Radiological Basics

INTRODUCTION

The reliance upon, and use of, radioactive material in agriculture, industry, and medicine continues to increase. As the manufacture, use, and disposal of radioactive material has increased, so has the need to transport it. Consequently, the potential for you as a responder to encounter an incident involving some type of radioactive material has increased. Having knowledge of radiological hazards, and the terminology used to describe them, will increase your ability to quickly recognize, safely respond, and accurately relay information during an incident involving radioactive material.

PURPOSE

Upon completion of this module, you will have a better understanding of the basic structure of an atom and the fundamentals of radiation.

MODULE OBJECTIVES

Upon completion of this module, you will be able to:

1. Identify the basic components of an atom.
2. Identify the four basic types of ionizing radiation.
3. Define ionizing radiation, radioactivity, radioactive material, and radioactive contamination.
4. Distinguish between radiation exposure and radioactive contamination.

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HISTORICAL BACKGROUND

Radiation is all around us and has been present since the birth of this planet. Today, both man-made and natural radioactive material are part of our daily lives. We use radioactive material for beneficial purposes, such as generating electricity and diagnosing and treating medical conditions. Radiation is used in many ways to improve our health and the quality of our lives.

In 1895, while working in his laboratory, Wilhelm Roentgen discovered a previously unknown phenomenon: rays that could penetrate solid objects. Roentgen called these rays "X-rays." The figure below shows Roentgen's wife's left hand—the first known X-ray. The practical uses of X-rays were quickly recognized and, within a few months, a medical X-ray picture was used to locate shotgun pellets in a man's hand.

Dr. Roentgen

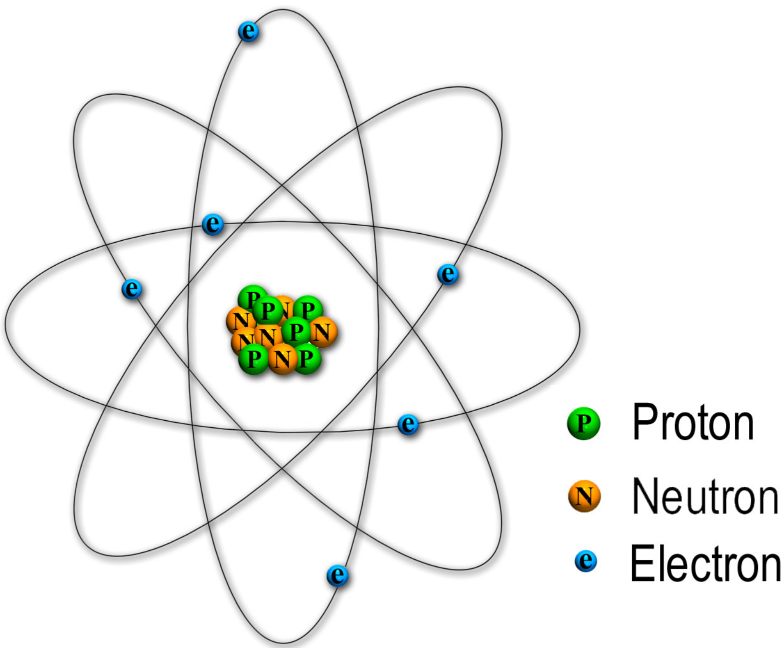
In 1896, Henri Becquerel reported observing a similar radiological phenomenon caused by uranium ore. Later that year, Pierre and Marie Curie identified the source of the radiation as a small concentration of radium, a radioactive material, in the ore.

These discoveries set the stage for using radiation in medicine, industry, and research. Since that time, scientists have developed a detailed understanding of the hazards and benefits of radiation. In fact, scientists understand radiological hazards better than hazards associated with most other physical and chemical agents.

BASIC RADIOLOGICAL CONCEPTS

Atomic Structure

All matter is made up of atoms. Atoms are invisible to the naked eye. The three basic components of the atom are protons, neutrons, and electrons. The central portion of the atom is the nucleus. The nucleus contains protons and neutrons, which are very close to each other. Electrons orbit the nucleus.



