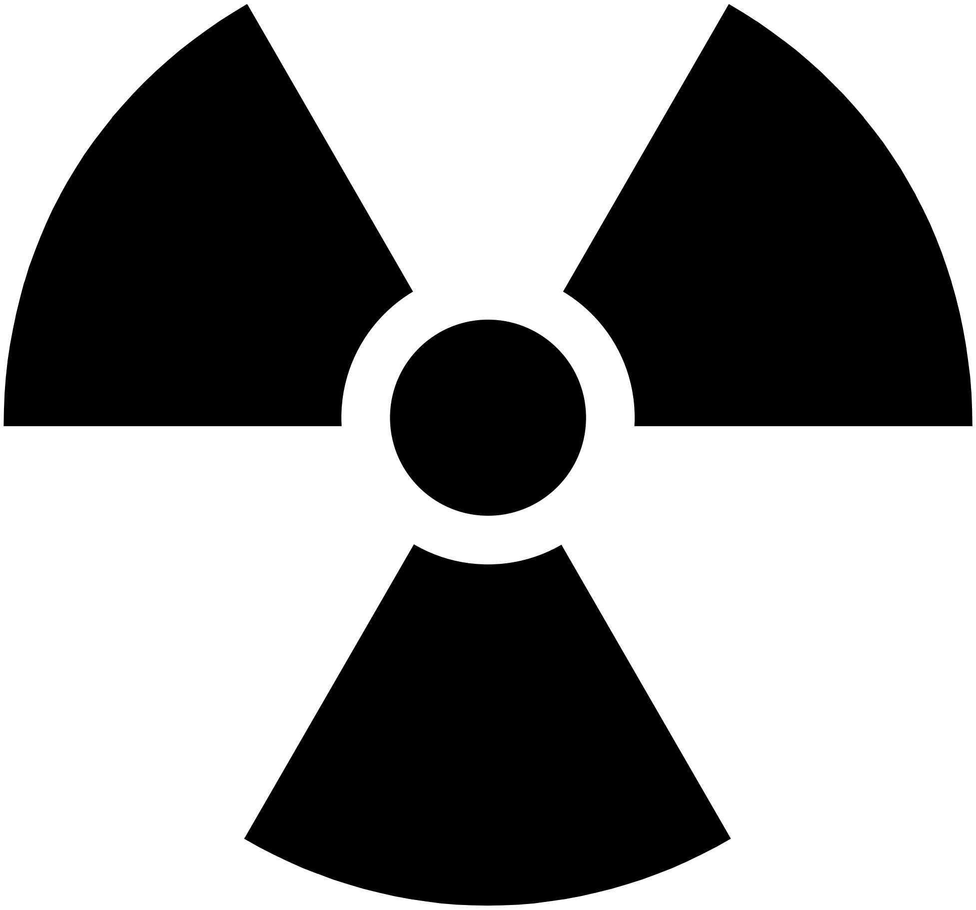
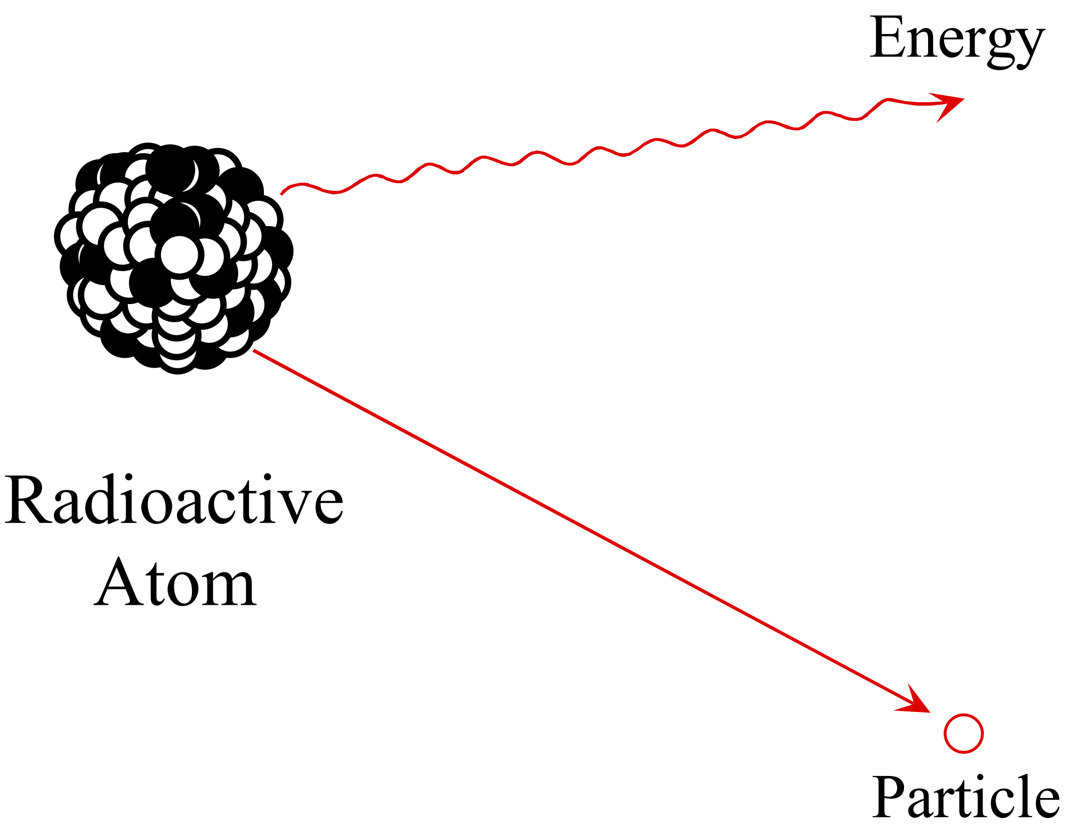
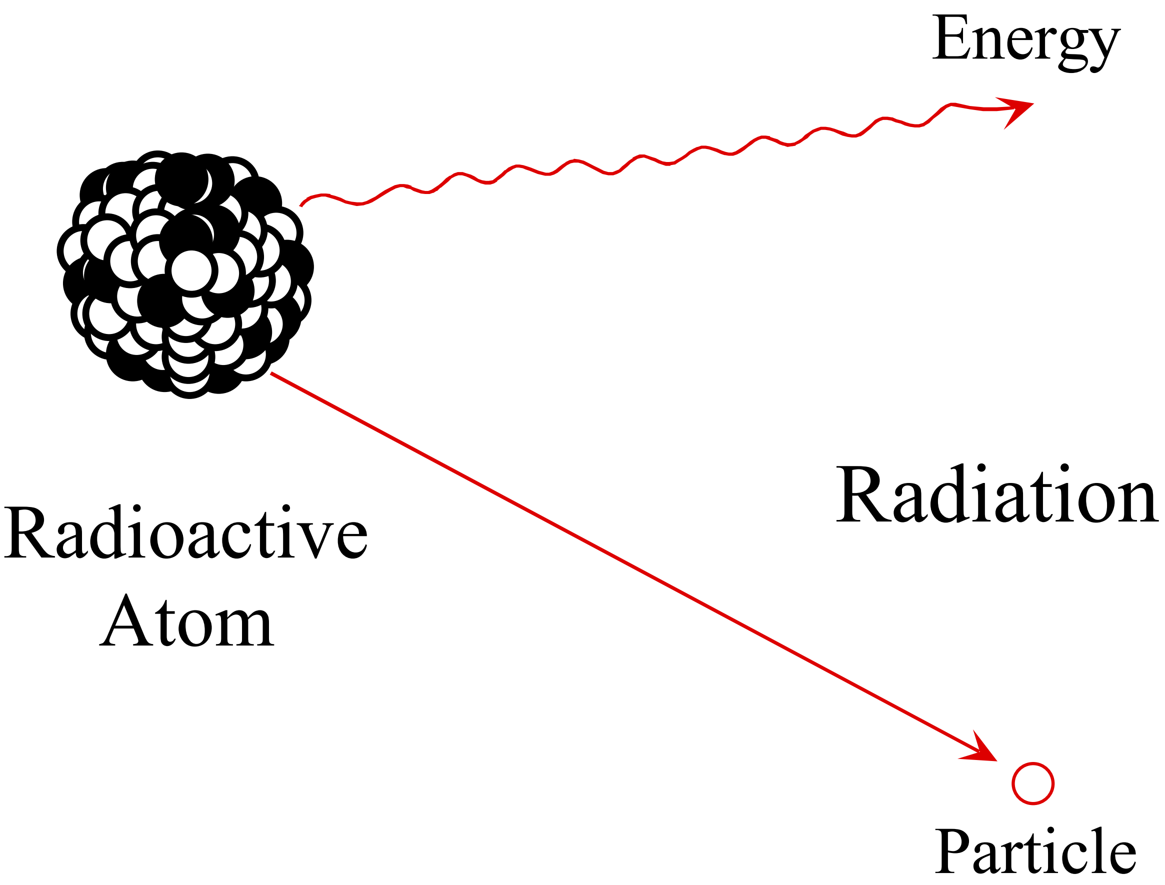
Radiation Terminology



