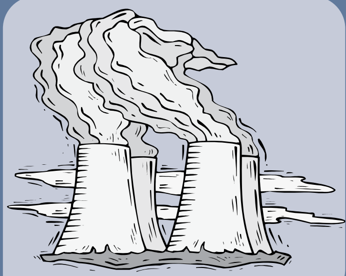


Dealing with Nuclear Waste

Students read information about nuclear wast disposal, write a position paper advocating a specific nuclear waste disposal option, and use candles and a shoebox to model the half-life of radioactive materials.

Grade Level: 5–8 (9–12)

Subject Areas: English Language Arts, Mathematics, Science

Setting: Classroom

Time:
Preparation: One hour
Activity: Four 50-minute periods

Vocabulary: Cask, Half-life, High-level waste, Low-level waste, Milling, Nuclear waste, Nuclear weapons proliferation, Radioactive decay, Radioactive tailings, Repository, Reprocessing, Spent fuel

Major Concept Areas:

- Quality of the environment
- Management of energy resource use
- Future outlooks for the development and use of energy resources

Getting Ready:
Either ask students to bring shoe boxes and candies from home or provide them. You may give students copies of the resources listed in the ***Summary of High-Level Nuclear Waste Disposal Options***. See ***Answers to Selected Questions*** for suggested responses.

Objectives

Students will be able to

- identify three types of nuclear waste and their sources;
- describe the decay pattern of radioactive isotopes using the concept of half-life; and
- assess different options for disposing of high-level nuclear waste and select the disposal option they think is best.

Rationale

By investigating nuclear waste and the issues surrounding its disposal, students recognize that disposing of nuclear waste is a difficult problem and that choosing a disposal option involves judging its risks and assessing its advantages and problems.

Materials

- Copies of the following pages:
  - ***What Is Nuclear Waste?***
  - ***The Half-Life of Radioactive Material***
  - ***Radioactive Decay Graph***
  - ***Summary of High-Level Nuclear Waste Disposal Options***
- Shoe boxes (each pair of students will need one box)
- Small candies or pennies (each pair of students will need 100 pieces of two different types of candies, the candies should be blank on one side and have a letter or decal on the other)
- Find additional resources related to this activity on keepprogram.org > Curriculum & Resources

Background

See the background information in ***What Is Nuclear Waste?***, ***The Half-Life of Radioactive Material***, and ***Summary of High-Level Nuclear Waste Disposal Options***. Additional information is found in ***Facts about Nuclear Energy***.

Procedure

Orientation

Prior to conducting the activity, ascertain students' current perceptions of nuclear energy and nuclear waste management. Do they know what nuclear waste is? What have they heard about its disposal? What are their current thoughts about where and how nuclear waste should be managed? Record their comments on the board or elsewhere.

Steps

1. Divide the class into pairs. Have each pair read ***What Is Nuclear Waste?*** (see “Read and Explain Pairs” for a suggested reading comprehension strategy). Have selected pairs share their answers with the class. Encourage students to raise other questions about the reading.
2. Have each pair of students read the “Introduction” and carry out the shoe box experiment titled “Modeling Radioactive Decay” in ***The Half-Life of Radioactive Material***. Hand out a ***Radioactive Decay Graph*** to each pair of students and have them graph the results of their experiment.
3. Have selected pairs share their graphs with the class. As an option, post the graphs produced by the class to show the variations and similarities of the half-life curves.
4. Have each pair of students answer the questions listed under “Modeling Radioactive Decay” in ***The Half-life of Radioactive Material*** and complete the section titled “How Long Do Radioactive Materials Have to Decay before They Are Safe?” in ***Radioactive Decay Graph***. Have selected pairs share their answers with the class. Encourage students to raise other questions about the reading.
5. Hand out the ***Summary of High-Level Nuclear Waste Disposal Options*** to each student. Have students review and briefly discuss the different options. Encourage students to come up with their own ideas for disposing of nuclear waste.
6. Instruct students to write a two- to three-page position paper on which option they think should be used to dispose of high-level nuclear waste from spent fuel. Remind students to include their own ideas. The paper may be done as a homework or research assignment outside of class, if desired. Papers should address the following points:
   - The disposal option they chose
   - The reasons why they chose a particular disposal option over other options
   - Whether or not spent nuclear fuel should be reprocessed, and why (see table)

   Direct students to the resources listed in the Summary of ***High-Level Nuclear Waste Disposal Options*** or to other resources that provide additional information on nuclear waste issues. As an option, have resources available for students (see **Getting Ready**).

Closure

When students have finished their position papers, re-create the following table on the whiteboard. Tabulate which of the disposal options students chose under each column and, for each disposal option, whether or not students think spent nuclear fuel should be reprocessed before disposal.

Select students to read their position papers to the class. Allow them time to answer other students’ questions and defend their positions before the class.

Assessment

Formative

- Did students work cooperatively in “Read and Explain” pairs?
- Can students describe the difference between high-level nuclear waste, low-level nuclear waste, and radioactive tailings?
- Can students explain where the different types of nuclear waste come from?
- Are students able to graph and interpret the half-life of a radioactive isotope using candies?
- Can students accurately describe the pattern of radioactive decay using the concept of half-life?
- How accurately did students answer questions associated with the readings?

	Should Spent Fuel be Reprocessed Before Disposal?	
Disposal Options	**Yes**	**No**
Bury Waste Underground		
Bury Waste Beneath the Ocean Floor		
Place Waste in a Specialty Constructed Facility above Ground		
Shoot Waste into Space		
(Other disposal option ideas)		

Summative

Consider how well students promoted and defended their choice of a disposal option for high-level nuclear waste.

Extensions

Encourage students to research the following topics related to nuclear waste disposal:

- How radiation affects human health
- How nuclear waste and other nuclear materials are transported
- How a high-level nuclear waste disposal site would be constructed at Yucca Mountain in southern Nevada
- The reasons surrounding local opposition to proposed nuclear waste sites, sometimes called the NIMBY (Not In My Back Yard) syndrome
- How other nations plan to dispose of their nuclear wastes
- Who is responsible for nuclear waste disposal in the United States

Have students investigate how the nuclear waste produced by Wisconsin's nuclear plant (Point Beach Units 1 and 2) is currently being disposed. This investigation could be tied in with a tour of one of the nuclear plants or a presentation on Wisconsin's nuclear plants given by a utility representative.

