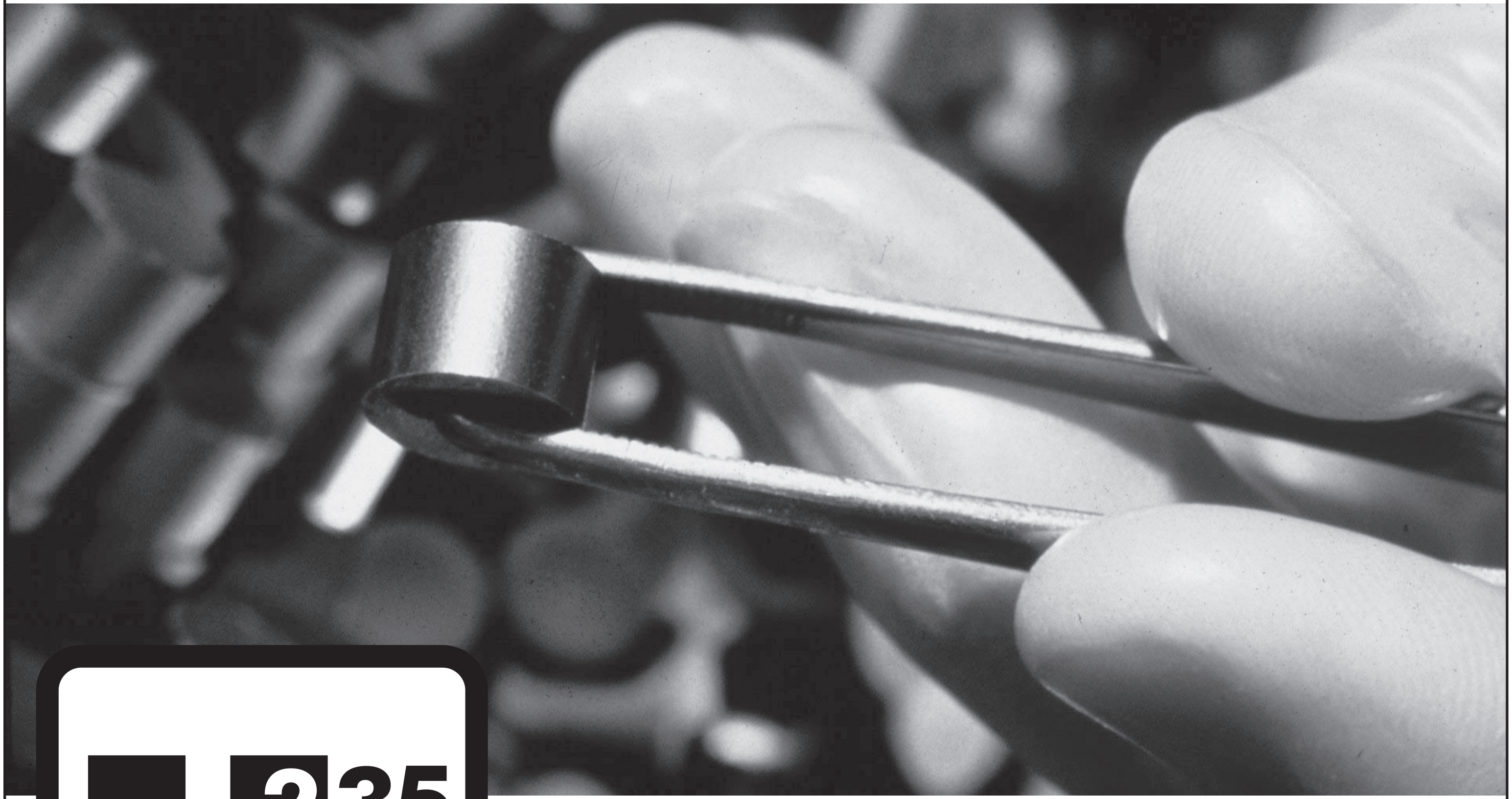
2018-2019

Energy From Uranium

Hands-on, multidisciplinary activities that introduce students to the chemistry and physics of uranium, the process of fission, the history of nuclear science, and the role of uranium in electricity generation.



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Grade Level:

Int Intermediate

Subject Areas:

- Science
- Social Studies
- Language Arts
- Technology

NEED
National Energy Education Development Project

Teacher Advisory Board

NEED Mission Statement

The mission of The NEED Project is to promote an energy conscious and educated society by creating effective networks of students, educators, business, government and community leaders to design and deliver objective, multi-sided energy education programs.

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Teacher Advisory Board

In support of NEED, the national Teacher Advisory Board (TAB) is dedicated to developing and promoting standards-based energy curriculum and training.

Energy Data Used in NEED Materials

NEED believes in providing teachers and students with the most recently reported, available, and accurate energy data. Most statistics and data contained within this guide are derived from the U.S. Energy Information Administration. Data is compiled and updated annually where available. Where annual updates are not available, the most current, complete data year available at the time of updates is accessed and printed in NEED materials. To further research energy data, visit the EIA website at www.eia.gov.

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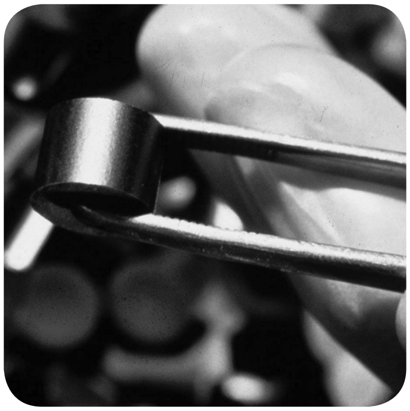


Energy From Uranium

Energy From Uranium was developed by The NEED Project with funding and technical support from The Lenfest Foundation and Washington and Lee University.

Table of Contents

Standards Correlation Information

www.NEED.org/curriculumcorrelations

Next Generation Science Standards

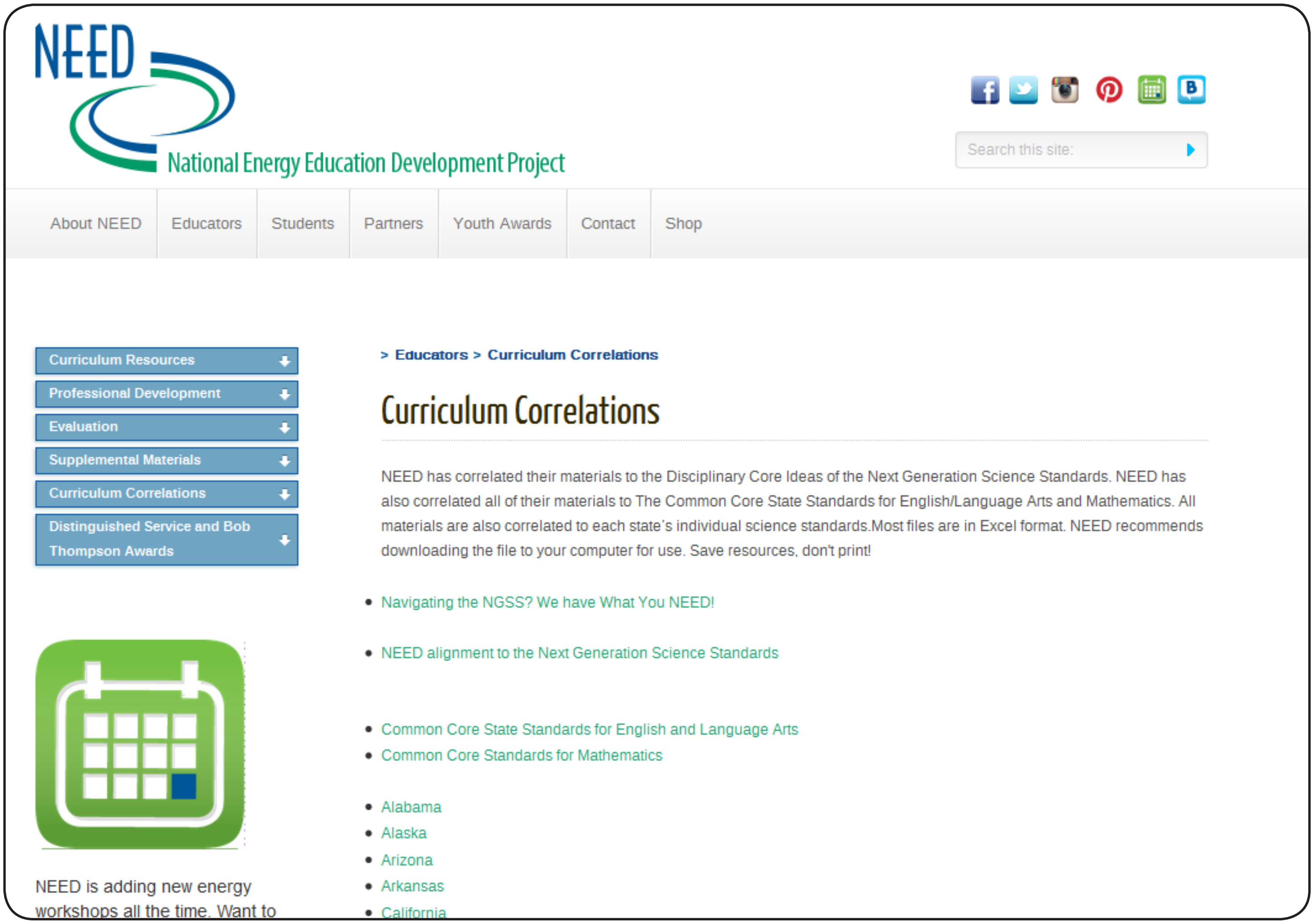
- This guide effectively supports many Next Generation Science Standards. This material can satisfy performance expectations, science and engineering practices, disciplinary core ideas, and cross cutting concepts within your required curriculum. For more details on these correlations, please visit NEED's curriculum correlations website.

Common Core State Standards

- This guide has been correlated to the Common Core State Standards in both language arts and mathematics. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED curriculum correlations website.

Individual State Science Standards

- This guide has been correlated to each state's individual science standards. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED website.



> Educators > Curriculum Correlations

Curriculum Correlations

NEED has correlated their materials to the Disciplinary Core Ideas of the Next Generation Science Standards. NEED has also correlated all of their materials to The Common Core State Standards for English/Language Arts and Mathematics. All materials are also correlated to each state's individual science standards.Most files are in Excel format. NEED recommends downloading the file to your computer for use. Save resources, don't print!

- Navigating the NGSS? We have What You NEED!
- NEED alignment to the Next Generation Science Standards

- Common Core State Standards for English and Language Arts
- Common Core Standards for Mathematics

- Alabama
- Alaska
- Arizona
- Arkansas
- California

NEED is adding new energy workshops all the time. Want to

Energy From Uranium Materials

ACTIVITY	MATERIALS NEEDED
Science of Electricity	▪Small bottle ▪Strong rectangle magnets ▪12″ x ¼″ Wooden dowels ▪Rubber stoppers with ¼″ hole ▪Foam tube ▪Spools of magnet wire ▪Masking tape ▪Permanent markers ▪Small nail ▪Large nail ▪Fine sandpaper ▪Multimeters ▪Sharp scissors ▪Alligator clips ▪Rulers ▪Hand operated pencil sharpeners ▪Push pins ▪Utility knife (optional)
Atomic Mass of Isotopes	▪Pennies* ▪Digital balances
Radioactive Decay: Candy Chemistry	▪M&M's® candies* ▪Small cups ▪Paper towels ▪Licorice ▪Graph paper
Detecting Radiation — Done as a class demonstration, no group set-up is required.	▪100% Alcohol ▪Dry ice ▪Cloud chamber with lid ▪Flashlight ▪Uranium ore or other radioactive sample ▪Neodymium magnet ▪Piece of sponge
Milling Simulation	▪Sand ▪Salt ▪Gravel ▪Screens ▪Filters ▪Water ▪Cooking pot ▪Heat source ▪Beakers ▪Safety glasses ▪Scales or balances ▪Stirrers
Nuclear Power Plant Simulation	▪Poster board ▪Blue plastic table cloth ▪Index cards ▪Red paper ▪Blue paper ▪String ▪Hole punch ▪Rope or extension cord ▪Flashlight ▪Masking tape ▪Poker chips, sticky notes, candies, or other counting pieces (60-100 needed) ▪Swivel stool (optional)
Nuclear Energy Expo	▪Tri-fold boards ▪Markers
Uranium in the Round	▪Cardstock
Culminating Activity: Advantages and Challenges of Nuclear Energy	▪Internet access for students

NOTE: Any marked, two-sided, identical objects can be used as a substitute for these activities, including coins, candies, disks, or chips. If using pennies, be sure they were all minted after 1982, to ensure similar masses.

Teacher Guide

Grade Level

- Intermediate, grades 6-8

Time

- Approximately 10-20 45-minute class periods or less, depending on the activities selected

Science Notebooks

This curriculum is designed to be used in conjunction with science notebooks. Experimental questions, procedures, sample data tables, and conclusion questions are provided. If you do not use notebooks in your classroom, students may require paper for recording data and conclusions. If you use notebooks in your classroom, your students may choose to incorporate the activity sheets into their notebooks.

Online Resources

See page 20 for a list of informative and interactive websites that support this content.

Background

This is an integrated curriculum designed to teach students about the use of uranium as an energy source.

Preparation

- Familiarize yourself with the activities and information contained within the guide. Select the activities that will be most appropriate for your students.
- Gather any materials you will need for the activities you select. A materials list can be found on page 5.

Activity 1: Introduction

Objective

- Students will be able to describe uranium's role in the process of generating power.

Time

- 1 class period

Materials

- *Think, Learn, Question (TLQ)*, page 41
- *Nuclear Energy Bingo,* pages 18-19, 70
- Student informational text, pages 22-39
- Culminating project rubric, page 17 (optional)

Preparation

- Make copies of the informational text and worksheets for each student.

✔ Procedure

1. Give students 3-5 minutes to brainstorm what they know about nuclear energy, and some questions they may have. When students are done, take two minutes and let students share their thoughts with a partner, then have a class discussion for students to share their thoughts.
2. During the discussion, write students' thoughts on the board or chart paper. Students may try to correct each other's misconceptions during the conversation. Allow this discussion to take place. However, if there is something that remains in dispute, do not correct the misconception yourself, but make note of it and add it to the question section. Let students know that they should be looking for supporting evidence for their ideas and answers to their questions in the coming days.
3. Play *Nuclear Energy Bingo* as an introduction to the unit.
4. If you are going to have your students participate in the mock nuclear power plant hearing, introduce the culminating project to your students and assign roles to students to take on as they learn about nuclear energy. Encourage students to analyze information from the viewpoint of their assigned character. Throughout the unit students should also conduct outside research to prepare for their presentation at the hearing. See pages 16 and 64-65 for more details about the hearing. You may also give students the rubric for assessment ahead of time.
5. Assign students to read the informational text. As students read, they should keep notes on key points and facts. This can be done in their notebooks, or using the *TLQ* handout. Students can complete the reading during class time or as homework, depending on your preference.

Activity 2: Science of Electricity

Objective

- Students will be able to describe how electricity is generated.

Time

- 1class period

Materials

- 1 Small bottle
- 1 Rubber stopper with ¼" hole
- 1 Wooden dowel (12" x ¼")
- 4 Strong rectangle magnets
- 1 Foam tube
- 1 Small nail
- 1 Large nail
- Spool of magnet wire
- Permanent marker
- 1 Pair sharp scissors
- Masking tape
- Fine sandpaper
- 1 Push pin
- 1 Multimeter with alligator clips
- Hand operated pencil sharpener
- Ruler
- Utility knife (optional)
- *Science of Electricity Model* instructions, pages 44-46
- *Science of Electricity Model* worksheet, page 47

Preparation

- Pre-assemble the *Science of Electricity Model* to showcase as a demonstration. Troubleshoot any concerns and test the model before demonstrating.
- Make copies of the *Science of Electricity Model* worksheet.

✔ Procedure

1. Show the class the model. Have students take turns operating it and record the highest output students are able to generate.
2. Ask students to complete the *Science of Electricity Model* worksheet.
3. If time allows, ask students to re-design the unit using the same or less materials, so that the unit would generate more voltage.

Extension

Provide your students extra time and materials to build their re-designed generators. Ask them to also add to their generator so that it produces energy from another source material, rather than their hands.

Activity 3: Atomic Mass of Isotopes

Objective

- Students will be able to identify the average atomic mass for 2 stable isotopes.

Time

- 1-2 class periods

Materials *FOR EACH GROUP*

- 100 Pennies*
- Digital balance
- *Atomic Mass Model* worksheet, page 48
- *Boron Isotopes and Atomic Mass* worksheet, page 49
- *Average Atomic Mass of Boron* worksheet, pages 50-51
- *Examining Nuclear Energy* worksheet, page 52

NOTE: If using pennies, be sure they were all minted after 1982. You may use any marked, two-sided, identical objects, including other coins, M&M's® candies, discs, or chips.

CONTINUED ON NEXT PAGE

Preparation

- Make copies of the student worksheets.
- Count out pennies for each group and prepare areas for students to calculate their masses.

✔ Procedure

1. Introduce students to the term isotope. Isotopes are atoms of the same element (number of protons) with differing atomic masses (numbers of neutrons). Explain to students that natural uranium, the material processed into fuel for a nuclear power plant, contains 99.28% uranium-238, 0.71% uranium-235, and 0.04% uranium-234. These are all isotopes of uranium, each having 92 protons but different numbers of neutrons (146, 143, and 142, respectively). Uranium, like most other naturally-occurring elements, exists with its isotopes in combination rather than separated from each other. The atomic mass listed on the periodic table of elements is the average of the isotopes, calculated as a weighted average. This weighted average proportions the average more heavily toward the isotopes that exist in higher abundance in nature. Because most uranium is U-238, the mass listed on the periodic table is skewed heavily toward 238.
2. Students will use their pennies (or other objects) and balance to complete the atomic mass activities. In these activities, the head side of the penny will represent a proton while the tail side will represent a neutron.
3. Discuss and review the activities and student conclusions. Remind students that the atomic mass of an atom is the sum of the total number of protons and neutrons in the atom; one atomic mass unit (amu) is approximately the mass of a proton or neutron. The mass listed on the periodic table is not actually the mass of one single atom of each element, but rather the weighted average of the naturally-occurring isotopes in any given sample of that element.
4. Explain to students that some isotopes decay over time if they are unstable, and these are called radioactive isotopes. All elements larger than bismuth (Bi, atomic number of 83) are radioactive. Thus, all uranium isotopes are radioactive and decay over time. Uranium-235 is special in that it can be fissioned to release energy. When this happens, tremendous amounts of energy are released, equal to the mass that was lost times the speed of light squared ($E=mc^2$). Nuclear fission is the way thermal energy is released in a nuclear power plant.
5. Have students complete *Examining Nuclear Energy* in class or for homework and discuss.

Social Studies Connection

Have students conduct further research on pioneers in nuclear science and give a presentation that gives the who, what, when, where, why, and how of the pioneer's accomplishments and research. The EIA Energy Kids page has good resources for students, www.eia.gov/kids/.

☑ Answer Key for Average Atomic Mass of Boron Activity, page 51

Element	Atomic Number	Listed Atomic Mass	Isotope likely to be of greatest abundance in nature
Helium	2	4.002602	Helium-4
Lithium	3	6.941	Lithium-7
Beryllium	4	9.012182	Beryllium-9
Boron	5	10.811	Boron-11
Carbon	6	12.0107	Carbon-12
Nitrogen	7	14.0067	Nitrogen-14
Oxygen	8	15.9994	Oxygen-16
Fluorine	9	18.9984032	Fluorine-19
Neon	10	20.1797	Neon-20

Activity 4: Radioactive Decay: Candy Chemistry

✪ Objective

- Students will be able to explain the concepts of radioactive decay and half-life using an exponential decay curve.

Time

- 1 class period

Materials *FOR EACH GROUP OR PAIR*

- 100 M&M's® candies*
- Small cup
- Paper towel
- 2 Pieces of licorice
- 2 Sheets of graph paper
- *Licorice Decay* worksheet, page 53
- *M&Mium Radioactive Decay* worksheet, page 54
- *Licorice and M&Mium Decay Graph* worksheet, page 55

NOTE: You do not have to use M&M's® candies for this activity. Any two-sided object will work, including other candies, coins, and two-sided discs. Also, on yellow candies, it is sometimes difficult to clearly see the printing on each piece.

Preparation

- Put 100 M&M's® in a small cup for each group or pair of students.
- Make copies of the student worksheets as needed.

✔ Procedure

1. Explain to students that unstable isotopes wish to become stable. In an effort to become stable, these isotopes emit particles and energy in a process called radioactive decay. For some elements, this process is quick (a few hours or less), and for some it takes a long time (years). When an element decays so that half of its atoms remain, this is called a half-life. Uranium decays slowly and naturally on its own or much more quickly during nuclear fission. As it decays, it emits radiation, making it "radioactive", thus the term "radioactive decay."
2. Pass out supplies and direct students to complete the *M&Mium Radioactive Decay* and *Licorice Decay* activities and create graphs for both activities using the graph worksheet or graph paper.
3. Discuss as a class what a half-life is, and how their graphs compared for each candy item. Discuss how their graphs and data might have looked if they had more M&M's®.

Extension

Display examples of decay curves for other radioactive elements and ask students to compare them to their own graphs.

Activity 5: Detecting Radiation

✪ Objectives

- Students will be able to describe radiation and when and where it is present.
- Students will be able to explain how a cloud chamber works.
- Students will be able to identify how the charge of a particle can be determined.

Time

- 2 class periods

⚠ Cautions

- Handle radioactive samples according to the safety directions included with the material.
- Uranium ore sample should not be made into a powder and should not be eaten.
- Alcohol is for lab use and not for consumption.

Materials

- 100% Alcohol
- Dry ice
- Cloud chamber with lid
- Flashlight
- Uranium ore or other radioactive sample
- Neodymium magnet
- Piece of sponge
- *Radiation Dose Chart** worksheet, page 56

Preparation

- Make a copy of the *Radiation Dose Chart* for each student.
- Visit the following website for more information on cloud chambers and instructions on how to create your own if you don't have one: https://www.classe.cornell.edu/rsrc/Home/Outreach/LessonPlans/cloudchamber.pdf
- Set up the cloud chamber according to the instructions below.

Cloud Chamber Set-up

1. Place a small piece of sponge in the black cloud chamber bowl.
2. Pour a small amount of alcohol over the sponge into the bottom of the cloud chamber bowl. There should be a small layer of alcohol along the bottom.
3. Place the radioactive source in the bottom of the container.
4. Cover the bowl with either plastic wrap using a rubber band to seal it or a lid that is very easy to see through clearly.
5. Place the cloud chamber on a block of dry ice.
6. Let the chamber sit for about 20-30 minutes.
7. Using a bright flashlight, light up the cloud chamber bowl from the side and view the condensation trails from the top.

✔ Procedure

1. Explain to students that cloud chambers can be used to show or detect radiation. Show the class the informational website on cloud chambers, if desired, or in place of the set-up if a cloud chamber is not available.
2. Once the cloud chamber is set up, have students make observations. Alpha particles (helium nuclei) should leave thicker trails than beta particles (electrons).
3. Add a neodymium magnet and see that alpha and beta particles will turn in the opposite direction when moving through the magnetic field.
4. Ask the class what other examples of vapor trails they have witnessed.
5. Pass out the *Radiation Dose Chart* to students and explain that radiation occurs naturally around us all the time. Help students to figure out their annual dose of radiation by filling out the chart. Students may need assistance determining their elevations. Ask students what surprises them about their results.

*The *Radiation Dose Chart* has been used with permission from the U.S. Nuclear Regulatory Commission.

Activity 6: Milling Simulation

✪ Objective

- Students will be able to describe how materials can be physically and chemically separated.

Time

- 1 class period

Materials *FOR EACH GROUP*

- 10 g Sand
- 10 g Salt
- 5 g Gravel
- Screen
- Filter
- 100 mL Water
- Beaker
- Cooking pot
- Heat source
- Scale or balance
- Stirrer

Materials *FOR EACH STUDENT*

- Safety glasses
- *Milling Simulation*, page 57

Preparation

- Make a copy of the worksheet for each student.
- Make a mixture for each group that, by mass, is 10 g sand, 10 g salt, and 5 g gravel.

✔ Procedure

1. Following the directions on the *Milling Simulation* worksheet, students will work to separate the salt from the sand that you have already prepared.
2. After students finish, have a class discussion about the similarities and differences between what they did in class and the processes used to separate and prepare uranium.
3. Explain that every uranium mine contains a different percentage of uranium. Canada has some of the best uranium ore and can recover as much as 20% uranium from their ore. Some mines have as little as 0.1% uranium that can be separated from the ore. Sometimes 900 kg of ore may only produce 10 kg of uranium!

Activity 7: Nuclear Power Plant Simulation

Background

The operation of a nuclear power plant can be complicated, with its many systems, gauges, valves, backup systems, and alarms. However, the basic process is quite simple, and this simulation allows students to walk through that process.

In the simulation, students will represent the major parts of a nuclear power plant system: control rods, fuel rods, circulating water, and generation and transmission lines. Energy is represented using "energy chips" and the simulation demonstrates how that energy is passed and distributed throughout the entire system.

The simulation is meant to show the very basic operation, and how the energy is transferred from one loop to another within the power plant operation. If students take an interest in the energy transfer process, a more complex but realistic version depicting the distribution of energy within the system can be found in the secondary version of this activity found in NEED's *Exploring Nuclear Energy*.

✪ Objectives

- Students will be able to describe how energy is transformed in a nuclear power plant
- Students will be able to explain how electricity is generated in a nuclear power plant.

CONTINUED ON NEXT PAGE

Time

- 1 class period

Materials

- Poker chips, sticky notes, small candies, or counting pieces (60-100 pieces needed)
- 3 Pieces of poster board
- Blue plastic table cloth
- Index cards
- String
- Hole punch
- Red construction paper
- Blue construction paper
- Rope or extension cord
- Flashlight
- Masking tape
- Swivel stool (optional)
- *Nuclear Power Plant Simulation Summary*, page 58

Preparation

- Cut two "turbine blades" from one piece of poster board.
- Using the index cards, make 3-4 hang tags that say "steam" on one side and "water" on the other. Laminate if you wish. Punch a hole in the top and thread string through the hole to make a loop big enough for a necklace.
- Make 6-7 two-sided hang tags from red and blue construction paper, so red is on one side and blue is on the other. Laminate if you wish. Punch holes and construct necklaces as before.
- If you would like, trim the plastic table cloth into a pond shape.
- Mark out three areas on the floor with masking tape using the diagram on page 14. One area will be the primary loop, one will be the secondary loop with generator and transmission, and one will be the cooling system. Indicate "exchange zones" where energy chips will be handed from one loop to another as the activity progresses.