This section discusses the terms and concepts which are necessary for a meaningful discussion of radiation, its sources, and its risks.



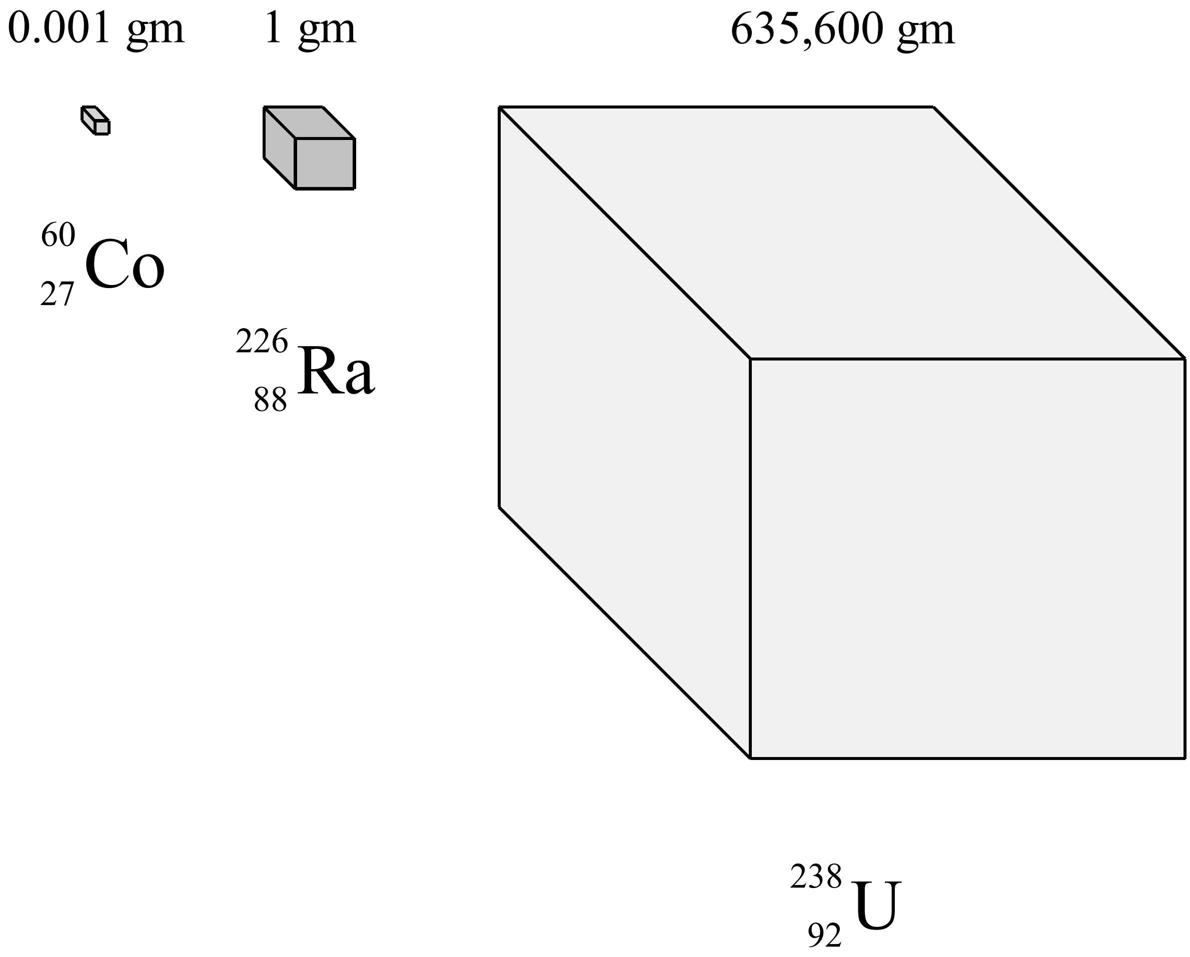
Atoms can be classified as stable or unstable. Unstable atoms have excess energy in their nuclei. A RADIOACTIVE MATERIAL contains atoms which are unstable and attempt to become more stable by ejecting particles, electromagnetic energy (photons), or both. When a radioactive atom ejects particles and/or photons, the atom undergoes a process called DISINTEGRATION (or decay).



