1 Storing Nuclear Waste

TALKING IT OVER
1–2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students are introduced to the compelling issue of determining a central location to store nuclear waste in the United States. In the activity, they learn about nuclear waste and begin to consider the challenges associated with storing radioactive material. The activity elicits students' initial ideas about natural hazards, which could have an impact on safety of a nuclear waste storage site. The crosscutting concept of patterns helps students make sense of the data presented in this activity.

Review the unit overview and assessment chart for a summary of the NGSS taught and assessed in this activity and how the standards are woven together throughout the unit. Decide in advance which assessments you plan to emphasize. Also, review the NGSS pathways on the SEPUP website, and the phenomena and storyline documents found in Teacher Resources IV, "Unit Specific Resources."

NGSS CORRELATIONS

Performance Expectations

Working towards MS-ESS3-2: Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

Disciplinary Core Ideas

MS-ESS3.B Natural Hazards: Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces, can help forecast the locations and likelihoods of future events.

Science and Engineering Practices

Analyzing and Interpreting Data: Analyze and interpret data to provide evidence for phenomena.

Asking Questions and Defining Problems: Ask questions to identify and clarify evidence of an argument.

Crosscutting Concepts

Patterns: Graphs, charts, and images can be used to identify patterns.

Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World: All human activity draws on natural resources and has both short- and long-term consequences, positive as well as negative, for the health of people and the natural environment.

Connections to Nature of Science: Science Addresses Questions about the Natural and Material World: Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes.

Common Core State Standards—Mathematics

MP.2: Reason abstractly and quantitatively.

Common Core State Standards—ELA/Literacy

RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

WHAT STUDENTS DO

Students read about what nuclear waste is, how it affects people, and how it should be stored safely. Then, they review maps that show population density by county and the locations of operating nuclear reactors in the contiguous United States to consider the social concerns related to deciding on a central location to store the country's nuclear waste. Students use what they have learned from the reading and the map analysis to identify the risks and challenges in selecting a long-term storage site for nuclear waste.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*
  - 1 Scoring Guide: EVIDENCE AND TRADE-OFFS (E&T)
- *For each student*
  - 1 Student Sheet 1.1, "Considering Where to Store Nuclear Waste"
  - 1 Scoring Guide: EVIDENCE AND TRADE-OFFS (E&T) (optional)

TEACHING SUMMARY

GET STARTED

1. Introduce the issue of nuclear waste storage.
   a. Turn the lights on and off, and ask, "Where does the electricity that runs these lights come from?"
   b. Direct students' attention to the introduction and Guiding Question.

DO THE ACTIVITY

2. Students learn more about the issue of nuclear waste storage by completing Part A of the Procedure.
    a. Have students work on the Procedure for Part A in groups of four.
    b. Elicit additional questions about nuclear waste that students may have after completing Part A.
3. Introduce crosscutting concepts.
    a. Explain that crosscutting concepts bridge disciplines.
    b. Give an example that makes sense for students.
    c. Introduce the crosscutting concept of patterns.
    d. Relate patterns to this activity.
4. Students complete Part B of the Procedure.
    a. Introduce the data presented on the maps in the Student Book.
    b. Introduce Student Sheet 1.1, "Considerations for Nuclear Waste Storage."
    c. When students complete their analysis of the maps and record their ideas on their Student Sheets, facilitate a class discussion.
5. Discuss the concept of risk analysis.

BUILD UNDERSTANDING

6. If you have not previously done so, introduce scientific evidence in science.
    a. Explain how scientists define and use evidence.
    b. Distinguish evidence from opinion.
    c. Discuss the sources, quality, and quantity of evidence.
7. If you have not previously done so, introduce the concept of trade-offs.
    a. Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.
    b. Provide an example of trade-offs.
    c. Develop some examples of trade-offs in students' lives.
8. If you have not previously done so, introduce the SEPUP Assessment System.
    a. Provide an overview of the Scoring Guides.
    b. Explain the expectations for student growth over time.

