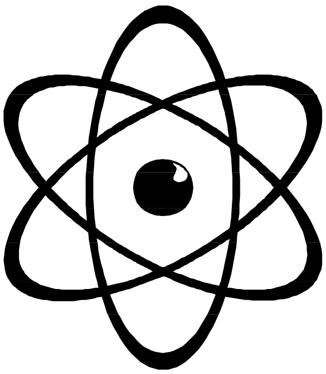
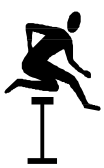
# UNIT TWO

# NUCLEAR PHYSICS FOR RADIOLOGICAL EMERGENCY RESPONSE



You have had the opportunity to study basic nuclear physics in at least two prerequisite courses, the *Fundamentals Course for Radiological Monitors* and the *Fundamentals Course for Radiological Response Teams.* For that reason, this unit will review concepts, with emphasis on application by the radiological emergency responder.

## *GATE FRAME QUESTION*



You have responded to an accident involving a truck containing radiopharmaceuticals. The Incident Commander tells you that a package found on the ground indicates that it contains 0.2 Ci or $7.4 \times 10^9$ Bq of Cs-137. He wants to know exactly what that means in terms of risk to responders. What will you tell him?

## *ANSWER*

*Your answer should include the adjacent information*

This package contains two-tenths of a curie, or 200 millicuries, of cesium (Cs). A curie is a unit of radioactivity. (Two-tenths of a curie is equal to 7,400,000,000 becquerels. A becquerel (Bq) is an international unit of radioactivity.)

Cesium has a half-life of 30 years, which means that the 0.2 Ci of Cs-137 will decay down to one-tenth of a curie in about 30 years.

Cs-137 is a cesium isotope that emits beta and gamma radiation. Beta radiation cannot travel very far in air and has little penetrating power. It can damage the outer layer of skin, but it is mainly an internal hazard. Gamma radiation can penetrate through the body, travels long distances in air, and is considered an external as well as an internal hazard.

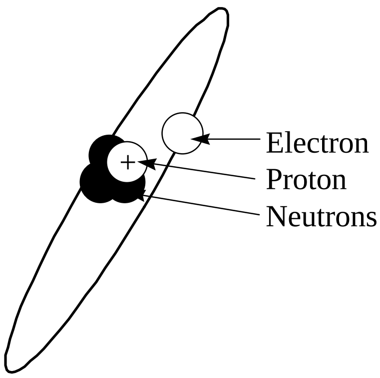
Practical steps that can be taken to reduce your internal risk to Cs-137 would include wearing anti-contamination clothing complete with face mask or respirator (if the responder is trained and respirator fitted.) Your exposure to the gamma emitter in Cs-137 can be reduced by relying on the exposure control methods of time, distance, and shielding. Time spent in the radiation field may be lessened by rotating the crew. Unless you have a designated function, stay out of the radiation field. Put as much shielding between you and the radiation source as possible. The denser the material the better the shielding. For example, a fire truck may provide better shielding than a concrete block wall.

*If your answer included all or most of the above points, you should be ready for the Summary Questions at the end of this unit.* *Turn to page 2-38.*

*If your answer did not include these points, it would be advisable for you to complete the programmed instruction for this unit.* *Turn to page 2-3.*

## ATOMIC STRUCTURE

Why should knowledge of atomic structure be vital to a radiological emergency responder? Because all radiation originates inside atoms and radiation may be harmful to living cells.




Atoms are basic building blocks of matter. In the center of the atom is the *nucleus*, which contains most of the "weight" of the atom. The nucleus is composed of *protons* that are large and positively charged and *neutrons* that are about the same weight as the protons and have no charge. The collective term for neutrons and protons is *nucleons* because they reside in the nucleus.

Orbiting around the nucleus are *electrons* that carry a negative charge and weigh about 1/2000 of a proton or neutron. The electrons in the outermost orbit determine the chemical properties of the atom. The area between the electrons of the atom is just empty space.

Although the proton is so much heavier than the electron, their opposite charges are equal. The attraction between these forces is what keeps the electrons in their orbits and keeps the atom electrically neutral.

*Let's check to see if you can visualize the structure of the minuscule atom. Answer the following question.*

## *QUESTION*

*Circle the correct answer.*

The structure of an atom is most similar to

a. the solar system.

b. children dancing around a maypole.

*Turn the page to check your answer.*

## *ANSWERS*

a. That's right. Electrons orbit around the nucleus in much the same way as the planets revolve around the sun. Both electrons and planets are held in their orbits by an attractive force—electrons by the attraction between opposite electrical charges and planets by the force of gravity.

