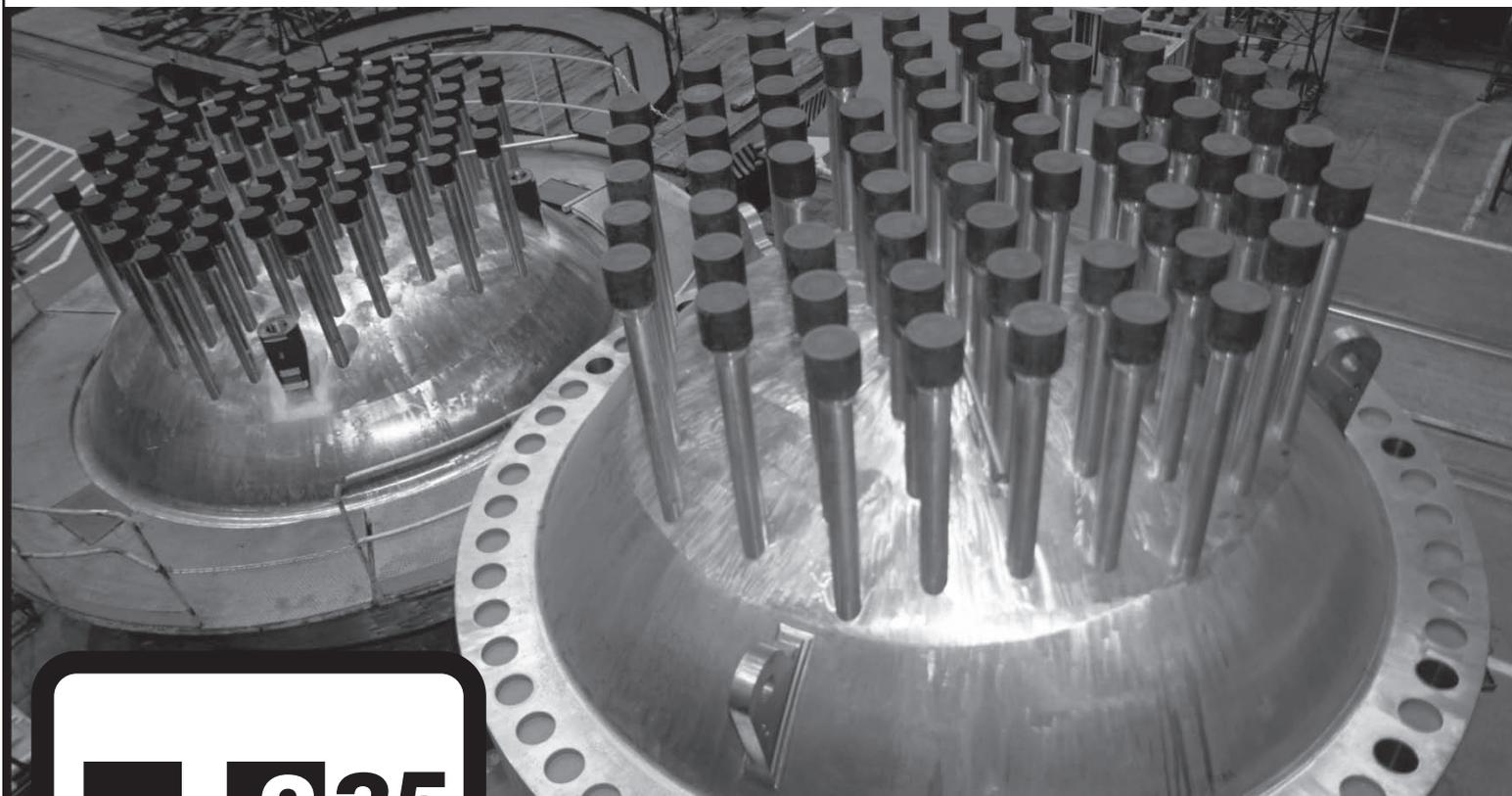


# Exploring Nuclear Energy

Integrated activities that provide a comprehensive understanding of the scientific, economic, environmental, technological, and societal aspects of nuclear energy to secondary students.



**Grade Level:**

- Secondary

**Subject Areas:**

- Science
- Social Studies
- Language Arts
- Technology



National Energy Education Development Project



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## 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.

## Teacher Advisory Board Statement

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

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## Energy Data Used in NEED Materials

NEED believes in providing the most recently reported energy data available to our teachers and students. Most statistics and data are derived from the U.S. Energy Information Administration's Annual Energy Review that is published in June of each year. Working in partnership with EIA, NEED includes easy to understand data in our curriculum materials. To do further research, visit the EIA web site at [www.eia.gov](http://www.eia.gov). EIA's Energy Kids site has great lessons and activities for students at [www.eia.gov/kids](http://www.eia.gov/kids).



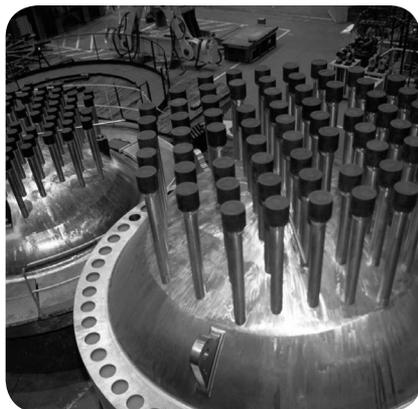
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# Exploring Nuclear Energy

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# Correlations to National Science Education Standards: Grades 9-12

This book has been correlated to National Science Education Content Standards.  
For correlations to individual state standards, visit [www.NEED.org](http://www.NEED.org).

## Content Standard B | *PHYSICAL SCIENCE*

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### ▪ **Structure of Atoms**

- Matter is made of minute particles called atoms, which are composed of even smaller components. These components have measurable properties, such as mass and electrical charge.
- Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called isotopes of the element.
- The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart.
- Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions.
- Fission is the splitting of a large nucleus into smaller pieces.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation.

### ▪ **Conservation of Energy and the Increase in Disorder**

- The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.
- All energy can be considered to be either kinetic energy—the energy of motion; potential energy—which depends on relative position; or energy contained by a field, such as electromagnetic waves.

## Content Standard F | *SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES*

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### ▪ **Natural Resources**

- Human populations use resources in the environment to maintain and improve their existence.
- The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and depletes those resources that cannot be renewed.
- Humans use many natural systems as resources. Natural systems have the capacity to reuse waste but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

### ▪ **Environmental Quality**

- Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.
- Materials from human societies affect both physical and chemical cycles of the earth.
- Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth.



## Correlations to National Science Education Standards: Grades 9-12

This book has been correlated to National Science Education Content Standards.  
For correlations to individual state standards, visit [www.NEED.org](http://www.NEED.org).

### ▪ **Natural and Human-induced Hazards**

- Normal adjustments of earth may be hazardous for humans.
- Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change.
- Some hazards are rapid and spectacular, others are slow and progressive.
- Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards—ranging from those with minor risk to a few people to major catastrophes with major risk to many people.

### ▪ **Science and Technology in Local, National, and Global Challenges**

- Science and technology can indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge.
- Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science and technology related challenges. However, understanding science alone will not resolve local, national, and global challenges.
- Individuals and society must decide on proposals involving new research and the introduction of new technologies into society.



# Materials

	<b>Materials Needed Per Group</b>	
<i>Science of Electricity</i>	<ul style="list-style-type: none"><li>▪ Small round bottle</li><li>▪ 4 Strong rectangle magnets</li><li>▪ 1 12" x ¼" Wooden dowel</li><li>▪ 1 Rubber stopper with ¼" center hole</li><li>▪ Magnet wire</li><li>▪ Tape</li><li>▪ Marker</li><li>▪ 1 Small nail</li><li>▪ 1 Large nail</li></ul>	<ul style="list-style-type: none"><li>▪ Fine sandpaper</li><li>▪ Multimeter</li><li>▪ Foam tube</li><li>▪ Sharp-pointed scissors</li><li>▪ Alligator clips</li><li>▪ Ruler</li><li>▪ Hand operated pencil sharpener</li><li>▪ Push pin</li></ul>
<i>Radioactivity</i>	<ul style="list-style-type: none"><li>▪ Graph paper</li></ul>	
<i>M&amp;M Chemistry: Radioactive Decay and Average Atomic Weight</i>	<ul style="list-style-type: none"><li>▪ 100 M&amp;M candies*</li><li>▪ Small cup for each pair of students</li><li>▪ Paper towel</li></ul>	<ul style="list-style-type: none"><li>▪ Digital balance</li><li>▪ Graph paper</li></ul>
<i>Nuclear Energy Expo</i>	<ul style="list-style-type: none"><li>▪ Tri-fold board</li><li>▪ Markers</li></ul>	
<i>Milling Simulation</i>	<ul style="list-style-type: none"><li>▪ Sand</li><li>▪ Salt</li><li>▪ Gravel</li><li>▪ Screen</li><li>▪ Filter</li><li>▪ 50 mL Water</li></ul>	<ul style="list-style-type: none"><li>▪ Beaker</li><li>▪ Evaporation dish</li><li>▪ Heating source</li><li>▪ Balance</li><li>▪ Safety glasses</li><li>▪ Stirrer</li></ul>
<i>Uranium in the Round</i>	<ul style="list-style-type: none"><li>▪ <i>Uranium in the Round</i> cards</li></ul>	
<i>Culminating Activity: Nuclear Power Plant Hearing or Letter Prompt</i>	<ul style="list-style-type: none"><li>▪ Internet access for students</li></ul>	

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



# Teacher Guide

Integrated activities that provide a comprehensive understanding of the scientific, economic, environmental, technological, and societal aspects of nuclear energy to secondary students.

## 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 list of materials can be found on page 6.

## 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.

## Activity 1: Introduction

### Objective

Students will develop a basic understanding of the principles of nuclear energy.

### Time

- 1 class period

### Materials

- *Think, Learn, Question (TLQ)*, page 16
- Student informational text
- Culminating Project Rubric, page 13 (optional)

### Procedure

1. Make copies of the informational text and *Think, Learn, Question (TLQ)* worksheet for each student.
2. 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.
3. 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.
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 12 and 35-36 for more details about the hearing.
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 notes, or using the *TLQ* handout. Students can complete the reading during class time or as homework, depending on your preference.

## Grade Level

- Secondary Grades 9-12

## Time

- Approximately 10-20 45-minute classes, depending on the activities selected

## Activity 2: Science of Electricity

### Objective

Students will understand how electricity is generated.

### Time

- 1–2 class periods

### Materials *FOR EACH GROUP*

- 1 Small round bottle
- 4 Strong rectangle magnets
- 1 12" x 1/4" Wooden dowel
- 1 Rubber stopper with 1/4" center hole
- Magnet wire
- Tape
- Marker
- 1 Small nail
- 1 Large nail
- Fine sandpaper
- Multimeter
- Alligator clips
- Foam tube
- Sharp-pointed scissors
- Ruler
- Hand operated pencil sharpener
- *Science of Electricity Model* Instructions, pages 19-21
- *Science of Electricity Hints and Tips*, page 22

### Procedure

1. Make copies of the *Science of Electricity Model* Instructions.
2. As a class, review how electricity is generated from previous reading.
3. Assign students to work in groups of four. Using the *Science of Electricity Model* instructions students should work together to build their own generator. See page 22 for magnet safety information and troubleshooting tips for your turbine.
4. After students have tested their generators by spinning them by hand, have them think about other ways that could be used to turn the dowel that would be easier and more consistent.

### Extension

Provide your students extra time and materials to add to their generators so they can produce electricity from another source, other than the motion energy of their hands.

## Activity 3: Radioactivity

### Objective

Students will understand that many different elements are radioactive and that radiation is present at all times in the environment.

### Time

- 1 class period

### Materials

- *Radioactivity: Stable and Unstable Isotopes* activity, pages 23-24
- Graph paper
- *Radiation Dose Chart\**, page 25

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

## Procedure

---

1. Make copies of the student activities.
2. As a class, review the topic of radiation and radioactive isotopes.
3. Using the *Radioactivity: Stable and Unstable Isotopes* activity, students find the missing information and complete the chart.
4. Students should plot the stable isotope points on a graph with the protons along the X axis and the neutrons along the Y axis.
5. When the points have been plotted, students should draw a curve through the points.
6. Students plot the points of the unstable isotopes on the same graph.
7. Give each student a copy of the *Radiation Dose Chart*. Help students determine elevation, if needed. Discuss with students the different sources of radiation and have them determine the yearly amount of radiation to which they are exposed. Are students surprised by the results?

## Technology Connection

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Have students search the *Table of Isotopes* at: <http://ie.lbl.gov/education/isotopes.htm>. Students can choose which element and isotopes they would like to graph. Using Excel or another graphing program, students will be able to more easily graph larger proton to neutron ratios.

## Activity 4 and 5: M&M Chemistry

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### Objective

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Students will understand how atoms decay and how different isotopes of the same element exist.

### Time

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- 1-2 class periods

### Materials FOR EACH GROUP

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- |                    |  |
|--------------------|--|
| ▪ 100 M&M candies* | ▪ <i>Radioactive Decay</i> worksheet, page 26        |
| ▪ Small cup        | ▪ Graph paper  |
| ▪ Paper towel      | ▪ <i>Average Atomic Weight</i> worksheet, page 27    |
| ▪ Balance          | ▪ <i>Examining Nuclear Energy</i> worksheet, page 28 |

### Preparation

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- Put 100 M&Ms in a small cup for each pair of students.
- Make copies of student worksheets.

### Radioactive Decay Procedure

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1. Review the concept that unstable (radioactive) elements want to be stable. Radioactive isotopes go through a process of decay to reach a stable state. When an element decays so that half of its atoms remain, this is a half-life.
2. Pass out the *Radioactive Decay* worksheet and have students complete the activity.
3. When all of the atoms have decayed, students should graph their data. Remind them not to eat M&Ms until they finish the next activity.  
\*NOTE: You do not have to use M&M candies for this activity. Any marked, two sided object will work, including other candies, pennies, and two-sided discs. Also, on yellow candies, it is sometimes difficult to clearly see the printing on each piece.

### **Atomic Weight Procedure**

---

1. Explain to students that natural uranium contains 99.28% U-238, 0.71% U-235, and 0.04% U-234. This is similar to other elements in nature, many of their isotopes are combined. Scientists look at the average atomic weight of the element, taking into account the weights of each isotope and the percentage that is found.
2. Students will need two separate colors of M&Ms and a balance. Pass out the *Average Atomic Weight* worksheet.
3. Students should follow the directions to find the average atomic weight of boron.
4. In nature, boron contains 18.4% of B-10 and 81.6% of B-11 so the results students obtain are close to real life.
5. Assign students to review the section on nuclear energy in the informational text, if needed. Pass out the *Examining Nuclear Energy* worksheet. Have students complete for class work or homework.