Protons

- Are located in the atom's nucleus
- Have a positive electrical charge
- Determine the element's identity

Neutrons

- Are located in the atom's nucleus
- Have a neutral electrical charge
- Determine the nuclear properties of the atom

Electrons

- Orbit the nucleus
- Have a negative electrical charge
- Determine the chemical properties of an atom

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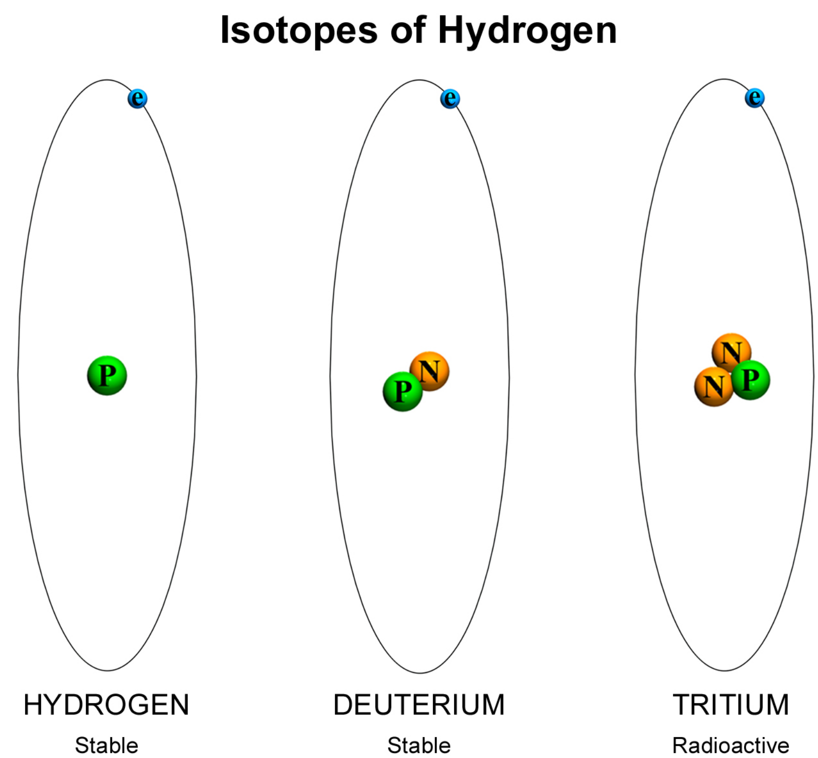
Atoms of a particular element will have the same number of protons but may have a different number of neutrons. These variants are called isotopes. Isotopes of the same element have the same chemical properties, regardless of the number of neutrons. The nuclear properties of isotopes, however, can be quite different. For example, the illustration below shows three isotopes of hydrogen. All three isotopes have the same chemical properties; however, tritium is a radioactive isotope or radioisotope.



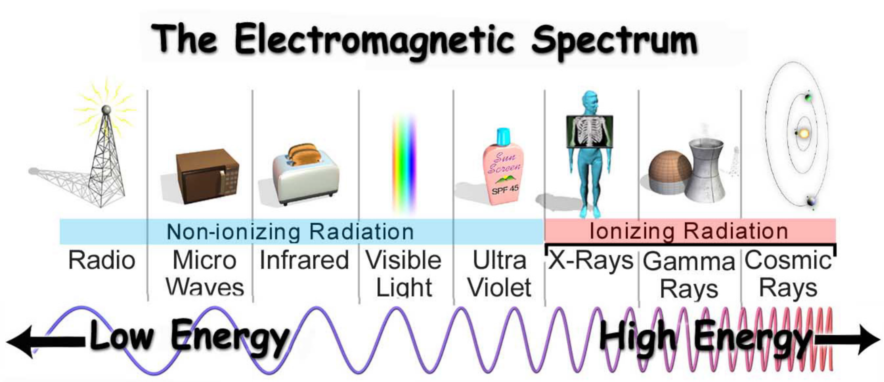
Stable and Unstable Atoms

Only certain combinations of neutrons and protons result in stable atoms.

- If there are too many or too few neutrons for a given number of protons, the resulting nucleus will have too much energy. This atom will not be stable.
- An unstable atom will try to become stable by giving off excess energy in the form of radiation (particles or waves). Unstable atoms are also known as radioactive atoms.

IONIZING RADIATION

As an emergency responder, you may already be familiar with some radiation terminology and with some radiological concepts. When most people think of radiation, they think of the type we are talking about in this course—the type that comes from atoms. There are, however, many different kinds of radiation. Visible light, heat, radio waves, and microwaves are all examples of radiation that, as a group, are referred to as electromagnetic radiation. The graphic below shows the electromagnetic spectrum. As the graphic illustrates, radiation such as radio waves and microwaves are much lower in energy than X-rays or cosmic rays. These lower energy radiations are referred to as non-ionizing radiation. Higher energy radiation like X-rays or cosmic rays are referred to as ionizing radiation.