*Proceed to page 2-6.*

b. No, the maypole does not work as well as an analogy. The children that dance around a maypole are attached to the pole or "nucleus" by streamers. Electrons are not connected to the nucleus by a physical bond but rather an attractive force. Another problem with this analogy is that the children may weigh as much or more than the pole, whereas electrons are much lighter than the nucleus of an atom.

*Try the next question.*

## *QUESTION*

*Circle the correct answer.*

The nucleus of an atom is composed of

a. protons and neutrons.

b. protons and electrons.

*Turn the page to check your answer.*

## *ANSWERS*

a. Correct. You understood that the nucleus is composed of the positively charged protons and neutrons, which carry no charge. Negatively charged electrons orbit around the nucleus.

*Proceed to the next section.*

b. Wrong answer. You have half the answer right. Protons do reside in the nucleus, along with neutrons. Electrons, on the other hand, orbit around the nucleus.

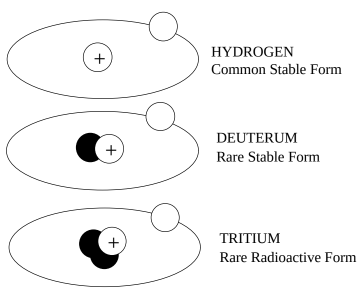
*Reread page 2-3 before moving to the next section.*

# ISOTOPES

Atoms that have an equal number of protons have the same number of electrons and therefore the same chemical properties. As a group they are called an *element* and have one or two letters assigned to them as a symbol. If you know that an atom has one proton in its nucleus, then you know it is an atom of the element hydrogen and that it has one electron orbiting around its nucleus. There are 92 naturally occurring elements, from hydrogen (H) with 1 proton to uranium (U) with 92. There are also artificially created elements, called transuranic elements, used in research and industry.

When atoms have the same number of protons but different numbers of neutrons, they are still the same element, but they are called *isotopes.* That is why elements are further identified with numbers as well as symbols.

Isotopes of the element Hydrogen




For example, $^{1}_{1}H$ identifies a form of hydrogen that has 1 proton in the nucleus. $^{2}_{1}H$ indicates deuterium, a hydrogen that has 1 proton and 1 neutron in the nucleus, because the upper number, called the mass number, always gives the number of protons *plus* the number of neutrons (as a group called nucleons), and the lower number, called the atomic number, indicates only the number of protons. $^{3}_{1}H$, tritium, is a hydrogen that has 1 proton and 2 neutrons.

These three forms of hydrogen are isotopes. Isotopes are important because many of them are radioactive and give off ionizing radiation. In the case of the hydrogen isotopes, $^{3}_{1}H$ is radioactive.

*It is important to be able to read the symbols associated with the radioisotopes you may be dealing with in an accident. Turn the page to practice.*

## *QUESTION*

*Circle the correct answer.*

What is the composition of ${}^{238}_{92}U$?

a. 238 protons, 146 electrons, and 92 neutrons. It is a nucleon of uranium.

b. 92 protons, 92 electrons, and 146 neutrons. It is an isotope of uranium.

*Turn the page to check your answer.*

## *ANSWERS*

a. You read the symbol incorrectly, so let's review using ${}^{238}_{92}U$ as an example. The 92 is the atomic number and tells the number of protons. Therefore, we know that uranium has 92 protons and an equal number of electrons. The mass number gives the sum of the number of protons plus neutrons; to find the number of neutrons, simply subtract the atomic number (92) from the mass number (238) to get 146.

Finally, *nucleon* is the incorrect term for this atom. U-238 has nucleons in its nucleus, but "nucleon" is not the correct term for the entire atom. U-238 is more correctly called an isotope of uranium because it is one of several forms of the element uranium.

*Try the next question.*

b. You are right on track. You know that the atomic number (92)indicates the number of protons in the nucleus, the mass number (238) indicates the total number of protons and neutrons, and that the number of electrons equals the number of protons. ${}^{238}_{92}U$ is one of many forms of uranium and therefore correctly described as an isotope.

*Proceed to the next section.*

## *QUESTION*

*Circle the correct answer.*

What is the atomic composition of ${}^{137}_{55}Cs$?

a. 55 protons, 55 electrons, 82 neutrons. It is an isotope of cesium.

b. 137 protons, 137 electrons, 82 neutrons. It is an isotope of uranium.