Related KEEP Activities

Precede this activity with "Harnessing Nuclear Energy." Other waste issues associated with energy use are found in "Dirty Half Dozen" and "Don't Throw Energy Away." Students can use the activity "Advertising Energy" to analyze public relations strategies employed by electric utilities and the nuclear industry.

Credits

Activity adapted from New York Energy Education Project. "Dealing with Radioactive Waste" *Nuclear Energy: Student Activities from the New York Energy Education Project*. Albany, N.Y. 1985. Used by permission of New York Science, Technology and Society Education Project (NYSTEP). All rights reserved.

Solid low-level waste is safely disposed of in shallow trenches. When the trench is full, a protective covering for erosion control will be placed on top.
Source: U.S. Department of Energy

The Wisconsin K-12 Energy Education Program is supported through funding from

Wisconsin K-12 Energy Education Program (KEEP)
College of Natural Resources
University of Wisconsin-Stevens Point

Read and Explain Pairs

It's often more effective to ask students to read assigned material in cooperative pairs than individually. The expected criterion for success is that both members be able to explain the meaning of the assigned material correctly. The task is for the pairs to ascertain the meaning of each section and the assigned material as a whole (a "section" is text covering a specific topic and introduced by a section heading shown in bold type). The cooperative goal is for both members to agree on the meaning of each section, formulate a joint summary, and be able to explain their answer.

Here's How It Works

1. Assign a high reader and a low reader to be a reading pair, telling them what specific pages (passages) that you want them to read.
2. Students read all section headings for an overview.
3. Students silently read the first section and then take turns acting as summarizer and accuracy coach. They rotate roles after each section.
4. The summarizer outlines in her own words the content of the section to her partner.
5. The accuracy coach listens carefully, corrects any misstatements, adds anything that was left out, and explains how the material relates to something they already know.
6. The students then move on to the next section and repeat the procedure. They continue until they have read all assigned material. At that point, they come to an agreement on the overall meaning of the assigned material.

During the lesson, systematically monitor each reading pair and assist students in following the procedure. To ensure individual accountability, randomly ask students to summarize what they have read so far. Remind students that there is intergroup cooperation—whenever it is helpful, they should check procedures, answers, and strategies with another group, or if they finish early, they should compare and discuss answers with another group.

Adapted from Johnson, David W., Roger T. Johnson, and Edythe J. Holubec. "Read and Explain Pairs" pp. 66–67 in Cooperative Learning in the Classroom. Alexandria, Va.: Association for Supervision and Curriculum Development.

Answers to Selected Questions

What Is Nuclear Waste?

Question Set 1

Introduction, Nuclear Waste and Human Health, and Types of Nuclear Waste

1. Nuclear power plants and defense activities may produce high-level and low-level nuclear waste.
2. High-level nuclear waste needs more shielding to protect humans and other living things because it is much more radioactive and therefore is much more hazardous.
3. Low-level waste does not need to be put in casks for transporting because its radiation levels are not very high. However it does need to be put in containers that may require some shielding while being transported.
4. Low-level wastes are buried in landfills and covered with soil. Radioactive tailings are also covered with soil.

Answers to Selected Questions Continued

Question Set 2

Reprocessing Spent Fuel from Nuclear Reactors

1. New nuclear fuel does not contain plutonium. The plutonium is created when the U^{238} in nuclear fuel absorbs neutrons. This transformation only occurs when the nuclear fuel is being used in a nuclear power plant.
2. The U^{235} and the plutonium that remain in spent nuclear fuel can be reprocessed and used in new nuclear fuel. Reusing these elements reduces the amount of uranium that has to be mined.

Question Set 3

Nuclear Proliferation and the Potential for Theft

1. It would be easier to build a nuclear weapon using plutonium from reprocessed fuel because its concentration is higher in reprocessed fuel than it is in spent fuel. This makes it easier to extract the plutonium.
2. Security personnel at a nuclear power plant would be guarding against the theft of nuclear fuel as well as trespassing, vandalism, and the theft of other materials and equipment.

The Half-Life of Radioactive Material

Question Set 1

Graphing Radioactive Decay and Challenge Question

6. 1995 minus 1875 equals 120 years; 120 years divided by the 30-year half-life of cesium-137 equals four half-lives. The amount of cesium-137 doubles when going back in time every 30 years. Since four half-lives have occurred in 120 years, the amount of cesium-137 present 120 years earlier would be 160 grams (10 grams × 2 × 2 × 2 × 2).
7. The half-life of uranium-238 is 4.5 billion years, so there was twice as much of it on Earth 4.5 billion years ago than there is today. Therefore, half the uranium-238 has decayed.
8. The candies in the box will turn up heads or tails at random after being shaken no matter how they are placed in the box before the first shake. Therefore, assuming that the candies are all tails-up (the atoms are not decayed) before the first shake rather than actually placing them tails up is acceptable, so long as the box is shaken several times.

Question Set 2

How Long Do Radioactive Materials Have to Decay before They Are Safe?

1. The time needed for each of the radioactive isotopes to become safe is equal to their half-lives multiplied by 20.

Radioactive Isotope in Spent Fuel	Half-Life	Time Needed to Become Safe
Iodine-131	8 days	160 days
Strontium-90	28 years	560 years
Cesium-137	30 years	600 years
Americium-243	7,370 years	147,400 years

2. Of the four isotopes listed, americium-234 requires the most stable and secure means of storage because it has the longest half-life and requires the longest amount of time before it is safe. Therefore, it needs to be enclosed in a location that will not be disturbed for a very long time.
3. Because cesium-137 and strontium-90 are taken up by green plants, these isotopes would contaminate many of the vegetables that humans eat. They would also be found in meat and dairy products produced by animals that had eaten grasses contaminated by these isotopes. Human who have eaten vegetables, meat, and dairy products contaminated with cesium-137 and strontium-90 could be exposed to radiation levels that may adversely affect their health.

What is Nuclear Waste?

