paper and place index cards (or pieces of cardstock paper) (one at a time) over the lens of the flashlight until the light penetration has been completely extinguished. How many cards/pieces did you have to use? _____
5. What factors in this experiment are constant? _____
6. What factors in this experiment are 'independent variables'? _____
7. What factors in this experiment are 'dependent variables'? _____
8. Write a short conclusion that best describes the results of your experiment. _____

   _____

   _____

B. Determining Shielding Effectiveness Based on Properties of Materials Other Than Thickness.

1. Compare the thickness of one piece of aluminum foil to the thickness of the three grades of paper you used in Part A of this simulation. Which type of paper do you think is closest in thickness to a single piece of aluminum foil? _____
2. Turn on the flashlight and hold it vertically on a table so the beam projects upwards. Place one piece of the aluminum foil over the lens of the flashlight and estimate the percentage of light that is blocked by that piece of foil. _____
3. Remove the foil and place one piece of your selected paper (from question #1) over the lens of the flashlight and estimate the percentage of light that is blocked by that piece of paper. _____
4. What is the independent variable? _____ What is the dependent variable? _____
   What factors are held constant in this experiment? _____
5. What is the most important difference between the foil and the paper? _____
6. Write a short conclusion that best describes the results of your experiment. _____

   _____

   _____

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TEACHER ANSWER KEY

KEY VOCABULARY AND CONCEPTS:

- **alpha particle** = a heavy, very short-range sub-atomic particle, emitted during the decay of certain radioactive isotopes, that is composed of two protons and two neutrons (basically a helium nucleus)
- **beta particle** = a light, short-range sub-atomic particle, emitted during the decay of certain radioactive isotopes, that is produced when a neutron decays into a proton (releasing an 'electron')
- **density** = the physical property of matter that is defined as the mass of an object per unit volume
- **gamma radiation** = a highly penetrating, high energy form of electromagnetic radiation released during the decay of certain radioactive isotopes
- **ionizing radiation** = any form of electromagnetic radiation that has enough energy to break chemical bonds in molecules or remove electrons from atoms
- **shielding** = any material used to absorb harmful emissions released through radioactive decay and thereby protect people and the environment from danger
- **spent nuclear reaction fuel** = a mixture of several dangerous radioisotopes generated by nuclear fission within the fuel rods used in nuclear power plants and other nuclear equipment

PROCEDURES:

1. Review basic principles of nuclear fission, including how alpha and beta particles and gamma radiation are produced during radioactive decay, and the electromagnetic spectrum.

Every radioactive isotope goes through one or more 'decay series' by which it transforms eventually to a stable isotope. Some isotopes decay by emitting only one type of sub-atomic particle or form of ionizing ray; others decay by emitting various combinations of these particles and rays. A good summary of nuclear processes is available at this website <http://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html>.

Alpha-emitting materials can be harmful to humans if the materials are inhaled, swallowed, or absorbed through open wounds. The particles travel only a short distance (a few inches) in air, and are therefore not a significant external hazard if minimal shielding is utilized.

Beta radiation can penetrate exposed human skin but some types of clothing can provide adequate protection. Beta radiation may travel several feet in air, but is only moderately penetrating through most shielding materials.

Gamma radiation is able to travel many feet in air and many inches in human tissue. Dense materials, such as lead and concrete, are typically utilized to shield and protect people from gamma radiation exposure.

Gamma radiation is the shortest wavelength portion of the electromagnetic spectrum. An excellent summary of the electromagnetic spectrum and its uses can be found at <https://www.youtube.com/watch?v=HPcAWNlVl-8>.

2. Ask student groups to perform the activities listed on Student Work Sheet Part I A.

This is a brainstorming activity to assess student preconceptions about the health effects of various types of radiation. Answers will vary. Be sure students can locate the 'gamma ray' portion of the spectrum. The numbers listed on the diagram on the Student Work Sheet are frequencies, measured in Hertz (Hz). Higher frequency waves have shorter wavelengths while lower frequency waves have longer wavelengths. Most questions on the Student Work Sheet have several possible answers, some of which are listed below.

	HOW IT AFFECTS HUMANS	HOW WE GET EXPOSED
1. ELF and VLF	*No known effects*	*Electric fields from power lines and electrical appliances*
2. radio waves	*No known effects*	*Radio and some television broadcasts, aircraft communications*
3. microwaves	*Burns, skin or eye damage Can affect people with pacemakers*	*Cell phones, microwave ovens, and some television channels*