*Turn the page to check your answer.*

## *ANSWERS*

a. Correct! From the atomic symbols you interpreted that this isotope of cesium has 55 protons and an equal number of electrons. With a mass number of 137, you subtracted the 55 protons and correctly calculated that there are 82 neutrons.

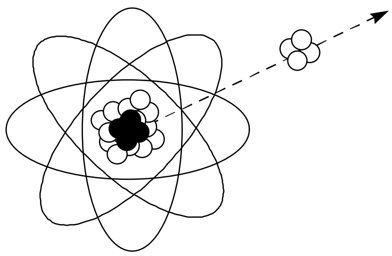
*Proceed to the next section.*

b. No, you have the atomic number and the mass number mixed up. The atomic number, 55, indicates the number of protons. You correctly assumed that there are an equal number of electrons. The mass number is 137, which is the total of protons plus neutrons, so you were on the right track when you subtracted 55 from 137 to get 82 neutrons. By the way, this is not uranium. Cs is the symbol for cesium. (If you are interested in becoming more familiar with the symbols, there is a Periodic Table of the Elements in most physical science books.)

*Return to page 2-6 and reread this sequence.*

## RADIOACTIVE DECAY

Any of the whole group of elements and their isotopes may be referred to as *nuclides.* Nuclides with high mass numbers have excessive energy in the nucleus, causing them to be unstable and radioactive. In general, the lighter nuclides tend to be more stable, which means they are less likely to transform into another configuration. There are exceptions, however, such as H-3 and C-14.



An unstable atom will attempt to reach stability by ejecting alpha or beta particles and/or releasing energy in the form of gamma radiation. This process is radioactive decay, or "radioactivity."

*To assess your understanding of radioactive decay, answer the following question.*

## *QUESTION*

*Circle the correct answer.*

Radiological emergency response personnel are called upon to deal with accidents that involve radioactive nuclides or "radionuclides." The nuclei of these atoms contain excessive energy that makes them

a. more stable and unlikely to transform into another nuclide.

b. more unstable and likely to eject alpha or beta particles and energy.

*Turn the page to check your answer.*

## *ANSWERS*

a. No, nuclides are radioactive when they have unstable nuclei. This often is a result of a large number of neutrons and protons in the nucleus. These "heavy" nuclei tend to want to get rid of some of these energetic particles to become stable.

*Try the next question.*

b. That's right. Unstable atoms emit protons or neutrons and energy in an effort to reach a stable form in the process known as radioactive decay.

*Move on to the next section.*

## *QUESTION*

*Circle the correct answer.*

When unstable nuclei eject neutrons or protons and release energy, the process is known as

a. radioactive decay.

b. ionization.

*Turn the page to check your answer.*

## ***ANSWERS***

a. That is correct. Radioactive decay, or radioactivity, is the process that results in the ionizing radiations that create a hazard to living things.

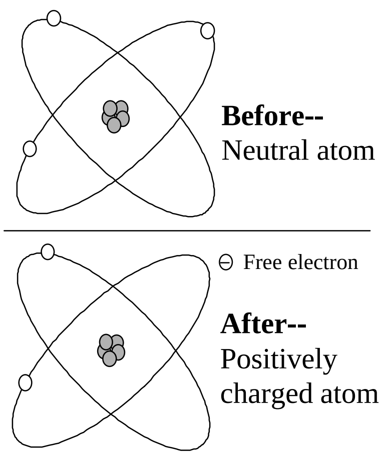
*Proceed to the next section.*

b. No, the result of radiation may be ionization, but the process of releasing the nucleons is radioactive decay.

*You should reread the sections on radioactive decay.*

## IONIZATION

The orbits in which electrons travel around the nucleus are also called shells. Each shell holds a maximum number of electrons, and the closest shells to the nucleus are full before any electrons will be found in outer shells. The outermost shell will not always be full, leaving space for one or more additional electrons. Atoms tend to seek to fill the outermost shell by sharing electrons with other atoms. When a single electron fills a place in the outer shell of two atoms, the atoms pair together and become a molecule of an element or compound.




Any atom that has lost an electron and thus becomes positively charged is an *ion*. The removed electron also is considered to be an ion because it is a loose, negatively charged particle. Ions tend to be chemically active and try to unite with other atoms or ions. The process of removing an electron, leaving two charged particles (the atom with a net positive charge and the free electron with a negative charge), is called *ionization.*

One of the important characteristics of ionizing radiation is its ability to split atoms on molecules into positively and negatively charged fragments that may realign and form new chemical compounds. When ionizing radiation penetrates living tissue it may cause a disruption of the chemical organization and function of the cells, thus causing a biological effect. Ionizing radiation can be detected and measured as an electrical charge by radiation detection instruments. Ionizing radiations include x-rays, gamma rays, neutrons, beta particles, and alpha particles.