### **Social Studies Connection**

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

## **Activity 6: Nuclear Energy Expo**

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### **Objective**

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Students will understand the processes and issues involved in and associated with using nuclear energy.

### **Time**

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- 3 class periods

### **Materials** FOR EACH GROUP

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- Tri-fold board
- Markers
- *Nuclear Energy Expo* questions, pages 29-30

### **Procedure**

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1. Divide students into small groups and have each group research their topic using the informational text, [www.NEED.org/nuclear](http://www.NEED.org/nuclear), and other resources as needed.
  - Fission
  - Nuclear Fuel Cycle
  - Nuclear Power Plants and Reactors
  - Safeguards and Fuel Waste
  - Nuclear Weapons and Proliferation
  - Economics of Nuclear Energy
  - The Nuclear Navy
  - Nuclear Medicine
  - Marie Curie
  - Nuclear Accidents
2. Project or give each student the questions that apply to his/her assignment. They should use these questions to guide the information that they will present.
3. Session 1—Students read their section, brainstorm ways to present the information to the class, and start to prepare presentations.
4. Session 2—Students finish preparations.
5. 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.

### **Technology Connection**

---

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

## Activity 7: Milling Simulation

### 🎯 Objective

Students will understand that materials can be physically and chemically separated.

### 🕒 Time

- 1 class period

### 📄 Materials FOR EACH GROUP

- Sand/salt/gravel mixture (see below for suggested ratios)
- Screen
- Filter
- 50 mL Water
- Evaporation dish
- Heat source
- Scale or balance
- Stirrer

### 📄 Materials FOR EACH STUDENT

- Safety glasses
- *Milling Simulation* worksheet, page 31

### ☑ Procedure

1. Make copies of the activity for each student.
2. Make different compositions by mass of the salt/sand/gravel mixture. Some suggested mixtures are: 10g/10g/5g or 5g/10g/10g, or 8g/12g/5g, or 10g/5g/10g or 12g/8g/5g. Each of these mixtures will be enough for one group of 2-3 students.
3. Following the directions on the *Milling Simulation* worksheet, students will work to separate the salt from the sand that the teacher has already prepared.
4. Do not tell students what the composition of their mixture is. After students have determined how much “uranium” they recovered, they should compare their results to the actual amount of salt in the mixture. When students have their recovered percentage, give them the known mass values of the mixture so students can calculate the percent error in the lab.
5. 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. Discuss the different percent errors and what may have led to the differences in values.
6. Explain that every uranium mine contains a different percentage of uranium. Canada has some of the best uranium ore and they 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 over 900 kg of ore may only produce 10 kg of uranium.

## Activity 8: Uranium in the Round

### 🎯 Objective

Students will become proficient at identifying information and vocabulary about nuclear energy.

### 📄 Materials

- *Uranium in the Round* cards, pages 32-34

### 🔧 Preparation

- Copy the squares onto card stock and cut into individual cards.

### ☑ 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 the informational text.
3. Choose any student to begin and have them read the question on their 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.

## Activity 9: Culminating Activity: Nuclear Power Plant Hearing and Letter Prompt

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### Objective

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Students will understand that there are advantages and challenges of nuclear energy.

### Time

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

### Materials

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- Copies of the *Nuclear Power Plant Hearing* or *Nuclear Energy Letter Prompt* directions, pages 35-37

### Procedure

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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 of the informational text. Discuss both lists. Are there some items that are more important than others? Why? What do you need to take into consideration if you were to decide whether or not a new nuclear plant should be built?
2. From the activities below, choose which culminating activity to do with your class.

### Mock Hearing

---

Assign pairs or small groups of students different roles to take. Explain to students that a Combined 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.

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 letter to the intended recipient. Further details of the letter assignment are on page 37.

### Extension

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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

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- Evaluate student work using the rubric provided or a rubric of your choice.
- A final assessment on nuclear energy is located on pages 38-40.
- Evaluate the unit with your students using the *Evaluation Form* on page 67 and return it to NEED.



# Rubric

	<b>CONTENT</b>	<b>ORGANIZATION</b>	<b>ORIGINALITY</b>	<b>WORKLOAD</b>
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.



# Internet Resources

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

**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 web sites 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.new.ans.org](http://www.new.ans.org).

**AREVA**—AREVA covers every stage of the fuel cycle, reactor design and construction, and related services. Based in France, AREVA is actively involved in the U.S. nuclear industry, [www.us.areva.com](http://www.us.areva.com).

**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](http://www.cfr.org). The CFR also has an online interactive Nuclear Energy Guide, [www.cfr.org/interactives/IG\\_Nuclear/index.html](http://www.cfr.org/interactives/IG_Nuclear/index.html).

**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](http://www.eia.gov).

**EIA Energy Kids Page**—Energy information tailored for students, [www.eia.gov/kids](http://www.eia.gov/kids).

**Environmental Protection Agency (EPA)**—For more information about radiation and radon visit, [www.epa.gov](http://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](http://www.iaea.org).

**Nuclear Chemistry and the Community**—A review and case study of nuclear chemistry, [www.chemcases.com/nuclear/index.htm](http://www.chemcases.com/nuclear/index.htm).

**Nuclear Education Resources (NEI)**—A searchable database of nuclear education materials. Narrow your search by education level, audience, media type, and topic, <http://nucleared.wlu.edu>.

**Nuclear Energy Institute**—The NEI is the policy organization for the nuclear technologies industry in the United States, [www.nei.org](http://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](http://www.nrc.gov).

**Office of Civilian Radioactive Waste Management (OCRWM)**—OCRWM's mission is to manage and dispose of high-level radioactive waste and spent nuclear fuel in a manner that protects health, safety, and the environment; enhances national and energy security; and merits public confidence, [www.doe.gov/downloads/office-civilian-radioactive-waste-management-0](http://www.doe.gov/downloads/office-civilian-radioactive-waste-management-0).

**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.nuclear.energy.gov](http://www.nuclear.energy.gov).

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



# Nuclear Energy Assessment Answer Key

1. Label the Atom
  - a. Electron—negatively charged particle, very small
  - b. Energy level—(shells) where electrons orbit
  - c. Nucleus—center of atom, composed of protons and neutrons, positively charged
  - d. Proton—positively charged, mass of 1
  - e. Neutron—no charge, mass of 1
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 Vessel—dual layered with a thick steel wall, holds the nuclear reactor.
  - b. Pump—keeps water circulating throughout the reactor.
  - c. Fuel Assemblies—holds the fuel rods (225-250 rods/assembly).
  - d. Pressurizer—in a pressurized water reactor, the pressurizer holds the water at a high pressure so that it doesn't boil.
  - e. Containment Building—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.
  - f. Control Rods—contain boron or cadmium to absorb or capture neutrons, slowing or stopping the nuclear fission chain reaction.
  - g. Moderator—material used to slow down neutrons in a reactor.
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 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 backup systems to cool reactors, modify hardware for use during emergencies, protect backup generators and batteries
12. Safety Features (possible answers include): containment building, training of operators/workforce, automatic shut down/control rods automatically drop, water in the containment shell, dual layers of containment building 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.



# 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



Group  
1  
IA

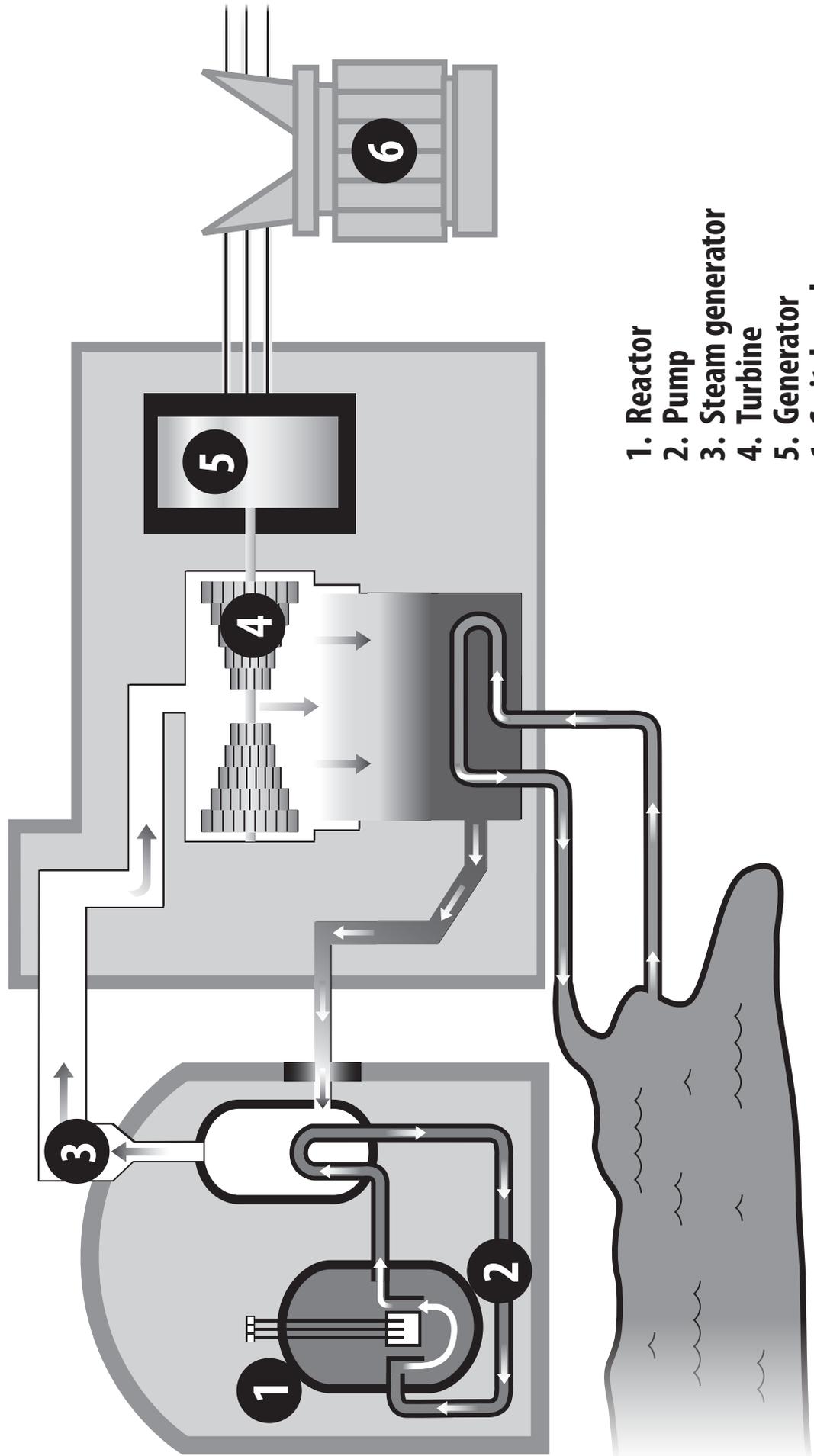
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18																																																																						
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602	3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182	5 <b>Na</b> Sodium 22.989770	6 <b>Mg</b> Magnesium 24.3050	7 <b>Sc</b> Scandium 44.955910	8 <b>Ti</b> Titanium 47.867	9 <b>V</b> Vanadium 50.9415	10 <b>Cr</b> Chromium 51.9961	11 <b>Mn</b> Manganese 54.938049	12 <b>Fe</b> Iron 55.845	13 <b>Co</b> Cobalt 58.933200	14 <b>Ni</b> Nickel 58.6934	15 <b>Cu</b> Copper 63.546	16 <b>Zn</b> Zinc 65.409	17 <b>Ga</b> Gallium 69.723	18 <b>Ge</b> Germanium 72.64	19 <b>As</b> Arsenic 74.92160	20 <b>Se</b> Selenium 78.96	21 <b>Br</b> Bromine 79.904	22 <b>Kr</b> Krypton 83.798	23 <b>Rb</b> Rubidium 85.4678	24 <b>Sr</b> Strontium 87.62	25 <b>Y</b> Yttrium 88.90585	26 <b>Zr</b> Zirconium 91.224	27 <b>Nb</b> Niobium 92.90638	28 <b>Mo</b> Molybdenum 95.94	29 <b>Tc</b> Technetium (98)	30 <b>Ru</b> Ruthenium 101.07	31 <b>Rh</b> Rhodium 102.90550	32 <b>Pd</b> Palladium 106.42	33 <b>Ag</b> Silver 107.8682	34 <b>Cd</b> Cadmium 112.411	35 <b>In</b> Indium 114.818	36 <b>Sn</b> Tin 118.710	37 <b>Pb</b> Lead 207.2	38 <b>Tl</b> Thallium 204.3833	39 <b>Po</b> Polonium (209)	40 <b>At</b> Astatine (210)	41 <b>Rn</b> Radon (222)	42 <b>Fr</b> Francium (223)	43 <b>Ra</b> Radium (226)	44 <b>Cs</b> Cesium 132.90545	45 <b>Ba</b> Barium 137.327	46 <b>Hf</b> Hafnium 178.49	47 <b>Ta</b> Tantalum 180.9479	48 <b>W</b> Tungsten 183.84	49 <b>Re</b> Rhenium 186.207	50 <b>Os</b> Osmium 190.23	51 <b>Ir</b> Iridium 192.217	52 <b>Pt</b> Platinum 195.078	53 <b>Au</b> Gold 196.96655	54 <b>Hg</b> Mercury 200.59	55 <b>Tl</b> Thallium 204.3833	56 <b>Po</b> Polonium (209)	57 <b>At</b> Astatine (210)	58 <b>Rn</b> Radon (222)	59 <b>La</b> Lanthanum 138.9055	60 <b>Ce</b> Cerium 140.116	61 <b>Pr</b> Praseodymium 140.90765	62 <b>Nd</b> Neodymium 144.24	63 <b>Pm</b> Promethium (145)	64 <b>Sm</b> Samarium 150.36	65 <b>Eu</b> Europium 151.964	66 <b>Gd</b> Gadolinium 157.25	67 <b>Tb</b> Terbium 158.92534	68 <b>Dy</b> Dysprosium 162.500	69 <b>Ho</b> Holmium 164.93032	70 <b>Er</b> Erbium 167.259	71 <b>Tm</b> Thulium 168.93421	72 <b>Yb</b> Ytterbium 173.04	73 <b>Lu</b> Lutetium 174.967	74 <b>Ac</b> Actinium (227)	75 <b>Th</b> Thorium 232.0381	76 <b>Pa</b> Protactinium 231.03588	77 <b>U</b> Uranium 238.02891	78 <b>Np</b> Neptunium (237)	79 <b>Pu</b> Plutonium (244)	80 <b>Am</b> Americium (243)	81 <b>Cm</b> Curium (247)	82 <b>Bk</b> Berkelium (247)	83 <b>Cf</b> Californium (251)	84 <b>Es</b> Einsteinium (252)	85 <b>Fm</b> Fermium (257)	86 <b>Md</b> Mendelevium (258)	87 <b>No</b> Nobelium (259)	88 <b>Lr</b> Lawrencium (262)

Atomic Number: 58  
Symbol: Ce  
Name: Cerium  
Atomic Weight: 140.116

Lanthanides  
Actinides



# Pressurized Water Reactor



- 1. Reactor
- 2. Pump
- 3. Steam generator
- 4. Turbine
- 5. Generator
- 6. Switchyard



# Science of Electricity Model

## Objective

To demonstrate how electricity is generated.

