

Let's Glow!:
**An Illuminating Look at the Realities, Risks, and Rewards of Nuclear
Radiation**

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Academic Setting:

This unit will be used at Jefferson Middle School – the first junior high in Albuquerque (and, coincidentally, a school marked with "Fallout Shelter" signs). I am designing the unit to be used with seventh grade special education (gifted) students. These students will be enrolled in my Physical Science class as part of their gifted program (they are also enrolled in one or two other gifted classes). The typical class size is ten to fifteen students.

Jefferson has a diverse student body. It has a student population that is about fifty percent Anglo and forty percent Hispanic. About ten percent of the students are of other ethnic backgrounds – primarily African-American and Native American. About thirty percent of the students receive free lunch. The subset of Jefferson's gifted students is less diverse than the population as a whole. The gifted students tend to be, on average, from higher socioeconomic groups and tend to be less often members of minority groups.

Rationale

With the atomic blasts of World War II having taken place late in the first half of the last century, and the arms race of the Cold War occurring well before the birth of today's secondary students, it might seem that the importance of "things nuclear" has waned. However, this is not the case. Thousands of nuclear warheads are still ready to be launched. The number of countries that have a nuclear weapon is thought to be increasing (witness Pakistan's recent underground nuclear test and the speculation about North Korea's intentions). Some pundits think that the threat of a nuclear attack has increased in recent years rather than decreased.

Yet, there are other reasons to be educated about nuclear radiation besides its use in atomic weapons. Despite no nuclear power plants being built recently in this country, nuclear energy still provides the United States with about twenty percent of its electrical power. In a world of finite fossil fuel supplies and in a world increasingly concerned about carbon dioxide emissions from power plants, citizens should be aware of alternate sources of power (both nuclear and non-nuclear) along with their associated benefits and costs. Nuclear technology also plays a role in people's lives in other ways – from food safety, to industrial purposes, to medicine. Citizens would be wise to have a basic understanding of nuclear radiation and the risks and rewards that come from the technologies arising from nuclear radiation. Gifted students, who are likely to become leaders in our country, would be well served by having a basic understanding of this important aspect of

their world.

In writing a curriculum unit for gifted students, special consideration needs to be taken for their particular needs and abilities. The curriculum must be properly differentiated for the gifted student. Curriculum content, for example, should be modified to include such factors as abstractness, complexity, and variety. Another modification that is appropriate for gifted students is in the cognitive processes that they will undertake. As gifted students learn, they should be challenged to engage in higher level thought, discovery, group interaction, and open ended learning opportunities. I believe the overarching theme of nuclear radiation will allow proper modifications to suit the gifted student. Many of the lessons in the unit will reflect the needs and abilities of the gifted learner and take advantage of the low pupil teacher ratio common to many special education classes.

Narrative

The Atom

Nuclear radiation originates in the atom. Atoms are the smallest part of an element that has all the properties of an element (the simplest pure substance). Atoms consist of three distinct particles: protons, neutrons, and electrons. Protons are positively charged particles that are found in the nucleus, or center, of the atom. The number of protons in an atom's nucleus determines what kind of element the atom is. Another particle found in the nucleus is the neutron. Neutrons are particles with no, or neutral, charge. Neutrons do not determine the type of element an atom is, but do affect an atom's weight. Different atoms of an identical element that have different numbers of neutrons are called isotopes of each other. Together, in the center of an atom, the protons and neutrons make up the atom's nucleus. Surrounding the nucleus are the electrons. Electrons are negatively charged particles that are about 1/2000 the mass of a proton or neutron (Maton, 1997). In a neutrally charged atom, the number of protons and electrons are the same. If an atom gains one or more electrons, it becomes a negatively charged ion. If it loses one or more electrons, it becomes a positively charged ion.

It is important for students to realize that an atom is mostly empty space. The tiny electrons that orbit the nucleus are very far away from it. In fact, if you could strip all the electrons away from the nuclei of lots of atoms, and pack these nuclei so that they were touching each other in a one centimeter cube, this cube would weigh 133 million tons (Hewitt, 1977). The neutrons in the nucleus do not dictate an atom's chemical characteristics, nor do they have any bearing on whether an atom is an ion. The neutrons can be an indicator of whether or not an atom will give off nuclear radiation. If an atom has too many, or too few neutrons (depending on the particular type of element), the nucleus will tend to become unstable. By giving off nuclear radiation, an unstable atom can become more stable.

Nuclear Reactions

Nuclear radiation originates from nuclear reactions. There are four basic types of nuclear reactions: radioactive decay, fission, fusion, and artificial transmutation (Maton 1997). Radioactive decay (sometimes called transmutation) results from the spontaneous breakdown of an unstable atomic nucleus. Nuclear fission is the splitting up of a large atomic nucleus into two smaller, similar sized, nuclei. Fusion is somewhat the reverse of fission. In nuclear fusion, two small atomic nuclei are joined to form a larger more massive nucleus. Artificial transmutation refers to the process, done by people, of bombarding the nucleus of an atom with particles (for example neutrons) to change an atom into a new element or isotope. All of the nuclear reactions have something in common – changes in the nucleus of the atom(s). However, the changes can occur in different ways: at a critical and uncontrolled rate (an atomic bomb), at a critical and controlled rate (in a nuclear power plant), and at a sub-critical rate (i.e. nuclear medicine).

Nuclear Radiation

Nuclear reactions result in three distinct types of radiation (four if you count neutron radiation from critical and sub-critical nuclear reactions). These three types of nuclear radiation are central to this curriculum unit. The three types of nuclear radiation are referred to as alpha, beta, and gamma (Maton 1997). I believe students (and teachers) will need to understand each of the types of radiation in some detail.

Alpha radiation, or an alpha particle, is given off from the nucleus of the atom. An alpha particle is in essence a helium nucleus – two protons, two neutrons, but no electrons. Since the alpha particle has two protons, it is a charged particle. Its charge is +2, and would be neutralized by the addition of two electrons (which would turn the alpha particle into a helium atom). An alpha particle has a mass of four atomic mass units (amu). When the alpha particle is ejected from the nucleus it travels from 3-8% of light speed (much slower than beta and gamma radiation). An alpha particle has little penetrating power. It can be stopped by a sheet of paper, or even by the layers of dead cells that make up the epidermis of our skin. It travels a few centimeters in air.

Like alpha, beta radiation is also a particle. It is simply an electron, but one traveling very fast as it leaves the nucleus of an atom. Its initial velocity is anywhere from 20-99% of light speed. Although beta radiation is a particle, electrons are so small that, for students' purposes, its mass can be thought of as negligible (an amu of zero). The penetrating power of beta is greater than that of alpha. Beta would not be stopped by a sheet of paper, but would typically be stopped by a centimeter of wood or three millimeters of aluminum. The denser the material, the less (in thickness) is needed to stop nuclear radiation. A beta particle might travel from ten centimeters to ten meters in air. The charge of a beta particle is -1 (since it is an electron).

The third type of nuclear radiation is gamma radiation. Gamma is different from alpha and beta in several respects. Gamma is not a particle — it is pure energy. It

has neither mass nor an electric charge. Since it is pure energy (and part of the electromagnetic spectrum), it travels at the speed of light. The penetrating power of gamma is the highest of all the types of nuclear radiation. It might travel 100 meters in air and several meters through water or flesh.