9. Use the Analysis items to summarize the key ideas.

   a. (E&T ASSESSMENT) Have students complete Analysis item 1.

   b. Use Analysis item 2 to identify students' prior knowledge about the scientific concerns regarding natural hazards that they will need to consider when deciding where to store nuclear waste.

TEACHING STEPS

GET STARTED

1. Introduce the issue of nuclear waste storage.

   a. Turn the lights on and off, and ask, "Where do you think that the electricity that runs these lights come from?"

      Elicit student ideas about where their electricity comes from. Prompt students to share if they've noticed any power plants near their community, what they look like, and if they are different from power plants they have seen in other places. Explain that most electricity is generated in power plants. Power plants need energy to produce electricity, and energy can be transformed in different ways, such as from burning fossil fuels like coal or from the heat released during nuclear reactions. Point out that one advantage of using nuclear reactions to produce electricity is that this process does not release carbon dioxide into the atmosphere, like other energy sources do. Use this point to emphasize that most methods of generating electricity have advantages and disadvantages. In the case of nuclear reactors, one of the disadvantages is the production of nuclear waste.

      If needed, distinguish between the hazards related to nuclear reactors and nuclear waste. In the event of a meltdown of core fuel, a nuclear reactor can explode, rapidly releasing radioactive materials. Nuclear waste does not present a risk of explosion but does pose a risk of release of radioactive material if the containers of nuclear waste were to leak. Stress that the risk from nuclear waste is not explosion but the health effects of radioactive materials should they get into the environment and be inhaled or ingested in food or drinking water.

   b. Direct students' attention to the introduction and Guiding Question.

      Read, or have students read, the introduction. Use the text to introduce the term *nuclear waste*. After reading, have students share what they would look for in a location to store nuclear waste based on what they learned. Hold a brief discussion of the Guiding Question. Explain to students that they will revisit this question several times during the unit before making a recommendation about nuclear waste storage in the final activity.

DO THE ACTIVITY

2. Students learn more about the issue of nuclear waste storage by completing Part A of the Procedure.

    a. Have students work on the Procedure for Part A in groups of four.

    They should begin by reading the background information on nuclear waste found in the Student Book. The Procedure asks students to read the background information out loud in groups of four. You may wish to select an additional literacy strategy to support reading comprehension as appropriate for your students. For more information about literacy strategies, see the Literacy section of Teacher Resources II, "Diverse Learners."

    b. Elicit additional questions about nuclear waste that students may have after completing Part A.

    As you respond to students' questions, keep the focus on the storage of nuclear waste that already exists. The activity is not about the trade-offs of nuclear power plants as an energy source, the dangers of radiation, etc. This activity is intended to initiate students' thinking about Earth and to introduce them to the social and scientific considerations that must be addressed when deciding where to store nuclear waste. (To have a meaningful discussion on topics such as the role of nuclear power plants as an energy source, it would be important to provide information about the trade-offs of other energy sources such as the primary source of electrical energy in the United States.)

3. Introduce crosscutting concepts.

    a. Explain that crosscutting concepts bridge disciplines.

    They can be a lens or touchstone through which students make sense of phenomena and deepen their understanding of disciplinary core ideas. Refer students to the chart in Student Book Appendix G, "Crosscutting Concepts," and point out the symbols and definitions provided.

    b. Give an example that makes sense for students.

    For example, students have almost certainly noticed patterns, such as the predictable pattern of the seasons every year. Earth scientists might study patterns in rock layers, physical scientists might study patterns in the behavior of chemicals, and life scientists might study patterns in the kinds of trees in different climates. Observing, questioning, and trying to explain patterns are things all scientists do. This is why patterns are considered a crosscutting concept.

c. Introduce the crosscutting concept of patterns.

