Defentect Radiation Primer

What is radiation and radioactivity?

Radiation is ubiquitous throughout our world and within our bodies. The continuous process of atomic nuclei working toward becoming stable by getting rid of excess energy produces constant emissions of energy and particles we call radiation. Radiation is energy transmitted in the form of high speed particles and electromagnetic waves. We are familiar with electromagnetic radiation in the form of visible light, radio and television waves and microwaves.

Sometimes the center of an atom, its nucleus, has too much energy in it. Atoms with too much energy in their nuclei are called radioactive. They get rid of their excess energy by emitting radiation at very high speeds in order to return to their normal stable state. When radiation collides with something it deposits some or all of that energy in the thing it collided with. You can compare radiation from an atom with radiation from the sun. The sun's rays deposit their energy and warmth in our bodies just as a radioactive atom deposits its energy in the object it has collided with.

What are the types of radiation?

There are four basic types of radiation:

Alpha – These are fast moving helium atoms. Alpha particles are emitted by radioactive nuclei such as uranium or radium in a process called alpha decay. In contrast to beta decay, alpha decay is mediated by strong nuclear force. Alpha particles have high energy, typically in the MeV (megaelectronvolt) range, but due to their large mass, particles are stopped by a few inches of air. Alpha is a positively charged particle emitted by certain radioactive material consisting of two neutrons and two protons, the nucleus of a helium atom. Alpha is a dangerous carcinogen when inhaled or ingested. Alpha radiation can penetrate the body to just below the dead skin, but is blocked by clothing or even a sheet of paper. When released inside our bodies from material we breathe or swallow, alpha rays are able to transfer their energy at short range to damage body cells.

Beta – These are fast moving electrons. They typically have energies in the range of a few hundred keV (kiloelectrons) to several MeV (megaelectronvolts). Since electrons are much lighter than helium atoms, they are able to penetrate further, through several feet of air, or several millimeters of plastic. Particles are stopped by aluminum foil or human skin. Unless they are ingested or inhaled, beta emitters pose little danger to people, although direct contact with a strong source can cause deep and serious beta burns on skin. A beta particle is a single high-energy electron moving at high speed and carrying a negative charge. Beta particles can travel about one meter through air and can penetrate the skin to reach internal tissue. They can cause skin burns, and when ingested, cancer. Beta rays are especially dangerous when emitted inside the body.

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Gamma – These are photons, just like light, except with much higher energy, typically from several keV to several MeV. Gamma rays are similar to X-Rays, but are much more powerful. The difference is in how they were produced. Depending on their energy, they can be stopped by a thin piece of aluminum foil, or they can penetrate several inches of lead. These particles go through many meters of air, a human being or many centimeters of lead shielding. Gamma rays are almost always emitted only after a nucleus decays. Gamma rays are electromagnetic waves or photons emitted from the nucleus (center) of an atom. They have no electrical charge and penetrate deeply into the body, or pass through it, creating ions as they collide with atoms along their path.

Neutron – Neutron radiation occurs when the nucleus of a heavy element like uranium decays into a lighter element and emits a neutron. Neutrons are the neutral particles that are normally contained in the nucleus of all atoms. In a nuclear reactor core or atom bomb, enough neutrons are released to split more uranium atoms, releasing more neutrons and creating a critical mass - a self sustaining reaction. In a nuclear weapon, the reaction is uncontrolled and leads to a massive explosion and burst of neutron radiation. In a nuclear reactor, the critical mass is 'moderated' or slowed, generating tremendous heat without actually exploding.

The nature of atoms

All matter is made up of atoms, tiny bubbles of force. Atoms exist as point-like knots of condensed energy (the **nucleus**) surrounded by a cloud of **electrons**. The nucleus itself is normally composed of two kinds of particles: positively charged **protons** and uncharged **neutrons**. For an atom to be considered electrically neutral (to have no charge) it must have one negatively charged electron in the cloud to balance each positively charged proton in the nucleus. The number of neutrons, while affecting the mass of the atom, has no influence on electric charge.

Hydrogen, the simplest kind of atom, normally has no neutrons at all. It is simply a single proton coupled to one whirling electron. Carbon, a more complex element, contains six protons, six electrons, and between six and eight neutrons.

It's a common misconception that matter and energy are two different things. Albert Einstein introduced the notion that an atom is a tightly concentrated, meta-stable bundle of energy arising from the universal field. According to the theory, this energy can be liberated under certain circumstances, when an atom is split, for example, or when it fused with other particles to make a heavier element.