Remember that nuclear radiation results from a nucleus going towards a more stable state. When an atom undergoes alpha decay (ejects an alpha particle), a new element is formed. Since students are typically taught that elements can not be created or destroyed, it is a novel notion that an atom of one element can change into an atom of a totally different element. Since an alpha particle is two protons and two neutrons, the nucleus of the atom it came from changes by this same amount. For example if the element polonium (atomic number 84) loses two of its protons through alpha decay, it now becomes an atom with the atomic number of 82, which is lead. The neutrons in the alpha particle also need to be considered — they decrease by two as well. For instance in the above example, if the polonium isotope was polonium 214 (84 protons and 130 neutrons) it would become the isotope lead 210 (82 protons and 128 neutrons). Note that the atomic mass of the polonium drops by 4 amu (the mass of the alpha particle), as it becomes lead. In this case, lead is sometime referred to as a "daughter product" or "decay product" of polonium.

In beta decay there is also a change in atomic number. Students often assume that since beta is an electron that it originated from outside the nucleus. This is not the case. In beta decay, as the unstable nucleus decays towards stability, a neutron breaks apart into a proton and an electron. The proton stays in the nucleus but the electron, the beta particle, is ejected. Lead 210 is not a stable atom. When it undergoes beta decay, it will change into bismuth 210. The lead (82 protons and 128 neutrons) becomes bismuth (83 protons and 127 neutrons). The atomic number increased by one but the atomic mass number does not change.

Gamma decay is different from alpha and beta decay in that it does not result in a new element being formed. The pure energy that is gamma, comes from the nucleus as it goes from a high-energy state to a lower, more stable, energy state. There is no change in the number of protons or neutrons in the nucleus due to gamma decay. However, gamma decay usually occurs along with both alpha and beta decay.

Each radioisotope has its own characteristic type of radioactive decay. In addition, each isotope gives off its radiation at a particular energy level. For example when carbon 14 undergoes beta decay, the electron is ejected with less energy than the electron ejected when lead 210 undergoes beta decay.

Half-life

It is impossible to know when an individual unstable, or radioactive, nucleus will undergo decay. However, a population of radioactive elements of the same kind decays at a characteristic rate. The period of time that it takes for half the atoms in

a radioactive substance to decay is called its half-life. Half-lives of different substances range from fractions of seconds (for highly radioactive isotopes) to near infinity (for isotopes that are stable). When half-lives are discussed, it is important to mention the specific isotope of the atom in question. For example, the half-life of lead 214 (a very radioactive isotope) is 27 minutes (Murray, 1994). The half-life of lead 210 (also radioactive) is nearly 23 years. But, the half-life of lead 206 (the most common, most stable non-radioactive isotope of lead) approaches infinity. When students are considering radioactive waste it is important for them to realize that isotopes that are the most radioactive are the ones with the shortest half-lives. They also need to appreciate that a particular radioisotope's half-life is the same regardless of the mass of the sample being considered.

Ionizing vs. Non-ionizing Radiation

Nuclear radiation is ionizing (U.S. Dept. of Energy 1995). This means that it has the potential to knock electrons from atoms creating an ion(s) or even of displacing the nuclei they hit. Whenever radiation is ionizing, there is the potential for biological effects. This is why there is such concern about nuclear radiation – it has the potential to make ions and damage human tissue. Students readily grasp why alpha and beta are ionizing. Since they are particles, it is easy to visualize them as bullets, doing damage. Gamma radiation is also ionizing, although it is not a particle.

Gamma radiation is pure energy. It is a part of the electromagnetic spectrum. The electromagnetic spectrum consists of electromagnetic waves categorized by their wavelength and frequency (and hence their energy level). At one end of the spectrum are waves with a large wavelength and low frequency such as AM radio waves. FM radio, television, radar, and microwaves have increasing frequency and progressively smaller wavelengths. Infrared light, visible light, and ultra-violet light are in the middle of the spectrum. X-rays, gamma rays, and finally cosmic rays have the highest frequency and energy and the smallest wavelengths. Most of the types of electromagnetic radiation are not ionizing (and therefore do not appear to be health concerns in the same way nuclear radiation is). Ultra-violet light can be ionizing (but it is not a type of nuclear radiation), and both X-ray and gamma rays are definitely ionizing.

Biological Effects of Nuclear Radiation

Since the three forms of nuclear radiation are all capable of making ions, they all are of concern to human health. Ions that are made in living cells and the heat energy given off as radiation is absorbed, can all lead to chemical reactions and interactions that would not otherwise have occurred (Murray 1994). If the amount of energy absorbed is small, no damage at all may be done. Indeed, cells have repair mechanisms. Even if radiation were to hit the DNA in a cell, it can usually be repaired. If the amount of energy absorbed is higher, damage may result. Cells may be killed, and if enough cells are killed, an organism may die. If DNA is not repaired, or repaired incorrectly, genetic problems may occur, including cancer. If

gametes (sex cells) are damaged, mutations on the DNA could be passed on to offspring (Encyclopedia Britannica 1995).

Different types of radiation will have different effects in living tissue. Damage depends on the amount of energy received and what parts of the cell are damaged. Different types of radiation also make different numbers of ions – due to their varying penetrating power and size. Gamma is very small in size (it is high energy light) and consequently may go through many cells (or even many human bodies) before it is totally absorbed. Beta is bigger in size and so may make more ions in a similar amount of tissue compared to gamma (although beta will not penetrate nearly as far). The skin on a person's body can stop alpha, which has a low penetrating ability. Since the outer layers of skin cells are dead, an alpha particle hitting someone externally would not make ions in living tissue. However, if an alpha particle is emitted inside the body, it will likely strike living tissue. Due to its large size (relative to other forms of ionizing radiation), it makes many more ions than beta or gamma in a thin layer of a cell (Encyclopedia Britannica 1995). DNA is readily repaired if a section of one of its two strands is damaged. DNA may not be so easily repaired if both strands are damaged, something that is more likely to occur with alpha radiation than the other types (in small doses).

Measuring Nuclear Radiation

Before one can discuss what amounts of radiation do what damage, it is useful to understand how radiation is measured and what the measurement units are. The units used to express amounts of radiation are many. They include the Becquerel, the Curie, the Gray, the Rad, the Rem, the Roentgen, and the Sievert (Murray 1994), (Encyclopedia Britannica 1995), and (Shelton 1999). The most common measurement unit that will be used in student activities will be *rems* and *mrems* (millirems) – they, and other radiation units are defined in the glossary below.

Detecting radiation is most commonly done with a Geiger counter. Geiger counters take advantage of the ionizing properties of nuclear radiation. The Geiger tube of a Geiger counter is filled with an inert gas (argon). Also in this tube is a wire that, when electrified, will almost ionize the gas in the tube. When radiation enters the tube, the gas is ionized. One particle or ray can induce many thousands of ions to form in the tube. The displaced electrons are attracted to the positively charged wire in the Geiger tube. These electrons going down the wire result in a pulse of electricity that will activate a counting device (Hewitt, 1977). The most sensitive Geiger counters will have a very thin window attached to the Geiger tube. The thin window will allow some alpha particles to pass through (as well as beta and gamma). If a thin window is not present on the Geiger tube, only beta and gamma can be detected. Most Geiger counters show radiation in mr/hr (milliroentgen per hour) or in counts per minute.

There are other ways of detecting nuclear radiation (Hewitt, 1977). These include scintillation counters, bubble chambers, cloud chambers, and dosimeters (film badges). Scintillation counters work by detecting photons, which are emitted when

some materials are hit by charged particles. Bubble chambers detect radiation by showing a trail of bubbles where radiation has passed through a super heated liquid. Cloud chambers contain a gas cooled below its usual condensation point. They work by showing droplets of liquid condensing (and making vapor trails) around ions made by radiation. Dosimeters are commonly worn by workers who may be exposed to radiation. Unexposed film is sealed from light and put in a badge. When the film is developed, a person's exposure to radiation can be determined by the relative darkness of the film.

