Introduction

Hi and welcome to Understanding Radiation, a Radiation Safety Institute of Canada online course.

This course introduces radiation and radiation safety to people who work in environments where radiation is used and for anyone wanting basic knowledge on the subject.

We'll describe what radiation is and how the types of radiation differ. We'll discuss various ways of quantifying radiation, describe how radiation affects the body, and see how that leads to setting radiation dose limits. Finally, we'll talk about common radiation exposures and briefly describe the Canadian regulatory bodies in charge of radiation protection.

Use of Radiation in Canada

Let's begin with a look at where radiation is used in Canada.

More than 150,000 Canadians are monitored annually for workplace radiation exposure. Approximately 19% of those workers are from the nuclear power or nuclear fuel industry, an industry which produces 15% of the power and electricity used in Canada. 50% of the monitored workers are associated with healthcare, 11% are in industry and research, and another 10% are students in various fields.

So let's see what radiation is.

Radiation and Energy

Radiation is simply a form of energy. All matter, whether at rest or in motion, has energy.

An object can possess potential energy by virtue of its position. An object in motion possesses kinetic energy.

With radiation, the energy can take the form of moving particles or bundles of pure energy. Either way, the important thing is that this energy can then be transferred to another material.

The type of radiation and its energy will affect how it interacts with matter.

Non-Ionizing (Low Energy) Radiation

Before going any further, note that in this course, we will only be discussing high energy radiation. Low energy radiation, also known as non-ionizing radiation, is radiation that is not energetic enough to knock electrons out of atoms. Examples of this type of radiation are radiowaves, microwaves, infrared light, and visible light. These types of radiation are all around us constantly.

Though there is still research being done to determine if low amounts of these types of radiation can be harmful, it is very important to stress that the health effects that we will be discussing today do not come from exposure to low-energy radiation.

Non-ionizing radiation interacts very differently with matter than the other types of radiation which we will discuss in this course. These types of radiation here, again, do not have sufficient energy to knock electrons out of atoms.

Ionizing Radiation

To understand how radiation interacts with matter, let's begin with what matter is actually made of. All matter is made up of miniscule particles called atoms. Atoms in turn are made up of protons, neutrons, and electrons. Protons and neutrons make up the nucleus, or centre, of the atom, and the electrons orbit the nucleus. Most atoms around us have as many protons, which are positively charged, and electrons, which are negatively charged. The positive and negative charges balance each other out, so atoms are electrically neutral.

When radiation with high enough energy interacts with one of the orbiting electrons, it can transfer some or all of its energy to the electron, knocking it out of orbit. This leaves the atom with more positive charges than negative charges, resulting in a positively charged atom. The electron is now free and travels away from the atom. This process of knocking an electron out of orbit is called ionization. In other words, ionizing radiation is radiation which is energetic enough to break atoms apart.

Sources of Radiation

There are two sources of ionizing radiation: radioactive atoms and man-made devices. We have already mentioned what atoms are: they have a nucleus made up of protons and neutrons, and have electrons orbiting around the nucleus. Most atoms in nature have a stable nucleus, in other words, a nucleus which will stay intact forever.

Some atoms, though, have an unstable nucleus, one that will emit radiation, or energy, to try to become stable. Examples of naturally occurring radioactive atoms include uranium, radium, and radon. We can also create radioactive atoms for medical purposes such as Iodine-131 and Technetium-99m.

When a radioactive atom emits energy, it either becomes stable, or changes into another element that may also be radioactive.

We can also build machines which produce ionizing radiation without the use of radioactive atoms. In this case, we are talking about X-ray units, which include CT scanners.

Types of Ionizing Radiation

There are several types of ionizing radiation. Alpha particles, beta particles, and gamma-rays are all emitted from the nuclei of radioactive atoms.
Neutrons are liberated during the fission, or breaking, of large atoms like uranium, and X-rays are created by man-made devices.

All of these types of radiation have enough energy to knock electrons out of their orbit around the nucleus of the atom.

Let's take a closer look at these different forms of radiation.

Alpha radiation is a large particle made up of two protons and two neutrons. This means that it has a positive two charge. Because negative electrons are attracted to the two positive protons, alpha particles interact a lot with the matter around them, specifically with the electrons orbiting nearby atoms. During each one of these interactions, the alpha particle gives up some of its energy, ionizing the matter around it. Alpha particles, therefore, do not travel far, because they lose their kinetic energy quickly through the large amount of ionization they cause. A sheet of paper, or even the dead layer of skin on our body, have enough electrons in them to quickly absorb all of the alpha energy, effectively stopping alpha radiation from traveling any farther.