Introduction

Waste that results from the use of radioactive materials is called nuclear waste (or radioactive waste). Nuclear waste comes primarily from the following sources:

- All the steps involved in using nuclear energy to produce electricity
- Defense activities, including the manufacture of nuclear weapons
- Hospitals, universities, and research laboratories
- Industry
- Mining and milling of uranium ore

Nuclear Waste and Human Health

The radioactive isotopes found in nuclear waste emit radiation while undergoing radioactive decay (see ***The Half-Life of Radioactive Material*** for more information about radioactive decay). This radiation, in the form of alpha particles, beta particles, and gamma rays, can disrupt living cells and interfere with the health of humans and other living things, depending on the amount of radiation received. All humans and living things are exposed to small amounts of background radiation from natural and human-made sources in the environment. Humans directly exposed to higher levels of radiation may suffer health effects such as cancer, genetic disorders, and other degenerative diseases.

Types of Nuclear Waste

Nuclear waste is classified in terms of how radioactive it is, where it comes from, and how harmful it may be to human health. The categories of classification are high-level waste, low-level waste, and radioactive tailings.

High-Level Waste

This is the most radioactive form of nuclear waste. It includes spent fuel (used fuel) from nuclear power plants and some waste from defense activities, including the manufacture or disassembly of nuclear weapons and spent fuel from nuclear submarines. High-level nuclear waste is extremely hazardous to humans and other living things. This waste must be stored in a place of maximum safety until it undergoes radioactive decay and loses enough radioactivity to be considered safe. Some radioactive isotopes in high-level waste lose radioactivity rather quickly, while others remain radioactive for thousands of years.

In addition, the initially high levels of radioactivity in spent fuel produce large amounts of heat that must somehow be absorbed or removed. For example, the fuel rods containing spent fuel from nuclear power plants are stored in large pools of water located in facilities next to the power plant. The water absorbs the heat produced by the spent fuel.

High-level waste is handled by operators using remote control equipment behind heavy protective shielding. They transport the waste in heavily shielded containers called casks. Storage of high-level waste is addressed in ***Summary of High-Level Nuclear Waste Disposal Options***.

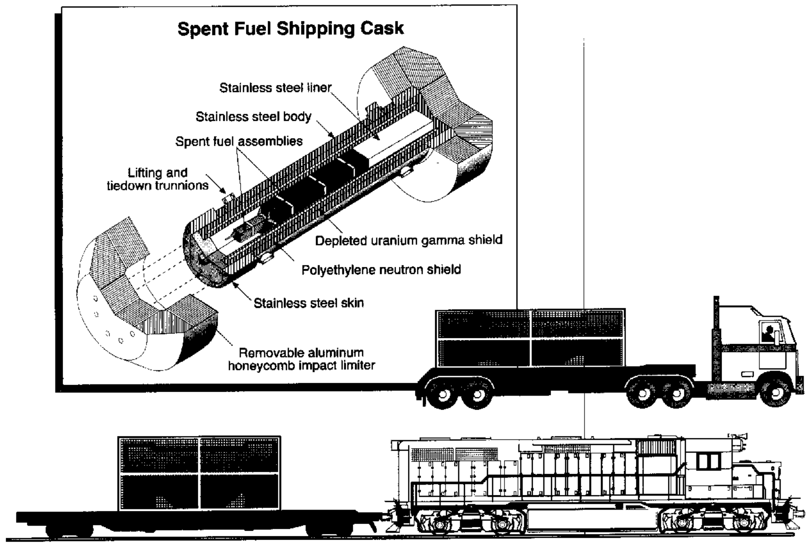
Low-Level Waste

Low-level waste usually contains only a small amount of radioactivity within a relatively large amount of material. It is less hazardous than high-level waste. Most low-level waste does not require extensive shielding. However, for certain low-level waste, some shielding may be necessary.

What is Nuclear Waste?

Hospitals, nuclear power plants, research labs, and many industries produce low-level waste. Also, some of the waste produced by defense activities is low-level waste. Low-level waste from research, medical activities, and nuclear power plants may include commonly used equipment such as empty containers, rags, papers, filters, broken tools, and used protective clothing that has been exposed to radioactive materials.

Low-level waste is placed in containers and then buried at special landfills licensed by the federal government. Two major burial sites are located at Barnwell, South Carolina, and Hanford, Washington.



Spent fuel shipping casks may be transported by rail or on interstate highways by flatbed truck.

Radioactive Tailings

The fuel used at a nuclear power plant comes from uranium ore, which is mined from the ground. After mining, the uranium ore is milled, a process that separates and removes the uranium from the rest of the ore by crushing and chemically treating it. The leftover rocks and soil from mining and milling are called tailings. The tailings contain radon-222, a radioactive gas, which can be harmful to human health if the exposure is in concentrated amounts. To prevent the release of radon-222 into the air, the tailings are usually covered with a layer of soil.

Questions

1. Name two sources that produce both high-level and low-level waste.
2. Why does high-level nuclear waste need more shielding than low-level waste?
3. Does low-level waste need to be placed in casks before it is transported? Explain.
4. How is the disposal of low-level nuclear waste similar to the disposal of radioactive tailings?

Reprocessing Spent Fuel from Nuclear Reactors

Nuclear fuel used in nuclear power plants in the United States contains a mixture of uranium-235 (U^{235}) and uranium-238 (U^{238}). The U^{235} nuclei undergo fission, releasing energy that is used by the power plant to produce electricity. While the fuel is being used, some of the U^{238} in the fuel will absorb neutrons and change into a new radioactive element called plutonium. Plutonium is a special element because it is not found in nature; it is created as part of the nuclear fission process only. Like U^{235} nuclei, the nuclei of certain plutonium isotopes easily undergo fission, which means that plutonium can be used in nuclear power plants and nuclear weapons.

What is Nuclear Waste?

After a period of time, most of the U^{235} in nuclear fuel has undergone fission, and the fuel is no longer able to produce enough energy to run the power plant. However, this spent fuel still contains some leftover U^{235} and plutonium. The leftover U^{235} and plutonium can be removed from spent fuel and made into new nuclear fuel through a procedure called reprocessing. One advantage of reprocessing is that it puts the remaining U^{235} and plutonium to further use rather than disposing of it. Another advantage is that since U^{235} and plutonium stay radioactive for many thousands of years, removing them from spent fuel leaves radioactive waste that decays more quickly. However, the remaining waste is still considered high-level waste. Reprocessing also creates a greater amount of low-level waste than does disposal of spent fuel without reprocessing.

