PSU RSEC & The Penn State American Nuclear Society

Presents the 2021

Scouts BSA

Nuclear Science Merit Badge Program

Radiation

What is radiation? The dictionary defines radiation as energy that is radiated or transmitted in the form of rays, waves, or particles. In fact, there are all kinds of radiation. The type of radiation you are probably most familiar with is visible light. Everything your eyes can see is communicated to you through radiation waves that bounce off of objects and then into your eyes. Similar radiation to visible light is invisible light. The kind of light you can't see unless you use special glasses. These include infrared and ultraviolet radiation. Radio waves, microwaves, heat and x-rays are also all forms of radiation.

The distinction between these types of radiation and the nuclear radiation we're concerned about for the nuclear science merit badge is that nuclear radiation is ionizing radiation. Ionizing radiation carries enough energy to ionize atoms. What does it mean to ionize an atom? Atoms are made up of protons, neutrons, and electrons. When one is ionized, it means that one of its electrons have been separated from the atom. After losing an electron, an atom gains an electrical charge. When this happens inside your body, a few different things can happen.

Most of the time, when you are exposed to ionizing radiation, the radiation travels through your cells without interacting with anything. The waves and particles, which can ionize atoms, are so small that often they can travel through you without hitting anything. Other times, the ionizing radiation affects an atom within one of your cells and the cell dies. It is a good thing we all have many billions of cells in our bodies that are constantly dying and being replaced with new ones. We are exposed to ionizing radiation every day, from places like the sun, the ground, the air we breathe and the food we eat. Bananas for example are high in potassium, a naturally radioactive element. Rocks within the Earth are often releasing radiation and the building materials, which we take from the ground, keep those elements with them.

Another place where we tend to be exposed to radiation is at the hospital. X-rays, PET scans, and other diagnostic procedures use the properties of nuclear radiation to help doctors learn about their patients and in some cases, treat them. One of the most harmful things that can happen when exposed to ionizing radiation is when the ionizing radiation enters a cell and instead of killing it, confuses it. When the cell is confused, it can multiply and form a tumor. Luckily, these tumors can also be treated with ionizing radiation. For example, the Gamma Knife is a device that a doctor can use to expose a tumor to radiation to kill it to make the patient better.

Between doctor's visits, eating radioactive food, and just living on this planet, we are exposed to about the same amount of radiation as a chest x-ray once a week, about 600 millirem. A millirem (mrem) is a unit of measurement like an inch or a centimeter that we use to measure radiation exposure. A typical chest x-ray is 10mrem, while a typical tooth x-ray is 1 mrem. People who work with radiation can be exposed to much more. That is why there are regulations from our government to help protect those people from too much radiation exposure. A nuclear worker receives, on average, 150 mrem of occupational exposure annually. The federal government has limited the dose of radiation to a nuclear worker to 5,000 mrem per year. This is about 8 times more than the average human gets from naturally occurring radiation and one quarter of the amount of radiation someone receives before we notice that it's become harmful. We also set rules to limit our exposure to keep our exposure As Low As Reasonably Achievable. We call this rule, ALARA (a-lar-a).

We are all exposed to radiation every day, all the time. Radiation is not something we should be scared about, but it's also something we shouldn't play with. It can do some bad things to your body and it can also do some really good things when used properly.

Answer the following questions about radiation:

What is radiation?

____

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What does ALARA stand for? ____

What are three things that can happen when radiation interacts with biological cells?

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How many mrem does an average person receive in a year normally?

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How many mrem does the federal government allow a radiation worker to receive in a year?