How Much Radiation is Too Much?

A question arises as to what the dangers of radiation are. The answers are complicated. Different forms of life have different tolerances for radiation. For example, fruit flies may survive a radiation dose that is 100 times stronger than a dose that would kill a mammal. The part of the cell hit by radiation also is important. Mutations and cancers can develop from changes in DNA, which can be caused by radiation. When cells are dividing, they are especially sensitive to radiation (thus the extra precautions taken with pregnant women). A dividing cell may be killed by 100-200 rem, but a non-dividing cell might not appear damaged by a much higher dose. This fact is used in cancer treatment since cancer cells are dividing more rapidly than the surrounding normal tissue.

The dose rate is also relevant to the damage done. Sixty percent of the cell damage due to a brief radiation exposure may be repaired within hours — especially if it is caused by beta or gamma radiation with its narrower path of destruction (Encyclopedia Britannica 1995). This repair can be either by natural cellular processes, or it can happen spontaneously – for example as DNA realigns back to its original structure. In addition, the body will tolerate a succession of doses better than an equivalent dose given at one time. The energy level of the particular alpha, beta, or gamma radiation also matters. All else being equal, radiation of higher energy does more damage.

If the radiation dose is received internally, it also matters what radioisotope the radiation came from. Different radioisotopes accumulate in different parts of the body (Encyclopedia Britannica 1995). If radioactive iodine, for example, is ingested, it will tend to accumulate in the thyroid gland. In the Windscale accident in the United Kingdom and the Chernobyl accident in Russia, radioactive iodine settled on grass that was eaten by cows that gave humans radioactive milk to drink – leading to increased incidences of thyroid cancer in children. If the body takes in radioactive strontium, it will tend to accumulate in the bones. The particular radioactive element also matters because some elements cycle through the body faster than others. Iodine may cycle out of the body in weeks or days, while strontium-90 (which behaves chemically like calcium and has a half-life of 50 years) may persist in one's bones for a lifetime (Murray 1994).

Studies have been done on animals and people (the history of this and its ethical implications would be an interesting student research topic) so that rough estimates

of radiation dosages and their effects are known – at least at high levels. The main data for people come from three groups: 1) the survivors of the atomic bombs dropped on Japan, 2) U.S. radiologists who used ionizing radiation from the 1920's to the 1940's to diagnose and treat medical problems, and 3) people given high X-ray exposures to treat spinal disease in the early days of radiation treatment (U.S. Dept. of Energy 1995).

Radiation dosages of 1000 rem (1,000,000 mrem) are typically fatal. A quick dose of 400-500 rem is fatal to fifty percent of persons receiving it (assuming no medical treatment). A dose of 100-400 rem may result in radiation sickness (U.S. Dept. of Energy, 1995). Radiation sickness can mean nausea, headache, loss of appetite, and changes in blood cells (occurring within hours or weeks). Longer-term radiation sickness can lead to loss of hair, hemorrhaging, diarrhea, and central nervous system effects. These usually can be successfully treated.

Data convincingly show that there are cancer risks and health effects with high radiation exposure. No convincing data exist for low exposures. Statistical risk for low levels of radiation, (and other potential risks that there is insufficient data for, such as smoking just one cigarette), is usually calculated by the "linear" or "straight line" hypothesis which assumes that the risk of cancer diminishes proportionally with decreasing dose (Murray 1994). Some people argue that at some low dose there is essentially no increased risk because of the body's ability to repair itself. Other people argue that any radiation is harmful. Some evidence on breast cancer support the linear hypothesis – studies show that radiation is additive and cumulative with respect to its carcinogenic effects on the breast (Encyclopedia Britannica, 1995). However, the studies involved women who received doses far in excess of background levels. These studies included Japanese atomic bomb survivors, radium paint workers, and patients exposed to multiple fluoroscopic examinations. If you do assume the linear hypothesis is correct, you can equate the risk of getting fatal cancer from one mrem to a few puffs on a cigarette, crossing a street five times, being .0007 ounces overweight, driving five miles, or using a bathtub for a few months (Shelton 1999). What has been found is that doses below 10 rem (10,000 mrem) have no directly observable effect.

The EPA seems to buy into the linear hypothesis. It notes three things in its publication "Radiation: Risks and Realities;" 1. The more radiation a person receives, the greater the chance of developing cancer; 2. The particular kind or severity of cancer is not determined by the radiation dose; and 3. Most cancers do not appear until many years after the radiation dose is received (typically 10 to 40 years). It helps to keep in mind that most cancers are naturally occurring. Only 1-3% of all cancers in the general population are thought to result from natural background ionizing radiation (Encyclopedia Britannica 1995). At the same time, up to 20% of lung cancers in nonsmokers may be due to inhalation of radon and its daughter products.

Human's Exposure to Naturally Occurring Radiation

Radiation has been present throughout the existence of life on earth. U.S. citizens get most of their radiation from radon gas (and its daughter products through decay). The U.S. average is 200 mrem per year from radon (Murray 1994). The next highest dose comes from internal radiation, primarily from carbon 14 and potassium 40, but other radioisotopes as well — about 7000 uranium atoms decay each hour in the average person (Encyclopedia Britannica 1995). Internal radiation accounts for about 40 mrem of one's annual dose. The next highest source is from rocks and soil and building materials – 28 mrem/year; these materials cause over 200 million gamma rays to enter the typical person's body per hour (Encyclopedia Britannica 1995). The next highest source, 27 mrem/year on average, comes from cosmic rays – high-energy waves as well as some neutrons and charged particles reaching earth from space. It is important to note that while the average annual American dose (from all sources, natural and manmade) is 360 mrem, it is highly variable (especially considering some types of medical diagnostic procedures and treatments). Someone living at sea level would only receive 26 mrem/year of cosmic radiation while someone at 10,000 ft would get more than 100 mrem/year (Shelton. 1999). Ground radiation varies with soil type. Persons living on the Colorado Plateau receive 63 mrem/year while someone living on the Gulf Coastal Plain would receive about 16 mrem/year.

Human's Exposure to Manmade Radiation

Part of the 360 mrem average annual American dose is due to manmade radiation sources (Murray 1994). Medical X-rays account for the bulk of this – (39 mrem/year). The second highest manmade source is due to nuclear medicine (14 mrem/year). Some other sources (and their annual doses in mrem/year) are: television and computers – up to one, smoke detectors - .008, nuclear weapons fallout - less than one, living within 50 miles of a nuclear power plant - .01, using thoriated gas camping lantern mantles - .2, and having porcelain dentures or crowns - .1 (Shelton 1999).

Nuclear Weapons

Nuclear fission is the splitting of an atom resulting from a neutron hitting it. For example when a uranium atom is split, it will fragment into smaller nuclei such as krypton and barium. Additionally, neutrons will be ejected from the nucleus as the atom splits. When the nucleus splits, some of the mass of the atom is converted directly to energy – a lot of energy. This is evidence of Einstein's famous equation $E = mc^2$. Evidence of fission was first discovered in Germany in 1939 (Hewitt 1977). Knowledge of this discovery led Einstein and other scientists to urge President Franklin D. Roosevelt to embark on a research program to develop the world's first nuclear bomb. This effort was known as the Manhattan Project and much of the essential weapons research was done at Los Alamos in New Mexico (Murray, 1994).

The first material that was found to be most readily fissionable was uranium-235.

Uranium-235 makes up only .7% of all uranium isotopes (99.3 % is uranium-238) (Murray 1994). Part of the Manhattan Project involved enriching the uranium, or increasing the concentration U-235 compared to U-238.