Questions

1. Does new nuclear fuel in a nuclear power plant contain plutonium? Explain.

2. How might reprocessing spent fuel reduce the amount of uranium that has to be mined?

Nuclear Proliferation and the Potential for Theft

One concern over the use of nuclear energy is that a quantity of U^{235} or plutonium of sufficient concentration can be extracted from nuclear fuel and used to make nuclear weapons. This may happen if other countries using nuclear power try to use a portion of their fuel for making weapons. Small quantities of nuclear fuel may also be stolen and sold to other nations for the same purpose or can be used by terrorists, whether or not they actually wish to create a weapon. The potential spread of nuclear weapons throughout the world is called nuclear weapons proliferation.

Extracting U^{235} or plutonium from spent fuel to make a nuclear weapon is a difficult process that requires specialized equipment costing millions of dollars. Extracting these isotopes from reprocessed nuclear fuel is somewhat easier because their concentrations are higher in reprocessed fuel than they are in spent fuel.

Because of concerns over nuclear weapons proliferation, President Carter halted commercial nuclear fuel reprocessing in the United States in 1977. The ban was lifted by President Reagan in the 1980s. However, currently, none of the spent fuel from nuclear power plants is being reprocessed, although the defense department reprocesses some of its spent fuel.

The likelihood of nuclear fuel being stolen in the United States is low, given the high degree of security present in our nation's nuclear power plants, fuel production sites, and defense operations. The security of nuclear fuel in other nations may vary and is of particular concern in the former Soviet Union, where mismanagement and economic hardship have led to lowered security.

Questions

1. Why would it be easier to build a nuclear weapon using plutonium from reprocessed nuclear fuel than from spent fuel?

2. What would security personnel at a nuclear power plant be guarding against?

The Half-Life of Radioactive Material

Introduction

All radioactive isotopes, including those found in nuclear waste, undergo radioactive decay. The decay process releases radiation that can be hazardous to humans and other living things. However, the amount of radiation released by these isotopes is not constant. Instead, the isotopes' radioactivity decreases over time to a point where they produce little or no radiation and are no longer hazardous. But how much time must pass before this happens?

How long it takes a single atom of a radioactive isotope to decay cannot be predicted; it is a random process. On the other hand, the rate of decay of large numbers of these atoms can be accurately measured. This rate, called the half-life, is defined as the time it takes for one-half of a radioactive isotope sample to decay into another isotope.

Each radioactive isotope has its own half-life, which may range from fractions of a second to billions of years. Also, the shorter the half-life, the greater the intensity of the radioactivity produced by the isotope. This relationship makes sense because in order for a radioactive isotope to decay quickly, its atoms must release large amounts of radiation. The amount of radioactivity released by an isotope is known as its specific radioactivity and is measured in curies per gram of material.

Many of the isotopes contained in high-level nuclear waste (see ***What Is Nuclear Waste?***) have short half-lives and high specific activities. High-level waste also contains isotopes such as americium and plutonium that have long half-lives. High-level nuclear waste contains a mixture of large amounts of radioactive isotopes with short and long half-lives that release large amounts of radiation, thereby making this waste hazardous.

At right is a list of selected radioactive isotopes, their half-lives, and their specific radioactivities.

Radioactive Isotope	Half-Life	Specific Radioactivity (curies/gram)
Molybdenum-99	66.7 hours	474,000
Iodine-131	8 days	123,500
Krypton-85	11 years	392
Strontium-90	28 years	141
Cesium-137	30 years	86.4
Americium-243	7,370 years	0.200
Plutonium-239	24,400 years	0.0613
Uranium-235	700 million years	0.00000241
Uranium-238	4.5 billion years	0.000000334

Modeling Radioactive Decay

What you'll need:

- A shoe box
- 100 pieces of Candy A (such as M&M's)
- 100 pieces of Candy B (such as Skittles)
  (Note that each of the candies is blank on one side and has a letter on the other; the side with the letter is the "heads" side of the candy).

The Half-Life of Radioactive Material

The process of radioactive decay and the concept of half-life can be modeled by putting candies into a shoe box, shaking the box, and removing the candies that come up heads. Heads means the side of the candy with a letter or logo on it (compared to the blank side of the candy, which is tails).

This model helps illustrate the random nature of radioactive decay. A candy that comes up heads is a radioactive isotope that has decayed. The heads up candies are replaced by another type of candy that represents the decayed atom. Candies that come up tails after each shake represent atoms that are still radioactive.

Shake	Candies Left
Start	100
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Directions

1. Put 100 pieces of Candy A in the box and put the lid on.
2. Holding the lid on firmly, shake the box several times.
3. Open the box and remove all the candies that are heads up.
4. Count the candies that are left and enter this number in the table above.
5. Replace the removed pieces of Candy A with Candy B.
6. Repeat Steps 2–4 nineteen more times, or until all the pieces of Candy A are replaced by Candy B (whichever comes first).

Graphing Radioactive Decay

To see what the pattern of radioactive decay looks like, plot the data from the table above on the ***Radioactive Decay Graph***. Draw a line that connects all the points.

Questions

1. According to the graph, what is the half-life of Candy A (the number of shakes needed for half of the candies to "decay," or to change from Candy A to Candy B)?

2. If you started with 50 pieces of Candy A instead of 100, would the half-life change? Explain.

3. How is the flipping of candies similar to the decaying of a radioactive isotope? How is it different? (Hint: Consider the probability of a flipped candy coming up heads or tails.)

4. How many shakes did it take to get rid of all the candies? How many half-lives does this equal?

5. What would you do with the candies and the shoe box to increase the length of the half-life?

The Half-Life of Radioactive Material

6. Cesium-137 has a half-life of 30 years. If there were 10 grams of cesium-137 in 1995, how many grams of cesium-137 were there in 1875?

7. The half-life of uranium-238 is 4.5 billion years. How much of the uranium-238 originally on earth has decayed if the earth was formed 4.5 billion years ago?