✔ Set-up Procedure

1. Assign students roles in the simulation based on the diagram and list on page 14.
2. Explain to students that you will be simulating how a nuclear power plant generates energy. You will place them in the simulation based on their job. They are to NEVER cross over from one section to another during the simulation.
3. Each "fuel rod" has five students in line. Form two fuel rods, for a total of 10 people.
4. One student will act as a control rod, with two pieces of poster board in his/her hands.
5. Assemble the primary loop using 3-4 students who act as pressurized water, and circulate with energy chips as described in the simulation and shown on the diagram.
6. Set up the secondary loop with 3-4 students who act as water/steam, circulating with hang tags that say "water" on one side and "steam" on the other.
7. Place one student with "blades" made from poster board sitting on a swivel stool or standing at the exchange zone between the secondary loop and transmission. This student will be the turbine.
8. The transmission lines will require 2-3 students holding rope or a cord to represent the transmission lines and electricity grid.
9. One student will hold the light to demonstrate energy use in our homes and schools.
10. Create the cooling system using 2-3 students with hang tags that are red on one side and blue on the other. They will circulate through a "pond" of a blue plastic table cloth on the floor. They will carry the energy chips to the pond (red) and leave the pond without most of them (blue).

Simulation Instructions

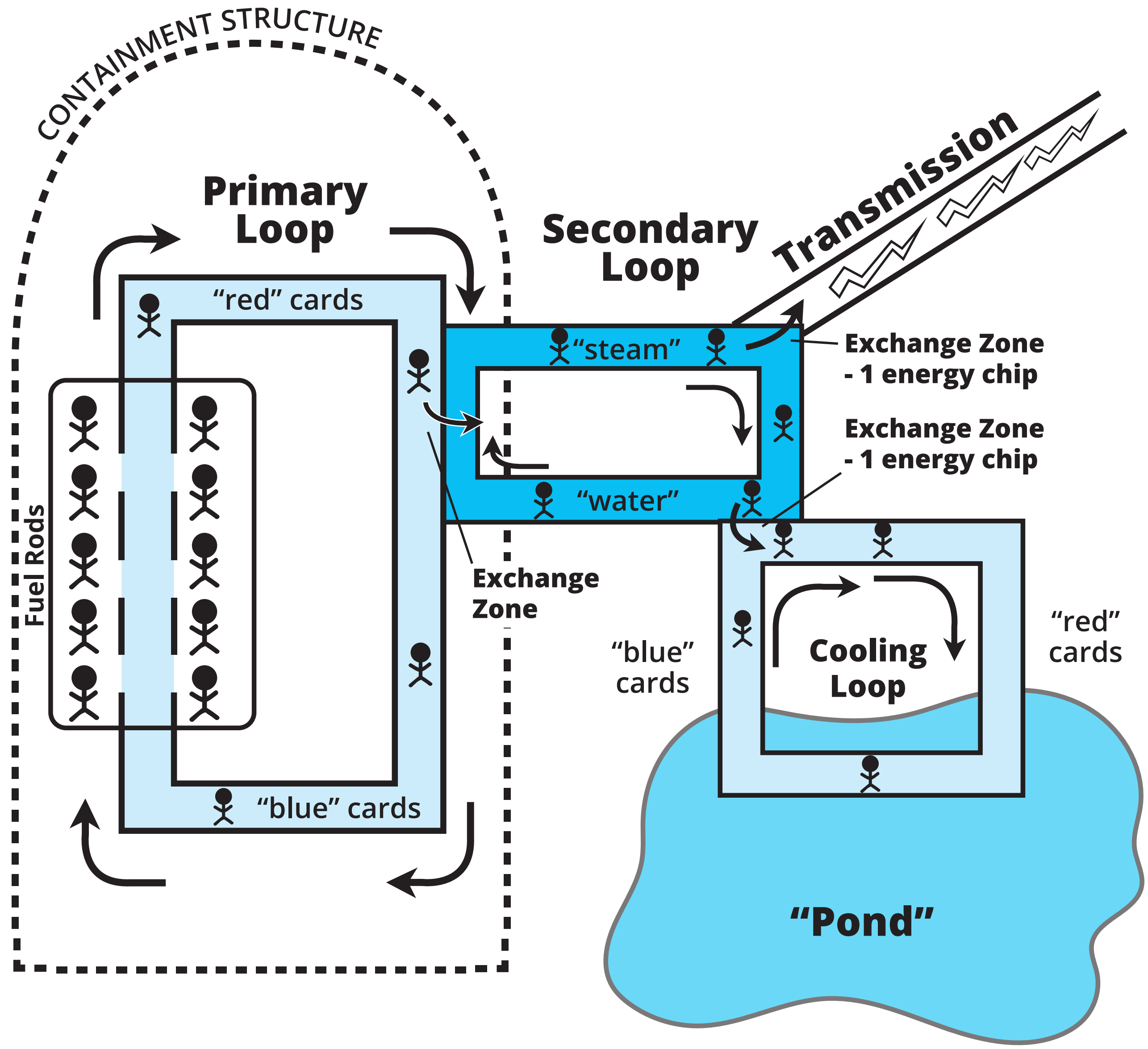
1. Begin with the control rod standing between the two fuel rods, blocking the way for the pressurized water students in the primary loop.
2. To start the process, the control rod will come out of the space between fuel rods.
3. The primary loop will circulate, walking between the fuel rods, each picking up two energy chips and turning their hang tags to red. When the primary loop reaches the exchange zone with the secondary loop, those two energy chips are handed to the secondary loop and the hang tags are turned back to blue.

CONTINUED ON NEXT PAGE

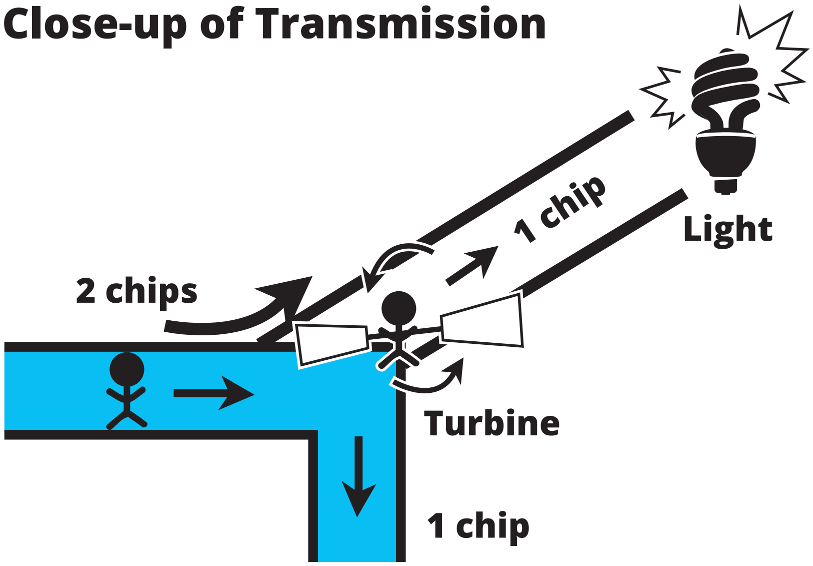
4. The secondary loop will turn their hang tags to “steam” when holding energy chips. In the appropriate exchange zones, one energy chip will be handed to the transmission line, and the other will be handed off to the cooling loop. At that point the hang tags will be turned back to “water”.
5. Along the transmission line, the energy chip will be passed first through the turbine, who will spin, and the transmission line will continue passing the energy chip to the person holding the light, which will be switched on when the energy chip reaches him or her.
6. In the cooling loop, hang tags will be turned to red while holding an energy chip. The loop will circulate through the pond, where the energy chips will be dropped off, and the hang tags turned back to blue.
7. All of the people in all of the three loops will continue to circulate until you are satisfied that students understand what is happening.
8. Redistribute the students and assign different roles to repeat the process.
9. Ask the class to identify where there are spots energy “builds up“ in their simulation. Discuss how a power plant might deal with that.
10. Remind students that energy is never truly created or destroyed; it transforms. But, no transformation is ever fully efficient. If this is the case, what would students do with their energy chips instead? Would they keep some and pass some off? Would some get “dropped“ somewhere in the plant? Discuss student thoughts and explain that a nuclear plant is only about 35% efficient, meaning that not all of the energy chips in the primary loop area make it out to become electricity. Ask students to discuss what they think happens to this energy and why this could be a challenge for a nuclear facility.
11. Point out that this demonstration is simulating a Pressurized Water Reactor (PWR). Ask students to read about how reactors work in the student text, and identify any items they might add to the simulation that are missing.

Extensions

- Once you have gone through the simulation, students may ask what happens if one of the systems fails. Simulate a cooling loop failure by stopping the cooling loop. Students continue as before, but the cooling loop does not circulate. Have students explain what will happen in the secondary loop and the primary loop. Instruct the control rod to intervene, shutting the system down to prevent overheating. Ask students to discuss if they think the shut down stops the circulation quickly or slowly.
- Simulate a failure in the secondary loop by having students stop. What will happen to the reactor over time? Again have the control rod intervene.
- Have students manipulate the simulation, making substitutions to the roles, infrastructure, and energy transformations included in a coal-fired power plant. Have students list or discuss similarities and differences between each plant.



Close-up of Transmission



Role List/Supplies

10 students	Fuel Rods - Give each student a few energy chips
1 acts as control rod	Give this student 2 pieces of poster board
3-4 students	Primary Loop - Give each student a red and blue tag
3-4 students	Secondary Loop - Give each student a water/steam tag
1 student	Turbine - Give two blades
1 student	Light - Give a light
2-3 students	Transmission Lines - Hold the rope
2-3 students	Cooling System - Give each student a red/blue tag

Activity 8: Nuclear Energy Expo

Objective

- Students will be able to list important facts related to the processes and issues involved in and associated with using nuclear energy.

Time

- 3 class periods

Materials *FOR EACH GROUP*

- Tri-fold board or posterboard
- Markers
- *Nuclear Energy Expo* questions, pages 59-60

Preparation

- Gather art supplies and presentation materials.
- Pre-determine groups and topics, as necessary, using the list on the following page.

✔ Procedure

1. Divide students into small groups and assign each group one of the following topics from the informational text:
    - *Nuclear Fission*
    - *Nuclear Fuel Cycle*
    - *Nuclear Power Plants and Reactors*
    - *Safeguards and Fuel Waste*
    - *Nuclear Weapons and Proliferation*
    - *Economics of Nuclear Energy*
   - Additional topics can be found online at www.NEED.org/nuclearmaterials:
        - *Influential Women in Nuclear Science*
        - *Nuclear Accidents*
        - *Radon*
        - *Nuclear Medicine*
        - *The Nuclear Navy*
        - *France's Nuclear Program*
2. Project or provide each student with the questions that apply to their assignment. They should use these questions to guide their research and presentation. Divide the project work over three or more class sessions, as suggested below.
    - **Session 1**: Students read their section, brainstorm ways to present the information to the class, and start to prepare presentations.
    - **Session 2:** Students finish preparations.
    - **Session 3:** Display the tri-fold boards around the room. Each student receives a copy of the *Nuclear Energy Expo* questions for each topic and should gather answers during classroom presentations or exhibition time.

Technology Integration

Have students create multimedia presentations in place of tri-fold boards.

Activity 9: Uranium in the Round

Objective

- Students will be able to identify and define nuclear energy vocabulary.

Time

- 20-40 minutes

Materials

- *Uranium in the Round* cards, pages 61-63
- Cardstock

CONTINUED ON NEXT PAGE

Preparation

- Copy the game onto cardstock and cut into individual cards.
- Make an extra copy of the game to use as an answer sheet.

✔ Procedure

1. Distribute one card to each student. If you have cards left over, give some students two cards so that all of the cards are distributed.
2. Have the students look at the bold word(s) at the top of the card. Give them a few minutes to review the information about their word, using their *TLQ* charts, notes, or the informational text.
3. Choose any student to begin and have him/her read the question on his/her card, "Who has...?" The student with the correct answer should stand up and read the bold word or phrase, "I have ...." That student will then read the question on his/her card, and the round will continue until the first student stands up and answers the final question signaling the end of the round. Keep track of student progress using your answer key. Allow students to debate or argue answers, where necessary, and conduct a class vote to determine the correct response.

Activity 10: Culminating Activity: Advantages and Challenges of Nuclear Energy

✪ Objective

- Students will identify and describe advantages and challenges of nuclear energy.

Time

- The amount of time for the final activity can be modified to meet the time you have available.

Materials

- Copies of *Nuclear Power Plant Hearing,* pages 64-65, or *Nuclear Energy Letter Prompt*, page 66

Preparation

- Choose which culminating activity will best suit your class based on the descriptions below and student activity sheets.
- Make a copy of the activity selected for each student.

✔ Procedure

1. Brainstorm with students some of the opportunities and challenges they see for using nuclear energy as an energy source. After the class has come up with a list, then read the advantages and challenges section on page 39 of the informational text. Discuss both lists. Are there some items that are more important than others? Why? What would you need to take into consideration if you were to decide whether or not a new nuclear plant should be built?

Nuclear Power Plant Hearing

Assign pairs or small groups of students different roles to take. Explain to students that a Combined Construction Permit and Operating License is one of the first steps to building a new nuclear power plant. In this stage, the NRC is open to hearing information on three issues: environmental protection, plant safety, and emergency procedures. In this mock hearing, economic issues will also be discussed. Students will present their position to a NRC Panel that will decide whether or not to allow plans for the plant to proceed. Further details of the assignment are on pages 64-65.

Suggestion: Rather than having students make up the NRC Panel, recruit members of your staff and/or community to be on the NRC Panel to hear student presentations.

Persuasive Letters

In this assignment, students complete additional research to write a persuasive letter to an elected representative, the Nuclear Regulatory Commission, or other decision makers. Letters may be submitted to the teacher, or, you may give students the option to actually send their letters to the intended recipients. Further details of the letter assignment are on page 66.

CONTINUED ON NEXT PAGE

Extension

Have students present an alternative choice to nuclear energy if they are against it, or share what issues need to be resolved before they could support nuclear power.

☑ Evaluation

- A final assessment on nuclear energy is located on pages 67-69. Answers can be found on page 21.
- Evaluate *Nuclear Energy Expos* and *Culminating Activity* projects using the rubric below or a rubric of your choice.
- Revisit *Nuclear Energy Bingo* and/or *Uranium in the Round* as formative assessments of vocabulary and concepts discussed.
- Evaluate the unit with your students using the *Evaluation Form* on page 74 and return it to The NEED Project.

☑ Rubric

This rubric can be used for *Nuclear Energy Expo* or for the *Culminating Activity*.

	CONTENT	ORGANIZATION	ORIGINALITY	WORKLOAD
4	Project covers the topic in-depth with many details and examples. Subject knowledge is excellent.	Content is very well organized and presented in a logical sequence.	Project shows much original thought. Ideas are creative and inventive.	The workload is divided and shared equally by all members of the group.
3	Project includes essential information about the topic. Subject knowledge is accurate.	Content is organized in a logical sequence.	Project shows some original work. Work shows new ideas and insights.	The workload is divided and shared fairly equally by all group members, but workloads may vary.
2	Project includes essential information about the topic, but there are 1-2 factual errors.	Content is logically organized but may have a few confusing sections.	Project provides essential information, but there is little evidence of original thinking.	The workload is divided, but one person in the group is viewed as not doing a fair share of the work.
1	Project includes minimal information or there are several factual errors.	There is no clear organizational structure, just a compilation of facts.	Project provides some essential information, but no original thought.	The workload is not divided, or it is evident that one person is doing a significant amount of the work.

Nuclear Energy BINGO Instructions

***Nuclear Energy Bingo* is a great icebreaker for a NEED workshop or conference. As a classroom activity, it also makes a great introduction to an energy unit.**

Preparation

- 5 minutes

Time

- 45 minutes

Bingos are available on several different topics. Check out these resources for more bingo options!

- Biomass Bingo— *Energy Stories and More*
- Change a Light Bingo—*Energy Conservation Contract*
- Coal Bingo—Coal guides
- Energy Bingo—*Energy Games and Icebreakers*
- Energy Efficiency Bingo—*School Energy Managers* and *School Energy Experts*
- Hydrogen Bingo—*H_2 Educate*
- Hydropower Bingo—Hydropower guides
- Oil and Natural Gas Bingo—Oil and Natural Gas guides
- Science of Energy Bingo—*Science of Energy* guides
- Solar Bingo—Solar guides
- Transportation Bingo—Transportation guides
- Wind Energy Bingo—Wind guides

Get Ready

Duplicate as many *Nuclear Energy Bingo* sheets (found on page 70) as needed for each person in your group. In addition, decide now if you want to give the winner of your game a prize and what the prize will be.

Get Set

Pass out one *Nuclear Energy Bingo* sheet to each member of the group.

Go

PART ONE: FILLING IN THE BINGO SHEETS

Give the group the following instructions to create bingo cards:

- This bingo activity is very similar to regular bingo. However, there are a few things you'll need to know to play this game. First, please take a minute to look at your bingo sheet and read the 16 statements at the top of the page. Shortly, you'll be going around the room trying to find 16 people about whom the statements are true so you can write their names in one of the 16 boxes.
- When I give you the signal, you'll get up and ask a person if a statement at the top of your bingo sheet is true for them. If the person gives what you believe is a correct response, write the person's name in the corresponding box on the lower part of the page. For example, if you ask a person question "D" and he or she gives you what you think is a correct response, then go ahead and write the person's name in box D. A correct response is important because later on, if you get bingo, that person will be asked to answer the question correctly in front of the group. If he or she can't answer the question correctly, then you lose bingo. So, if someone gives you an incorrect answer, ask someone else! Don't use your name for one of the boxes or use the same person's name twice.
- Try to fill all 16 boxes in the next 20 minutes. This will increase your chances of winning. After the 20 minutes are up, please sit down and I will begin asking players to stand up and give their names. Are there any questions? You'll now have 20 minutes. Go!
- During the next 20 minutes, move around the room to assist the players. Every five minutes or so tell the players how many minutes are remaining in the game. Give the players a warning when just a minute or two remains. When the 20 minutes are up, stop the players and ask them to be seated.

PART TWO: PLAYING BINGO

Give the class the following instructions to play the game:

- When I point to you, please stand up and in a LOUD and CLEAR voice give us your name. Now, if anyone has the name of the person I call on, put a big "X" in the box with that person's name. When you get four names in a row—across, down, or diagonally—shout "Bingo!" Then I'll ask you to come up front to verify your results.
- Let's start off with you (point to a player in the group). Please stand and give us your name. (Player gives name. Let's say the player's name was "Joe.") Okay, players, if any of you have Joe's name in one of your boxes, go ahead and put an "X" through that box.
- When the first player shouts "Bingo," ask him (or her) to come to the front of the room. Ask him to give his name. Then ask him to tell the group how his bingo run was made, e.g., down from A to M, across from E to H, and so on.

- Now you need to verify the bingo winner's results. Ask the bingo winner to call out the first person's name on his bingo run. That player then stands and the bingo winner asks him the question which he previously answered during the 20-minute session. For example, if the statement was "can name two renewable sources of energy," the player must now name two sources. If he can answer the question correctly, the bingo winner calls out the next person's name on his bingo run. However, if he does not answer the question correctly, the bingo winner does not have bingo after all and must sit down with the rest of the players. You should continue to point to players until another person yells "Bingo."

NUCLEAR ENERGY BINGO

ANSWERS

A. Knows the atomic mass of the uranium isotope used in nuclear power plants

B. Knows the name of the process that releases energy in a nuclear power plant

C. Knows the percentage of electricity produced by nuclear power in the U.S.

D. Knows how much CO_2 is produced by nuclear power plants

E. Can name at least one other use for nuclear energy

F. Has visited a nuclear power plant

G. Knows how many nuclear reactors are operating in the U.S.

H. Knows the country that generates the most electricity from nuclear power

I. Can name the country that generates the highest percentage of its electricity from nuclear energy

J. Knows where nuclear waste is currently stored in the U.S.

K. Can name something in our everyday lives that exposes us to radiation

L. Knows the name of the part of the nuclear power plant where thermal energy is released

M. Knows the atomic number of uranium

N. Knows what uranium is processed into for use as nuclear fuel

O. Knows the name of an acceptable on-site storage method for spent fuel

P. Can name at least one part of the nuclear fuel cycle

A U-235	**B** fission	**C** 19.89%	**D** 0
E weaponry medicine	**F** ask for location/description	**G** 99 reactors 61 plants	**H** U.S.
I France (78%)	**J** on-site at reactors	**K** air travel, foods, medical technologies, smoke alarms, ceramics, clocks, etc.	**L** reactor
M 92	**N** ceramic pellet	**O** spent fuel pool or dry storage cask	**P** mining, milling, refining, conversion, enrichment generation

Internet Resources

Many websites have interactive simulations of fission, decay, and models of nuclear power plants. Recommended sites include:

ALSOS Nuclear Database—Nuclear weapons and nuclear power have greatly influenced history from 1945 to the present. This digital library provides an annotated bibliography of over 2,700 books, articles, films, CDs, and websites about a broad range of nuclear issues, *http://alsos.wlu.edu*.

American Nuclear Society (ANS)—The American Nuclear Society is a not-for-profit, international, scientific, and educational organization. The core purpose of ANS is to promote the awareness and understanding of the application of nuclear science and technology, *www.ans.org*.

Council on Foreign Relations (CFR)—The CFR aims to be a resource to government officials, business executives, journalists, educators and students, civic and religious leaders, and other interested citizens to help them better understand the world and the foreign policy choices facing the United States and other countries, *www.cfr.org/energy-and-environment/nuclear-energy*.

Energy Information Administration (EIA)—The EIA keeps statistical data on nuclear production and consumption, and all of our other energy sources as well, *www.eia.gov*.

EIA Energy Kids Page—Energy information tailored for students, *www.eia.gov/kids*.

Environmental Protection Agency (EPA)—For more information about radiation and radon visit, *www.epa.gov*.

International Atomic Energy Agency (IAEA)—The IAEA works with its members and partners worldwide to promote safe, secure, and peaceful nuclear technologies, *www.iaea.org*.

The National Energy Education Development Project (NEED)—The Nuclear Energy Conference for Educators gathers interested educators and partners to learn more about nuclear energy in the U.S. This site houses industry information and presentations that can be informative, *www.NEED.org/nuclearmaterials*.

Nuclear Energy Institute (NEI)—The NEI is the policy organization for the nuclear technologies industry in the United States, *www.nei.org*.

Nuclear Regulatory Commission (NRC)—The NRC is the governing body overseeing the nuclear energy industry in the United States, *www.nrc.gov*.

Orano—A leading technology and services provider for decommissioning, used fuel management, site clean-up and closure, and the sale of uranium services. Orano USA is headquartered in Washington, D.C., *www.us.areva.com*.

United States Department of Energy, Office of Nuclear Energy—A division of the U.S. DOE, the Office of Nuclear Energy promotes nuclear power as a resource capable of meeting the nation's energy, environmental, and national security needs by resolving technical and regulatory barriers through research, development, and demonstration. Sites are specifically designed for teachers and students, *www.energy.gov/ne/office-nuclear-energy*.

U.S. Department of Energy (DOE)—For more information about energy sources you can visit the DOE site, *www.energy.gov*.

U.S. Department of Energy (DOE), *The Harnessed Atom*—This is a STEM curriculum geared towards middle school students, that may provide a great foundation for secondary students. Lessons and presentations can be downloaded for free in PDF format, *www.energy.gov/ne/information-resources/stem-resources.*

Nuclear Energy Assessment Answer Key

1. Label the Atom
   a. Energy level—(shells) where electrons orbit
   b. Nucleus—center of atom, composed of protons and neutrons, positively charged
   c. Proton—positively charged, mass of 1
   d. Neutron—no charge, mass of 1
   e. Electron—negatively charged particle, very small
2. Five Renewable Energy Sources: hydropower, biomass, wind, solar, geothermal
3. Five Nonrenewable Energy Sources: coal, petroleum, natural gas, uranium, propane
4. Answers may vary. Students may draw pictures of their model generator with coils of wire and magnets in motion.
5. Nuclear reactions may release: heat, light, alpha particles, beta particles, energy
6. Uranium must be enriched because less than 1% of natural uranium is U-235, but only U-235 can undergo fission. Uranium is enriched to bring the level of U-235 to 3-5% to create a sustained fission/chain reaction.
7. A moderator slows neutrons and controls the rate of the chain reaction. Moderators are graphite, purified natural (light) water, or heavy water.
8. Label the Nuclear Reactor
   a. Reactor—contains the fuel assembly, control rods, and water.
   b. Fuel Rods—contain uranium fuel that undergoes chain reaction.
   c. Pressurizer—in a pressurized water reactor, the pressurizer holds the water at a high pressure so that it doesn't boil.
   d. Containment Structure—an important security layer made of cement with a steel lining, designed to prevent leakage of radioactive gases, steam, and water into the atmosphere should a leak occur inside.
   e. Control Rods—contain boron or cadmium to absorb or capture neutrons, slowing or stopping the nuclear fission chain reaction.
9. Nuclear proliferation describes the spread of nuclear weapons, fissile materials, and nuclear technology. The Non-Proliferation Treaty was designed to help control proliferation. Uncontrolled nuclear proliferation is cause for concern when safeguards and peacekeeping are considered.
10. The biggest challenge with spent fuel in the U.S. is storage and disposal of high level waste.
11. Lessons from Nuclear Accidents
    a. Three Mile Island—safety designs are effective, but also led to additional improved safety features being implemented in nuclear plant designs
    b. Chernobyl—automatic plant safety features should not be turned off, secondary containment is important, improved training for operators is needed
    c. Fukushima—ensure back-up systems to cool reactors, modify hardware for use during emergencies, protect back-up generators and batteries
12. Safety Features (possible answers include): containment structure, training of operators/workforce, automatic shut down/control rods automatically drop, water in the containment structure, dual layers of containment structure and reactor vessel (cement and steel)
13. Historical Event—Answers will vary. Events may include the use of the atomic bomb in WWII, the first nuclear power reactor, the incidents at Chernobyl, Three Mile Island, and/or Fukushima.
14. Nuclear science has benefited society through nuclear medicine (x-rays, nuclear imaging, cancer treatments, etc.), smoke detectors, powers Navy vessels, food irradiation, etc.