Radioactive Atoms Emit Radiation

RADIATION is the term given to the particles and/or energy emitted by radioactive material as it disintegrates.

1 Curie:

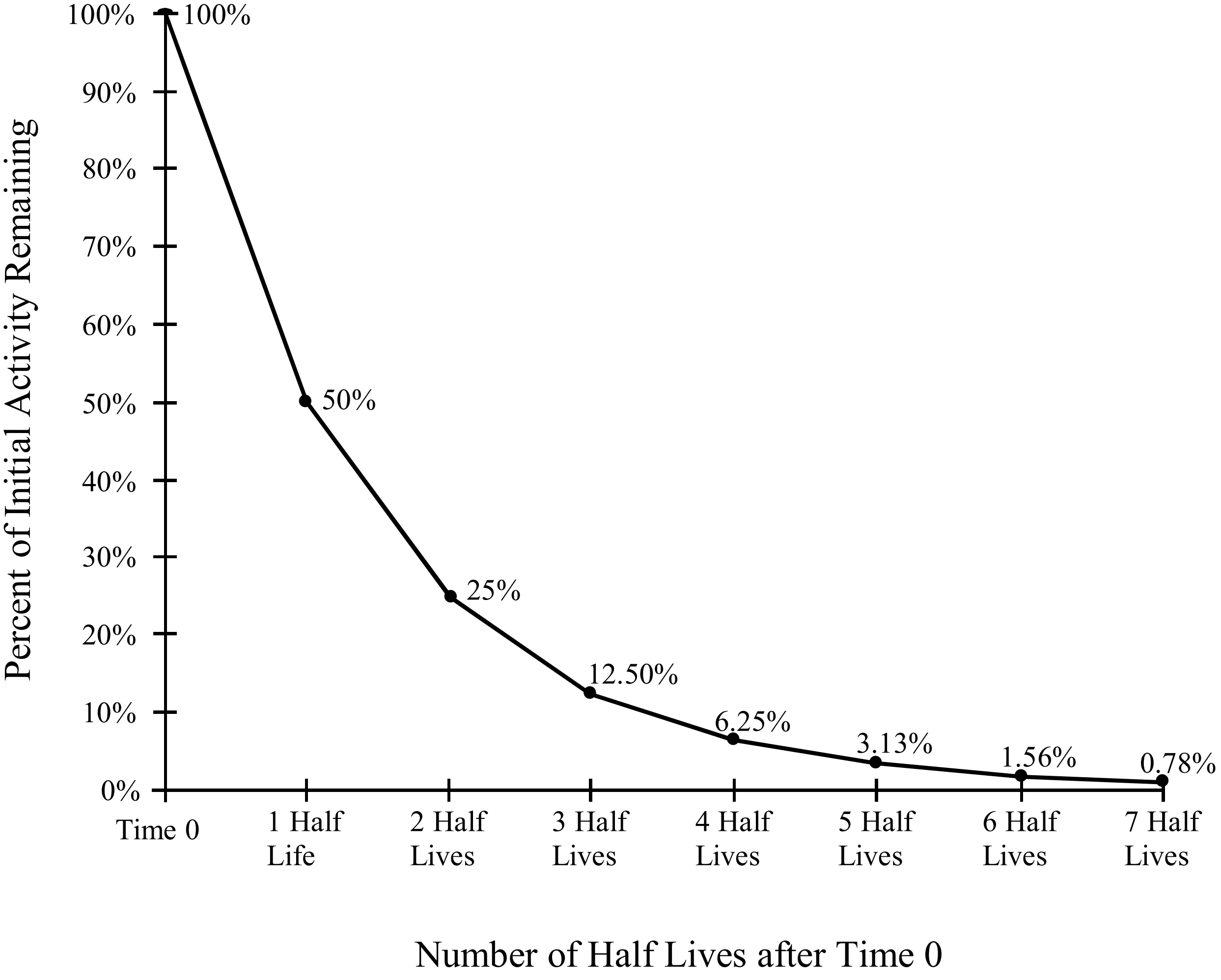


3.7×10^{10} Disintegrations per second = 1 Curie

RADIOACTIVITY is a term which indicates how many radioactive atoms are disintegrating in a time period and is measured in units of CURIES. One curie is defined as that amount of any radioactive material that will decay at a rate of 37 billion disintegrations per second (based upon the disintegration rate of 1 gram of radium-226).

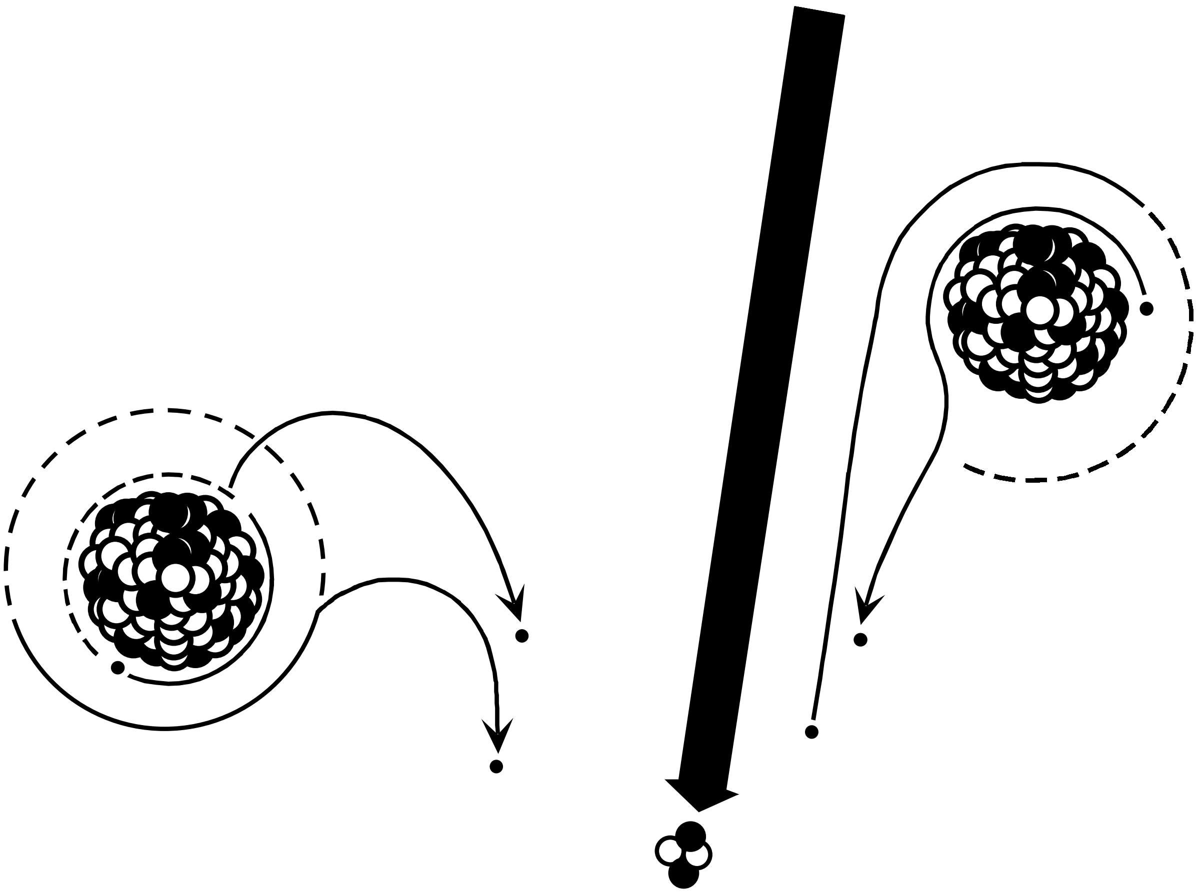
As shown above, the amount of material necessary for 1 curie of radioactivity can vary from an amount too small to be seen (cobalt-60, for example) to more than half a ton (uranium-238).

