RADIATION SAFETY REFERENCE MANUAL

GLOSSARY

Activity: The number of nuclear disintegrations occurring per unit time in a radioactive material.

Acute radiation exposure: A large exposure to ionizing radiation within a short period of time.

Acute radiation syndrome: A serious illness, also known as radiation poisoning, caused by exposure to high amounts of ionizing radiation. Onset usually occurs within 24 hours of exposure.

Adult: An individual of 18 or more years of age.

Agreement State: A State that has signed an agreement with the NRC authorizing the State to regulate certain uses of radioactive materials within the State.

ALARA ("As Low As Reasonably Achievable): A radiation safety principle in which practical measures are used to minimize exposure to ionizing radiation. Common methods include a combination of minimizing exposure time and increasing the distance and appropriate shielding.

Annual limit on intake (ALI): The derived annual limit for the amount of radioactive material inhaled or ingested into the body of an adult radiation worker. See the Table of Radioisotopes in this manual for a list of radionuclides and their ALIs.

Attenuation: The decrease in exposure rate of radiation as it passes through matter. This is a result of absorption and scattering.

Background radiation: Radiation in the natural environment including cosmic radiation and radiation of naturally radioactive elements.

Bioassay: The determination of radiation intake due to inhalation, ingestion and uptake. There are two methods of performing the bioassay:

- <u>In Vivo</u>: direct measurement, or counting, to localize and characterize radiation intake.
- <u>In Vitro</u>: analysis of human excreta.

Bremsstrahlung radiation: Electromagnetic radiation resulting from the interaction and resultant loss of energy by high energy electrons passing through the fields of nuclei.

Byproduct material: Radioactive material produced in nuclear reactors or accelerators.

Committed effective dose equivalent (CEDE): The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

Carcinogenesis: The development of cancerous cells from normal ones.

Contamination: occurs when radioactive material is deposited on or in an object or a person.

Cosmic radiation: A source of natural background radiation, which originates in outer space and is composed of penetrating ionizing radiation (both particulate and electromagnetic).

Decay Products (or Daughter products): Radionuclides that are formed by the radioactive decay of parent radionuclides.

Declared Pregnant Woman (DPW): A radiation worker who voluntarily informs her employer, *in writing,* of her pregnancy.

Disintegration: Any change in a nucleus of an atom, whether spontaneous or induced, in which one or more particles, photons, etc. are emitted.

Deep Dose Equivalent (DDE): The dose equivalent at a tissue depth of 1 cm (1000 mg/cm2). This applies to external whole-body exposure.

Dose Equivalent: A calculated dose used to characterize the human dose with use of the quality factor.

Effective whole body dose equivalent (EDE): The sum of the products of the dose equivalent to the organ or tissue (H_T) and the weighting factors (W_T) applicable to each of the body organs or tissues that are irradiated ($H_E = \sum W_T H_T$).

Electromagnetic radiation: A form of radiant energy released by certain electromagnetic processes. Familiar forms of electromagnetic radiation are: x-rays, gamma rays, ultraviolet, visible, and infrared light.

Electron capture: A mode of decay for radioactive nuclei in which an orbital electron is captured by the nucleus, converting a proton into a neutron.

Electron volt: One eV is equivalent to the energy gained by an electron when accelerated by a potential difference of one volt.

Epilation: Loss of hair. May occur following large radiation doses.

External radiation: Exposure to ionizing radiation when the radiation source is located outside the body.

Extremities: From your elbows to the tips of your fingers, and from your knees to the bottom of your feet.

Fission: The splitting of a heavy nucleus into two or more parts accompanied by the release of relatively large amounts of energy, neutrons and gamma radiation.

Geiger-Mueller (GM): A portable radiation detection and measuring instrument used to survey the external radiation present. The GM is most useful to localize contamination and contamination intensity in counts per second.

Half-life, biological: The time required for the body to eliminate, by biological processes, one-half of the material originally taken in.

Half-life, effective: The time required for a radionuclide contained in a biological system to reduce its activity by half as a combined result of radioactive decay and biological elimination.

Half-life, physical: The time in which one-half of the activity of a particular radioactive substance is lost due to radioactive decay.

Health Physics: The science concerned with recognizing and evaluating the effects of ionizing radiation on the health and safety of people and the environment, monitoring radiation exposure, and controlling the associated health risks and environmental hazards to permit the safe use of technologies that produce ionizing radiation.

High radiation area: An area in which external radiation levels could exceed 1 mSv/hr (100 mrem/hr) 30 cm from a radiation source.

Hot spot: The region in a radiation or contamination area where the activity, or intensity, is highest.

Internal radiation exposure: Ionizing radiation (alpha and beta particles and gamma radiation) resulting from an intake of radioactive substances within the body.