## Materials

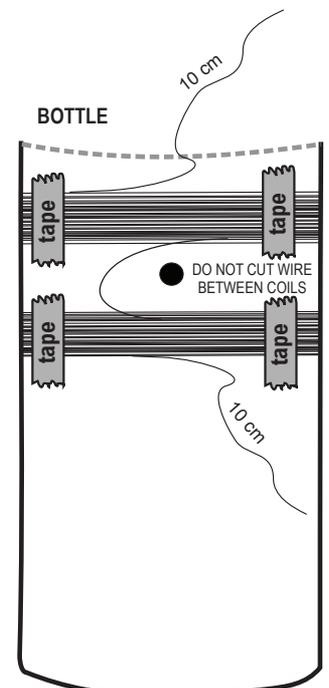
- |                                 |                          |                                   |
|---------------------------------|--------------------------|-----------------------------------|
| ▪ 1 Small round bottle          | ▪ 1 Large nail           | ▪ 1 Push pin                      |
| ▪ 1 Rubber stopper with ¼" hole | ▪ Magnet wire            | ▪ Multimeter with alligator clips |
| ▪ 1 Wooden dowel (12" x ¼")     | ▪ Permanent marker       | ▪ Hand operated pencil sharpener  |
| ▪ 4 Strong rectangle magnets    | ▪ Sharp-pointed scissors | ▪ Ruler                           |
| ▪ 1 Foam tube                   | ▪ Masking tape           |                                   |
| ▪ 1 Small nail                  | ▪ Fine sandpaper         |                                   |

## 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.
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 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 in a hand operated pencil sharpener (the dowel does not have to sharpen into a fine point). Push the sharpened end of the dowel 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.
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

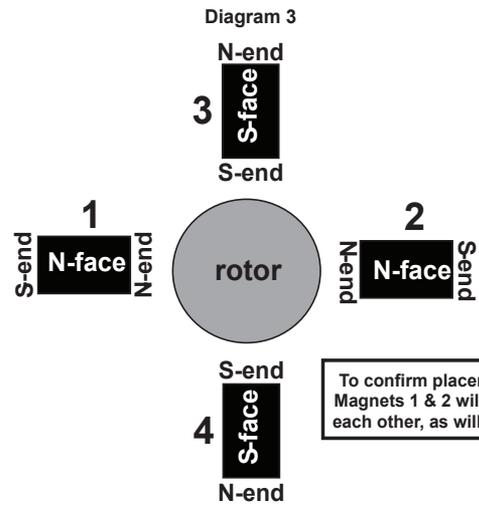
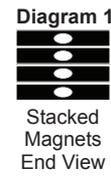
1. Tear 6 pieces of tape approximately 6 cm long each and set aside.
2. Take the bottle and the magnet wire. Leave a 10 cm tail, and tape the wire to the bottle about 2 cm below hole A. Wrap the wire clockwise 200 times, stacking each wire wrap on top of each other. Keep the wire wrap below the holes, do not cover 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 (see diagram).
4. Without cutting the wire, move the wire about 2 cm above the hole to begin the second coil of wraps. Tape the wire to secure it in place.
5. Wrap the wire 200 times clockwise, again stacking each wrap on top of each other. Hold the coil in place with tape (see diagram).
6. Unwind 10 cm of wire (for a tail) from the spool and cut the wire.
7. Check your coil wraps. Using your fingers, pinch the individual wire wraps to make sure the wire is close together. Re-tape the coils in place as needed.
8. Using fine sandpaper, remove the enamel coating from 4 cm of the end of each wire tail.



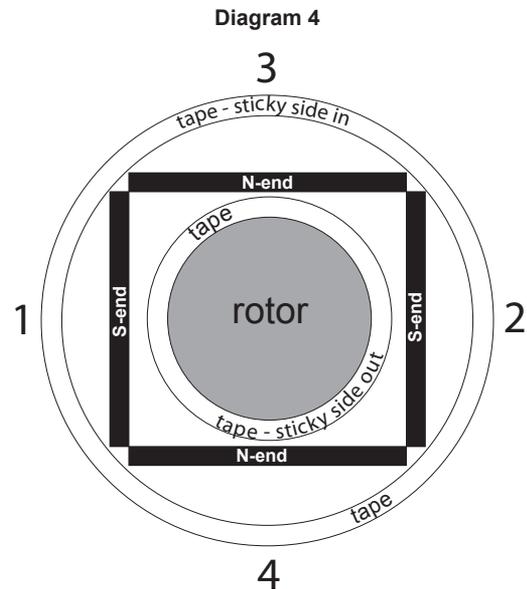
## Rotor Assembly

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 is 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 a small nail directly through the rotor's center using your mark as a guide.
4. Remove the small nail and insert a bigger nail.
5. Remove the nail and push the dowel through, then remove the dowel and set aside.
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 to indicate the N-end as shown in Diagram 1.
7. Mark the top face of each stacked magnet with an N using a permanent marker (Diagram 2) as you remove the magnets from the top one at a time. Place them around the foam piece as shown in Diagram 3. Make sure you place the magnets at a distance so they do not snap back together. The unmarked faces and ends of the magnets will indicate the south poles.
8. Wrap a piece of masking tape around the curved surface of the rotor, sticky side out.
9. Lift the S-end of Magnet 1 to a vertical position and attach it to the rotor. Repeat for Magnet 2.
10. Lift the N-end of Magnet 3 to a vertical position and attach to the rotor. Repeat for Magnet 4.
11. Secure the magnets in place by wrapping another piece of masking tape over the magnets, sticky side in (Diagram 4).

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

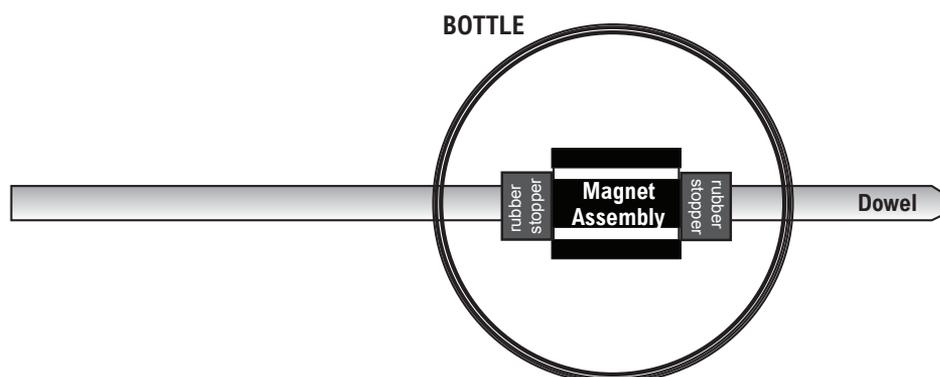


To confirm placement, Magnets 1 & 2 will repel each other, as will 3 & 4.



## Generator Assembly: Part 2

1. Cut the rubber stopper in half to create two stoppers.
2. Slide the sharp end of the dowel through hole A.
3. 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.
4. Slide the sharp end of the dowel through hole B until it sticks out about 4 cm from the bottle.
5. Make sure your dowel can spin freely. Adjust the rotor so it is in the middle of the bottle.







# Science of Electricity Hints and Tips

## **⚠ Magnet Safety**

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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.

## **Hints and Tips**

---

1. Test the model with the multimeter.
2. Was the wire coating removed from the ends of the wire? Has the exposed wire oxidized?
3. Were the coils of wire placed on the template as directed, rotating clockwise and counter-clockwise?
4. Are the magnets alternating north and south facing?



# Radioactivity: Stable and Unstable Isotopes

The Periodic Table of the Elements lists all of the chemical elements that have been identified so far. On the table you will see one listing per element. However, many elements have variations called isotopes. They have the same number of protons, but a different number of neutrons.

Isotopes are identified by their atomic mass. An atom's atomic number represents the number of protons in the element. When you subtract the atomic number from the atomic mass you find the number of neutrons in the element or isotope.

Unstable isotopes want to be stable. Atoms undergo a variety of different processes to change the proton/neutron ratio in the nucleus as it becomes stable. Atoms with 83 or more protons in the nucleus can emit alpha particles, which reduce the size of the nucleus. Atoms can also decay by losing a beta particle, which converts a neutron into a proton. Other methods for becoming stable include positron emission where a proton is converted to an electron, or electron capture where protons are converted to neutrons. Gamma radiation, a very short wavelength of pure energy, can also be released during radioactive decay.

There are multiple decay paths for isotopes, and some isotopes decay faster than others. Below is a table showing one decay path for Uranium-238.

Isotope	Half-Life	Decay Mode
Uranium-238	4.5 billion years	alpha
Thorium-234	24.1 days	beta
Protactinium-234	1 minute	beta
Uranium-234	245,000 years	alpha
Thorium-230	76,000 years	alpha
Radium-226	1,600 years	alpha
Radon-222	3.8 days	alpha
Polonium-218	3.0 minutes	alpha
Lead-214	27 minutes	beta
Bismuth-214	20 minutes	beta
Polonium-214	<1 second	alpha
Lead-210	22.3 years	beta
Bismuth-210	5 days	beta
Polonium-210	138.4 days	beta
Lead-206	stable	

## Directions

1. Complete the tables on the following page. Use the Periodic Table of the Elements to find the atomic number and number of protons.
2. On a separate piece of graph paper, draw a vertical Y axis and label it "Neutrons" with a scale from 0-150.
3. Draw a horizontal X axis and label it "Protons" with a scale from 0-100.
4. Plot the points of the stable isotopes. When all isotopes have been plotted, draw a bold curve through the points. Make the curve as smooth as possible. This is the "band of stability."
5. Next, plot the unstable points on the graph. Use a key so you can identify the different isotopes.
6. Where do the unstable isotopes fall relative to the band of stability?



## Radioactivity: Stable and Unstable Isotopes

Stable Isotope	Atomic Number	Protons (X axis)	Neutrons (Y axis)
Helium-4			
Carbon-12			
Silicon-28			
Scandium-45			
Iron-56			
Silver-109			
Xenon-131			
Gadolinium-160			
Tungsten-184			
Lead-206			

Unstable Isotope	Atomic Number	Protons (X axis)	Neutrons (Y axis)
Carbon-14			
Silicon-32			
Iron-52			
Xenon-135			
Lead-214			
Radium-226			

There are currently 243 isotopes identified as stable, and 70 naturally occurring unstable isotopes, and many more that are unstable as a result of processes such as nuclear fission. These charts are only a small representation of the stable and unstable isotopes.



# 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 use luggage inspection at airports (using a typical x-ray machine), add 0.002.....
10. For each smoke detector you have add 0.008 .....
11. If you wear a plutonium-powered cardiac pacemaker, add 100 .....
12. 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), add 14 .....
13. If you live within 50 miles of a nuclear power plant (pressurized water reactor), add 0.0009 .....
14. 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 360mrem of whole body radiation each year from all sources.

Activity from www.nrc.gov.





# Average Atomic Weight

In this activity you will assemble two stable isotopes of boron, boron-10, and boron-11, and calculate the average weight of boron.

## Materials

- M&Ms (two colors)
- Digital balance

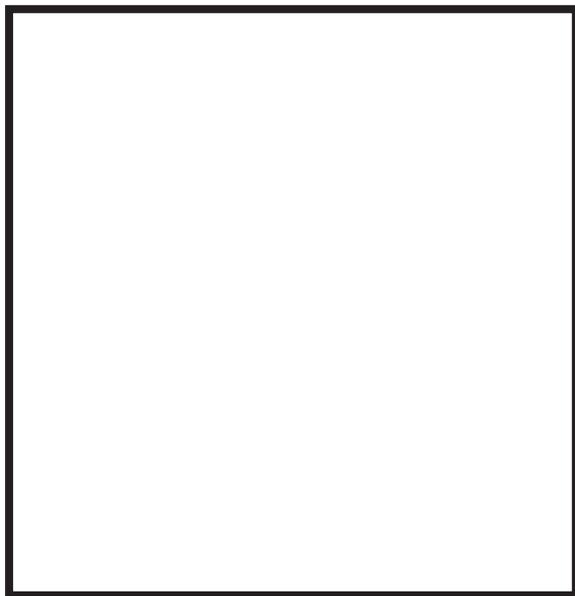
## Procedure

1. Choose one color to represent protons and the other color will represent neutrons.
2. Make one atom of boron-10 with five protons and five neutrons.
3. Make four atoms of boron-11, each boron-11 atom has five protons and six neutrons.
4. Measure the weight of boron-10.
5. Measure the weight of boron-11.
6. Calculate the average weight of boron by dividing the total weight by the number of atoms (five).

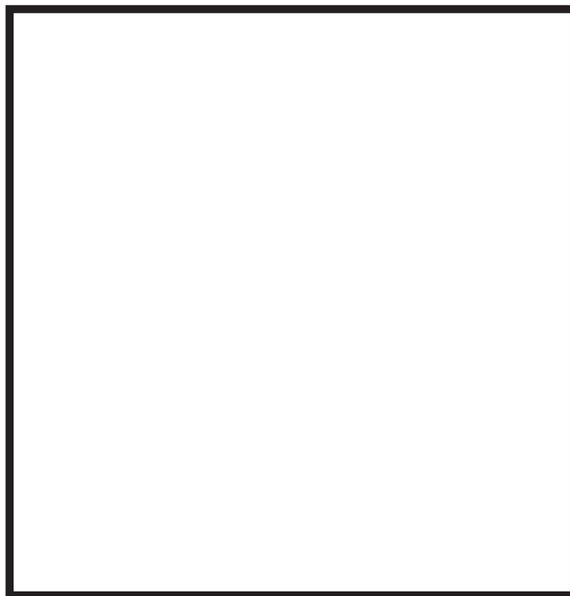
## Data

Draw a diagram of each boron atom. Label the protons and neutrons.