When a uranium atom is split and neutrons are released, these neutrons are free to strike other uranium atoms, instigating a chain reaction. In a nuclear chain reaction, billions of fission reactions may take place each second (Maton 1997). In a fission bomb this chain reaction happens in an uncontrolled explosive manner, releasing massive amounts of energy. In a fission bomb, the chain reaction is initiated by conventional explosives that bring together pieces of uranium (or plutonium – another fissionable element) into a so-called "critical mass." The first fission bomb was exploded in New Mexico at the Trinity site. The bomb dropped on Hiroshima contained uranium that was about the size of a baseball (Hewitt 1977)

Another type of nuclear bomb, the fusion bomb, or hydrogen bomb, was developed after WWII and first tested in 1954 (Hewitt 1977). Nuclear fusion is the joining of two atomic nuclei of smaller masses to form a single nucleus of larger mass (Maton 1997). Fusion requires temperatures of over a million degrees Celsius. This process occurs in stars. In a fusion bomb, fission explosives are used to achieve the extreme temperatures necessary for fusion to occur. As in all types of nuclear reactions, fusion converts some mass into energy. The products formed by fusion have a mass that is about one percent less than the reactants. This one percent represents the mass that is converted to energy. Hydrogen bombs can be immensely destructive – their power is measured in "megatons" – millions of tons of TNT.

Nuclear Power

In a nuclear fission bomb, the chain reaction is carried out in a very quick and uncontrolled fashion. If this process is slowed down, for example by having material interspersed between some of the uranium to absorb some of the extra neutrons generated, then useful energy can be obtained. This is exactly what happens in a nuclear reactor. The world's first nuclear reactor was built in Chicago in 1942 under the leadership of Enrico Fermi (Murray 1994). This reactor was used for research, not power production. It was only a few years later, in 1951, that the first commercial electricity was generated from nuclear power at Arco, Idaho. In 1955, the Nautilus, the first nuclear submarine was launched and was able to go 62,000 miles on its first loading of fuel (Murray 1994). Today, nuclear power is an essential component of our Navy and it generates approximately 19 percent of the United States' electricity. Other countries generate even more of their power from the atom than the U.S. France generates 75 percent of its electricity from nuclear power (Easterbrook 1996). Its worth noting that although nuclear power does generate radioactive waste, it does not generate the greenhouse gas carbon dioxide that all fossil fuels do.

Should fusion energy ever be controlled, it would be a boon to humanity. Whereas uranium and fossil fuels are finite (if still plentiful), the fuel for fusion, hydrogen,

is essentially limitless. Fusion, when compared to fission, generates much less radioactive waste and generates more energy for a given amount of fuel (Maton 1997). Scientific research continues on how to make fusion a practical energy source.

Nuclear Waste

Radioactive waste is normally discussed in two broad categories, defense waste and commercial waste. Defense waste is generated by the government in the production and testing of nuclear weapons and from reactors for Navy vessels. Commercial waste is generated mainly from reactors that produce electricity (Murray 1994). Within these groups, nuclear waste is further categorized as either high-level, transuranic, or low-level.

High-level waste results from spent reactor fuel or from the reprocessing of reactor fuel. High-level waste contains fission products and small amounts of plutonium. It is very radioactive, gives off heat, and must be handled with extreme care.

Transuranic waste includes wastes with elements beyond uranium on the periodic table. It originates in weapons production, fuel assembly, and in fuel reprocessing. The amount of radiation is lower than in high-level waste, but it may contain some isotopes with long half-lives. Transuranic waste does not give off much heat and can be handled without remote control techniques. Low-level wastes include anything other than high-level and transuranic waste. Most low-level waste has relatively little radioactivity and may usually be handled by direct contact (without shielding and without remote control methods). The term "mixed waste" refers to low-level waste that is mixed with non-radioactive hazardous chemicals (Murray 1994).

Most students are vaguely aware that radioactive waste is dangerous. In fact, if one were to stand within three feet of an *unshielded* pile of spent fuel rods (high level waste), it would take only seven minutes to receive a fatal dose (Easterbrook 1996). But radiation decreases rapidly with increased distance. At 300 feet, a person would receive 500 mrem in an hour, or about the dose someone would receive by living in Denver for a year.

Some radioactive isotopes found in nuclear waste are radioactive for a long time. It has been calculated that it would take ten thousand years for the radioactivity in high-level waste to fall to that of natural uranium ore (Murray 1994). The volume of high-level waste generated is considerable - the annual spent fuel volume from America's 100 or so reactors is about 40,000 cubic feet, about the size of a football field covered to a depth of one foot (Murray 1994).

Students should be aware, and probably are aware, of some of the disadvantages of nuclear power. They may not be aware of some of its advantages. Nuclear power does not produce air pollution or greenhouse gases. Surprisingly, nuclear power plants actually emit less radiation (from the plant) than does petroleum production (Easterbrook, 1996). Even considering that coal generates two and a half times as

much electricity as uranium, uranium mining seems to be much safer than coal mining. An average of two people per year die in uranium mining accidents, while an average of 30 people a year die in coal mining accidents. Uranium miners do experience health problems, with 750 miners having died, or are expected to die, from mining induced lung cancer. However, this is much less than the 600,000 miners who have died, or will die prematurely, from black lung disease (Easterbrook 1996).

Nuclear power has proven to be a safe technology. Through 1992, with up to 421 commercial reactors running (most constructed *without* modern safety devices), there has only been one tragic event (Chernobyl). In the Three Mile Island event, the average individual exposure was 10 mrem and there was no immediate loss of life —long-term studies have not yet shown that cancer risk is different in people who live upwind vs. downwind of the incident (Easterbrook 1996). The issue of nuclear waste, and nuclear waste disposal is complicated and controversial. Space does not allow a complete discussion of these issues.

Uses of Nuclear Radiation and Radioisotopes

The uses of radiation extend beyond nuclear weapons and nuclear power. There are a many uses and possible career options that students can be made aware of. What follows is a summary of a few of the uses. Most of this information comes from the book "Understanding Radioactive Waste" by Raymond Murray.

Tracers: Tracers are radioisotopes that allow for complicated physical, chemical, and biological processes to be studied. For example, the flow of a liquid through a pipeline can be measured by injecting a small amount of a radioisotope at one end and looking for its radiation at the end or at points along its flow. Another example is using phosphorus-32 (which has a half-life of 14.3 days) as part of a plant's fertilizer, and watching how fast and to what degree the radioactivity is transported in the plant.

Imaging: In nuclear medicine, certain radioisotopes, which have particular affinities for particular tissues, are given to help doctors better visualize a particular organ or structure. For example, chromium-51 can be injected into the bloodstream and it will collect in the spleen. Certain radioisotopes used in imaging, for example technetium-99, must be made in a nuclear reactor.

Radiation Therapy: Radiation can be used to fight cancer and can also be used to relieve pain. Radiation affects fast-dividing cells, such as cancer cells, more readily than slower growing normal cells. Radiation can be given internally and externally. Internal radiation is usually given in the form of implants. Implants may help to kill or shrink tumors, or after surgery, they may be used to help reduce the chance of tumor reoccurrence. Externally, radiation from x-rays, electron beams, or gamma rays (usually from cobalt-60) are used in fighting cancerous tumors. Even if the tumor is not destroyed, shrinkage of the tumor often results in reduced symptoms, including pain, and can increase a patient's quality of life. External

radiation therapy is often given several times per week over six to seven weeks. Common short-term side effects can include hair loss, skin changes, pain, fatigue, nausea, blood changes, and diarrhea. Long term side effects, which may take months or years to develop, are usually permanent. Long term side effects may include the increased risk of future cancer. Radiotherapy is not undertaken unless the potential benefits to the patient are thought to exceed the potential disadvantages (National Institutes of Health 1993).