Radiation units and measurements

What is a "rem?"

A rem (acronym for Roentgen Equivalent Man) is a unit or measurement of potential damage done by radiation. It is used to describe how much radiation energy is deposited in someone or something. A millirem is one thousandth (1/1,000) of a rem. A microrem is one millionth (1/1,000,000) of a rem. Every year, the average person is exposed to 360 millirem. This means we are exposed to about 1 millirem on a daily basis.

What is a "rad?"

Radiation Absorbed Dose is a unit measuring the quantity called absorbed dose. This is the amount of energy actually absorbed in some material. The difference between a rad and a rem is a rad is a measurement of radiation absorbed by materials, not the potential effect of the radiation. Rad can be used for any type of radiation, but it does not describe the biological effects of the different radiations.

What is a "roentgen?"

A roentgen (R) describes the amount of gamma rays to which a target (e.g. fly, mouse, human, etc.) is exposed. The roentgen relates to the ability of X-rays and gamma rays to remove electrons from atoms in the air. One roentgen is equal to depositing enough energy in dry air to cause 2.58E-4 coulombs per kg.

What does the term "rate" mean?

A rate is the amount of a particular unit of measurement that occurs over a specific time period. Millirems per hour is a dose rate, or the amount of energy deposited in a one hour period of time.

What is a "curie?"

A curie is equivalent to the radiation from one gram of pure radium. The curie tells us how many radioactive atoms in a particular collection of atoms are giving off radiation. One curie (Ci) is the quantity of radioactive material that will have 37,000,000,000 transformations in one second. (1 Ci = 3.7 to the 10^{th} power disintegrations per second or dps) A millicurie is one thousandth (1/1,000) of a curie. A microcurie is one millionth (1/1,000,000) of a curie. A picocurie is one trillionth (1/1,000,000,000) of a curie.

What is a "Becquerel?"

A becquerel (Bq) is the Standard International derived unit of radioactivity, defined as the activity of a quantity of radioactive material in which one nucleus decays per second. It is named for Henri Becquerel who shared a Nobel Prize with Pierre and Marie Curie for their work in discovering radioactivity. Curie (Ci) is an older, non-SI unit of radioactivity. It is equivalent to 3.70×10^{10} disintegrations per second, which is approximately the amount of activity produced by 1 g of radium-226. Thus the curie is defined as 3.7×10^{10} becquerels or 37 GBq. Both the becquerel and curie tell us how many radioactive atoms in a particular collection of atoms are giving off radiation. The strength of a radioactive source is determined by how many nuclei decay each second. The modern unit is becquerel. One Bq is equal to one disintegration per second.

What is a "sievert?"

A sievert (Sv) reflects the biological effects of radiation as opposed to the physical aspects, which are characterized by the absorbed dose, measured in grays. Named for Rolf Sievert, a Swedish medical physicist who researched the biological effects of radiation, the sievert is the unit for dose equivalent. The rem is the same, but is an older conventional unit used at an operational level in the United States. 1 Sv = 100 rem.T

How do you distinguish between "rems" and "curies"?

Using the analogy of a wood burning fireplace, the amount of burning wood (fuel) in analogous to the number of "curies" of radioactive material. The amount of heat (energy) given off by the fireplace is analogous to the number of "rems" of radiation energy deposited in someone or something.

What is "keV" and "MeV"?

A kiloelectron (keV) = 1,000 electron volts. 1 megaelectron volt (MeV) = $1.60217646 \times 10^{-13}$ joules.

What is a "radioactive isotope"?

A radioactive isotope has an unstable nucleus that stabilizes itself by emitting ionizing radiation. Not all isotopes are radioactive. Most naturally occurring elements are mixtures of several isotopes, and many of these are stable under normal conditions. Each isotope has its own electron volt or thumb print associated with it referring to the actual energy it gives off. A radioactive isotope is one of two or more atoms with the same number of protons but a different number of neutrons with a nuclear composition. It is an isotope having an unstable nucleus that decomposes spontaneously by emission of a nuclear electron or helium nucleus and radiation, thus achieving a stable nuclear composition.

Cesium-137 is, for example, a radioactive isotope of Cesium which is formed mainly by nuclear fission. It has a half-life of 30.23 years, and decays by pure beta decay to a meta-stable nuclear isomer of barium-137 (Ba-137m). Barium-137m has a half-life of 2.55 minutes and is responsible for all of the gamma ray emission. The ground state of barium-137 is stable.

What is a "half life"?