Display the definition and symbol used for Patterns in Appendix G, "Crosscutting Concepts." A pattern can be structural, as shown in the diagram, or a pattern in events, such as the phases of the moon. Point out to students that seeing patterns in nature can lead scientists to organize and classify their observations. It can also lead them to ask questions about relationships and the causes of patterns. Students will look for patterns when they analyze and interpret data, ask questions about the patterns they observe, and suggest cause-and-effect relationships to explain patterns.

d. Relate patterns to this activity.

In Part B of this activity, students analyze and interpret data presented on two maps to identify patterns. The patterns they identify in the data may help them think more deeply about what must be considered when deciding where to store nuclear waste.

4. Students complete Part B of the Procedure.

a. Introduce the data presented on the maps in the Student Book.

Direct students' attention to the two maps in the Student Book. Point out that the maps are of the Contiguous U.S. This includes the 48 adjoining U.S. states plus Washington D.C. and does not include Alaska, Hawaii, and U.S. territories. Explain that one map shows the human population density by county, which is the average number of people per square mile. The data on this map came from the 2010 U.S. Census, which is an official count of every resident and records where they live in the United States. The second map shows the locations of operating nuclear reactors in the Contiguous United States. This is where nuclear waste is produced as a result of using nuclear reactions to generate electricity.

b. Introduce Student Sheet 1.1, "Considerations for Nuclear Waste Storage."

Hand out Student Sheet 1.1. Explain that students will use this Student Sheet throughout the unit to keep track of their ideas about considerations to address when deciding where to store nuclear waste. They will also record their ideas about the recommended actions they think should be taken in regard to each consideration. Consider how to best store the sheets so students can easily return to them throughout the unit. You may wish to model how to complete the chart using the Procedure steps.

Students are likely to have different ideas based on their interpretations of the data presented in the maps and the patterns they identify as relevant to the issue. Encourage students to discuss their ideas with their group

members as they record their explanation about their recommended actions for each consideration. Tell students that their explanations will be strengthened if they refer to observations that they made and the patterns that they identified.

c. When students complete their analysis of the maps and record their ideas on their Student Sheets, facilitate a discussion.

Ask students what they think about the considerations of human population density and the locations of nuclear reactors. Use student responses to create a class version of Student Sheet 1.1 on the board or chart paper. Throughout the unit, you can return to this chart as students build deeper understanding of the scientific and social concerns related to the issue and how these considerations might inform decision-making.

5. Discuss the concept of risk analysis.

Use the ideas shared from the Student Sheet as an opportunity to discuss the concept of risk analysis. While storing nuclear waste near people increases the risk of radiation exposure, it does not mean that it is certain to happen. Determining the level of risk involves identifying how likely the event is to happen. For example, the Consumer Product Safety Commission collected data about the causes of injuries to patients under age 14 at 101 selected emergency hospital rooms in the United States. They found there were 3.2 million reports of injuries related to sports and recreation and 282,000 reports of injuries from being a passenger in a motor vehicle. These data show that each year more children under the age of 14 are injured from playing sports than from being a passenger in a motor vehicle. Using these data, you could conclude that the risk of injury from sports and recreation is greater than that from being a passenger in a car. You may want to use this example to discuss how people's perception of risk influences their decision-making (perception of risk vs. probability).

When making a decision, people often evaluate the likelihood that something will happen as well as the trade-offs involved. For example, even though participating in sports increases the risk of injury, most people determine that the level of risk is worth the pleasure of participating. Most people prefer to have low levels of risk for actions in which they may have little control or perceive little benefit. The storage of nuclear waste is such an issue. A low-probability event with high-stakes consequences (e.g., an earthquake, tsunami, or accidental exposure to high levels of radiation) may be perceived to carry more risk than a higher-probability event with high-stakes consequences (e.g., a severe car accident), even if there are data to the contrary.

Ask, "Imagine that a site near our city or town is being considered for long-term storage of nuclear waste. Would you agree to have nuclear waste stored where we live? Why or why not?" Encourage students to consider how evaluating risk may not only depend on relevant evidence but also on how much emphasis is placed on pieces of evidence, and on the perspective of the individual.