Boron-10



Boron-11



Mass of boron-10 atom \_\_\_\_\_

Mass of boron-11 atom \_\_\_\_\_

Percentage of Isotope \_\_\_\_\_

Percentage of Isotope \_\_\_\_\_

Average Weight of Boron \_\_\_\_\_



# 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:



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

Mass of U-235 = 235.044

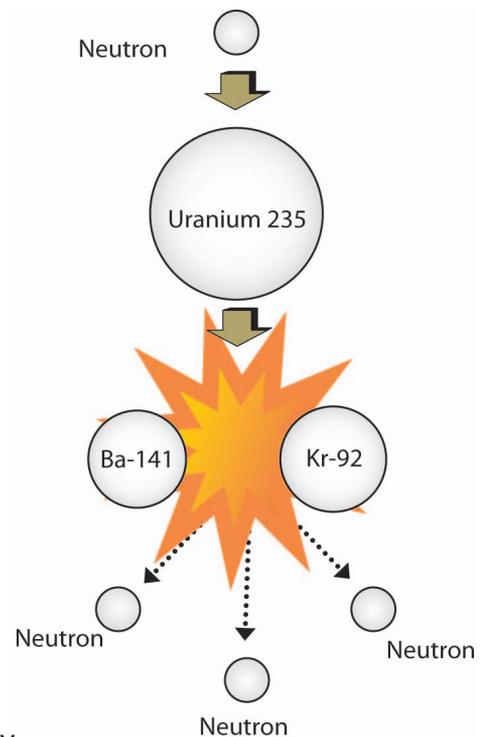
Mass of Kr-92 = 91.926

Mass of Ba-141 = 140.914

Mass of one neutron = 1.00866

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

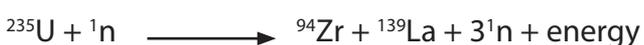
Left Side	→	Right Side
U-235 _____		Kr-92 _____
+ n _____		+ Ba-141 _____
		+ n _____
		+ n _____
		+ n _____
Total = _____		Total = _____



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:





# 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 do you see 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 “yellow cake”?

## 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 Used Fuel

---

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 nuclear used 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?

## **Influential Women In Nuclear Science**

---

1. What influenced Madame Curie to start work in the sciences?
2. What did she 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?

## **Nuclear Navy**

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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**

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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?



# Milling Simulation

## Background

When uranium is mined it has to be separated from the ore from 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 be extracted from a mixture?

## Materials

- Salt/sand/gravel mixture
- 50 mL of Water
- Evaporation dish
- Heat source
- Screen
- Filter
- Beaker
- Safety glasses
- Stirrer

## 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, stir.
4. Put a filter over the beaker and pour the water mixture over the filter. The material collected on the filter is your "waste rock." Set this aside.
5. Pour the water from the beaker into an evaporation dish or crucible. Boil the solution until all of the water evaporates.
6. Collect the solid material left in the evaporating dish or crucible. 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 gravel and large pieces 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.
9. Calculate the percent error in the recovery process.

## Data

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

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

$$\text{Mass of "Uranium"} = \text{Mass of Uranium} / 25 \text{ g}$$

$$\text{Percent Error} = \frac{|\text{Measured Value} - \text{Actual Value}|}{\text{Actual Value}} \times 100$$

## Conclusions

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?



# Uranium in the Round

**I have thermal energy.**

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

**I have fusion.**

Who has the form of energy emitted into space from the sun by fusion?

**I have energy.**

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

**I have radiant energy.**

Who has the process in which an atom is split?

**I have chemical energy.**

Who has the center of an atom?

**I have fission.**

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

**I have nucleus.**

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

**I have uranium.**

Who has the types of energy released during nuclear fission?

**I have nuclear energy.**

Who has the process that combines hydrogen atoms into helium in the sun?

**I have thermal energy and radiant energy.**

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

<p><b>I have nonrenewable.</b></p> <p>Who has the neutron-bombardment process that keeps fission going in a nuclear reactor?</p>	<p><b>I have 19.6%.</b></p> <p>Who has the place where fission occurs in a nuclear power plant?</p>
<p><b>I have chain reaction.</b></p> <p>Who has the production facility where electricity is generated?</p>	<p><b>I have reactor.</b></p> <p>Who has the isotope of uranium used for nuclear fuel whose atoms are easily split?</p>
<p><b>I have power plant.</b></p> <p>Who has the number of nuclear reactors operating in the United States?</p>	<p><b>I have U-235.</b></p> <p>Who has the form into which uranium is processed to be used for nuclear fuel?</p>
<p><b>I have 104.</b></p> <p>Who has the usable energy produced by a nuclear power plant?</p>	<p><b>I have ceramic pellet.</b></p> <p>Who has the term for a bundle of fuel rods in a reactor's core?</p>
<p><b>I have electricity.</b></p> <p>Who has the percentage of electricity produced by nuclear energy in the U.S.?</p>	<p><b>I have fuel assembly.</b></p> <p>Who has the term for U-235 that has been fissioned and removed from a reactor?</p>

**I have spent fuel.**

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

**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 radioactive.**

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

**I have the USS Nautilus.**

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

**I have radioactive decay.**

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

**I have reactor operator.**

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

**I have repositories.**

Who has an acceptable storage method for spent fuel?

**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 spent fuel pools.**

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

**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.

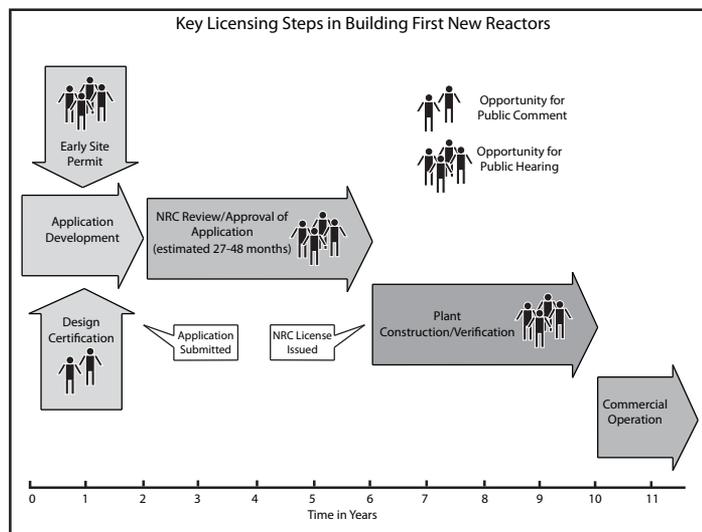
## The NRC Licensing Process

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 Licensing Board 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 sub 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

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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 at the ASLB, which will determine, based on the evidence before it, whether the COL should be issued.

## Roles

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- 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<sub>2</sub> 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.

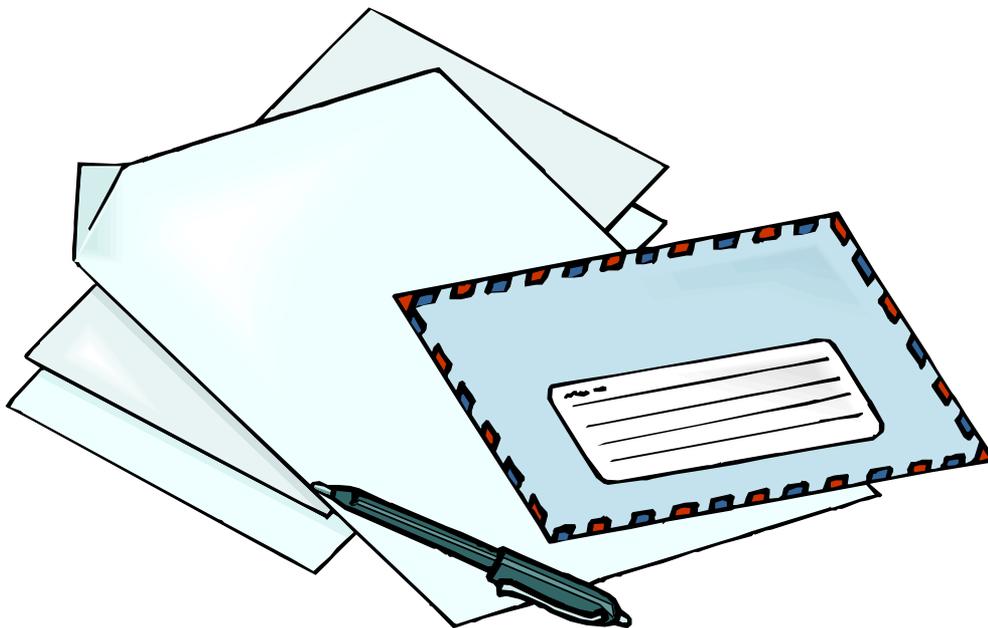


# Culminating Activity: Nuclear Energy Letter Prompt

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.

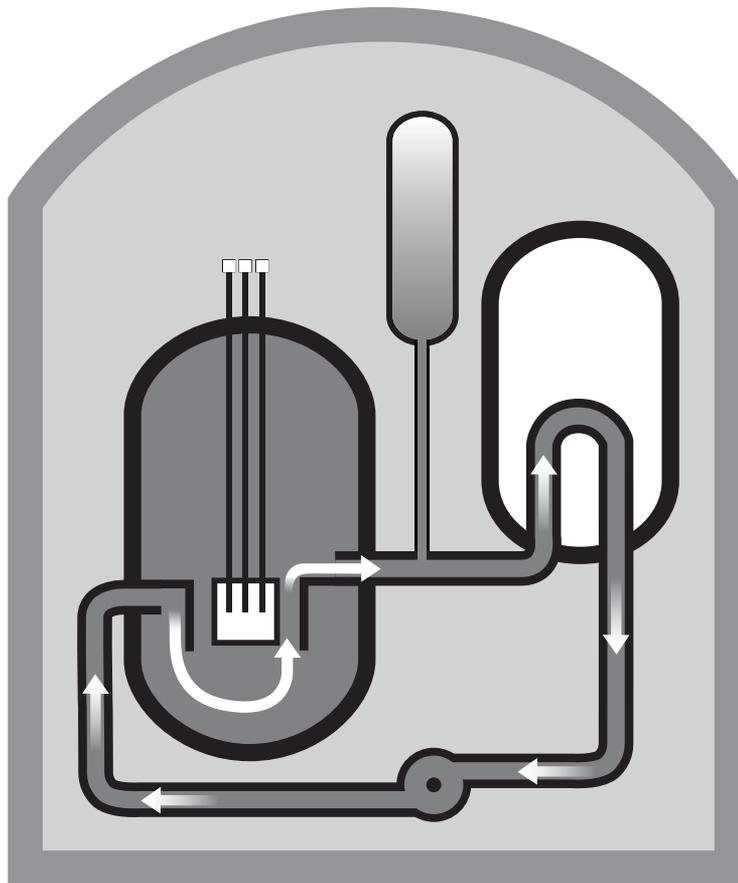




# Nuclear Energy Assessment

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 vessel, pump, fuel assemblies, control rods, moderator, pressurizer, containment building. 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 each of the accidents at Chernobyl, Three Mile Island, and Fukushima.

12. What are at least three 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.



# Introduction to Energy

## What is Energy?

Energy does things for us. It moves cars along the road and boats on the water. It bakes a cake in the oven and keeps ice frozen in the freezer. It plays our favorite songs and lights our homes at night so that we can read good books. Energy helps our bodies grow and our minds think. Energy is a changing, doing, moving, working thing.

**Energy** is defined as the ability to produce change or do work, and that work can be divided into several main tasks we easily recognize:

- Energy produces light.
- Energy produces heat.
- Energy produces motion.
- Energy produces sound.
- Energy produces growth.
- Energy powers technology.

## Forms of Energy

There are many forms of energy, but they all fall into two categories—potential or kinetic.

### POTENTIAL ENERGY

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

▪**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.

During photosynthesis, sunlight gives plants the energy they need to build complex chemical compounds. When these compounds are later broken down, the stored chemical energy is released as heat, light, motion, and sound.

▪**Stored mechanical energy** is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of stored mechanical energy.

▪**Nuclear energy** is energy stored in the nucleus of an atom—the energy that binds the nucleus together. The energy can be released when 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 into helium atoms in a process called **fusion**. In both fission and fusion, mass is converted into energy, according to Einstein's Theory,  $E = mc^2$ .

▪**Gravitational energy** is the energy of position or place. A rock resting at the top of a hill has gravitational potential energy because of its position. Hydropower, such as water in a reservoir behind a dam, is an example of gravitational potential energy.

## Forms of Energy

### POTENTIAL

Chemical Energy



Stored Mechanical Energy



Gravitational Energy



Nuclear Energy



### KINETIC

Electrical Energy



Radiant Energy



Thermal Energy



Motion Energy



Sound Energy



### KINETIC ENERGY

**Kinetic energy** is energy in motion—the motion of electromagnetic waves, electrons, atoms, molecules, substances, and objects. Forms of kinetic energy include:

▪**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. Light is one type of radiant energy. Solar energy is an example of radiant energy.

▪**Thermal energy**, or heat, is the internal energy in substances—the vibration and movement of atoms and molecules within substances. The faster molecules and atoms vibrate and move within substances, the more energy they possess and the hotter they become. Geothermal energy is an example of thermal energy.

▪**Motion energy** is the movement of objects and substances from one place to another. According to Newton's Laws of Motion, objects and substances move when an unbalanced force of acts on them. 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 wave.



# Introduction to Energy

## Conservation of Energy

Your parents may tell you to conserve energy. "Turn out the lights," they say. But to scientists, conservation of energy means something quite different. The law of conservation of energy says energy is neither created nor destroyed.

When we use energy, we do not use it up—we just change its form. That's really what we mean when we say we are using energy. We change one form of energy into another. A car engine burns gasoline, converting the chemical energy in the gasoline into motion or mechanical energy that makes the car move. Old-fashioned windmills changed the kinetic energy of the wind into motion energy to grind grain. Solar cells change radiant energy into electrical energy.

Energy can change form, but the total quantity of energy in the universe remains the same. The only exception to this law is when a small amount of matter is converted into energy during nuclear fusion and fission.

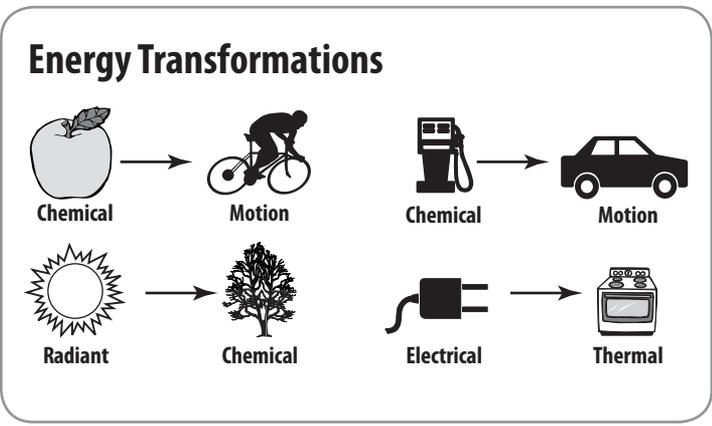
## Efficiency

**Energy efficiency** is how much useful energy you can get out of a system. In theory, a 100 percent energy efficient machine would change all of the energy put in it into useful work. Converting one form of energy into another form always involves a loss of usable energy, usually in the form of thermal energy.