The amount of time it takes for half of the atoms in a radioactive sample to decay.

Cesium-137, for example, has a half-life of 30.23 years. Uranium-238, the most prevalent isotope in uranium ore, has a half-life of about 4.5 billion years; that is, half the atoms in any sample will decay in that amount of time. Uranium-238 decays by alpha emission into thorium-234, which itself decays by beta emission to protactinium-234, which decays by beta emission to uranium-234, and so on. The various decay products, (sometimes referred to as "progeny" or "daughters") form a series starting at uranium-238.

After several more alpha and beta decays, the series ends with the stable isotope lead-206. The property of uranium important for nuclear weapons and nuclear power is its ability to fission, or split into two lighter fragments when bombarded with neutrons releasing energy in the process. Of the naturally occurring uranium isotopes, only uranium-235 can sustain a chain reaction -- a reaction in which each fission produces enough neutrons to trigger another, so that the fission process is maintained without any external source of neutrons. In contrast, uranium-238 cannot sustain a chain reaction, but it can be converted to plutonium-239, which can.

Plutonium-239, virtually nonexistent in nature, was used in the first atomic bomb tested July 16, 1945 and the one dropped on Nagasaki on August 9, 1945.

What are atomic and mass numbers?

Each element is commonly referred to as having an atomic number and a mass number. The atomic number is simply the number of protons in the nucleus, and the mass number is the combined total of protons and neutrons.

Elements are sometimes written in the following format: $_{238}U$ or Uranium-238. The 238 is the mass number of the element.

Knowing that uranium has an atomic number of 92, you can calculate that it must also have 146 neutrons by subtracting 92 from 238. On the scale of atoms, this makes it a monster.

Is there radioactivity in the world around us?

Yes. The earth, everyone and everything that has ever lived has always been radioactive.

A natural type of radiation is cosmic radiation given off by the sun and stars. Because some of the earth's atmosphere absorbs some of this radiation, people living at higher altitudes receive a greater dose than people at lower altitudes. For example, in Ohio the average resident receives a dose of about 40 millirem in one year from cosmic radiation. In Colorado, it is about 180 millirem in one year. Generally, for each 100-foot increase in altitude, there is an increased dose of one millirem per year.

Flying in an airplane increases our exposure to cosmic radiation. A coast-to-coast round trip flight gives us a dose of about four millirem.

Our TV's emit radiation. Most smoke detectors contain small amounts of radioactive material. The potassium found in bananas, P 40, is a radioactive element. While radiation can harm us, it plays an integral part in our lives.

Radioactivity is in the ground, the air, the buildings we live in, the food we eat, the water we drink. The average person in the U.S. receives a dose of about 360 millirem per year from natural sources of radioactivity.

It takes a short-term dose of well over 500,000 millirem to cause a fatality.

Is there radioactivity in our bodies?

During our lifetimes, our bodies harbor measurable amounts (billions) of radioactive atoms. About half of the radioactivity in our bodies comes from Potassium-40, a naturally radioactive form of potassium. Potassium is a vital nutrient.

We have about 120,000 picocuries of radioactivity in our bodies. These naturally occurring radioactive substances expose our bodies to about 25 millirem per year (mR/year).

What is the definition of a lethal dose (LD) of radiation?

According to the United States Nuclear Regulatory Commission, it's the dose of radiation expected to cause death to 50 percent of an exposed population within 30 days (LD 50/30).

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Typically, the LD 50/30 is in a range from 400 to 450 rem (4 to 5 sieverts) received over a very short period.

The result of cell exposure to these microscopic explosions with the resultant sudden influx of random energy and ionization may be either cell death or cell alteration. The change or alteration can be temporary or permanent. It can leave the cell unable to replace itself. Radiation damage can cause the cell to produce a slightly different hormone or enzyme than it was originally designed to produce, still leaving it able to reproduce other cells capable of generating this same altered hormone or enzyme. In time there may be millions of such altered cells.

How does Defentect compensate for background radiation?

Defentect's Gammatect Plus™ sensors automatically subtract naturally occurring predictive background radiation so even high count locations may be monitored. The adjustable threshold may be automatically set to 2 times background, or manually set as desired. Set in 'patient mode,' individuals undergoing medical treatments pass without triggering innocent alarms. GammaTect Plus™ sensors set in 'patient mode' won't alarm for isotopes below 500 keV (the measure of energy within an isotope).