Beta particles are about 8000 times less massive than alpha particles and have an identical mass to electrons orbiting the nucleus. They also originate from the nucleus of a radioactive atom and can either have a positive charge or a negative one. Because they only possess half of the charge that alpha particles have, they will interact less than alpha particles with the matter around them.

Still, because they possess charge, they do interact with nearby electrons, ionizing matter and losing energy with every interaction.

Although beta radiation travels farther than alpha, it still doesn't travel very far. It can penetrate our dead layer of skin and deposit energy in our "live" skin, but generally can't penetrate further into the body. A shield made of plastic, glass, or aluminum contains enough electrons to absorb all beta radiation energy and stop it from traveling farther.

X-rays and gamma rays are examples of electromagnetic radiation, just like radiowaves, microwaves, infrared, visible, and UV light. They are all what we call photons or bundles of energy which travel through space at the speed of light. They are pure energy and do not have charge or mass.

The difference between these types of electromagnetic radiation is their energy (or their wavelength or frequency). X-rays and gamma rays are much more energetic than other types of electromagnetic radiation, and as we mentioned earlier, they have enough energy to break bonds in atoms, contrary to the other types of electromagnetic radiation, like visible light or microwaves.

The difference between X-rays and gamma rays is their origin—gamma rays are emitted from the nucleus of a radioactive atom, following alpha or beta radiation. X-rays are created when electrons hit a target.

How are X-rays Produced?

The first step in X-ray production is to accelerate electrons, by sending them through a voltage in an electrical circuit. The electrons gain a lot of energy, and then they are sent crashing into a target, typically a piece of tungsten.

As the electrons quickly stop, their energy of motion, or kinetic energy, is lost and has to be dissipated. If the electrons are energetic enough when they crash into the material, the kinetic energy will be released as X-rays, which are emitted in all directions.

Gamma Rays and X-Rays

Like alpha and beta radiation, gamma rays and X-rays are forms of ionizing radiation. However, because gamma-rays and X-rays don't have mass or charge, they don't interact as easily with matter. They need to crash directly into an electron to knock it out of orbit, as opposed to alpha and beta particles, which interact at a distance with orbiting electrons, due to the force of their charge.

Gamma-rays and X-rays can, therefore, theoretically travel forever in matter, until they directly interact with an electron. No amount of shielding will stop all gamma or X-ray radiation, but the more material that shields a photon beam, and the denser that shield is, the more the intensity of the beam will be reduced, as more and more of the gamma rays or X-rays do directly crash into electrons.

Radiation Penetration

To summarize, shielding alpha radiation is very easy.

A single piece of paper will stop all of the alpha particles.

Most beta particles will get past a piece of paper, but a thin sheet of aluminum or plastic contains enough electrons to stop all of that radiation.

X-rays and gamma rays penetrate materials a lot easier, because they have no charge or mass. They might lose a bit of energy in aluminum, but thicker, denser materials, like lead, are needed to appreciably decrease the beam's intensity.

Activity

The activity of a radioactive substance is the rate of radioactive decay, in other words, the number of radioactive decays which occur per second.

The unit of activity that is used is the SI system. The system of units used in Canada is the becquerel, named after the person who discovered radioactivity, Henri Becquerel. A becquerel is simply one radioactive decay per second.

The old unit, still used in the United States, is the curie. 1 curie is equal to 37 billion becquerels.

Half-Life

Another important property of a radioactive material is the half-life. The half-life is an indication of how long a substance remains radioactive. Specifically, it is the time required for half of the radioactive atoms in a material to have decayed or emitted radiation. After one half-life, the activity will have decreased by 50%. After two half-lives, it will be down to half of a half of the original activity, or 25%. This will continue until the material is basically no longer radioactive.

The half-life is a quantity which is unalterable for a specific element, but all of the different radioactive substances have a unique half-life, which can range from fractions of a second to billions of years.

For example, the most common type of uranium has a half-life of 4.5 billion years, regardless of whether it is attached to other atoms, or whether it is a solid, liquid, or gas. You can heat up, cool down, and change the pressure of your uranium sample, and it will still have the exact same rate of decay and half-life. On the other hand, Technitium-99m, commonly used in hospitals, has a half-life of only 6 hours.

Radiation Dose

When we discuss radiation dose, we are looking to measure the amount of energy that is transferred from radiation to your body. Remember that when radiation interacts with electrons, it gives up all or some of its energy to the electrons and knocks them from their orbits. This is the transfer of energy that we are talking about when discussing radiation dose.