Radioactivity can also be expressed in units of becquerels, which are discussed on page 5-24.



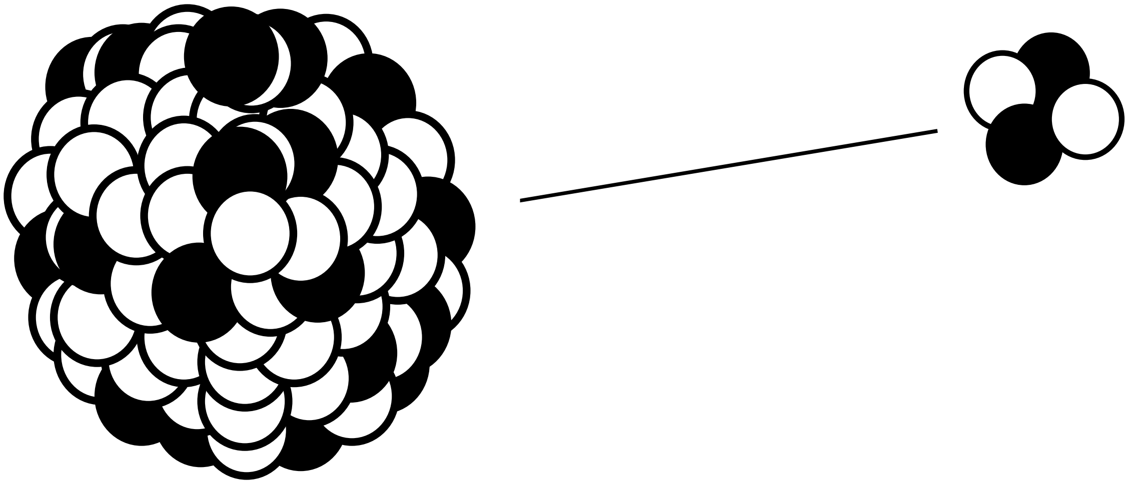
The rate of nuclear decay is measured in terms of HALF LIVES. The half life of any radioactive material is the length of time necessary for one half of the atoms of that material to decay to some other material. During each half life, one half of the atoms which started that half life period will decay.

Half lives range from millionths of a second for highly radioactive fission products to billions of years for long-lived materials (such as naturally occurring uranium). No matter how long or short the half life is, after seven half lives have passed, there is less than 1 percent of the initial activity remaining.



Ionization

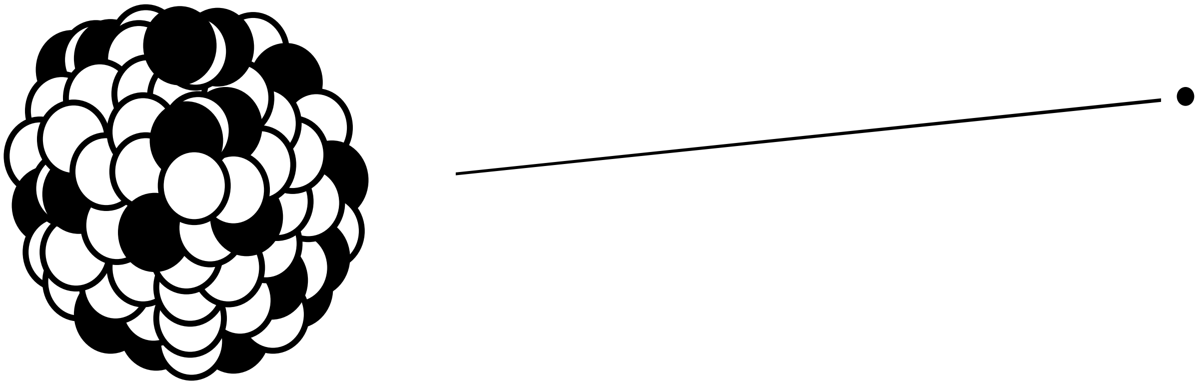
Radiation emitted by radioactive material can produce IONIZATIONS and, therefore, is called IONIZING RADIATION. Ionization is the process of stripping, knocking off, or otherwise removing electrons from their orbital paths, creating "free" electrons and leaving charged nuclei. The negatively charged electrons and positively charged nuclei may interact with other materials to produce chemical or electrostatic changes in the material where the interactions occur. If chemical changes occur in the cells of our bodies, some cellular damage may result. The biological effects of radiation exposure are discussed in Chapter 6.



Alpha Particle

An ALPHA PARTICLE is an ionizing radiation that consists of two protons and two neutrons. The neutrons and protons give the alpha particle a relatively large mass as compared to other ionizing radiation particles. Because of this large size, the alpha particle has a relatively low speed and low penetrating distance (one or two inches in air). The particle tends to travel in a straight line, causing a large number of ionizations in a small area.

