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The Future of Nuclear Energy: Forbidden Joules

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Introduction

While atoms are tiny particles that make up every object in the universe, the bonds that hold atoms together can yield enormous energy. Releasing energy from the nucleus of an atom is achieved in two ways: nuclear fusion and nuclear fission. Historically, the advantages of nuclear power generation both precede and outnumber the disadvantages when presenting recommendations to prevent or at least mitigate further global warming. Consequently, the following summary of arguments for and against nuclear power can both initiate and substantiate those assessments, reviving reconsideration by the public, or at least by politicians. Advantages of nuclear power generation: a)Nuclear power generation does emit relatively low amounts of carbon dioxide (CO2). The emissions of green house gases and therefore the contribution of nuclear power plants to global warming is therefore relatively little; b}This technology is readily available, it does not require development time; and c) Vast amounts of electrical energy can be generated at one single plant.

The disadvantages of nuclear power generation however, appear overwhelming: a)The radioactive waste from nuclear energy is extremely dangerous and requires caretaking for several thousand years (10,000 years according to United States Environmental Protection Agency standards); b)High risks: Despite high security standards, the possibility of accidents prevails. While it is technically impossible to build a plant with 100% security, a small probability of failure will always remain. The consequences of an accident could be absolutely devastating both for humans and for the rest of nature. As the number of nuclear power plants and nuclear waste storage shelters increase, so does the probability of catastrophic failures increase; c)Nuclear power plants as well as nuclear waste could be preferred targets for terrorist attacks because no atomic energy plant engineering can endure an attack similar to the 9/11 attack of New York City. Such an act of terrorism would initiate cataclysmic events affecting our entire planet; d)The radioactive waste that is produced during the operation of nuclear power plants can be used for the production of nuclear weapons despite the global goals of decommissioning Weapons of Mass Destruction. Similarly, the same abilities and knowledge used to design nuclear power plants can be applied to building nuclear weapons and encourage nuclear proliferation; e)The resource and energy source for nuclear energy is Uranium however, Uranium is a scarce resource, estimated to last for only the next 30 to 60 years depending on the actual demand; and f)The time frame needed for formalities, planning and building of a new nuclear power generation plant is in the range of 20 to 30 years in the western democracies, making it impossible to build new nuclear power plants in a short time.

Clearly, nuclear power is neither "green" nor sustainable: both nuclear waste and retired nuclear plants are far-from-green, life-threatening legacies for future generations. Subsequently, the spirit of sustainability is flagrantly contradicted if future generations are destined to manage hazardous radioactive waste inherited from preceding generations. Uranium, the source of energy for nuclear power, is neither abundant on Earth nor a non-renewable resource expended or converted during the nuclear reactions at nuclear power plants. While predictions vary, the supply of Uranium is expected to last for the next 30 to 60 years, respective of the actual demand.

1. Low Pollution

As our demand for electricity soars, the pollution produced from fossil fuel-burning plants approaches dangerous levels to supply our demand. Coal, gas and oil burning power plants are already responsible for half of America's air pollution. Burning coal produces carbon dioxide, which depletes the protection of the ozone. Many power plants burn soft coal that also contains sulfur, which becomes sulfuric acid precipitation when the gaseous byproducts are absorbed in clouds. Surprisingly, coal also contains radioactive material; a coal-fired power plant emitsmore radiation into the air than a nuclear power plant. The world's reserves of fossil fuels are headed for depletion. The sulfurous coal which many plants use is more polluting than the coal that was previously used. As the use of soft coal increases, the pollution increases. Most of the anthracite, which plants also burn, has been depleted. According to estimates, fossil fuels will be burned up within fifty years. Conversely, there are large reserves of Uranium and new breeder reactors that can produce more fuel than they use. Unfortunately this doesn't mean we can have an endless supply of fuel Breeder reactors need a feedstock of Uranium and Thorium, so when we run out of these two fuels, in about 1000 years, breeder reactors will cease to be functional. This solution has more longevity than burning coal, gas, or oil.

2. Reliability

Nuclear power plants need little fuel, so they are less vulnerable to shortages because of strikes or natural disasters. Global markets and international relations will have little effect on the supply of fuel to the reactors because Uranium is evenly deposited around the globe. One disadvantage of Uranium mining is that it leaves the residues from chemically processing the ore, which leads to radon exposures for the public. These effects do not outweigh the benefits by the fact that mining Uranium out of the ground reduces future radon exposures. Coal burning leaves ashes that will increase future radon exposures. The estimates of radon show that it is safer to use nuclear fuel than burn coal. Mining of the fuel required to operate a nuclear plant for one year will avert a few hundred deaths, while the ashes from a coal-burning plant will cause 30 deaths.

3. Safety

Safety is both a pro and con, depending on which way you see it. The results of a compromised reactor core can be disastrous, but the precautions have prevented meltdowns in all but a few cases in history. Nuclear power is one the safest methods of producing energy. Each year, 10,000 to 50,000 Americans die from respiratory diseases due to the burning of coal, and 300 are killed in mining and transportation accidents.[1] In contrast, no Americans have died or been seriously injured because of a reactor accident or radiation exposure from American nuclear power plants. There are a number of safety mechanisms that make the chances of reactor accidents very low. A series of barriers separates the radiation and heat of the reactor core from the outside. The reactor core is contained within a 9-inch thick steel pressure vessel. The pressure vessel is surrounded by a thick concrete wall. This is inside a sealed steel containment structure, which itself is inside a steel-reinforced concrete dome four feet thick. The dome is designed to withstand extremes such as earthquakes or a direct hit by a crashing airliner. Many sensors are in place to pick up increases in radiation or humidity. An increase in radiation or humidity could mean there is a leak. There are systems that control, manage, and even stop the chain reaction as required, such as the Emergency Core Cooling System, which ensures that cooling water is abundantly available to cool the reactor in the event of an accident.

4. Meltdowns

If there is a loss of coolant water in a fission reactor, the rods would overheat. The rods that contain the Uranium fuel pellets would dissolve, leaving the fuel exposed. The temperature would increase with the lack of a cooling source. When the fuel rods heat to 2800°C, the fuel would melt, and a white-hot molten mass would melt its way through the containment vessels to the ground below it. This is a worst-case scenario, and there are many precautions in place to minimize this possibility. Emergency water reservoirs are designed to immediately flood the core in the case of sudden loss of coolant. There are normally multiple sources of water to draw from, as the low pressure injection pumps, containment spray system, and refueling pumps are all potentially available, and all draw water from different sources. The disaster at Three Mile Island was classified as a partial meltdown, caused by the failure to supply coolant to the core. Although the core was completely destroyed, the radioactive mass never penetrated the steel outlining the containment structure. Several feet of special concrete, a standard precaution, was capable of preventing leakage for several hours, giving operators enough time to fix the flooding system of the reactor core. The worst case of a nuclear disaster was in 1986 at the Chernobyl facility in the Ukraine. A fire ripped apart the casing of the core, releasing radioactive isotopes into the atmosphere. Thirty-one people died as an immediate result. And estimated 15,000 more died in the surrounding area after exposure to the radiation. Three Mile Island and Chernobyl are just examples of the serious problems that meltdowns can create.