Introduction to Energy

What is Energy?

Energy makes change; it does things for us. It moves cars along the road and boats over the water. It bakes a cake in the oven and keeps ice frozen in the freezer. It plays our favorite songs on the radio and lights our homes. Energy makes our bodies grow and allows our minds to think. Scientists define energy as the ability to do work.

Forms of Energy

Energy is found in different forms, such as light, heat, sound, and motion. There are many forms of energy, but they can all be put into two categories: potential and kinetic.

POTENTIAL ENERGY

Potential energy is stored energy or the energy of position, or gravitational energy. There are several forms of potential energy.

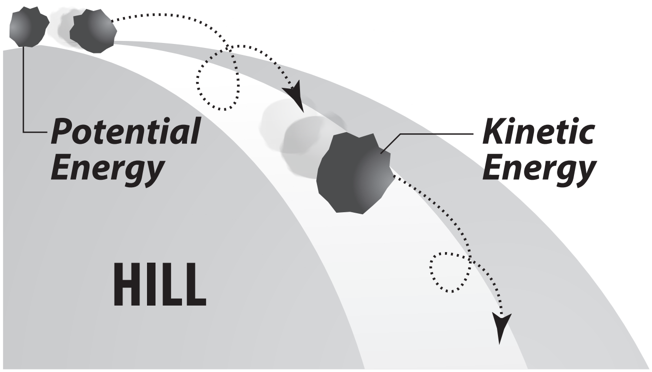
- **Chemical energy** is energy stored in the bonds of atoms and molecules. It is the energy that holds these particles together. Biomass, petroleum, natural gas, and propane are examples of stored chemical energy.
- **Elastic energy** is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of elastic energy.
- **Nuclear energy** is energy stored in the nucleus of an atom; it is the energy that holds the nucleus together. The energy can be released when the small nuclei are combined or large nuclei split apart. Nuclear power plants split the nuclei of uranium atoms in a process called **fission**. The sun combines the nuclei of hydrogen atoms in a process called **fusion**.
- **Gravitational potential energy** is the energy of position or place. A rock resting at the top of a hill contains gravitational potential energy. Hydropower, such as water in a reservoir behind a dam, is an example of gravitational potential energy.

KINETIC ENERGY

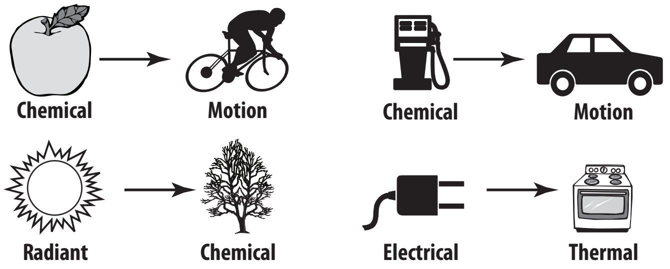
Kinetic energy is motion; it is the motion of waves, electrons, atoms, molecules, substances, and objects.

- **Electrical energy** is the movement of electrons. Everything is made of tiny particles called atoms. Atoms are made of even smaller particles called electrons, protons, and neutrons. Applying a force can make some of the electrons move. Electrons moving through a wire are called electricity. Lightning is another example of electrical energy.
- **Radiant energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Solar energy and light are examples of radiant energy.
- **Thermal energy**, or heat, is the internal energy in substances; it is the vibration and movement of the atoms and molecules within substances. The more thermal energy in a substance, the faster the atoms and molecules vibrate and move. Geothermal energy is an example of thermal energy.

Potential and Kinetic Energy



Energy Transformations



- **Motion energy** is the movement of objects and substances from one place to another. Objects and substances move when an unbalanced force is acting on them, according to Newton's Laws of Motion. Wind is an example of motion energy.
- **Sound energy** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate. The energy is transferred through the substance in a longitudinal wave.

Law of Conservation of Energy

The Law of Conservation of Energy is not about saving energy, like it may sound. This law states that energy is neither created nor destroyed. However, it can change from one form to another. Energy does not disappear, it is converted.

A car engine, for example, burns gasoline, converting the chemical energy in the gasoline into useful motion energy. Some of the energy is also converted into light, sound, and heat. Photovoltaic (solar) cells convert radiant energy into electrical energy. Energy changes form, but the total amount of energy in the universe remains the same.

Energy Efficiency

Energy efficiency is the amount of useful energy you get from a system. A perfect energy efficient machine would convert all of the energy put into it into useful work, which is technologically impossible at this time. Converting one form of energy into another form always involves a loss of usable energy—usually in the form of heat—from friction and other processes. This "waste heat'" dissipates quickly and is very difficult to recapture.

Typical coal-fired, natural gas, biomass, and nuclear power plants convert about 30 to 35 percent of the heat they produce into electricity. A hydropower plant, on the other hand, converts about 95 percent of the kinetic energy in the water flowing through the system into electricity. Most energy transformations are not very efficient. For example, a typical car converts only about 15 percent of the gasoline used into work. The human body is another example of a low efficiency "machine." Your body's fuel is food. Food gives you the energy to move, breathe, and think. Your body is very inefficient at converting food into useful work. Most of the energy in your body is released as heat.

Sources of Energy

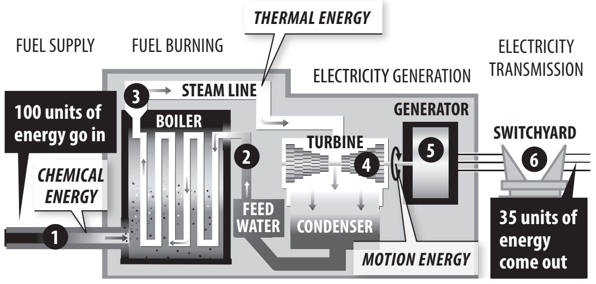
We use many different sources to meet our energy needs every day. They are usually classified into two groups—renewable and nonrenewable.

In the United States, most of our energy comes from **nonrenewable energy** sources. Coal, petroleum, natural gas, propane, and uranium are nonrenewable energy sources. They are used to make electricity, heat our homes, move our cars, and manufacture all kinds of products. These sources are called nonrenewable because their supplies are limited. Petroleum, for example, was formed hundreds of millions of years ago, before dinosaurs existed, from the remains of ancient sea plants and animals. **Fossil fuels**, like petroleum, cannot be made quickly.

Renewable energy sources include biomass, geothermal energy, hydropower, solar energy, and wind energy. They are called renewable because they are replenished in a short time. Day after day, the sun shines, the plants grow, the wind blows, and the rivers flow. We use renewable energy sources mainly to make electricity.

The energy sources discussed so far are known as primary sources. Electricity is known as a **secondary energy source** because it must be produced from a primary source. For example, the heat from burning coal, a primary energy source, produces steam, which turns turbines to generate electricity. Electricity is sometimes called an energy carrier because it is an efficient and safe way to move energy from one place to another, and it can be used for many tasks. As we use more technology, the demand for electricity grows.

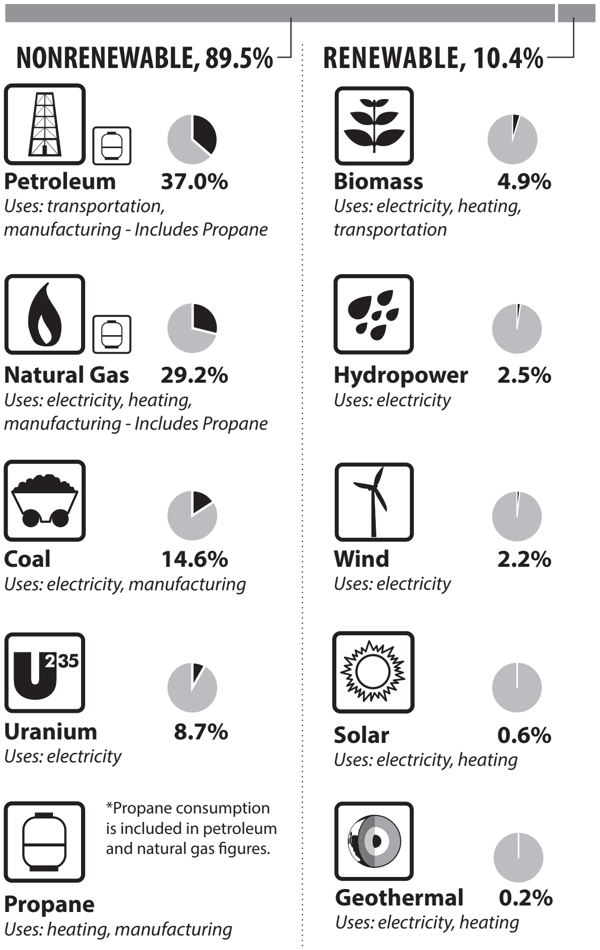
Efficiency of a Thermal Power Plant



How a Thermal Power Plant Works

1. Fuel is fed into a boiler, where it is burned to release thermal energy. Nuclear fuel is not burned, however.
2. Water is piped into the boiler and heated, turning it into steam.
3. The steam travels at high pressure through a steam line.
4. The high pressure steam turns a turbine, which spins a shaft.
5. Inside the generator, the shaft spins coils of copper wire inside a ring of magnets. This creates an electric field, producing electricity.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

U.S. Energy Consumption by Source, 2016



Data: Energy Information Administration
**Total does not equal 100% due to independent rounding.

Electricity

Electricity is moving electrons. What are electrons? They are tiny particles found in atoms. Everything in the universe is made of atoms—every star, every tree, and every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. Atoms are so small that millions of them would fit on the head of a pin.

Atomic Structure

Atoms are made of smaller particles. The center of an atom is called the **nucleus**. It is made of particles called **protons**, which carry a positive (+) charge, and **neutrons**, which carry no charge, that are approximately the same size. Nuclear energy is held within the nucleus and is a very strong force holding the protons and neutrons together.

Protons and neutrons are very small, but electrons are even smaller. **Electrons** carry a negative (-) charge and move around the nucleus in energy levels at different distances from the nucleus. If the nucleus were the size of a tennis ball, the atom would be the size of the Empire State Building. Atoms are mostly empty space.

If you could see an atom, it might look a little like a tiny center of spheres surrounded by giant invisible clouds (or energy levels). Electrons are found in these energy levels. Since protons have a positive charge and electrons have a negative charge, they are attracted to each other. This electrical force holds the electrons in their energy level. The energy level closest to the nucleus can hold up to two electrons. The next energy level can hold up to eight. Additional energy levels can hold more than eight electrons.

The electrons in the energy levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost energy level—the valence energy level—do not. These electrons, called **valence electrons**, easily leave their energy levels creating electricity. Other times, there is a strong attraction between valence electrons and the protons. Often, extra electrons from outside the atom are attracted and enter a valence energy level. Sometimes when the arrangement of electrons is changed, energy is gained or transformed. This energy from electrons is called electrical energy.

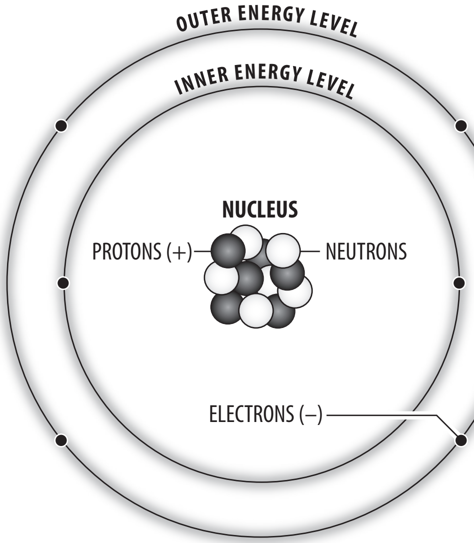
When an atom is neutral, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons help hold the nucleus together.

Elements

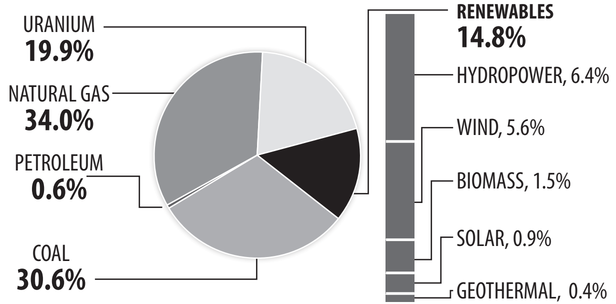
A substance whose atoms all have the same number of protons is called an element. The number of protons is given by an element's **atomic number**, which identifies elements. For example, all atoms of hydrogen have an atomic number of one and all atoms of carbon have an atomic number of six. This means that all hydrogen atoms contain one proton and that all carbon atoms contain six protons. An atom is measured by its **atomic mass**, based on its combined mass of protons, neutrons, and electrons.

Carbon Atom

A carbon atom has six protons and six neutrons in the nucleus, two electrons in the inner energy level, and four electrons in the outer energy level.



U.S. Electricity Production, 2016



Data: Energy Information Administration
*Total does not equal 100% due to independent rounding.

Isotopes

Atoms of the same element will always have the same number of protons. However, atoms of the same element can have a different number of neutrons and, therefore, a different mass. Atoms of a particular element with different numbers of neutrons are called **isotopes**. For example, there are three common isotopes of carbon. All of them have six protons. However, one type of carbon has six neutrons, one has seven neutrons, and the third has eight neutrons. Isotopes are identified by their approximate atomic masses given by the number of protons and neutrons added together. The carbon isotope that contains six protons and six neutrons is called carbon-12, the carbon isotope that contains six protons and seven neutrons is called carbon-13, and the carbon isotope that contains six protons and eight neutrons is called carbon-14. Not all isotopes are stable, but all desire to be. Unstable isotopes emit energy in order to become stable, and are called **radioactive**.

Nuclear Energy

Nuclear energy is the energy released from the nucleus of an atom when the number of protons and neutrons in a nucleus is changed to become stable. Neutrons colliding with the nuclei of uranium and plutonium atoms can split these atoms into smaller atoms under certain conditions. Splitting of the atoms is known as nuclear fission.

When nuclei undergo fission, energy is released in the form of thermal, kinetic, and radiant energy. This thermal energy can be harnessed and put to work. Along with the release of energy, neutrons are also released, creating a **chain reaction**.

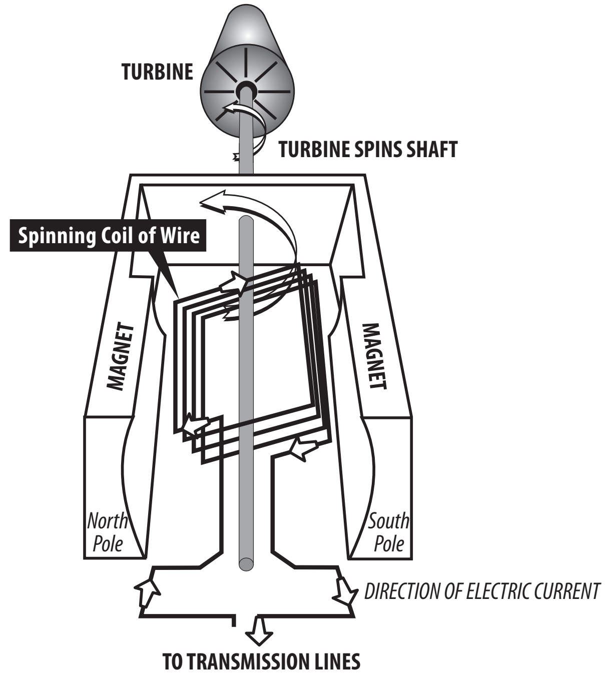
Uranium

Uranium is the heaviest of all naturally occurring elements. Uranium is an element that has three isotopes: uranium-238 with 92 protons and 146 neutrons, U-235 with 92 protons and 143 neutrons, and U-234 with 92 protons and 142 neutrons. Natural uranium consists of 99.28 percent U-238, 0.71 percent U-235, and 0.0054 percent U-234. This is important because it is the U-235 nuclei which splits, or fissions, to produce heat in a nuclear reactor. Uranium occurs in small concentrations in rocks, soil, and bodies of water. Uranium is 500 times more common than gold (Au) and about as plentiful as tin (Sn). Estimates vary, but most believe that there is enough uranium to last us hundreds, if not thousands, of years.

Electricity and Magnetism

The positive and negative charges within atoms and matter usually arrange themselves so that there is a neutral balance. However, sometimes there can be a buildup of charges creating more negative than positive charges, or more positive charges than negative charges. This imbalance produces an electric charge. Unlike electric current where electrons are moving, these electrons don't move until there is another object for them to move to. This is called **static electricity**. When the charges become too unbalanced there is a discharge of electrical energy between positively and negatively charged areas. This is what causes lightning to jump from cloud to cloud, or between a cloud and the ground.

Turbine Generator



Magnets

In most objects the molecules that make up the substance have atoms with electrons that spin in random directions. They are scattered evenly throughout the object. Magnets are different—they are made of molecules that have north- and south-seeking poles.

The molecules in a magnet are arranged so that most of the north-seeking poles point in one direction and most of the south-seeking poles point in the other.

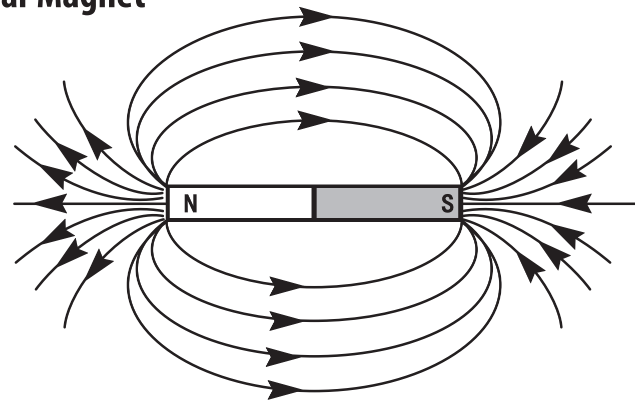
Spinning electrons create small magnetic fields and act like microscopic magnets or micro-magnets. In most objects, the electrons located around the nucleus of the atoms spin in random directions throughout the object. This means the micro-magnets all point in random directions cancelling out their magnetic fields. Magnets are different—most of the atoms' electrons spin in the same direction, which means the north- and south-seeking poles of the micro-magnets they create are aligned. Each micro-magnet works together to give the magnet itself a north- and south-seeking pole.

Electromagnetism

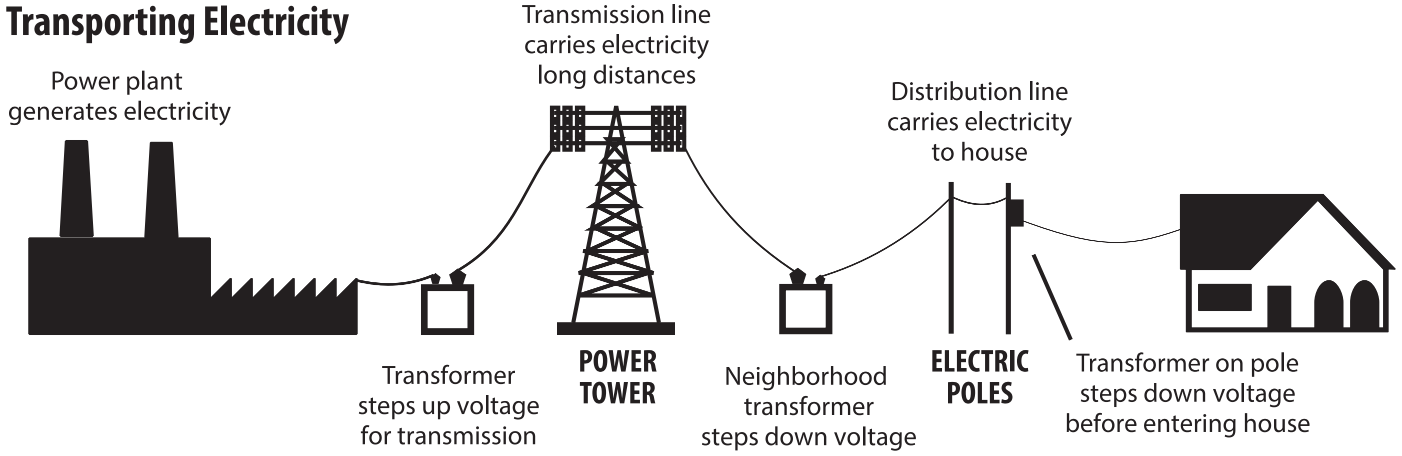
A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called electromagnetism. A changing magnetic field can produce electricity. Every time there is a change in a magnetic field, an electric field is produced. Every time there is a change in an electric field, a magnetic field is produced. We can use this relationship to produce electricity. Some metals, such as copper, have electrons that are loosely held. They can be pushed from their valence levels by the application of a magnetic field. If a coil of copper wire is moved in a magnetic field, or if magnets are moved around a coil of copper wire, an electric current is generated in the wire.

Electric current can also be used to produce magnets. Around every current-carrying wire is a magnetic field, created by the uniform motion of electrons in the wire. Magnets used to produce electric currents are called electromagnets.

Bar Magnet



Transporting Electricity



Generating Electricity

When it comes to the commercial production of electricity, it's all about turbines and generators. A turbine is a device that converts the flow of a fluid such as air, steam, or water into motion or mechanical energy to power a generator. A generator converts motion or mechanical energy into electrical energy using electromagnetism.

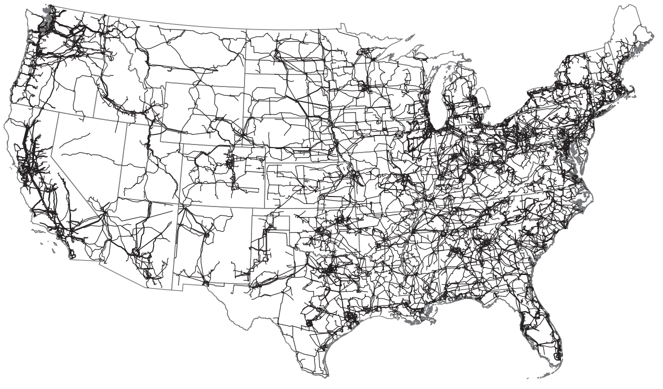
An electric generator is actually an electric motor that runs backward. Work is done to cause magnets to spin within coils of wire to produce electricity. Depending on the generator's design, work can also cause the wires to move. When the wire moves through the external magnetic field, electrons in the wire are pulled and move through the wire. These electrons can be directed out of the generator as electricity.

Although electric motors and generators may seem complicated, the principle of electromagnetism is simple. When electricity moves through a wire, a magnetic field is created around the wire. In an electric motor, the motor's wire is placed between external magnets. When electricity is sent through the wire, the magnetic field created around the wire interacts with the magnetic field of the external magnets. This interaction causes the wire to move. If the wire is designed so it is free to turn, the wire will spin and you have an electric motor.

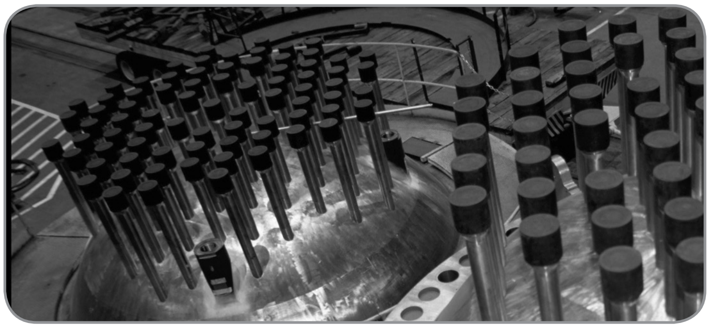
Power plants use huge turbine generators to generate the electricity that we use in our homes and businesses. Different types of power plants use different fuels to change water into steam. Power plants can burn coal, oil, biomass, or natural gas to heat water into high-pressure steam, which is used to spin the turbines. Splitting uranium atoms in a nuclear power plant can also produce the thermal energy needed to generate steam.

Once the electricity is produced, it is moved to our homes and businesses. It moves through large electrical lines. Electricity moves most efficiently under high voltage. When the electricity leaves the power plant, its voltage must be drastically increased. When it reaches our homes and businesses, the voltage must be reduced so it will not burn up or damage things that use the electricity. The voltage of electricity is easily increased or decreased by a transformer. Transformers are commonly seen in our neighborhoods. Electrical substations are a series of transformers used to increase or decrease voltage. If you have an overhead electrical line that goes into your house, you will see a transformer on the pole where the overhead line leaves the larger power line. Usually, these overhead transformers are grey cylinders or boxes. They reduce the voltage so that the electricity can safely enter your house.

The Continental U.S. Electric Grid



NUCLEAR REACTOR



Generating Electricity With Nuclear Energy

Just like burning coal and natural gas, thermal energy from nuclear reactions can be used to heat water and create steam to turn the blades of a turbine. The motion of the turbine turns a generator and makes electricity that we use to power our homes, businesses, and schools. A nuclear power plant uses the heat from controlled fission of uranium atoms to produce steam to turn the turbine. None of the fuel is burned.

History of Nuclear Energy

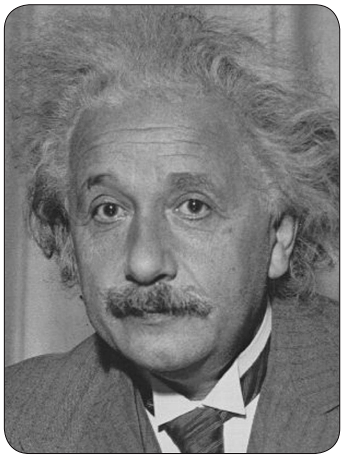
Nuclear reactions have occurred in the Earth's crust since the beginning of time. However, man's working knowledge of nuclear energy occupies a very small portion of Earth's history. This knowledge was started by a chain of events beginning in 1895 with the experiments of German physicist Wilhelm Roentgen. He was working with gas discharge tubes and discovered that the tubes caused certain materials to glow in the dark. Shadows of the bones of his fingers were recorded on cardboard coated with the element barium. He named the energy given off by these gas discharge tubes x-rays.