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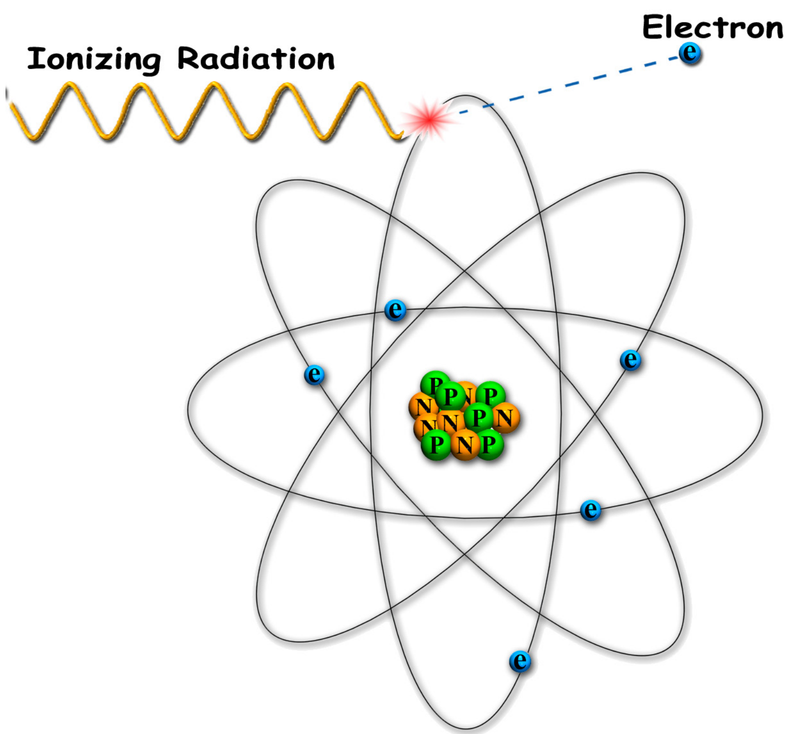
Ionizing radiation has enough energy to remove electrons from atoms. The process of removing electrons from atoms is called ionization. Ionizing radiation's ability to remove electrons from atoms is what makes it potentially hazardous. In this course, when we speak of radiation, we are talking about ionizing radiation. The ionization process is illustrated in the graphic below:



THE FOUR BASIC TYPES OF IONIZING RADIATION

Most of the commonly transported radioactive material emit one or more forms of ionizing radiation. The four basic types of ionizing radiation are alpha radiation, beta radiation, gamma/X-ray radiation, and neutron radiation. All four types differ in their penetrating power and the manner in which they affect human tissue. To give you a general understanding of each type, they are discussed here.

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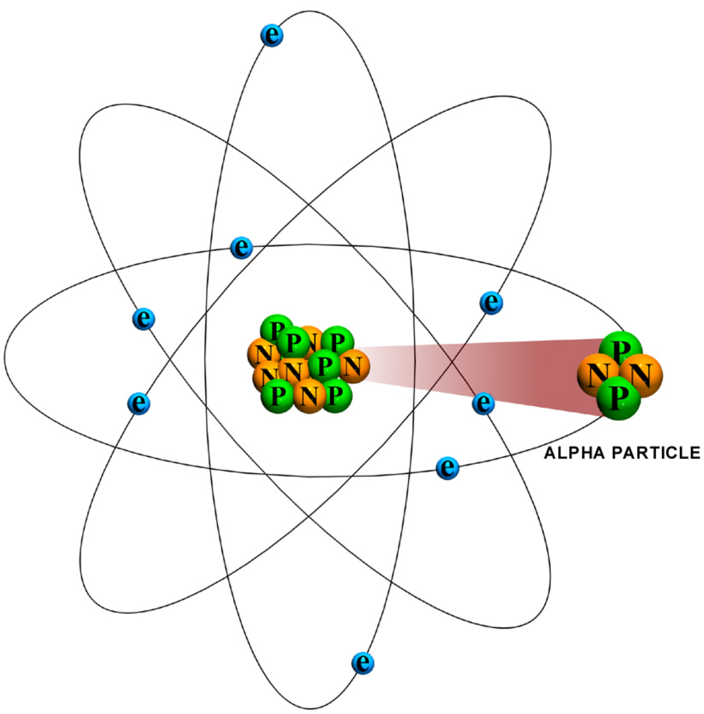
Alpha

