Nuclear Energy

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Background

Nuclear power is the process of generating heat through **nuclear fission**, the splitting of a nucleus in two. In nuclear reactors, uranium pellets – each containing millions of uranium nuclei – are used. As uranium nuclei split, a huge amount of energy is released; while some of the energy is radiation, most is the kinetic energy used to produce heat. The heat is then used to turn water into steam, which powers a turbine to produce electricity, much like any other power plant (Emirates Nuclear Energy Corporation).

There are two large differences between a coal and a nuclear power plant; we will describe each below.

First, nuclear power plants use much less material to produce the same amount of power/energy. Worldwide, each year coal-fired power stations consume over 4500 million tonnes of coal to make 40% of the electricity, while nuclear power plants consume over 70,000 tonnes of natural uranium to make 13.5% of the electricity. A global average (over all power plant capacities) reveals that coal power needs about 20,000 times as much fuel as nuclear power to produce the same amount of electricity (World Nuclear Association). To power a single 1000 **megawatt (MW)** power plant for a day, either 8600 tonnes of coal or 0.074 tonnes (74 kgs) of uranium are needed (World Nuclear Association), a difference of over 100,000 times. This ratio is equivalent to the ratio between the weights of an average human male and a 68 car train. Note, while more coal than uranium is needed to power identically sized plants, the reserves of coal are much much larger than the reserves of uranum. At current levels of usage, known (proven) uranium reserves is expected to run out sometime late this century, while known coal reserves are expected to run out in a couple centuries.

Second, nuclear power is very clean and does not emit harmful emissions to the environment. Annually, a single 1000 MW coal power plant emits 7 million tonnes of carbon dioxide, 200,000 tonnes of sulfur dioxide, and various nitrous oxides, volatile organic carbons, and particulate matter. Virtually all the wastes from the 1000 MW nuclear power plants are contained in the 27 tonnes or so of used fuel which are not released to the environment, but rather stored in radiation-shielded containers and stored safely (World Nuclear Association).

While nuclear power requires less material and displaces harmful emissions, there are still concerns about the technology. One of the major concerns is the cost of constructing a nuclear power plant. The overnight capital cost of a nuclear power plant – which takes into account the construction of the plant, owners' costs, and escalating costs due to increased materials – was $5,530 per kW in 2012, while that of a corresponding coal plant was only $2,934-$3,246 per kW (Energy Information Administration).

However, the cost of running a nuclear power plant is \$2.40 / **kilowatt-hour (kWh),** while the cost of running a coal power plant is \$3.27 / kWh, making the nuclear plant cheaper to run on a day to day basis (Nuclear Energy Institute).

Another primary concern associated with nuclear power plants is whether or not they are safe. There have been three major reactor accidents in the history of nuclear power: Three Mile Island, Chernobyl, and Fukushima. Of the three, only Chernobyl had significant health and environmental consequences; the recent Fukishima pales in comparison. The casualties associated with these three incidents, however, are the only casualties associated with nuclear reactors; no nuclear workers or members of the public have ever died as the result of exposure to radiation (or increased rates of cancer) from a nuclear power plant. Ultimately, compared to other sources of energy – particularly coal, hydro, and gas – nuclear has the fewest number of deaths associated with it (World Nuclear Association). Car accidents kill 1 out of 83 people; 1 in 210 people are murdered; 1 in 630 people die walking down the street; 1 in 1100 die from drowning; only 1 in 125,000 people die in a nuclear accident (Bailey, Ronald).

In addition, there is a lot of concern associated with the disposal of nuclear and radioactive waste. Currently, waste is placed in on-site spent fuel pools, which are steel-lined concrete pools where the waste is surrounded on either end by about 20 feet of water. After five years have passed, the radioactivity of the pool has decreased, and the waste can be moved to a concrete storage container (Nuclear Energy Institute). While the pools were the subject of controversy after the Fukushima earthquake damaged the nuclear plant, a recent Nuclear Regulatory Commission study found that fuel pools were a safe way to store nuclear waste (United States Nuclear Regulatory Commission). Dry cask storage is also used to store nuclear waste. After waste has already been in fuel pools and has decreased in radioactivity, it can be moved to a dry cask – often a steel or concrete cylinder bolted shut (Nuclear Regulatory Commission). In addition, nuclear fuel waste can also be reprocessed such that the waste is recycled. However, given the current technologies, this process is too expensive to be feasible (World Nuclear Institute).