5. Radiation

Radiation doses of about 200 rems cause radiation sickness, but only if this large amount of radiation is received all at once. The average person receives about 200 millirems a year from everyday objects and outer space. This is referred to as background radiation. If all our power came from nuclear plants we would receive an extra 2/10 of a millirem a year.[2] The three major effects of radiation(cancer, radiation sickness and genetic mutation) are nearly untraceable at levels below about 50 rems. In a study of 100,000 survivors of the atomic bombs dropped on Hiroshima and Nagasaki, there have been 400 more cancer deaths than normal, and there is not an above average rate of genetic disease in their children. During the accident at Three Mile Island in America, people living within a 50 mile radius only received an extra 3/10 of one percent of their average annual radiation. This was because of the containment structures, the majority of which were not breached. The containment building and primary pressure vessel remained undamaged, fulfilling their function.

6. Waste Disposal

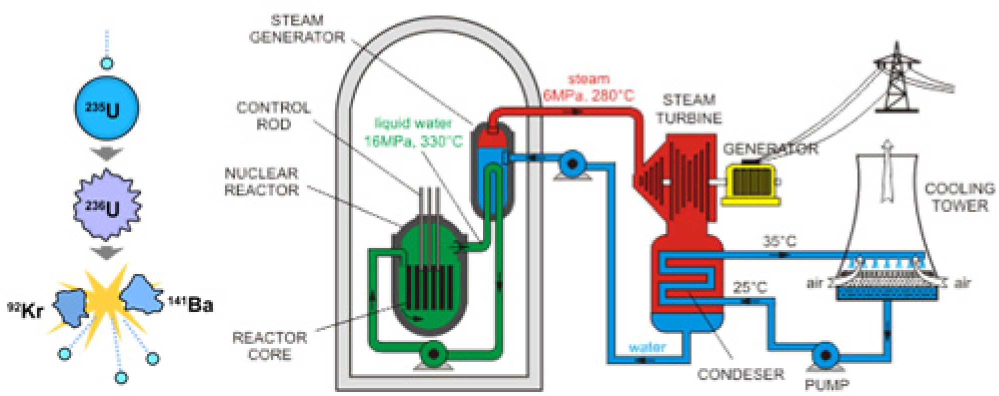
The byproducts of the fissioning of Uranium-235 remain radioactive for thousands of years, requiring safe disposal away from populated areas until they lose their significant radiation values. Many underground sites have been constructed, only to be filled within months. Storage facilities are not sufficient to store the world's nuclear waste, which limits the amount of nuclear fuel that can be used per year. Transportation of the waste is risky because many unknown variables affect the containment vessels and the potential for compromised vessels, the results of which would be lethal. Instead, the highly radioactive depleted fuel assemblies are initially stored in pools resembling large swimming pools specially designed to cool the fuel and act as a radiation shield. An increasing number of reactor operators now store their depleted fuel assemblies in dry storage facilities using outdoor-rated concrete or steel containers with air cooling systems. The United States

Department of Energy's long range plan is for permanent storage of depleted fuel assemblies beneath the earth's surface in a geologic repository, at Yucca Mountain, Nevada.

Yucca Mountain: site of the nation's first long-term geological repository for nuclear waste.

Nuclear Fission: The Heart of the Reactor and Plutonium

The fuel most widely used by nuclear plants for nuclear fission is Uranium. Uranium is neither renewable nor scarce however; nuclear plants use a certain kind of Uranium, U-235, because those atomic nuclei are easily split. Although Uranium is common, and about 100 times more common than silver; U-235 is relatively rare and most Uranium from the United States is mined in the Western United States. The U-235 must be extracted from the mined Uranium and processed before it can be used as a fuel. During nuclear fission, a small particle called a neutron hits the Uranium atom nucleus and splits it, releasing a great amount of energy as heat and radiation. More neutrons are also released that proceed to bombard other Uranium atoms, and the process repeats, initiating a chain reaction.



Fission: one neutron splitting the Uranium 235 atom into two elements and two neutrons; and the components of a nuclear reactor.

Nuclear fission also occurs naturally when Uranium undergoes spontaneous fission, but emitting radiation at a very slow rate, and Uranium is a superior choice for the induced fission of nuclear power plants. Uranium is a common element on Earth and has existed since the planet formed. As soon as the nucleus captures the neutron, it splits into two lighter atoms and throws off two or three new neutrons (the number of ejected neutrons depends on how the U-235 atom splits). The process of capturing the neutron and splitting happens very quickly. The decay of a single U-235 atom releases approximately 200 MeV million electron volts, and there are lots of Uranium atoms in a pound (0.45 kilograms) of Uranium.

Consequently, a pound of highly enriched Uranium as used to power a nuclear submarine is equal to about a million gallons of gasoline. The splitting of an atom releases an incredible amount of heat and gamma radiation **,** or radiation made of high-energy photons. The two atoms that result from the fission later release beta radiation (superfast electrons) and gamma radiation of their own. Interdependently, scientists over-enrich a sample of Uranium to three-percent enrichment, which is sufficient for nuclear power plants, as compared to the 90 percent U-235 for weapons-grade Uranium.

Another fissionable material is Plutonium-239, created by bombarding U-238 with neutrons as commonly occurs in a nuclear reactor. Despite all the drama surrounding the word *nuclear* , power plants that depend on atomic energy operate similarly to a traditional coal-burning power plant because both heat water into pressurized steam that drives a turbine generator. The key difference between the two plants is the method of heating the water. While older plants burn fossil fuels, nuclear plants depend on the heat that develops during nuclear fission from atoms splitting and releasing energy. Nuclear reactors are machines that contain and control chain reactions, while releasing heat at a controlled rate. In electric power plants, the reactors supply the heat to turn water into steam, which drives the turbine-generators.

Two types of reactors are commissioned in the United States: boiling-water reactors (BWRs), and pressurized-water reactors (PWRs). In the BWR, the water heated by the reactor core turns directly into steam in the reactor vessel and is then used to power the turbine-generator. In a PWR, the water passing through the reactor core is kept under pressure so that it does not turn to steam but remains liquid. Steam to drive the turbine is generated in a separate piece of equipment called a steam generator, a giant cylinder with thousands of tubes through which the hot radioactive water can flow. Outside the tubes in the steam generator, nonradioactive water or clean water boils and eventually turns to steam. The clean water is replenished from one of several sources: oceans, lakes or rivers, whereas the radioactive water recirculates to the reactor core, where it is reheated and pumped back to the steam generator. Approximately seventy percent of the reactors operating in the United States are PWR.