In 1896, Henri Becquerel, a French scientist, accidentally discovered that a uranium compound left in the dark near a photographic plate produced an image on the plate. Marie Curie, a student of Becquerel's, and her husband Pierre, a professor of physics, continued to investigate these emissions from uranium and named them **radioactivity**. Two years later, the Curies announced that they had discovered two radioactive elements in the ore **pitchblende**, polonium (named for Marie Curie's native country of Poland), and radium.

Scientific work related to radioactivity continued throughout the early to middle twentieth century. In England, Ernest Rutherford identified two different types of radiation given off by uranium atoms, alpha rays and beta rays (streams of alpha and beta particles). Rutherford's experiments with radiation showed that a radioactive element changes into a different element when it gives off energy. This change in an element is called **transmutation**. Other significant events included the discovery of the electron by J. J. Thompson and Rutherford's observation that almost all of the mass and all of the positive charge of an atom were contained in its tiny nucleus. The general structure of an atom containing protons and neutrons in the nucleus and electrons outside the nucleus was completed in 1932 with the discovery of the neutron by James Chadwick.

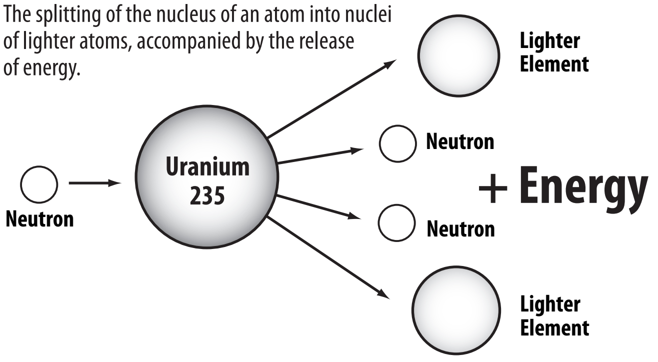
MARIE CURIE

ALBERT EINSTEIN



Fission

The splitting of the nucleus of an atom into nuclei of lighter atoms, accompanied by the release of energy.



In 1905, Albert Einstein suggested that mass and energy are interchangeable. According to his theory, when the mass of a substance increases, its amount of energy decreases; when the mass of a substance decreases, its amount of energy increases. The relationship between the mass and energy of matter is calculated by the equation $E = mc^2$. It took over thirty years for scientists to prove Einstein's theory correct, but this led to the understanding that energy could be released from radioactive materials.

In 1938 two German chemists, Otto Hahn and Fritz Strassmann, found that when uranium was bombarded with neutrons, the element barium (a much lighter element) was produced. An Austrian physicist, Lise Meitner, and her nephew, Otto Frisch, first explained nuclear fission, a process in which the nucleus splits into two nuclei of approximately equal masses. Using Einstein's equation, they calculated that this fission released a tremendous amount of energy. Immediately, the world's scientific community recognized the importance of the discovery. With the coming of World War II, the race was on to see which nation could unleash the power of the atom and create the most powerful weapon ever imagined.

The first controlled nuclear fission occurred in 1941 at the University of Chicago under the guidance of Leo Szilard and Enrico Fermi. Graphite blocks (a "pile" of graphite) were stacked on the floor of the Stagg Field squash court. Natural uranium was inserted among the graphite blocks. Using natural uranium, the scientists were able to produce the first controlled nuclear chain reaction. A chain reaction requires the correct amount of nuclear fuel, **critical mass**, to keep the reaction going, neutrons of the proper speed (energy), and a way to control the number of neutrons available for fission. The first large scale reactors were then built in 1944 in Hanford, Washington, to produce plutonium for nuclear weapons.

On July 16, 1945, all of the theory about nuclear energy became reality. The first release of nuclear energy from an atom bomb occurred with the Trinity Test in south central New Mexico. The explosion was dramatic and demonstrated the huge amounts of

THE ENOLA GAY

energy stored in uranium. Enough nuclear fuel for two more atomic bombs was available. The bombs were immediately shipped to the Pacific for use against Japan. Many scientists and U.S. politicians hoped the bombs would end World War II without requiring an invasion of the islands of Japan.

On August 6, 1945, the B-29 Enola Gay took off from its airbase on the small Pacific island, Tinian. The bomber carried and dropped a uranium atomic bomb that exploded 1900 feet above the city of Hiroshima, Japan. Hiroshima was a city of 300,000 civilians and an important military center for Japan. The effects of the bomb were devastating. People and animals closest to the explosion died instantly, and nearly every structure within one mile of ground zero was destroyed. Fires started and consumed the city. Those who survived the initial blast were injured or later died from effects of the radiation. In the end, about half of the city's population was dead or injured.

Japan was asked to surrender immediately after the Hiroshima explosion, but chose not to do so. So, on August 9, 1945, a plutonium atomic bomb was dropped on the industrial city of Nagasaki with results similar to those of Hiroshima. On August 10, some in the Japanese government started the process of surrender. On August 14th Japan's surrender was officially declared, and was accepted by the United States and allies on August 15, 1945. The tremendous energy inside the tiny nucleus of the atom helped end the worst war in history.

Although at the end of World War II nuclear energy was seen as very destructive, scientists started work to harness and use nuclear energy for peaceful purposes. The first use of nuclear power to generate electricity occurred in December 1951 at a reactor in Idaho. In 1954, a nuclear reactor in Obninsk, Russia, was the first connected to an electricity grid. The Nautilus, the world's first submarine powered by a nuclear reactor, was placed into service by the U.S. Navy in 1954. In 1957, the first commercial nuclear reactor to produce electricity went on-line at Shippingport, Pennsylvania. Other nuclear plants of different designs soon followed.

In 1946 the Atomic Energy Commission (AEC) was the first agency assigned the task of regulating nuclear activity. In 1974 the AEC was replaced by the **Nuclear Regulatory Commission (NRC)**, which was established by Congress as part of the Energy Reorganization Act. The NRC's primary responsibility is to protect public health and safety. To accomplish this, the NRC has oversight of reactor and materials safety, waste management, license renewal of existing reactors, materials licensing, and the evaluation of new nuclear power plant applications.

Lise Meitner

Lise Meitner was head of physics at the Keiser Wilhelm Institute in Germany and worked closely with radiochemist, Otto Hahn. When Nazis came to power in 1933, many Jewish scientists left.

Meitner, who was Jewish by birth, stayed to continue her work at the Institute. In 1938 she was forced to move to Sweden for her safety.

Meitner and Hahn continued corresponding about their research. Hahn wrote to Meitner perplexed that bombarding a uranium nucleus produced barium. Meitner discussed Hahn's findings with her nephew, Otto Frisch. They interpreted Hahn and Strassmann's results as nuclear fission, explaining that a large amount of energy is released when the nucleus splits.

Meitner was offered a position working on the Manhattan Project, but refused to be a part in the making of a bomb. In 1944, without acknowledgement of Meitner's work, Hahn was awarded the Nobel Prize for Chemistry for the discovery of nuclear fission.

USS RONALD REAGAN

Nuclear-powered ships and submarines are used worldwide.

As of 2016, 99 nuclear reactors are operating in the United States, with two new reactors currently under construction in Georgia. Over 400 nuclear reactors are generating power throughout the world. Following the Fukushima Daiichi incident in Japan in 2011 (see page 36), several countries have voted to scale back or phase out nuclear generation in the coming years. These countries include Germany, Switzerland, and Italy. After the Fukushima Daiichi incident, Japan had made the descision to halt nuclear power generation. In 2014 no power was produced by nuclear. However in 2015, Japan began opening nuclear facilities for power generation, with 42 reactors currently operational.

Despite the success of peaceful uses of nuclear energy, some remain hesitant about increasing usage of nuclear energy. This is due to its potential to be used in non-peaceful ways, often called **nuclear proliferation**.

Nuclear Fuel Cycle

Energy used to generate electricity in a nuclear power plant is released by a process called fission. Fission does not occur on its own. In order to harness the energy that is released during fission, uranium has to be mined, milled, refined, converted, enriched (for fueling most commercial reactors), and manufactured into fuel. After the fuel has been used it can be reprocessed to make new fuel or safely stored as spent (used) fuel, which is highly radioactive. Reprocessing the spent fuel also generates radioactive waste that requires safe storage. This whole process is known as the **nuclear fuel cycle**. The first four steps are referred to as the "front end" and the last two steps are referred to as the "back end."

URANIUM ORE

Front End

Mining and Milling

There are three different methods used to mine uranium ore. If the ore lies close to the Earth's surface, it is removed by open pit mining. Ore that is deep in the ground is removed by deep mining methods. The third way to retrieve uranium is by "in situ" methods, where chemicals are pumped into the ground dissolving the ore. The chemical-ore mixture is then pumped to the surface. Whichever method is used, the ore is moved to a mill for processing.

At the mill, the ore is crushed and treated with an acid solution that separates the uranium from the rock and other waste materials. If in situ mining is used, the uranium is already dissolved in solution called a slurry. The solution is then separated from its surrounding rock and waste materials. The solution undergoes further chemical treatments to separate the uranium. Uranium is collected and dried as **uranium oxide (U_3O_8)** concentrate. The concentrate is a bright yellow powder and is called **yellowcake**. The yellowcake is then packaged in steel drums and transported to conversion plants.

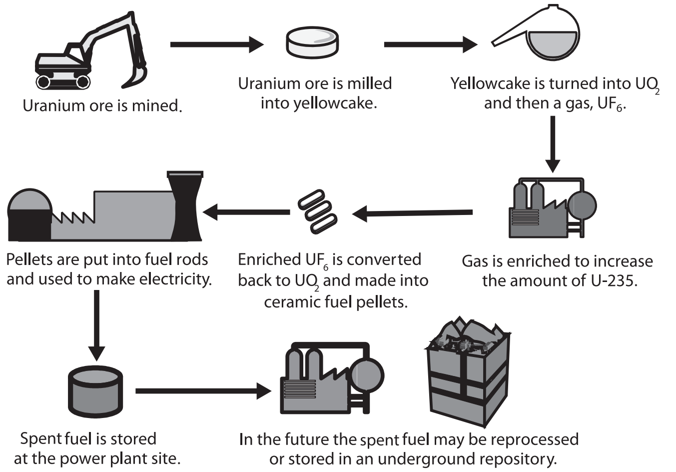
Refining and Conversion

During this step, the solid yellowcake is first refined into **uranium dioxide (UO_2)**. Next, it is converted into a gas, **uranium hexafluoride (UF_6)**. Below 60°C (140°F) UF_6 is a solid compound. When temperatures near 60°C UF_6 turns into a gas, allowing impurities to be removed. The gas is then turned back into a solid so it can be shipped to the enrichment plant.

Enrichment

Over 99% of the solid uranium received at the enrichment plant is mostly U-238 with small amounts of U-235 mixed in. Since only the U-235 undergoes fission in a reactor, its concentration must be increased. UF_6 is converted back into a gas where it goes through gas diffusion or centrifugation for enrichment. The enrichment process separates the lighter U-235 from the U-238. This increases the concentration of U-235 from 0.7 percent to three to five percent required for reactor fuel. The enriched fuel is reconverted into enriched uranium dioxide (UO_2) in the form of a black powder.

Uranium Fuel Cycle



URANIUM FUEL PELLET

Fuel Manufacturing

During fuel manufacturing, the UO_2 is pressed into small cylindrical shapes, and baked at a very high temperature (1,600-1,700 degrees Celsius). This baking turns the UO_2 into ceramic pellets that are about the size of a pencil eraser, called **fuel pellets**. Approximately 300 pellets are then placed into **fuel rods** and sealed. Fuel rods are bundled into fuel assemblies of 179-264 rods.

▪ Reasons for Refining, Conversion, and Enrichment

Only the U-235 nucleus has a high likelihood to go through fission under normal conditions in a reactor. The likelihood of fission depends mainly on four factors: the concentration of fissionable U-235, the number of neutrons in the reactor, the speed of those neutrons, and the concentration of materials such as U-238 that absorb neutrons without usually resulting in fission.

Think of the materials in the reactor core as competing for neutrons. If too few U-235 atoms absorb neutrons or too many U-238 atoms absorb neutrons, the chain reaction stops and energy production grinds to a halt. Slower neutrons generally are more likely to be absorbed by U-235 and cause fission. These slow neutrons are often called "thermal" neutrons because their kinetic energy is typical of the kinetic energy of atoms moving at room temperatures.

A **thermal reactor** uses materials to slow down or moderate the speeds of neutrons. A typical moderator is water. Ordinary water, also called **light water**, slows the neutrons down so they are more likely to cause the fission of a neighboring U-235 atom. However, the concentration of U-235 must be increased to between three percent and five percent for use as fuel in a thermal light water reactor to sustain the chain reaction. All U.S. commercial reactors are thermal light water reactors and require **enriched uranium**. Another type of thermal reactor that uses **heavy water** does not require uranium enrichment because the heavy water, which consists of a heavier isotope of hydrogen, is even better at moderating or slowing down the electrons. This increases the cross-section for the neutron, making it even more likely to fission another U-235 atom. Thus, natural uranium fuel that has not been enriched can be used in a thermal heavy water reactor. Canada and India use many of these reactors.

Back End

Open and Closed Cycles

After the ceramic pellets are used to generate electricity there are two possibilities of how to complete the nuclear fuel cycle. In the United States we have an "open cycle." After being used once the used or **spent fuel** is put into long term storage at the reactor site.

Some countries, including France, use a "closed cycle" where used nuclear fuel is reprocessed. The nuclear materials are separated and reusable materials are recycled into new fuel pellets. More detailed information about these two options is found on page 33.

Nuclear Power Plants

The center of a nuclear power plant is the nuclear reactor. Inside the reactor is where fission takes place. The purpose of the reactor is to create favorable conditions for a controlled chain reaction. If fission is not monitored carefully, an uncontrolled chain reaction could result in a nuclear explosion or **meltdown**. Safety is the top priority at nuclear power plants.

There are two common types of thermal reactors: a **boiling water reactor** (BWR) and a **pressurized water reactor** (PWR). They both have many of the same parts and safety features:

Containment Structure

This is a thick-walled concrete and steel building designed to prevent radioactive gases, steam, and water from entering the environment should a leak occur.

Reactor Vessel

This holds the nuclear reactor and is dual-layered with a thick steel wall so radioactive gases and liquids are contained in the vessel should a crack occur in one of the layers.

REACTOR VESSEL

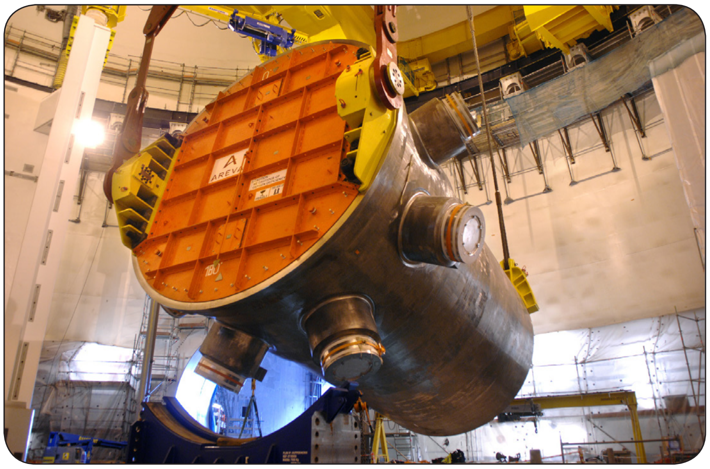
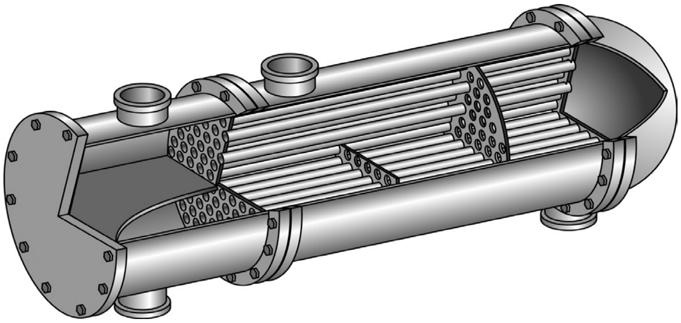


Image courtesy of Areva

Installation of the reactor pressure vessel at the Olkiluoto Nuclear Plant in Finland.

Heat Exchanger



Fuel and Fuel Rods

These rods are filled with the UO_2 pellets that have already been enriched (nuclear fuel). The fuel rods isolate the fuel from the water in the reactor vessel.

Control Rods

Control rods usually contain boron, silver, or cadmium, elements that absorb or capture neutrons to slow or stop the nuclear fission chain reaction. The control rods move up and down among the fuel rods, increasing or decreasing the number of neutrons exposed to the fuel in order to control the chain reaction and the fission process.

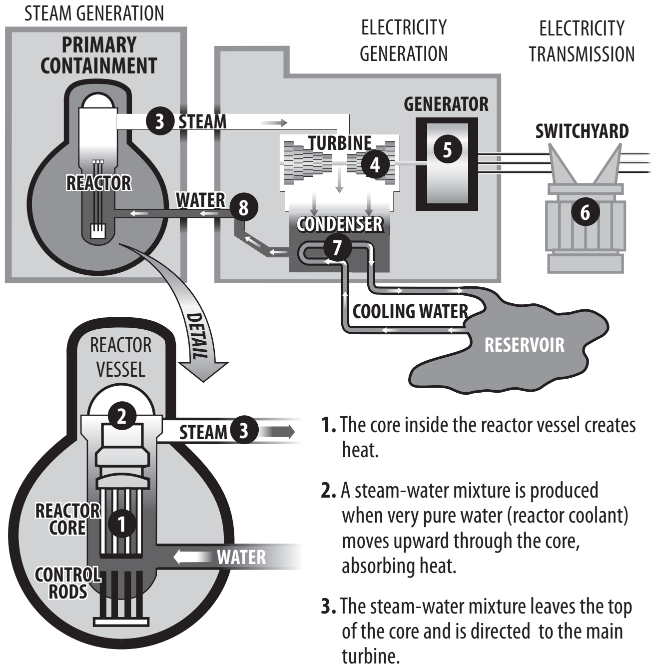
Moderator

Moderators are substances that slow down neutrons so that a chain reaction can be maintained. The moderator is usually purified natural water or heavy water (**deuterium oxide**). Graphite, a form of carbon, can also be used as a moderator. Unlike graphite in school pencil "leads," nuclear-grade graphite is almost pure carbon. Graphite reactors are not used in the U.S., but are used in Russia and the United Kingdom.

Heat Exchange System

A nuclear plant's thermal energy is used to make steam and generate electricity. The steam carries energy from the reactor vessel to the turbines. After the steam turns the turbines, it is condensed back into water and returned to the reactor vessel. This is done by the heat exchange systems, or **heat exchanger**.

Boiling Water Reactor



1. The core inside the reactor vessel creates heat.

2. A steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat.

3. The steam-water mixture leaves the top of the core and is directed to the main turbine.

4. The high pressure steam turns a turbine, which spins a shaft.

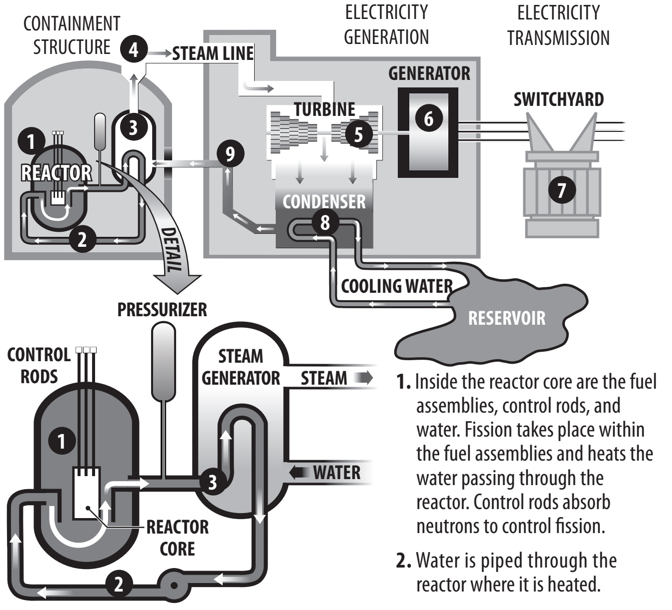
5. Inside the generator, the shaft spins coils of copper wire inside a ring of electromagnets. This creates an electric field, producing electricity.

6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

7. The unused steam continues into the condenser where cool water from the environment (river, ocean, lake, reservoir) is used to condense it back into water. The cooling water never comes in direct contact with the steam, so it is safe to return to the environment.

8. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the reactor vessel.

Pressurized Water Reactor



1. Inside the reactor core are the fuel assemblies, control rods, and water. Fission takes place within the fuel assemblies and heats the water passing through the reactor. Control rods absorb neutrons to control fission.

2. Water is piped through the reactor where it is heated.

3. It then travels to the steam generator where it heats a secondary system of water.

4. The steam generator keeps the steam at a high pressure. The steam travels through a steam line to the turbine.

5. The high pressure steam turns the turbine as it passes through, which spins a shaft. The steam then travels through the condenser where it is condensed by cooling water and is pumped back into the steam generator to repeat its cycle.

6. The turbine spins a shaft, which travels into the generator. Inside the generator, the shaft spins coils of copper wire inside a ring of magnets. This generates electricity.

7. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

8. The unused steam continues into the condenser where cool water from the environment (river, ocean, lake, reservoir) is used to condense it back into water. The cooling water never comes in direct contact with the steam, so it is safe to return to the environment.

9. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the reactor vessel.

Production

How a Nuclear Reactor Works

In a BWR the water flows through a single, primary loop from the reactor core to the turbine. In this system, water in the reactor core comes into contact with the fuel rods. As the water is heated by nuclear fission, it changes to steam.

The steam then flows out of the reactor to the turbines. The steam turns the turbines of the generator to produce electricity. At the generator, there is an outside system that uses water from the environment (river, ocean, lake, reservoir) to condense the steam in the primary loop back into water.

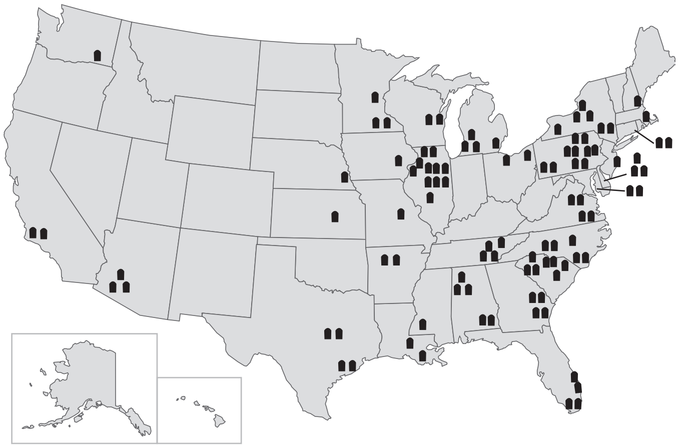
Water in the primary loop is then pumped back into the reactor vessel where the cycle is repeated. Impurities in the water in the primary system can absorb radiation from the reactor and may become radioactive. Water in the **external system** does not come into contact with the reactor vessel or water in the **primary system**. Thus, it is not radioactive and can be returned to the environment after use.

The PWR is the most popular commercial reactor type worldwide. Unlike a BWR, a PWR has primary, secondary, and external heat exchange systems, or loops. In the primary loop, heated water from around the reactor is sent to a steam generator or heat exchanger. (A pressurizer prevents the water in the primary loop from boiling.) Here, thermal energy is transferred from the reactor water to a separate **secondary system**, which includes a water and steam mixture. The water from the primary loop does not physically mix with water and steam in the steam generator. The steam in the secondary system flows into the turbine where it turns the generator and generates electricity. This steam is then condensed by water from the external loop before it returns to the steam generator where it is heated and repeats the cycle.

The BWR and the PWR both use an external source of cooling water to transfer waste heat to the environment. Generally, there are two methods for accomplishing this transfer of thermal energy. If the reactor is located on a large body of water, the warm coolant water can be pumped from the plant into the body of water. The warm water is replaced by cool water from the outside water supply. However, as this heat is released, the temperature of the body of water increases. This temperature increase is closely monitored to make sure the increase does not exceed regulated limits. This system is similar to those of many fossil fuel fired generating plants that also transfer heat from the power plant into an external body of water.

The second method of energy transfer involves releasing thermal energy from the external cooling system into the atmosphere. This is usually done using a **cooling tower** where air flows past the warm water in the coolant water. The air evaporates some of the water, which leaves the cooling towers as vapor. This evaporation cools the remaining water, which is condensed and returned to the plant to be reheated and converted to steam in the heat exchanger. Cooling towers are designed to maximize the draft of air they create. Usually the cooling towers are concave shaped and are the most visible feature of many nuclear plants and other power plants. They release only water vapor or steam into the atmosphere. They do not release radiation or emissions as is sometimes thought.

U.S. Nuclear Power Reactors, 2016



Data: Energy Information Administration

Additional Safeguards in a Nuclear Power Plant

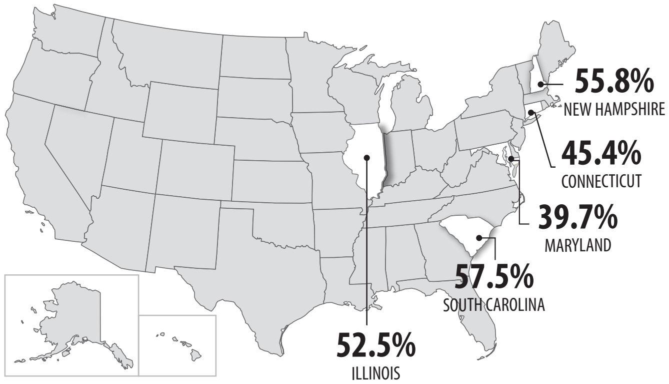
Generally, there are two classes of newer nuclear reactor designs, **evolutionary** and **passive**. Evolutionary reactors are those that have the same basic design as pre-1990s reactors but have improved safety systems. The safety systems are larger with more cooling capacity, more dependable with increased back-up systems, more controlled by the latest technology that monitors and controls the safety systems, and are more easily maintained and upgraded.