Alpha radiation consists of high-energy particles that are relatively large, heavy, and only travel a short distance. Because they are so large and heavy, alpha particles lose their energy very rapidly, have a low penetrating ability, and short range of travel—only a few inches in air. Because of the alpha particle's short range and limited penetrating ability, external shielding is not required. A few inches of air, a sheet of paper, or the dead (outer) layer of skin that surrounds our bodies easily stops alpha particles. Alpha radiation poses minimal biological hazard outside the body. The greatest hazard from alpha-emitting material occurs when the material is inhaled or ingested. Once inside the body, the alpha radiation can cause harm to individual cells or organs.



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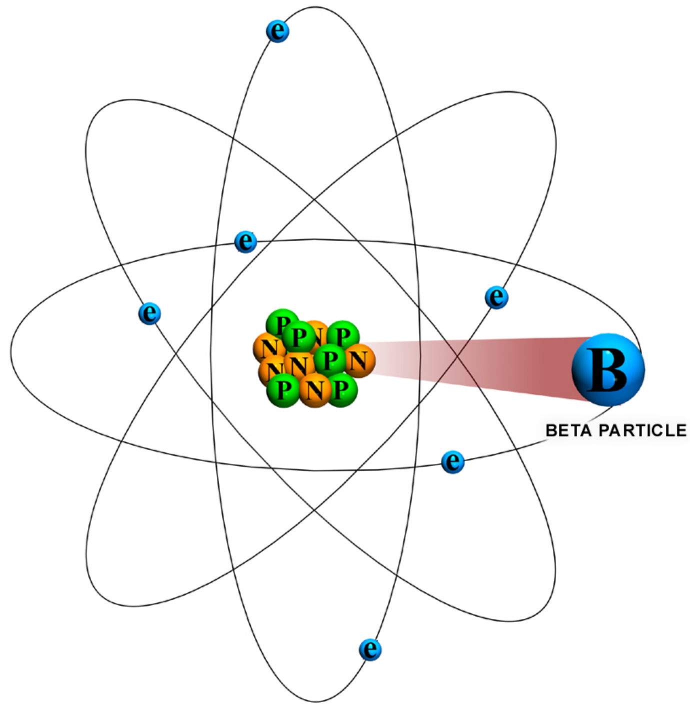

Beta

Beta radiation consists of particles that are smaller, lighter, and travel farther than alpha radiation. Because they are smaller and lighter, beta radiation is more penetrating than alpha radiation. The range of penetration in human tissue is less than ¼ inch. In air, beta radiation can travel several feet. Beta radiation may be blocked or shielded by plastic (SCBA face shield), aluminum, thick cardboard, several layers of clothing (bunker gear) or the walls of a building.

Outside the body, beta radiation constitutes only a slight hazard. Because beta radiation penetrates only a fraction of an inch into living skin tissue, it does not reach the major organs of the body. However, exposure to high levels of beta radiation can cause damage to the skin and eyes. Internally, beta radiation is less hazardous than alpha radiation because beta particles travel farther than alpha particles and, as a result, the energy deposited by the beta radiation is spread out over a larger area. This causes less harm to individual cells or organs.

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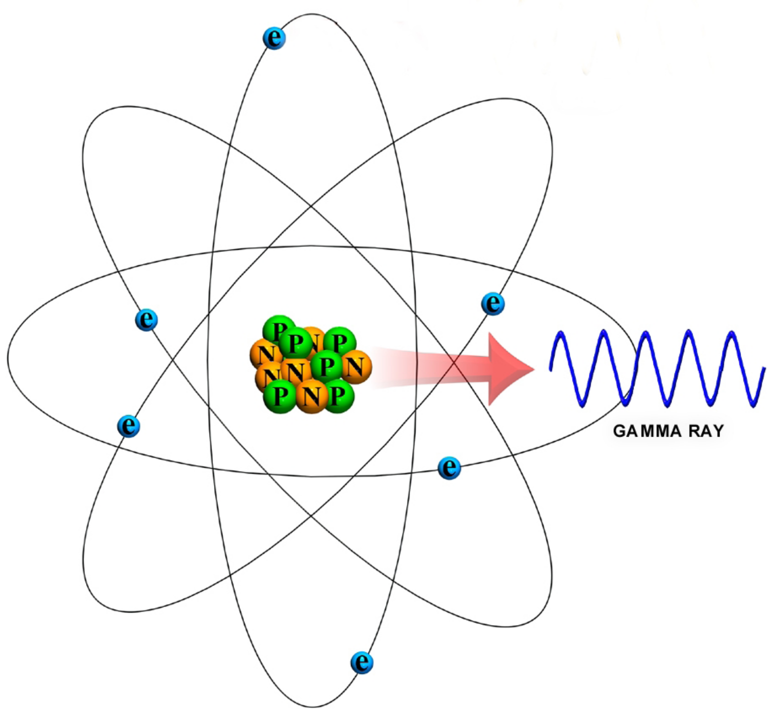
Gamma