Challenge Question

8. You may have noticed that you were not asked to carefully put all 100 candies into the shoe box tails up (or heads down) before doing the first shake. You could have done this if you wished, but it was not necessary. Explain why. (Hint 1: What are you assuming about the candies before the first shake? Hint 2: Does putting the candies carefully in the box or throwing them in the box beforehand affect whether the candies come up heads or tails after the first shake?)

How Long Do Radioactive Materials Have to Decay before They Are Safe?

Many radioactive materials in nuclear waste give off dangerous amounts of radiation even after one half-life has passed. Nuclear scientists generally believe that the radioactivity of such waste reaches a safe level after 20 half-lives, where safe means no more hazardous to health than the radiation received from the surrounding environment. Given the different half-lives of these isotopes, clearly some elements will become safe much sooner than others.

Questions

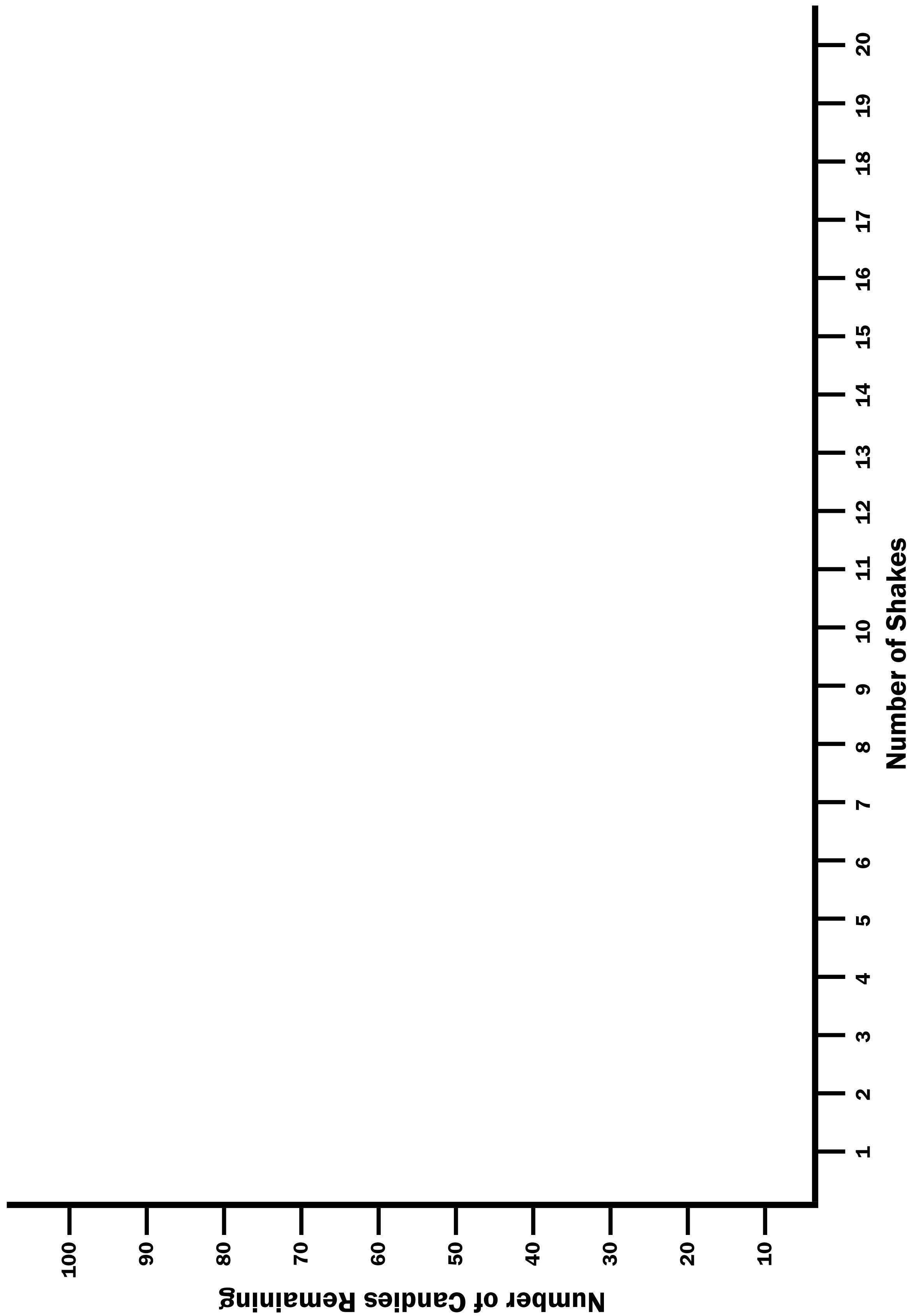
1. Four of the radioactive isotopes that are found in spent nuclear fuel are listed below. For each of the isotopes, compute the time required for the isotope to reach a level of radioactivity that is considered safe. Write the time periods in the space to the right.

Radioactive Isotope in Spent Fuel	Half-Life	Time Needed to Become Safe
Iodine-131	8 days	
Strontium-90	28 years	
Cesium-137	30 years	
Americium-243	7,370 years	

2. Which of the isotopes listed on the table requires the most stable and secure means of isolation and storage? Why?

3. Cesium-137 and strontium-90 are readily taken up by green plants. How might this pose a health hazard to human beings?

Radioactive Decay Graph



Summary of High-Level Nuclear Waste Disposal Options

Introduction

Because of its hazardous nature, great care must be taken to isolate high-level nuclear waste from the environment. Thousands of years may need to pass before this waste is considered safe. Most of the high-level waste produced in the United States is in the form of spent fuel from nuclear power plants, which is being temporarily stored at facilities near the power plants themselves.

A Summary of Temporary Spent Fuel Storage

Description:

Currently, all nuclear plants in the United States, as well as the Point Beach nuclear plant in Wisconsin, store their spent nuclear fuel in facilities located at the power plant site. Most spent fuel is stored in pools of water that absorb the heat released by the fuel. However, some spent fuel is stored in dry casks. For example, dry casks are used to store the older spent fuel from the Point Beach nuclear plant.

Advantages:

Waste is stored in facilities near nuclear power plants and does not have to be transported. Power plant personnel can monitor the waste and take action if problems occur. Spent fuel is available for reprocessing.