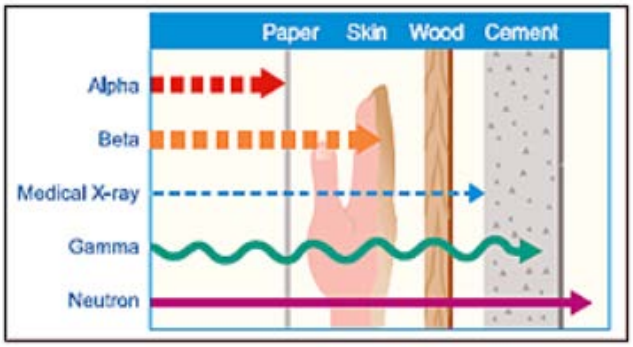
4.	infrared waves	*Burns, skin or eye damage*	*Remote controls for electronic appliances, heat lamps*
5.	visible light	*Enables our eyes to see*	*Sunlight and artificial lighting*
6.	ultraviolet	*Causes sunburn on skin*	*Sunlight and tanning booths*
7.	'x' rays	*Causes cellular damage*	*Medical applications, airport security scanners*
8.	gamma rays	*Causes cellular damage*	*Medical applications, exposure to radioactive isotopes*

3. Have student groups present their answers and discuss health issues.

Although the common understanding is that ELF, Radio, Microwave, and Infrared radiation are not harmful to humans; some studies have indicated that long-term exposure to any of these forms of radiation could create certain health issues. Students will be most familiar with the effects of Ultraviolet radiation (causing sunburn), and this example could be used to explain the damage done by higher-energy waves like X-rays and Gamma Rays. For more details about health effects, see: <http://www.epa.gov/radiation/understand/health_effects.html>.

4. Discuss various types of shielding (Student Work Sheet, Part I, B) and reinforce concepts.

Lower frequency radiation, that presumably does no damage, does not require shielding. However, students may have experienced certain places (basements of buildings perhaps) where radio signals do not reach well or cell phone reception is very poor. The building materials (and sometimes a lack of windows) in such places can partially or total shield the area from those specific radiation frequencies. Most students will be familiar with the use of 'sunscreen' to protect skin from ultraviolet radiation and the resulting sunburn. Point out that higher 'SPF' levels of sunscreen have a greater shielding potential to block incoming rays. Remind students that the medical technician leaves the room whenever medical X-rays are taken in order to protect themselves from cumulative exposure. For some X-rays, patients are asked to wear a lead vest or other heavy garment to shield other parts of the body from accidental exposure. For nuclear radiation, point out the relative penetrating power of alpha, beta, and gamma radiation and the importance of providing shielding materials sufficient to protect workers at nuclear power plants as well as the general public and the environment. The diagram below, and other similar graphics, can be found at the website: <http://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html>.



5. Explain the simulation experiment in which light from a flashlight represents gamma radiation and paper/foil represents the shielding material (Student Work Sheet, Part II).

Each student group should receive one flashlight, one pair of scissors, and one ruler (in addition to paper/foil). All materials used should have dimensions approximately 3-4" tall x 4'5" wide. The teacher can pre-cut the various papers and foil to save time, or the student groups may do the cutting. The exact dimensions are not important as long as the piece of paper will be stable when placed on top of the flashlight lens. The following grades of paper are recommended (and the answers given are appropriate for these weights of paper), but any grade of paper can be used as long as the thicknesses are significantly different. Information on the recommended papers/foil follows:

Paper/Foil Type	*Recommended Specifications*	*Approximate Thickness of one sheet*
Toilet paper	*one-ply tissue paper*	*.015 mm*
Copy paper	*20-pound printer paper*	*.1 mm*
Cardstock paper	*65-pound standard cardstock*	*.2 mm*
Aluminum foil	*standard-grade aluminum foil*	*.016 mm*

The other variable is the strength of the flashlight bulb. All answers provided below are generated from a 'standard' flashlight powered by two C-Cell Batteries. In reality, any flashlight can be used (because the light generated will remain constant throughout the experiment); but answers will vary considerably depending on the power of the light beam. However the ratios of number of pieces of paper needed to shut out the light should be similar.

Tell students to follow the instructions written on the Student Work Sheet, Part II. Select a 'reporter' from each group to take notes and summarize results to present to the whole class. Explain that visible light (like gamma radiation) is part of the electromagnetic spectrum and that any wavelength of light can be stopped (absorbed) by blocking the energy path with the appropriate shielding material.

6. Review conclusions from Student Work Sheet, Part II. Be sure students know the difference between 'density' and 'thickness' of shielding materials and understand the effect of each.

Specific answers may vary significantly because of variations in the power of the light beam from various flashlights. Also, these answers were generated using the specific grades of paper/foil mentioned in the previous section. Nevertheless, the pattern of results should be consistent no matter what specific materials are used. Density is defined as "mass per unit volume", so materials of the same thickness may have different densities and therefore different shielding capabilities.