Gamma radiation, like X-rays, is electromagnetic radiation. This means that it does not consist of particles like alpha and beta radiation but, rather, waves of energy that have no mass and no electrical charge. Because they have no mass and no electrical charge, they are able to travel great distances and require dense material as shielding. Gamma radiation poses a hazard to the entire body because it can easily penetrate human tissue. Lead, steel, and concrete are commonly used to shield gamma radiation.

The difference between gamma radiation and X-rays is that gamma radiation is emitted from the nucleus of the atom; X-rays are emitted when electrons surrounding the nucleus change energy levels as they move between orbital shells.



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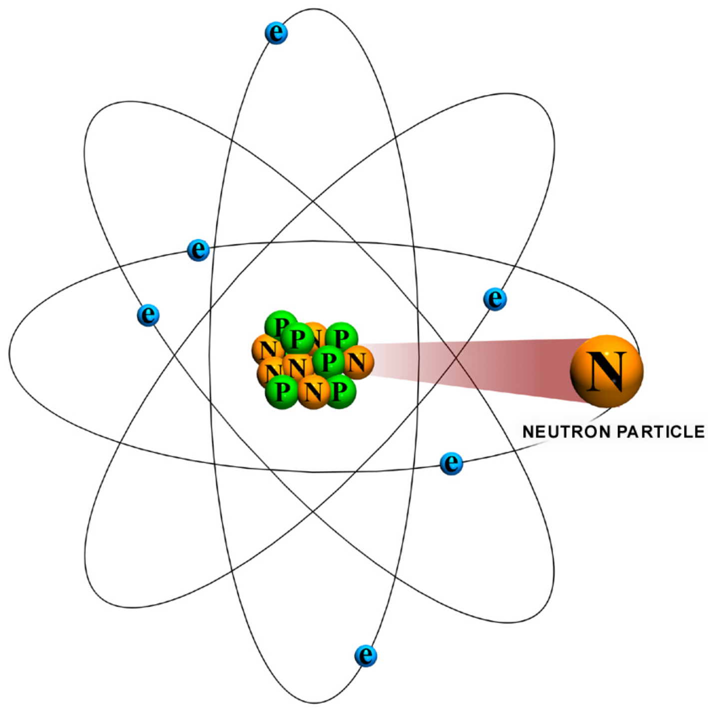
Neutron

Neutron radiation consists of neutron particles that are ejected from an atom's nucleus. Neutron radiation can travel great distances and is highly penetrating like gamma radiation. It is best shielded with high hydrogen content material (e.g., water, plastic). In transportation situations, neutron radiation is not commonly encountered.



Radioactive Material and Radioactivity

Radioactive material is any material that spontaneously emits ionizing radiation. The process of an unstable atom emitting radiation is called radioactivity. Radioactive atoms can be generated through nuclear processes but they also exist naturally in material such as uranium ore, thorium rock, and some forms of potassium. When a radioactive atom goes through the process of radioactivity, also called radioactive decay, it will change to another type of atom. In fact, a radioactive atom may change from one element to another element during the decay process. For example, the element uranium will eventually change through radioactive decay to lead. This stabilizing process may take from a fraction of a second to billions of years, depending on the isotope.

The rate of radioactive decay is unique to each type of radioactive atom and is measured in half-lives, the time it takes for half of the radioactive atoms in a sample to decay to another form. Different radioactive material have different half-lives. For example, some radioactive pharmaceutical products (called radiopharmaceuticals) have half-lives that range from a few hours to a few days. It is important to note that radioactivity, regardless of the material, is constantly decreasing. After seven half-lives, the material will be at <1% of its original activity. The table below lists some common radioisotopes and their approximate half-life.