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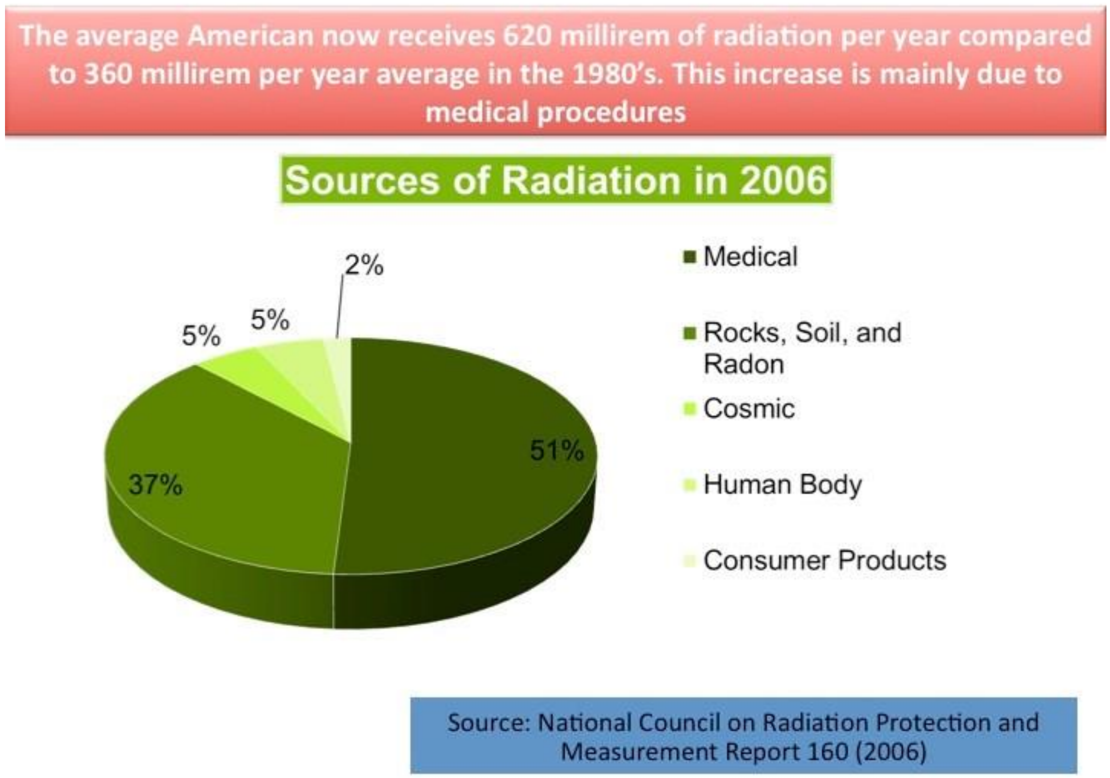

Radiation Warning Signs

Wherever there is radiation present you can be sure to see the above image posted nearby. The signs are posted at each entrance to an area where radioactive material is stored or used. Any equipment or container used for temporary or long-term handling or storage of radioactive material may also be required to be labeled with the "Caution - Radioactive Material" label.

This general shape is known as a “trefoil”. The three-bladed radiation warning symbol, as we currently know it, was "doodled" out at the University of California Radiation Laboratory in Berkeley in 1946. It is supposed to look like radiation coming from an atom. The first signs printed at Berkeley had a magenta symbol on a blue background. They chose those colors because they were unique and made the sign stand out.

The colors were soon changed to the current yellow background and magenta or black foils. Blue was not supposed to be used on warning signs, and it faded, especially outdoors. The use of yellow was standardized at Oak Ridge National Lab in early 1948.

So if you see these signs it is important to understand that there is a chance, even if it is small, that you may be exposed to radiation. That is why when you see this symbol it is you should be sure to follow the instructions of a trained professional.

A second symbol was recently created by the Nuclear Regulatory Commission (NRC) to be placed inside sealed containers with radioactive materials inside. They included a skull and cross bones and a person running to illustrate the danger involved with whatever was just opened. Because of the graphic images on the sign it will only be placed inside containers so it does not frighten people.

Draw your own trefoil below:

Nuclear Vocabulary

Atom – is the basic unit of matter. It consists of the nucleus containing protons and neutrons with orbiting electron(s).

Neutron – is an atomic, neutral-charged particle found in the nucleus. It weighs 1.008701 atomic mass unit, amu.

Proton – is an atomic, positively-charged particle found in the nucleus. It weighs slightly more than a neutron, 1.007316 amu.