Non-ionizing radiation includes visible light, radio waves, radiant heat, and microwaves. These low-energy radiations do not remove electrons from atoms. They occur when electrons are excited by some external energy source and give off heat and light.

## *QUESTION*

*Circle the correct answer.*

Ionization is an important concept for the radiological emergency responder to understand because

a. it is the basis for the biological effect caused by radiation and it provides the evidence that radiation is present.

b. it describes how protons are removed from the nucleus of an atom, causing biological damage to a cell.

*Turn the page to check your answer.*

## *ANSWERS*

a. You are right. Ionizing radiation can knock electrons out of their shells and create ions that may pair together and create new molecules of different compounds. You also understand that the elimination or addition of an electron creates charged particles that are measurable with specially designed equipment.

*Move on to the next section.*

b. No, ionization is when electrons are knocked out of their shells, not protons out of the nucleus.

*Try the next question.*

## *QUESTION*

*Circle the correct answer.*

An ion is any atom that has lost _____.

a. a proton.

b. an electron.

*Turn the page to check your answer.*

## *ANSWERS*

a. No, ions and ionization are related to losing electrons, not protons. The protons are bundled up in the nucleus of the atom, whereas the electrons travel in orbits around the nucleus. It is the electrons in the shells that may be knocked loose, creating charged particles that eventually partner with other oppositely charged ions.

*You should go back and reread this section again.*

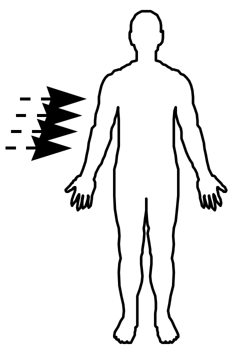
b. Now you've got it. When these atoms are missing electrons they tend to combine with other atoms and/or ions, often forming new compounds. Ionizing radiation can cause biological effects in living cells by disrupting (breaking up) molecules of essential cell structures, consequently affecting cell function and organization. Ions are charged particles and therefore measurable evidence of the presence of the radiation causing the ionization.

*Proceed to the next section.*

# IONIZING RADIATIONS

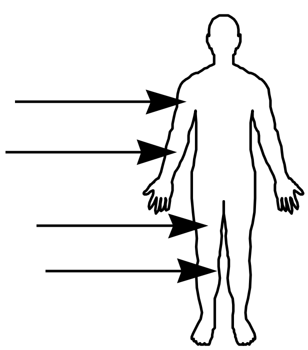
There are several types of ionizing radiation. Because radiological emergency response personnel are most likely to encounter alpha, beta, and gamma radiation, we will concern ourselves with those three types. You have studied the characteristics of ionizing radiation in other courses; this section will consist of a brief review.

**ALPHA**



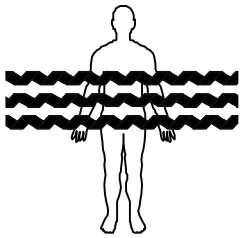
When large, unstable nuclides such as uranium or radium decay and break down, they may give off radiation that is identical to the nuclei of helium atoms (two protons and two neutrons). This type of radiation is called *alpha*. Because these radiations are relatively heavy and carry a positive charge, alpha travels only a few centimeters in air and has little penetrating power. In fact, alpha cannot even penetrate the outer layer of dead skin on the body. For that reason alpha is an internal hazard only—it must get inside the body to cause biological damage.

**BETA**



Another form of radiation, *beta,* is emitted when a neutron breaks down into a proton and an electron. The electron is ejected from the nucleus at high energy as a beta particle and the atom is transformed into a different nuclide because the number of protons increased. At high exposures beta-emitting radionuclides can cause injury to the skin and superficial body tissues. Otherwise they present mostly an internal hazard.

**GAMMA**



*Gamma* rays, which are emitted during most radioactive decay events, have no mass and no charge; they are pure electromagnetic energy. Gamma rays travel great distances in air—a few thousand yards to miles, at the speed of light. They have great penetrating power and are considered to be an external hazard to living things.

*To test your knowledge, answer the following question.*

## *QUESTION*

*Circle the correct answer.*

If you identified the radionuclides involved in a transportation accident and found that they emit alpha, beta, and gamma radiation, you would conclude that

a. the radiation presents an internal hazard only.

b. the radiation presents an external as well as an internal hazard.