In fact, most energy transformations are not very efficient. The human body is no exception. Your body is like a machine, and the fuel for your "machine" is food. Food gives us the energy to move, breathe, and think. But your body isn't very efficient at converting food into useful work. Your body's overall efficiency is about 15 percent. The rest of the energy is transformed into thermal energy.

An incandescent light bulb isn't efficient either. A light bulb converts ten percent of the electrical energy into light and the rest (90 percent) is converted into thermal energy. That's why a light bulb is so hot to the touch.

Most electric power plants that use steam to spin turbines, are about 35 percent efficient. It takes three units of fuel to make one unit of electricity. Most of the other energy is lost as waste heat. The heat dissipates into the environment where we can no longer use it as a practical source of energy.



## Energy at a Glance, 2010

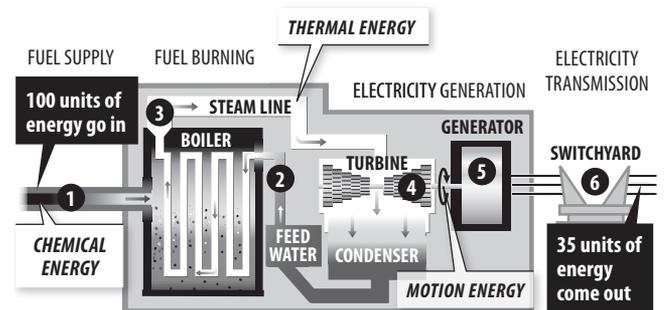
	2009*	2010
<b>World Population</b>	6,776,800,000	6,852,500,000
<b>U.S. Population</b>	306,700,000	309,100,000
<b>World Energy Production</b>	484.15 Q	n/a
<b>U.S. Energy Production</b>	72.60 Q	75.03 Q
• Renewables	7.60 Q	8.06 Q
• Nonrenewables	65.00 Q	66.97 Q
<b>World Energy Consumption</b>	482.97 Q	n/a
<b>U.S. Energy Consumption</b>	94.48 Q	98.00 Q
• Renewables	7.59 Q	8.05 Q
• Nonrenewables	86.77 Q	89.87 Q

Q = Quad (1016 Btu) see Measuring Energy on page 10.

\*The latest year for which final data for World and U.S. is available from EIA.

Note: 2010 data for World Energy Production and World Energy Consumption is not available at time of printing.

## 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.
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.



# Introduction to Energy

## Sources of Energy

People have always used energy to do work for them. Thousands of years ago, early humans burned wood to provide light, heat their living spaces, and cook their food. Later, people used the wind to move their boats from place to place. A hundred years ago, people began using falling water to make electricity.

Today, people use more energy than ever from a variety of sources for a multitude of tasks and our lives are undoubtedly better for it. Our homes are comfortable and full of useful and entertaining electrical devices. We communicate instantaneously in many ways. We live longer, healthier lives. We travel the world, or at least see it on television and the internet.

The ten major energy sources we use today are classified into two broad groups—nonrenewable and renewable.

**Nonrenewable energy sources** include coal, petroleum, natural gas, propane, and uranium. They are used to generate electricity, to heat our homes, to move our cars, and to manufacture products from candy bars to MP3 players.

These energy sources are called nonrenewable because they cannot be replenished in a short period of time. Petroleum, a **fossil fuel**, for example, was formed hundreds of millions of years ago, before dinosaurs existed. It was formed from the remains of ancient sea life, so it can not be made quickly. We could run out of economically recoverable nonrenewable resources some day.

**Renewable energy sources** include biomass, geothermal, hydropower, solar, and wind. They are called renewable energy sources because their supplies 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.

## Measuring Energy

“You can’t compare apples and oranges,” the old saying goes. That holds true for energy sources. We buy gasoline in gallons, wood in cords, and natural gas in cubic feet. How can we compare them? With British thermal units (Btu), that’s how. The energy contained in gasoline, wood, or other energy sources can be measured by the amount of heat in Btu it can produce.

One Btu is the amount of thermal energy needed to raise the temperature of one pound of water one degree Fahrenheit. A single Btu is quite small. A wooden kitchen match, if allowed to burn completely, would give off about one Btu of energy. One ounce of gasoline contains almost 1,000 Btu of energy.

Every day the average American uses about 868,500 Btu. We use the term quad (Q) to measure very large quantities of energy. A quad is one quadrillion (1,000,000,000,000,000) Btu. The United States uses about one quad of energy every 3.75 days. In 2007, the U.S. consumed 101.36 quads of energy, an all-time high.

Is electricity a renewable or nonrenewable source of energy? The answer is neither. Electricity is different from the other energy sources because it is a **secondary source of energy**, which means we have to use another energy source to make it. In the United States, coal is the number one fuel for generating electricity.

## U.S. Energy Consumption by Source, 2010

### NONRENEWABLE, 91.8%



**Petroleum** 35.1%  
*Uses: transportation, manufacturing*



**Natural Gas** 25.2%  
*Uses: heating, manufacturing, electricity*



**Coal** 21.3%  
*Uses: electricity, manufacturing*



**Uranium** 8.6%  
*Uses: electricity*



**Propane** 1.6%  
*Uses: heating, manufacturing*

### RENEWABLE, 8.2%



**Biomass** 4.4%  
*Uses: heating, electricity, transportation*



**Hydropower** 2.6%  
*Uses: electricity*



**Wind** 0.9%  
*Uses: electricity*



**Geothermal** 0.2%  
*Uses: heating, electricity*



**Solar** 0.1%  
*Uses: heating, electricity*

Data: Energy Information Administration



# Elements and Isotopes

What exactly is the mysterious thing we call electricity? It is charged particles, called electrons, that are in motion. What are electrons? They are tiny particles found in atoms. Everything in the universe is made of atoms or particles derived from 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 contained within the nucleus and the strong nuclear force holds the protons and neutrons together.

Protons and neutrons are very small, but electrons are much smaller. **Electrons** carry a negative (-) charge and move around the **nucleus** in areas of probability, called energy levels. These areas are 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 clouds (or energy levels). Electrons are found in these energy levels. Since protons have a positive charge and electrons have a negative charge they create an electrical charge and 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. In this case, these electrons (the valence electrons) easily leave their energy levels. 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.

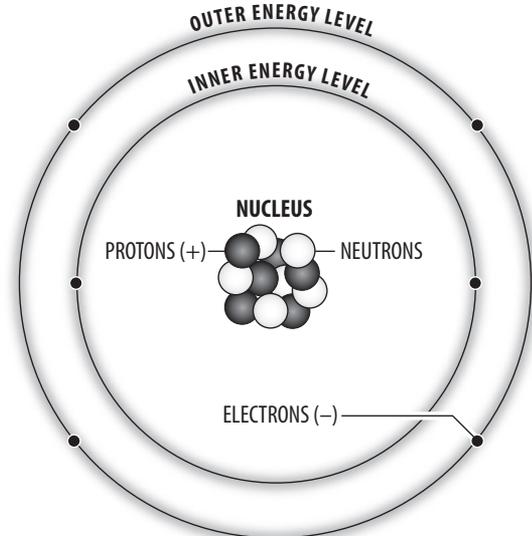
When an atom is neutral, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons help hold the nucleus together.

## Elements

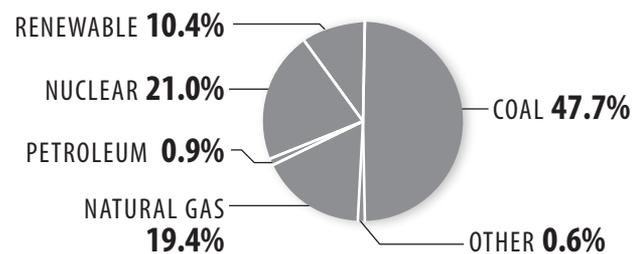
A substance whose atoms all have the same number of protons is called an element. The number of protons is given by an element's **atomic number**, which identifies elements. For example, all atoms of hydrogen have an atomic number of one and all atoms of carbon have an atomic number of six. This means that all hydrogen atoms

## 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, 2010



Data: Energy Information Administration

contain one proton and that all carbon atoms contain six protons. An atom is measured by its **atomic mass**, which is based on its number of protons, neutrons, and electrons.

## Radioactive Isotopes

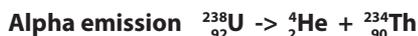
While many **isotopes** of the elements are stable, some isotopes are unstable and their nuclei emit particles and/or energy to become more stable. Isotopes of elements that are unstable and emit particles or energy are labeled radioactive because they are radiating particles or energy. When particles are given off, isotopes of new elements are usually made. The most common particles given off are **alpha** (a helium nucleus without electrons  ${}^4_2\text{He}$ ) and **beta** (an energetic electron  ${}^0_{-1}\beta$ ). Release of high energy **gamma**



# Elements and Isotopes

**radiation** is also a common method of achieving stability, but the type of isotope remains the same. Unstable isotopes may give off an alpha or beta particle, but never both together. However, gamma radiation may be given off along with either alpha or beta emissions.

The following are two examples of unstable isotopes that change identities when they release particles:



In the first example, a neutron in the nucleus of carbon-14 releases a beta particle ( ${}^0\beta$ ) and changes into a proton. Since the atom now has seven protons instead of six, it has become a different element nitrogen but still has an atomic mass of 14. It is now the isotope nitrogen-14.

In the second example, **uranium-238** releases an alpha particle. The alpha particle is made of two protons and two neutrons. That means the atom now contains 90 protons and 144 neutrons (giving a total of 234 nucleons or particles in the nucleus). With 90 protons, it is now the element thorium and has an atomic mass of 234. It is the isotope thorium-234.

The process of nuclei becoming more stable is called **radioactive decay**. The time required for one half of the atoms of the original radioactive isotope to decay into another isotope is known as its **half-life**. Some substances have half lives measured in milliseconds while others take billions of years. Uranium-238 has a half life of 4.6 billion years. Short half-lives result in high activities since a large number of particles or amounts of energy are emitted in relatively short time periods.

## What is Radiation?

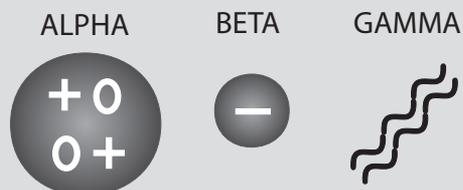
Energy traveling in the form of waves or high speed particles is called **radiation**. The sun produces radiant energy—energy that travels in electromagnetic waves. Wireless technologies, radar, microwave ovens, medical x-rays, and radiation therapy to treat cancer are all examples of how radiation can 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. 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.

## 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 natural sources. Much of our exposure to artificial sources is attributable to medical procedures.

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 emitted from 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 CT scans and medical and dental x-rays), 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 natural radiation is from **radon** gas, a gas commonly found in the Earth.

## Radon

Radon is a colorless and odorless radioactive gas found throughout the United States. It is formed during the natural radioactive decay of uranium and thorium 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. Behind smoking, exposure to radon gas is the second leading cause of lung cancer in the U.S.

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.



# Electricity and Magnetism

## Electrical Energy

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.

## 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.

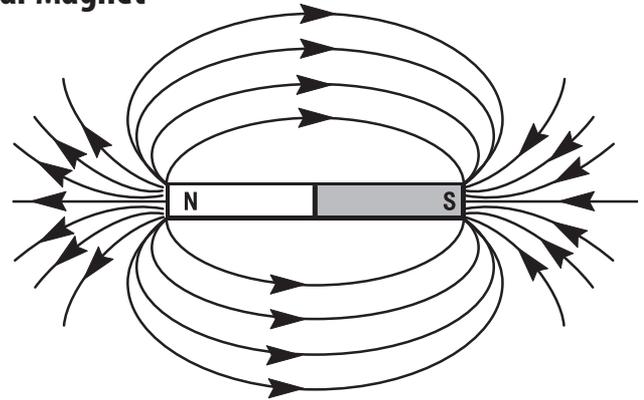
Spinning electrons create small magnetic fields and act like microscopic magnets or micro-magnets. In most objects, the electrons located around the nucleus of the atoms spin in random directions throughout the object. This means the micro-magnets all point in random directions cancelling out their magnetic 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

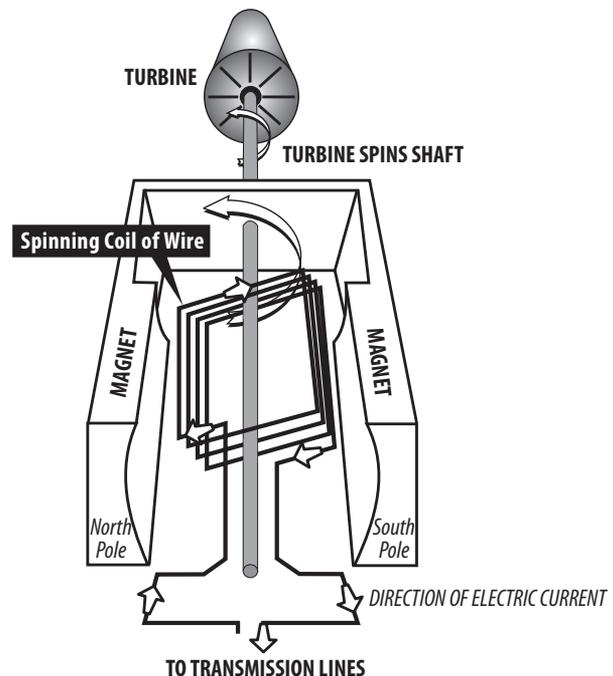
A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called electromagnetism. A changing magnetic field can produce electricity. Every time there is a change in an electric field, a magnetic field is produced. We can use this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

## Bar Magnet



## Turbine Generator



## Generating Electricity

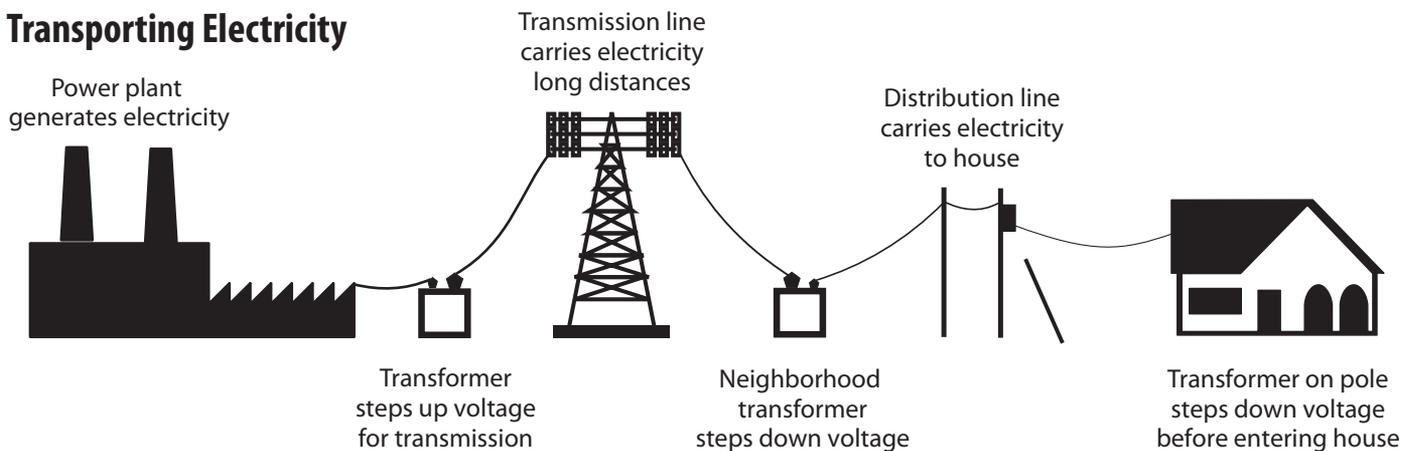
When it comes to the commercial production of electricity, it's all turbines and generators. A turbine is a device that converts the flow of a fluid such as air, steam, or water into mechanical energy to power a generator. A generator converts mechanical energy into electrical energy using electromagnetism.