A. Comparing Light-Shielding Capacity of Different Grades of Paper. *Answers may vary considerably*

1. If the different grades of paper and foil have not been pre-cut by the teacher, use scissors to cut the foil, copy paper and cardstock paper into pieces approximately 3-4 " tall by 4-5 " wide.
2. Turn on the flashlight and hold it vertically on a table so the beam projects upwards. Place sheets of toilet paper (one at a time) over the lens of the flashlight until the light penetration has been completely extinguished. How many sheets did you have to use? *~ 50 sheets of toilet paper*
3. Remove all the toilet paper from the flashlight and place pieces of copy paper (one at a time) over the lens of the flashlight until the light penetration has been completely extinguished. How many pieces did you have to use? *~ 15 pieces of copy paper*
4. Remove all the copy paper and place index cards (or pieces of cardstock paper) (one at a time) over the lens of the flashlight until the light penetration has been completely extinguished. How many cards/pieces did you have to use? *~ 6 pieces of cardstock paper*
5. What factors in this experiment are constant? *Important constants are the amount of light emitted by the flashlight and the type of material (paper) used. Other 'constant' factors that could be mentioned are the color of the paper (white) or the air temperature in the room.*
6. What factors in this experiment are 'independent variables'? *Paper thickness is the most important.*
7. What factors in this experiment are 'dependent variables'? *The number of pieces of paper needed to completely absorb the light from the flashlight*
8. Write a short conclusion that best describes the results of your experiment. *The thicker the stack of paper placed over the flashlight lens, the less light is able to penetrate. Also, thicker paper needs fewer pieces to achieve the same light-blocking ability (shielding). Thinner paper requires more pieces to get the same result.*

B. Determining Shielding Effectiveness Based on Properties of Materials Other Than Thickness.

1. Compare the thickness of one piece of aluminum foil to the thickness of the three grades of paper you used in Part A of this simulation. Which type of paper do you think is closest in thickness to a single piece of aluminum foil? *The toilet (tissue) paper is the closest match: The thickness of one-ply toilet paper averages .015 mm while the thickness of standard aluminum foil is .016 mm.*

2. Turn on the flashlight and hold it vertically on a table so the beam projects upwards. Place one piece of the aluminum foil over the lens of the flashlight and estimate the percentage of light that is blocked by that piece of foil. *For a 'standard' flashlight, one piece of foil will block 100% of the light.*
3. Remove the foil and place one piece of your selected paper (from question #1) over the lens of the flashlight and estimate the percentage of light that is blocked by that piece of paper. *Toilet paper blocks less than 5% of the light.*
4. What is the independent variable = *Type of material*
   What is the dependent variable = *% light penetration*
   What factors are held constant in this experiment? *Amount of light generated; thickness of material*
5. What is the most important difference between the foil and the paper? *The best answer is 'density' which expresses how tightly packed the atoms are within the material. Other differences that could be mentioned include the 'color' of the material; but you would need another experiment (with aluminum colored toilet tissue) to actually determine if color makes a difference in light penetration. For our particular experiment, we will assume that color does not produce a significant difference in results.*
6. Write a short conclusion that best describes the results of your experiment. *Denser materials block radiation better than less dense materials of the same thickness. For general information, the density of standard aluminum foil is 2.7 g/cm^3 and the density of copy paper and cardstock averages .75 g/cm^3. The density of toilet paper (tissue paper) is approximately .375 g/cm^3.*

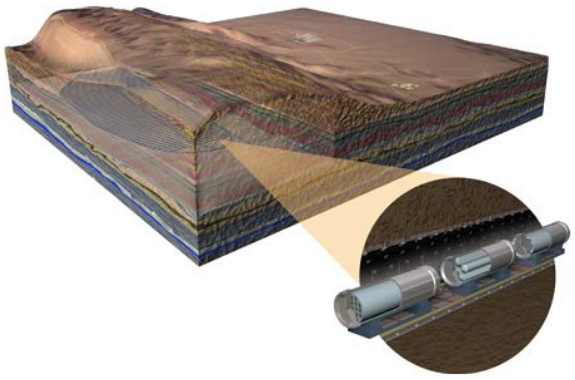
7. [optional] Ask students to research three sites where nuclear waste and/or spent nuclear reaction fuel is stored and determine how these sites provide shielding from the harmful radiation.

The three suggested sites are: Yucca Mountain (Nye County, Nevada); Oconee Nuclear Station (Oconee County, South Carolina); and the Savannah River Site (Barnwell County, South Carolina). Brief descriptions of each site follow.

Yucca Mountain; Nye County, Nevada

Discuss with students an overview of Yucca Mountain, NV using the information and website below. Have the students visit the website below with their group and list three other facts about Yucca Mountain and its role in nuclear waste management in their packets.

Yucca Mountain, designated by the Nuclear Waste Policy Act amendments of 1987, was to be a deep geological repository storage facility for spent nuclear reactor fuel and other high level radioactive waste. The proposed repository was within Yucca Mountain, a ridge line in the south-central part of Nevada near the California border.