*Turn the page to check your answer.*

## *ANSWERS*

a. No. While all three types of radiation present would become a hazard if inside the body, because of its penetrating power gamma radiation constitutes an external hazard.

*Try another question.*

b. Correct. All three ionizing radiations can affect the internal organs. Alpha and beta must be ingested or inhaled whereas gamma radiation has the ability to penetrate the body and cause biological effects.

*Move on to the next section.*

## *QUESTION*

*Circle the correct answer.*

Your radiation detection instrument indicates the presence of gamma radiation. Gamma radiation _____by protective clothing.

a. can be stopped

b. cannot be stopped

*Turn the page to check your answer.*

## *ANSWERS*

a. You should never rely upon protective clothing to protect you from gamma radiation because gamma has great penetrating power and can pass through material much thicker and denser than protective clothing.

*Return to page 2-17 and reread this section.*

b. Right. While protective clothing safeguards against radioactive contamination, it cannot stop gamma radiation from penetrating the body.

*Proceed to the next section.*

## RADIOACTIVE HALF-LIFE

| Day 1 | 8 Days Later | 8 More Days Later |
|---|---|---|
| 100 Ci I-131 | 50 Ci I-131 | 25 Ci I-31 |

As you read a few pages ago, radioactive nuclei give off radiation and transform into stable, other unstable, or nonradioactive nuclei. The number of atoms undergoing this decay during a given time depends not only on the total number of atoms present, but also on a characteristic called *half-life*. The radioactive half-life of a nuclide is the time it takes for half of the radioactive nuclei to decay. Radioactive decay is measured in terms of half-life.

Some materials decay at a slower rate and will be radioactive for a long time. Californium-249 (Cf 249) has a half-life of 351 years. Plutonium-239 (Pu 239) has a half life of approximately 24,100 years. Conversely, some radioactive materials decay very quickly. Iodine-131 (I-131) has an 8-day half-life, and carbon-11 (C-11) has a half-life of only 20 minutes.

The concept of half-life is particularly significant when considered in terms of internal deposition in the human body. Nuclides that have short radioactive half-lives give up their energy quickly; inside the body this can cause serious problems because of the damage caused by the resulting ionization. I-131 tends to settle in the thyroid and has a short half-life. Protection of the thyroid is a serious consideration if an accidental release contains radioactive iodine. Strontium-90 (Sr-90) tends to collect in the bones. Because Sr-90 has a longer half-life—29 years—it decays less quickly, but it can cause ongoing damage if it stays in the body for a long time.

*Let's pause now and apply this concept by answering the question on the next page.*

## *QUESTION*

*Circle the correct answer.*

An accident involving a radiopharmaceutical shipment includes chromium-51 (Cr-51), which has a half-life of about 27 days. If 800 curies of the Cr-51 spilled and were not diminished by any natural effects, at the end of 27 days __________________ due to radioactive decay processes.

a. there would be no Cr-51 left

b. only 400 curies of Cr-51 would remain

*Turn the page to check your answer.*

## ***ANSWERS***

a. No, the Cr-51 would not be completely transformed to a stable material. The half-life refers to the time it takes for one-half of the radioactive material to decay to a stable nuclide.

*Try the next question.*

b. That's right. You have correctly applied the concept of half-life.

*Move on to the next section.*

## ***QUESTION***

If a material has a half-life of 1 minute, how long will it take for 100 curies of that material to decay to 25 curies?

*Circle the correct answer.*

a. one minute.

b. two minutes.

*Turn the page to check your answer.*

## *ANSWERS*

a. No, one minute is one half-life for this material, and 50 curies would be remaining after one half-life. The material would decay to 25 curies in another half-life. Therefore, it would take two minutes for this transformation to occur.

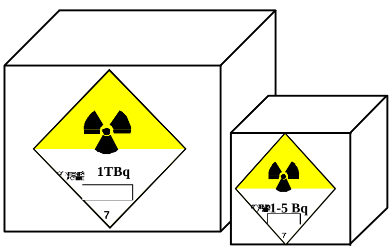
*Return to page 2-21 and reread this section.*

b. Correct. You calculated that it took one half-life to decrease to 50 curies of the material and another half-life to decrease the amount of radioactive material to 25 curies.

*Proceed to the next section.*

## MEASURING PROPERTIES OF RADIATION

There are three important properties of radioactive materials that must be measured. Members of radiological emergency response teams should be able to interpret units in which these properties are measured because they must be able to read meters, packages, shipping papers, labels and placards, in order to analyze the radiological hazard.