Electron – a subatomic, negatively-charged particle found orbiting a nucleus. It weighs significantly less than either neutron or proton 0.000549 amu.

Quark – an elementary particle of matter when combined forms protons and neutrons.

Isotope – an atom of the same chemical element, so same number of protons, but different number of neutrons. Some isotopes are radioactive (**radioisotopes**), while others are not (stable).

Ionization – is the conversion of an atom or molecule into an ion by removing or adding electrons. Cations have fewer electrons than protons giving a net positive charge. Anions have more electrons than protons giving a net negative charge.

Radioactivity – is a random emission of ionizing particles from the nucleus. Some elements are naturally radioactive, while others can be man-made with accelerators, nuclear reactors, and explosions.

Radiation – is energetic particles or waves traveling through a medium or space (vacuum). When radiation has enough energy to ionize atoms, they call it ionizing radiation. Radiation such as x-rays, alpha, beta, gamma, and neutron are ionizing. Non-ionizing radiation does not have enough energy to ionize atoms, which are electromagnetic waves such as light, infrared, radio, and microwaves.

Background radiation – is always present in the environment we live in through either natural or artificial resources. It is in the air, water, food, ground, building materials and even some consumer products.

Half-life ($t_{1/2}$) – is the amount of time it takes for radioactivity (radiation levels) to decrease by one half.

Alpha particle (α) – consists of two protons and two neutrons bounded together usually forming a helium nucleus. A piece of paper can stop most alpha particles.

Beta particle (β) – are either negatively or positively charged electrons. When it is positively charged, they are known as positrons. A thin piece of aluminum can stop beta particles.

Gamma Ray (γ) – is high frequency radiation that can be extremely energetic and are usually smaller than atoms. Photons can also be defined as "gamma rays".

X-ray – is high frequency radiation that are less energetic than gamma rays, but more energetic than UV rays. X-rays are produced inside an x-ray tube when electrons are accelerated in a vacuum to high velocities colliding with a metal target. When getting an x-ray at the hospital, they pass through flesh more easily than bone, thus leaving a shadow.

Radon – a radioactive noble gas that is colorless, odorless, and tasteless. It's given off by rocks containing radium, thorium, or uranium (as decay products). ^{222}Rn is the main isotope. The main health concern is the solid decay products of the Radon gas.

Curie (Ci) – is a measured unit of radioactivity. Named after French physicists, Marie and Pierre Curie, a curie is equal to the radioactivity of 1 gram of radium.

Becquerel (Bq) – The SI (metric) unit of radioactivity. One Bq measures the activity of a material to decay one per second.

RAD – is an older measured unit of the amount of absorbed radiation dose. Absorbed radiation dose is the amount of energy per unit mass.

Gray –SI unit of a rad. One gray is equal to 100 rads.

REM – is a unit of radiation dose equivalent. The product of the absorbed radiation dose multiplied by a weighting factor defines the rem. It is more biologically significant because it is an attempt to see the amount of radiation required for biological effects to occur.

Sievert (Sv) –SI equivalent of a rem. One Sv equals 100 rem.

ALARA – is an acronym for "as low as reasonably achievable". The nuclear industry follows this principle to minimize the radiation exposure of its workers.

Contamination – is radioactive material left on or in other substances including liquids, gases, and solids (such as a human).

Nuclear energy – Energy, in the form of heat or electricity, is produced by reactions involving the nucleus of an atom. This could be heat from radioactive decay or the process known as nuclear fission when an atom splits into two nuclei.

Nuclear reactor – a device in which a nuclear fission or fusion chain reaction takes place.

Particle Accelerator – a device using electromagnetic fields to increase the speed of charged particles that are usually smashed with another particle. Physicists are then able to study the forces and subatomic particles that compose atoms.