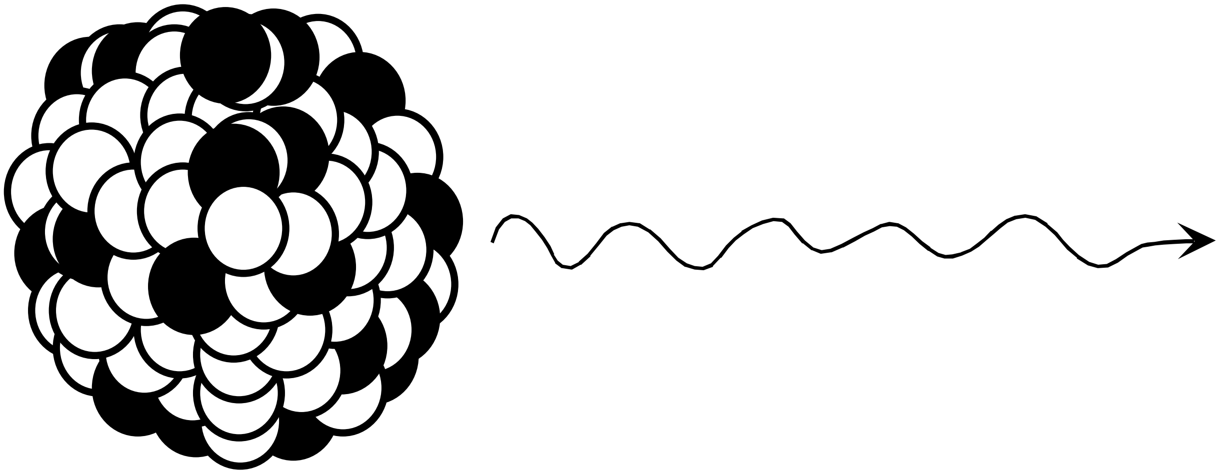
Alpha particles are easily shielded (or stopped) by a thin sheet of paper or the body's outer layer of skin. Since they do not penetrate the outer (dead) layer of skin, they present little or no hazard when they are external to the body. However, alpha particles are considered to be an internal hazard, because they can be in contact with live tissue and have the ability to cause a large number of ionizations in a small area. INTERNAL and EXTERNAL HAZARDS refer to whether the radioactive material is inside the body (internal) or outside the body (external).



Beta Particle

A BETA PARTICLE is a high speed ionizing radiation particle that is usually negatively charged. The charge of a beta particle is equal to that of an electron (positive or negative), and its mass is equal to about 1/1800th of that of a proton or neutron. Due to this relatively low mass and charge, the beta particle can travel through about 10 feet of air and can penetrate very thin layers of materials (for example, aluminum). However, clothing will stop most beta particles.

The beta particle can penetrate into the live layers of the skin tissue and is considered both an internal and an external hazard. Beta particles can also be an external hazard to the lens of the eye. Beta particles are best shielded by thin layers of light metals (such as aluminum or copper) and plastics.

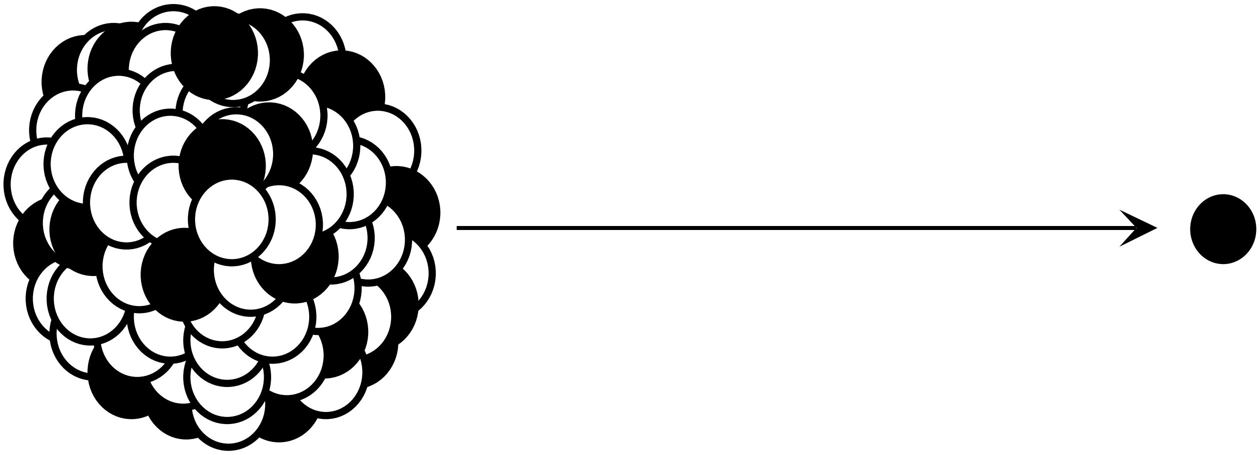


Gamma Ray

A GAMMA RAY is an ionizing radiation in the form of electromagnetic energy (no rest mass, no charge) similar in many respects to visible light (but far more energetic). Due to the high energy, no charge, and no rest mass, gamma rays can travel thousands of feet in air and can easily pass through the human body.

Because of their penetrating capability, gamma rays are considered both an internal and external hazard. The best shielding materials for gamma rays are very dense materials such as lead, concrete, and uranium.

> NOTE: X-rays are similar to gamma rays in penetration and damage potential. X-rays, however, are produced by changes in electron orbit position rather than by nuclear decay or fission.



Neutron Particle

The NEUTRON PARTICLE is an ionizing radiation emitted by nuclear fission and by the decay of some radioactive atoms. Neutrons can range from high speed, high energy particles to low speed, low energy particles (called thermal neutrons). Neutrons can travel hundreds of feet in air and can easily penetrate the human body.

Neutrons are considered both an internal and external hazard, although the likelihood of an internal, neutron emitting, radioactive material is extremely unlikely. The best shielding materials for neutrons would be those that contain hydrogen atoms, such as water, polyethylene, and concrete.

The nucleus of a hydrogen atom contains a proton. Since a proton and a neutron have almost identical masses, a neutron hitting a hydrogen atom gives up a great amount of its energy, and therefore, the distance traveled by the neutron is limited. This is like a cue ball hitting another billiard ball. Since they are the same size, the cue ball can be made to stop and the other ball will start moving. But, if a ping pong ball is thrown against a bowling ball, the ping pong ball will bounce off with very little change in velocity, only a change in direction. Therefore, heavy atoms, like lead, are not good at stopping neutrons.