Radioisotope	Half-life
Nitrogen-16	7 seconds
Technetium-99m	6 hours
Thallium-201	73 hours
Cobalt-60	5 years
Cesium-137	30 years
Americium-241	432 years
Uranium-238	4.5 billion years

Radioactive Contamination

Any material that spontaneously emits ionizing radiation is a radioactive material. If radioactive material is in a place where we don't want it (e.g., deposited on the surfaces of or inside structures, areas, objects, or people) it is called radioactive contamination. The photo below illustrates contamination by showing a radiopharmaceutical package broken open with the contents spilled on the ground.

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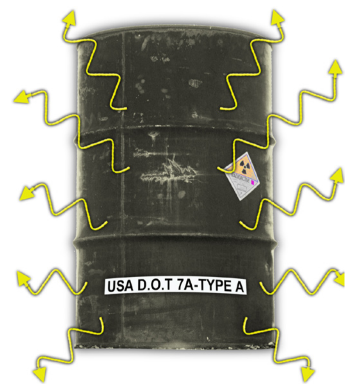
When radioactive material is properly used and controlled, there are many beneficial applications. Most smoke detectors, for instance, use radioactive material, as do certain medical diagnostic tools and treatment procedures. It is only when radioactive material is where it is not wanted (e.g., on the ground, in water, or on you) that we refer to it as contamination.

RADIATION VERSUS CONTAMINATION

One of the most important concepts for the responder to understand is the difference between radiation and contamination. Radiation is energy emitted by radioactive material (as illustrated by arrows). Contamination is radioactive material in a location where it is not wanted.



A person can be exposed to radiation and not become contaminated. On the other hand, radioactive contamination emits radiation. If a person is contaminated with radioactive material, the person continues to be exposed to radiation until the contamination is removed.

Put another way, radiation exposure is like being in front of a heat lamp. When the lamp is on, you can feel the heat. When you turn the lamp off, the heat is no longer felt. The heat is similar to exposure. The source of the energy is not in or on you and the exposure stops when you turn off the lamp. Contamination of a person happens when the source of radiation (radioactive material) gets on or in the person. You can be exposed to radiation and not be contaminated. However, if you become contaminated, you will continue to be exposed to radiation until the contamination is removed.

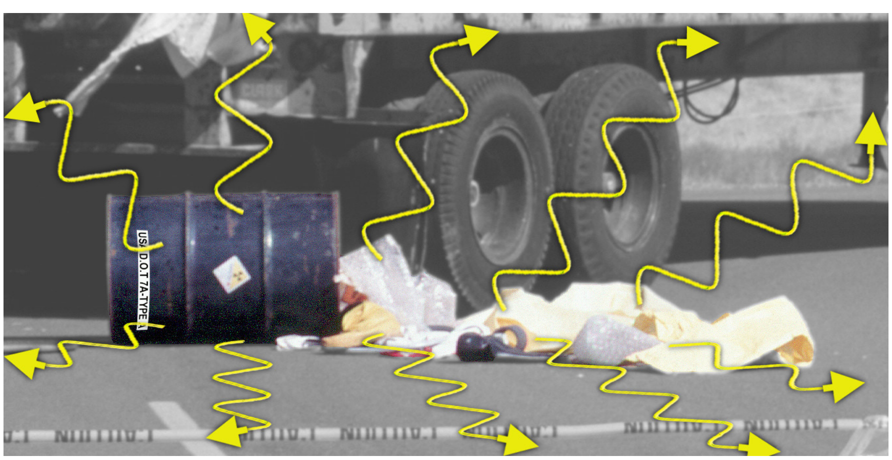
Exposure to Radioactive Material

If you encounter radioactive material at an incident scene, you may be exposed to radiation. Even with the tightest package and the best protection, low levels of radiation can pass through the package. This radiation is at a level that is (based on numerous scientific studies by a variety of industry, scientific, and government organizations) considered safe for people working near the packages. If the packages are intact, you should not expect unsafe exposure.

You should remember that we are exposed to radiation every day from common sources such as cosmic rays, X-rays, and even the bricks used to make buildings. Being exposed to radiation at these controlled levels is a very low hazard and should not prevent you from taking normal emergency actions. Exposure to radiation alone will not contaminate you.