Rewrite the definitions for the following terms, below:

Atom: ____

____

____

Neutron: ____

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Isotope: ____

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Radioactivity: ____

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Nucleus: ____

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Now think of two terms that you may have heard before that are used in nuclear science like, "nuclear reactor" or "radioactive waste," and look those up in a dictionary and write them here:

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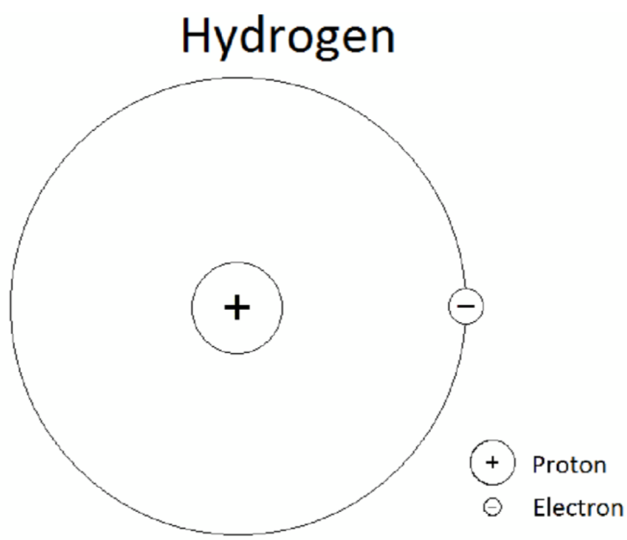
Fill in the BINGO card with terms from this section. At Penn State we will play a BINGO game where we will call out the definitions and you'll have to know which words they go with to win!

B	I	N	G	O
		Free Space		

Hydrogen and Its Isotopes

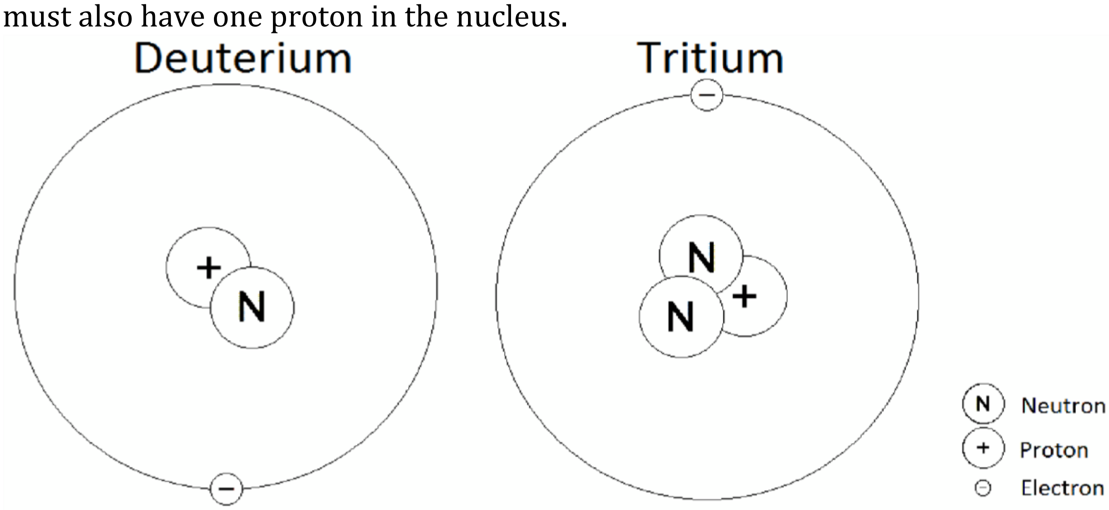
The simplest atom is the **hydrogen** atom. Only one **proton** makes up a hydrogen **nucleus**. Remember a proton is a positively (+) charged particle and the nucleus is the center of the atom.

Usually, one **electron** orbits the nucleus. An electron is a negatively (-) charged particle and it is smaller than a proton. That means a hydrogen atom is basically an electron orbiting a proton:



However, hydrogen also has **isotopes**. Isotopes are atoms with a different number of **neutrons** in the nucleus. Neutrons are about the same size as protons, but they do not have a charge. They are considered "neutral."