Problems:

Spent fuel storage facilities at nuclear power plants were designed only to store waste temporarily until a permanent disposal option was available. Many sites are becoming crowded and need to be expanded. Loss of water in pools could lead to overheating of spent fuel and the possibility of a major accident. Many spent fuel storage sites, like nuclear plants themselves, are located near populated areas.

Permanent Disposal Options

Presently, no permanent disposal site or method of disposal exists in the United States for high-level nuclear waste. A number of permanent disposal options have been proposed over the years. The United States and other countries are seriously studying some of the options, while others are not being considered at all. The following summaries describe different permanent disposal options and address their advantages and problems.

Bury Spent Fuel Deep Underground

Description:

Place spent fuel in casks and bury it in a mined repository deep underground. The ideal underground site would be geologically stable (no earthquakes or volcanic activity) and would not come in contact with groundwater or with surface water filtering into the ground. Once the repository is filled, it would be permanently sealed.

Advantages:

This option provides greater isolation from living organisms than storing it above ground. High-level waste would be stored in one location instead of at each nuclear power plant.

Problems:

The geologic stability of a site cannot be predicted with certainty. Earthquakes may occur and groundwater levels may change. Location markers and warning signs may not be understood by future residents or those considering mining the area. Once the waste is buried, it would be difficult to retrieve if problems developed or if reprocessed nuclear materials were needed in the future. Local residents may be strongly opposed to having a disposal site near where they live.

Summary of High-Level Nuclear Waste Disposal Options

Status:
Geologic burial is the only option being considered by the United States. Specific sites have been extensively studied, with Yucca Mountain in southern Nevada being final candidate for permanent disposal of spent fuel. The project has experienced many delays since its approval in 2002. It has been studied extensively but has never accepted spent fuel for storage. The project is currently under governmental review.

Yucca Mountain Nuclear Waste Repository Site. Nevada, USA.

Bury Spent Fuel Beneath the Ocean Floor

Description:
Place spent fuel in casks and bury it by placing it in holes drilled 30 to 300 feet beneath the ocean floor.

Advantages:
Certain ocean floor sites may be more geologically stable and may provide greater isolation than many underground sites on land. Clay material found beneath the ocean floor can potentially absorb radioactive materials should leakage occur.

Problems:
Burial of waste beneath the ocean floor may violate current international laws. Persuading countries to change the laws may take a great deal of time and effort. Transporting the waste overseas to the disposal site may also pose risks. Once the waste is buried, it would be nearly impossible to retrieve it if problems developed or if reprocessed nuclear materials were needed in the future.

Status:
The United States is not considering this disposal option, although other countries are studying it.

Store Spent Fuel in Specially Constructed Facilities above Ground

Description:
Special facilities would be built above ground to permanently store spent fuel and other high-level nuclear waste. The facilities would be guarded and managed by a permanent staff of workers who might even live near the site.

Summary of High-Level Nuclear Waste Disposal Options

Advantages:
Like underground burial, the high-level waste would be stored in one location instead of at each nuclear power plant. Personnel would monitor the waste and take action if problems occur. Spent fuel would be available for reprocessing.

Problems:
It is not clear whether such a site could be managed for the thousands of years that need to pass before the radioactivity level in the waste is considered safe. Society may experience many changes in the future, some of which may be disruptive (such as war or a plague). Local residents may be strongly opposed to having a disposal site near where they live.

Status:
This option is not actively being studied at this time.

Bury Spent Fuel in the Antarctic Ice Cap

Description:
Bury waste in the Antarctic ice cap.

Advantages:
Antarctica is one of the most remote and isolated places on Earth. Little life exists there, and it is practically uninhabited by humans. Antarctica is also far away from most human settlements and most of Earth's other ecosystems.

Problems:
The Antarctic ice cap may not be as stable as an underground location, since ice sheets move on occasion. Heat from nuclear waste could melt the ice and possibly cause an ice sheet to move. Burying waste in the Antarctic ice cap may violate current international laws. Persuading countries to change the laws may take a great deal of time and effort. Once the waste is buried, it would be difficult to retrieve if problems developed or if reprocessed nuclear materials were needed in the future. Transporting the waste to Antarctica may pose risks.

Status:
This option is not being considered at this time.

Place Spent Fuel in Rockets and Shoot It into Space

Description:
Shoot nuclear waste into space where it would either orbit the sun or be captured by it.

Advantages:
Ideally, the best way to isolate high-level nuclear waste from the environment is to remove it from Earth entirely.

Problems:
An accident or explosion during launch could spread hazardous high-level waste over a wide area of Earth. Shooting waste into space is very expensive because of the high cost of rocket launches and the limited amount of waste each rocket could hold. Retrieving the waste would be nearly impossible and very risky.

Status:
This option is not being considered at this time.

Summary of High-Level Nuclear Waste Disposal Options

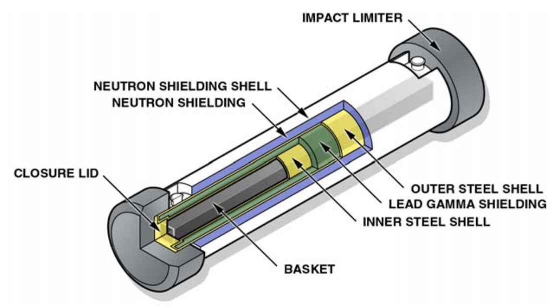
Nuclear Power in Wisconsin

As of 2017, Wisconsin has two nuclear power units that are located in Two Rivers. These units produce about fifteen percent of all electric power in the state of Wisconsin.

Wisconsin previously had two other nuclear power plants. The Kewaunee Power Plant was located in Carlton, Wisconsin (27 miles from Green Bay). It closed in May of 2013 due to falling electricity prices that resulted from falling prices of natural gas. The plant will be decommissioned which comes with substantial cost. Because the plant is privately owned, it cannot impose the decommissioning cost on its utility customers. The owner selected an option called SAFSTOR nuclear decommissioning, which means the plant will be monitored for up to 60 years before the plant will be completely decontaminated and dismantled. At that time, a the less radioactive materials will be moved from the reactor and the fuel assemblies will be moved into the spent fuel pool.