Sources:

http://www.iem-inc.com/primrite.html

http://www.nrc.gov/reading-rm/basic-ref/glossary/lethal-dose-ld.html

http://www.anawa.org.au/health/radiation.html

http://www-tech.mit.edu/Bulletins/Radiation/rad5.txt

See CHARTS ONE, TWO and THREE for more information on half life, radiation health effects and measurements.

CHART ONE

Source: http://www.stevequayle.com/ARAN/rad.conversion.html

STANDARD INTERNATIONAL RADIATION MEASUREMENT UNITS: CONVERSION FACTORS

What's the Difference Between *Roentgen*, *Rad* and *Rem* Radiation Measurements?

A: Since nuclear radiation affects people, we must be able to measure its presence. We also need to relate the amount of radiation received by the body to its physiological effects. Two terms used to relate the amount of radiation received by the body are exposure and dose. When you are exposed to radiation, your body absorbs a dose of radiation.

As in most measurement quantities, certain units are used to properly express the measurement. For radiation measurements they are:

* **Roentgen:** The roentgen measures the energy produced by gamma radiation in a cubic centimeter of air. It is usually abbreviated with the capital letter "R". A milliroentgen, or "mR", is equal to one one-thousandth of a roentgen. An exposure of 50 roentgens would be written "50 R".

* **Rad:** Or, Radiation Absorbed Dose recognizes that different materials that receive the same exposure may not absorb the same amount of energy. A rad measures the amount of radiation energy transferred to some mass of material, typically humans. One roentgen of gamma radiation exposure results in about one rad of absorbed dose.

* **Rem:** Or, Roentgen Equivalent Man is a unit that relates the dose of any radiation to the biological effect of that dose. To relate the absorbed dose of specific types of radiation to their biological effect, a "quality factor" must be multiplied by the dose in rad, which then shows the dose in rems. For gamma rays and beta particles, 1 rad of exposure results in 1 rem of dose.

Other measurement terms: Standard International (SI) units which may be used in place of the rem and the rad are the sievert (Sv) and the gray (Gy). These units are related as follows: 1Sv = 100 rem, 1Gy = 100 rad. Two other terms which refer to the rate of radioactive decay of a radioactive material are curie (Ci) and becquerel (Bq).

Bottom Line: Fortunately, cutting through the above confusion, for purposes of practical radiation protection in humans, most experts agree (including FEMA Emergency Management Institute) that Roentgen, Rad and Rem can all be considered equivalent. The exposure rates you'll usually see will be expressed simply in terms of roentgen (R) or milliroentgen (mR).

Source: http://www.radmeters4u.com/#1b

Other Radiation Measurements

1 terabecquerel (TBq)	~	27	curie (Ci)
1 gigabecquerel (GBq)	~	27	millicurie (mCi)
1 megabecquerel (MBq)	~	27	microcurie (µCi)
1 kilobecquerel (kBq)	~	27	nanocurie (nCi)
1 becquerel (Bq)	~	27	picocurie (pCi) = 1 dps
1 curie (Ci)	~	37	gigabecquerel (GBq)
1 millicurie (mCi)	~	37	megabecquerel (MBq)
1 microcurie	~	37	kilobecquerel (kBq)
1 nanocurie (nCi)	~	37	becquerel (Bq)
1 picocurie (pCi)	~	37	millibecquerel (mBq)
1 Gray (Gy)	=	100	rad (rad)
1 milligray (mGy)	=	100	millirad (mrad)
1 microgray (µGy)	=	100	microrad (µrad)
1 nanogray (nGy)	=	100	nanorad (nrad)
1 kilorad (krad)	=	10	gray (Gy)
1 rad (rad)	=	10	milligray (mGy)
1 millirad (mrad)	=	10	microgray (µGy)
1 microrad (µrad)	=	10	nanogray (nGy)
1 coulomb/kg (C/kg)	~	3876	roentgen (R)
1 millicoulomb/kg (mC/kg)	~	3876	milliroentgen (mR)

1 microcoulomb/kg (μC/kg)	~	3876	microroentgen (μR)
1 nanocoulomb/kg (nC/kg)	~	3876	nanoroentgen (nR)
1 kiloroentgen (kR)	~	258	millicoulomb/kg (mC/kg)
1 roentgen (R)	~	258	microcoulomb/kg (μC/kg)
1 milliroentgen (mR)	~	258	nanocoulomb/kg (nC/kg)
1 microroentgen (μR)	~	258	picocoulomb/kg (pC/kg)
1 sievert (Sv)	=	100	rem (rem)
1 millisievert (mSv)	=	100	millirem (mrem)
1 microsievert (μSv)	=	100	microrem (μrem)
1 kilorem (krem)	=	10	sievert (Sv)
1 rem (rem)	=	10	millisievert (mSv)
1 millirem (mrem)	=	10	microsievert (μSv)

CHART TWO

Source: http://www.ccohs.ca/oshanswers/phys_agents/ionizing.html

What is ionizing radiation?