It's important to note that this transfer of energy is done immediately, as the radiation reaches the tissue. Just like a physical punch, the energy is transferred only when there is contact between the more energetic object (the radiation, or the fist) and the tissue. Once the radiation is gone, there is no more transfer of energy.

One measure of radiation dose is to simply measure the amount of energy transferred per unit mass of tissue. This is called Absorbed Dose, and is measured in gray, where 1 gray = 1 joule per kilogram. One gray is a very large dose, so often we refer to milli-gray (1/1000th of a gray), or even micro-gray (1/1 millionth of a gray) when we measure radiation dose.

Equivalent Dose

Different types of radiation produce different amounts of biological damage, however, for the same absorbed dose.

We therefore needed a different unit to take this into account. The equivalent dose is the absorbed dose, in Gray, multiplied by a radiation weighting factor, which indicates how biologically damaging that type of radiation is.

The unit of equivalent dose is the sievert, or more commonly the millisievert, equal to one one-millionth of a sievert.

Absorbed Dose

Gamma, X-ray, and beta radiation all produce about the same amount of biological damage as they interact with tissues. Their radiation weighting factor is therefore set to 1. One unit of absorbed dose of internal alpha radiation, on the other hand, produces approximately 20 times more damage than the same amount of absorbed dose from gamma, x-ray, and beta radiation. In other words, 1 mGy of internal alpha radiation is as damaging as 20 mGy of gamma, beta, or X-ray radiation. The radiation weighting factor for alpha radiation is therefore 20.

Equivalent dose takes the biological damage into consideration, making 1 mSv of one type of radiation equivalent to 1 mSv of any of the other types of radiation.

Interaction with the Body

Radiation interacts with atoms in the human body in the same way as with any other atom—by transferring its energy and ionizing the atom.

When radiation strikes living tissue, there are a number of possible outcomes. For one thing, there can be no effect at all. The radiation can, for example, ionize an atom which serves no crucial purpose in the body. Because we are made of more than a trillion trillion atoms, these types of events are very common.
On the other hand, radiation can also interact with more important atoms in our body, damaging certain cells. Our body has several layers of defence against this type of event. Primarily, the cells in our bodies have enzymes and proteins whose purpose it is to locate damage and repair it. Cell damage is

therefore often not problematic at all. Our cells' secondary defence mechanism is to kill itself if it does not have the capacity to repair. We have trillions and trillions of cells in our body, so if a few die because of radiation, it is not a problem. Cells are dying naturally in our body continuously. This only becomes problematic when you are exposed to a very large amount of radiation over a short period of time, at which point a large number of cells will die at once, potentially leading to serious consequences such as illness, or, in very extreme cases, death.

Finally, there could be damage within the cell, specifically to the chromosomes, which hold genetic information—the instructions for the cell to function correctly. It is possible for the damage to the chromosome to be improperly repaired. This low probability event is called a mutation, which has in turn a certain chance of leading to cancer, several years in the future.

Potential Risks

The production of a radiation-induced mutation in a cell which leads to cancer is a probabilistic event. Radiation exposure increases the likelihood of developing cancer: the more you are exposed, the greater your chance of getting cancer.

But for any one individual, there is no way of saying if cancer will occur or not, no matter how much radiation to which that person is exposed. Probabilistic events are meaningless on an individual basis, but rather apply to a large number of people.

A good example of this *type* of event is how smoking leads to lung cancer. We know smoking increases the risk of developing lung cancer, but for a single individual, that doesn't mean much. You could smoke 10 packs per day your whole life and never get lung cancer. However, if we take a group of one million smokers and compare it to a group of one million non-smokers, there will be significantly more cases of lung cancer in the smoking group. Smoking increases your likelihood of getting cancer, but you can never say for sure that an individual will get cancer from smoking. It is the same principle with radiation exposure and cancer.

Cancer Risk from Radiation

Let's look at what the increased risk of cancer from radiation exposure is. The International Commission on Radiological Protection, an independent body which reviews all scientific literature on radiation and publishes standards and guidelines, estimates that the risk of developing a fatal cancer increases by 4% for every 1000 mSv of radiation exposure.

These numbers are actually the ones used to set limits on the amount of occupational radiation exposure a worker can receive yearly.

If we take 1000 people, the Canadian Cancer Society tells us that 25% of them, or 250 of them, will develop a fatal cancer in their lifetime. Now if this group of 1000 people get exposed to 20 mSv per year for 50 years, for a total working lifetime dose of 1000 mSv, then we would expect the number of people who develop fatal cancers to increase from 250 to 290.

Taking the previous numbers into consideration, along with what might be considered an acceptable risk, limits are set for the amount of occupational exposure a worker is allowed to receive each year. People who work with radiation on a regular basis are called Nuclear Energy Workers, and can receive up to 50 mSv in one year, but no more than 100 mSv in 5 years.