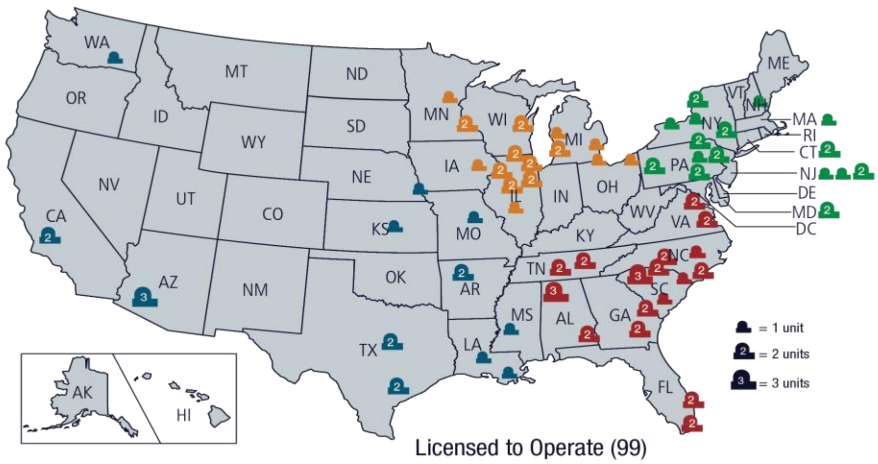
When a hydrogen atom has one neutron, the atom is called **deuterium**. When a hydrogen atom has two neutrons, the atom is called **tritium**. Remember, all isotopes of hydrogen must also have one proton in the nucleus.



During the workshop at Penn State we will make 3D models of these isotopes. Try to remember what they are for when we build them.

U.S. Nuclear Power Plants

U.S. Operating Commercial Nuclear Power Reactors



Licensed to Operate (99)

REGION I

CONNECTICUT
- Millstone 2 and 3

MARYLAND
- Calvert Cliffs 1 and 2

MASSACHUSETTS
- Pilgrim

NEW HAMPSHIRE
- Seabrook

NEW JERSEY
- Hope Creek
- Oyster Creek
- Salem 1 and 2

NEW YORK
- FitzPatrick
- Ginna
- Indian Point 2 and 3
- Nine Mile Point 1 and 2

PENNSYLVANIA
- Beaver Valley 1 and 2
- Limerick 1 and 2
- Peach Bottom 2 and 3
- Susquehanna 1 and 2
- Three Mile Island 1

REGION II

ALABAMA
- Browns Ferry 1, 2, and 3
- Farley 1 and 2

FLORIDA
- St. Lucie 1 and 2
- Turkey Point 3 and 4

GEORGIA
- Edwin I. Hatch 1 and 2
- Vogtle 1 and 2

NORTH CAROLINA
- Brunswick 1 and 2
- McGuire 1 and 2
- Harris 1

SOUTH CAROLINA
- Catawba 1 and 2
- Oconee 1, 2, and 3
- Robinson 2
- Summer

TENNESSEE
- Sequoyah 1 and 2
- Watts Bar 1 and 2*

VIRGINIA
- North Anna 1 and 2
- Surry 1 and 2

REGION III

ILLINOIS
- Braidwood 1 and 2
- Byron 1 and 2
- Clinton
- Dresden 2 and 3
- LaSalle 1 and 2
- Quad Cities 1 and 2

IOWA
- Duane Arnold

MICHIGAN
- Cook 1 and 2
- Fermi 2
- Palisades

MINNESOTA
- Monticello
- Prairie Island 1 and 2

OHIO
- Davis-Besse
- Perry

WISCONSIN
- Point Beach 1 and 2

REGION IV

ARKANSAS
- Arkansas Nuclear 1 and 2

ARIZONA
- Palo Verde 1, 2, and 3

CALIFORNIA
- Diablo Canyon 1 and 2

KANSAS
- Wolf Creek 1

LOUISIANA
- River Bend 1
- Waterford 3

MISSISSIPPI
- Grand Gulf

MISSOURI
- Callaway

NEBRASKA
- Cooper

TEXAS
- Comanche Peak 1 and 2
- South Texas Project 1 and 2

WASHINGTON
- Columbia

Note: NRC-abbreviated reactor names listed. Data is as of May 2017. For the most recent information, go to the Dataset Index Web page at https://www.nrc.gov/reading-rm/doc-collections/datasets/