Given that nuclear power requires less material, displaces emissions harmful to health (NO_X, SO_X, black carbon, volatile organic carbons), and does not emit greenhouse gases, many organizations are looking to further develop nuclear power. One in particular is the International Atomic Energy Agency, which aims to increase worldwide safe and economic development of nuclear power. They support global nuclear programs, conduct nuclear research, and promote safe use of the technology (International Atomic Energy Agency).

NB: A tonne is a metric unit of mass equal to 1,000kg. It is not equivalent to a US ton (2,000 lbs).

Objective

Students will be able to:

- Explain how nuclear power is generated.
- Explain the difference between nuclear power plants and coal power plants.
- Explain the differences between coal and nuclear plant energy outputs and emissions.
- Explain the concerns people still have with nuclear power.
- Explain what the IAEA is and what its mission is for the future of nuclear power.

Materials Needed

- A diorama that shows the process of power generation with removable modules for a containment structure and a boiler.
- Power Point with pictures of different turbine set ups (if no diorama)
- One pound of white rice
- Two (preferably see-through containers)
- White board and white board marker

Safety Concerns

- None.

Vocabulary

- Nuclear fission: the process of generating heat by splitting a nuclear in two.
- Energy: the capacity of something to do work; an amount. Measured in watt-hours, kilowatt-hours, megawatt-hours. A typical American household used 940 kWh per month in 2011.
- Power: describes how much energy can be produced in a given time. Also to supply a device with electricity; the product of voltage and current. A common unit of measurement is a *watt* (W); also measured in watts, kilowatts, megawatts, etc.

Procedure

Time	Activity	Description	Supplies
5	1. Introduction	1. Ask each student what they think of when they hear the words "nuclear power."	
10	2. How Nuclear Plants Produce Power	1. Review the concept of coal, oil, and gas power plants with the students. a. Have the students walk through as much of	Diorama, removable containment

		the power generation process as possible. b. Show the students a diorama (or Power Point slide) with a removable boiler in place to visually show how the process works. 2. Explain the difference between nuclear power plants and coal power plants. a. Replace the removable boiler module with a containment module to show how heat generation is different, or switch the coal Power Point slide to one on nuclear power. 3. Qualitatively explain the process of nuclear power generation.	structure, removable boiler, "Diorama Slides.pptx"
15	3. How Much Power?	1. On a white board, write the amount of coal needed to power a 1000 MW coal power plant for a day. 2. Have students guess the amount of uranium before writing the amount of uranium needed to power a 1000 MW nuclear plant for a day. 3. Illustrate the difference in energy production between coal and nuclear power plants as well. a. Have a container with approximately two thirds of the bag of white rice (there are about 29,000 grains of white rice in one pound, and about 20,000 should be in the container). b. Have another container with a single grain of rice inside. c. The containers represent the fact that coal plants need 20,000 more fuel to generate one kilowatt-hour of energy than nuclear plants. 4. Explain the difference in carbon dioxide emissions between coal and nuclear plants. Write the numbers on the white board to clarify the stark contrasts.	White board, writing utensil for board, one pound of white rice, two (preferably see-through) containers
15	4. Nuclear Power Concerns	1. Address any of the students' initial concerns about nuclear energy mentioned at the start of the class, assuming that those concerns do not fall into any of the following categories (cost, safety, and waste). 2. Discuss the cost differences between installing and running nuclear power plants and coal power plants. a. Highlight the fact that while the capital cost might be higher for nuclear, it's cheaper in the long run. 3. Discuss the safety of nuclear power plants. a. Provide the students with statistics about nuclear power plants. b. Ask the students if they would be comfortable living next to a nuclear power plant to highlight the "not in my backyard" issue associated with them. 4. Discuss the issues associated with nuclear waste. a. Explain what nuclear fuel pools are, the controversy associated with them and the earthquake in Japan, and whether or not they are safe overall. b. Briefly describe dry cask storage and	

		reprocessing.	
10	5. The Future of Nuclear Power	1. Talk about the International Atomic Energy Agency and what it does. Use their mission – safe worldwide development of nuclear power – to show what the future of nuclear power hopefully is and should be.	

Additional Resources

Reputable

Department of Energy. "Office of Nuclear Energy." Office of Nuclear Energy. Web. 18 Jul 2013. <http://energy.gov/ne/office-nuclear-energy>

The Department of Energy's Nuclear Energy page primarily describes – in great detail – their initiatives and the progress they've made with each of them. Teachers looking for good descriptions of current nuclear energy work could look here.