Ionization chamber (IC): A portable radiation detection and measuring instrument used to survey the external radiation present. The IC will read the exposure rate in units of Rad/hr. This is recommended portable instrument to use when measuring exposure rate.

Ionizing radiation: A form of radiation, which includes particulate (alpha particles, beta particles, neutrons and protons) and electromagnetic radiation (also called photons; x-rays and gamma rays).

Isomeric transition: A form of radioactive decay where a gamma photon is emitted by a nucleus in an excited metastable state.

Latent Period: The period of time between exposure to ionizing radiation and the onset of a specified biological effect.

$LD_{50/30}$: An acute radiation dose expected to cause death to 50 % of an exposed population within 30 days. This dose threshold ranges from 4 to 5 Sv (400 - 450 rem).

Lens Dose Equivalent (LDE): The calculated dose equivalent to the lens of the eye at a tissue depth of 0.3 centimeter (300 mg/cm^2).

Linear Energy Transfer (LET): A term used to describe the average energy deposited in matter per unit length of travel for a charged particle.

Minor: An individual less than 18 years of age.

Neutron, thermal: A neutron that has, by collision with other particles, reached an energy state equal to that of its surroundings.

Nonstochastic or Deterministic Effects: Health effects that will occur due to ionizing radiation exceeding an acute dose threshold.

Occupational dose: The dose received by an individual in the course of employment in which the individual's assigned duties involve exposure to radiation and/or to radioactive material from registered, unregistered, licensee, registrant or other person.

Photon: A quantum or packet of energy in the form of electromagnetic radiation. Gamma rays and x-rays are examples of photons.

Pig: A shielding container (usually lead) used to store or ship radioactive materials.

Prefixes for fractions or multiples of the basic units:

pico = p = 10^{-12}	kilo = k = 10^{3}
nano = n = 10^{-9}	mega = M = 10^{6}
micro = µ = 10^{-6}	giga = G = 10^{9}
milli = m = 10^{-3}	tera = T = 10^{12}

Public dose: The dose received by a member of the public from exposure to radiation and radioactive material released by a licensee, or another source of radiation in a licensee's or registrant's unrestricted areas.

Quality factor: A factor which represents the effectiveness of different types of ionizing radiation and is used in calculating the dose equivalent.

Radioactivity: The process by which a nucleus of an unstable atom loses energy by spontaneously emitting energy in the form of radiation.

Radiation area: An area in which external radiation levels could exceed 50 µSv/hr (5 mrem/hr) 30 cm from a radiation source.

Restricted area: An area in which access is limited by the licensee or registrant for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials.

Sealed source: Any special nuclear material or byproduct encased in a capsule designed to prevent leakage or escape of the material.

Shallow Dose Equivalent, Whole Body (SDE, WB): Shallow dose to the whole body due to external radiation sources at a tissue depth of 0.07 centimeter (7 mg/cm^2).

Somatic effects of radiation: Effects of radiation limited to the exposed individual. Not genetic.

Specific gamma-ray constant, Γ: The exposure rate at a defined distance produced by the unfiltered gamma rays and x-rays from a point source of given activity for a specific radionuclide.

Stochastic effects: Effects that occur by chance and which may occur without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose. In the context of radiation protection, the main stochastic effect is cancer.

Total Effective Dose Equivalent (TEDE): The sum of the effective dose equivalent (external exposures) and the committed effective dose equivalent (internal exposures).

Total Organ Dose Equivalent (TODE): The total internal dose with respect to the organ which receives the highest dose.

Very high radiation area: An area in which external radiation levels could exceed 5 Gy/hr (500 rad/hr) 30 cm from a radiation source.

Whole body: For purposes of external exposure, head, trunk (including male gonads), arms above the elbow and legs above the knee.

Wipe test: A test for radioactive contamination in which the suspected area is wiped with a filter paper and then tested for the presence of radioactivity. Also called a smear or swipe test.

RADIOACTIVITY AND IONIZING RADIATION

The Nature of Radioactivity

Radioactivity is the property of certain nuclides of spontaneously disintegrating, with the emission of radiation such as alpha, beta or gamma, in order to attain a more stable energy configuration. During this decay, the nuclide is often transformed from one element to another. The half-life is the time required for a sample of a specific radionuclide to decay to half the original amount, and is a characteristic of each radionuclide. Half-lives for radionuclides range from less than a second to billions of years.

Radiation Terms & Units

It is important to know that two sets of units exist. In the United States a special system of units is used, (curie, roentgen, rad and rem) and more commonly known is the International system of units or, SI system (becquerel, gray, and sievert). Prefixes are commonly used, and defined in the glossary of this manual for reference.