To convert nuclear fission into electrical energy, the energy discharged by the enriched Uranium in the nuclear power plant heats water into steam. Enriched Uranium is typically formed into one-inch-long, or 2.5-centimeters-long, ceramic pellets, each with approximately the same diameter as a dime. Each fingertip-sized ceramic pellet produces the same amount of energy as 150 gallons of oil. These energy-rich pellets are stacked end-to-end in 12-foot metal fuel rods, and the rods are collected together into bundles called *fuel assemblies* . The fuel assemblies are submerged in water inside a pressure vessel where the water acts as a coolant, without which the Uranium would eventually overheat and melt. To prevent overheating, *control rods* made of a material that absorbs neutrons are inserted into the Uranium bundle with a mechanism that raises or lowers them to control the rate of nuclear reaction. Consequently, to produce more heat from the Uranium core, the control rods are lifted out of the Uranium bundle, absorbing fewer neutrons and increasing the chain reactions with more neutrons. To reverse this process and reduce heat the rods are lowered into the Uranium bundle. When the rods are completely lowered into the Uranium bundle, the reactor can be shut-down in response to an accident or to change the fuel. The Uranium bundle acts as an extremely high-energy source of heat, heating the water and producing steam. The steam rotates a turbine that spins a generator to produce electricity or electrical power. Harnessing the expansion of water into steam has been applied to significant tasks in many cultures for hundreds of years.

In some nuclear power plants, the steam from the reactor goes through a secondary, intermediate heat exchanger to exchange heat to another loop of water converting it to steam, which drives the turbine. The advantage to this design is that steam from the radioactive water/ never contacts the turbine. Also, in some reactors, the coolant fluid in contact with the reactor core is gas (carbon dioxide) or liquid metal (sodium, potassium); these types of reactors allow the core to be operated at higher temperatures. The radioactive elements inside a nuclear power plant require thicker walls than you'd find at a coal power plant, including various protective barriers containing the atomic heart of the plant.[3]

Outside Nuclear Power Plants

Once you get past the reactor itself, there's very little difference between a nuclear power plant and a coal-fired or oil-fired power plant, except for the source of the heat to create steam. But as that source can emit harmful levels of radiation, extra precautions are required.

The nuclear power plant in Brokdorf, Germany.

Concrete liners encase the reactor's pressure vessels as radiation shields. Those liners are encased within much larger steel containment vessels. These vessels contain the reactor cores, as well as the equipment plant workers use to refuel and maintain the reactors. The steel containment vessels serve as a barrier to prevent leakage of any radioactive gases or fluids from the plant. An outer concrete building serves as the final layer, protecting the steel containment vessel. This concrete structure is designed to be strong enough to survive the kind of massive damage that might result from earthquakes or a crashing jet airliner. Those secondary containment structures are necessary to prevent the escape of radiation/radioactive steam in the event of an accident. The absence of secondary containment structures in Russian nuclear power plants allowed radioactive material to escape in Chernobyl. Workers in the control room at the nuclear power plant can monitor the nuclear reactor and take action if something goes wrong. Nuclear facilities also typically feature security perimeters and added personnel to help protect sensitive materials.

Applied Mathematics and Physics

This curriculum unit is intended to assist me in teaching about the seminar subject in my own classroom. Mathematics, Physics, and Computer Science introduce a variety of algorithms and equations for studying both the benefits and risks associated with nuclear energy, independent of fossil fuels and unaffected by fluctuating oil and gas prices. Coal and natural gas power plants emit carbon dioxide into the atmosphere, which contributes to climate change. With nuclear power plants, CO_2 emissions are minimal. According to the Nuclear Energy Institute, the power produced by the world's nuclear plants would translate to 2 billion metric tons of CO_2 per year if that power were produced by fossil fuels. In fact, a properly functioning nuclear power plant actually releases less radioactivity into the atmosphere than a coal-fired power plant.[4] In addition, the fuel requirement is much less. Nuclear fission produces roughly a million times more energy per unit weight than fossil fuel alternatives.

Historically, mining and purifying Uranium hasn't been a very clean process. Even transporting nuclear fuel to and from plants poses a contamination risk. And once the fuel is spent, you can't just throw it in the city dump. It's still radioactive and potentially deadly. On average, a nuclear power plant annually generates 20 metric tons of used nuclear fuel, classified as high-level radioactive waste. When you take into account every nuclear plant on Earth, the combined total climbs to roughly 2,000 metric tons a year. All of this waste emits radiation and heat, meaning that it will eventually corrode any container that holds it. It can also prove lethal to nearby life forms. As if this weren't bad enough, nuclear power plants produce a great deal of low-level radioactive waste in the form of radiated parts and equipment.

Managing Nuclear Energy

When compared to burning fossil fuels to generate electricity, nuclear energy from nuclear power plants produces neither air pollution nor carbon dioxide and only a small amount of emissions result from processing the Uranium that is used in the nuclear reactions. Over time, spent nuclear fuel decays to safe radioactive levels, but this process takes tens of thousands of years. Even low-level radioactive waste requires centuries to reach acceptable levels. Currently, the nuclear industry cools waste for years before mixing it with glass and storing it in massive cooled, concrete structures, to be maintained, monitored and guarded.

The industrial processes of nuclear power generation have by-product wastes: depleted fuels, other radioactive waste, and heat. Depleted fuels and other radioactive wastes are the principal environmental concern for nuclear power. Most nuclear waste is low-level radioactive waste. It consists of ordinary tools, protective clothing, wiping cloths and disposable items that have been contaminated with small amounts of radioactive dust or particles. These materials are subject to special regulations that govern their disposal so they will not come in contact with the outside environment. All of these services and added materials cost money -- on top of the high costs required to build a plant.

At the heart of every nuclear reactor is a controlled environment of radioactivity and induced fission. When this environment spins out of control, the results can be catastrophic, resulting in a nuclear catastrophe and reactor shutdown. For many years, the Chernobyl disaster stood as a prime worst-case example of nuclear malfunction. In 1986, the Ukrainian nuclear reactor exploded, spewing 50 tons of radioactive material into the surrounding area, contaminating millions of acres of forest. The disaster forced the evacuation of at least 30,000 people, and eventually caused thousands to die from cancer and other illnesses. Chernobyl was poorly designed and improperly operated. The plant required constant attention to keep the reactor from malfunctioning however; all modern nuclear power plants require constant supervision and even well-designed nuclear power plants are susceptible to natural disasters.

Nuclear waste storage facility near the site of the Chernobyl Nuclear Power Plant.

On Friday, March 11, 2011, Japan suffered the largest earthquake in modern history. A programmed response at the country's Fukushima-Daiichi nuclear facility instantly lowered all of the reactor's control rods, shutting down all fission reactions within ten minutes. Radioactivity from previous fission reactions however, continued to generate heat from the decay process for the first few hours after the nuclear reactor shut down. Similarly, nuclear waste continues to generate heat years after initial reactions in a nuclear power plant.

The March 2011 earthquake manifested a deadly tsunami, destroying the backup diesel generators that the facility relied upon to power the water coolant pumps after Japan's power-grid failed. These pumps circulate water through the reactor to remove heat from decaying radioactive material. Consequently, both the water temperature and water pressure inside the reactor continued to rise. Furthermore, the reactor radiation began to separate the water molecules into oxygen and hydrogen atoms, the volatility of which resulted in hydrogen explosions that breached the steel containment panels of the reactor building. While the Fukushima-Daiichi facility had several safety contingency plans to summarily shut down operations in the event of severe seismic activity, there was no countermeasure for a power failure to their coolant pumps.