Passive reactors are designed so that safety systems operate automatically, and are powered by gravity or natural air circulation. These systems are designed to minimize the chance for operator error. Passive safety systems contain no moving parts, and if valves are needed, the valves are air or battery-operated. In either case, no electricity is needed for valve operations, and thus a loss of electricity does not affect the valves and the safety system. New safety designs place large amounts of emergency coolant (water) inside the containment shell above the reactor vessel. In the event of an accident, coolant above the reactor vessel is released and floods the reactor core with water.

Earlier designs place the emergency cooling system outside the containment building. In these designs, pumps and back-up electricity sources are needed to move emergency coolant into the reactor. In later-design reactors, emergency coolant and air circulates by natural convection to remove built-up thermal energy by natural convection. Again, pumps and fans are not needed and back-up electrical systems are not required.

No matter what type of safety systems are in place, it is still necessary for strict Nuclear Regulatory Commission procedures to be followed and inspections carried out as required.

States with the Largest Percentage of Electricity Generated by Nuclear Energy, 2016



Data: Energy Information Administration

Nuclear Fuel and Nuclear Proliferation

Spent Fuel Options

Radioactive Waste Handling and Storage-Open Cycle

A typical thermal reactor fuel assembly remains in the reactor for three years. Reactors are typically shut down for one month out of every 18 months for refueling and maintenance. Approximately one-third of the fuel assemblies are removed and replaced with fresh fuel assemblies. The level of radioactivity of spent fuel is initially extremely high due to the products of U-235 fission and the radioactive **transuranic** elements (elements with atomic numbers greater than 92) resulting from the absorption of neutrons by U-238. The spent fuel is placed in pools of water near the reactor to allow both the radioactivity and heat to decrease. After approximately five years, the fuel can be removed from the pools and placed in secure containers known as dry casks for intermediate storage.

The storage of spent fuel presents a challenge for which a long term solution has yet to be determined. Currently, all nuclear spent fuel in the United States is stored in water-filled pools or in dry storage casks on site at nuclear power plants. In 1987, the U.S. Congress chose Yucca Mountain in southwest Nevada as the site for long term high-level waste storage. (Nuclear spent fuel is considered high-level waste.) Yucca Mountain is considered geologically stable and an example of an area where radioactive material can be stored deep underground and security can be maintained.

In 2010, the U.S. Department of Energy filed a motion to withdraw the license application for a high-level waste geological repository at Yucca Mountain. The Blue Ribbon Commission on America's Nuclear Future was formed to review nuclear spent fuel management policies and made recommendations for future management of nuclear spent fuel to the Secretary of Energy. The United States has not developed plans for another repository site. Currently there are no countries with an operational disposal facility, although France, Finland, and Sweden are considering development by the year 2025.

Reprocessing Used Fuel

Closed Cycle

Reprocessing spent fuel uses chemistry to separate the uranium and plutonium from the other components of the fuel. The extracted uranium-238 is recycled once to produce additional reactor fuel. The plutonium can be mixed with enriched uranium to produce metal oxide (MO_x) reactor fuel for both thermal and fast neutron reactors. The small amount of remaining high-level radioactive waste can be stored in liquid form and solidified in glass for permanent storage. While reprocessing recovers uranium and plutonium for use as additional nuclear fuel and reduces the mass of waste to be managed, it also produces waste that is both radioactive and chemically toxic.

USED FUEL POOL

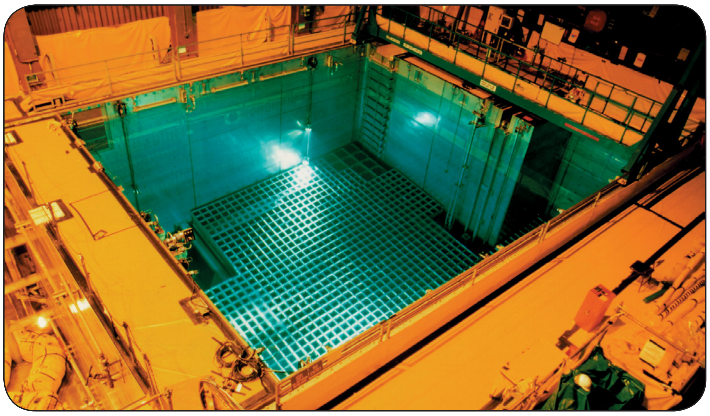


Image courtesy of NRC

After it has been used in a reactor, fuel is placed in pools to allow the radioactivity and heat to decrease.

CONTAINMENT BUILDING

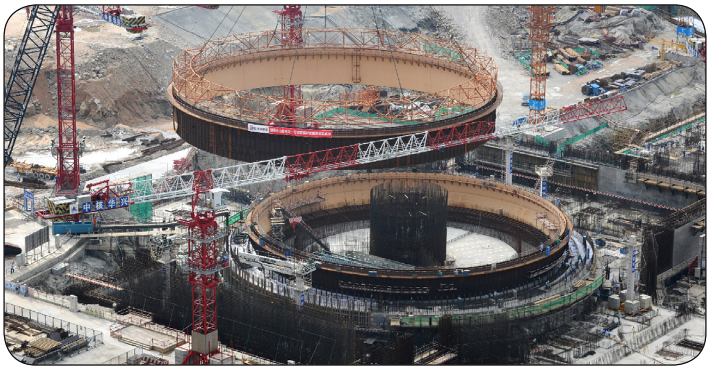


Image courtesy of Areva

Taishan 1 construction site in China. The construction team is lifting the second ring of the containment liner.

Nuclear Proliferation and Its Risks

While many countries have desired nuclear weapons, only a few are currently known to possess them (the United States, Russia, France, the United Kingdom, China, India, Pakistan, and North Korea). There are many international concerns about nuclear weapons falling into the hands of terrorists and "rogue" states. Controlling the proliferation of nuclear weapons materials and technology involves political, financial, and technical solutions.

Beginning with the use of the first nuclear weapons on Japan, the spread of nuclear weapons (proliferation) has been a global concern. To combat this concern the "Atoms for Peace" agency, known as the International Atomic Energy Agency was formed in 1959. The IAEA works closely with the United Nations (UN) but is a separate organization. Its job is to inspect and verify that nuclear materials in countries around the world are used for peaceful purposes. They also help countries upgrade nuclear safety and security, and help countries develop peaceful uses for nuclear science and technology.

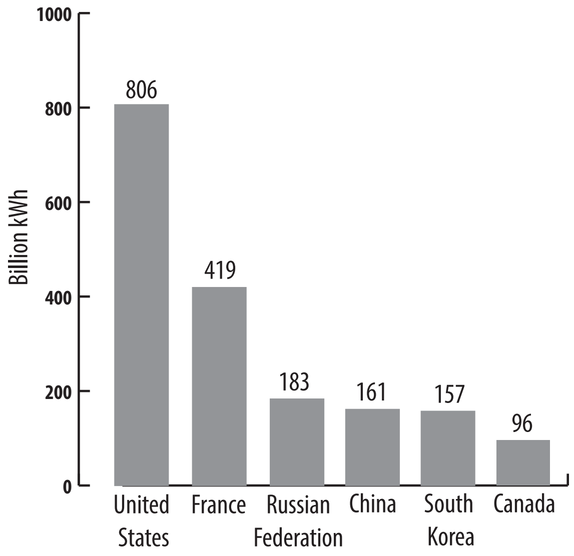
Further prevention of the use of nuclear materials for military purposes was accomplished by the United States and the Soviet Union. In 1968, acting through the United Nations, these two countries wrote the **Non-Proliferation Treaty** (NPT). Article IV of the NPT, declares that a state (country) has the "right" to peaceful nuclear technologies as long as the state maintains safeguards on its peaceful nuclear program and does not manufacture nuclear explosives. Some non-nuclear weapon countries such as Argentina, Brazil, and Japan, have pursued enrichment or reprocessing or both, and have maintained safeguards on these programs.

In 2015, a plan was created to monitor the Islamic Republic of Iran to be sure their nuclear energy program can continue, while prohibiting enrichment, and research and development related to **plutonium**. Sometimes, plans like this are organized by groups of countries to ensure global security. Under this plan, Iran will be monitored for fifteen years, however the U.S. has opted to not support this plan, as of 2018.

A country desiring a large nuclear power program may still want to enrich and reprocess fuel so that it can operate nuclear plants. Generally, if a country has fewer than eight nuclear plants, it is not economically sound for that country to make its own nuclear fuel. In this case, a group of countries could become partners to make fuel. This means that nuclear fuel making activities would take place in each of the partnership countries. Each of the partner countries would have access to the nuclear facilities of the other countries. This should mean that the proliferation risk is reduced because more than one country would be involved in those activities, and each country would monitor its partners.

Whether partner countries watch over each other or agencies like the UN use outside inspectors to watch over some countries, openness and accountability are the keys to preventing proliferation of nuclear materials.

Top Nuclear Energy Generating Countries, 2015



Data: Energy Information Administration

Image courtesy NRC

Routine inspections at nuclear power plants are important.

Nuclear Accidents

Three events that have influenced people's perception of nuclear energy are the accidents at Three Mile Island in Pennsylvania, Chernobyl in the Ukraine (former Soviet Union), and Fukushima in Japan.

Three Mile Island

In 1979 there was an accident at the Three Mile Island (TMI) reactor. In the morning, feed-water pumps that moved coolant into one of the reactors stopped running. As designed, the turbine and reactor automatically shut down, but an automatic valve that should have closed after relieving pressure inside of the reactor stayed open. This caused coolant to flow out of the reactor and the reactor overheated, and the nuclear fuel started to melt. By evening, the reactor core was stabilized. Over the next few days there were additional dilemmas, including the release of some radioactive gas into the atmosphere, which led to a voluntary evacuation of pregnant women and pre-school aged children who lived within a five mile radius of the plant.

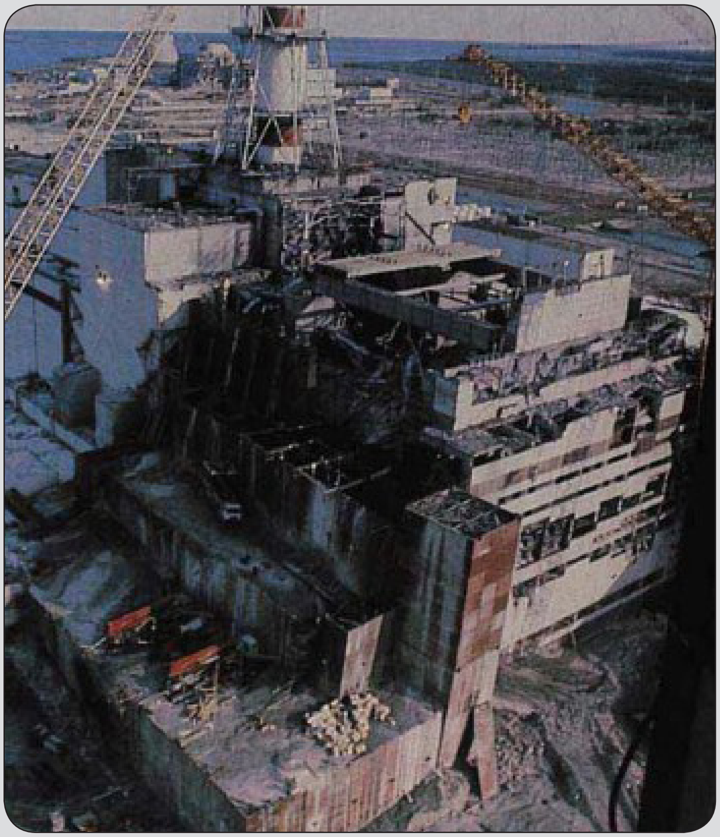
The accident at TMI has been the most serious in U.S. commercial nuclear power plant history, however there were no serious injuries and only small amounts of radiation were measured off-site.

Chernobyl

In the Ukraine, they rely heavily on nuclear power to generate electricity. In 1986, there were four reactors operating at the Chernobyl Power Complex with two more reactors under construction. On April 26, 1986, while conducting tests of Unit 4's reactor behavior at low power settings, plant operators turned off all of the automatic plant safety features. During the test the reactor became very unstable and there was a massive heat surge. Operators were unable to stop the surge and two steam explosions occurred. When air entered the reactor the graphite moderator burst into flames and the entire unit became engulfed in fire. The steam explosions, along with burning graphite used to moderate the reactor, released considerable amounts of radioactive material into the environment. Two workers died in the initial explosion and by July, 28 additional plant personnel and firefighters had also died. Between May 2-4, about 160,000 persons living close by the reactor were evacuated. During the next several years an additional 210,000 people were resettled from areas within an approximate 20 mile radius of the plant. Soon after the accident Unit 4 was encased in a cement structure allowing the other reactors nearby to continue operating.

Today about 1,000 people have unofficially returned to live within the contaminated zone. A New Safe Confinement structure was built in 2016-2017 to more securely contain the radioactive materials that remain in Unit 4. Built with a stainless steel skin and slid into place over the damaged building, it now encompasses Unit 4 and the decaying concrete shelter. The structure is 344 feet high, 492 feet long, and 843 wide, which is larger than six football fields.

CHERNOBYL POWER PLANT



The damaged reactor number four of Chernobyl Nuclear Power Plant
Photo courtesy of Garvey STS via wikimedia commons.

Nuclear Accidents

Fukushima

On March 11, 2011, one of the largest earthquakes in recorded history occurred off the coast of Japan. This earthquake created a tsunami that killed nearly 20,000 people as it destroyed buildings, roads, bridges, and railways. When the earthquake occurred, the seismic instrumentation systems worked as designed and automatically shut down the reactors at the Fukushima Daiichi Nuclear Power Station. Fukushima lost off-site power due to the earthquake damaging transmission towers. This resulted in the emergency diesel generators automatically starting to maintain the cooling of the reactors and the spent fuel pools on site. When the tsunami arrived about 45 minutes later, it was estimated to be nearly 50 feet high—much taller than the 16' seawall constructed to protect the site. When the tsunami hit, all but one of the emergency diesel generators stopped working and DC power from batteries was lost due to the flooding that ensued. Both the emergency diesel generators and the batteries were located in the basement of the turbine building. Beyond that, four of the six reactor units were significantly damaged by the tsunami.

The loss of both AC power from the emergency diesel generators and DC power from the batteries disabled instrumentation needed to monitor and control the situation and disabled key systems needed to cool the reactor units and spent fuel pools. This resulted in damage, which is suspected to include the breech of reactor pressure vessels, leaks in primary containment vessels, and significant damage of nuclear fuel that was partially uncovered. Continued investigation will confirm exact damage as the reactor units and local areas are analyzed. Hydrogen is produced when uncovered zirconium fuel cladding reacts with water, which also resulted in two hydrogen explosions occurring in the upper part of certain reactor buildings.

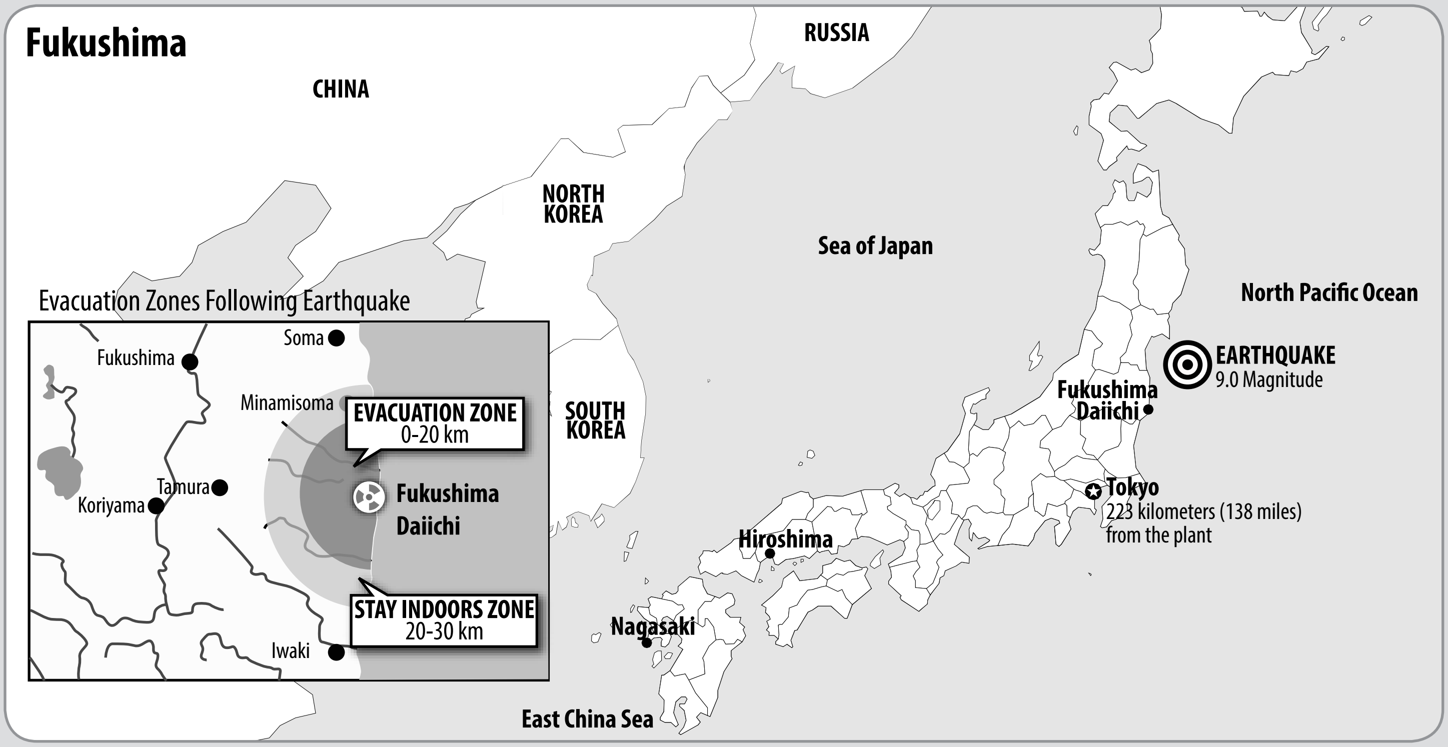
Lessons Learned

Much was learned by nuclear engineers and operators from these accidents. Although the reactor of Unit 2 at TMI was destroyed, most radioactivity was contained as designed. No deaths or injuries occurred. Lessons from TMI have been incorporated into both evolutionary and passive nuclear plant designs.

While some Chernobyl-style reactors are still operating in Eastern Europe, they have been drastically improved. Training for nuclear plant operators in Eastern Europe has also been significantly improved with an emphasis on safety.

Nearly 20,000 people lost their lives due to the tsunami in Japan, while no deaths have been attributed to radiological causes from the Fukushima accident. Radioactive material was, however, released into the air and water as a result of the accident. The effects of this contamination on the flora and fauna will continue to be monitored and studied. The Fukushima accident will improve nuclear safety as power plant operators and regulators take a closer look at the potential of natural disasters, protecting backup emergency diesel generators and batteries from being disabled, ensuring back-up systems to cool reactors and spent fuel pools are redundant and robust, and modifying hardware to improve function during emergencies.

Nuclear energy remains a major source of electricity in the United States and around the globe. The safe operation of nuclear power plants is important to quality of life and to the health and safety of individuals worldwide.



Fukushima

Nuclear Radiation

What is Radiation?

Energy traveling in the form of waves or high speed particles is called **radiation**. The sun produces radiant energy—energy that travels in electromagnetic waves. Wireless technologies, radar, microwave ovens, medical x-rays, and radiation therapy to treat cancer are all examples of how radiation can be used. Radiation can come in the form of electromagnetic waves (radio, microwave, infrared, visible light, ultraviolet light, x-rays, and gamma rays) and high speed particles (alpha and beta particles). Radiation is classified into two categories—**ionizing** radiation, which has enough energy to ionize atoms, and non-ionizing. When discussing nuclear science, radiation generally refers to ionizing radiation such as alpha particles, beta particles, and gamma rays.

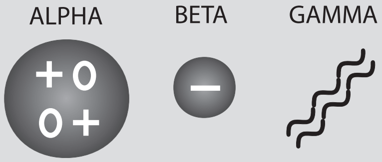
Alpha particles, **beta particles**, and/or **gamma rays** can be emitted from different isotopes of elements in order to become stable. We say these isotopes are radioactive and also call them **radionuclides**. An isotope is stable when there is close to a 1:1 ratio of protons and neutrons. If an isotope has too few or too many neutrons, the isotope becomes unstable and radioactive. Many elements with fewer than 84 protons have stable isotopes and radioactive isotopes; however, all isotopes of elements with 84 or more protons are radionuclides.

Radiation Exposure

Did you know that we live in a radioactive world? There are many natural sources of radiation that have been present since the Earth was formed. In the last century, we have added to this natural background radiation with some artificial sources. It may surprise you to know that for an average person, 50 percent of all exposure to radiation comes from naturally occurring sources. Much of our exposure to is due to medical procedures, and commercial and industrial sources.

There are three major sources of naturally occurring radiation. They are cosmic radiation, terrestrial radiation, and internal radiation. Cosmic radiation is the radiation that penetrates the Earth's atmosphere and comes from the sun and outer space. Terrestrial radiation is the radiation found in the earth, rocks, building materials, and water. The human body naturally contains some radiation. This is called internal radiation.

We are constantly using radioactive materials in our daily lives. These include medical radiation sources such as medical and dental x-rays, CT scans, PET scans, older TV's, older luminous watches, some smoke detectors, left-over radiation from the testing of nuclear weapons, and a variety of industrial uses. Another major source of radiation is from **radon** gas, a gas commonly found in the ground.



Radon

Radon is a colorless and odorless radioactive gas found throughout the United States. It is formed by the natural radioactive decay of uranium atoms in the soil, rocks, and water. Since radon is a gas, it can get into the air of the buildings where we live, work, and play. According to the Environmental Protection Agency (EPA), radon causes thousands of deaths from lung cancer each year. In fact, exposure to radon gas is the second leading cause of lung cancer in the U.S. behind smoking.

Most radon enters buildings from the soil. Radon enters buildings through cracks in solid floors, construction joints, cracks in walls, gaps in suspended floors, gaps around service pipes, and cavities inside walls. Some radon can also enter a home through the water supply. Both new and older homes are susceptible to radon gas build-up. Since most exposure to radon occurs at home, it is important to measure the level of radon in your home, and limit radon exposure where necessary.

The EPA recommends that all homes be tested for radon. Simple test kits are available at most home improvement stores, are inexpensive, and are easy to use. Qualified testers can also be used and are a good choice to perform tests when buying or selling a home.

X-RAY

We are constantly using radioactive materials in our daily lives. X-rays are a medical radiation source.

Economics of Nuclear Energy

Building new nuclear power plants will be costly. Cost estimates for building two nuclear units at an existing nuclear power plant site range from $8 billion to $18 billion. At these costs, the construction and operation of a nuclear reactor that enters service in 2019 will be approximately 5-45 percent higher than those of a conventional coal or natural gas plant that goes on-line at the same time. However, when compared to alternative sources of energy and advanced technology coal and natural gas plants, the expense of building and operating a nuclear power plant becomes economically competitive.

U.S. Average Levelized Costs (2017 $/Megawatthour) for Selected Plants Entering Service in 2022

Coal with 30% CCS	130.1
Coal with 90% CCS	119.1
Natural Gas-fired Conventional Combined Cycle	50.1
Natural Gas-fired Advanced Combined Cycle	49
Natural Gas-fired Advanced CC with CCS	74.9
Natural Gas Conventional Combustion Turbine	98.7
Natural Gas Advanced Combustion Turbine	85.1
Advanced Nuclear	92.6
Geothermal	44.6
Biomass	95.3
Wind	59.1
Wind - Offshore	138
Solar PV	63.2
Solar Thermal	165.1
Hydro	61.7

CCS = Carbon Capture and Storage; CC = Combined Cycle

Levelized costs for new power plants include the cost of constructing the plant, construction time, non-fuel operating costs, fuel costs, the cost of financing, and the utilization of the plant. Not included in the levelized costs are any state or federal tax credits or other incentives that may play a role in the future.

Costs are listed based on 2017 cost / MWh

Data: Annual Energy Outlook 2018

Licensing Procedures

Prior to the 1990s, the approval and licensing for nuclear plants was expensive and time-consuming. Under the old process, the NRC issued a construction permit that allowed a power company to build a nuclear plant. Companies built expensive nuclear energy plants with no guarantee that the government would allow them to be used. Some plants were built or almost built, but never went on-line, and power companies lost huge amounts of money. In 1989, the NRC changed the licensing procedure. Now, the plant site is approved by the NRC before any construction is started, and standard designs for nuclear plants are encouraged. This should speed up the approval and building process. Finally, all licensing hearings are held and completed before any construction occurs. This will prevent expensive delays after the plant is completed.

Starting in 2011, construction and operating licenses for 28 new units had been submitted to the NRC under the new licensing process. If construction proceeds on schedule, the first two of the approved plants will go on-line in 2021 and 2022 in Georgia.

Despite new licensing procedures, investors are hesitant to invest in new nuclear power plants. To make nuclear plants more affordable and to encourage companies to build, the U.S. Congress passed the Energy Policy Act of 2005 that contains economic incentives for projects, including the construction and operation of nuclear plants, that avoid, reduce, or sequester air pollutants or greenhouse gas emissions. These incentives include tax credits for the power companies building nuclear power plants, government-backed insurance to cover economic losses of power companies if operations are delayed, and loan guarantees to make sure companies can get financing for new nuclear plants.

Local Economic Impacts

Despite high capital costs to build new nuclear power plants, the local and state economies can benefit in the long run. Building a new nuclear power plant will create many jobs. During construction 1,400-1,800 jobs will need to be filled, at some construction phases the number could be as many as 3,500 jobs. After the plant begins operating, 400-700 permanent jobs will remain. These jobs pay approximately 36 percent more than the average salaries in the local area.

The average nuclear power plant and its employees generate about $470 million in local sales of goods and services. The average nuclear power plant also pays local and state taxes that total about $17 million every year, and federal tax payments of almost $67 million.

Climate Change

Another issue that affects the economics of all types of power plants is **climate change**. Carbon dioxide (CO_2) emissions are believed to be a leading factor in climate change. Generating electricity from fossil fuels contributes to about 37 percent of CO_2 emissions in the United States. No **greenhouse gases** are emitted when generating electricity from uranium. Several proposals in Congress have included taxes or tariffs on CO_2 emissions to encourage decreased use of fossil fuels and reductions in greenhouse gas emissions. If such proposals are adopted, generating electricity from coal and natural gas will have increased costs, and nuclear power will become more economically competitive even without financial incentives from the government.