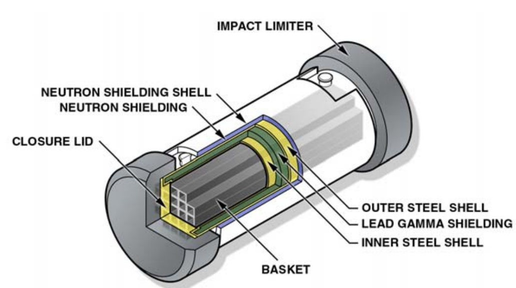
The other plant was the LaCrosse Boiling Water Reactor located at Genoa, Wisconsin (17 miles from LaCrosse). The site is owned and was operated by Dairyland Power Cooperative. Because the plant was no longer economically viable, it was closed in April of 1987. The plant began the SAFSTOR option in 199l, and a gradual dismantle of the plant has been underway. Because there is currently no federal storage available for the spent fuel, it is currently being stored onsite in dry casks. The reactor's pressure vessel was removed and transported via a specially designed rail car to a low-level radioactive waste facility in South Carolina.

TYPICAL SPENT FUEL TRANSPORTATION CASKS



Generic Truck Cask for Spent Fuel

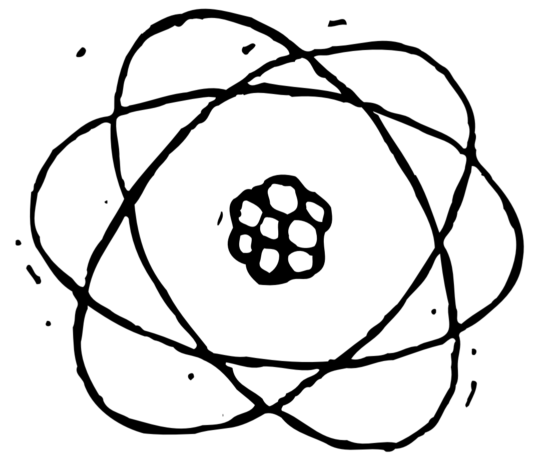
Typical Specifications
Gross Weight (including fuel): 50,000 pounds (25 tons)
Cask Diameter: 4 feet
Overall Diameter (including Impact Limiters): 6 feet
Overall Length (including Impact Limiters): 20 feet
Capacity: Up to 4 PWR or 9 BWR fuel assemblies



Generic Rail Cask for Spent Fuel

Typical Specifications
Gross Weight (including fuel): 250,000 pounds (125 tons)
Cask Diameter: 8 feet
Overall Diameter (including Impact Limiters): 11 feet
Overall Length (including Impact Limiters): 25 feet
Capacity: Up to 26 PWR or 61 BWR fuel assemblies

Facts about Nuclear Energy



Introduction

A recent revival on the energy scene, nuclear energy is associated with the promise of vast quantities of energy. It is also associated with health issues and environmental problems due to radiation and nuclear waste disposal. Despite the controversy surrounding it, nuclear energy supplies a significant amount of electricity for Wisconsin, the United States, and the world.

Uranium

Mineral ores contain uranium in the form of uranium oxide. Two types of uranium atoms, called isotopes, are found in these ores: uranium-235 (U^{235}) and uranium-238 (U^{238}). Of these two, only U^{235} can undergo nuclear fission. However, 99.3 percent of naturally occurring uranium is U^{238} while only 0.7 percent is U^{235}.

Generally, foreign ores have a higher uranium content than those found in the United States. Ores found in the United States contain from 0.05 to 0.3 percent pure uranium. The uranium content of foreign ores ranges from 0.035 percent in southern Africa to 2.5 percent in northern Saskatchewan, Canada.

Nuclear Fission

Nuclear energy can be obtained by a process called nuclear fission (or simply “fission”). Fission occurs when a neutron splits the nucleus of a U^{235} atom into two smaller nuclei, releasing energy and additional neutrons. The extra neutrons then split other U^{235} nuclei, releasing still more neutrons that split more U^{235} nuclei, and so on. This process is called a nuclear chain reaction.

A nuclear chain reaction cannot take place using naturally-occurring uranium. Nuclear power plants use fuels with a mixture of 3 percent U^{235}; this fuel is produced from natural ores by an enrichment process. Nuclear fuel can produce immense amounts of energy. One kilogram of U^{235} can produce two to three million times the energy of one kilogram of coal.

Nuclear Power Plants

In a nuclear power plant, energy from nuclear fission is produced in the reactor. A nuclear reactor is made up of the fuel assemblies, control rods, a moderator, a cooling tower, and the pressure vessel.

The fuel assemblies, control rods, and cooling system make up the reactor’s core. U^{235} in the fuel assemblies undergoes fission, releasing neutrons and large amounts of heat. Control rods are moved up and down between the fuel assemblies to absorb some of the neutrons, thereby regulating the rate of fission. A moderator, such as graphite, slows down the neutrons so that the fission reaction is more efficient. A coolant circulates through the reactor’s core to remove the heat so that it can be used to make steam in another part of the plant. The steam spins a turbine connected to a generator that produces electricity.

The core is surrounded by the pressure vessel, which is located inside the containment building, a structure made of thick concrete reinforced with steel bars.

A special type of nuclear reactor called a fast breeder reactor converts U^{238} into plutonium (Pu^{239}) while also

Facts about Nuclear Energy

producing electricity. Because plutonium is fissionable, breeder reactors could greatly increase the amount of usable nuclear fuel. Breeder reactor projects were once considered in Germany, the United Kingdom, Japan, and the United States but research has since been discontinued due to the extreme risk in extracting plutonium and the cost of developing the reactors.

Electricity Production

There were 61 nuclear power plants with 99 reactors located in 30 states in 2016. Combined they produced 805.3 kWh of electricity in the United States in 2016, close to 20 percent of the nation's electricity. Nuclear power plant construction ceased in the late 1990's, but has rebounded and several new power plants are ordered and at the same time many existing plants have been extended to continue operations.

The United States has more nuclear capacity than any other country in the world. France has the second, Russia the third, and South Korea the fourth. In 2016, 63 reactors are under construction in 15 countries throughout the world, mostly in the Asian region. Nuclear power capacity worldwide has been increasing steadily.

