Nuclear Energy: Radiation Exposure

Introduction

U.S. Nuclear Program

Nuclear energy was going to make the world a much better place during the 1950's. The promise of an almost limitless supply of cheap energy that did not produce any soot or atmospheric pollutants almost seemed to good to be true. During the 1960's and 1970's, the United States nuclear industry expanded, as fears of a looming end to oil and gas reserves fueled construction. But by the late 1970's, though, the wheels had come off of the nuclear wagon. The cheapness of the energy never did pan out, as prices of electricity from nuclear energy rivaled those of fossil fuels. Furthermore, the fear of a major catastrophe caused some to question the prudence of using such a lethal source of energy. In March of 1979, the movie "The China Syndrome", a fictional tale about a near meltdown in a California nuclear power plant, was released to theaters. At the time, it opened up a debate about the safety of nuclear power and whether such an incident as portrayed in the film could ever occur. Less than two weeks after the release of the movie, an accident occurred at the Three Mile Island nuclear facility that caused a shutdown of the system and a small release of radioactive steam.

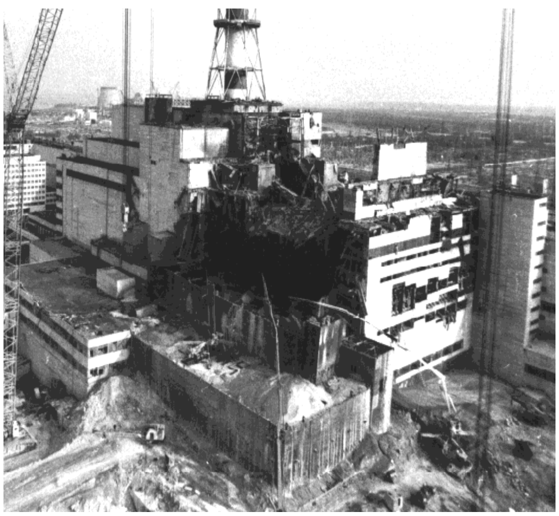

Figure 1: Picture of Chernobyl facility after explosion

The panic that ensued after this incident furthered the tailspin in which the U.S. nuclear industry found itself. By the time that the former Soviet Union experienced the world's largest nuclear disaster at Chernobyl, the United States nuclear industry was, for the most part, finished with expansion. The last time that construction had begun on a new reactor was in 1977, and several of the ones that had started before that date were converted to coal or natural gas powered plants. All that was left for the nuclear power companies was to finish up construction on the few that were left incomplete and to continue the operations at the ones that were still going. The last of these reactors, the Watts Bar facility in Tennessee, was finished in 1996 after initial construction started in 1970. Currently, America has 104 commercial nuclear reactors that provide almost 800 billion kilowatt-hours of electricity per year, which is about 20% of our total usage.

The current state in which the U.S. nuclear industry finds itself is due, in large part, to people's fear of the words "nuclear" and "radiation". For most people, anything radioactive is to be feared and placed at great distances away behind many layers of shielding. Is this fear unfounded? The answer to that question depends on a lot of factors.

Ionizing Radiation

Most radiation produced by nuclear decay falls within a category called **ionizing radiation**. Because of its charge and/or its energy, this type of radiation has the ability to turn neutral atoms into ions. This, in and of itself, is not necessarily a bad thing. Ions are found throughout nature and are essential to many physical and biological processes. However, if this ion is created in or near certain parts of the cells in your body, it can be quite hazardous. For instance, if the ionizing radiation where to hit one of the atoms that comprise the DNA in one of your cells, it could change the bonding properties of the atom, and thereby, physically change the DNA. If this cell and DNA were to survive, it will have undergone a mutation, which could be either harmless or lethal, depending upon where in the DNA molecule it occurs.

Not all of the different types of nuclear radiation have the same ability to perform such feats. Some of them have higher probabilities for impinging upon atoms and being absorbed, which makes them more likely to ionize atoms. For instance, alpha radiation is a helium nucleus (two protons bond to two neutrons), whereas gamma radiation is electromagnetic radiation of very short wavelengths. The alpha particle, with its physical mass, size, and net charge, is much more likely to be absorbed by an atom than gamma radiation. By the same token, though, alpha radiation can be more readily blocked. A beam of alpha particles can be stopped by a thin sheet of paper, while a beam of gamma radiation requires either several inches of dense lead or many feet of wood or water to be shielded.