BUILD UNDERSTANDING

6. If you have not previously done so, introduce scientific evidence in science.

   a. Explain how scientists define and use evidence.

      Analysis item 1 provides an opportunity to introduce the definition of *evidence* provided in the Student Book. Explain that scientists collect information (data) with various tools and strategies, including observation and experimentation. Like scientists, students will use evidence to develop explanations, construct scientific arguments, and recommend solutions to problems.

   b. Distinguish evidence from opinion.

      Explain that evidence is information that supports a claim. In contrast, an opinion is the view someone takes about a certain issue based on their own judgment. An opinion might not be based on evidence. An informed opinion might be based on evidence; however, another person may have a different opinion based on the same evidence. To distinguish evidence from opinion in science, it is helpful to determine if a statement describes information gathered through reliable and appropriate procedures and is likely to be reproducible. The question is: Could someone else gather similar information under similar circumstances? If the answer is yes, the statement is not opinion and is likely to be evidence.

   c. Discuss the sources, quality, and quantity of evidence.

      When evaluating evidence, scientists consider the source, quality, and quantity of the evidence available. Biased or insufficient evidence compromises the validity of scientific conclusions. Scientific conclusions should logically follow the evidence collected, and should not be overly generalized beyond the context of the investigation.

      The criteria for quality evidence may vary among the scientific disciplines. However, evidence is generally considered of higher quality if it is obtained through systematic investigation and is reproducible, meaning another investigation under the same set of circumstances would obtain similar data.

Criteria for quantity also vary but might include the sample size or number of trials in an experiment, the number of observations that support a conclusion, or the availability of multiple studies or multiple lines of evidence that lead to the same conclusion.

7. If you have not previously done so, introduce the concept of trade-offs.

   a. Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.

      This unit includes issues that relate to science and/or engineering and that may lead to decisions about the best solutions or designs for solving problems. One goal of this curriculum is to teach students that

      - decisions about possible solutions often involve trade-offs.
      - identifying trade-offs involves analyzing evidence.

      Explain to students that in this unit, they will make several decisions about where to store nuclear waste. In this activity, students make a decision about whether the current situation for nuclear waste storage is better than having a central storage facility deep underground. In a decision involving trade-offs, something positive (or desirable) is given up to gain another positive (or desirable) outcome. Since many decisions involve trade-offs, students should understand that a perfect choice is often not possible. It is possible, however, to recognize and analyze the trade-offs associated with each decision.

   b. Provide an example of trade-offs.

      For example, when asked, "Paper or plastic?" at a store checkout counter, most shoppers make the choice quickly. But there are several trade-offs attached to choosing paper or plastic. A shopper who chooses paper over plastic may do so to avoid generating plastic waste. In requesting the paper bag, though, they are contributing to other environmental problems, such as increased water and energy use, and the higher amounts of solid waste and CO_2 emissions associated with making paper bags. Neither choice is ideal, and both choices have a downside. Identifying the trade-offs helps clarify the reasoning that is being applied to make a decision.

   c. Develop some examples of trade-offs in students' lives.

      To further explore trade-offs, brainstorm with the class a list of decisions they make every day that involve trade-offs. Choose one, and talk through the associated trade-offs of deciding one way or another. This practice will familiarize students with ways of identifying and considering trade-offs in this and subsequent activities.

8. If you have not previously done so, introduce the SEPUP Assessment System.

   a. Provide an overview of the Scoring Guides.

      Explain that Analysis item 1 is the first assessment in this unit, and you will use it to introduce the SEPUP Assessment System to your students. See Teacher Resources III, "Assessment," to be sure you are familiar with the overall system.

      Before assigning the assessment, distribute the EVIDENCE AND TRADE-OFFS (E&T) Scoring Guide, and use it to model how the system works. Point out the levels in the first column of the Scoring Guide. Tell students these levels are the same for all Scoring Guides and range from 0–4. Then review the descriptions of each level. For example, a Level-4 response is complete and correct in all Scoring Guides. Point out that the scores (0–4) are based on the quality of their responses and do not correspond to letter grades. Allow students to refer to the Scoring Guide as they prepare their answers. Be sure that they understand that the Scoring Guides do not include the specific content students must provide in their responses; rather, they explain the overall expectations for responses at various levels of performance on the task. For more information about the Scoring Guides and how you and students can use the system to improve their work, see Teacher Resources III, "Assessment."

   b. Explain the expectations for student growth over time.