The largest earthquake in history and the ensuing tsunami caused a nuclear catastrophe in Japan.

Conclusions

Clearly, from the above preceding discussion of nuclear power plant issues, nuclear energy cannot be considered an apparent solution to any problem, whereas it has a history of being the source of many further problems. Also, the electrical energy industry is aware of the substantial drawbacks of nuclear power generation. Nevertheless this industry is now spending an incredible amount of money and time, lobbying for the revival of nuclear energy. The main interest of the owners of existing nuclear power plants is however to prolong the life-span for existing nuclear plants. Because the existing plants will be amortized at the end of their originally planned life time, huge financial profits can be realized for any day longer which these plants can be kept in operation. This is much more lucrative than building new nuclear plants however, to operate nuclear power plants longer than originally planned can be quite dangerous since any plant or technical appliance usually starts to fail towards the end of its planned life expectancy.

Nuclear power plants incite our greatest hopes and deepest fears for the future. While atomic energy offers a clean energy alternative that frees us from the shackles of fossil fuel dependence, it summons images of disaster: quake-ruptured Japanese power plants emitting radioactive steam, and the dead zone surrounding Chernobyl's concrete sarcophagus. Plants such as Japan's Fukushima-Daiichi facility, Russia's Chernobyl and the United States' Three Mile Island will forever haunt the nuclear power industry, often diminishing some of the environmental advantages that nuclear technology has to offer.

Lesson Plans

Lesson 1: Radiation

Lesson 2: The Uses of Radiation

Lesson 3: Nuclear Reactors/Energy Generation

Lesson 4: Radioactive Waste

Lesson 1: Radiation

Objectives

To stimulate students' interest in the biological effects of radiation, help students become more literate in the benefits and hazards of radiation, and inform students about the NRC's role in regulating radioactive materials. At the conclusion of this unit the student should be able to distinguish between natural and man-made radiation, detect and measure radiation using a Geiger counter, investigate the "footprints" of radiation using the Cloud Chamber, describe the principle of half-life of radioactive materials and demonstrate how half-lives can be calculated, and identify and discuss the different types of radiation.

Investigation

Hypothesis made before conducting the Cloud Chamber experiment: While radiation cannot be seen, the cloud chamber allows one to see the tracks it leaves in dense gas.

1. General

1. Materials needed for the Cloud Chamber: small transparent container with transparent lid; flat black spray paint; blotter paper; pure ethyl alcohol; radioactive source; masking tape; dry ice; styrofoam square; flashlight; gloves or tongs to handle the dry ice.

2. Materials for measuring radiation with the Geiger counter; Geiger counter; radioactive sources; shielding material such as paper, aluminum foil, brick, jar of water, piece of wood, glass pane, sheet of lead.

After Cloud Chamber Experiment

Because you could not see the radiation, what kind of observation did you experience?

What is happening to the radioactive source?

What radiation "footprints" did you see? Describe them.

After the Geiger Counter Measurements

Why do we measure radiation exposure?

When you use a Geiger counter to survey a radioactive substance, why is it important to know what the background radiation level is?

Has anyone you know been helped or harmed by radiation?

Lesson Plan

Note: Give each student a 5x7 index card as he/she enters the classroom. Ask students to share their thoughts about radiation by writing on the card what they thought about. Do not put your name on the card! Initiate a discussion about radiation by reading several index cards to the class without associating any student with a particular thought. Write key words from student opinion on the board for future reference.

Radiation surrounds us, coming from the Earth and from outer space. Many forms of radiation are invisible -- we can't feel it, see it, taste it, or smell it. Yet, it can be detected and measured when present. We measure ionizing radiation in units called millirems. But what is radiation? Radioactive materials are composed of atoms that are unstable. An unstable atom gives off its excess energy until it becomes stable. The energy emitted is radiation. We can classify radiation as being either natural or man-made.

The Earth is surrounded by radiation: radon, a radioactive gas from Uranium found in soil dispersed in the air; from radioactive potassium in our food and water; from Uranium, radium, and thorium in the Earth's crust; and from cosmic rays and the sun. These types of radiation are called natural or background radiation. In the U.S. we are exposed to an average of 300 millirems of natural radiation each year (a millirem is a unit of measure for exposure to radiation). This amounts to natural radiation accounting for nearly 85 percent of our total annual exposure. The remaining 15 percent come from man-made sources. Man-made radiation sources that people can be exposed to include tobacco, television, medical x-rays, smoke detectors, lantern mantles, nuclear medicine, and building materials.

Adding it all up, the average American is exposed to a total of about 360 millirems a year from natural and man-made radiation. The sources of radiation are shown in Classroom Activity 1. Generally, when we think of exposure to radiation, we need to look at radioactive atoms produced in nuclear reactors and described as being unstable. They are unstable because they undergo a disintegrating process called decaying. During this process, unstable atoms become stable, throwing off (emitting) radiation in the form of rays and/or particles. How fast a radioactive atom decays into a stable atom depends on the atom itself. For example, the range in the rate of decay among isotopes goes from fractions of seconds to several billion years (e.g., Uranium). Let's take a look at Uranium-238 to illustrate the decay chain.

As U-238 decays it changes into thorium-230, which changes into radium-226, which changes into radon-218, which changes into bismuth-214, and finally into lead-206 (a stable element). One peculiar thing about radioactive atoms is that no one knows exactly when the element will decay and give off radiation. There is, however, a pattern relating to how long it takes for an isotope to lose half of its radioactivity. This pattern is called half-life. If an atom, for example, has a half-life of 10 years, half of its atoms will decay in 10 years. Then in another 10 years half of that amount will decay and so on. While there are several different forms of radiation, we're concentrating on three that result from the decay of radioactive isotopes: alpha, beta, and gamma.

Beta particles are high energy electrons. Both alpha and beta particles are emitted from unstable isotopes. The alpha particle, consisting of two protons and two neutrons, is relatively large compared to beta particles. Gamma rays have no mass. Because of its size and electrical charge (+2), the alpha particle has a relatively slow speed and low penetrating distance (one to two inches in air). Alpha particles are easily stopped by a thin sheet of paper or the body's outer layer of skin. Since they do not penetrate the outer (dead) layer of skin, they present little or no hazard when they are external to the body.

However, alpha particles are considered internal hazards, because when they come into contact with live tissue they cause a large number of ionizations to occur in small areas, thus causing damage to tissues and cells. Beta radiation, while faster and lighter than alpha radiation, can travel through about 10 feet of air and penetrate very thin layers of materials such as aluminum foil. However, while clothing will stop most beta particles, they can penetrate the live layers of skin tissue. Therefore, beta radiation is considered to be both an internal and external (to skin only) hazard. Thin layers of metals and plastics can be used to shield individuals from beta radiation.

Gamma radiation, high energy light, is a little different. It is a type of electromagnetic wave, just like radio waves, light waves, and x-rays. Gamma radiation is a very strong type of electromagnetic wave, traveling at the speed of light with no mass. This is much faster than alpha and beta radiation. Because of their penetrating capability, gamma rays are considered both internal and external hazards. Thick walls of cement, lead, or steel are needed to block gamma radiation.