Wisconsin utilities currently have two nuclear power units, both at Point Beach in Two Rivers, Wisconsin. These units produce about one-sixth of all electric power in Wisconsin. There are now 444 operable civil nuclear power reactors around the world.

Uranium Reserves

Uranium reserves are described in terms of how much it costs per pound to mine the ore. Ores with a high concentration of uranium cost less to mine than those with low concentrations. The U.S. Department of Energy estimates that there were about 66 million pounds of $30 per pound uranium reserves and 362 million pounds at up to $100 per pound uranium reserves in the United States in 2015. (Plutonium from decommissioned weapons can also be used as a nuclear fuel).

U.S. uranium deposits in 2014 were over 207,400 tons of uranium, which is 4 percent of the world reserves. Wisconsin, however, has no known reserves. Other countries with major reserves include Australia, Kazakhstan, Canada, Russia, and South Africa.

Mining and Processing Uranium

Most uranium ore is mined using surface mining, also called "open mining." At a mill near the mine the ore is crushed and ground and the uranium oxide is chemically extracted. This yields uranium concentrate, also referred to as yellowcake. The ore, rocks, and soil left over after mining and milling are called tailings. The tailings contain radioactive materials and must be buried.

Other types of mining include underground mining, in situ leach (ISL) mining (where fortified groundwater is pumped into the aquifer, dissolving the uranium from the host sand), and heap leaching.

Trucks or trains then ship the uranium concentrate to a chemical plant where it is converted into a gas. This gas is then enriched, which increases the amount of U^{235} in the uranium mixture from 0.7 percent to 3.5-5 percent.

After enrichment, the gaseous uranium compound is converted into ceramic fuel pellets. The pellets, which are the size of a fingertip, are sealed inside metal tubes called fuel rods. Each 12- to 14-foot fuel rod contains about 200 pellets. Fuel rods are bound together in assemblies, each containing about 240 rods. Trucks or trains transport finished fuel assemblies to a nuclear power plant.

Facts about Nuclear Energy

Other Uses

Nuclear energy is widely used in the military to power submarines and aircraft carriers. Nuclear power plants aboard naval vessels offer great reliability and allow ships and submarines to sail for long periods of time without refueling. Nuclear weapons use U^{235} or plutonium to produce nuclear explosions. Nuclear energy also has important uses in medical diagnosis and treatment.

Effects

Nuclear energy has some important benefits. Because large amounts of energy can be obtained from a small amount of U^{235}, some of the environmental effects of mining uranium for energy are not as great as they are for coal. Also, nuclear power plants do not produce air pollutants or release carbon dioxide (a cause of global climate change) into the atmosphere. Some experts believe that nuclear energy is better able to meet the world's growing demand for energy than fossil fuels or renewable energy resources.

The main disadvantage of nuclear energy is that uranium and the waste materials produced from nuclear fission are radioactive. Radioactive materials emit alpha and beta particles and gamma rays, which can harm living cells. Radioactive materials are present in the mining, production, and transportation of nuclear fuel; in the operation of nuclear power plants; and in nuclear waste. Transportation is one of the most serious concerns related to nuclear energy use. After the fuel is mined, it needs to be transported to the plant and after the fuel is spent, it is transferred to the storage site. Transporting the fuel many miles to a permanent storage site adds even more risk and complications. On a global scale, there is fear associated with countries exporting and importing fuel by sea and by air. All these operations must be designed and managed to protect the environment from the release of radioactive materials. This often requires expensive and complex technology.

Although nuclear power plants are designed with many safety protocols to prevent releases of radiation, accidents at the Three Mile Island power plant in the United States in 1979 and the Chernobyl plant in the Ukraine in 1986, as well as the Fukushima plant in Japan in 2011, increased public concern about their safety. Safer nuclear reactors have been designed and tested, and are being put into use today.

Radioactive waste is classified as one of the following: Exempt waste; very low-level waste, low-level waste, intermediate-level waste, or high level waste. Low-level waste, for example, contains a small amount of radioactivity within a relatively large amount of material. These wastes include tools, equipment, and protective clothing exposed to radioactive materials. They must be stored in steel drums and buried for several decades until their radioactivity decreases to a safe level. The U.S. government has burial sites for low-level wastes in Barnwell, South Carolina; Richland, Washington; Clive, Utah; and Andrews, Texas.

Nuclear fuel from power plants is an example of a high-level waste. These wastes are extremely hazardous and must be safely stored for thousands of years until their radioactivity decreases to a safe level.

New research in reusing radioactive wastes is being conducted. It may be feasible at some point in time to remove the uranium, plutonium, and minor actinides for recycling in a fast breeder reactor. Currently, however, this recycling of radioactive wastes is not available on a commercial scale.

In the U.S., no permanent storage site for high-level waste exists. Currently, all nuclear power plants in the U.S. store their spent nuclear fuel in steel-lined concrete pools. These are temporary facilities near the plant; some of which are nearly full. Storing wastes deep underground is the option most likely to be used in the near future. The wastes would be sealed in metal canisters and buried about half a mile underground in a

Facts about Nuclear Energy

location where earthquakes do not occur and contact with groundwater is avoided. (However, it is difficult to predict whether an underground site will be geologically stable for thousands of years). Yucca Mountain in southern Nevada has been the leading candidate for a permanent disposal site since the 1980s. Studies of the area have been conducted to ensure the repository would be safe and environmentally sound for a one-million-year period of waste isolation. No final decision has been made about use of the site as of 2017.

Outlook

Nuclear energy has some important benefits. Because large amounts of energy can be obtained from a small amount of U^{235}, some of the Reserves of uranium will last for the projected lifetimes of the world's current nuclear power plants. Because only a small fraction of uranium is U^{235} (0.7 percent), uranium reserves are only thought to be enough to last about 90 years. However, new technologies could potentially extend this outlook past 200 years supply.

The expense and complexity of nuclear power plants and concerns about radiation exposure, disposal, and long-term safe containment of nuclear wastes have led many people to oppose nuclear energy. On the other hand, nuclear energy does not add pollutants or carbon dioxide to the atmosphere. It can also meet the world's growing demand for energy. Nuclear energy will continue to be used to produce electricity in the near future, but its long-term fate is somewhat uncertain.

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Nuclear Power Plant Diagram