Advantages and Challenges of Nuclear Energy

Nuclear power plants currently generate about 20 percent of the electricity consumed in the United States. As the demand for electricity grows in the coming years, it will be necessary to build more nuclear power plants in order to keep nuclear energy meeting 20 percent of our needs. As the country moves forward in planning how to meet electricity demands, individuals and organizations will debate the costs and benefits of each energy source.

Advantages of Nuclear Energy

- Nuclear power plants do not emit carbon dioxide.
- Nuclear power plants do not give off pollutants such as soot, ash, or sulfur dioxide.
- There is a large supply of uranium fuel available—enough for several hundred to many thousands of years, and uranium costs are low relative to coal and natural gas.
- Nuclear energy can provide baseload electricity where renewable sources are intermittent.
- The operating cost of a nuclear power plant is low, and will continue to be reduced as plants become more efficient and operate for longer periods of time.
- New plant designs are safer and more efficient than those of older plants.
- Increasing the number of nuclear plants in the U.S. can reduce our dependence on foreign oil if Americans buy and drive electric-powered vehicles. This requires a dramatic increase in the design and production of electric-powered vehicles by car manufacturers and an increase of electricity generated.

Challenges of Nuclear Energy

- Overall costs of construction and spent fuel storage are high and highly political.
- It takes longer to build a nuclear power plant than a coal or natural gas plant.
- Radiation released from nuclear reactions must be contained, and radioactive spent fuel and nuclear waste must be safely and securely stored.
- A portion of the public continues to have major concerns about the safety of nuclear power plants.
- Transporting nuclear waste across the country will have challenges both regulatory and political.
- While environmental impact studies have been conducted to make predictions, it is unknown exactly how long-term storage of radioactive high-level waste, including nuclear spent fuel, will impact the environment.
- Uranium enrichment and nuclear fuel reprocessing technologies created during enriching and reprocessing can be used in producing fissile materials for nuclear weapons (nuclear proliferation).
- There are limited material resources and manufacturing plants to make reactor components, and an increased demand for raw materials, including concrete and copper, that are used in construction of these facilities.
- Most nuclear power plants in the U.S. were built over 30 years ago. Even with upgrades and regular maintenance, there are safety concerns regarding extending their operating licenses.

Careers in the Nuclear Industry

The following are examples of careers that require training in the use of nuclear energy or that help support nuclear industries.

Nuclear Power:

Entry-Level Engineer—Helps to develop complex plans to support plant operations. The engineer also monitors, assesses, and improves the performance and reliability of plant systems and components.

Experienced Engineer—An experienced or senior engineer at a nuclear power plant plans and coordinates programs and large-scale engineering projects or several medium projects while acting as a technical specialist for a specific engineering field.

Mechanical Technician—Performs preventive, corrective, and special maintenance on systems, components, and structural facilities to ensure the reliability of a nuclear power plant.

Electrical Technician—Performs maintenance and repair of highly complex electrical/electronic equipment required for a nuclear plant. Responsibilities include troubleshooting, testing, and inspecting the equipment in a highly skilled manner.

Instrumentation and Control Technician—Responsible for calibrating, testing, troubleshooting, reworking, modifying, and inspecting nuclear plant instrumentation and control components and systems.

Chemistry Technician—Measures and records plant chemistry and radioactivity levels, and operates chemical and radiochemical instrumentation and equipment.

Radiation Protection Technician—Radiation protection technicians measure and record radiation levels; in addition, they service and calibrate radiation protection instruments and equipment. They play a vital role in ensuring the safety of employees working in radiation areas, as well as the facility's compliance with radiation requirements.

Non-Licensed Operator—Supports the licensed reactor operators and senior reactor operators. Duties include opening and closing valves, electrical breakers, and other devices as well as directly monitoring plant equipment performance.

Reactor Operator—A reactor operator, licensed by the U.S. Nuclear Regulatory Commission, is responsible for operating a reactor's controls in cooperation with the remainder of the shift team. The reactor operator moves control rods, starts and stops equipment, implements operations procedures, conducts surveillance tests, and records data in logs.

Senior Reactor Operator—A senior reactor operator is licensed to operate a nuclear power plant in accordance with all regulations. Duties include operating the mechanical, electrical, and reactor systems from the plant control room in a safe and efficient manner to ensure maximum electrical generation in compliance with regulations.

Industrial Machinery Mechanic—Repairs, maintains, and helps install mechanical systems of reactors and generators.

Skilled Trade Workers—Includes electricians who repair, maintain, and help install electrical systems that supply reactors and generators.

Electrical Line Workers—Repair, maintain, and help install electrical lines feeding and leaving electrical generators.

Welders—Install and repair various parts of reactors generators, and cooling systems.

Non-Nuclear Power:

Archaeologist and Paleontologists—Use radiation to determine age and composition of fossils.

Biologist—Uses radiation in experiments to develop new varieties of crops.

Biological Research Assistants—Help scientists and food engineers collect and analyze data to improve food supply.

Civil Engineer—Designs, constructs, and/or supervises the building of roads, tunnels, bridges, facilities, water supply, and sewer systems.

Gamma Facilities Operators—Use radiation to destroy microorganisms like salmonella or E. coli in food supplies.

Health Physicists—Assure safe exposure levels of radiation in all areas where human radiation exposure may occur.

Medical Staff—Doctors, nurses, and other health practitioners use nuclear medicine to diagnose and treat diseases.

Nuclear Medicine Technologists—Run various tests in hospitals that use radiation.

Public Affairs—A career in public affairs often involves communicating with the public on nuclear energy and/or radiation topics. This may include writing press releases, attending public meetings, website administration, or leading tours at facilities.

Radiobiologist—Studies the effects of ionizing radiation on cells and organisms.

Radioecologist—An environmental scientist that studies and determines how radioactive material is transported through the environment and through ecosystems.

X-ray technicians—Administer and develop x-rays in health care settings.

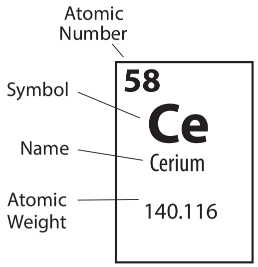
Others—Persons trained in the use of radiation are needed in crime investigation, science education, policy making, and art appraisal and authentication.

Think, Learn, Question

What Do I Think I Know About Nuclear Energy?	New Learning About Nuclear Energy

Questions I Have About Nuclear Energy

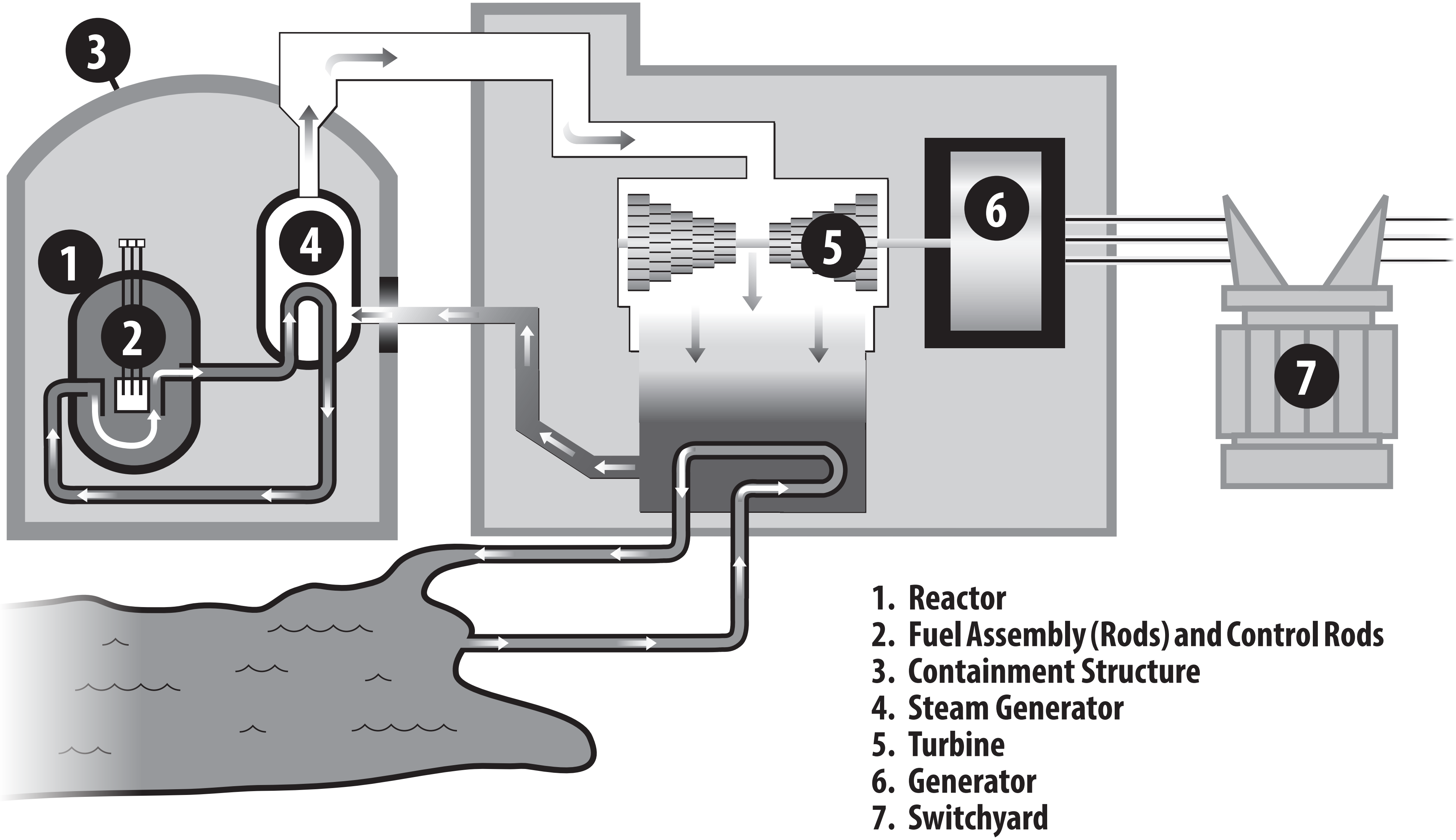
The Periodic Table of the Elements



Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 **H** Hydrogen 1.00794																	2 **He** Helium 4.002602
2	3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.0067	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
3	11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.065	17 **Cl** Chlorine 35.453	18 **Ar** Argon 39.948
4	19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.409	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.64	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.798
5	37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.293
6	55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327		72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
7	87 **Fr** Francium (223)	88 **Ra** Radium (226)		104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (268)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (280)	112 **Cn** Copernicium (285)	113 **Nh** Nihonium (286)	114 **Fl** Flerovium (289)	115 **Mc** Moscovium (289)	116 **Lv** Livermorium (293)	117 **Ts** Tennessine (294)	118 **Og** Oganesson (294)

Lanthanides	57 **La** Lanthanum 138.9055	58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.500	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.259	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
Actinides	89 **Ac** Actinium (227)	90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.02891	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

Pressurized Water Reactor



1. Reactor
2. Fuel Assembly (Rods) and Control Rods
3. Containment Structure
4. Steam Generator
5. Turbine
6. Generator
7. Switchyard

Science of Electricity Model

✪ Objective

To demonstrate how electricity is generated.

⚠Caution

- The magnets used in this model are very strong. Refer to page 46 for more safety information.
- Use caution with nails and scissors when puncturing the bottle.

Materials

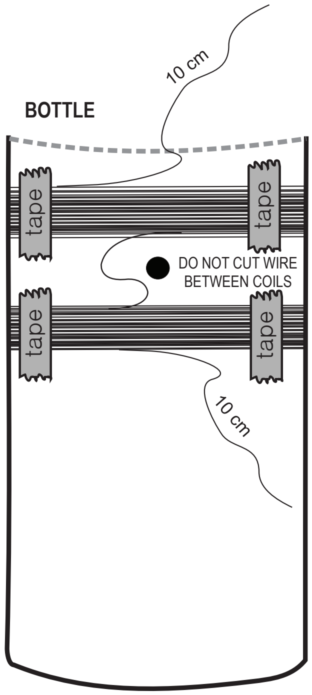
- 1 Small bottle
- 1 Rubber stopper with ¼″ hole
- 1 Wooden dowel (12″ x ¼″)
- 4 Strong rectangle magnets
- 1 Foam tube
- 1 Small nail
- 1 Large nail
- Spool of magnet wire
- Permanent marker
- 1 Pair sharp scissors
- Masking tape
- Fine sandpaper
- 1 Push pin
- 1 Multimeter with alligator clips
- Hand operated pencil sharpener
- Ruler
- Utility knife (optional)

Preparing the Bottle

1. If needed, cut the top off of the bottle so you have a smooth edge and your hand can fit inside. This step may not be necessary. If necessary, a utility knife may be of assistance.
2. Pick a spot at the base of the bottle. (HINT: If the bottle you are using has visible seams, measure along these lines so your holes will be on the opposite sides of the bottle.) Measure 10 centimeters (cm) up from the base and mark this location with a permanent marker.
3. On the exact opposite side of the bottle, measure 10 cm up and mark this location with a permanent marker.
4. Over each mark, poke a hole with a push pin. Do not distort the shape of the bottle as you do this.
   CAUTION: Hold a rubber stopper inside the bottle behind where the hole will be so the push pin, and later the nails, will hit the rubber stopper and not your hand, once it pokes through the bottle.
5. Widen each hole by pushing a nail through it. Continue making the hole bigger by circling the edge of the hole with the side of the nail. (A 9/32 drill bit twisted slowly also works, using a rubber stopper on the end of the bit as a handle.)
6. Sharpen one end of the dowel using a hand operated pencil sharpener (the dowel does not have to sharpen into a fine point). Push the sharpened end of the dowel rod through the first hole. Circle the edge of the hole with the dowel so that the hole is a little bigger than the dowel.
7. Remove the dowel and insert it into the opposite hole. Circle the edge of the hole with the dowel so that the hole is a little bigger than the dowel. An ink pen will also work to enlarge the hole. Be careful not to make the hole too large, however.
8. Insert the dowel through both holes. Hold each end of the dowel and swing the bottle around the dowel. You should have a smooth rotation. Make adjustments as needed. Take the dowel out of the bottle and set aside.
9. With a permanent marker, label one hole "A" and the other hole "B."

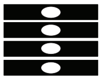
Generator Assembly: Part 1

1. Tear 6 pieces of tape approximately 6 cm long each and set aside.
2. Take the bottle and the magnet wire. Leave a 10 cm tail, and tape the wire to the bottle about 2 cm below hole A. Wrap the wire clockwise 200 times, stacking each wire wrap on top of each other. Keep the wire wrap below the holes, but be careful not to cover the holes, or get too far away from the holes.
3. DO **NOT** cut the wire. Use two pieces of tape to hold the coil of wire in place; do not cover the holes in the bottle with tape (see diagram).
4. Without cutting the wire, move the wire about 2 cm above the hole to begin the second coil of wraps in a clockwise direction. Tape the wire to secure it in place.



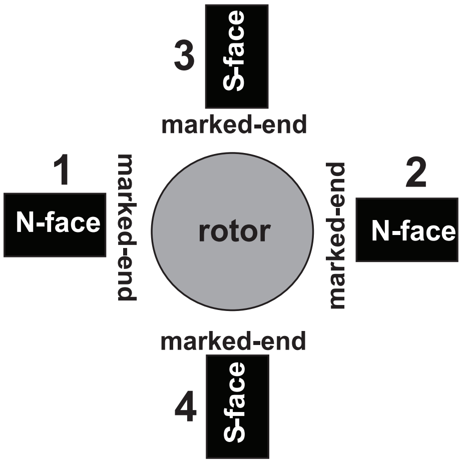
1. Wrap the wire 200 times clockwise, again stacking each wrap on top of each other. Hold the coil in place with tape.
2. Unwind 10 cm of wire (for a tail) from the spool and cut the wire.
3. Check your coil wraps. Using your fingers, pinch the individual wire wraps to make sure the wire is close together and close to the holes. Re-tape the coils in place as needed.
4. Using fine sandpaper, remove the enamel coating from 4 cm of the end of each wire tail, leaving bare copper wires. (This step may need to be repeated again when testing the model, or saved for the very end).

Diagram 1



Stacked Magnets End View

Diagram 2

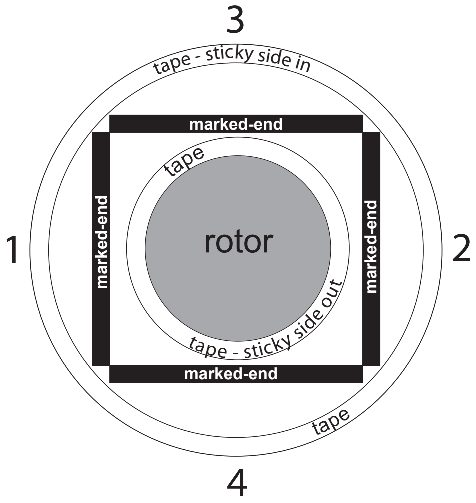


Rotor Assembly

1. Measure 4 cm from the end of the foam tube. Using scissors, carefully score a circle around the tube. Snap the piece from the tube. This piece is now your rotor.
2. On the flat ends of the rotor, measure to find the center point. Mark this location with a permanent marker.
3. Insert the small nail directly through the rotor's center using your mark as a guide.
4. Remove the small nail and insert the bigger nail.
5. Remove the nail and push the dowel through, then remove the dowel and set aside. Do **NOT** enlarge this hole.
6. Stack the four magnets together. While stacked, mark one end (it does not matter which end) of each of the stacked magnets with a permanent marker as shown in Diagram 1.
7. Place the magnets around the foam piece as shown in Diagram 2. Make sure you place the magnets at a distance so they do not snap back together.
8. Wrap a piece of masking tape around the curved surface of the rotor, sticky side out. Tape it down at one spot, if helpful.
9. Lift the marked end of Magnet 1 to a vertical position and attach it to the rotor. Repeat for Magnets 2, 3, and 4.
10. Secure the magnets in place by wrapping another piece of masking tape over the magnets, sticky side in (Diagram 3).

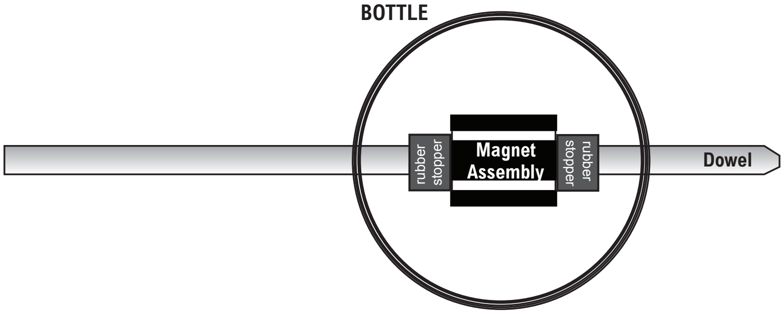
WARNING: These magnets are ***very*** *strong. Use caution when handling.*

Diagram 3



Generator Assembly: Part 2

1. Slide the sharp end of the dowel through Hole A of the bottle.
2. Inside the bottle, put on a stopper, the rotor, and another stopper. The stoppers should hold the foam rotor in place. If the rotor spins freely on the axis, push the two stoppers closer against the rotor. This is a pressure fit and no glue is needed.
3. Slide the sharp end of the dowel through Hole B until it sticks out about 4 cm from the bottle.
4. Make sure your dowel can spin freely. Adjust the rotor so it is in the middle of the bottle.



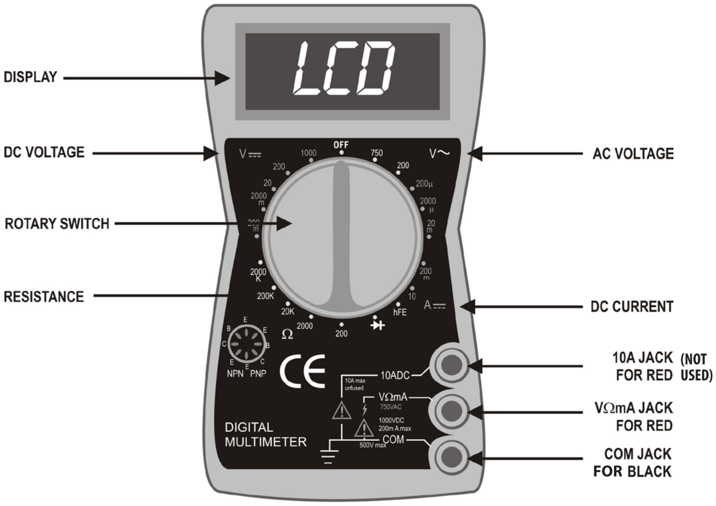
Assembly Notes

- The stoppers can be cut in half so that one stopper is made into two, to allow for more materials. These often slide more easily on the dowel. This must be done using sharp scissors or a utility knife, and can often be dangerous. As this step is not required (the kit supplies you with two stoppers to use), exercise extreme caution.
- If the foam rotor fits snugly on the dowel, put the stoppers on the outside of the bottle to help center the rotor in the bottle. Leave enough space to allow free rotation of the rotor.
- The dowel may be lubricated with lip balm or oil for ease of sliding the stoppers, if necessary.
- If a glue gun is available, magnets can be attached to the rotor on edge or on end to get them closer to the coils of wire. Use the magnet to make an indentation into the foam. Lay down a bead of glue, and attach the magnets. If placing the magnets on end, however, make sure they clear the sides of the bottle for rotation.

Testing the Science of Electricity Model

1. Connect the leads to the multimeter to obtain a DC Voltage reading.
2. Connect one alligator clip to each end of the magnet wire. Connect the other end of the alligator clips to the multimeter probes.
3. Set your multimeter to DC Voltage 200 mV (millivolts). Voltage measures the pressure that pushes electrons through a circuit. You will be measuring millivolts, or thousandths of a volt.
4. Demonstrate to the class, or allow students to test, how spinning the dowel rod with the rotor will generate electricity as evidenced by a voltage reading. As appropriate for your class, you may switch the dial between 200 mV and 20 volts. Discuss the difference in readings and the decimal placement.*
5. Optional: Redesign the generator to test different variables including the number of wire wraps, different magnet strengths, and number of magnets.

*Speed of rotation will impact meter readings.



Note: Your multimeter may look different than the one shown. Read the instruction manual included in the multimeter box for safety information and complete operating instructions.

Troubleshooting

If you are unable to get a voltage or current reading, double check the following:

- Did you remove the enamel coating from the ends of the magnet wire?
- Are the magnets oriented correctly?
- The magnet wire should not have been cut as you wrapped 200 wraps below the bottle holes and 200 wraps above the bottle holes. It should be one continuous wire.
- Are you able to spin the dowel freely? Is there too much friction between the dowel and the bottle?
- Is the rotor spinning freely on the dowel? Adjust the rubber stoppers so there is a tight fit, and the rotor does not spin independently.

Notes

- The *Science of Electricity Model* was designed to give students a more tangible understanding of electricity and the components required to generate electricity. The amount of electricity that this model is able to generate is very small.
- The *Science of Electricity Model* has many variables that will affect the output you are able to achieve. When measuring millivolts, you can expect to achieve anywhere from 1 mV to over 35 mV.
- More information about measuring electricity can be found in NEED's *Intermediate Energy Infobook*. You may download this guide from shop.NEED.org.

Magnet Safety

The magnets in the *Science of Electricity Model* are very strong. In order to separate them, students should slide/twist them apart. Please also take the following precautions:

- When you set the magnets down, place them far enough away from each other that the magnets won't snap back together.
- The tape should hold the magnets on. If you want something stronger and more permanent you can use hot glue.
- When you are finished with the magnets and ready to store them, put a small piece of cardboard between them.
- Keep magnets away from your computer screen, cell phone, debit/credit cards, and ID badges.

Science of Electricity Model

Observe the science of electricity model. Draw and label the parts of the apparatus.

Explain how electricity is generated using appropriate vocabulary.

Atomic Mass Model

Background

In this activity, pennies will be used to model protons and neutrons in an atom. A heads-up penny will represent a proton, and a tails-up penny will represent a neutron. All protons are identical to each other, and all neutrons are identical to other neutrons. Pennies minted after 1982 are all made the same way from the same materials, like protons and neutrons have almost exactly the same mass from one to the other. Neutrons are very slightly heavier than protons, but this difference is difficult to notice without the most advanced instruments. For all practical purposes, one proton and one neutron have the same mass.

Materials

- 60 Pennies
- Digital balance

✔ Procedure

1. Find carbon on the Periodic Table of the Elements.
2. Carbon's atomic number is ______________.
   The atomic number is the number of protons in an element, and identifies the element. The number of protons determines the element as listed on the Periodic Table of the Elements.
3. How many protons does ***every*** carbon atom have? ______________
4. The mass listed for carbon is ____________ amu. When rounded to the nearest whole number, carbon's mass number is _____________.
5. The mass of an atom is the sum of the number of protons and number of neutrons. If every carbon atom has _________ protons, and the mass of carbon on the periodic table is _________, the number of neutrons in most carbon atoms is _________.
6. Using pennies to represent protons (heads) and neutrons (tails), create a carbon nucleus. With all the protons and neutrons for the carbon atom lying flat on the table, move them together in a tight circle. Draw a diagram of the carbon nucleus in the box. Label the protons and neutrons with P's and N's instead of heads and tails.
7. How many total protons and neutrons are in the carbon nucleus you made?
   ____
   This isotope of carbon is called carbon-12 because it has 12 total protons and neutrons.
8. Which other question above was answered with "12"? _________ This is not a coincidence! Atomic mass on the periodic table is given in units of atomic mass units. One atomic mass unit (amu) is defined as one-twelfth the mass of a carbon-12 atom.
9. Using the digital balance, measure the mass in grams of all the pennies (protons and neutrons) making up your carbon-12 nucleus.
   ______________ g
10. Divide the total mass by 12 to get one-twelfth the mass of your carbon-12 nucleus. ___________ g
11. Using the digital balance, measure the mass of one of the pennies from your nucleus. ___________ g

Carbon Atom Nucleus

⁂ Conclusion

How does the measurement in #11 compare to the calculation you did in #10 above? What does the mass tell you about an atom?