The strength or radioactivity of a material is defined by how fast it is decaying or disintegrating and emitting radiation. The *curie* is the traditional unit used to measure this activity. One curie equals 37 billion disintegrations per second.. Because of the great differences in activity of radionuclides, an ounce of one material could be more radioactive, or have more curies, than a pound of another material.

- For smaller amounts of radiation, the millicurie (mCi), which is one one-thousandth of a curie (.001 or 1/1000 Ci), is used.

The international (SI) unit for radioactivity is the *becquerel* (Bq). One becquerel is equal to one disintegration per second.

- One terabecquerel (TBq) equals one trillion becquerels (1,000,000,000,000 Bq).
- One gigabecquerel (GBq) equals one billion becquerels (1,000,000,000 Bq). One curie (Ci) equals 37 GBq (37,000,000,000 Bq).

When regulatory agencies describe how much radioactive material is allowable in a shipping package, that amount is described in curies and in terabecquerels. Package labels describe the activity contained in the package in terms of the appropriate SI units (becquerels and terabecquerels) or in SI units followed by customary units (curies, millicuries, etc.)

| Property | Tradi-tional Units | SI Units |
|---|---|---|
| Radioactivity | curie | becquerel |
| Ionization in Air | roentgen | coulombs /Kg |
| Radiation Absorbed Dose | rad | gray |
| Dose Equivalence | rem | sievert |

Another property of radiation that needs to be measured is how much ionization it is causing.

- The *roentgen* (R) is a unit that indicates the amount of x or gamma radiation that produces a given amount of ionization in each unit of air, or the intensity of the radiation. The roentgen is the unit of radiation exposure.

- A milliroentgen (mR) is one one-thousandth of a roentgen and is often used to indicate exposure. Frequently it is important to describe a rate of exposure over a period of time. This is indicated by roentgens or milliroentgens per hour.

Since the roentgen applies only to x and gamma radiation exposure in air, a different unit is needed to deal with radiation energy absorbed in materials.

- One unit is the *rad*, which stands for radiation absorbed dose. It describes the amount of any radiation absorption occurring in any material. For example, if a person is exposed to beta and gamma radiations, both may interact with and cause ionization in the body. In this case, the actual dose in rads may be greater than the exposure in roentgens because the beta is taken into consideration. The SI unit of radiation absorbed dose is the *gray* (Gy). 1 Gy =100 rad.

- When the dose is a great deal smaller than one rad, the term millirad (mrad), meaning one one-thousandth of a rad, is used.

Biological effect upon tissue is not the same for all types of radiation. Therefore, a different unit, called the *rem*, is used to account for biological damage or risk.

- The rem is known as a unit of dose equivalence. Rem is an acronym for *roentgen equivalent man*. One rem involves the same risk regardless of the type of radiation, but the dose required to produce one rem may vary depending upon the type of radiation. The SI unit of dose equivalence is the Sievert (Sv). 1 Sv = 100 rem.
    - The unit millirem (mrem or .001 rem) is often used for smaller dose equivalents.

The units just described may be encountered on the scene in many places. Here are a few examples.

- Radiation detection instruments such as survey meters and pocket ionization chambers or dosimeters measuring the amount of radiation ionized in air use the measurements of roentgens (R) and milliroentgens (mR). Other instruments that measure dose equivalents read in rems.
- Radiation packages should be labeled and placarded. You will find the international units of becquerel (Bq), terabecquerel (TBq), or gigabecquerel (GBq) on labels or placards, and you may find the radiation described in the traditional units such as curie or millicurie. The radioactivity level whether displayed in traditional units or international units should correspond between the package labels and the shipping papers necessary in the transport of any radioactive material.

*The following question is intended to test your grasp of the concepts and units used to measure properties of radiation.*

## ***QUESTION***

*Circle the correct answer*

If you were exposed to a beta-gamma source such as iodine-131 (I-131), which term would be used to describe the radiation energy absorbed by your body?

a. roentgen.
b. rad.

*Turn the page to check your answer.*

## ANSWERS

a. No, roentgen describes only the intensity of gamma radiation in air. In this situation we want to know how much beta and gamma radiation energy was absorbed in the body. This amount is better represented by the rad, which describes the radiation absorbed in the body.

*Try the next problem.*

b. Good. You realize that the term roentgen only indicates the intensity of the gamma radiation in air, while the term rad refers to the dose received from both types of radiation.