Units for Exposure and Dose Measurements

ROENTGEN

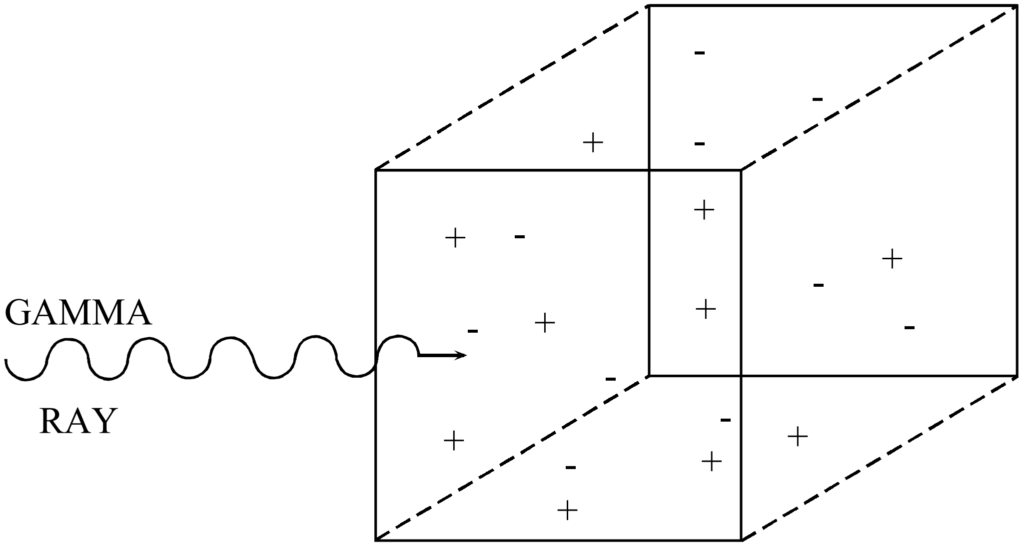
RAD

REM

When ionizing radiation interacts with a material, it can cause ionizations. The ionizations can be measured, and the effects of the radiation can be estimated. Because of these ionizations, radioactive material and exposure to ionizing radiation can be monitored and controlled.

The commonly used units in the United States for radiation exposure and dose measurements are the ROENTGEN, the RAD, and the REM.

> NOTE: The unit of Roentgen is no longer recognized in 10 CFR Part 20, and consequently, the roentgen is being phased out as an official unit for dose of record. It will, however, still be seen on radiation survey instruments, and on radiation surveys, until the older models can be replaced. The radiation dose of record must be recorded in rad or rem.

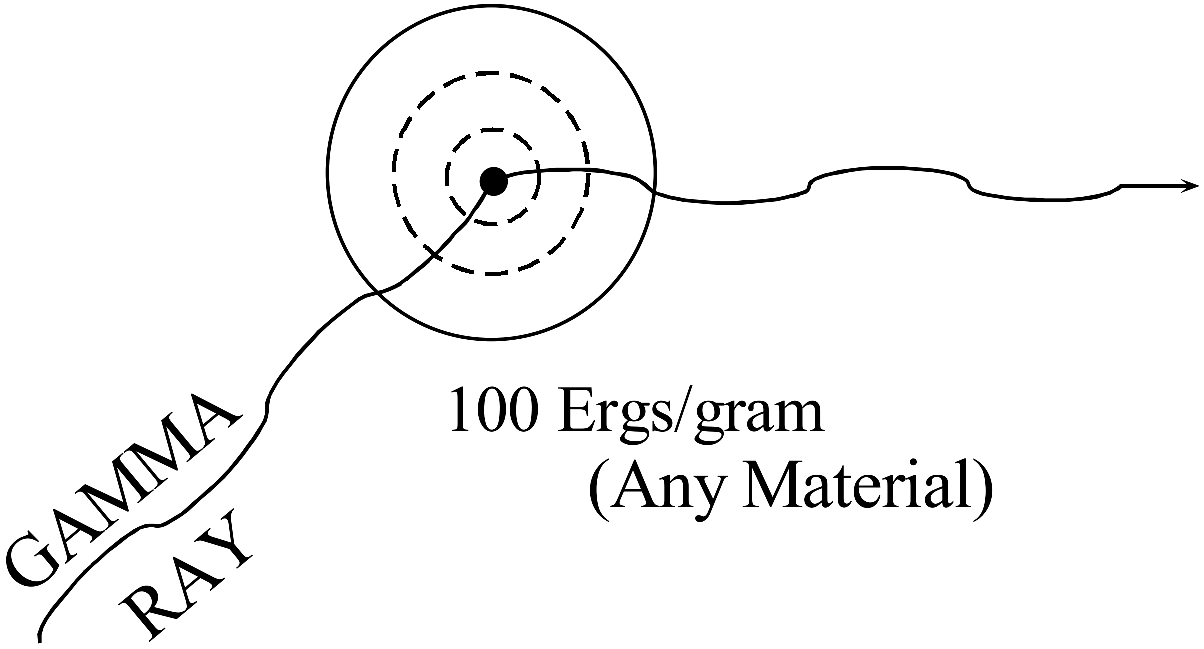


1 ESU/cm^3 Dry Air

Roentgen

The ROENTGEN (R) is a measure of exposure to X-ray or gamma ray radiation. One roentgen is that amount of X-ray or gamma radiation that will deposit enough energy to strip about two billion electrons from their orbits (called one electrostatic unit) in one cubic centimeter of dry air. The roentgen technically applies only to ionization in dry air from X-ray or gamma radiation and does not apply to damage to body tissues.

NOTE: As stated earlier, the unit of roentgen is being phased out as an official record of dose, but radiation survey instrument faces will still read out in R or multiples of R until they can be replaced with instruments reading out in rem or rad.



Radiation Absorbed Dose (RAD)

The RAD (Radiation Absorbed Dose) is a measure of the absorbed dose (energy deposited) in a material. One RAD is the deposition of one hundred ergs of energy in one gram of any material (NRC Regulations use per gram of body tissue) due to the ionization from any type of radiation. One erg of energy is equal to about one ten billionth of a BTU, or about one ten millionth of a watt.

REM

Damage produced

by 1 RAD

in body tissue

The REM is based on the biological damage caused by ionization in human body tissue. It is a term for dose equivalence and equals the biological damage that would be caused by one RAD of dose.

The REM accounts for the fact that not all types of radiation are equally effective in producing biological change or damage. That is, the damage from one rad deposited by beta radiation is less than that caused by one rad of alpha radiation. The REM is numerically equal to the dose in RADs multiplied by a QUALITY FACTOR, which accounts for the difference in the amount of biological damage caused by the different types of radiation.