      Explain to students that they aren't expected to always produce complete and correct work on their first attempts. Instead, they should work toward developing consistent Level-3 and Level-4 answers as they become more proficient with the concepts (both disciplinary core ideas and crosscutting concepts) and science and engineering practices being assessed. It is not necessary (or even expected) that an "A" student will always write Level-4 responses, especially at the beginning of the course or when they are introduced to a new Scoring Guide.

9. Use the Analysis items to summarize the key ideas.

   a. (E&T ASSESSMENT) Have students complete Analysis item 1.

      Analysis item 1 in this activity can be assessed using the E&T Scoring Guide. A sample Level-4 response is provided in Sample Responses to Analysis. For more information, see Teacher Resources III, "Assessment."

      In addition to being an assessment for evidence and trade-offs, student responses to Analysis item 1 can also be used to reinforce that nuclear waste is a long-term consequence of using energy from nuclear reactions to generate electricity.

Use this question to generate a discussion about how science has helped us to better understand the risks involved with exposure to radiation from nuclear waste; however, the decisions regarding where and how to store nuclear waste are complex.

b. Use Analysis item 2 to identify students' prior knowledge about the scientific concerns regarding natural hazards that they will need to consider when deciding where to store nuclear waste.

Point out to the class that in this unit, they will learn about other factors that can influence the decision on where to store nuclear waste, such as those of natural hazards. You may wish to record student ideas regarding natural hazards, such as the amount of rainfall at a potential site or the risks associated with volcanoes and earthquakes. Also, as part of the unit, students will consider the trade-offs of selecting a site to build a storage facility in proximity to other valuable natural resources. You will refer back to each of these topics in future lessons when their concerns become relevant to the focal science concepts.

SAMPLE RESPONSES TO ANALYSIS

1. (E&T ASSESSMENT) Do you think that storing nuclear waste in one or two sites deep in the ground would be better than the current situation where nuclear waste is stored at the sites where it is produced? Explain by

   a. stating your decision.

   b. supporting your decision with as many pieces of evidence as you can. Evidence is factual information or data that support or refute a claim.

   c. discussing the trade-offs of your decision. A trade-off is a desirable outcome given up to gain another desirable outcome.

   Student responses may vary.

   SAMPLE LEVEL-4 RESPONSE

   I think storage deep underground would be better than the current situation where nuclear waste is stored in many different locations all over the country. At each of these sites, there is risk that the waste might leak radiation that could get into the air or water. If this happened, it could be bad for people's health. Burying the waste deep underground and in a remote area would keep it away from people. And one or two storage sites would be easier to control. One trade-off is that it is easier to store nuclear waste at the place where it is produced because you do not have to move it long distances, but if it is stored in one or two central locations, more people will be safe.

2. What other information would you like to have before you make a decision about a proposed long-term nuclear waste site? Be sure to explain how this information would be helpful.

   Student responses may vary. One sample response is shown here:

   I would like to know more information about how earthquakes, volcanic eruptions, and/or landslides, could affect the safe storage of nuclear waste. Would the nuclear waste be buried deep enough to avoid its being affected by these types of natural hazards? Or could these events create problems for the safe storage of the radioactive material?

3. Choose one of the recommended actions you described on Student Sheet 1.1. Are there any disadvantages associated with taking this action? Explain why or why not.

   Student responses may vary. One sample response is shown here:

   There are both advantages and disadvantages to storing nuclear waste in an area where not many people live. One advantage is that if there is an accident with the radioactive material and it leaks into the air or water, then not many people will be affected. One disadvantage is that people who work at the facility may need to drive long distances to get to work.