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,



# Electricity and Magnetism

## Transporting Electricity



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.

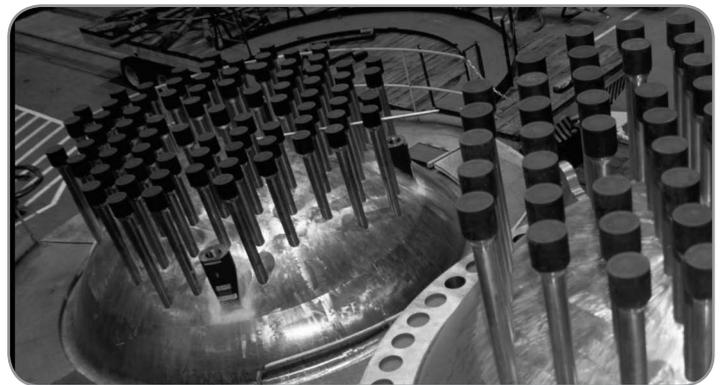
Power plants use huge turbine generators to generate the electricity that we use in our homes and businesses. Different types of power plants use different fuels to change water into steam. Power plants can burn coal, oil, biomass, or natural gas to heat water into high-pressure steam, which is used 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. 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

Fission occurs when an atom's nucleus splits into smaller nuclei. Nuclear energy is released from the nucleus of atoms as they fission and is transformed into thermal energy, kinetic energy, and radiant energy. Just like burning coal and natural gas, thermal energy from nuclear reactions can be used to convert water to steam for turning the blades of a turbine. The motion of the turbine turns a generator and makes electricity to power our homes, businesses, and schools.



# Uranium and the History of Nuclear Energy

## What is Uranium?

Uranium is a naturally occurring radioactive element, that is very hard and heavy and is classified as a metal. It is also one of the few elements that is easily fissioned. It is the fuel used by nuclear power plants.

Uranium was formed when the Earth was created and is found in rocks all over the world. Rocks that contain a lot of uranium are called uranium ore, or pitch-blende. Uranium, although abundant, is a nonrenewable energy source.

Three forms (isotopes) of uranium are found in nature, uranium-234, uranium-235, and uranium-238. These numbers refer to the number of neutrons and protons in each atom. Uranium-235 is the form commonly used for energy production because, unlike the other isotopes, the nucleus splits easily when bombarded by a neutron. During fission, the uranium-235 atom absorbs a bombarding neutron, causing its nucleus to split apart into two atoms of lighter mass.

At the same time, the fission reaction releases energy as heat and radiation, as well as releasing more neutrons. The newly released neutrons go on to bombard other uranium atoms, and the process repeats itself over and over. This is called a **chain reaction**.

## 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 William 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 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 alpha or beta particles. This change in an element is called **transmutation**. Other significant events included the discovery of the electron by J.J. Thompson and Rutherford's

## Uranium at a Glance, 2010

### Classification:

- nonrenewable

### Major Uses:

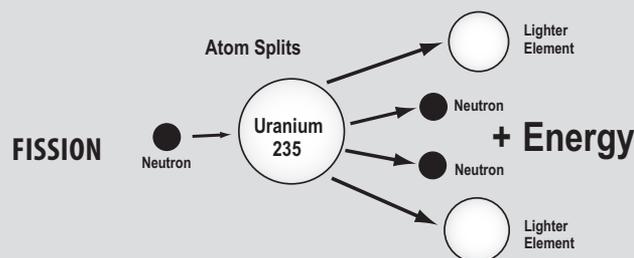
- electricity

### U.S. Energy Consumption:

- 8.44 Q
- 8.6%

### U.S. Energy Production:

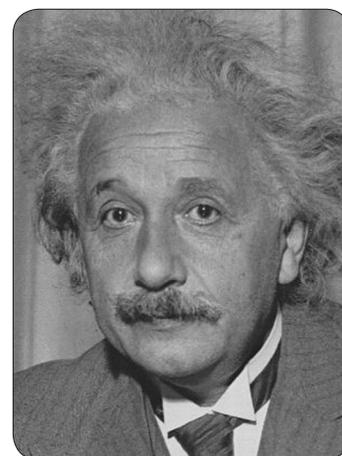
- 8.44 Q
- 11.3%



MARIE CURIE



ALBERT EINSTEIN



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.

In 1905, Albert Einstein theorized that mass and energy are interchangeable. According to his theory, mass can be converted into energy and energy can be converted into mass. 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 large amounts of energy could be released from radioactive materials.

# Uranium

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 sustain the reaction, neutrons of the proper speed (energy), and a way to control the number of neutrons available for fission. The first large scale reactors were 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 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 1,900 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 deadliest 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.

As of 2010, 104 nuclear reactors are operating in the United States, and 435 nuclear reactors are generating power throughout the world. Despite the success of peaceful uses of nuclear power, some people remain hesitant about increasing usage of nuclear energy because of its potential to be used in non-peaceful ways—**nuclear proliferation**.

## 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.



# Generating Electricity with Nuclear Energy

## Fission

Energy used to generate electricity in a nuclear power plant is released from the nucleus by a process known as fission, the breaking apart of a nucleus. In a uranium fission reaction, a neutron from outside the atom hits the nucleus of the U-235 atom, is momentarily captured by the nucleus, and then breaks the nucleus into two smaller fragments, of nearly equal masses creating two lighter elements. As a nucleus undergoes fission it also ejects two or more neutrons which are then able to collide with additional U-235 nuclei.

If this reaction occurs under conditions favorable for the rapid release of energy, we can see two neutrons bombard and fission two additional U-235 nuclei, then four neutrons bombard and fission four, eight bombard and fission eight, and so on. This forms what is called an explosive chain reaction where the energy released rapidly doubles from one round of fissions to another. This is the type of reaction needed for a nuclear weapon. Inside a reactor, a controlled chain reaction takes place where one fission leads to one additional fission and so on. While there is the potential for accidents due to high pressures or excessive thermal energy production, reactors cannot produce an explosive chain reaction like a nuclear bomb.

### URANIUM ORE



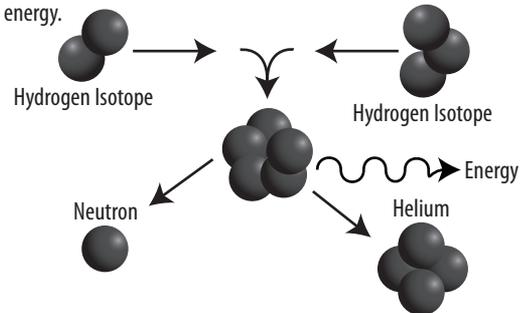
When the mass of the fission products and neutrons produced by the fission reaction are added and compared to the original mass of the U-235 nucleus and the initial neutron, we find a small difference in mass; the mass of the original U-235 and neutron is greater than the mass of the fission products and neutrons produced. During a fission reaction, this “lost” mass has actually been converted into energy. One of the fundamental laws of nature is the Law of Conservation of Mass/Energy. This law states that mass/energy cannot be created or destroyed, but can change forms. A fission reaction is transforming a small amount of mass into energy. The amount of energy released can be calculated using Einstein’s equation,  $E=mc^2$ . At first glance, it looks like mass was destroyed during the reaction. However, the difference in mass before and after the fission reaction has actually been transformed into energy released from the U-235 during the nuclear reaction.

## Nuclear Fuel Cycle

The **fuel cycle** is made up of a series of processes that manufacture reactor fuel, burn the fuel in a reactor to generate electricity, and manage the used reactor fuel. These processes are grouped into three components, the front end—which includes all activities prior to placement of the fuel in the reactor, the service period—when the fuel is used to release energy in the reactor, and the back end—which covers all activities dealing with used fuel from the reactor. If the used fuel is sent directly to storage, the cycle is referred to

## Fusion

The process of fusion most commonly involves hydrogen isotopes combining to form a helium atom with a transformation of matter. This matter is emitted as radiant energy.



In nuclear fission an atomic nucleus splits creating two lighter elements and energy is released. Nuclear fusion also releases energy, but in this process light atoms combine to form a heavier nuclei.

The sun is a big ball of gases, mostly hydrogen and helium atoms. The sun’s extremely high pressure and temperature cause hydrogen atoms to come apart and their nuclei to fuse. Hydrogen nuclei fuse to become one helium atom. The helium atom that is created contains less mass than the hydrogen atoms that fused. The “lost” mass is emitted as radiant energy.

as open. If it is reprocessed to recover useful components, it is known as closed. The United States employs an open fuel cycle, while France, Russia, China, and Japan reprocess their used fuel in a closed cycle.

## 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. 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.



# Generating Electricity with Nuclear Energy

## 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  $60^\circ C$  ( $140^\circ F$ )  $UF_6$  is a solid compound. When temperatures near  $60^\circ C$ ,  $UF_6$  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 received at the enrichment plant is U-238 mixed with small amounts of U-235. 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 slowly 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 converted back into uranium dioxide ( $UO_2$ ) in the form of a black powder.

## Fuel Manufacturing

During fuel manufacturing, the  $UO_2$  is pressed into small cylindrical shapes, and baked at a very high temperature (1600-1700 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.

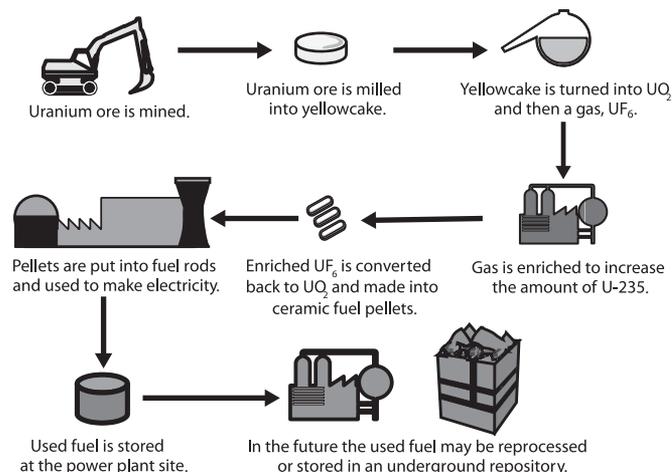
## Reasons for Refining, Conversion, and Enrichment

Only the U-235 nucleus has a high likelihood to undergo 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,

## Uranium Fuel Cycle



## URANIUM FUEL PELLET



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 Cycle

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 fuel is placed into storage pools containing water and then are eventually transferred to dry cask storage at the reactor site. Plans for future underground storage of used fuel at a national repository are currently on hold.

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. (See page 53 and 56 for more information on open and closed cycles.)



# Generating Electricity with Nuclear Energy

## Nuclear Power Plants

The center of a nuclear power plant is the nuclear reactor. The purpose of the reactor is to release energy at a controlled rate. This allows the thermal energy produced during fission to produce the steam that turns a turbine and generates electricity.

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 Building

This is a thick-walled concrete and steel building designed to prevent radioactive gases, steam, and water 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.

### 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 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.

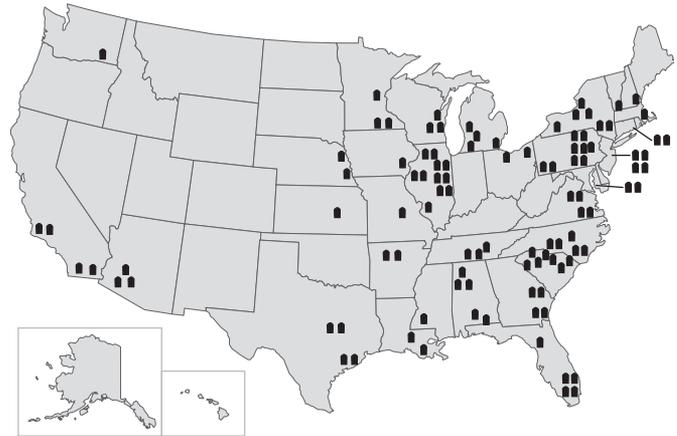
### Moderator

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

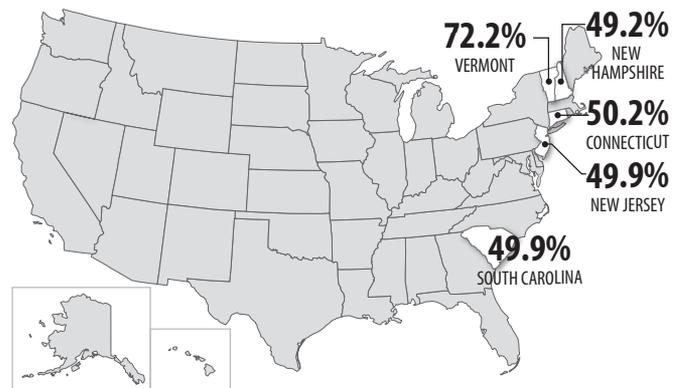
A nuclear plant's thermal energy is used to make steam and generate electricity. The steam carries energy from the reactor vessel to the turbines. After the steam turns the turbines, it is condensed back into water and returned to the reactor vessel. This is done by the heat exchange systems.