Ionizing radiations: alpha, beta, and gamma alter chemical structures including the delicate chemistry of the human body and other living organisms. Radiation causes the potential for malignant tumors by altering the normal body cells and normal body cell functions, resulting in uncontrolled cell growth and abnormal cell functions. The only known method of preventing the harm of ionizing radiation is to avoid exposures. Large amounts of radiation levels above the levels normally encountered can produce cancers and genetic defects in living organisms. All biological damage begins when radiation interacts with atoms forming cells, whether the source of radiation is natural or man-made, a small dose of radiation or a large dose. Radiation causes ionizations of those atoms that will affect molecules that may affect cells that may affect tissues that may affect organs that may affect the whole body.

Experiment A: The Cloud Chamber While radiation cannot be seen, the cloud chamber allows you to see the tracks it leaves in a dense gas. [Complete Classroom Activity, see http://scidiv.bellevuecollege.edu/Physics/Cloudchmbr.htm]

Experiment B: Using the Geiger Counter How radioactive are different materials? [Complete Classroom Activities, see http://www.charlesedisonfund.org/Experiments/HTMLexperiments/Chapter8/8-Expt8/p1.html]

Questions with Answers from the Radiation Lesson Outline:

1. Q: Why are elements that break apart called unstable? A: They are unstable because in the process of emitting gamma rays they become stable or change into another element by emitting alpha and beta particles.

2. Q: How do things become less radioactive as time goes by? A: Unstable elements break down bit by bit emitting alpha and beta particles and gamma rays. Each unstable element also loses its radioactivity at a different rate that is defined by its half-life. Half-lives range from fractions of a second to several billion years.

3. Q: What materials are best for shielding? A: Denser materials such as lead or concrete are more effective for stopping radiation because a high density and high atomic number provides many more atoms per volume and many more electrons with which photons can interact.

Lesson 2: The Uses of Radiation

Objectives

At the conclusion of this lesson students should be able to discuss the uses of radiation in science, industry, and medicine; identify different man-made radiation sources that result in exposure to members of the public and compare and contrast the benefits and risks of radiation.

Investigation

While the Earth and all things on it are constantly being bombarded by radiation from space, there are two distinct groups exposed to man-made radiation: members of the public and radiation workers. Members of the public are exposed to the most significant source of man-made radiation from medical procedures and treatments. Conversely, radiation workers are exposed according to their occupations and to the sources with which they work.

Lesson Plan

Although scientists have only known about radiation since the 1890s, they have developed a wide variety of uses for this natural force. Today, to benefit mankind, radiation is used in science, medicine, and industry, as well as for generating electricity. Radiation has useful applications in such areas as agriculture, medicine, space exploration, architect/engineering, industry/manufacturing, government, geology (including mining), ecology, and education. Radiation is used by doctors to diagnose illness and helps archaeologists find the age of ancient artifacts. Electricity produced by nuclear fission -- splitting the atom -- is one of its greatest uses. A reliable source of electricity is needed to give us light, help to groom and feed us, and to keep our homes and businesses running. Let me give you some specific examples of how the radiation has been used to:

1. Diagnose and treat illnesses

2. Kill bacteria and preserve food without chemicals and refrigeration

3. Process sludge for fertilizer and soil conditioner

4. Locate underground natural resources and differentiate a dry hole from a gusher

5. Make smoke detectors, nonstick cookware, and ice cream

6. Grow stronger crops

7. Power satellites and provide future electrical needs for space laboratories with people onboard

8. Design instruments, techniques, and equipment; measure air pollution

9. Validate the age of works of art and assist in determining their authenticity

Radiation in Medicine

X-rays are a type of radiation that can pass through our skin. Our bones are denser than our skin, so when x-rayed, bones and other dense materials cast shadows that can be detected on photographic film. The effect is similar to placing a pencil behind a piece of paper and holding them in front of a light. The shadow of the pencil is revealed because most light has enough energy to pass through the paper, while the denser pencil stops all the light. The difference is that we need film to see the x-rays for us. Today, doctors and dentists use x-rays to see structures inside our bodies. This allows them to spot broken bones and dental problems. X-ray machines have now been connected to computers in the development of machines called CAT scanners. These instruments provide doctors with color TV pictures that show the shape of internal organs.

Approximately 10 million nuclear medicine procedures are performed in the United States annually. Diagnostic x-rays and or radiation therapy were administered to about seven out of every 10 Americans. Medical procedures using radiation have saved thousands of lives through the detection and treatment of conditions ranging from hyperthyroidism to bone cancer. In such procedures, doctors administer slightly radioactive substances to patients, which are attracted to certain internal organs such as the pancreas, kidney, thyroid, liver, or brain, to diagnose clinical conditions. Moreover, radiation is often used to treat certain types of cancer. Radioactive iodine, specifically iodine-131, is being used frequently to treat thyroid cancer, a disease which strikes about 11,000 Americans every year.

Radiation in Science

Radiation is used in science in many ways. Just as doctors can label substances inside people's bodies, scientists can label substances that pass through plants, animals, or our world. This allows us to study such things as the paths that different types of air and water pollution take through the environment. It has also helped us learn more about a wide variety of things, such as what types of soil different plants need to grow, the size of newly discovered oil fields, and the track of ocean currents. Scientists use radioactive substances to find the age of ancient objects by a process called carbon dating. For example, in the upper levels of our atmosphere, cosmic rays hit nitrogen atoms and form a naturally radioactive isotope called carbon-14. Carbon is found in all living things, and a small percentage of this carbon is carbon-14. When a plant or animal dies, it no longer takes in new carbon and the carbon-14 it contains begins the process of radioactive decay. However, new isotopes of carbon-14 continue to be formed in our atmosphere, and after a few years the percent of radioactivity in an old object is less than it is in a newer one. By measuring this difference, scientists are able to determine how old certain objects are. The measuring process is called carbon dating.

Radiation Used To Solve Crimes

After detectives search the scene of a crime for traces of paint, glass, hair, gunpowder, or blood, evidence is collected and often exposed to radiation and then analyzed to find out its exact makeup. If material is exposed to streams of neutrons, some of the neutrons can be absorbed into the nucleus of the exposed material. This makes these materials slightly radioactive and because they are unstable and decay with time, scientists are then able to read the exact chemical signatures of these substances. This laboratory process, called activation analysis, is precise enough to determine if a single hair found at a crime scene came from a certain person. Activation analysis is also used to find out the chemical makeup of materials when scientists only have small samples, as well as to prove that older works of art are not made of modern materials.

Radiation in Industry

Exposure to some types of radiation, such as x-rays, can kill germs without harming the items that are being disinfected or making them radioactive. When treated with radiation, foods take much longer to spoil, and medical equipment such as bandages, hypodermic syringes, and surgical instruments don't have to be exposed to toxic chemicals or extreme heat to be sterilized. Radiation may soon replace chlorine, a toxic and difficult-to-handle chemical, in the future to disinfect drinking water and eradicate germs in sewage.