Ionizing radiation is radiation that has enough energy to remove electrons from atoms or molecules (groups of atoms) when it passes through or collides with some material. The loss of an electron with its negative charge causes the atom (or molecule) to become positively charged. The loss (or gain) of an electron is called ionization and a charged atom (or molecule) is called an ion.

What are some examples of ionizing radiation?

Forms of ionizing radiation include:

- Gamma rays
- X rays
- Alpha particles
- Beta particles
- Neutrons

X rays refer to a kind of electromagnetic radiation generated when a strong electron beam bombards metal inside a glass tube. The frequency of this radiation is very high - 0.3 to 30 Ehz (exahertz or million gigahertz). By comparison FM radio stations transmit at frequencies around 100 MHz (megahertz) or 0.1 Ghz (gigahertz).

Some compounds like uranium are radioactive and give off radiation when the nucleus breaks down or disintegrates. The three kinds of radiation generated by radioactive materials or sources are alpha particles, beta particles and gamma rays.

What properties are considered when ionizing radiation is measured?

Ionizing radiation is measured in terms of:

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- the strength or radioactivity of the radiation source,
- the energy of the radiation,
- the level of radiation in the environment, and
- the radiation dose or the amount of radiation energy absorbed by the human body.

From the point of view of occupational exposure, the radiation dose is the most important measure. Occupational exposure limits like the ACGIH TLVs are given in terms of the permitted maximum dose. The risk of radiation-induced diseases depends on the total radiation dose that a person receives over time.

What units are used for measuring radioactivity?

Radioactivity or the strength of radioactive source is measured in units of becquerel (Bq).

1 Bq = 1 event of radiation emission per second.

One becquerel is an extremely small amount of radioactivity. Commonly used multiples of the Bq unit are kBq (kilobecquerel), MBq (megabecquerel), and GBq (gigabecquerel).

1 kBq = 1000 Bq, 1 MBq = 1000 kBq, 1 GBq = 1000 MBq.

An old and still popular unit of measuring radioactivity is the curie (Ci).

1 Ci = 37 GBq = 37000 MBq.

One curie is a large amount of radioactivity. Commonly used subunits are mCi (millicurie), µCi (microcurie), nCi (nanocurie), and pCi (picocurie).

1 Ci = 1000 mCi; 1 mCi = 1000 µCi; 1 µCi = 1000 nCi; 1 nCi = 1000 pCi.

Another useful conversion formula is:

1 Bq = 27 pCi.

Becquerel (Bq) or Curie (Ci) is a measure of the rate (not energy) of radiation emission from a source.

What does half-life mean when people talk about radioactivity?

Radiation intensity from a radioactive source diminishes with time as more and more radioactive atoms decay and become stable atoms. Half-life is the time after which the radiation intensity is reduced by half. This happens because half of the radioactive atoms will have decayed in one half-life period. For example a 50 Bq radioactive source will become a 25 Bq radioactive source after one half-life.

Table 1 Radioactive Decay	
Number of half-lives elapsed	**Percent radioactivity remaining**
0	100
1	50
2	25
3	12.55
4	6.25
5	3.125

Half-lives widely differ from one radioactive material to another and range from a fraction of a second to millions of years.

What units are used for measuring radiation energy?

The energy of ionizing radiation is measured in electronvolts (eV). One electronvolt is an extremely small amount of energy. Commonly used multiple units are kiloelectron (keV) and megaelectronvolt (MeV).

6,200 billion MeV = 1 joule

1 joule per second = 1 watt

1 keV = 1000 eV, 1 MeV = 1000 keV

Watt is a unit of power, which is the equivalent of energy (or work) per unit time (e.g., minute, hour).

What units are used for measuring radiation exposure?

X-ray and gamma-ray exposure is often expressed in units of roentgen (R). The roentgen (R) unit refers to the amount of ionization present in the air. One roentgen of gamma- or x-ray exposure produces approximately 1 rad (0.01 gray) tissue dose (see next section for definitions of gray (Gy) and rad units of dose).

Another unit of measuring gamma ray intensity in the air is "air dose or absorbed dose rate in the air" in grays per hour (Gy/h) units. This unit is used to express gamma ray intensity in the air from radioactive materials in the earth and in the atmosphere.