## U.S. Nuclear Power Reactors, 2010



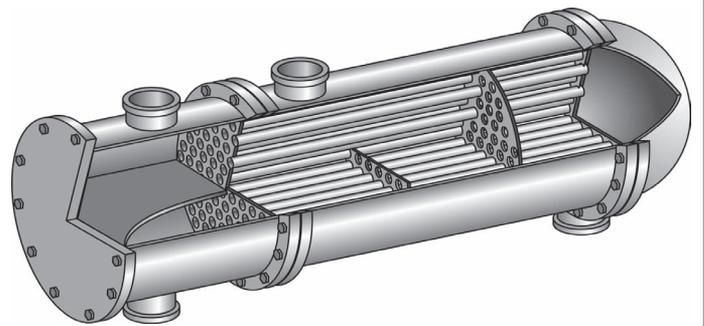
Data: Energy Information Administration

## States with the Largest Percentage of Electricity Generated by Nuclear Energy, 2010



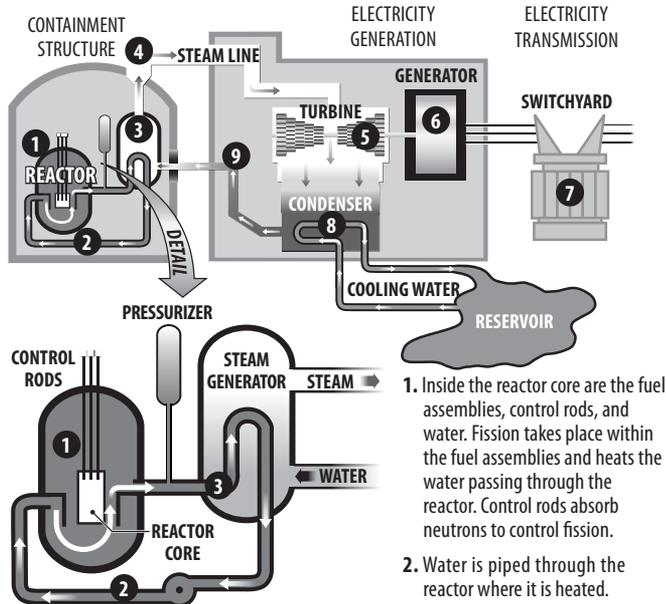
Data: Energy Information Administration

## Heat Exchanger



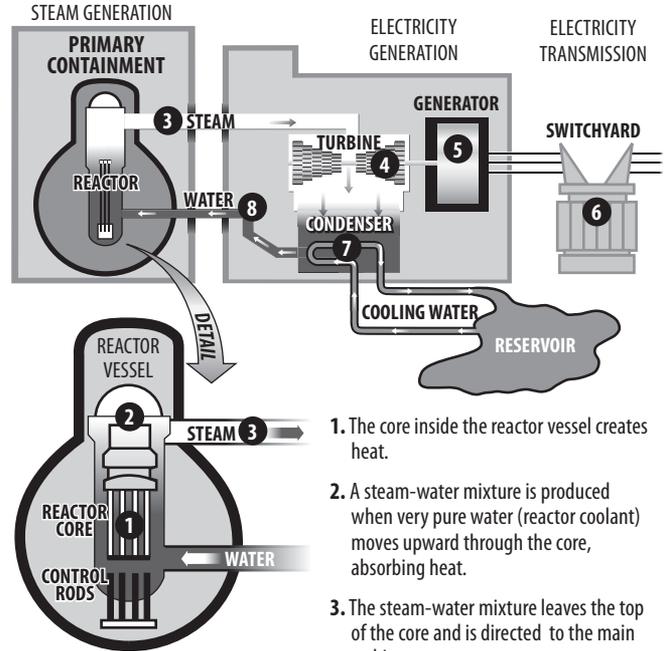
# Generating Electricity with Nuclear Energy

## 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.

## 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.

## 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 external 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 in the primary system 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 chamber. 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 chamber where it is heated and repeats the cycle.

The BWR and the PWR both use an external source of cooling water required 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 thermal energy is released, the temperature of



## Generating Electricity with Nuclear Energy

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 thermal energy 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 accomplished using a **cooling tower** where warm water is sprayed in small droplets through a draft of dry air. The dry air causes some of the water to evaporate, which leaves the remaining water cooler. This is called evaporative cooling. The cooled water droplets are collected at the bottom of the tower and pumped back to the plant to be reheated. 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 steam into the atmosphere, not radioactive substances as is sometimes thought.

### Additional Safeguards in a Nuclear Power Plant

Generally, there are two classes of safety systems in new reactor designs, evolutionary and **passive**. Reactors with evolutionary safety systems have the same basic design as pre-1990s reactors but with improved safety systems. The safety systems are larger with more cooling capacity, more dependable with increased back-up systems, controlled by the latest technology that monitors and controls the safety systems, and are easier to maintain and upgrade.

New reactors can be designed with passive safety systems that operate automatically, powered by gravity or natural convection. These systems are designed to minimize operator error. In passive safety systems if valves are needed, they are air or battery-operated. In either case, no outside electricity is needed for valve operations, and thus a loss of electricity does not affect the valves.

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. 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 (NRC) procedures to be followed and inspections carried out as required to prevent **meltdowns** and accidents.

### Used 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 used fuel is removed and replaced with fresh fuel assemblies. The level of radioactivity of used fuel is initially extremely high due to the short half-lives of 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 **used fuel** is placed in pools of water near the reactor to allow both the

### REACTOR VESSEL



Image courtesy of Areva

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

radioactivity and residual 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 a geologically stable 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. More than 20 years after its selection, it is not certain Yucca Mountain will be used as a long term high-level waste repository. 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. Because Yucca Mountain has not been opened to accept nuclear spent fuel and another repository has not been developed, no nation currently has a permanent repository for storage of radioactive nuclear spent fuel.

### Reprocessing Nuclear Waste: Closed Cycle

**Reprocessing** spent fuel uses chemical methods to separate the uranium and plutonium from the other components of the fuel from the reactor. 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 relatively small volume of remaining 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 amount of waste to be managed, it also produces waste which is both radioactive and chemically toxic.

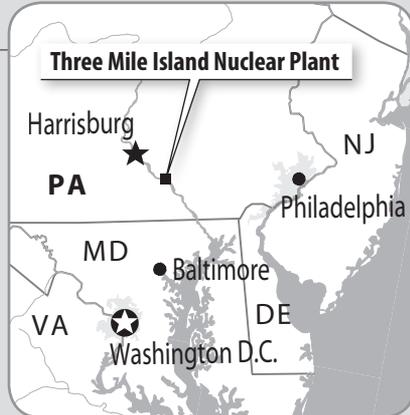


# Nuclear Accidents

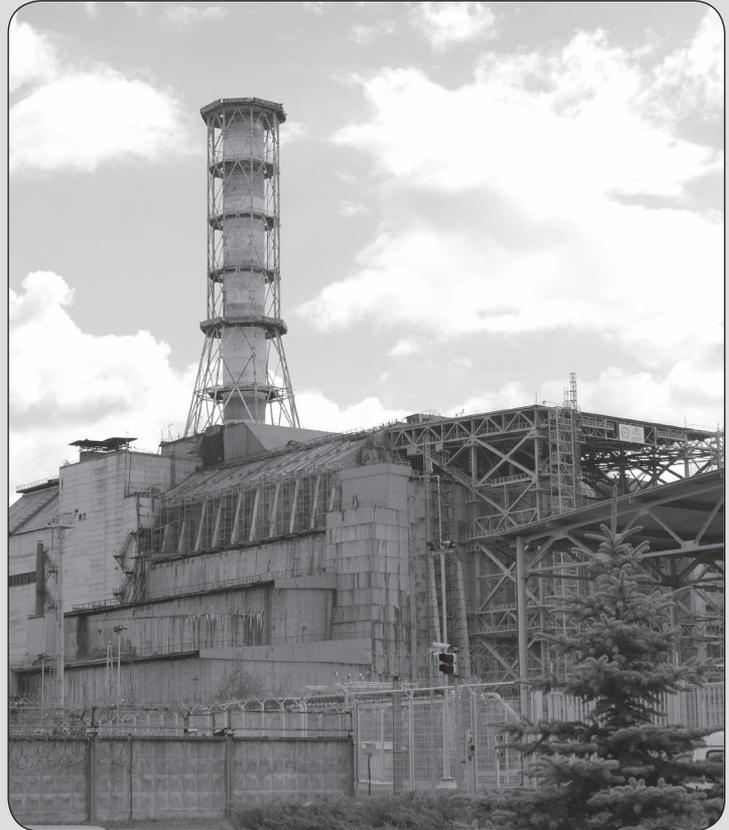
Three events that have influenced people's perception of nuclear energy are the accidents at Three Mile Island in Pennsylvania, Chernobyl in the Ukraine (former Soviet Union), and Fukushima in Japan.

## 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 the reactor 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 POWER PLANT



The damaged reactor number four of Chernobyl Nuclear Power Plant

## Chernobyl

In the Ukraine, they rely heavily on nuclear power to generate electricity. In 1986 at the Chernobyl Power Complex there were four reactors operating 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 is being built to more securely contain the radioactive materials that remain in Unit 4. The new structure will encompass Unit 4 and the existing concrete shelter. Scheduled to be completed in 2014, the structure will be 344' high, 492' long, and 843' wide. This is larger than six football fields.



## 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 which 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 breach 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 are dismantled and 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 reactor buildings.

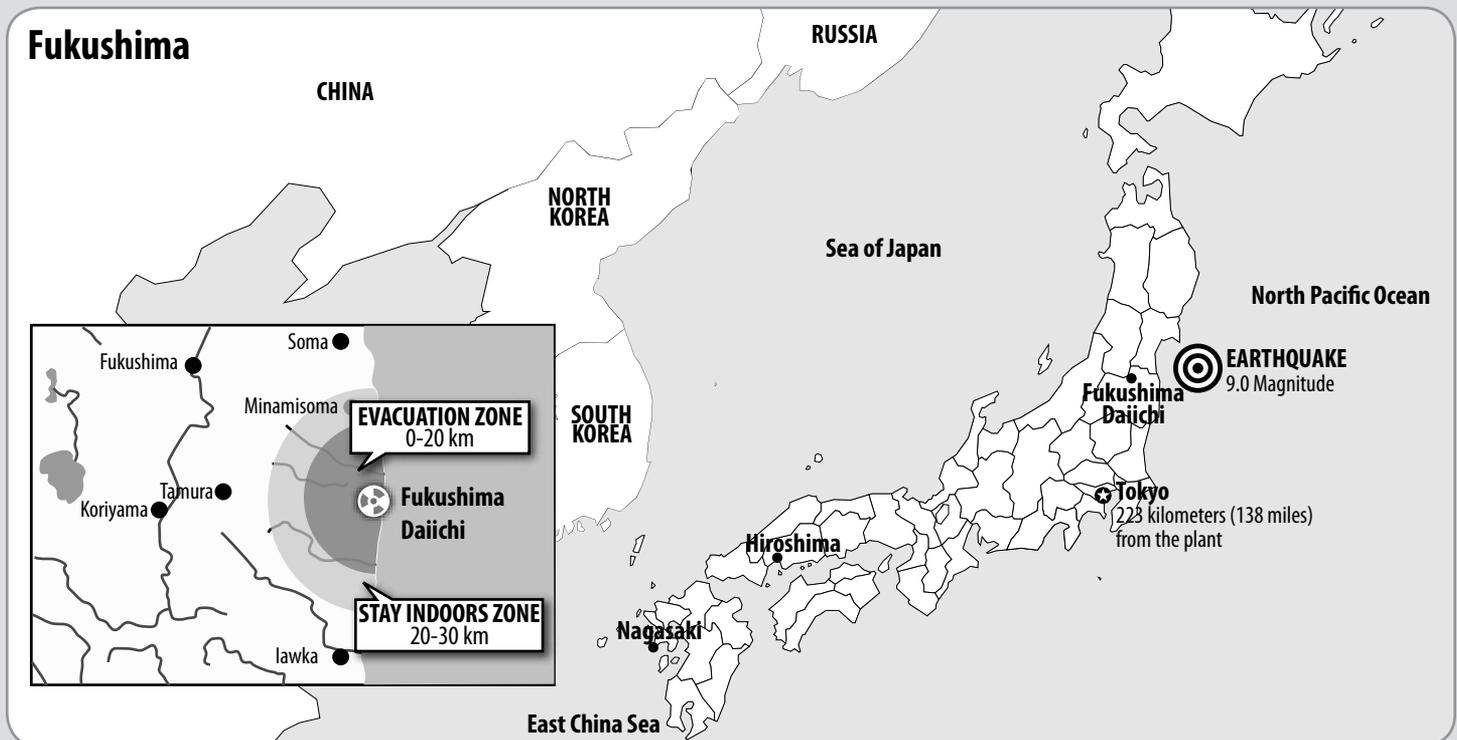
## Lessons Learned

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 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 backup 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.





# Nuclear Proliferation

## Proliferation Risks of Nuclear Power Programs

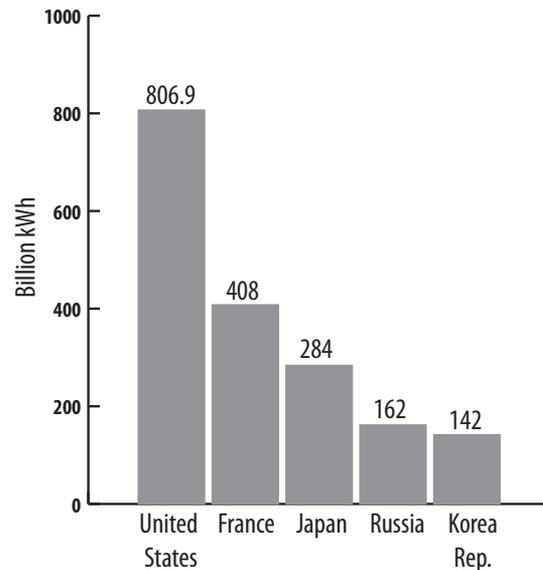
Beginning with the use of the first nuclear weapons on Japan, the spread of nuclear weapons (nuclear proliferation) has been a world-wide concern. Four issues have occurred within the last several years that have caused many world leaders to become concerned that nuclear materials designed for peaceful nuclear power uses could be used for weapons. First, after September 11, 2001, there has been an increasing threat of nuclear terrorism. Second, since 2002 Iran has made substantial progress in enriching uranium and building a nuclear research reactor that could produce **plutonium**. Both cases could lead to the development of nuclear weapons by Iran. Third, in December 2003 it was learned that a Pakistani scientist, A. Q. Khan, was selling nuclear secrets to other countries and groups. Finally, the renewed interest in nuclear power as a way to reduce greenhouse gases has led to many countries expressing interest in starting or increasing nuclear power programs. However, there is a fear that some of these countries would use peaceful activities to hide the development of a nuclear weapons program. Furthermore, terrorist groups would not have to actually build a nuclear weapon to create a terror situation. Radioactive substances can be placed inside weapons that use ordinary explosives. These are called dirty bombs. Activation of a dirty bomb could spread radioactive material into the environment, contaminating the exposed areas.

The same technologies that make fuel for nuclear reactors can also produce materials that are usable for nuclear weapons. These technologies include uranium enrichment and extracting plutonium from spent nuclear fuel. Therefore, a major concern exists where a country may say it is developing nuclear power for peaceful purposes while creating fuel that could be used in a nuclear weapon.