Ultraviolet light is presently used to disinfect residential drinking water. The agricultural industry makes use of radiation to improve food production. Plant seeds, for example, have been exposed to radiation to bring about new and better types of plants. Besides making plants stronger, radiation can also be used to control insect populations, thereby decreasing the use of pesticides. Engineers use radioactive substances to measure the thickness of materials and an x-ray process called radiography to find hard to detect defects in many types of metals and machines. Radiography is also used to check such things as the flow of oil in sealed engines and the rate and way various materials wear out. The radioactive element Uranium is used as a fuel to make electricity for our cities, farms, towns, factories, etc.

In outer space, radioactive materials are also used to power space craft. Such materials have also been used to supply electricity to satellites sent on missions to the outermost regions of our solar system. Radiation has been used to help clean up toxic pollutants, such as exhaust gases from coal-fired power stations and industry. Sulfur dioxides and nitrogen oxides, for example, can be removed by electron beam radiation. Indubitably, radiation and radioactive materials have played and will continue to play a significant role in our lives. For example, polyester-cotton blend shirts are made from chemically treated fabric that has been irradiated, or treated with radiation, before being exposed to a soil-releasing agent. Radiation makes chemicals bind to fabric, keeping shirts fresh and pressed all day however, the shirt is not radioactive. Additionally, nonstick pans are treated with gamma rays, and the thickness of an eggshell is measured by a gauge containing radioactive material before packaged into an egg carton.

The turkey stored in a refrigerator and covered with irradiated polyethylene shrink wrap. Once polyethylene has been irradiated, it can be heated above its usual melting point and wrapped around the turkey to provide an airtight cover. Reflective road signs are treated with radioactive tritium and phosphorescent paint. During lunch, brother Bob has some ice cream. The amount of air whipped into that ice cream was measured by a radioisotopic gauge. After you and your family return home this evening, some of you may have soda and others may sit and relax. Nuclear science is at work here: The soda bottle was carefully filled -- a radiation detector prevented spillover. And your family is safe at home because the ionizing smoke detector, using a tiny bit of americium-241, will keep watch over you while you sleep.

Questions with Answers from the Uses of Radiation Lesson Outline:

1. Q: How can we use radioactive isotopes to detect illness? A: By replacing a few regular atoms with radioactive isotopes in substances like hormones, food, or drugs we are able to trace the path they take through our bodies. Instruments can be used to trace the isotope through the body, or parts of the body, to find problems.

2. Q: How can we use radiation to detect a weakness in the construction of buildings? A: X-rays can be used to see into many metals and machines to help find flaws that cannot be seen on the outside. This type of examination is called radiography.

3. Q: Have you ever had a bone x-rayed? Teeth x-rayed? How did this help your doctor or dentist treat you? A: The doctor or dentist is able to see exactly what the problem is and then knows how to treat it.

4. Q: Do you think the additional radiation received when people have medical x-rays, about 40 millirems per year, is worth the benefits they receive? A: Answers will vary.

5. Q: Are there advantages to using radiation instead of pesticides to control pests, such as insects? A: Radiation can be used to control pests by sterilizing male insects that have been raised in captivity and then released into the environment. They will not be able to produce offspring. Therefore, the numbers of insects will be reduced. Another advantage is that there will be fewer chemicals added to the environment.

Lesson 3: Nuclear Reactors/Energy Generation

Objectives

To ensure students understand how nuclear energy is generated, help students learn how a nuclear power plant works, and understand how the NRC regulates commercial nuclear energy.

At the conclusion of this lesson students should be able to describe the fission process, identify the various kinds of nuclear power plants, and discuss the process of energy generation with nuclear power plants.

Investigation

The purpose of a nuclear power plant is to produce or release heat, boil water into steam, and generate electricity from a generator that is driven by a steam-turbine. It should be noted that while there are significant differences, there are many similarities between nuclear power plants and other electrical generating facilities. Uranium is used for fuel in nuclear power plants to make electricity.

Lesson Plan

Increasingly, our country has become a nation of electricity consumers. We depend on an abundant and affordable supply of energy to power the many machines we use in our complex society. About one-third of our energy resources are used to meet this electricity requirement.

Electricity can be produced in many ways -- most of which you already know about. Today, we're going to talk about one of those ways -- nuclear fission. In America, nuclear energy plants are the second largest source of electricity after coal -- producing approximately 21 percent of our electricity. There is something I want all of you to be aware of: The purpose of a nuclear power plant is to produce electricity. While nuclear power plants have many similarities to other types of electricity generating plants, there are some significant differences. With the exception of solar, wind, and hydroelectric plants, all others including nuclear convert water to steam that spins the propeller-like blades of a turbine that spins the shaft of a generator. Inside the generator coils of wire and magnetic fields interact to create electricity.

The energy needed to boil water into steam is produced in one of two ways: by burning coal, oil, or gas (fossil fuels) in a furnace or by splitting certain atoms of Uranium in a nuclear energy plant. Nothing is burned or exploded in a nuclear energy plant. Rather, the Uranium fuel generates heat through a process called fission. Uranium is an element that can be found in the crust of the Earth. This element, quite abundant in many areas of the world, is naturally radioactive. Certain isotopes of Uranium can be used as fuel in a nuclear power plant. The Uranium is formed into ceramic pellets about the size of the end of your finger. [Reactor Fuel Assembly] These pellets are inserted into long, vertical tubes (fuel rods) within the reactor. The reactor is the heart of the nuclear power plant. Basically, it is a machine that heats water. A reactor has four main parts: the Uranium fuel assemblies, the control rods, the coolant/moderator, and the pressure vessel. The fuel assemblies, control rods, and coolant/moderator make up what is known as the reactor core. The core is surrounded by the pressure vessel. [Franklin's Core]

We also have to understand that Uranium cannot just be thrown into a reactor the way we shovel coal into a furnace. The fuel rods, containing the Uranium, are carefully bound together into fuel assemblies, each of which contains about 240 rods. The assemblies hold the rods apart so that when they are submerged into the reactor core, water can flow between them. When the Uranium atom splits, it releases energy and two or more neutrons from its nucleus. These neutrons can then hit the nuclei of other Uranium atoms causing them to fission. The sequence of fission-triggering is called a chain reaction, releasing energy in the form of heat when the atoms split. The heat is transferred from the reactor core to the steam generator and converted to high pressure steam that turns the turbine in the electric generator.

The control rods slide up and down in between the fuel assemblies in the reactor core. They control or regulate the speed of the nuclear reaction by absorbing neutrons. Here's how it works: When the control rods absorb neutrons, fewer neutrons hit the Uranium atoms thus slowing down the chain reaction. On the other hand, when the core temperature goes down, the control rods are slowly lifted out of the core, and fewer neutrons are absorbed. Therefore, more neutrons are available to cause fission. This releases more heat energy. Just as there are different types of houses and cars, there are different types of nuclear power plants that generate electricity. The two basic types being used in the United States are the boiling water reactor (BWR) and the pressurized water reactor (PWR). These power plants are often referred to as light water reactors.

Pass out Activities 4 - Boiling Water Reactor (BWR) and 5 - Pressurized Water Reactor (PWR).