Pharmaceutical Research: Drugs undergoing FDA approval require extensive research on the behavior of the proposed drug. Radioisotopes such as carbon-14, iodine-125, sulfur-35, chlorine-36, and others are useful in researching new drugs.

Radiography: X-rays have been used for many decades for medical diagnosis. Nuclear radiation is not necessary for the generation of x-rays. However, certain applications are better suited to the use of gamma ray imaging. Cobalt-60 gamma rays are very penetrating and are useful for checking welded metal joints in reactor cooling systems or locating areas of metal fatigue in aircraft.

Gauging: The variance in the radiation going in and coming out of a substance can be useful in making measurements. For example, the level of liquid in soft drink cans can be checked at the rate of 2000 cans per minute using radiation.

Dating: The approximate ages of archeological and historical objects can be found by the carbon-14 dating technique. This process is explained in most physical science textbooks. Mineral deposit ages can be dated using the ratio of uranium-238 and lead-206.

Elimination of Pathogens: Using nuclear radiation to sterilize medical instruments and food (especially dried spices) has been used for decades. Gamma rays from cobalt-60 and cesium-137 can inactivate virus particles and kill bacteria, fungi, and other disease causing agents. The World Health Organization has given a strong recommendation in favor of using food irradiation as a way of reducing food losses due to insects and spoilage. Irradiation with alpha, beta, or gamma radiation does not make the object being irradiated become radioactive.

Elimination of Insect Pests: A chemical free way of combating insect pests has been developed using radiation. Male insects of the species in question are sterilized, but not killed, using radiation. These sterile (non-radioactive) males are then released into the wild to mate. Since no offspring result from these matings, the population of the pest rapidly falls. There is a "fly factory" in Mexico that supplied millions of sterile flies that were dropped by plane into Libya to reduce the screwworm fly, which plagues cattle, in 1988-1990.

Special Power Sources: The heat given off by the beta decay of strontium-90 has been used as a thermoelectric generator. This has been used in remote locations, for example, as a navigational beacon. Plutonium-238, with a half-life of 88 years, is produced in nuclear reactors. This alpha emitting isotope has been used as a

thermoelectric generator in applications ranging from heart pacemakers to space probes. Tritium gas is used in self-luminating exit signs, watches, and in some airport runway lighting systems. The alpha particles given off by the americium-241 in smoke detectors ionize air and allow an electrical circuit to be completed (unless, of course smoke is present).

Implementation

Before the unit starts, it would be advisable to send a letter home to parents letting them know that their students will be studying nuclear radiation and working with some materials that do have low levels of radioactivity. Emphasize that students will be expected to behave safely and follow directions. Invite parents to call if they have concerns. Teacher will need to teach Geiger counter use and safe handling techniques. This unit could be done over 4-5 weeks, but is easily modified depending on the depth of study undertaken.

Activity 1: Radioactive or Not? (Estimated time: ½ period.)

Students will be presented with a variety of items, some radioactive (detectable above background levels) and some not radioactive. The items will be shown and described and students will guess (on paper) whether or not each item is radioactive. After being shown all items, and after making predictions, students will check their hypotheses with Geiger counters. It's useful to have a variety of items to test. Before beginning to use the Geiger counter, it would be appropriate to discuss how it is used and how it works (see narrative above).

Some examples of radioactive items could be (most of these ideas are from Shelton, 1999):

- Old orange/red "Fiesta ware" dishes (the glaze has uranium in it). This type of glaze can also be found under the name of "Riviera", "Harlequin", and "Vistosa". Since these are collectable, look for pieces with cracks and blemishes – they should be less expensive. These types of ceramics can be found at antique malls and in auctions on the Internet.
- Another collectable item with uranium used for color is old greenish "Vaseline" glass.
- If you happen to have an old pair of dentures lying around, these too would be fun for kids to test. Many porcelain dentures contain uranium to give them a more natural color.
- Many camping lantern mantles (i.e. the Coleman type) contain thorium (the label should give you information about this).
- A welding supply store can sell you a thoriated-welding rod.
- Some lenses have coatings containing thorium.
- Old watches and clock dials may contain radium. Check second hand stores. Take your Geiger counter and get some strange

looks.

- Most smoke alarms contain americium. (The americium primarily an alpha emitter is shielded by a bit of metal, but it could be carefully exposed.)
- Many rocks and fossils have radioactive ores. A rock and mineral shop will have inexpensive samples, for example carnotite, uranophane, and others. Trinitite, the rock created by the first atomic explosion at the Trinity site in New Mexico would be fun for students to test.
- If your class has good Geiger counters, things high in potassium can give off detectable radiation. Try a fertilizer with a high potassium content or even cream of tartar.

Some good items that are not radioactive might include: irradiated spices (to help make the point that when something gets hit by alpha, beta, or gamma radiation, it doesn't make that thing radioactive), glow in the dark toys, interesting looking rocks and minerals, ceramic items, and weird stuff that might make kids think. Things made with the element polonium (some old spark plugs and anti-static devices) are particularly good distracters. Kids will know polonium is radioactive (if they look on a periodic chart), but when they test it, it will not be radioactive. This is a good lead-in to a preliminary discussion of half-lives (the half-life of polonium is so short that it has nearly all decayed to non-radioactive lead.)

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will use elementary scientific devices to measure objects and simple phenomena.

Activity 2 – More Playing with Expensive Toys (Estimated time: ½ period.)

Let students again view and use the radioactive materials. Have them measure (with Geiger counters) how far they need to be from particular item for the radioactivity to get down to background levels. (Remind them that even if the materials were not there, there would still be some radiation in the room). Another thing to do is to let them see what kind of shielding will block the radiation from reaching the Geiger counter. Some possible shielding you might let kids try are glass, Plexiglas, aluminum foil, plastic wrap, paper, Styrofoam, wood pieces of different thicknesses, metal sheeting, etc.

Note: Not all Geiger counters are created equal. The most expensive, most sensitive, ones will have a thin window that will allow alpha radiation to be detected. Geiger counters with a metal probe will detect beta and gamma, but not alpha.

The best way to let students learn about the penetrating power of radiation in an inductive manner would seem to require the teacher to provide pure emitters of

either alpha, beta, or gamma radiation. This would let students just measure one type of radiation at a time. (Most of the radioactive sources mentioned in activity 1 emit more than one type of radiation simultaneously). Pure emitters are available from some science supply centers, but they are expensive.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 5: Students will acquire the abilities to do scientific inquiry. Students will use the scientific method within the classroom and school environment; and employ a variety of techniques and information sources to gather, analyze, and interpret data.

Activity 3: Alpha, Beta, and Gamma in depth. (Estimated time: ½ period.)

Discuss previous activity's findings with students. Then lecture on the electromagnetic spectrum, ionizing vs. non-ionizing radiation, and nuclear radiation (see narrative above). Students will need to take detailed notes, particularly of nuclear radiation since it will be the basis of much to follow – the information can be condensed into a logical table and much of it is standard physical science text information.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is: Standard 7: Students will know and understand the properties of matter. Students will discriminate between elements based on the characteristic ways in which they react with other elements to form compounds that are different substances with unique characteristic properties.

Activity 4: Can You See Radiation? Cloud Chamber Lab. (Estimated time: 1 period.)