FOR GAMMA AND X-RAYS:

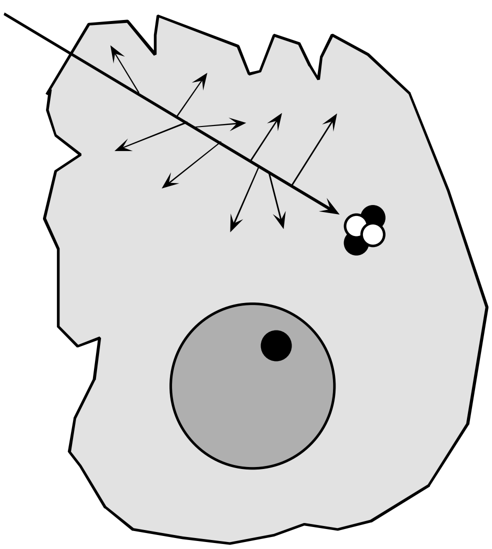
1 Roentgen =

1 RAD =

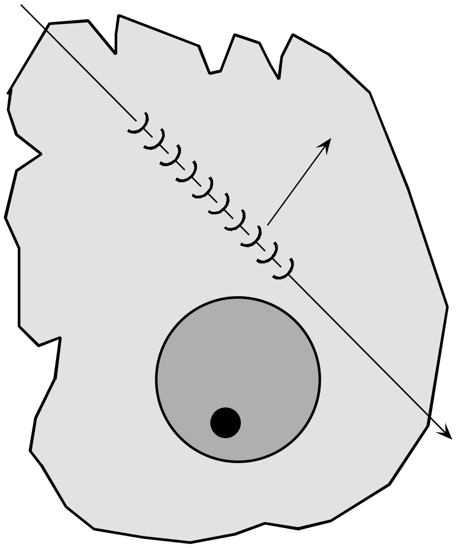
1 REM

Gamma ray radiation provides the consistency among the units of exposure and dose. Although slight corrections have been made to early historical data, one Roentgen of exposure of gamma or X-ray radiation is approximately equal to one RAD of absorbed energy (dose), which equals one REM of biological damage in humans (dose equivalent).

Again, this relationship is only true for gamma and X-ray radiation and is not true for the particulate (alpha, beta, or neutron) radiations. For this reason, and also the fact that the Roentgen is NOT a fundamental unit, the Roentgen is being phased out as a unit for the official dose of record.



1 RAD Alpha
or
20 Rem (Q = 20)



1 RAD Gamma
or
1 Rem (Q = 1)

Particulate ionizing radiation (alpha and neutron) has been found to cause more biological damage than electromagnetic radiation (gamma and X-ray), even when the same amount of energy has been deposited. For example, one RAD of alpha radiation can be expected to cause about twenty times the damage caused by one RAD of gamma radiation. This difference in ability to cause damage is corrected for by a QUALITY FACTOR (Q).

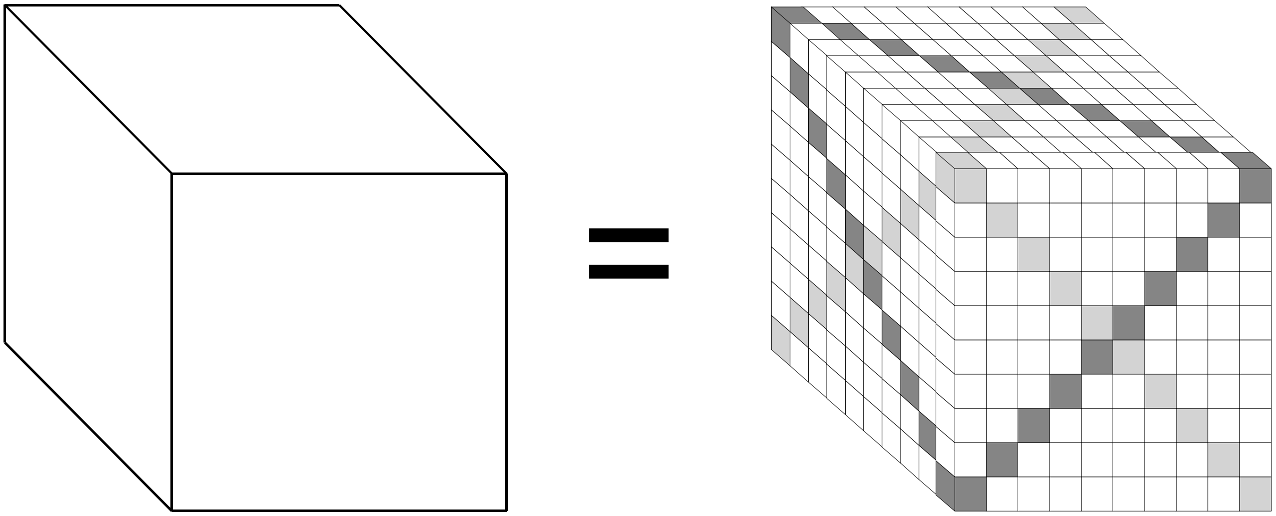
DOSE

Energy Deposition		“Damage”
1 RAD Gamma	=	1 REM
1 RAD Beta	=	1 REM
1 RAD Neutron	=	10 REM
1 RAD Alpha	=	20 REM

REM = RAD X Quality Factor

The QUALITY FACTOR converts the absorbed dose in RAD to the dose equivalent in REM. As shown, quality factors are highest for the alpha radiation, which deposits its energy within the smallest volume.

REM vs. MILLIREM

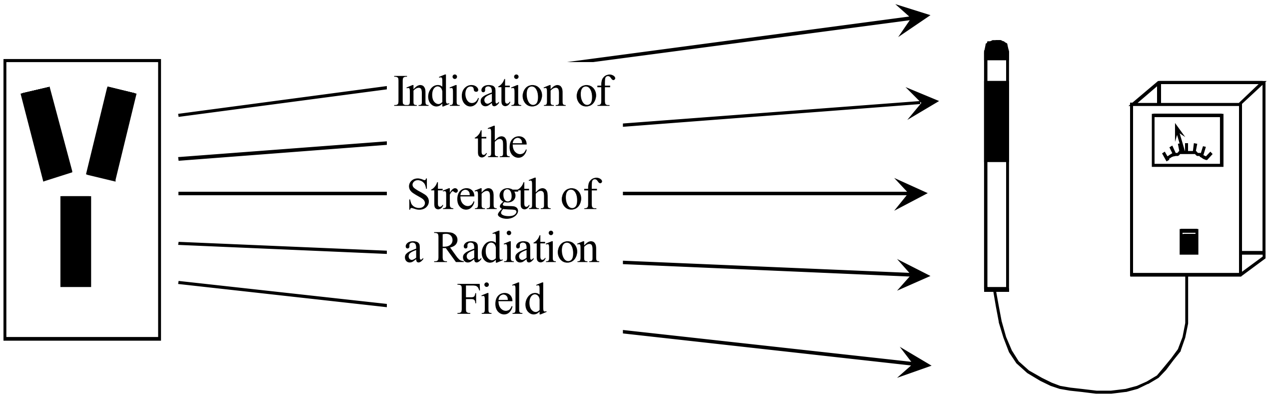


1 REM = 1000 mREM
1 mrem = 1/1000th REM

The units used in a discussion of radiation and radioactivity may be prefixed to indicate fractions (or multiples) of the standard unit. The table below lists the more common prefixes for scientific use.