Boron Isotopes and Atomic Mass

Materials

- At least 54 pennies

✔ Procedure

1. Find boron on the Periodic Table of the Elements.
2. Boron's atomic number is __________. How many protons does every boron atom have? __________
3. The atomic mass listed for boron is _____________ rounded to the nearest tenth.

   In the previous activity you learned that atomic mass is measured in atomic mass units (amu) and that one amu is approximately the mass of a proton or neutron. You also discovered that the atomic mass indicates how many total protons and neutrons are in the nucleus of an atom. Where does the listed atomic mass for boron come from? You can't have 0.8 of a proton or neutron in an atom.

   In naturally occurring boron, about one of every five atoms is boron-10 and the remaining four of every five atoms is boron-11. Boron-10 and boron-11 are isotopes of boron, meaning they each have the same number of protons, but different numbers of neutrons.
4. How many neutrons are in a boron-10 nucleus? __________
5. How many neutrons are in a boron-11 nucleus? _________
6. Using pennies again as protons (heads) and neutrons (tails), make ONE boron-10 nucleus and FOUR boron-11 nuclei.
7. In the boxes below, diagram each boron isotope. Draw only one atom in each box. Label the protons and neutrons with P's and N's instead of heads and tails.

Boron-10 **Boron-11**

Average Atomic Mass of Boron

Materials

- At least 45 Pennies
- Digital balance

Procedure

1. As in the previous activity, use pennies to make one atom of boron-10 and four atoms of boron-11. Protons are the head side of pennies and neutrons are the tail side of pennies.
2. Measure the mass of the one boron-10 atom you made. Record it in the data table below.
3. Measure the total mass of all four of the boron-11 atoms you made. Record it in the data table below.
4. Calculate the average mass of one atom in your sample of boron-10. Do this by dividing the mass of boron-10 by the number of boron-10 atoms.
5. Calculate the average mass of one atom in your sample of boron-11. Do this by dividing the mass of boron-11 by the number of boron-11 atoms.
6. Calculate the proportion of your entire boron sample (all five atoms combined) that is boron-10. Boron-10 is _______ atom out of ________ total.
7. Calculate the proportion of your entire boron sample (all five atoms combined) that is boron-11. Boron-11 is _______ atoms out of _______ total.

   Why is the proportion of boron-11 four times greater than the proportion of boron-10? It is because there are four times as many boron-11 atoms as there are boron-10 atoms in the penny-boron sample you made. Thus, the proportion of boron-11 is four times greater.
8. Multiply the average mass of one atom of each isotope times the proportion for that isotope, and write the number in the last column. Do not round.
9. Add the two proportioned average masses together to get the total average atomic mass of penny-boron. Round this number to the nearest tenth of a gram.

Data

ISOTOPE	NUMBER OF ATOMS	TOTAL MASS OF ATOMS	AVERAGE MASS OF ONE ATOM	PROPORTION OF ENTIRE SAMPLE	PROPORTION X AVERAGE MASS
Boron-10				0.20	
Boron-11				0.80	
			Total Average Atomic Mass of Sample		

⁂ Conclusion

When we multiply the average mass of atoms times their proportion in the sample, we are calculating weighted averages. The atomic masses listed on the periodic table are weighted averages of all the stable isotopes that are naturally occurring for each of those elements. The proportions used to calculate are known as the relative abundance of each isotope. In our example of penny-boron, boron-10 has a relative abundance of twenty percent (one in five) and boron-11 has a relative abundance of eighty percent (four out of five). Fill in the table below, making good guesses about the isotopes of each element and their relative abundances. Boron and carbon have been completed for you.

Element	Atomic Number	Listed Atomic Mass	Isotope likely to be of greatest abundance in nature
Helium			
Lithium			
Beryllium			
Boron	5	10.811	Boron-11
Carbon	6	12.0107	Carbon-12
Nitrogen			
Oxygen			
Fluorine			
Neon			

Why do you think the average mass of penny-boron was greater than the average mass of boron from the periodic table?

Examining Nuclear Energy

Uranium is the source used to generate heat in a nuclear reactor, but how does this work and what happens to the uranium? Let's take a closer look.

Here is a common decomposition of uranium where "n" stands for neutron:

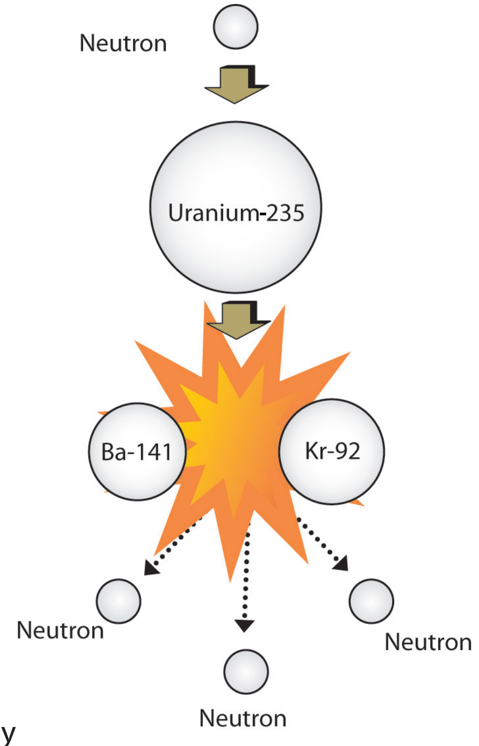
$$^{235}U + n \xrightarrow{\qquad\qquad} {}^{92}Kr + {}^{141}Ba + 3\,{}^{1}n + \text{energy}$$

Use the following masses given in amu (atomic mass units) to solve the nuclear equation.

Mass of U-235 = 235.044
Mass of Kr-92 = 91.926
Mass of Ba-141 = 140.914
Mass of one neutron = 1.00866

Next, add the masses on both sides of the equation:

Left Side →		Right Side	
U-235	___________	Kr-92	___________
+ n	___________	+ Ba-141	___________
		+ n	___________
		+ n	___________
		+ n	___________
Total =	___________	Total =	___________



Albert Einstein presented the theory, $E=mc^2$ as part of his Theory of Relativity. "E" stands for energy, "m" stands for mass, and "c" is the speed of light (in a vacuum), used as a constant in this equation. This equation says that energy equals mass and mass equals energy. They are somehow related, or can be converted back and forth.

This means that during nuclear fission, mass is not lost, it is released as energy! Energy is measured as megaelectron volts, or MeV. One MeV equals one million electron volts. The average energy released by U-235 fission is about 200 MeV. In this scenario the energy is 170 MeV.

Uranium-235 does not always fission the same way. Some other products of fission include:

$$^{235}U + {}^{1}n \xrightarrow{\qquad} {}^{144}Ba + {}^{90}Kr + 2\,{}^{1}n + \text{energy}$$

$$^{235}U + {}^{1}n \xrightarrow{\qquad} {}^{94}Zr + {}^{139}Te + 3\,{}^{1}n + \text{energy}$$

$$^{235}U + {}^{1}n \xrightarrow{\qquad} {}^{94}Zr + {}^{139}La + 3\,{}^{1}n + \text{energy}$$

Licorice Decay

Background

Radioactive decay is when an element spontaneously transforms into another by changing the number of protons in its nucleus. Certain isotopes are radioactive and emit energy as they decay to become stable. The time it takes for half of the atoms in a given mass to emit radiation and change to a more stable state is called a half-life.

Questions

1. What happens when you cut something in half and then in half again and again and again?
2. What kind of graph does it create?
3. How many times can you cut an item in half before it gets too small to handle?

Materials

- Two licorice sticks
- *Licorice and M&Mium Decay Graph* (or graph paper)

✔ Procedure

1. Place a full length licorice stick above the 0 on the graph.
2. Take the second licorice stick and cut its length in half.
3. Place one half on the graph above the 1 with the bottom end touching the horizontal (bottom) axis. It should start to look like a bar graph.
4. Take the second half and cut its length in half.
5. Repeat, placing each consecutive half on the graph at the correct Half Cut location.
6. When you are unable to split the licorice any further, use your pen to place a dot at the top of each piece of licorice.
7. Dispose of licorice either in your gullet or in the garbage.
8. Draw a smooth line or curve to connect the dots on your graph.

⁂ Conclusion

1. Describe the shape of the graph.

2. How many times were you able to cut the licorice in half before it became too small? ______

M&Mium Radioactive Decay

Background

Radioactive isotopes emit particles and energy in an effort to become stable. For some elements, this takes a long time and in other cases it happens very quickly.

Half-Lives	Radioactivity

Question

Do all half-life graphs look similar?

Materials

- *Licorice and M&Mium Decay Graph*
- 100 M&M's® in a cup
- Paper towel

✔ Procedure

1. Create a data table in your science notebook (like the one to the right) with Half-Lives as the independent variable and Radioactivity as the dependent variable.
2. Count out 100 "radioactive" M&M's®. (Discard any yellow M&M's® as they are too difficult to read! Make sure you replace them with a different color.)
3. In your data table, enter 0 for "Half-Lives" and under "Radioactivity" enter the TOTAL number of "radioactive" M&M's® you are starting with—100.
4. Put the "radioactive" candies in a container (cup or bag), shake them up and then carefully dump them onto the paper towel.
5. Remove all the M&M's® that are face down (with the M not showing)—these have "decayed" and become stable in the simulation.
6. Enter 1 for half-lives and record the number of remaining "radioactive" candies in your data table.
7. Place the candies that remained "radioactive" back into the cup, shake lightly and repeat this process until all the "radioactive" candies have become stable. Be sure to increase the number of half-lives by one for each shake.
8. On the same graph you used in *Licorice Decay*, place the number 100 at the same height along the vertical y-axis as you placed the mark above the full length licorice for 0 half cuts.
9. Appropriately scale the rest of the vertical axis based on the origin being 0 and the mark you just made being the total number of "radioactive" M&M's® you started with at 0 half-lives—100. Graph the rest of your data from the candy trials.

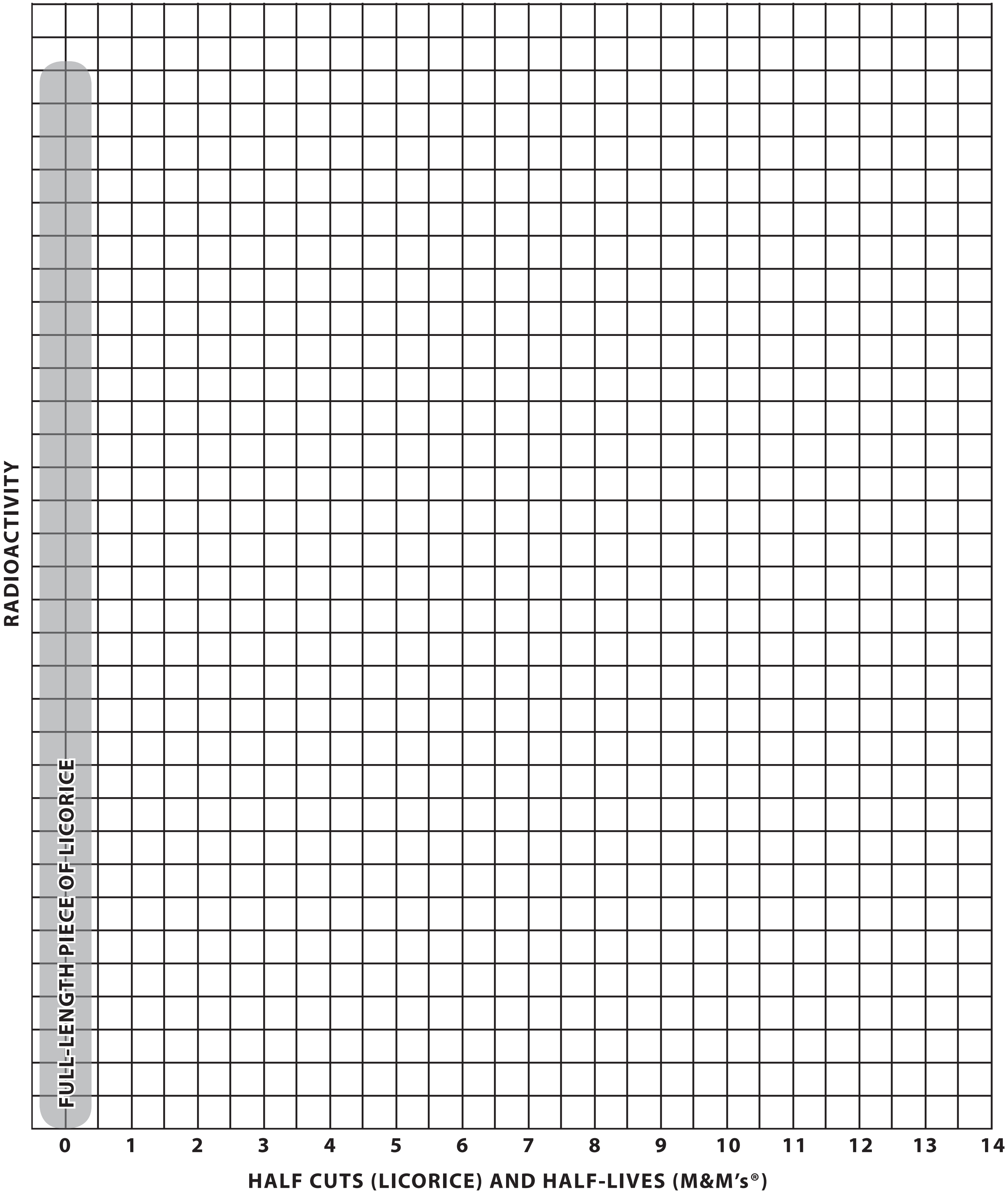
Analysis

1. Compare your graph to a neighbor's. What similarities and differences do you see?

Conclusion

1. As you look at your graph and your neighbor's, what do you notice? How is this activity similar to what happens in the natural world?
2. How does the graph for the licorice compare to the graph for the M&M's® decaying?

Licorice and M&Mium Decay Graph



Radiation Dose Chart

We are exposed to radiation from the natural environment and some everyday activities. Complete the information below to find out how many millirems of radiation you are exposed to each year.

mrems dose

Where You Live

1. Cosmic radiation (from outer space) at sea level 26

2. Select the number of millirems for your elevation (in feet above sea level) .... ____

up to 1000 = 2
1000-2000 = 5
2000-3000 = 9
3000-4000 = 9
4000-5000 = 21
5000-6000 = 29
6000-7000 = 40
7000-8000 = 53
8000-9000 = 70

3. Terrestrial (from the ground):

If you live in states that border the Gulf of Mexico or Atlantic Coast, add 23 .... ____

If you live in the Colorado Plateau area (around Denver), add 90 .... ____

If you live in the rest of the U.S., add 46 .... ____

4. House Construction

If you live in a stone, brick, or concrete building, add 7 .... ____

What You Eat and Drink

5. Internal radiation (in your body)*

From food and water........ 40

From air (radon) 200

Other Sources

6. Weapons test fallout**:........ 1
7. Jet plane travel: For each 1,000 miles you travel, add 1 .... ____
8. If you wear a luminous (LCD) wristwatch, add 0.006 .... ____
9. If you have false teeth or porcelain crowns, add 0.07 .... ____
10. If you use gas lantern mantles for camping, add 0.03 .... ____
11. If you use a video display terminal or computer monitor, add 1.** .... ____
12. If you use luggage inspection at airports (using a typical x-ray machine), add 0.002 .... ____
13. For each smoke detector you have, add 0.008 .... ____
14. If you watch TV, ** add 1 .... ____
15. If you wear a plutonium-powered cardiac pacemaker, add 100 .... ____
16. If you have had medical exposures:*

Diagnostic x-rays (e.g., upper and lower gastrointestinal, chest, dental), add 40 .... ____

If you have had nuclear medical procedures (e.g., thyroid scans, PET scans), add 14 .... ____

17. If you live within 50 miles of a nuclear power plant (pressurized water reactor), add 0.0009 .... ____
18. If you live within 50 miles of a coal-fired power plant, add 0.03 .... ____

My total annual mrems dose: ____________

Some of the radiation sources listed in this chart result in an exposure to only part of the body. For example, false teeth result in radiation close to the mouth. The annual dose numbers given here represent the "effective dose" to the whole body.
* These are yearly average doses.
** The value is actually less than 1.
In the United States the average person is exposed to 620 mrem of whole body radiation each year from all sources.
Activity from www.nrc.gov.

Milling Simulation

Background

When uranium is mined it has to be separated from the ore in which it is found. This separation is done through the milling process. The ore is brought to the mill where it is ground into fine particles. Chemicals are added to dissolve the uranium, allowing it to be separated from the waste rock. In this activity you will be separating salt and sand, with salt representing uranium and sand representing waste rock.

Question

How can salt and sand be separated?

Materials

- Salt/sand/gravel mixture
- 50 mL of Water
- Cooking pot
- Heat source
- Screen
- Filter
- Beaker
- Safety glasses
- Stirrer
- Scale or balance

✔ Procedure

1. Collect 25 g of "uranium ore" (salt/sand/gravel mixture) from the "mine" (your teacher).
2. Filter the mixture through a screen to remove the largest particles, set these aside.
3. Mix the remaining ore with 50 mL of water, stirring well.
4. Put a filter over the beaker and pour the water over the filter. The material collected on the filter is your "waste rock." Set this aside.
5. Pour the water from the beaker into the pot. Boil the solution until all of the water evaporates.
6. Collect the solid material left in the pot. This represents your "uranium."
7. Measure the mass of "uranium" you mined. Also measure the mass of the waste materials you separated earlier (including the material removed with the screen). Record the data below.
8. Calculate the percentage of ore compared to waste rock from your initial mass of mined material.

Data

	Mass (grams)	Mass as Percentage
Mass of Total Ore Materials	25	100%
Mass of Waste Rock		
Mass of Uranium		

Finding the Percentages of Mined Materials

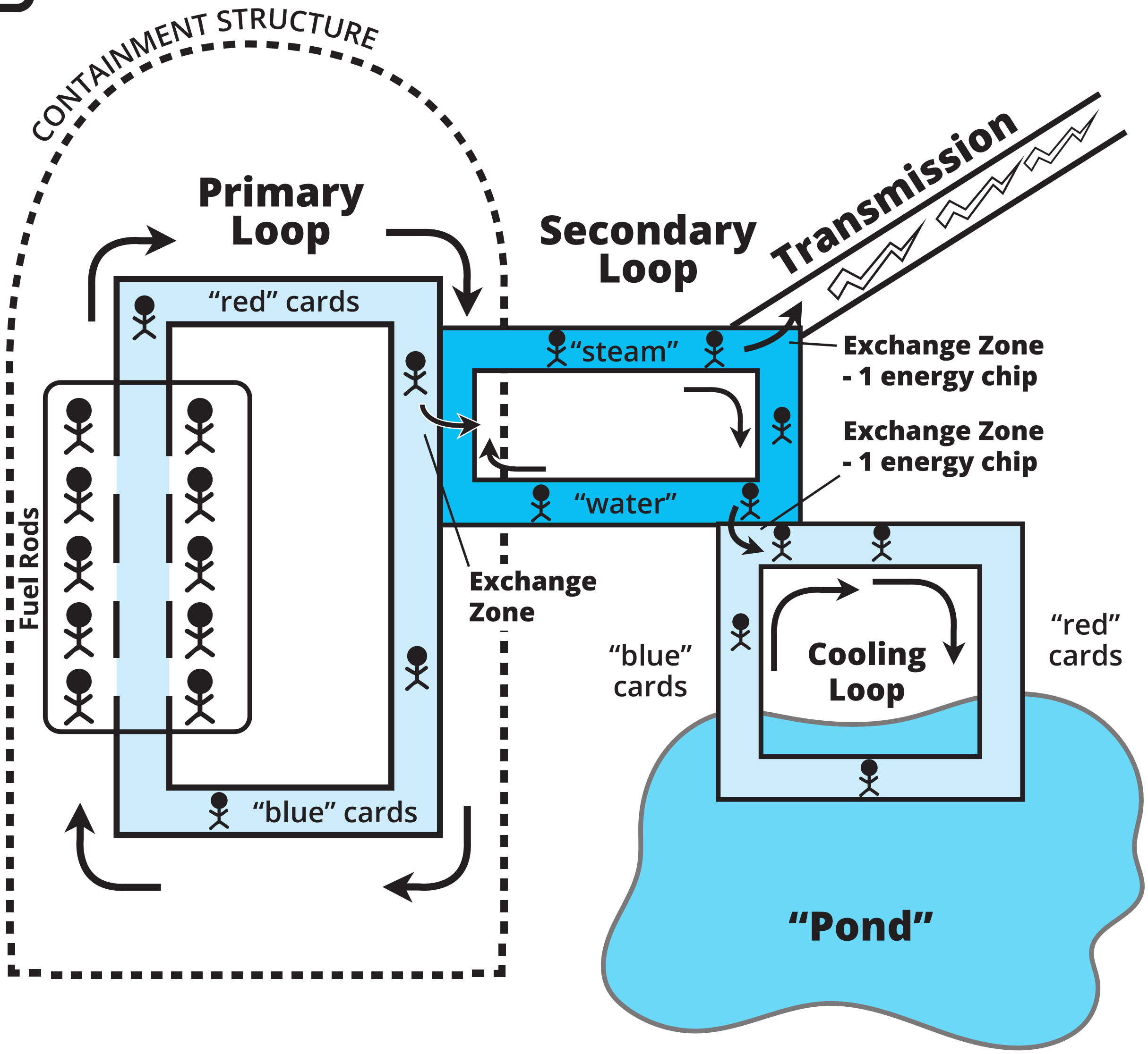
$$\text{Percentage of Waste Rock} = \frac{\text{Mass of Waste Rock}}{25\text{ g}}$$

$$\text{Percentage of Uranium} = \frac{\text{Mass of “Uranium”}}{25\text{ g}}$$

Conclusion

1. What process was used to separate the salt and the sand?
2. Create a pie chart showing the percentage of uranium and waste rock produced from the original ore material.
3. How is this process similar to milling uranium?

Nuclear Power Plant Simulation Summary



1. Pretend you are an energy chip in the primary loop. In a few sentences, describe where you originated, and how you might transfer through the power plant at all of the different exchange zones to describe how energy transfers through the plant.

2. On the diagram above, label with a large "X" a location where energy could be likely to build up in the power plant. In the space below, describe what the power plant might do to help make sure energy is evenly distributed through the loops and no one area becomes too warm.

3. How would you redesign this simulation to include a pressurizer? Are there any other parts in this model you would change?

Nuclear Energy Expo

Nuclear Fission

1. What is nuclear fission?
2. How do we use fission to generate electricity?
3. Why is uranium a unique element?
4. Who were the major contributors to the discovery of fission and what impact did they have?
5. What special properties were found in uranium and how have they made a difference in our lives?
6. How did the discovery of nuclear fission impact history?
7. What is nuclear fusion? How is fusion different from fission?

Nuclear Fuel Cycle

1. How does the nuclear fuel cycle work?
2. What is the "front end" and "back end" of the cycle?
3. What potential problems might there be with the "back end"?
4. Why do we need to "enrich" the uranium?
5. Which do you think is better, the "open" or "closed" cycle? Why?
6. What is "yellowcake"?

Nuclear Power Plants and Reactors

1. What is the purpose of the nuclear reactor?
2. What are the two most common types of reactors used in nuclear power plants and how are they similar/different?
3. Why is the PWR the most popular reactor in the world today?
4. What are the two methods of transferring waste heat to the environment?
5. What advantages and disadvantages do you see with either type of heat transfer?

Safeguards and Fuel Waste

1. What safeguards came out of the accidents at Three Mile Island, Chernobyl, and Fukushima?
2. How did the formation of the World Association of Nuclear Operators and the International Atomic Energy Agency improve nuclear power plant safety?
3. What is the role of the NRC in the United States?
4. What advantage do passive reactors have over evolutionary reactors?
5. What methods do we currently use to store used fuel?
6. What are the issues concerning the storage of spent nuclear fuel?
7. How can we reduce the risk of radon gas in our homes?

Nuclear Weapons and Proliferation

1. What is the purpose/job of the IAEA?
2. How have we used nuclear fission for peaceful technologies?
3. Why do countries believe that we need to revisit the issues concerning nuclear proliferation, even though nuclear bombs have not been used since WWII?
4. What are the problems with the Non-Proliferation Treaty (NPT)?
5. How do you think proliferation should be controlled?

Economics of Nuclear Energy

1. How does the cost of nuclear power plants compare to those that use fossil fuels?
2. Why is there reluctance from investors to support the building of more nuclear power plants?
3. How does climate change impact the use of nuclear power for generating electricity?
4. How much electricity is generated from nuclear power in the U.S.? How does this compare to France? How does it relate to both countries' total energy production?
5. What are the advantages/disadvantages for using nuclear power to generate electricity?

Optional/Additional Topics

Influential Women In Nuclear Science

1. What influenced Madame Curie to start work in the sciences?
2. What did Madame Curie do in order to receive the prestigious Nobel Prize award?
3. Why is Lise Meitner sometimes referred to as the mother of the atomic bomb?
4. What awards and recognition did Lise Meitner receive for her work?
5. Why was Lise Meitner not a recipient of the Nobel Prize?
6. How did these women influence/impact modern nuclear science?

Nuclear Accidents

1. What is the significance of Chernobyl, Three Mile Island, and Fukushima for today's nuclear industry?
2. What is a nuclear meltdown?
3. How are these accidents similar? How are they different?
4. Why did the Chernobyl officials want to keep the accident a secret?
5. Name two changes or lessons learned as a result of each accident, that made the nuclear industry safer.

Radon

1. What is radon and how is it formed?
2. Where are you most likely to encounter radon in a house and why?
3. How does radon enter into our environment?
4. What is a safe level of radon?
5. What can we do to reduce our risk?

Nuclear Medicine

1. How do we use nuclear medicine?
2. What does PET stand for? How does it work?
3. Why is radiation used to treat cancer?
4. What are the risks involved in nuclear medicine?
5. How do these risks weigh in comparison to the benefits?

The Nuclear Navy

1. How was the importance of nuclear aircraft carriers proven during WWII?
2. Who is Admiral Hyman G. Rickover, and what is his contribution to the nuclear navy?
3. Who is the AEC? What do they do?
4. What benefits does a nuclear submarine have?
5. What was the significance of January 17, 1955?