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

1. **The United States Nuclear Regulatory Commission (NRC) divides the country into different regions of jurisdiction. How many regions are there?**

____

2. **What region is Pennsylvania located in?**

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3. **How many nuclear power plants are in Pennsylvania?**

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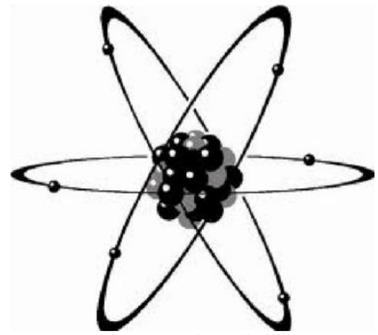
Next, we've summarized how many people use nuclear science at their jobs. Please read about each section and then write a field that interests you and how you think nuclear science could be used in it.

Nuclear Medicine



Nuclear medicine is a type of medicine and medical imaging that uses radioactive nuclides and their decay properties in the diagnosis and treatment of disease. These radionuclides have several useful applications:

Cancer treatment: Penetrating high energy rays from an accelerator are used to kill tumors. Sometimes radioactive Cobalt-60 (which emits gamma radiation) is used to irradiate tumors. Iridium-192 is implanted in tumors and encapsulated in platinum to seal the radioactive material in and the radiation kills the tumor cells.

Computed Tomography CT Scans: These machines use x-rays to take a 3-D image. Sometimes a contrast chemical such as iodine or barium is used to block the x-rays.

Radio Tracers: Iodine-131 is used to measure activity in the thyroid, while Thorium-201 uses gamma radiation to examine the heart and arteries.

Positron emission topography (PET): A compound like glucose is labeled with a positron (electron with positive charge) emitter (Carbon-11, Flourine-18, Oxygen-15, and Nitrogen13). The glucose is then ingested by the patient, the positron emission is detected, and that radiation is then made into a 3D image through the use of computer imaging. The normal images are then compared with abnormal images to figure out what is wrong with the patient.

Magnetic Resonance Imaging (MRI): MRI's are used in medicine for imaging tissue. They can diagnoses many diseases such as multiple sclerosis, tumors, infections, strokes and tendonitis. They are also used to visualize injuries in areas such as the ligaments and shoulders. This type of imaging does not typically use radioactive material.

Environmental Applications

Radiocarbon Dating:

Radiocarbon Dating is a method that scientists use to determine the age of ancient fossils and artifacts. Every living thing on Earth whether it be animals, plants or bugs are made up of a high percentage of the element carbon. A very small percentage of carbon is radioactive. This means since all living things take carbon in their bodies, they will also take up small amounts of the radioactive isotope of carbon. Radiocarbon Dating specifically uses the naturally occurring isotope carbon-14. Carbon dating was developed by American scientist Willard Libby and his team at the University of Chicago. Libby first demonstrated the accuracy of radiocarbon dating by accurately estimating the age of wood from an ancient Egyptian royal barge for which the age was known from historical documents.

After the living organism dies, they no longer take in any new carbon. The carbon in their bodies at the time of their death will remain in their bodies until they decompose, or if they become fossilized, then forever. With the help of nuclear science, we can determine the rate at which carbon radioactively decays. Knowing this decay rate, scientists can examine ancient fossils to determine the amount of carbon decay that has occurred. By determining how much carbon has decayed, they can also determine the time it took for that carbon to decay. Knowing the time and the fact that after the living organism dies it doesn't take anymore carbon, scientists can determine approximately how long ago the living organism lived. The half-life of carbon-14 is approximately 5730 years. This dating technique is widely used in the field of dendrochronology (a scientific method used to study and date trees) as well.

Unfortunately radiocarbon dating is only effective for objects and fossils that are less than 50,000 years old. However, scientists can look at the decay of other elements in these objects allowing them to date them up to 2.2 billion years.

These dating techniques are by no means perfect, but they are always improving.