This is a standard radiation lab and is included in many physical science textbooks. The *Science, Society, and Americas Nuclear Waste* series (see references) has a good write up. The basic idea of this lab is that it allows students to see visual evidence of alpha radiation. Students, of course, will not see radiation itself, but will see the path it makes in the form of vapor trails. Cloud chambers are constructed by placing a radioactive source in a clear container that is saturated with alcohol vapor (soak some construction paper in alcohol and place it on the sides to accomplish this). Cover the container with plastic wrap and place the container on dry ice. After about five minutes, in a darkened room, students may shine a flashlight in through the top of the container to see the vapor trails. As the alpha particles go through the air, they ionize gas. Alcohol will condense around these ions – this is what the students will hopefully see. Cloud chambers can be purchased from science supply companies, but it should not be too much trouble to have students construct their own. A single small strand from a mantle lantern is an adequate source, but you might try other materials as well. N.B. It is recommended that teachers try this in advance so that they have confidence in the method shown to students.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will use elementary scientific devices to measure objects and simple phenomena.

Activity 5: Rem Race. Calculating individual annual radiation dose.
(Estimated time: 15 minutes.)

It is possible for students to estimate their annual radiation dose in millirems. The U.S. average is 360 mrems. Jay Shelton (see references) has a nice student worksheet from which much of these data were taken – all numbers refer to mrems/year. Cosmic radiation varies by altitude as well as latitude. People living in the Rio Grande valley will receive 68, while people living in the foothills of the Sandias will receive 90-95 (Brookins 1992). I will use a figure of 75 for my students. To this, students can add 200 (the U.S. average) for radon gas. If students live in an adobe or brick house, they add 7. If they cook with natural gas, they need to add 2 (for additional radon brought into the home). They need to add 40 for the food they eat (mainly carbon-14 and potassium-40). They need to add another 2 for radon dissolved in water. Ground radiation changes based on geology of local soil and rock – the U.S. average is 32, but New Mexico rock has more radioactive minerals than the US average. My students will use a figure of 60 (Brookins, 1992) for their ground radiation dose. Flying measurably increases one's cosmic radiation dosage - .5 mrem/hour in the air. Students can add in their medical exposure: CAT scan 110, pelvis/hip x-ray 65, chest x-ray 6, hand/arm/foot/leg x-ray 1, dental x-ray 1. Radiotherapy, which few students have had, occurs in much higher doses. For example, President George Bush's thyroid was treated with 5000 mrems (Easterbrook 1996).

There are other small potential radiation sources in students' lives. While their contribution to a student's annual dose may seem trivial and almost not worth mentioning, factoring them in does help a student put radiation amounts and risks in perspective. These small additional sources include: living within 50 miles of a nuclear power plant .01, living within 50 miles of a coal-fired power plant .03 (coal can contain radioactive elements such as radium), living on the WIPP route .01, smoking a pack a day ~5, using gas lantern mantles .2, having a smoke detector .008, nuclear weapons fallout <1, airport luggage x-ray inspection .002, viewing TV or computer screen - a maximum of 1, and having porcelain dentures and crowns .01.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will employ mathematics to quantify properties of objects and phenomena.

Activity 6: What is a millirem? (Estimated time: 1 period.)

Now would be a good time to go over the biological effects of nuclear radiation

with students (see narrative above). Remember there are no observable effects on human beings at doses less than 10 rems (10,000 mrem) (Murray, 1994). Students might be interested to know that the following can give them an extra mrem (Shelton 1999): Drinking Santa Fe well water for a year, sleeping a few feet closer to a brick wall for a year, going camping in the Rocky Mountains for a few days, and being indoors an extra 7 minutes per day for a year. Additionally, living in a house that is two feet higher in elevation for 30 years can increase one's dose by one mrem (by exposure to more cosmic radiation since there is less atmosphere for shielding at higher elevations).

Also at this time, it would be appropriate to review the straight-line hypothesis (see narrative above) and compare the risks of a millirem to other risks.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to are: Standard 6: Students will understand the process of scientific inquiry. Students will explain that in areas where there is not a great deal of experimental or observational evidence, it is typical for scientists to differ with one another about the theory, hypothesis, or evidence being investigated. Standard 10: Students will know and understand the characteristics that are the basis for classifying organisms. Students will use information about living things including: cells as the fundamental unit of life; cell division; that small genetic differences between offspring and parents may accumulate in succeeding generations and may or may not be advantageous for the species; and disease as a breakdown in the structures or functions of an organism.

Activity 7: Radioactive Decay Series: It's Elementary. (Estimated time: ½ period.)

Most physical science textbooks include information on radioactive decay and examples of at least one of the radioactive decay series. It is a good idea for students to chart or diagram an atom and show what it becomes as it gives off radiation and moves toward stability. Good worksheets of this for the U-235, U-238, and Thorium-232 series can be found in the *Science, Society, and America's Nuclear Waste* series.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to are: Standard 1: Students will understand science concepts of order and organization. Students will apply information about the predictability and organization of the universe and its subsystems. Standard 2: Students will use evidence, models, and explanations to explore the physical world. Students will organize phenomena into hypotheses, models, laws, theories, principles, and paradigms.

Activity 8: Half-life. (Estimated time: ½ period.)

Students will simulate atoms undergoing radioactive decay and graph the results. This can be done with U.S. cents (or any two sided object – even M&M's). For example, start with 100 or more cents (all undecayed atoms), and shake them onto

a table. Any time a tails comes up, it indicates that the atom has decayed and it can be removed from the rest of the coins. This can be repeated until no heads (original atoms) are remaining. (Note: theoretically, an individual atom might never decay, just as a student might never flip a coin tail side up). Students can keep track of this data and graph the results. The overall shape of the graph is similar to that for the decay of all radioactive isotopes (but the rate varies by type of isotope, see narrative above). A variation on this idea, which would make this simulation more realistic, would be to have different students (or groups) shake the coins at specified time intervals. For example, one group could shake the coins every minute, another group every minute and a half, and another group every two minutes. This would help simulate that different isotopes have different half-lives. This would also reinforce the idea that the general shape of the graph is the same even if the time scales are different.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is: Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will employ mathematics to quantify properties of objects and phenomena.

Activity 9: Hot Food. Internal Radiation from Carbon and Potassium.
(Estimated time: ½ period.)

Carbon and potassium are essential to life. Carbon-12, the most common isotope of carbon is stable. However, carbon-14 is radioactive. People eat both kinds of carbon. Carbon-14, created when a neutron from space hits a nitrogen-14 atom creating carbon-14 plus a proton (Murray 1994). So the radioactive C-14 is created in the atmosphere and taken up by plants (via carbon dioxide in photosynthesis) that people eat. People are about 23% carbon and a little of this is carbon-14. It accounts for 1.2 mrem of our annual average exposure. On average, 227 carbon-14 atoms decay (and give off radiation) each second for each kilogram of body weight. Students can calculate the activity of carbon-14 in their bodies by first finding their weight in kilograms (weight in pounds/2.2 lbs. = weight in kgs). Multiplying weight in kilograms by .23 gives students the amount of carbon in their bodies. Multiplying the weight of carbon by 227 disintegrations/second gives students the total activity of carbon (in disintegrations/second). Carbon-14 undergoes beta decay, so the carbon atom is transformed into nitrogen while an electron is ejected from the nucleus, free to ionize bits of student's tissue.

Potassium, another essential element, also has a radioactive isotope – potassium-40. Radioactive potassium gives people an average of 18 mrem of their annual exposure. In each kilogram of a person's body, an average of 60 disintegrations of potassium-40 occur per second. Students can calculate the number of disintegrations per second, minute, hour, year, etc. for their own body size.