Prefixes

d	deci	10^{-1}			
c	centi	10^{-2}	da	deka	10
m	milli	10^{-3}	h	hecto	10^{2}
F	micro	10^{-6}	k	kilo	10^{3}
n	nano	10^{-9}	M	mega	10^{6}
p	pico	10^{-12}	G	giga	10^{9}
f	femto	10^{-15}	T	terra	10^{12}
a	atto	10^{-18}			



DOSE RATE

The DOSE RATE is the rate at which a person would (or did) receive a radiation dose (or dose equivalent). It is a measure of radiation dose intensity (or strength). Commonly used dose equivalent rates are:

mrem/hr rem/hr mrem/wk rem/wk rem/quarter rem/year

$$\text{DOSE} = \text{Dose Rate X Time}$$

$$= 50\ \text{mrem/hr} \times \tfrac{1}{2}\ \text{hour}$$

$$= 25\ \text{mrem}$$

The DOSE is equal to the strength of the radiation field (dose rate) multiplied by the length of time spent in that field. The example above indicates a person could expect to receive a dose of 25 millirems by staying in a 50 millirems/hour field for thirty minutes.

STAY TIME CALCULATIONS

$$\text{Stay Time} = \frac{\text{Dose “Limit”}}{\text{Dose Rate}}$$

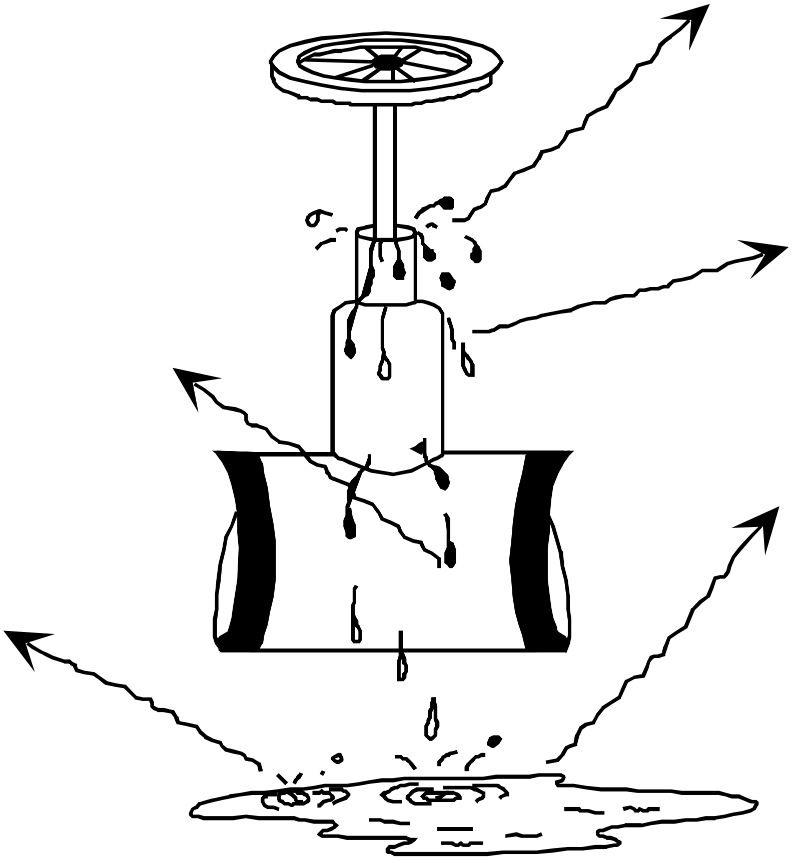
For Example:

$$\text{Stay Time} = \frac{\text{100 millirems limit}}{\text{50 millirems/hr}}$$

$$= \text{2 hours}$$

STAY TIME is an exposure control value equal to the length of time a person can remain in a radiation field before exceeding some DOSE LIMIT. In the example above, a dose limit of 100 millirems has been established. With a dose rate of 50 millirems/hour, the stay time is calculated to be two hours by dividing the dose limit by the dose rate.

Contamination



CONTAMINATION is generally referred to as some quantity of radioactive material in a location where it is not intended or desired to be. Radioactive contamination is radioactive atoms (material) that have escaped the system or structure that would normally contain them. Radioactive contamination can be wet or dry, fixed or removable, and settled or airborne. Since radioactive contamination is radioactive material, ionizing radiation is emitted by the contamination.

A CONTAMINATED AREA is an area that contains some type of radioactive contamination. Some examples of contaminated areas that require periodic access would be the primary side of the steam generator for a pressurized water reactor and the main turbine for a boiling water reactor. Methods of protection against radiation and contamination are discussed in Chapter 9.

International System of Units (SI)

Special Units	SI Units
Curie	Becquerel
RAD	Gray
REM	Sievert

USNRC regulations (10 CFR Part 20) now lists both the special units and the equivalent internationally accepted system of units and measures (SI). The SI units shown above have replaced the curie, RAD, and REM in some technical literature.

The relationships between the special units and the SI units are shown on the following pages.

1 Curie = 3.7×10^{10} disintegrations/second

1 Becquerel = 1 disintegration/second

1 Becquerel = 2.7×10^{-11} Curie

One curie is defined as the amount of any radioactive material that decays at the rate of 37 billion disintegrations per second. The SI unit for activity is the becquerel. It is equal to one disintegration per second. Therefore, one curie equals 37 billion becquerels.

1 RAD = 0.01 Gray

1 Gray = 100 RADs

The Gray is the SI unit of absorbed dose. A Gray is equal to 0.1 Joule of energy deposited in one kilogram of matter. Therefore, one RAD is equivalent to 1/100 of a gray, and one gray is equal to 100 RADs.

1 REM = 0.01 Sievert

1 Sievert = 100 REM

The sievert is the SI unit of dose equivalent. In the same way that converting from the absorbed dose (RAD) to the dose equivalent (REM) involved the use of quality factors, the conversion of grays to sieverts also uses quality factors.

One rem equals 1/100th of a sievert, and one sievert equals 100 rems.