Radioactive Contamination Types

A more serious concern is the possibility of radioactive contamination. The probability of radioactive material being released during an incident is extremely low. If radioactive material is released (as illustrated in the photo below), it is possible for responders, victims, and onlookers to become contaminated. This is especially true where the material is in the form of a liquid or powder.



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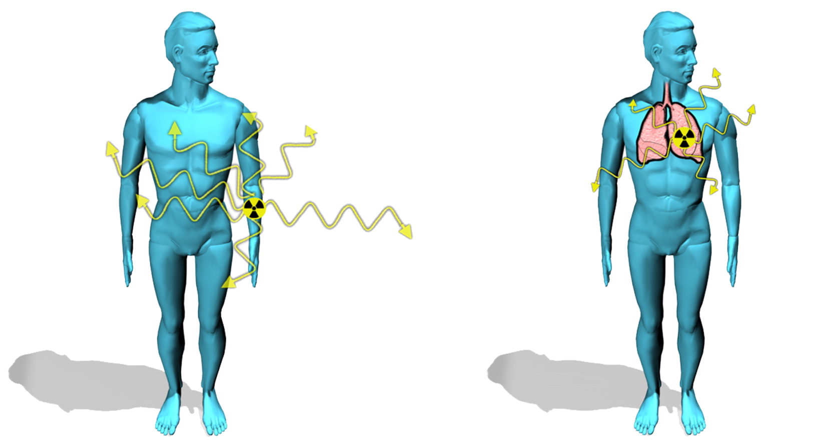
There are two basic types of radioactive contamination: external or internal. Radioactive contamination is serious because as long as the material is on you, your clothing, or inside your body, you are still being exposed. While a short exposure to these materials may be safe, prolonged or very close exposure may not be.



External Contamination   Internal Contamination

A special concern is the possibility of internal contamination. This happens when a radioactive material—usually a liquid, powder, or gas—is accidentally ingested, inhaled, or otherwise gets inside the body. Once inside the body, it can be difficult to remove.

Radioactive material that might not be very dangerous outside the body may be dangerous if allowed to enter the body. For this reason, throughout this training, we will emphasize the use of personal protective equipment (PPE) and the importance of not eating, drinking, smoking, or chewing while on the scene of a radioactive material incident.

Another concern is that people who are contaminated externally may contaminate others, either directly or by secondary contamination. Secondary contamination occurs when a contaminated person or object touches something, that is then touched by another, who then becomes contaminated.

Radiological Basics

The following example describes how contamination is often spread. Imagine chalk on a blackboard as being radioactive material. If the chalk dust is transferred to your hands, you are considered contaminated. From your hand, the chalk dust can then be transferred to your shirt. The transfer of contamination from your hands to your shirt is an example of secondary or cross contamination.

RADIOLOGICAL UNITS

In 1975, the 15th General Conference of Weights and Measures adopted new names for certain basic units in radiation protection technology. These new units are consistent with the metric system or with the International System of Units (SI system) developed by the International Committee for Weights and Measures. The traditional radiological units of measure are still widely used in the United States. Both the traditional and SI units will be discussed here.

Measuring Radiation

Radiation exposure is measured in the traditional units of roentgen (R), rad (radiation absorbed dose), and rem (roentgen equivalent man). For our purposes, these units are all equal. Because one roentgen, rad, or rem of radiation is a fairly large amount of radiation, the prefix milli is often used. Milli means one one-thousandth (1/1,000). In other words, there are 1,000 milliroentgens (mR) in one roentgen, or 1,000 millirem (mrem) in one rem. Radiation doses to the human body are typically measured in units of mrem or rem. A typical radiation dose from a medical chest X-ray is about 4 mrem.

The SI unit for radiation absorbed dose is the gray which is equal to 100 rad. The SI unit for radiation dose equivalence is the sievert which is equal to 100 rem.

	Exposure	Absorbed Dose	Dose Equivalent
Common Units	roentgen (R)	rad	rem
SI Units	coulomb/kilogram (C/kg)	gray (Gy)	sievert (Sv)

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According to the National Council on Radiation Protection (NCRP), the average person is exposed to a dose of approximately 620 mrem per year from both man-made and natural sources (NCRP Report No. 160, 2009).