We should also point out that the location of the radiation's origin is important, too. If the radiation is emanating from outside of your body, then you worry about how penetrating the radiation is. As we have just discussed, alpha radiation can be blocked from entering your body by a thin sheet of paper. Gamma radiation has a much greater likelihood of getting into your body and being absorbed in this case. However, if the radiation is emanating from inside your body, then alpha particles are going to have a much tougher time to not be absorbed by something in your body. In this case, gamma has a much greater likelihood of not being absorbed and getting out of your body.

Rads versus Rems

This does not mean, though, that alpha particles are much more dangerous than gamma radiation, or vice versa. The potential lethality of radiation that a person receives also depends on the amount of energy that is absorbed by a body. Measuring this is fairly straightforward. Historically, we have measured this in a unit called the **rad**, which is equal to 100 ergs of energy absorbed by 1 gram of tissue. The more modern unit of absorbed radiation is the **gray**, which is equivalent to 100 rads. It is important to note that these units are the amount of energy absorbed per mass of tissue, and not the total amount of energy to which a body might be exposed.

Measuring the amount of potential biological damage, though, requires merging this information about the amount of energy absorbed with the knowledge of how well the different types of radiation ionize material. This leads us to what we call an equivalent dosage. Since alpha particles are more readily absorbed by biological material than gamma rays, a smaller energy dosage of alpha hitting a sample of biological material will produce the same effect as a much larger amount of gamma radiation. The **equivalent dosage** is measured in units called Rems (**R**oentgen **E**quivalent **M**an) and is equal to the absorbed dosage (in rads) times a quality factor, i.e.

Equivalent Dose (in rems) = absorbed dose (in rads) x quality factor

This quality factor depends upon what type of radiation it is. The table below lists some of these for commons forms of radiation.

Radiation Type	Quality Factor
Gamma and Beta	1
Low energy neutrons and protons	5
Alpha, high energy neutrons and protons	10-20

Lethal Dose

Knowing how we measure radiation absorbed by the body, the next question is "How much is too much?" Many people incorrectly assume that any radiation is bad. Most dosages of radiation that are received by people do little to no harm to our bodies for various reasons. The radiation may not be that strong; it might hit a portion of the body that will not cause death or harm; it might ionize a portion of a cell and cause it to die, preventing it from mutating. But, at some point, radiation begins to have lethal consequences. There are two major problems, though, with trying to answer at what level this occurs. The first of these is that there is no theoretical way of determining what is the threshold for a lethal dose. We can approximate how much of a dose would cause cells to rupture or for tissue to burn. But, we do not have anyway of knowing how much will be necessary to cause a cell to mutate into a cancer causing cell or to keep it from further divisions. Secondly, everybody's body reacts differently to radiation. Some people seem to have built in mechanism that can repair the damage due to radiation better than do others. These people can withstand much larger doses than their counterparts and feel no ill effects.

These problems lead us to a statistical approach to the issue based upon years of observational data. The best that we can do is to define the levels of exposure that will cause sickness or death in a certain percentage of the population within a given time frame. These levels are generated for exposure over different time frames and to different parts of the body. For instance, the L.D. 50/30 level, or the dose that would be lethal to 50% of the human population within 30 days after irradiation, is about 350 rems of radiation delivered to the entire body at one time[1]. One-time dosages that are slightly less than this will kill fewer people, while exposures greater than this will kill more. If the exposure is only to part of the body, or if the dosage is delivered over a longer period of time (weeks, months, years), the lethal dose will be greater. While there are exposure levels beyond which nobody could survive, there is no way of determining how an individual person will respond to these lower levels of radiation. We should point out that some of this data comes from epidemiological studies of people who were naturally exposed to radiation and from animal studies, while some of it actually comes from radiation experiments that were carried out on human subjects.