What units are used for measuring radiation dose?

When ionizing radiation interacts with the human body, it gives its energy to the body tissues. The amount of energy absorbed per unit weight of the organ or tissue is called absorbed dose and is expressed in units of gray (Gy). One gray dose is equivalent to one joule radiation energy absorbed per kilogram of organ or tissue weight. Rad is the old and still used unit of absorbed dose. One gray is equivalent to 100 rads.

1 Gy = 100 rads

Equal doses of all types of ionizing radiation are not equally harmful. Alpha particles produce greater harm than do beta particles, gamma rays and x rays for a given absorbed dose. To account for this difference, radiation dose is expressed as *equivalent dose* in units of sievert (Sv). The dose in Sv is equal to "absorbed dose" multiplied by a "radiation weighting factor" (W_R - see Table 2 below). Prior to 1990, this weighting factor was referred to as Quality Factor (QF).

Table 2
Recommended Radiation Weighting Factors

Type and energy range	Radiation weighting factor, WR
Gamma rays and x rays	1
Beta particles	1
Neutrons, energy < 10 keV > 10 keV to 100 keV > 100 keV to 2 MeV > 2 MeV to 20 MeV > 20 MeV	 5 10 20 10 5
Alpha particles	20

Equivalent dose is often referred to simply as "dose" in every day use of radiation terminology. The old unit of "dose equivalent" or "dose" was rem.

Dose in Sv = Absorbed Dose in Gy x radiation weighting factor (WR)

Dose in rem = Dose in rad x QF

1 Sv = 100 rem

1 rem = 10 mSv (millisievert = one thousandth of a sievert)

1 Gy air dose equivalent to 0.7 Sv tissue dose (UNSEAR 1988 Report p.57)

1 R (roentgen) exposure is approximately equivalent to 10 mSv tissue dose

What effects do different doses of radiation have on people?

One sievert is a large dose. The recommended TLV is average annual dose of 0.05 Sv (50 mSv).

The effects of being exposed to large doses of radiation at one time (acute exposure) vary with the dose. Here are some examples:

10 Sv - Risk of death within days or weeks

1 Sv - Risk of cancer later in life (5 in 100)

100 mSv - Risk of cancer later in life (5 in 1000)

50 mSv - TLV for annual dose for radiation workers in any one year

20 mSv - TLV for annual average dose, averaged over five years

What are the limits of exposure to radiation?

The Threshold Limit Values (TLVs) published by the ACGIH (American Conference of Governmental Industrial Hygienists) are used in many jurisdictions occupational exposure limits or guidelines:

20 mSv - TLV for average annual dose for radiation workers, averaged over five years

1 mSv - Recommended annual dose limit for general public (ICRP - International Commission on Radiological Protection).

What is the relationship between metric (SI) units and non-metric units?

Table 3 shows SI units (International System of Units or Système Internationale d'unités), the corresponding non-SI units, their symbols, and the conversion factors.

Table 3
Units of Radioactivity and Radiation Dose

Quantity	**SI unit and symbol**	**Non-SI unit**	**Conversion factor**
Radioactivity	becquerel, Bq	curie, Ci	1 Ci = 3.7 x 10^{10} Bq = 37 Gigabecquerels (GBq) 1 Bq = 27 picocurie (pCi)
Absorbed dose	gray, Gy	rad	1 rad = 0.01 Gy
"Dose" (Equivalent dose)	sievert, Sv	rem	1 rem = 0.01 Sv 1 rem = 10 mSv

What is a "committed dose"?

When a radioactive material gets in the body by inhalation or ingestion, the radiation dose constantly accumulates in an organ or a tissue. The total dose accumulated during the 50 years following the intake is called the committed dose. The quantity of committed dose depends on the amount of ingested radioactive material and the time it stays inside the body.

What is an "effective dose"?

The effective dose is the sum of weighted equivalent doses in all the organs and tissues of the body.

Effective dose = sum of [organ doses x tissue weighting factor]

Tissue weighting factors (Table 4) represent relative sensitivity of organs for developing cancer.

Table 4 **Tissue Weighting Factors for Individual Tissues and Organs**	
Tissue or Organ	**Tissue Weighting Factor (WT)**
Gonads (testes or ovaries)	0.20
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid gland	0.05
Skin	0.01
Bone surfaces	0.01
Remainder**	0.05
Whole body	1.00

** The remainder is composed of the following additional tissues and organs: adrenal, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus.