## Controlling the Proliferation Risks

While many countries have desired nuclear weapons, only eight are currently known to possess them (the United States, Russia, France, the United Kingdom, China, India, Pakistan, and North Korea). There is a strong possibility that Israel also has nuclear weapons. 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.

## Top 5 Nuclear Energy Generating Countries



Data: Energy Information Administration



Image courtesy NRC

Routine inspections at nuclear power plants are important.



## Nuclear Proliferation

An important international treaty related to nuclear technology is the nuclear **Non-Proliferation Treaty** (NPT). Article IV of the NPT, declares that a state 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. The rights of countries under the NPT are not clearly defined. This article does not specifically mention uranium enrichment and plutonium reprocessing technologies as part of a state’s right to peaceful nuclear technologies. Many countries want to interpret the NPT as giving them the right to enrich uranium and extract plutonium from nuclear wastes. Thus, non-nuclear-weapon countries such as Argentina, Brazil, and Japan, for example, have pursued enrichment or reprocessing or both, and have maintained safeguards on these programs. Iran claims that it wants to be like Japan and have a peaceful nuclear program that includes enrichment and possibly reprocessing. However, the International Atomic Energy Agency (IAEA) and the UN Security Council have ruled that Iran is not in compliance with its safeguards commitments.

Discussion of how to guard access to weapons-grade nuclear materials while allowing access to needed fuel for nuclear reactors is continuing. Possible solutions to the problem include having a few countries that are closely monitored by the nuclear community supply nuclear fuel to other countries who wish to operate a few nuclear power plants. These “fuel service contracts” would include management of spent fuel to make sure it cannot be accessed so that plutonium would not be extracted for weapons programs.

A country desiring a large nuclear power program may still want to enrich and reprocess fuel so that it can operate nuclear plants. Because these countries will enrich uranium or reprocess spent nuclear fuel, the nuclear industry should work to significantly reduce proliferation risks in those activities. Currently, reprocessing methods that do not isolate plutonium from fission products or other radioactive materials such as transuranics are being investigated. This would leave higher amounts of radioactive materials near the plutonium, making it more dangerous to steal or store. International safeguards and inspections would need to be maintained since a country could continue to reprocess the fuel and extract more plutonium.

Although proliferation could be substantially reduced if nuclear power were phased out, nuclear power has many advantages over other forms of energy. Some countries are planning to expand their nuclear power programs, and concerns about proliferation will remain for the foreseeable future. In the end, the international community must balance the benefits of nuclear energy with its risks. Faced with the continued use of nuclear energy in the foreseeable future, the international community must be vigilant about controlling the risks of proliferation.

### USED FUEL POOL

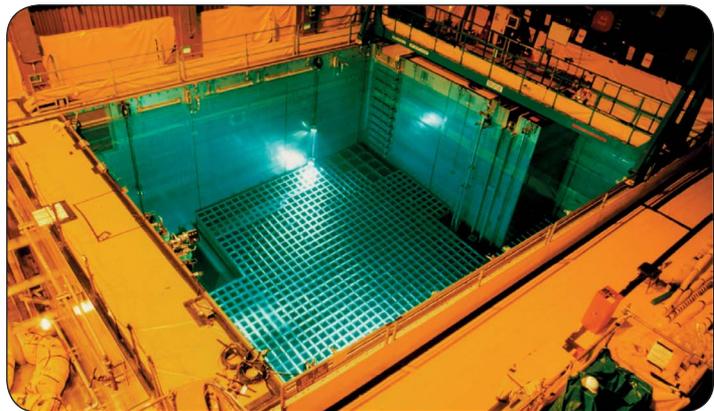


Image courtesy of NRC

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.



# 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 2016 will be approximately 20-40 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.

## 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 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.

As of 2009, construction and operating licenses for 28 new units had been submitted to the NRC under the new licensing process. If licensing procedures and construction proceeds on schedule, the first of these plants will go on-line in 2016.

Despite new licensing procedures, there has still been reluctance by investors 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. In 2010, the first conditional loan guarantee for a nuclear power facility was issued by the Department of Energy to support the building of two nuclear reactors at the Vogtle Electric Generating Plant in Burke County, GA.

## Local Economic Impacts

Despite high capital costs to build new nuclear power plants, the local and state economies will 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

## U.S. Average Levelized Costs (\$/Megawatthour) for Selected Plants Entering Service in 2016

Natural Gas-fired	
Conventional Combined Cycle	65.1
Advanced CC with CCS	88.4
Hydropower	90.5
Conventional Coal	95.1
Wind	96.1
Geothermal	99.8
Biomass	112.6
Advanced Nuclear	114
Advanced Coal with CCS	136.5
Solar PV	211
Wind—Offshore	243.7
Solar Thermal	312.2

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.

Data: Annual Energy Outlook 2010

the number could be as many as 2,400 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 \$430 million in local sales of goods and services. The average nuclear power plant also pays local and state taxes, which total almost \$20 million every year, and federal tax payments of almost \$75 million.

## Climate Change

Another issue that affects the economics of all types of power plants is **climate change**. Carbon dioxide (CO<sub>2</sub>) emissions are believed to be a leading factor in climate change. Generating electricity from fossil fuels contributes to 40 percent of CO<sub>2</sub> 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<sub>2</sub> 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

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- 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 base load 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

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- Overall costs of construction and used 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.



# Glossary

<b>alpha particle</b>	A particle released from the nucleus of an atom made of two protons and two neutrons stuck together.
<b>atomic mass</b>	The number of neutrons and protons in the nucleus of an atom. Also known as the atomic weight.
<b>atomic number</b>	The number of protons in the nucleus of an atom, used to identify the atom.
<b>beta particle</b>	A negatively charged electron released from the nucleus of an atom.
<b>Boiling Water Reactor (BWR)</b>	A reactor in which water is used as both a coolant and a moderator. The water is allowed to boil in the core. This makes steam which is used to drive a turbine and electrical generator, and produce electricity.
<b>chain reaction</b>	A fission reaction that keeps itself going as one reaction releases neutrons, causing more to follow. Depending on how fast neutrons are released, a chain reaction can be controlled or uncontrolled.
<b>climate change</b>	The change in Earth's overall climate patterns since the mid-20th century, which includes an increase in the average measured temperature of the Earth's near-surface air and oceans.
<b>containment building</b>	A concrete and steel enclosure around a nuclear reactor that confines fission products that otherwise might be released into the atmosphere.
<b>control rod</b>	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.
<b>cooling tower</b>	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.
<b>critical mass</b>	The smallest mass of nuclear material that will support a chain reaction.
<b>deuterium</b>	An isotope of hydrogen with one proton and one neutron in the nucleus.
<b>electricity</b>	Moving electrons.
<b>electron</b>	One of three main subatomic particles (electrons, protons, and neutrons). It is the smallest of the three. It is only 1/1836 the mass of a proton and has a -1 charge. Electrons can be shared or transferred in chemical bonds to create new compounds. The moving of electrons produces electricity.
<b>electron volt (eV)</b>	A very small unit of energy equal to the energy gained by an electron as it passes from a point of low potential to a point one volt higher in potential.
<b>energy</b>	The ability to do work.
<b>energy efficiency</b>	The amount of useful energy in a system's output compared to its input.
<b>enriched (uranium)</b>	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.
<b>external (cooling) system</b>	The part of the cooling system that interacts with the environment and does not contain radioactive material.
<b>fission</b>	The splitting of a nucleus into at least two smaller nuclei and the release of a large amount of energy. Two or three neutrons are usually released during this reaction.
<b>fossil fuel</b>	A hydrocarbon such as petroleum, coal, or natural gas, derived from prehistoric plants and animals and used for fuel.
<b>fuel cycle</b>	The series of steps involved in supplying fuel for nuclear power reactors. It includes mining, milling, enrichment, making fuel rods, use in a reactor, and handling and storage of spent fuel.
<b>fuel pellets</b>	A small cylinder approximately the size of a pencil eraser containing uranium fuel (uranium dioxide, $UO_2$ ) in a ceramic pellet.
<b>fuel rod</b>	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.
<b>fusion</b>	Process where smaller nuclei combine and form one atom with the release of energy.
<b>gamma radiation</b>	Energy in the form of high-energy, short wavelength, electromagnetic radiation released by the nucleus. Gamma rays are similar to x-rays and are best stopped or shielded by dense materials, such as lead.

<b>greenhouse gases</b>	The gases in the atmosphere, both natural and manmade, that trap and hold thermal energy within the Earth's atmosphere.
<b>half-life</b>	Time required for half the atoms contained in a sample of radioactive substance to decay naturally.
<b>heat exchanger</b>	A device that transfers thermal energy from one fluid (liquid or gas) to another fluid or to the environment.
<b>heavy water (D<sub>2</sub>O)</b>	Water that contains a significant amount of deuterium, in place of hydrogen, making it more massive. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively.
<b>ionizing</b>	The process of adding or removing one or more electrons to or from atoms or molecules creating charged particles.
<b>isotope</b>	Atom of the same element but with a different mass number.
<b>kinetic energy</b>	Energy of motion.
<b>light water</b>	Ordinary water (H <sub>2</sub> O) as distinguished from heavy water (D <sub>2</sub> O).
<b>meltdown</b>	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. This causes the fuel to melt. Even a partial meltdown can release radioactive material.
<b>moderator</b>	A material, such as ordinary water, heavy water, or graphite, that is used in a reactor to slow down high-velocity neutrons. This increases the chances of fission of U-235.
<b>neutron</b>	A fundamental subatomic particle that has nearly the same mass as the proton and no charge.
<b>Non-Proliferation Treaty (nuclear)</b>	A treaty to limit the spread of nuclear weapons, opened for signature on July 1, 1968. There are currently 189 countries party to the treaty, five of which have nuclear weapons.
<b>nonrenewable energy sources</b>	Energy sources that have a limited supply.
<b>nuclear energy</b>	The energy given off by a nuclear reaction (fission or fusion) or by radioactive decay.
<b>nuclear fuel cycle</b>	See fuel cycle.
<b>nuclear proliferation</b>	The spread of nuclear weapons or materials that can be used to build nuclear weapons. Also see Non-Proliferation Treaty (nuclear).
<b>Nuclear Regulatory Commission (NRC)</b>	An independent agency created by the United States Congress in 1974 to allow the nation to safely use radioactive materials for civilian purposes. The NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as for medical purposes.
<b>nuclide</b>	A general term referring to all stable (279) and unstable (about 2,700) isotopes of the chemical elements.
<b>nucleus</b>	The center of an atom.
<b>oxide</b>	a compound in which oxygen is bonded to one or more electropositive atoms (U <sub>3</sub> O <sub>8</sub> ).
<b>passive nuclear reactor</b>	A nuclear reactor designed so that safety systems operate automatically.
<b>pitchblende</b>	It is the main component of high-grade uranium ore and also contains other oxides and sulfides, including radium, thorium, and lead components, U <sub>3</sub> O <sub>8</sub> .
<b>plutonium (Pu)</b>	Chemical element with the atomic number 94. Plutonium-239 is a fissile isotope produced in nuclear reactors from uranium-238.
<b>potential energy</b>	Energy of position; stored energy.
<b>pressurized water reactor (PWR)</b>	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.
<b>primary (heat exchange) system</b>	A term that refers to the reactor coolant system.
<b>proton</b>	A fundamental particle of an atom that has the nearly the same mass as a neutron and a +1 charge.
<b>radiation (ionizing)</b>	Energy capable of producing ions. Examples of ionizing radiation include alpha particles, beta particles, gamma rays, x-rays, neutrons, and high-speed protons. Radiation, as frequently used in the nuclear industry, does not include non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light.
<b>radioactivity</b>	The process by which unstable atoms try to become stable, and as a result, emit radiation.
<b>radionuclide</b>	A radioactive isotope.

<b>radon</b>	A naturally occurring radioactive gas found in the earth around the world, where uranium and thorium decay.
<b>reactor vessel</b>	The main steel vessel containing the reactor fuel, moderator, and coolant.
<b>renewable energy sources</b>	Energy sources that can be replenished in a short period of time.
<b>reprocessing</b>	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.
<b>secondary energy source</b>	A source of energy that requires the use of another source to be produced.
<b>secondary (heat exchange) system</b>	The part of a PWR that contains the steam used to turn turbines and generate electricity. In a PWR, the steam is not in contact with radioactive material.
<b>spent fuel (used fuel)</b>	Nuclear reactor fuel that has been used until it can no longer sustain a nuclear reaction.
<b>thermal reactor</b>	A reactor in which the fission chain reaction is sustained primarily by thermal (relatively slow) neutrons. Most current reactors are thermal reactors.
<b>transmutation</b>	A process involving a change in the number of protons or neutrons in the nucleus, resulting in the formation of a different isotope. This occurs during alpha and beta emissions.
<b>transuranic</b>	Chemical elements with an atomic number greater than that of uranium (92).
<b>uranium (U)</b>	Chemical element with the atomic number 92. Uranium has three natural isotopes, U-234, U-235, and U-238. U-235 is the isotope fissioned in a nuclear reactor.
<b>uranium dioxide (UO<sub>2</sub>)</b>	An oxide of uranium that is a black, radioactive, crystalline powder. It is used as fuel in nuclear fuel rods in nuclear reactors.
<b>uranium hexafluoride (UF<sub>6</sub>)</b>	A white solid obtained by chemical treatment of U <sub>3</sub> O <sub>8</sub> and which forms a vapor at temperatures above 56°C. UF <sub>6</sub> is the form of uranium required for the enrichment process.
<b>uranium oxide (U<sub>3</sub>O<sub>8</sub>)</b>	See pitchblende.
<b>used fuel (spent fuel)</b>	Nuclear reactor fuel that has been used until it can no longer sustain a nuclear reaction.
<b>yellowcake</b>	A bright yellow powder obtained from uranium ore that contains uranium oxides used to make nuclear fuel.



## 2013 Youth Awards for Energy Achievement

All NEED schools have outstanding classroom-based programs in which students learn about energy. Does your school have student leaders who extend these activities into their communities? To recognize outstanding achievement and reward student leadership, The NEED Project conducts the National Youth Awards Program for Energy Achievement.

This program combines academic competition with recognition to acknowledge everyone involved in NEED during the year—and to recognize those who achieve excellence in energy education in their schools and communities. What's involved? Students and teachers set goals and objectives, and keep a record of their activities. In April, students combine their materials into scrapbooks and send them in and write summaries of their projects for inclusion in the Annual Report. Want more info? Check out [www.NEED.org/Youth-Awards](http://www.NEED.org/Youth-Awards) for more application and program information, previous winners, and photos of past events.







# Exploring Nuclear Energy 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?

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Other Comments:

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Please fax or mail to: **The NEED Project**  
P.O. Box 10101  
Manassas, VA 20108  
FAX: 1-800-847-1820

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