4. As you learned in this activity, advances in technology often lead to advances in science. Sometimes they also lead to new challenges.

   a. In what ways has the development of nuclear energy led to advances as well as new challenges for society?

      Student responses may vary. One sample response is shown here:

      Nuclear energy is used to generate electricity which helps people in their daily lives. One challenge it has presented is figuring out where to store the radioactive waste that is produced in the process.

   b. What other developments in technology have led to advances as well as challenges for mankind?

      Student responses may vary. One sample response is shown here:

      One development in technology that has led to advances is the smartphone. It has allowed people to connect in new ways with each other digitally. But it presents challenges when people use their devices when they are driving or have problems with their eyes or neck because they use their devices too much.

EXTENSION

In this Extension, students learn more about Yucca Mountain. In 1987, the U.S. government selected Yucca Mountain in southern Nevada as a place to build an underground storage site for the country's nuclear waste. However, in 2011, government officials decided not to build an underground storage facility there.

REVISIT THE GUIDING QUESTION

What factors must be considered when deciding where to store nuclear waste?

The radiation from nuclear waste can cause health problems for people if it is not stored properly. One thing that must be considered when choosing a place to store nuclear waste is how many people live near the facility. If nuclear waste leaks into water or air, people in the local area may ingest or breathe in radiation that could be harmful. This is why nuclear waste should be stored away from areas where a lot of people live. Another consideration is how close the location is to the nuclear power plants where the nuclear waste is generated. Nuclear waste would need to be transported to the central storage facility. Transportation and related accidents may increase the risk that the nuclear waste could leak into water or air and cause harm to people living on the route.

ACTIVITY RESOURCES

KEY VOCABULARY

evidence

nuclear waste

trade-offs

BACKGROUND INFORMATION

RADIOACTIVITY

Radiation is energy released in the form of waves or particles (e.g., alpha, beta, and gamma radiation). Elements that release such energy are described as *radioactive*, and there are over 60 naturally occurring radioactive elements. As a result, there are many natural sources of low-level radiation, including radon gas, and soil.

Exposure to high levels of radiation or exposure to lower levels over long periods of time can increase the risk of cancer. In the United States, most people receive an average annual background radiation dose of about 360 millirem (mrem) from a combination of both natural and manufactured sources. Radon gas is the primary

natural source of radiation, and it accounts for about 200 mrem. Medical X-rays, the primary manufactured source, accounts for another 40 mrem. (A typical chest X-ray results in a 10 mrem dose.)

WASTE FROM NUCLEAR POWER PLANTS

Nuclear energy is the heat energy produced from the splitting of uranium atoms (known as *fission*) in a nuclear reactor. A nuclear power plant uses this heat to produce electricity. Nuclear power plants produce two types of radioactive waste: high-level and low-level. Nearly all high-level waste is from used fuel rods. Low-level waste includes tools and equipment that may contain small amounts of radioactive material. High-level waste is handled remotely and stored in steel-lined concrete pools filled with water or in large steel-lined concrete containers. Low-level waste may be stored or shipped to a disposal facility.

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Name_____ Date_____

STUDENT SHEET 1.1

CONSIDERING WHERE TO STORE NUCLEAR WASTE

Considerations	Recommended action	Explanation

Name *Sample student response* Date

STUDENT SHEET 1.1

CONSIDERING WHERE TO STORE NUCLEAR WASTE

Considerations	Recommended action	Explanation
Human population	*Select a site located in an area with low population density.*	*If the nuclear waste from the facility leaks into water and air, it could expose a lot of people to radiation in the surrounding area. To lower risk to humans the nuclear waste should be stored in an area with low population density.*
Location of operating nuclear reactors	*Select a site located near most operating nuclear reactors.*	*If the storage site is close to the reactors where the waste is produced, it won't need to be transported as far. Transporting nuclear waste involves many risks, which could be reduced if the storage site is as close as possible to many operating nuclear reactors where the waste is generated.*