*Move on to the next section.*

## QUESTION

*Circle the correct answer.*

Which quantity or term accounts for the difference in biological risk resulting from equal doses of different types of radiation?

a. rem.

b. rad.

*Turn the page to check your answer.*

## ***ANSWERS***

a. Good. You know the difference between the rad, which is a unit of dose absorbed in any material, and the rem, which deals with the difference in biological effect upon tissue of different types of radiation.

*Proceed to the next section.*

b. While the term rad is used to describe radiation energy absorbed by the body, it does not indicate the relative effectiveness of the particular radiation involved. The purpose of using the term rem is to reduce the measurement of effects of all types of radiation to a common scale.

*Review this section before continuing.*

## EXPOSURE AND CONTAMINATION

Alpha, beta, and gamma radiations are emitted from a radioactive source. You do not necessarily have to touch the source to be exposed to its radiation, in much the same way you feel the warmth of the campfire and the aroma from cooking without touching the fire or the food. The reason you do not have to touch a source to be exposed is because the radiations from the source can travel in air.

- Gamma travels a long way, so you do not even have to be close to the source to be affected by it.

- Alpha radiation travels approximately 3 cm in air and beta travels up to 10 meters. You have to be a lot closer to the source to be exposed to those types of radiation. In fact, you would actually have to inhale or ingest some of the radioactive source to be affected by the alpha radiation emitting from it.

When you have radioactive material on or in your body, then you are contaminated.

*Exposed only*

*Contaminated and exposed*

- For example, if you moved some damaged boxes of radiopharmaceuticals and one of the small vials broke open, spilling the contents on your hand, your hand would be contaminated. If nothing got on or in your body, and the substance was a gamma emitter, you would be exposed to radiation but not contaminated.

- If you tramped through a patch of spilled radioactive material and got it on your person, you would be contaminated as well as exposed.

- If you inhaled or ingested radioactive particles airborne from a burning source, you would be internally contaminated until the particles are eliminated from the body or lose their radioactivity through decay processes.

The good news is that in most cases of external contamination, the radioactive material can be washed off the body or removed when outer contaminated garments are removed. Internal contamination problems are dealt with by medical professionals.

*Test your understanding of these concepts by answering the following question.*

## ***QUESTION***

*Circle the correct answer.*

To illustrate that you can apply this concept to your radiological emergency response role, read the following statements and select the one which is accurate.

a. You can be contaminated without being exposed.

b. You can be exposed without being contaminated.

*Turn the page to check your answer.*

## ANSWERS

a. No, that would be a very dangerous premise to live by. If radioactive material is on or in your body or on your clothing, you are being exposed to the radioactive source that is contaminating you. The type and amount of radioactive material will determine how much exposure and effect occurs.

*Try another question.*

b. Certainly. A radioactive source emits radiation. Depending on the type and intensity of the radiation, you can be exposed to radiation without even being near the source.

*Move on to the next section.*

## QUESTION

*Circle the correct answer.*

Due to a sudden change in wind direction, you find yourself standing in the middle of a radioactive plume from an accident involving burning radioactive material. You would incur

a. contamination only.

b. contamination and exposure to radiation.

*Turn the page to check your answer.*

## ***ANSWERS***

a. No, if there is radioactive contamination, that means there is radioactive material that is decaying and emitting radiation, from which you could become exposed.

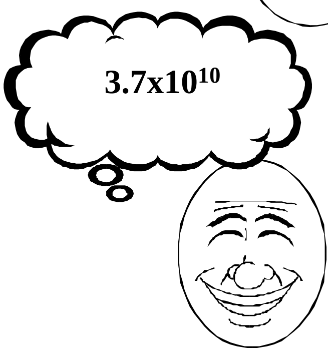
*You should go back and review beginning on page 2-30.*

b. That's right. The airborne radioactive material that lands on you in the form of ash is a type of contamination. That radioactive material undergoes decay processes and produces the ionizing radiation to which you are being exposed. Inhalation (breathing in) of the radioactive material is more dangerous because the ionizing radiation is on the inside of the body affecting organs and tissue.

*Proceed to the next section.*

**SCIENTIFIC NOTATION**
If you are not regularly involved with mathematics, this section is included to briefly explain the type of shorthand used to indicate very large and very small numbers. That shorthand is called *scientific notation.*


Consider two of the numbers mentioned earlier in this unit. An atom has an average diameter of one ten-trillionth of a centimeter. Written in decimal form, that number is 0.0000000000001 cm. The curie equals 37 billion disintegrations per second (dps). In decimal form that is 37,000,000,000 dps.