The above information on carbon and potassium was taken from the *Science, Society, and America's Nuclear Waste* series. It includes student worksheets and

also includes a list of potassium content of different foods which students may find interesting.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will employ mathematics to quantify properties of objects and phenomena. Students will illustrate that energy and matter can be transformed and changed but the sum remains the same.

Activity 10: Half-life Math. (Estimated time: 1½ periods.)

Students need to work through multiple problems involving half-life to completely understand this concept and the idea that radioisotopes with long half-lives are less radioactive than radioisotopes with short half-lives. Most physical science textbooks have problems regarding half-life that teachers can use. The *Science, Society, and Americas Nuclear Waste* series has a number of exercises ranging in difficulty from regular education middle school level through high school level. Several of the problems involve uranium-235 and uranium-238 including some problems regarding the spontaneous fission chain reaction that occurred in Africa at Oklo, Gabon two billion years ago. Not all students are likely to find these problems as interesting as this teacher does.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will employ mathematics to quantify properties of objects and phenomena. Students will illustrate that constancy and change are properties of objects and processes.

Activity 11: Bill Gates Freaks Out. (Estimated time: 2 periods.)

By now, students should realize that radiation is ubiquitous. Some may be worried about the effects of low level radiation, some might not be. If a student wanted to avoid all radiation, or as much as possible, how would they do it? That is the idea behind the next exercise.

Have students assume that Bill Gates starts to worry about his mortality and starts to be preoccupied by an (irrational?) fear of radiation. (Remember Howard Hughes and his germ phobia?) Bill has decided to hire several teams of students to devise the best plan for letting him lead a radiation free existence. In their planning, students can assume that they have Mr. Gates' considerable fortune at their disposal. Student teams will share their final plans with the class in a format of their choice. Students will need to consider the various radiation sources discussed in activity 5.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to are: Standard 2: Students will use evidence, models, and explanations to explore the physical world. Students will design and develop

models. Standard 10: Students will know and understand the characteristics that are the basis for classifying organisms. Students will use information about living things including the roles of structure and function as complementary in the organization of living systems.

Activity 12: Fission and Fusion. (Estimated time: 3-5 periods.)

Fission and fusion are topics covered in physical science textbooks. Students will likely be interested in fission and fusion bombs and nuclear power. Hewitt (see references) has explanations that are not too technical but will help the teacher extend the curriculum beyond the cursory treatment given in middle school textbooks. In addition to this basic information, one might supplement these topics with selected films on Chernobyl, WIPP, and nuclear weapons (see references for film list).

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 14: Students will know and understand the differences between and the interactions of science and technology. Students will demonstrate trade-offs in safety, cost, efficiency, and appearance related to technological solutions provided through science. Students will compare and contrast a variety of scientific and technological solutions to problems.

Activity 13: Half-day field trip to the National Atomic Museum.

The museum is located on Kirtland Air Force Base – telephone # 505-284-3243 (but they may be relocating).

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 15: Students will know and understand the impact between science and technology in society. Students will demonstrate how the direction for scientific investigations is related to social issues and challenges. Students will differentiate between ethical and unethical scientific practices and research.

Activity 14: Interpretation of Data lesson (Taba discussion). (Estimated time: 1 period.)

The data for this Interpretation of Data lesson will be a historical record of important events in nuclear technologies that have occurred since the 1940's. The discussion will be interdisciplinary in nature, tying together history, science, and economics. There will be a high level of abstraction for students as they try to verbalize the effects of some aspects of nuclear technology as well as drawing conclusions and making generalizations based on our discussions and previous lessons. The main generalization that is hoped to be developed is that nuclear technology has both costs and benefits. The concepts involved in exploring this generalization are: risk, costs and benefits, global warming and carbon dioxide production, generation of electrical power from nuclear energy, nuclear waste storage issues, costs and benefits of non-nuclear electrical generation, radiation

hazards and half-life, and the interconnectedness of local, national, and global economies.

The data that students will enumerate are major events, uses, and statistics regarding nuclear technology. The data will come as a result of previous class discussions and activities and from a handout titled "Nuclear Technology Milestones" (Shelton, 1999). However any brief historical record of major events in nuclear technology, especially nuclear power, would work.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to are: Standard 14: Students will know and understand the differences between and the interactions of science and technology. Students will demonstrate trade-offs in safety, cost, efficiency, and appearance related to technological solutions provided through science. Standard 16: Students will know and understand the relationship between natural hazards and environmental risks for organisms. Students will analyze environmental risks for personal and social costs.

Activity 15: Rad Art. (Estimated time: two 15-minute blocks.)

Students will recreate Henri Becquerel's experiment exposing film to radiation. Using their knowledge of the penetrating power of different types of radiation, they will try to use common objects (coins, keys, test tubes, plastic forks, whatever) to make a controlled, planned, artistic image on the film (in this case Polaroid film). Since there is a paper cover on the film, alpha particles will not reach the film. The miscellaneous items will be placed on a radioactive source (see activity 1 above), with the film placed on top. This assembly needs to be placed in a darkened area for up to a week (or more depending on specific film type) before development. Students' projects should not be stacked on top of each other so that radiation will not hit the film from more than one side. The best film, which is less expensive if it's "expired," is Polaroid Type 57 (3000 speed) (Shelton, 1999). In order to develop the film, a brayer, rolling pin, or straight edge is necessary to spread the chemicals evenly over the film. After the developer is spread, wait about 25 seconds before opening the film. Teachers should try this on their own well before doing with their class.

State Science Content Standards (Grades 5-8) - Among the content standards that this lesson teaches to is Standard 6: Students will understand the process of scientific inquiry. Students will use their own understanding of science to guide their scientific investigations.

Activity 16: Independent research. (Estimated time: 5 periods – including presentations).

Students will do independent library/internet research on a particular nuclear technology (see narrative above for ideas), radioactive element, or famous scientist in the field of nuclear physics. Students will be given the following directions:

- They must adopt a role as they write their paper. They need to adopt the perspective of this role as they write. The nature of this role should be clear to the reader of the paper as it is read. Some possible roles: detective, teacher, parent, elected official, expert in..., engineer, biologist, curator, political candidate, curator, advertiser, newscaster, reporter, biographer, curator, ?.
- Students must choose a particular format for their final product. Some possible formats: magazine article, editorial, brochure, short story, play, novel, journal, diary, biography, interview, letter, ?.
- Students must write their paper with a particular audience in mind. Some possible choices: friends, parents, young children, public figures, general public, people from other time periods, people from other places, an investor, school board, judge, professional in some discipline, ?.
- Students must write their paper with a particular purpose (or purposes) in mind. Some possible choices: explain, inform, change thinking, tell a story, initiate action, change action, instruct, ?.
- Students must use one or more approaches to achieve their purpose. Some possible approaches: analyze, challenge, classify, compare, conclude, contrast, defend, define, demonstrate, describe, evaluate, explain, interpret, justify, persuade, predict, propose, question, reflect, ?.

Research projects will be shared with the class.

State Science Content Standards (Grades 5-8) – Standards will vary depending on the subject and approach chosen.

Web links

American Nuclear Society – public information page. Has links for teachers, teacher workshop locations and dates, publications, and other information about ANS. <<http://www.ans.org/pi/>>.

Environmental Protection Administration's Radiation Protection page. Links to information on radon, WIPP, Yucca Mountain, other EPA publications, and a teacher and student section (interactive radiation dose calculator, crossword puzzle, basic information, etc.). <<http://www.epa.gov/radiation/>>.

Environmental Protection Agency's page on Radiation: Risks and Realities. <<http://www.epa.gov/radiation/rrpage/rrpage1.html>>.

FusEdWeb: Fusion Energy Educational Web Site. Links to ways to learn about

fusion – including an online slide show. <<http://FusEdWeb.pppl.gov/>>.