Space Exploration

Nuclear power not only helps us on Earth, it also can help us explore the vast regions of our solar system. Many satellites and unmanned spacecraft's use nuclear fission to explore our galaxy. Some spacecraft's that use nuclear power are Voyager 1 and 2, Pioneer 10 and 11, numerous satellites that are in orbit around Earth today and The Cassin Space Craft (which is somewhere near one of Saturn's moons right now). Nuclear power for space travel has many advantages. One advantage is the fuel. 1 kilogram of nuclear fuel has 10 million times more energy than 1 kilogram of today's chemical reactions. This means that a spacecraft power under nuclear energy can travel 10 million times further than other rocket propelled ships. A second advantage is the life of the fuel. Most rockets today use millions of gallons of fuel just to get out of the Earth's atmosphere. Once this fuel is used, it cannot be reused. Plutonium, which is used as the fuel for nuclear space reactors, has a half-life of about 87.4 years. This means that if you traveled in space for 87.4 years, you still have half the amount of fuel you began your trip with, which could be used for the return trip perhaps.

Industrial Settings

Today, practically every industry uses radiation in some way. Manufacturers use radioisotopes to improve the quality of goods in thousands of industrial facilities around the world.

Radiation loses energy as it passes through substances. Industry has used radioisotopes to develop highly sensitive gauges to measure the thickness and density of many materials. It also has used radioisotopes as imaging devices to inspect finished goods for weaknesses and flaws.

Manufacturers commonly use small amounts of radioisotopes as tracers in process materials. The tracers make it possible to track leakage from piping systems and monitor the rate of engine wear and corrosion of processing equipment. They also make it possible to observe the velocity of materials through pipes and to gauge the efficiency of filtration systems.

Radioactive materials also are used in industry to inspect metal parts and welds for defects; to measure, monitor and control the thickness of sheet metal, textiles, paper napkins, newspaper, plastics, photographic film and other products; to calibrate instruments; to manufacture ceramics and glassware; and to generate heat or power for remote weather stations, space satellites and other special applications.

Industries that use radioactive materials include:

- The automobile industry, to test the quality of steel in vehicles
- Aircraft manufacturers, to check for flaws in jet engines
- Mining and petroleum companies, to locate and quantify oil, natural gas and mineral deposits
- Can manufacturers, to obtain the proper thickness of tin and aluminum
- Pipeline companies, to look for defects in welds
- Construction crews, to gauge the density of road surfaces and subsurfaces.

Here is where you write about a subject that interests you:

And here's some space to write down questions you'd want to ask the radiation workers, reactor operators, and nuclear engineering students during your visit to Penn State. We hope you're as excited as we are!

Cloud Chambers (To be completed at PSU)

At Penn State, we will be making cloud chambers. Inside the cloud chambers are two radioactive objects, a rock and a lantern mantle. The rock is giving off alpha particles from uranium while the lantern mantle has thorium inside and is giving off beta particles. We use a chemical called ethanol, which is a vapor at room temperature, to see the paths the alpha and beta particles take through the chamber.

Below, draw what you see in the cloud chamber:

Counting Radiation (To be completed at PSU)

In this lab, members of the Penn State American Nuclear Society will instruct you. We will test different ways we can protect ourselves from radiation. In one part of the lab, we will move a radioactive source closer and farther away from a detector that we will use to count how many radioactive particles and waves are emitted, depending on its distance from the counter. In the second part of the lab, we will use different types of shielding materials such as paper, plastic, and lead to see which type of shielding blocks the radiation, best.

Part 1: Distance

For this part, move the source to different shelves of the detector device and record the amount of counts you receive.

	Balloons	Atom	"m"
Contact			
Distance 1			
Distance 2			

Part 2: Shielding

This time, use different shielding materials placed between the source and the detector and record how many counts you receive for each one. Compare the results you get to those in Part 1, when you didn't use any shielding.

	Balloons	**Atom**	**"m"**
Paper			
Plastic			
Lead			

What type of Radiation?

Balloons - ______________ Atom ___________________ "m" ______________________

How can Time, Distance and Shielding reduce radiation dose?__________________________