Students can label components of each type reactor during the discussion.

Boiling Water Reactor (BWR)

The boiling water reactor operates in essentially the same way as a fossil fuel generating plant. Neither of these types of power plants have a steam generator. Instead, water in the BWR boils inside the pressure vessel and the steam water mixture is produced when very pure water (reactor coolant) moves upward through the core absorbing heat. The water boils and produces steam. When the steam rises to the top of the pressure vessel, water droplets are removed, the steam is sent to the turbine generator to turn the turbine. [BWR schematic]

Pressurized Water Reactor (PWR)

The pressurized water reactor differs from the BWR in that the steam to run the turbine is produced in a steam generator. Water boils at 212/F or 100/C, expanding into steam as it boils. A pressure cooker encloses an increasing pressure inside the pot because the steam cannot escape. As the pressure increases, so does the temperature of the water in the pot. In the PWR plant, a pressurizer unit keeps the water that is flowing through the reactor vessel under very high pressure to prevent it from boiling. The hot water then flows into the steam generator where it is converted to steam. The steam passes through the turbine which produces electricity. About two-thirds of the reactor power plants in the U.S. are of the PWR type. [PWR schematic]

Questions with Answers from Nuclear Reactors/Energy Generation Lesson Outline:

1. Q: Is there a nuclear power plant near where you live? What type is it? A: Example: 40 miles south of Annapolis, MD -- Calvert Cliffs 1 & 2 (PWR).

2. Q: Why don't boiling water reactors have steam generators? A: Because the water is boiled inside the pressure vessel and the steam is used directly to turn the turbine.

3. Q: What is the purpose of a "cooling tower"? A: To remove excess heat from the reactor circulating water system.

4. Q: What percentage of our electricity in the U.S. is produced in nuclear power plants? A: Approximately 20 percent.

5. Q: Name the two types of reactor power plants in operation the U.S. What are the basic differences? A: a. Boiling Water Reactor (BWR) -- water is boiled in the pressure vessel and the steam is used directly to turn the turbine. b. Pressurized water reactor (PWR) -- water flows through a steam generator where it is heated to produce steam that then flows to the turbine to generate electricity.

Lesson 4: Radioactive Waste

Objectives

To make students aware of nuclear waste shipments and the safeguards in place, and recommend that students become more familiar with the Federal agencies involved in waste transportation and pertinent public policy issues. At the conclusion of this lesson students should be able to describe the sources, handling, and disposal of radioactive wastes generated by nuclear power plants, distinguish between high- and low-level radioactive wastes, and identify the agencies having oversight responsibilities in the designation and storage of radioactive waste.

Investigation

Radioactive waste is material that is radioactive, no longer needed at the plant, and can be disposed of.

Lesson Plan

Nuclear waste raises many questions that will be addressed and hopefully answered in this lesson. Quantifying garbage that people produce on a weekly, daily, or even per restaurant visit should be the basis of student reflections. Visualize how much trash results from just one visit to a fast-food restaurant -- from bags, to straws, to soft drink containers. Many other industries generate garbage from manufacturing something and the leftovers of an industrial process are called wastes and nuclear power plants produce nuclear waste. One of the main concerns about nuclear power plants is what to do with the waste. Student should assemble the nuclear waste cube to observe that in the U.S. one person's share of high-level radioactive waste from nuclear power plants for a period of 20 years could be placed inside the cube. This is the amount of waste that would be left over after all stable materials had been recycled.

The problem with nuclear power plants wastes are not the amounts, which are quite small compared to other industries, but that nuclear power plants wastes can be radioactive. Nuclear power plants are not the only producers of radioactive waste however, a large amount of radioactive waste is produced by hospitals and other industrial processes. All producers of radioactive waste must ensure that special rules and regulations are followed to transport and dispose of these materials, thereby protecting the employees, the public, and the environment. Radioactivity of the waste, half-life of the waste, and physical or chemical properties of the waste are attributes that align with acceptable methods for disposing of nuclear waste.

Radioactive waste includes solid, liquid, and/or gaseous materials that are neither needed nor valued at the nuclear power plant, ready for disposal:

1. Radioactive fission products inside the cladding of fuel assemblies.

2. Radioactive activation products that are collected in filters and demineralizers in the reactor cleanup

systems.

3. Paper towels or rags used to wipe up radioactive water.

4. Contaminated pieces of equipment.

5. The pressure vessel, plumbing, and containment structures from a closed or decommissioned facility.

6. Radioactive waste from nuclear power plants is classified as being either low- or high-level waste.

Waste that is only slightly radioactive and gives off small amounts of radiation is called low-level waste. Low-level waste is produced in virtually every state by hospitals, universities, companies, and nuclear energy plants. This waste includes such things as filters, cleanup rags, lab supplies, and discarded protective clothing. Most radioactive waste from a nuclear power plant is low-level. The principle sources of low-level radioactive waste are the reactor coolant water and the components and equipment that come in contact with the coolant. The major constituents of low-level waste from a nuclear power plant are activation products and a very small percentage of fission products (if any leaks out of the fuel rods). It does not include used fuel from the reactor fuel assembly. Because it emits only small amounts of radiation, low-level waste is usually sealed in steel drums and buried at special sites. Today, most of the low-level waste from nuclear power plants in the U.S. is disposed of at two sites: Barnwell, South Carolina, and Hanford, Washington. Drums containing low-level waste are placed in specially designed trenches and are covered with at least six feet of soil and packed clay. To ensure that the materials remain undisturbed, the trenches are constantly monitored to detect radiation.

The radioactive particles in low-level waste emit the same types of radiation that everyone receives from nature. Most low-level waste fades away to natural levels of radioactivity in months or years. Virtually all of it diminishes to natural levels in less than 300 years. In the U.S. there is strict regulation of low-level waste. The U.S. Nuclear Regulatory Commission, for example, licenses many of the facilities that produce low-level waste, including nuclear power plants. It also regulates low-level waste disposal. The U.S. Environmental Protection Agency, on the other hand, develops general standards to protect the public from radiation. The U.S. Department of Energy coordinates national planning with the states for managing low-level waste. The U.S. Geological Survey offers technical assistance with studies of hydrology and geology of proposed sites. Legislation passed by Congress requires state governments to be responsible for disposing of the low-level waste generated in their states or for joining a regional compact. State governments are also responsible for selecting and licensing a site according to Federal standards and monitoring its operation.

Waste from power plants that is highly radioactive is called high-level waste. For example, about 99 percent of high-level waste from commercial nuclear power plants comes from used or spent nuclear fuel (Uranium pellets inside metal fuel rods) that has released much of its energy. Certain changes take place in the fuel during the fission process. Most of the fragments of fission, including the pieces left over after the atom has split, are radioactive. Over time, these trapped fission fragments reduce the efficiency of the chain reaction. About every 18 months or so, the oldest fuel assemblies, which have already released their energy, are removed and replaced with fresh fuel. Fuel that has been removed from the reactor is called spent fuel. Spent fuel is highly radioactive, and this radioactivity produces a lot of heat. Spent fuel, after being removed from the reactor, is stored at nuclear plant sites in steel-lined, concrete vaults filled with water or in dry storage casks that are air cooled. The water cools the used fuel and acts as a shield to protect workers from radiation.