In other words, they should not receive more than 20 mSv/year, on average. This means a person's maximum lifetime occupational dose over a 50-year career would be 1000 mSv.

There are different limits for pregnant nuclear energy workers, who can receive far less radiation during their pregnancy, and people that are not designated as nuclear energy workers are only allowed to receive 1 mSv of radiation per year—a very strict limit.

Chronic Exposure

The types of effects we just discussed mostly come from chronic exposure to radiation, in other words, receiving small amounts of radiation over months or years. The main concern with these types of exposures is cancer.

Acute Exposure

Acute exposures, on the other hand, are exposures to high amounts of radiation within a short period of time. Though they are extremely uncommon, they can still occur in the event of an accident or if radiation safety procedures are not followed. The more immediate effects from acute exposure are deterministic, which again means that they will certainly happen above a radiation dose. Along with deterministic effect, acute exposures also increase a person's risk of developing cancer.

The severity of the effect will be determined by the amount of dose received and the area of the body exposed, but will typically involve nausea, diarrhea, malaise, and can lead to death at high radiation doses.

Acute Dose Effects

As indicated, deterministic effects are not generally observed below an acute dose of 250 mGy. Changes in the blood counts will be noticeable at a dose of 250 mGy. Higher doses will lead to more severe effects, which can include nausea, malaise, diarrhea, and more.

At a dose of about 3000 mGy, or 3 Gy, half of the people will die if left untreated, and higher doses still will increase the odds of death and the speed at which the effects occur.

Doses to specific organs will also lead to acute effects. Damage to the skin and hair loss can occur at 3-5 Gy. Acute doses of 3.5-5 Gy specifically to the reproductive regions can result in sterility.

Remember that a nuclear energy worker is only allowed to receive on average 20 mSv/year, so we are talking about very large doses here!

Radiation Exposure

An important thing to realize is that every one is exposed to radiation constantly. We live in a radioactive world! We are exposed to radiation from the Sun and from radioactive particles in soil, foods, and air. We call these sources of radiation the natural background radiation. This background radiation exposure gives Canadians approximately 2-4 mSv of radiation dose per year. Cosmic radiation, terrestrial radiation, and the radiation exposure we get from foods is unavoidable.

Radiation Exposure

Radon gas, a naturally occurring decay product of uranium, which is found naturally in the soil everywhere, is present in every home. More than half of the total radiation exposure you receive annually from background sources will likely be from radon. It is estimated that every year around 1,600 Canadians will die from lung cancer as a result of exposure to radon in the home. Homes can be tested for radon and simple steps can minimize your exposure to it.

If we compare this exposure to the maximum amount of occupational exposure a non-Nuclear energy worker is allowed in a year, 1 mSv, we can see how strict the national limit is.

The Canadian Nuclear Safety Commision (CNSC)

The Canadian Nuclear Safety Commission (CNSC) is the regulating body in Canada responsible for protecting the health, safety, and security of Canadians, as well as protecting the environment in relation to radioactive sources. They oversee the mining, processing, manufacturing, use, storage, transport and disposal of nuclear materials and radiation devices.

Under the current regulations, radiation devices containing nuclear sources must be certified by the CNSC, in order to be sold and possessed. Unless the device contains an extremely small quantity of nuclear material, the owner must have a licence from the CNSC.

The CNSC also regulates very-high-energy X-ray units, such as linear accelerators, which are used to produce radioactive materials and treat cancers. All lower-energy X-ray units, for example, most medical X-ray units, CT scanners, baggage X-ray units, and units used in manufacturing and industry are regulated provincially.

You can visit our website to find information on all provincial regulations.

Resources

We hope you have enjoyed this introduction to radiation.

Founded in 1980, the Radiation Safety Institute of Canada is an independent, not-for-profit organization offering a variety of information, consultation, and laboratory services focused on radiation safety.

If you have any further questions about ionizing or non-ionizing radiation, please feel free to contact us toll free at 1-800-263-5803 or by email at info@radiationsafety.ca. Visit us on the web at www.radiationsafety.ca or find us on Facebook and LinkedIn.

Summary

You have now completed the Understanding Radiation course.

In this course, you learned:

- What radiation is
- How types of radiation differ

- How to quantify radiation
- How radiation affects the body
- How to determine radiation limits
- What are common radiation exposures
- What are the Canadian regulatory bodies

We hope that you now have a better understanding of the types of radiation, how they affect people in work and every day life, and know more about the organizations in Canada that work to regulate and educate about radiation safety.