This means that, in some sense, radiation exposure is a gamble. All that we can do is to generate odds that exposure to a certain amount of radiation will do damage to a person. As we generate new data based on new research (people and animals are continually being exposed to radiation), we can develop new sets of odds. But we can never tell you that you are 100% completely safe. All that one can do is to try to limit their exposure to remain within what are regarded as safe levels.

Exposure Sources

One might be led to believe that, if they stay away from a nuclear reactor, they will be safe from radiation. While you might be safer to do so, you can never be free from nuclear radiation. As you go about your daily activities, you are constantly being exposed to radiation from various sources. As we mentioned in the Nuclear Decay Activity, radioactive isotopes behave chemically similar to their non-radioactive twins. Some of these sources come from the world around you; some of them come from within you. For instance, potassium-40 is an unstable isotope that comprises about .012% of all of the potassium in your body. You take it into your body in the food you eat (bananas are an excellent source) and the water your drink. It has a half-life of about 1.3 billion years, and accounts for about 40 millirems (mrems) of radiation being absorbed in the body each year.

You are also being bombarded with radiation from sources outside of the Earth. High-energy particles from the Sun and outer space that are not absorbed by the atmosphere can make it to the ground and strike you. If you live or travel higher in the atmosphere, you will be exposed to more radiation. If you live at 1000 feet above sea level, you receive about 2 mrems of radiation each year; if you live at 5000 feet, you receive about 21 mrems.[1] For every 1000 miles that you travel in a jet airplane, you receive another 1 mrem of radiation.

Some of the radiation that you receive comes from manmade sources. During the 1940's, 50's, and 60's, the U.S. and the former USSR, as well as a few others, engaged in above ground nuclear testing. These explosions released radioactive isotopes into the air, which eventually fell out all over the land and water. As this residue decays, it provides about 4 mrems of radiation to each of us. We also are irradiated by our television sets. The tube in your television set (this does not apply to plasma televisions) operates by firing electrons at a phosphorescent screen, where they are rapidly decelerated by impact. This deceleration produces what is known as bremsstrahlung radiation, which is in the x-ray region of the spectrum. The amount of radiation is not that much, as an average of one hour viewing per day will only contribute about .15 mrems of radiation per year. You receive a much larger dose getting an x-ray from your doctor, which can contribute up to 10 mrems of radiation.

Radon

The largest source of radiation for many people comes from radon gas exposure. As we saw in the Decay Activity, radon-222 is a natural daughter product in the decay chain of uranium, which is found in rocks throughout the world. It is unique from the other daughter products in two ways: it is a gas at room temperature, and it is inert. When the other daughter products are produced, they are solids, which means that they stay put in the rock matrix. However, when radon is produced, it slowly starts to migrate through cracks in the rocks up to the Earth's surface. Once it reaches the surface, it mixes in the atmosphere, which we breathe.

If your home happens to be sitting on the ground above the location where the radon exits the earth, then it is possible for it to move through cracks in your foundation and enter your home. Over time, the concentration of radon in the home can build up, as radon is both non-reactive and heavy, which keeps it nearer the surface of the planet. It is estimated that about 1 in every 15 homes in the U.S. has elevated levels of radon. It is also possible for this same thing to happen in offices and schools. Since most people in the U.S. spend the majority of their time during the day either in their house or in a school or office building, this can have some serious consequences. The only way to know for sure how bad the situation is in your home or building is to test for the presence of radon decay. This can be done with very inexpensive kits (some less than $10) that require very little time or knowledge to operate.

Additional Reading

The following link discusses the history of radiation experiments that were performed on humans under the auspices of the Department of Energy or any of its predecessors. The site also contains a link to a similar website run by the Department of Defense for radiation experiments that they also performed.

The following link provides information about radon gas build up in homes and offices. It discusses the sources of radon gas, as well as methods for testing for radiation and for fixing problems.