During storage, the spent fuel cools down and also begins to lose most of its radioactivity through radioactive decay, which we've already discussed. In three months, for example, the spent fuel will have lost 50 percent of its radiation; in one year it will have lost about 80 percent; and in 10 years it will have lost 90 percent. Nevertheless, because some radioactivity remains hazardous for thousands of years, the waste must be carefully and permanently isolated from the environment. While storage on site has been environmentally safe, what is needed today is a permanent disposal site, or repository, for existing and future high-level waste. To date, scientists around the world agree that deep underground disposal is the way to solve the high-level waste storage problem. In fact, deep underground geologic repositories have been endorsed by independent scientific organizations such as the National Academy of Sciences. In 1982, the U.S. Congress passed the Nuclear Waste Policy Act. This law set up a schedule for selecting a site, constructing, and operating America's first high-level nuclear waste storage facility. In 1987, Congress directed DOE to explore Yucca Mountain for a repository.

In February 2002, DOE recommended that Yucca Mountain be developed as America's first high-level nuclear waste storage facility however, before the site can be approved, or a repository built and operated, there must be scientific proof that public health and safety will be protected for thousands of years. The facility must meet strict safety requirements of the U.S. Nuclear Regulatory Commission. Additional oversight would be provided by the U.S. Environmental Protection Agency, the State of Nevada, and a Technical Review Board appointed by the President of the United States. This high-level waste will most likely be converted into a ceramic material that will not rust, melt, or dissolve, even over very long periods. This ceramic waste will then be sealed in heavy metal canisters which will be buried deep underground in solid rock formations. Repositories may be located in stable, dry types of rock formations because it is absolutely necessary that radioactive substances do not leak into underground water. Nuclear energy, a powerful force that should never be treated lightly, requires a high degree of professional and technical care. But neither should its risks be exaggerated. The technology exists to isolate high-level waste safely and responsibly, without harm to humans or the environment. Creating a permanent repository will help ensure that. And, with the help of nuclear energy, America will have clean, abundant electricity in the years ahead.

Classroom Activity 6: Nuclear Waste Cube

Experiment: Student assembly of the nuclear waste cube. In the U.S. one person's share of high-level radioactive waste from nuclear power plants for a 20-year period could be placed inside the cube. This is the amount of waste that would be left over after all stable materials had been recycled.

Questions with Answers from Radioactive Waste Lesson Outline:

1. Q: Would a small leak of radioactive waste from a nuclear repository be detected? Why or why not? A: Yes, radiation can be detected with devices similar to and including Geiger counters.

2. Q: How would immediate detection of even a very small leak of radioactive waste differ from leak detection of other types of industrial toxic wastes? A: Because radioactivity can be easily detected with Geiger counters, it would be easier to detect than most other hazardous or toxic wastes. Leaks of hazardous or toxic wastes other than radioactive wastes are often detected by smell, color, or sensitive chemical analytical methods which take time to perform.

3. Q: Why are there special sites for disposal of low-level waste? A: Because it must be isolated from the environment.

4. Q: Why have some states formed compacts to support a single nuclear waste disposal site that would serve

several states? A: The Low-Level Radioactive Waste Policy Act passed by the U.S. Congress in 1980 requires each State to provide for disposal of the low-level waste produced within its borders.

5. Q: Why is there a controversy over the selection of a high-level nuclear waste disposal site? A: Because the waste that will be stored in these sites is highly radioactive and will remain so for thousands of years, many people don't want it located near them. They are worried that some of the radioactive material may somehow get (leak) into the environment.

6. Q: How would it affect health care in your State (e.g., Maryland) if there were no low-level waste disposal sites available? A: If no low-level waste site is available, radioactive materials may not be used in the state.

7. Q: Are special packaging containers built to protect the contents or keep the contents from getting in contact with the environment? How are containers or a burial site designed to prevent the contents from entering the environment? A: They are designed to keep the contents from getting in contact with the environment.

8. Q: How are liquids processed to remove radioactive impurities? A: a. filtering; b. routing through demineralizers; c. boiling off the water and leaving the solid impurities to be processed as solid waste; d. storing the liquid to allow the radioactive material to decay.

Glossary

BWR - Nuclear Power Plants Boiling Water Reactor

curie - a unit of radioactivity equal to 3.7 × 1010 disintegrations per second

fission - The splitting apart of atoms. This splitting releases large amounts of energy and one or more neutrons. Nuclear power plants split the nuclei of Uranium atoms in a process called fission.

fusion - When the nuclei of atoms are combined or fused together. The sun combines the nuclei of hydrogen atoms into helium atoms in a process called fusion. Energy from the nuclei of atoms, called nuclear energy is released from fusion.

film badge - a small pack of sensitive photographic film worn as a badge for indicating exposure to radiation

Geiger counter - an instrument for detecting the presence and intensity of radiations (as cosmic rays or particles from a radioactive substance) by means of their ionizing effect on an enclosed gas which results in a pulse that is amplified and fed to a device giving a visible or audible indication

isotope - any of two or more species of atoms of a chemical element with the same atomic number and nearly identical chemical behavior but with differing atomic mass or mass number and different physical properties

millirem - one thousandth of a rem

nuclide - a species of atom characterized by the constitution of its nucleus and hence by the number of protons, the number of neutrons, and the energy content

PWR - Nuclear Power Plants Pressurized Water Reactor

Rad - a unit of absorbed dose of ionizing radiation equal to an energy of 100 ergs per gram of irradiated material

radiation - the process of emitting radiant energy in the form of waves or particles

rem - lthe dosage of an ionizing radiation that will cause the same biological effect as one roentgen of X-ray or gamma-ray exposure

roentgen - of or relating to X-rays

Uranium 235 - a light isotope of uranium of mass number 235 that constitutes less than one percent of natural uranium, that when bombarded with slow neutrons undergoes rapid fission into smaller atoms with the release of neutrons and energy, and that is used in nuclear reactors and atomic bombs

Uranium 238 - an isotope of uranium of mass number 238 that is the most stable uranium isotope, that constitutes over 99 percent of natural uranium, that is not fissile but can be used to produce a fissile isotope of plutonium, and that has a half-life of 4.5 billion years

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Appendix

Alignment with the NCTM standards requires that the mathematics curriculum should make mathematics more accessible and relevant to students. These developed concepts and skills should be integrated throughout all subject areas. The following standards are addressed within this curriculum unit:

Standard 8: Communication.

The communication standard states that students should be given the opportunity to:

1. Organize and consolidate their understanding of mathematics through Communication.

2. Communicate their mathematical thinking coherently and clearly.

3. Analyze and evaluate their mathematical thinking and strategies to others.

4. Use the language of mathematics to express mathematical ideas.

Standard 9: Connections.

This standard states that:

1. Students should be given the opportunity to recognize and use connections among mathematical ideas.

2. Recognize and use mathematics in contexts outside mathematics.