Your annual radiation dose also depends upon where and how you live, and what you eat, drink, and breathe. If you are interested in calculating your annual dose, there are several websites that have on-line radiation dose calculators. A few of these sites are listed below:

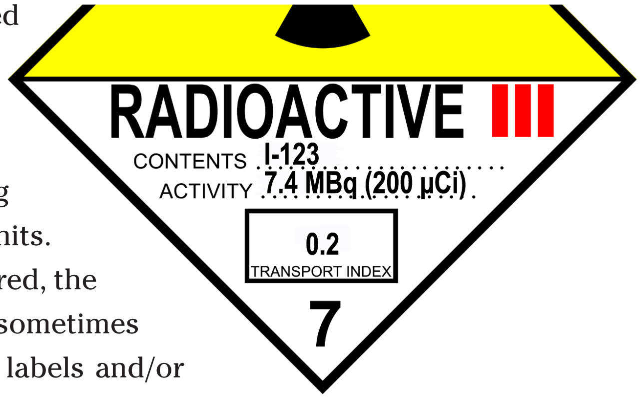
https://www.epa.gov/radiation/calculate-your-radiation-dose
https://ans.org/pi/resources/dosechart/
https://www.nrc.gov/about-nrc/radiation/around-us/calculator.html

Measuring Radioactivity

Radioactivity is measured in the number of nuclear transformations or disintegrations that occur in a sample during a specific time. This is known as the activity of the sample. The SI unit for activity is the becquerel (Bq), which equals 1 disintegration per second (dps). The conventional unit of activity is the curie (Ci), which is 3.7×10^{10} or 37 billion (37,000,000,000) disintegrations per second. Both the curie and becquerel measure the same thing—activity.

One curie is considered to be a large amount of activity, whereas one becquerel is a very small amount of activity. To account for this, prefixes are often used to change the size of the unit. Many of the commonly used prefixes are shown in the table below.

Symbol	Prefix	Prefix Value	Example
p	pico	1 trillionth, or 10^{-12}	pCi = 1 trillionth of a curie
n	nano	1 billionth, or 10^{-9}	nCi = 1 billionth of a curie
μ	micro	1 millionth,or 10^{-6}	μCi = 1 millionth of a curie
m	milli	1 thousandth, or 10^{-3}	mCi = 1 thousandth of a curie
k	kilo	1 thousand, or 10^{3}	kBq = 1 thousand becquerel
M	mega	1 million, or 10^{6}	MBq = 1 million becquerel
G	giga	1 billion, or 10^{9}	GBq = 1 billion becquerel
T	tera	1 trillion, or 10^{12}	TBq = 1 trillion becquerel
P	peta	1 quadrillion, or 10^{15}	PBq = 1 quadrillion becquerel



Activity is required (by federal law) to be listed on radiation-warning labels and shipping papers in the SI units. Although not required, the activity in curies is sometimes shown on warning labels and/or shipping papers in parentheses after the activity in becquerels. For example, in the illustration above, the activity listed on the label of 7.4 MBq is equal to 200 µCi. The "M" and "µ" shown before the Becquerel and Curie abbreviations are prefixes.

Activity may also be expressed as a measure of its concentration or specific activity. Common terms for measuring specific activity are Ci/g (curies per gram) and Bq/kg (becquerels per kilogram). It is important to note that there is no direct relationship between activity and the physical quantity of material present. Very high activity material can come in very small packages. For example, one gram of cobalt-60 (commonly used in radiation therapy) has an activity of about 42 TBq or 42 trillion disintegrations per second. On the other hand, one gram of thorium-232 (the radioactive material found in some lantern mantles) has an activity of about 4 kBq or 4,000 disintegrations per second. You would need to have well over 10 billion grams (23,000,000 pounds) of thorium-232 to equal the radioactivity in one gram of cobalt-60.

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Check Your Understanding

1. Atoms are made up of _______, ________, and _________.

2. The four basic types of ionizing radiation are ______, _____, _______and ________.

3. Radioactive material is any material that spontaneously emits ________ __________.

4. The process of an unstable atom emitting radiation is called _____________.

5. Radioactive material in an unwanted location is called ____________.

6. _________ can pass through the body; ____________ can be deposited in or on the surface of the body.

7. The SI unit for measuring radioactivity (activity) is the _________.

ANSWERS

1. protons
   neutrons
   electrons
2. alpha
   beta
   gamma
   neutron
3. ionizing
   radiation
4. radioactivity
5. contamination
6. Radiation
   contamination
7. becquerel