Emirates Nuclear Energy Corporation. "ENEC: How Does Nuclear Energy Work?" Emirates Nuclear Energy Corporation. Web. 19 Jul 2013. <http://www.enec.gov.ae/learn-about-nuclear-energy/how-does-nuclear-energy-work/>

The Emirates Nuclear Energy Corporation gives a succinct summary of how nuclear power works with an accompanying video to demonstrate the process. Teachers looking for a reputable source to explain the basics behind nuclear power could look here.

Organisation for Economic Co-operation and Development. "Nuclear Energy Agency." *Nuclear Energy Agency*. Web. 17 Jul 2013. <http://www.oecd-nea.org>

The NEA page primarily describes the work and research they're doing to create safe and economical use of nuclear power. Teachers looking to update themselves on current research projects could look here.

United States Nuclear Regulatory Commission. "Draft Report – Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a US Mark I Boiling Reactor." Regulations.gov. June 2013. Web. 19 Jul 2013. <http://www.regulations.gov/#!documentDetail;D=NRC-2013-0136-0001>

The NRC released this draft report which ultimately describes nuclear fuel pools as safe, even in earthquakes. Teachers looking for reputable evidence about the safety of nuclear fuel pools could look here.

United States Nuclear Regulatory Commission. "NRC: Dry Cask Storage." United States Nuclear Regulatory Commission. 26 March 2013. Web. 19 Jul 2013. <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Processing-of-Used-Nuclear-Fuel/#.Uemoi41QGSo>

The NRC page on dry cask storage gives a brief description of what it is, difference designs, and when the storage method was first used. Teachers looking for a brief introduction to the concept could look here.

United States Nuclear Regulatory Commission. "NRC: Home Page." *United States Nuclear Regulatory Commission*. Web. 17 Jul 2013. <http://www.nrc.gov>

The Nuclear Regulatory Commission's page gives a few descriptions on different types of nuclear reactions, but mostly discusses what the NRC does in relation to nuclear power. This includes everything from the materials they use and the regulations associated with those materials to information about their public meetings. Teachers looking to get a brief introduction to the government side of nuclear power could look here.

United States Nuclear Regulatory Commission. "NRC: Teachers' Lesson Plans. United States Nuclear Regulatory Commission. 29 Mar 2012. Web. 18 Jul 2013. <http://www.nrc.gov/reading-rm/basic-ref/teachers/html>

The Nuclear Regulatory Commission has a sample curriculum for teaching radiation, complete with sources, experiments, and a background introduction.

Teachers looking for a new radiation lesson – or to supplement their current lesson plan – could look here.

U.S. Energy Information Administration. "How much electricity does an American home use?" U.S. Energy Information Administration. 19 Mar 2013. Web. 22 Jul 2013. <http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3>

The US Energy Information Administration cites the amount of electricity used in an average home, as well as links to other pages and more electricity information. Teachers looking for statistics could look here.

U.S. Energy Information Administration. "US Energy Information Administration (EIA)." U.S. Energy Information Administration. 12 Apr 2013. Web. 19 Jul 2013. <http://www.eia.gov/forecasts/capitalcost/>

The US Energy Information Administration provides information and data about the capital costs of electricity generating plants. Teachers looking for the numbers to back up their claims about competing cost of construction for electricity generating plants could look at some of the reports listed here.

Opinion / Newspaper

American Nuclear Society. "ANS / Public Information / Resources / Top 10 Myths and Nuclear Energy." *American Nuclear Society*. 27 Jun 2012. Web. 18 Jul 2013. <http://www.ans.org/pi/resources/myths/>

The American Nuclear Society page on nuclear energy myths uses a number of sources (all listed) to support their debunking of the common myths. While the site is biased in favor of nuclear energy, teachers looking to show support for why nuclear energy isn't as dangerous as it's perceived could look here.

Bailey, Ronald. "Don't Be Terrorized." Reason.com. 11 Aug 2006. Web. 23 Jul 2013. <http://reason.com/archives/2006/08/11/dont-be-terrorized>

Ronald Bailey compares the risk of dying of mundane events – such as walking across the street – to the risk of dying from a terrorist attack. In this situation, the mundane statistics were compared to nuclear power plant accidents instead, making this source a great place to find chances of casualties.

International Atomic Energy Agency. "Nuclear Science and Applications – IAEA." *International Atomic Energy Agency*. Web. 19 Jul 2013. <http://www-naweb.iaea.org/na/index.html>

The IAEA promotes safe and economic development of nuclear power globally. Teachers looking for an example of where the future of nuclear power is going could look here for information on the research and work that they are doing.

National Energy Education Development Project. "Nuclear Energy." National Energy Development Education Project. Web. 18 Jul 2013. <http://www.need.org/nuclear>

The National Energy Education Development Project offers a series of curricula options for teachers who want to teach nuclear power.