Environmental Protection Agency	**Topic**: A Citizen's Guide to Radon **Summary**: Contains information about radon in the home, how to measure its activity, and how to remedy the situation **Link**: http://www.epa.gov/iaq/radon/pubs/citguide.html

References

1 Energy: Its Use and the Environment, 2^{nd} Edition by Roger A. Hinrichs, Saunders College Publishing, Orlando, 1996

Activity

The average American receives about 360 mrems of radiation each year. In this activity, we are going to try to estimate what your yearly exposure is from the various sources. In order to increase the accuracy of this estimate, we will need to know a few details about where and how you live. It should be stressed that this is only an estimate of your exposure and should not be relied upon as a full accounting of what your actual exposure is. There may be unusual factors in your case, which will cause the estimate to differ radically from what it actually is. If you are concerned about your exposure actually is, you should consider purchasing a dosimetry badge or consulting with a health physicist.

Since radon gas is the largest factor for most people, we will start the investigation there. You can estimate your exposure to radon by measuring the concentration of radon in your home using a home test kit. Using this and an estimate for the amount of time that you spend indoors will allow us to estimate your radon exposure levels. EPA has resources on these kits, and radon in general, at https://www.epa.gov/radon.

There are a few other facts about your home that we will need in order to estimate exposure due to your location. First, we will need to know the elevation of your community above sea level. As one goes higher in the atmosphere, there is less protection from the atmosphere from radiation coming from outer space. Therefore, if you live at 5000 feet above sea level, you will receive more radiation than if you live at 4000 feet above sea level. Consultation with a decent map should give you this value. We will also need to know in what region of the U.S. your home is located. Different regions have different rocks underlying them, which results in differing amounts of terrestrial radiation. Areas overlying a large amount of sediment (Gulf Coast and Atlantic Coast) receive only about 23 mrems of radiation; areas with igneous rock very near the surface (Colorado Plateau) receive about 90 mrems. Besides these two things, we need to know what the exterior of your home is (earth materials have more radioactive substances in them), how far you live from a nuclear and coal power plant (both emit radiation, with a coal plant emitting more), and whether you have a smoke detector in your home (smoke detectors use a very small amount of americium, which will give you about .008 mrems of radiation each year).

There are also some activities and lifestyles contribute to your radiation exposure. Some of them, such as jet travel, we have mentioned above. Most of these activities or lifestyles add very little to your overall exposure. About the only one that does add a fair amount is the use of a pacemaker, which has a plutonium-powered battery that will give you about 100 mrems of exposure each year.

The last area of information that we need for the estimate concerns medical procedures. These fall into two categories: diagnostic and treatment. Radiation is used in diagnostic procedures in order to peer into the body without opening it up. More than likely, you have had several of these in your lifetime, especially if you have ever been to a dentist. The amount of exposure you get from these can be as small as 2-3 mrems from a dental x-ray up to 1000 mrems from an abdominal CT scan. The radiation in a treatment procedure is used to kill cells, usually cancerous, that are in your body. Since this radiation is used to target specific cells and kill them, we have not included them in this estimate. If you want to know more about how much radiation the rest of your body received during one of these procedures, we suggest that you consult your physician.

Now that we have acquired all of the information required for the estimate, we will proceed to the online calculator. This calculator will sum up the contributions from all of these sources and add it to the 66 mrems of radiation that you receive from on average other sources (ex. food and water) for which we have no way of personalizing. Once you have done so, you will need to answer the questions on the following page.

ESA21: Environmental Science Activities

Activity Sheet
Radiation Exposure

Name:

Enter your current data into the online calculator. Then, see how your total exposure would change if you made the following changes.

		Total Radiation Exposure
a.	Current data	_________ mrems
b.	The radon concentration in your home were to double.	_________ mrems
c.	You lived in Denver, CO.	_________ mrems
d.	You lived in Death Valley, CA.	_________ mrems
e.	You had a chest x-ray each year	_________ mrems
f.	You lived 1 mile from a nuclear reactor	_________ mrems
g.	You doubled the amount of jet travel	_________ mrems
h.	You had a pacemaker installed	_________ mrems

Answer the following questions:

1. Which of these scenarios gave you the greatest exposure? Which gave you the least?

2. Compared to other things in your life, how does living near a nuclear reactor affect your total exposure?

3. After completing this exercise, are you as worried about living near a nuclear reactor? Are there other things to consider about this situation?