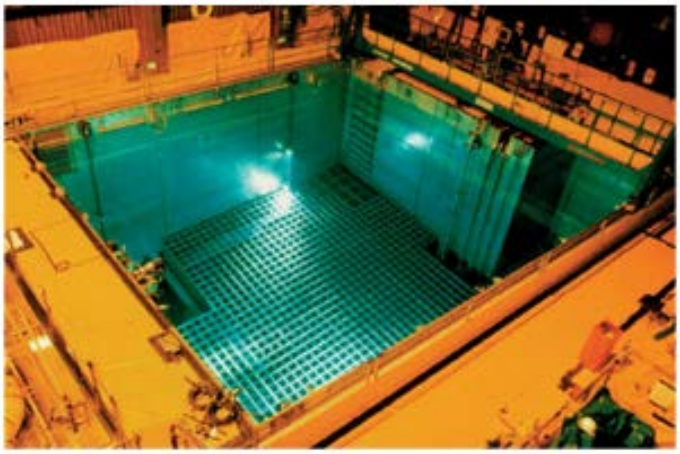


<http://www.nei.org/issues-policy/nuclear-waste-management/disposal>

Oconee Power Plant; Oconee County, South Carolina
Discuss with students an overview of Oconee Power Plant, SC using the information and website below. Have the students visit the website below with their group and list three other facts about Oconee Power Plant and its role in nuclear waste management in their packets.

The spent nuclear fuel consists of fuel rods that are removed from the nuclear reactors. They store the fuel rods in large pools of water, which are equipped with systems to cool the water that surrounds the hot fuel rods.

Spent Fuel Pool



<http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nuclear_power/nuclear-power-in-south-carolina.pdf>

Savannah River Site; Aiken, South Carolina
Discuss with students an overview of the Savannah River Site, SC using the information and website below. Have the students visit the website below with their group and list three other facts about the Savannah River Site and its role in nuclear waste management in their packets.

Facility dedicated to dispose of and store nuclear waste. Some of the nuclear waste is being stored in underground tanks. Some of the nuclear waste is being transferred to small glass pellets for long-term storage. This process is called vitrification. For more information on the disposal and storage of nuclear waste at the Savannah River Site see this website: <http://www.srs.gov/general/programs/solidification/>

SAMPLE CULMINATING ASSESSMENT:

- Ask students to answer two multiple-choice questions. Correct answer is in 'bold' print.

- MULTIPLE-CHOICE QUESTIONS ON EXAM:

Which type of nuclear emission would penetrate farthest into a concrete wall?

a. alpha particle ***c. gamma radiation ****
b. beta particle *d. all three would travel the same distance*

** Note that gamma radiation has the highest energy of the listed radiation types*

Which six inch thick wall would provide the greatest protection from gamma radiation exposure?

a. wall made of solid rock *c. wall made of cardboard*
b. wall made of steel * *d. wall made of glass*

** Note that steel has the highest density of the various materials listed.*

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Websites Used – Radiation Shielding Activity

[note that some websites may be blocked by school or district policies]

1. **A Good Summary of Nuclear Processes**
   <http://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html>.
   - describes physical forms of radiation and radioactive decay
   - explains nuclear fission and different types of ionizing radiation
   - shows different penetrating power of different types of ionizing radiation

2. **Electromagnetic Spectrum**
   <https://www.youtube.com/watch?v=HPcAWNlVl-8>
   - middle level video produced by NASA [first 4 minutes are most useful to this activity]
   - an extended tour of the electromagnetic spectrum including how we gather and use data

3. **Health Effects of Radiation**
   <http://www.epa.gov/radiation/understand/health_effects.html>
   - shows radiation sources and doses
   - how to protect yourself from radiation exposure
   - "RadTown USA" – learn about radiation in your town

4. **Effects of Radiation on Matter**
   http://chemwiki.ucdavis.edu/Physical_Chemistry/Nuclear_Chemistry/Radioactivity/The_Effects_of_Radiation_on_Matter
   - production of X-rays and electromagnetic radiation
   - diagram of electromagnetic spectrum
   - effects of radiation on living matter
   - radiation dosage and decay

5. **Yucca Mountain Nuclear Waste Disposal Site**
   <http://www.nei.org/issues-policy/nuclear-waste-management/disposal>
   - the 'nuclear waste policy' act
   - general description of the Yucca Mountain Project

6. **Oconee Nuclear Station Waste Storage Facility**
   <http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nuclear_power/nuclear-power-in-south-carolina.pdf>
   - spent fuel storage hazards
   - spent fuel summary in South Carolina

7. **Savannah River Site Waste Storage Facility**
   <http://www.srs.gov/general/programs/solidification/>
   - waste solidification program
   - vitrification process