The New York Times. "Nuclear Energy – The New York Times." Energy & Environment – The New York Times. Web. 18 Jul 2013. <http://topics.nytimes/top/news/business/energy-environment/atomic-energy/index.html>

The New York Times dedicates this part of the site to current news updates on nuclear energy. A chronology section and highlights from archives are also featured. Teachers looking to show nuclear energy's presence in the news – or perhaps find present day updates to the technology – could look here.

Nuclear Energy Institute. "Nuclear Energy Institute – economicgrowth." Nuclear Energy Institute. Web. 19 Jul 2013. <www.nei.org/Key-Issues/Reliable-Afforable-Energy/Economic-Growth>

The Nuclear Energy Institute page gives four clear numbers illustrating the difference in operating costs between four different types of power plants. Teachers looking for numbers to support their conclusion on operating costs could look here.

Nuclear Energy Institute. "Nuclear Energy Institute – NEI site." *Nuclear Energy Institute*. Web. 17 Jul 2013. <http://www.nei.org>

The Nuclear Energy Institute offers a biased series of updates on nuclear energy policy, issues, and news releases. Teachers looking for positive information about nuclear energy or a current event approach to nuclear energy could look here.

Nuclear Energy Institute. "Nuclear Energy Institute – Used Fuel: Used Fuel Pools at Nuclear Power Plants." Nuclear Energy Institute. May 2011. Web. 19 Jul 2013. <http://www.nei.org/resourcesandstats/Documentlibrary/Nuclear-Waste-Disposal/factsheet/used-fuel-pools-at-nuclear-power-plants>

The Nuclear Energy Institute provides a detailed summary on what nuclear fuel pools are, how they are used, and whether or not they are safe. Teachers looking for a well-organized site to explain nuclear fuel pools could look here.

Skoog, Gerald; Brasher, Treasure. “Activities for Teaching Fundamental Concepts of Nuclear Energy or Related Topics.” West Texas A&M University. 1996. Web. 18 Jul 2013. <http://www.uraweb.org/reports/skoog/pdf>

Skoog and Brasher provide a list of activities for middle school students all about nuclear energy and radiation. Teachers looking for examples of potential applications of a nuclear energy lesson could look here.

Westinghouse. “What is Nuclear Energy?” Westinghouse Nuclear. Web. 18 Jul 2013. <http://www.westinghousenuclear.com/Community/WhatIsNuclearEnergy.stm>

The Westinghouse page on nuclear energy gives a brief summary of how nuclear energy works, offers accompanying links to the effects of nuclear energy on factors like the environment, and shows a detailed series of diagrams explaining the process of generating nuclear energy. Teachers who want to demonstrate how the process works in relation to the equipment could show the flash diagram from here.

World Nuclear Association. “Processing of Used Nuclear Fuel.” World Nuclear Association. Jun 2013. Web. 19 Jul 2013. <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Processing-of-Used-Nuclear-Fuel/#.Uemoi41QGSo>

The World Nuclear Association page on reprocessing fuel goes into great detail about the process behind recycling uranium and the current technologies being used. Teachers looking for a detailed introduction to the topic could look here.

World Nuclear Association. “Safety of Nuclear Reactors.” World Nuclear Association. 31 May 2012. Web. 19 Jul 2013. <http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Safety-of-Nuclear-Power-Reactors/#.UemhtI1QGSo>

The World Nuclear Association goes into great detail about the safety issues associated with nuclear energy, especially in terms of large accidents and in relation to other energy sources. Teachers looking for an abundance of information on nuclear power plants could look here.

World Nuclear Association. “Uranium, Electricity, and Climate Change.” World Nuclear Association. Web. 19 Jul 2013. < http://www.world-nuclear.org/info/Energy-and-Environment/Uranium,-Electricity-and-Climate-Change/#.Ueltko1QGSo>

The World Nuclear Association talks about the environmental effects of using nuclear energy by using charts, graphs, and other number-based figures. Teachers looking to begin a comparative discussion about nuclear energy and other forms of energy could look here.

World Nuclear Association. “World Nuclear Association.” *World Nuclear Association*. Web. 18 Jul 2013. <http://world-nuclear.org>

The World Nuclear Association provides a large amount of content about what nuclear energy is, as well as the basics behind nuclear energy. Teachers looking to get easily explainable background information on the topic could look here.

Author(s)

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Next Generation Science Standards Alignment

HS-PS1-8: Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

HS-ESS3-1: Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.