Nuclear Energy Institute. Information on nuclear energy – facts, a quiz, Q. & A., and maps showing power plant locations.

<<http://www.nei.org/>>.

Nuclear Regulatory Commission homepage. Library references, information on nuclear power and radioactive waste, information on school programs with a "teacher corner" and a "student corner", and other links as well.

<<http://www.nrc.gov/>>.

Radwaste.org – list of nuclear related links and a teacher resources section.

<<http://www.radwaste.org/>>.

The Virtual Nuclear Tourist. Extensive information and links on nuclear technology, radiation safety, radioactive waste, and related topics.

<<http://www.cannon.net/~gonyeau/nuclear/index.htm>>.

Waste Isolation Pilot Project homepage. Everything the government wants you to know about WIPP can be found here.

<<http://www.epa.gov/radiation/wipp/>>.

Glossary

Alpha particle: A helium nucleus (2 protons & 2 neutrons) emitted from the nucleus of an atom after undergoing radioactive decay.

Atom: The smallest unit that still has the properties of an element.

Atomic energy: Energy derived from a nuclear reaction.

Atomic mass: The mass of a neutral atom – expressed in atomic mass units.

Atomic number: The number of protons in the nucleus of a given element.

Atomic weight: The average mass of the isotopes of a given element as normally found in nature.

Background radiation: Radiation that is normally present, over and above a particular source being measured.

Becquerel (Bq): A unit that is that quantity of a radioactive material that will have one disintegration, or incident of radioactive decay, in one second.

Beta particle: A high speed electron that originating from the nucleus of an atom.

Breeder reactor: A reactor that produces more fissile material than it consumes.

Cancer: A general term for more than 100 diseases that have uncontrolled,

abnormal growth of cells that can invade and destroy healthy tissues.

Chemotherapy: Treatment with anticancer drugs.

Cobalt 60: A radioisotope often used as a radiation source in cancer treatment.

Core: In a nuclear reactor, it is the area where fissionable material is located.

Cosmic rays: Any radiation received by our planet from outside our atmosphere.

Curie (Ci): One curie is the quantity of a radioactive material that will have 37 billion disintegrations per second. (1 Ci = 37 billion Bq).

Daughter product: A nucleus that results from radioactive decay.

Electromagnetic radiation: A form of energy that has no charge or mass and is generally defined in terms of its wavelength and frequency. Among the forms are gamma rays, visible light, x-rays, microwaves, and radio waves.

Electron: A subatomic particle mainly found surrounding the nucleus of atoms. It has a negative charge and a mass about 2000 times smaller than that of a proton.

Fallout: Radioactive material that has dropped to the earth after a nuclear explosion.

Fission: The breaking of heavy nuclei into lighter nuclei with the release of large amounts of energy.

Fusion: The combining of light nuclei into larger nuclei with the release of very large amounts of energy.

Geiger counter: A device that measures the amount of ionizing radiation.

Gray (Gy): Measures a quantity called the absorbed dose. This refers to the amount of energy actually absorbed in any given material. (1 Gy = 100 rads).

Half-life: The time it takes for half of a sample of radioactive substance to decay.

Internal radiation: A type of therapy in which a radioactive substance is implanted into or close to the area needing treatment.

Ion: Any atom that has lost or gained an electron(s).

Ionizing radiation: Radiation that is capable of knocking electrons off atoms or molecules. Has the potential to damage living tissue.

Isotope: Nuclei having the same number of protons but containing a different number of neutrons.

Millirem: One thousandth of a rem.

Neutron: A subatomic particle usually found in the nucleus of an atom that has no

charge, and a mass that is similar (slightly larger) to the mass of a proton.

Oncologist: A doctor who specializes in treating cancer.

Proton: A subatomic particle, usually found in the nucleus of an atom that has a positive charge.

Rad: Short for "radiation absorbed dose." A measurement of the amount of radiation absorbed by tissues; it is the amount of radiation that will deposit 1/100 joule per kilogram. (100 rads = 1 Gy).

Radiation therapy: The use of high-energy penetrating rays or subatomic particles to treat disease. Types of radiation used include x-ray, electron beam, alpha and beta particles, and gamma rays.

Radioactive (nuclear) decay: The change in a nucleus from an unstable state to a more stable state.

Radioisotope: An isotope that is radioactive.

Rem: Short for "Roentgen equivalent man." A unit used to derive a quantity called the equivalent dose. This is used because not all radiation has the same effect on living human tissue, even for the same amount of absorbed dose. (1 rem = .01 Sv = 1000 mrem (Millirem).)

Roentgen (R): Measures the ability of photons (gamma rays and x-rays) to make ions in the air (not in tissue or other materials).

Sievert (Sv): Another measurement of equivalent dose in humans. (1 Sv = 100 rem.)

X-ray: High-energy radiation that can be used at low levels to diagnose disease or at high levels to treat cancer.

Videotapes:

Atomic Cafe. Produced and directed by Kevin Rafferty, Jayne Loader, and Pierce Rafferty. Videocassette. First Run Features, 1982.

From the movie box "A stunner, a movie that has one howling with laughter, horror and disbelief." This movie combines archival footage from the 1940's and 50's to show some of aspects of the Cold War.

Atomic Energy Inside the Atom. Videocassette. Chicago: Ebe, 1982. (APS # 10010549 – 14 min.)

Chernobyl, Lessons Learned. Hacienda Productions. Videocassette. Altschul Group, 1997.

Interviews with people affected by the Chernobyl accident, including children. Shows the Chernobyl site and discusses contamination. APS #10029579 – 20 min.

Nova - Strategy for Beginners. Videocassette. Time-Life, 1984.
Shows evolution of nuclear weapons strategy from 1940's-1980's. Tries to explain U.S. and Soviet perspectives through interviews with policy makers. Discusses the idea of Mutual Assured Destruction. APS #10012835 – 57 min.

Nuclear Power Pro and Con. Videocassette. McGraw-Hill, 1977. (APS #10011183 – 50 min.)

Nuclear Waste. Videocassette. Altschul Group, 1997.
Tours the WIPP site. Includes interviews with scientists and local residents. Film would claim to be balanced but seemed to be anti-nuclear to me. APS # 10029413 – 13 min.

Ostrich People. Videocassette. Churchill Films, 1990.
APS says this film is animated and for grades 7–12. Includes a woman psychiatrist who discovers a nuclear weapons silo near her uncle's farm. She then tries to organize a protest against it. APS #10026572 – 11 min.

Physics in Action the Generation of Nuclear Power. Videocassette. Lucern Media, 1985.
Describes and compares nuclear power station with those that use fossil fuels. The advantages and disadvantages of nuclear power are examined. APS #10020675 – 19 min.

Principles of Technology 12. Videocassette. Agency for Instructional Technology, 1986.
The subject of the film is radiation. APS #10017509 – 50 min.

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Observes the creation of a short lived radioactive isotope, plots its decay curve, and shows an experiment of how air becomes charged using a radioactive isotope. APS #10016852 – 20 min.

Ring of Truth Change. Produced and directed by Sanford H. Low. Written by Philip and Phylis Morrison. Public Broadcasting Associates, 1987.
Focus is on the laws of conservation of mass and energy. The conclusion includes a section about mass being converted to energy. If a teacher didn't have time to show the whole film, kids would enjoy seeing the section with the penguins marching and the firecrackers going off in the sealed box. APS #10029299 – 55 min.

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I'm indebted to Mr. Shelton for many of my lesson plan ideas and for sparking my curiosity about radiation - through participation in one of the highly recommended workshops that he helps run.

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