What are "working level" and "working level month"?

In underground uranium mines, as well in some other mines, radiation exposure occurs mainly due to airborne radon gas and its solid short-lived decay products, called radon daughters or radon progeny. Radon daughters enter the body with the inhaled air. The alpha particle dose to the lungs depends on the concentration of radon gas and radon daughters in the air.

The concentration of radon gas is measured in units of picocuries per litre (pCi/L) or becquerels per cubic metre (Bq/m3) of ambient air. The concentration of radon daughters is measured in working level (WL) units this is a measure of the concentration of potential alpha particles per litre of air.

The worker's exposure to radon daughters is expressed in units of Working Level Months (WLM). One WLM is equivalent to 1 WL exposure for 170 hours.

1 WL = 130,000 MeV alpha energy per litre air

= 20.8 μJ (microjoules) alpha energy per cubic meter (m^3) air

WLM = Working Level Month

= 1 WL exposure for 170 hours

Often people use the concentration of radon gas (pCi/L) in the air to estimate the WL level of radon daughters. Such estimates are subject to error because the ratio of radon to its decay products (radon daughters) is not constant.

Equilibrium factor is ratio of the activity of all the short-lived radon daughters to the activity of the parent radon gas. Equilibrium factor is 1 when both are equal. Radon daughter activities are usually less than the radon activity and hence the equilibrium factor is usually less than 1.

Conversion of radon exposure units (equilibrium factor = 0.40)

1 WLM = 3.54 mJ-h/m^3

1 MBq-h/m^3 = 2.22 mJ-h/m^3

1 MBq-h/m^3 = 0.628 WLM

Annual exposure from measured radon concentration

(A) At home : assuming 7,000 hours spent indoors per year

1 Bq/m^3 = 0.0156 mJ-h/m^3

1 Bq/m^3 = 0.0044 WLM
1 WLM = 4 mSv
1 $mJ\text{-}h/m^3$ = 1.1 mSv
(B) At work : assuming 2,000 hours work per year
1 Bq/m^3 = 0.00445 $mJ\text{-}h/m^3$ = 0.00126 WLM
1 $mJ\text{-}h/m^3$ = 1.4 mSv
1 WLM = 5 mSv

Source: ICRP Publication 65, Protection Against Radon at Home and at Work

$mJ\text{-}h/m^3$ = millijoule hours/per cubic metre

$MBq\text{-}h/m^3$ = megabecquerel hours per cubic meter

Joule is unit of energy

1 J = 1 Watt-second = Energy delivered in one second by a 1 Watt power source

1 calorie = 4.2 J

MBq/m^3 = megabecquerel per cubic metre

WLM = Working Level Months

CHART THREE

Source: http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/R/Radiation.html

Radiation

For biologists, the most significant forms of radiation are light, heat, and ionizing radiation. Ionizing radiation can penetrate cells and create ions in the cell contents. These, in turn, can cause permanent alterations in DNA; that is, **mutations**.

Ionizing radiation includes:

- X rays
- gamma rays

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- neutrons
- electrons ("beta" particles)
- alpha particles (helium nuclei)

Units of measurement

rad

The rad represents a certain dose of energy absorbed by 1 gram of tissue. It is a unit of concentration. So if we could uniformly expose the entire body to radiation, the number of rads received would be the same whether we were speaking of a single cell, an organ (e.g., an ovary) or the entire body (just as the concentration of salt in sea water is the same whether we consider a cupful or an entire ocean).

rem

Some forms of radiation are more efficient than others transferring their energy to the cell. To have a level playing field, it is convenient to multiply the dose in rads by a quality factor (Q) for each type of radiation. The resulting unit is the rem ("roentgen-equivalent man"). Thus, rem = rad x Q. X rays and gamma rays have a Q about 1, so the absorbed dose in rads is the same number in rems. Neutrons have a Q of about 5 and alpha particles have a Q of about 20. An absorbed dose of, say, 1 rad of these is equivalent to 5 rem and 20 rem respectively.