France's Nuclear Program

1. How much of France's electricity comes from nuclear power compared to the U.S.?
2. What caused France to move to such a high level with nuclear power?
3. What benefits has France experienced since building its nuclear power plants?
4. What is the greatest concern for France's nuclear industry now?
5. What are three reasons that French citizens are more accepting of nuclear power than American citizens?

Uranium in the Round

I have thermal energy.

Who has the term defined as the ability to cause change or do work?

I have energy.

Who has the form of energy stored in the bonds between atoms in molecules?

I have chemical energy.

Who has the center of an atom?

I have nucleus.

Who has the form of energy stored in the nucleus of an atom?

I have nuclear energy.

Who has the process where very small nuclei are combined into larger nuclei, releasing enormous amounts of energy?

I have nuclear fusion.

Who has the form of energy emitted into space by stars?

I have radiant energy.

Who has the process in which the nucleus of an atom is split?

I have nuclear fission.

Who has the fuel used in nuclear power plants for nuclear fission?

I have uranium.

Who has the forms of energy released during nuclear fission?

I have thermal energy and radiant energy.

Who has the term for energy sources, such as uranium, that cannot be replenished quickly?

Uranium in the Round

I have nonrenewable.

Who has the neutron-bombardment process that keeps fission going in a nuclear reactor?

I have about 20.

Who has the place where fission occurs in a nuclear power plant?

I have chain reaction.

Who has the production facility where electricity is generated?

I have reactor.

Who has the isotope of uranium used for nuclear fuel whose atoms are easily split?

I have power plant.

Who has the number of nuclear reactors operating in the United States?

I have U-235.

Who has the form into which uranium is processed to be used for nuclear fuel?

I have 99.

Who has the usable energy produced by a nuclear power plant?

I have ceramic pellet.

Who has the term for a bundle of fuel rods in a reactor's core?

I have electricity.

Who has the percentage of electricity produced by nuclear energy in the U.S.?

I have fuel assembly.

Who has the term for U-235 that has been fissioned and removed from a reactor?

Uranium in the Round

I have spent fuel.

Who has the term describing spent fuel from a nuclear power plant that is dangerous for many years and must be stored carefully?

I have radioactive.

Who has the natural process that describes how used fuel cools and loses most of its radioactivity?

I have radioactive decay.

Who has the term for places to store spent nuclear fuel underground?

I have repositories.

Who has an acceptable storage method for spent fuel?

I have spent fuel pools.

Who has the greenhouse gas that is NOT produced by a nuclear power plant since no fuel is burned?

I have carbon dioxide.

Who has the first submarine that ran on nuclear power for more than two years and traveled 62,562 miles before refueling?

I have the USS Nautilus.

Who has a career that starts up, shuts down, and monitors operations at a nuclear power plant?

I have reactor operator.

Who has a career that protects nuclear power plant workers and the general public from radiation?

I have health physicist.

Who has a career that uses nuclear energy for electricity, space exploration, world food and water supply, environmental production, medicine, and transportation?

I have nuclear engineer.

Who has the form of energy produced deep within the Earth by the slow decay of radioactive particles?

Culminating Activity: Nuclear Power Plant Hearing

The Background:

You live in a rural community with 2,450 people within the city limits. Your county, which is 500 square miles, has an overall population of 25,000 people.

Your state has long been known for coal production; however, the legislature recently implemented a policy that requires energy companies to decrease their greenhouse gas emissions. The state population is rapidly growing and the demand for electricity continues to increase. In order to meet energy demand, Atomic Energy Inc., an independent energy company (not affiliated with any state electric utility), has just announced that it intends to submit an application to the Nuclear Regulatory Commission (NRC) for a Combined Construction Permit and Operating License (COL) seeking permission to build and operate a nuclear power plant in your area. The COL relies on a reactor type already certified by the NRC but includes site approval as a part of the application. Atomic Energy Inc. will operate the plant and will sell its output to local electric utilities within the state, including the utility that supplies your city. If the state utilities cannot absorb the entire output of the plant, Atomic Energy Inc. plans to sell the excess output on the open market to any buyer it can find.

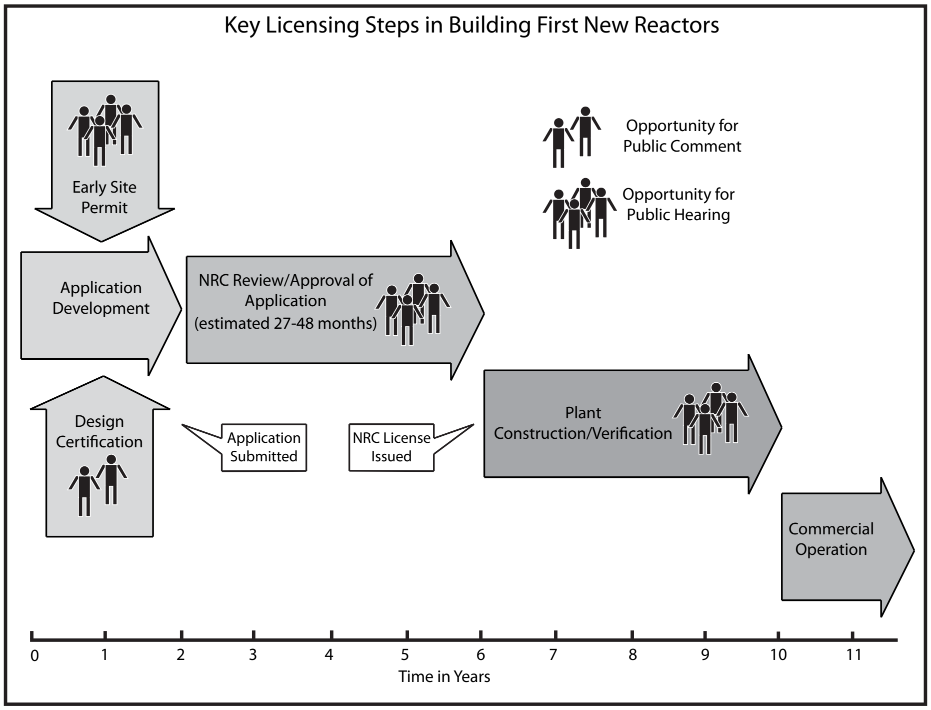
The NRC Licensing Process

The issues involved in the COL application will be evaluated by a three member Atomic Safety and Licensing Board (ASLB) panel from the NRC. Interested parties will present their evidence to the ASLB, and if the Board determines that the COL should be issued based on the evidence, it will recommend the action to the Commission. It is the full Commission that will make the final determination as to whether the COL should be issued. If the COL is granted, Atomic Energy Inc. will be able to begin construction of the plant and subsequently to operate it. If the permit is denied, the company will have to start over and, at a minimum, choose a new site if it wants to continue.

The COL Application

The site in question is more than 1,200 acres of open and wooded land, which includes almost a mile of shoreline along the city's public lake. The southern boundary of the site is approximately a quarter of a mile from the city limits. Atomic Energy Inc. seeks permission to construct and operate two pressurized water reactors, each with a rated capacity of 1,100 megawatts, enough electricity to power more than 450,000 homes. The reactors are a Westinghouse design that has already been approved by the NRC.

During consideration of the COL application, the questions before the Board include: 1) whether the site is suitable for the type of reactors proposed; 2) if so, whether the already-approved reactor design can be successfully "married" to the site; 3) the environmental impacts of construction and operation of the reactors at the site; and 4) whether the plant will be constructed in accordance with the approved designs as "fitted" to the specific site. Each question involves a number of related issues. For example, consideration of site suitability includes seismology, hydrology, meteorology, geology, and emergency planning. Although the reactor design itself has already been approved by the NRC and thus cannot be debated in the COL proceeding, questions as to whether there are characteristics of the site that raise safety issues with respect to operation of the plants are, if properly presented, appropriate for consideration in the hearing. Issues pertaining to the cost of building on the site, recurring costs after plant construction, and costs to the local community are also appropriate for consideration.



Public participation is encouraged throughout the licensing process for new nuclear reactors.
Graphic Source: Nuclear Energy Institute

Your Assignment

You will represent a citizen's group either for or against the proposed nuclear power plant. You need to research the topic from the perspective of your assigned role and find evidence to support your position. Give at least three reasons for your position and support each reason with three facts. You also need to address at least one argument that the opposite viewpoint might bring up. Write a persuasive letter based on your viewpoint to be presented to the ASLB, which will determine, based on the evidence before it, whether the COL should be issued.

Roles

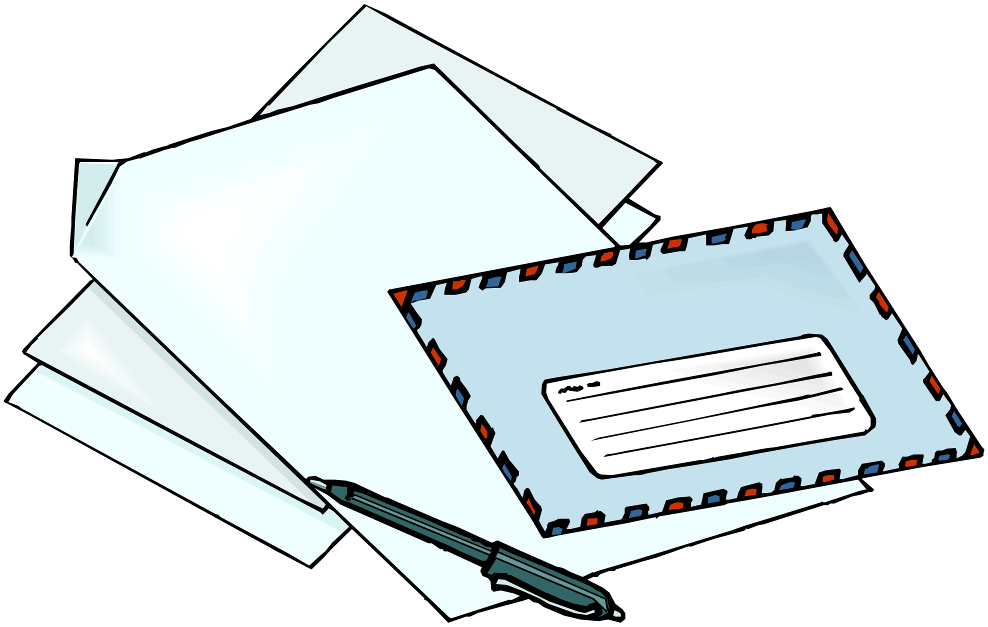
- ASLB Panel of the NRC—Will hear all sides and make a ruling on the COL.
- Local Electric Utility—Obligated to provide its consumers their electric needs with the most cost effective energy it can obtain. Utilities are subject to state legislative and regulatory requirements.
- Residential Consumer—Wants cheap electricity, does not want to pay higher rates.
- NRC Resident Inspector—Provides oversight for the safe construction and operation of the nuclear power plant.
- Parent—Concerned about health risks children will be exposed to.
- Global Warming Activist—Proponent of nuclear energy as a non-CO_2 energy source.
- Mayor and City Council—Wants to improve business options and way of life. See the taxes to be paid and the additional jobs created as a solution to many serious budget problems.
- Nuclear Scientist—Enthusiast for advancing nuclear energy technology.
- Director of Transportation—Focuses on the transportation of products associated with the construction and operation of the nuclear power plant.
- Biologist—Studies impacts on the local environment and animal populations.
- Environmentalist—Looks at impact of the power plant on the environment.
- Sustainable Energy Enthusiast—Wants sustainable energy development.
- Coal Miner—Wants to ensure job security.
- Representative from the U.S. Environmental Protection Agency (EPA)—Responsible for environmental impacts of the new plant.
- Representative of U.S. Homeland Security Department—Responsible for protection from terrorist attack, and remedial actions necessary as the result of a terrorist attack.
- Local Law Enforcement—Concerned about how their own department will be impacted by the building of a nuclear power plant in their jurisdiction.
- Representative of Atomic Energy Inc.—Explains type of nuclear reactor and its advantages over older types.
- Representative of the Press—Reports news of the proposed plant construction to region.
- Representative of State Utility Commission—Determines electricity rates.
- Representative of Financial Organization—Determines if financing for the construction of the plant is feasible for the company.
- Nuclear Power Opponent—Opposed to using nuclear energy because of safety, environmental, or proliferation risks.

Culminating Activity: Nuclear Energy Letter Prompt

As the United States looks to increase electricity production while cutting greenhouse gas emissions, increasing the use of nuclear energy is one option. Write a persuasive letter to a local or state representative presenting your position for or against nuclear energy.

Your letter should have three parts, while following proper format for persuasive writing.

- Explain your understanding of energy and why this is an important topic.
- Explain your understanding of how a nuclear power plant works.
- State your position for or against the use of nuclear energy. Support your position with at least three reasons and at least two pieces of evidence for each reason. Clearly communicate your position so that the representative might be persuaded to agree with you and think about your letter when he or she makes energy policy recommendations and decisions. This may include discussing and refuting possible counter arguments.



Nuclear Energy Assessment

1. Draw and label a diagram of an atom including the following parts: energy level, nucleus, proton, neutron, electron. Beside each label, give a brief description of the function of the part.

2. List five renewable energy sources.

3. List five nonrenewable energy sources.

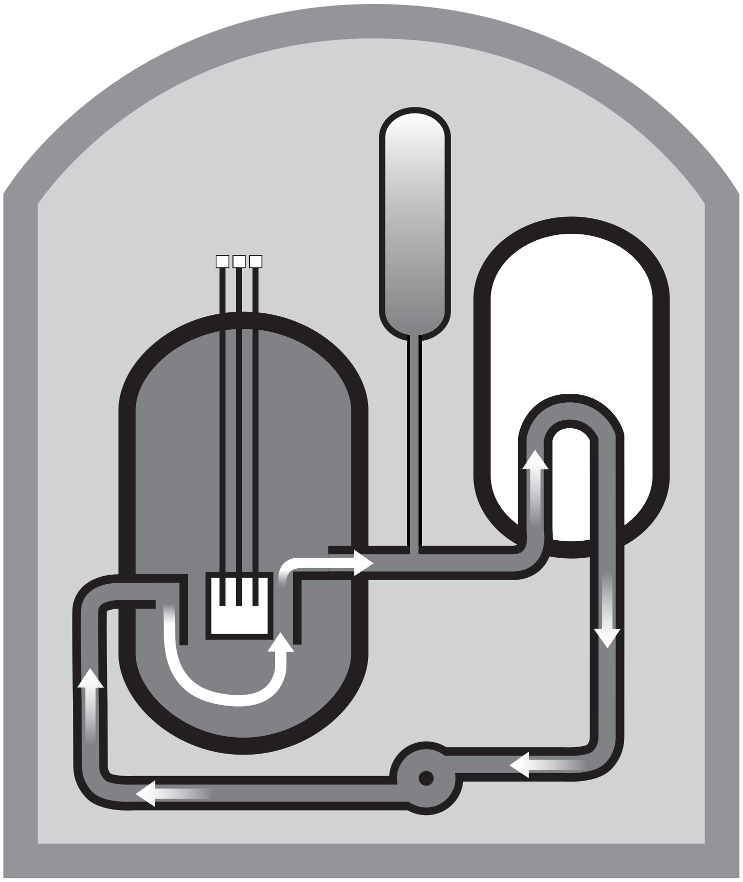
4. Make a diagram that shows the relationship(s) between electricity and magnetism, and then describe the relationship.

5. What are the two things that nuclear reactions may release?

6. Why must uranium be enriched before it can be used as a fuel source in a nuclear reactor?

7. What is the purpose of a moderator in a chain reaction? Name two different moderators used in common nuclear reactors.

8. On the following diagram of a nuclear reactor, label the following parts: reactor, fuel rods, pressurizer, containment structure, control rods. Next to each term, describe its main purpose in one sentence.



9. What does the term nuclear proliferation mean? Why should people be concerned about uncontrolled nuclear proliferation?

10. What is the biggest challenge with spent fuel in the United States?

11. Describe at least one lesson learned from one of the accidents at Chernobyl, Three Mile Island, and Fukushima.

12. What are at least two safety features built into a nuclear power plant?

13. Choose one historical event related to nuclear energy and tell how it shapes people's views about nuclear energy.

14. Other than a fuel source to create electricity, name at least two other ways that nuclear science has benefited society.

NUCLEAR ENERGY BINGO

A. Knows the atomic mass of the uranium isotope used in nuclear power plants

B. Knows the name of the process that releases energy in a nuclear power plant

C. Knows the percentage of electricity produced by nuclear power in the U.S.

D. Knows how much CO_2 is produced by nuclear power plants

E. Can name at least one other use for nuclear energy

F. Has visited a nuclear power plant

G. Knows how many nuclear reactors are operating in the U.S.

H. Knows the country that generates the most electricity from nuclear power

I. Can name the country that generates the highest percentage of its electricity from nuclear energy

J. Knows where nuclear waste is currently stored in the U.S.

K. Can name something in our everyday lives that exposes us to radiation

L. Knows the name of the part of the nuclear power plant where thermal energy is released

M. Knows the atomic number of uranium

N. Knows what uranium is processed into for use as nuclear fuel

O. Knows the name of an acceptable on-site storage method for spent fuel

P. Can name at least one part of the nuclear fuel cycle

A NAME	**B** NAME	**C** NAME	**D** NAME
E NAME	**F** NAME	**G** NAME	**H** NAME
I NAME	**J** NAME	**K** NAME	**L** NAME
M NAME	**N** NAME	**O** NAME	**P** NAME

Glossary

alpha particle	a particle released from the nucleus of an atom made of two protons and two neutrons stuck together
atomic mass	the number of neutrons and protons in the nucleus of an atom; also known as the atomic weight
atomic number	the number of protons in the nucleus of an atom, used to identify the atom
beta particle	a negatively charged electron released from the nucleus of an atom
boiling water reactor (BWR)	a reactor in which water is used as both a coolant and a moderator; the water is allowed to boil in the core, making steam, which is used to drive a turbine, and produce electricity
chain reaction	a fission reaction that keeps itself going as one reaction releases neutrons, causing more to follow
climate change	the change in Earth's overall climate patterns since the mid-20th century
containment structure	a concrete and steel enclosure around a nuclear reactor that confines fission products that otherwise might be released into the atmosphere
control rod	a rod, plate, or tube containing a material such as cadmium, boron, etc., used to control the power of a nuclear reactor; by absorbing neutrons, a control rod slows down or stops a chain reaction
cooling tower	a heat exchanger used to cool water that comes from the inside of a nuclear reactor; cooling towers transfer the exhaust heat into the air instead of into a body of water
critical mass	the smallest mass of nuclear material that will support a chain reaction
deuterium (oxide)	an isotope of hydrogen with one proton and one neutron in the nucleus
electricity	moving electrons
electron	the smallest of the three subatomic particles; negatively charged; it can be shared or transferred in chemical bonds to create new compounds; the moving of electrons produces electricity
energy	the ability to do work or produce change
energy efficiency	the amount of useful energy in a system's output compared to its input
enriched uranium	uranium ore contains mostly U-238 and a small amount of U-235; enriched uranium has its concentration of U-235 increased above its natural concentration
evolutionary nuclear reactor	a nuclear reactor designed so that safety systems have the latest technologies and are easy to maintain and monitor
external (cooling) system	the part of the cooling system that interacts with the environment and does not contain radioactive material
fission	the splitting of a nucleus into at least two smaller nuclei and the release of a large amount of energy
fossil fuel	a hydrocarbon, such as petroleum, coal, or natural gas, derived from prehistoric plants and animals and used for fuel
fuel cycle	the series of steps involved in supplying fuel for nuclear power reactors, including mining, milling, enrichment, making fuel rods, use in a reactor, and handling and storage of spent fuel
fuel pellet	a small cylinder approximately the size of a pencil eraser containing uranium fuel (uranium dioxide, UO_2) in a ceramic pellet
fuel rod	a long, slender tube that holds nuclear fuel pellets for reactor use; fuel rods are bundled together in assemblies and placed into the reactor core
fusion	process where smaller nuclei combine and form one atom with the release of energy
gamma radiation	energy in the form of high-energy, short wavelength, electromagnetic radiation released by the nucleus; similar to x-rays and are best stopped or shielded by dense materials, such as lead

greenhouse gases	the gases in the atmosphere, both natural and manmade, that trap and hold thermal energy within the Earth's atmosphere
half-life	time required for half the atoms contained in a sample of a radioactive substance to decay naturally
heat exchanger	a device that transfers thermal energy from one fluid (liquid or gas) to another fluid or to the environment
heavy water (D_2O)	water that contains a significant amount of deuterium, in place of hydrogen, making it more massive; used as a moderator in some reactors because it slows down neutrons effectively
ionizing	the process of adding or removing one or more electrons to or from atoms or molecules creating charged particles
isotope	atom of the same element but with a different mass number
kinetic energy	energy of motion
light water	ordinary water (H_2O) as distinguished from heavy water (D_2O)
meltdown	a severe nuclear reactor accident that can happen if a nuclear power plant system fails, causing the reactor core to no longer be properly controlled and cooled, causing the fuel to melt
moderator	a material, such as ordinary water, heavy water, or graphite, that is used in a reactor to slow down high-velocity neutrons to increase the chances of fission of U-235
neutron	a fundamental subatomic particle that has nearly the same mass as the proton and no charge
Non-Proliferation Treaty (nuclear)	a treaty to limit the spread of nuclear weapons, opened for signature on July 1, 1968
nonrenewable energy sources	energy sources that have a limited supply and cannot be replenished as quickly as they are consumed
nuclear energy	the energy given off by a nuclear reaction (fission or fusion) or by radioactive decay
nuclear fuel cycle	see fuel cycle
nuclear proliferation	the spread of nuclear weapons or materials that can be used to build nuclear weapons; see Non-Proliferation Treaty (nuclear)
Nuclear Regulatory Commission (NRC)	an independent agency created by the United States Congress in 1974 to allow the nation to safely use radioactive materials for civilian purposes; regulates commercial nuclear power plants and other uses of nuclear materials, such as for medical purposes
nucleus	the center of an atom
oxide	a compound in which oxygen is bonded to one or more electropositive atoms
passive nuclear reactor	a nuclear reactor designed so that safety systems operate automatically
pitchblende (U_3O_8)	the main component of high-grade uranium ore and also contains other oxides and sulfides, including radium, thorium, and lead components
plutonium	chemical element with the atomic number 94; plutonium-239 is a fissile isotope produced in nuclear reactors from uranium-238
potential energy	energy of position; stored energy
pressurized water reactor (PWR)	a nuclear reactor in which thermal energy is transferred from the core to an exchanger by high temperature water kept under pressure in the primary system; steam that turns turbines is generated in a secondary circuit; many reactors producing electric power are pressurized water reactors
primary (heat exchange) system	a term that refers to the reactor coolant system
proton	a fundamental particle of an atom that has nearly the same mass as a neutron and a +1 charge
radiation (ionizing)	energy capable of producing ions; examples of ionizing radiation include alpha particles, beta particles, gamma rays, x-rays, neutrons, and high-speed protons
radioactive	a material that emits or releases radiation in the form of alpha or beta particles or gamma rays
radioactivity	the process by which unstable atoms try to become stable, and as a result emit radiation
radionuclide	a radioactive isotope

radon	A naturally occurring radioactive gas found in the earth around the world, where uranium and thorium decay
reactor vessel	The main steel vessel containing the reactor fuel, moderator, and coolant
renewable energy sources	Energy sources that can be replenished in a short period of time
reprocessing	Chemical treatment of nuclear spent fuel to separate uranium and plutonium and possibly other radioactive elements from other waste products to use in new fuel
secondary energy source	A source of energy that requires the use of another source to be produced
secondary (heat exchange) system	The part of a PWR that contains the steam used to turn turbines and generate electricity
spent fuel (used fuel)	Nuclear reactor fuel that has been used until it can no longer sustain a nuclear reaction
static electricity	unbalanced charge that is transferred
thermal reactor	A reactor in which the fission chain reaction is sustained primarily by thermal (relatively slow) neutrons
transmutation	A process involving a change in the number of protons or neutrons in the nucleus, resulting in the formation of a different isotope; occurs during alpha and beta emissions
transuranic	Chemical elements with an atomic number greater than that of uranium (92)
uranium (U)	Chemical element with the atomic number 92; has three natural isotopes, U-234, U-235, and U-238; U-235 is the isotope fissioned in a nuclear reactor
uranium dioxide (UO_2)	An oxide of uranium that is a black, radioactive, crystalline powder; used as fuel in nuclear fuel rods in nuclear reactors
uranium hexafluoride (UF_6)	A white solid obtained by chemical treatment of U_3O_8 and which forms a vapor at temperatures above 56ºC; is the form of uranium required for the enrichment process
uranium oxide ($U_3 O_3$)	See pitchblende
used fuel (spent fuel)	Nuclear reactor fuel that has been used until it can no longer sustain a nuclear reaction
valence electrons	Electrons found in the outer energy level that may leave their level to create electricity
yellowcake	A bright yellow powder obtained from uranium ore that contains uranium oxides used to make nuclear fuel

Energy From Uranium
Evaluation Form

State: ____________ **Grade Level:** ____________ **Number of Students:** ___________

1. **Did you conduct the entire unit?** ☐ Yes ☐ No
2. **Were the instructions clear and easy to follow?** ☐ Yes ☐ No
3. **Did the activities meet your academic objectives?** ☐ Yes ☐ No
4. **Were the activities age appropriate?** ☐ Yes ☐ No
5. **Were the allotted times sufficient to conduct the activities?** ☐ Yes ☐ No
6. **Were the activities easy to use?** ☐ Yes ☐ No
7. **Was the preparation required acceptable for the activities?** ☐ Yes ☐ No
8. **Were the students interested and motivated?** ☐ Yes ☐ No
9. **Was the energy knowledge content age appropriate?** ☐ Yes ☐ No
10. **Would you teach this unit again?** ☐ Yes ☐ No

Please explain any 'no' statement below.

How would you rate the unit overall? ☐ excellent ☐ good ☐ fair ☐ poor

How would your students rate the unit overall? ☐ excellent ☐ good ☐ fair ☐ poor

What would make the unit more useful to you?

Other Comments:

Please fax or mail to: **The NEED Project**
8408 Kao Circle
Manassas, VA 20110
FAX: 1-800-847-1820

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