There is an easier way to write these numbers. When converting numbers to that easier system, the decimal point is the starting point. Most of the zeroes in these long numbers can be eliminated by using “powers” of 10, or exponents, written above and to the right of the number 10.

When a number is smaller than 1, it has integers (digits) to the right of the decimal point and the exponent of 10 has a minus sign. For example, the diameter of the atom may be written as $1 \times 10^{-13}$ centimeters because there are 13 powers of 10 between 1 and 10 trillion.

When a number is 1 or greater the exponent of 10 has a positive sign, but the + is generally not written. For example, the equivalent of the curie may be written as $3.7 \times 10^{10}$ dps, which means that you have to multiply 3.7 by 10 ten times to get 37 billion. Or, simply count the number of places you would need to move the decimal point to the left to get to 3.7.

Scientific notation usually operates under the following “rules of thumb.” The number by which you multiply the powers of 10 has one integer left of the decimal point and usually is rounded off to 2 numbers to the right of the decimal. For example, $2.34 \times 10^2$ rather than $23.4 \times 10^1$ or $.23 \times 10^3$. If the number by which you want to multiply the exponent is 1, it is usually written as $10^5$ or $10^6$ rather than

$1.00 \times 10^5$ or $1.00 \times 10^6$.

Some of the units used to describe radiation characteristics can be translated into scientific notation.

| | | |
|---|---|---|
| .001 | milli | $10^{-3}$ |
| .000001 | micro | $10^{-6}$ |
| .000000001 | nana | $10^{-9}$ |
| .000000000001 | pico | $10^{-12}$ |
| 1,000,000,000,000 | tera | $10^{12}$ |

*Let's see how well you can convert from standard to scientific notation. It will be helpful to you in reading about radioactive material amounts and quantities. Answer the following question.*

## *QUESTION*

*Circle the correct answer.*

The curie represents ___ disintegrations per *minute* (37,000,000,000 dps x 60 sec/min = 2,220,000,000,000 dpm).

a. $2.22 \times 10^{12}$

b. $2.22 \times 10^{-12}$

*Turn the page to check your answer.*

## *ANSWERS*

a. Correct. You indicated by the exponent of 12 that the decimal point was moved 12 places to the left in order to leave 1 integer to the left of the decimal point.

*Move on to the Summary Questions.*

b. No, a negative exponent indicates that the decimal point has been moved to the right and that the number is less than zero. When the decimal point is moved to the left (the number is greater than one) the exponent is positive. In this case the number is much larger than one.

*Try another question.*

## *QUESTION*

*Circle the correct answer.*

The approximate diameter of the nucleus of the atom is 0.0000000000001 cm. In scientific notation that can be written

a. $10^{13}$ cm.

b. $10^{-13}$ cm.

*Turn the page to check your answer.*

## ANSWERS

a. This time the decimal was moved 13 places to the right because the number is much smaller than one. Instead of .0000000000001, $10^{13}$ is 10,000,000,000,000.

*You should go back and review this section.*

b. Right! $10^{-13}$ indicates that you moved the decimal 13 places to the right.

*Proceed to the Summary Questions.*

## *QUESTION*

*Circle the correct answer.*

**SUMMARY QUESTIONS**

1. A radioactive material that emits beta and gamma radiation has a half life of six hours. Another beta-gamma emitter has a half life of 30 years. If an equal number of curies of each material were involved, which material presents a longer-term problem.

a. The radionuclide with a six hour half-life.

b. The radionuclide with a 30 year half-life.

*Turn the page to check your answer.*

## *ANSWERS*

a. Incorrect. A short half-lived material is decaying at a more rapid rate than a long half-lived material. The radiation levels may be higher initially, but the material will decay to less than 1% of the original amount in two days.

*Move on to the next Summary Question.*

b. Correct. It will take 210 years for this material to decay to less than 1% of the original amount.

*Go back to page 2-21 and review.*

## *QUESTION*

*Circle the correct answer.*

2. The number 0.00000000000040517 is equal to

a. $4.05 \times 10^{-13}$

b. $40.517 \times 10^{14}$

*Turn the page to check your answer.*

## *ANSWERS*

a. Correct.

*Move on to the next unit.*

b. Incorrect.

- When moving the decimal to the right, the exponent in scientific notation is always negative.
- The decimal point should be located after the four rather than the zero.
- The integers to the right of the decimal point in scientific notation should be limited to two.

*Go back to page 2-34 and review.*