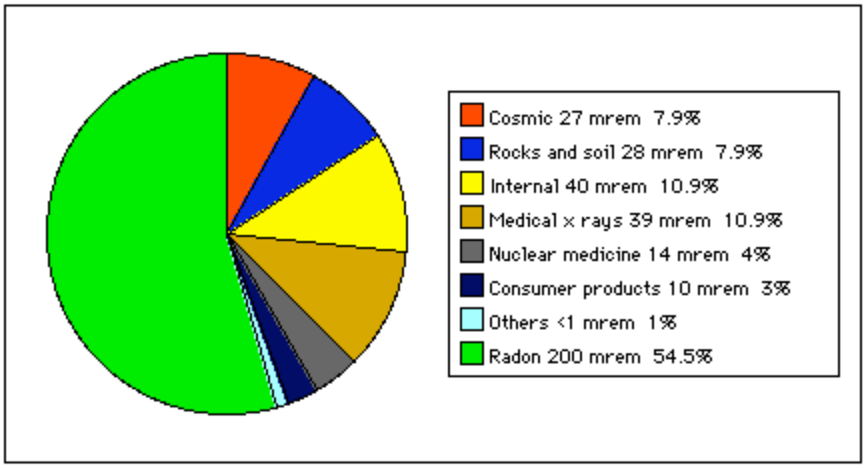
The sievert (Sv) and gray (Gy)

Despite the years of high-quality research reported in rems and millirems (mrem, 10^{-3} rem), the International Commission on Radiation Units and Measurements wants us to give up the rad in favor of the gray (Gy), a unit 100 times larger. Similarly, the rem is to be replaced by the sievert (Sv), again so that 100 rem = 1 Sv. Unfortunately, the rad and rem were already a little large to work with (why the table below is expressed in millirems) and converting to grays and sieverts makes the problem worse. Happily, many workers continue to use the rad and rem, and so shall we. In fact, I will try to express all radiation doses in a single unit, the millirem.

An assortment of typical radiation doses (in mrem)	
Used to destroy the bone marrow in preparation for a marrow transplant (given over several days)	1,000,000
Approximate lethal dose ("LD_{50}") if no treatment and given to the entire body in a short period	450,000
Causes radiation sickness (when absorbed in a short period)	>100,000
Increase in lifetime dose to most heavily exposed people living near Chernobyl	43,000
Average annual dose (excluding natural background) for medical X-ray technicians	320
Maximum permissible annual dose (excluding natural background and medical exposure) to general public	170
Natural background, Boston, MA, USA (per year)(excluding radon)	102
Natural background, Denver, CO, USA, (per year)(excluding radon)	180
Additional annual dose if you live in a brick rather than a wood house	7

Annual dose in some houses in Ramsar, Iran	>13,000
Average dose to person living within 10 miles of Three-Mile Island (TMI) caused by the accident of 28 March 1979	8
Most heavily exposed person (a fisherman) near TMI	<100
Approximate dose received by a person spending 1 year at the fence surrounding a nuclear power station	0.1–0.6
Average dose to each person in the U. S. population from nuclear power plants (per year)	0.002
Received by the bone marrow during a set of dental x rays*	9.4
Annual dose to the gonads from TV sets	0.2–1.5
Received by the colon during a barium enema	1,500
Received by the lungs during a chest x ray	1
Received by breast during mammogram	~300
Dose from a single full-body computed tomography (CT) scan	2,000
When delivered in a single dose, increases the risk of developing cancer by 1%	10,000
Average airline passenger (10 flights/year)	3
Flight crew and cabin attendants (per year)	160
Hourly dose to skin holding piece of the original "Fiesta Ware" (a brand of pottery)	200–300
Annual dose to each person in the U. S. population from fallout (former weapons testing plus Chernobyl)	0.06

* Dose much higher (several thousand mrem) to the skin in the path of the beam, but bone marrow is more susceptible to damage (e.g., leukemia).



Estimated average annual radiation exposure from various sources (in millirems) of an inhabitant of the United States. Individual exposures, especially to radon and medical sources, vary widely from these average values. Furthermore, only the lungs are exposed to radon doses; the alpha particles emitted by radon cannot penetrate other tissues. (Data from the National Council on Radiation Protection and Measurements, Bethesda, MD.)

Background Radiation

About 27% of our annual exposure to radiation is from background radiation:

- cosmic radiation (27 mrem). The value increases with altitude, so the dose for people in Denver, Colorado is about 50 mrem.
- rocks and soil (28 mrem). This value varies with the geology of a region: people in Louisiana get as little as 15 mrem/yr; people on the Colorado plateau (incl. Denver!) get 140 mrem/yr.
- from within the body (40 mrem). Most of this comes from potassium-40. About 0.02% of the potassium in nature is in the form of the radioactive isotope ^{40}K. Living tissue cannot discriminate between radioactive and nonradioactive versions, so the same 0.02% of the total potassium in the body (about 1.7 g in a 70-kg person) is radioactive.