Energy

Ionizing radiation energies are expressed in terms of the *electron volt* (eV). The *joule* (J) is the SI unit for energy, but is rarely used in this application.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

Activity

The strength of the radioactive material is measured in terms of 'Activity.' The *becquerel* (Bq) is the SI unit that has replaced the traditional unit of the *curie* (Ci) in scientific and regulatory literature. Activity is also often expressed in terms of the number of radioactive decay per unit time, i.e. *disintegrations per second* (dps) or *disintegrations per minute* (dpm).

1 Bq = 1 dps = 60 dpm

1 Ci = 3.7E+10 Bq = 37 GBq = 2.22E+12 dpm

1 µCi = 3.7E+4 Bq = 37 kBq = 2.22E+6 dpm

Over time, the activity of the radioactive material will decay at an exponential rate specific to the radionuclide. The following equation allows us to calculate the activity *A(t)* at any time *t* after the initial activity Ao is measured:

$$A(t) = A_0 \times e^{-\lambda * t}$$

$$\lambda = \frac{ln(2)}{T½}$$

where A_0 is the initial activity (or reference activity), and λ is the decay constant and T½ is the radioactive half-life.

Exposure

Exposure defines the amount of ionizations produced in air by photon radiation. The roentgen (R) is the unit to describe the radiation exposure in air.

$$1\text{R} = 2.58\text{E}^{-4} \text{ coulombs/kg}_{air}$$

1R = 1000 mR

1 R = 0.95 rad = 0.95 rem*

**this quantity is the equivalent dose in water or soft tissue in the human body from 1 R of photon radiation.*

The rate of exposure from a point source can be calculated with the following equation:

$$I = \frac{A\Gamma}{d^2}$$

where I is the exposure rate in R/h, A is the activity of the source in mCi, d is the distance from the source in cm, and Γ is the specific gamma ray constant for that radionuclide.

Absorbed Dose

Absorbed dose is defined as the amount of ionizing radiation energy deposited per unit mass in an organ or tissue. The traditional unit to describe absorbed dose is the *rad*, and the *gray* (Gy) is the SI unit.

1 Gy = 1 J/kg

1 rad = 0.01 Gy = 10 mGy

Dose Equivalent, H

The types of ionizing radiation all interact with human tissue differently and Equivalent dose is a dose quantity that takes this into account by use of a Quality Factor, *Q*. Equivalent dose is expressed in the traditional unit, rem, or the SI unit, sievert (Sv).

H = D x Q

1 rem = 0.01 Sv = 10 mSv

Quality Factor, Q

The relative effectiveness of a type of ionizing radiation is accounted for in calculating the dose equivalent by use of the Quality Factor, *Q*.

Type of Radiation	Q (rem/rad) or (Sv/Gy)
γ, X, β and e^-	1
Protons	10
Alphas	20

The Properties of Radiation

The radiation emitted from radioactive materials differs from other types of radiation such as heat, light, radio waves, etc., in that it has sufficient energy to cause ionizations in the materials in which it is absorbed. Thus it is referred to as *ionizing radiation*.

Alpha particles (α)

Alpha particles are slow, heavy, high linear energy transfer (LET) particles having a positive electric charge. They consist of 2 neutrons and 2 protons and are identical with the nucleus of the He-4 atom. Alpha radiation penetrates poorly, usually being stopped by a sheet of paper, and travels only a few centimeters in air. Consequently, the alpha radiation from alpha-emitting material outside the body, even if the material is on the surface of the skin, does not pose a significant hazard. However, if the alpha-emitter is taken into the body by inhalation, ingestion or through an open wound, it can be hazardous. Because the energy is deposited over so short a range, alpha particles leave a very dense trail of ionization and can therefore be more damaging biologically than more penetrating radiation. Alpha particles are generally emitted only by elements of high atomic number (82 or higher) and are usually accompanied by one or more of the other types of radiation. An atoms' atomic number decreases by two and its mass number decreases by four when it emits an alpha particle.

Beta radiation (ß)

Beta radiation consists of very light particles, each carrying an electrical charge. Negatively charged beta particles are identical with electrons except that they originate in the nucleus. Positively charged beta particles are referred to as positrons and are the antimatter equivalent of the electron. Beta particle energies and penetrating power are dependent on the radionuclide from which they are emitted. Typically, the range could be a few meters in air or a few millimeters in tissue. Beta particles are an external hazard for the eyes and sensitive layers of the skin as well as an internal hazard. Many beta emitters also emit gamma radiation. Beta particles are emitted as a neutron is transformed to a proton by neutron abundant nuclei: $n \rightarrow p^{+} + e^{-}$. Similarly, for proton abundant nuclei, a proton may change into a neutron, emitting a positron in the process: $p^{+} \rightarrow n + e^{+}$.

The fraction of the decay energy possessed by the beta particle varies from decay to decay, ranging from nearly zero to E_{max}. The *average* beta energy is approximately 1/3 E_{max}.

Gamma radiation (γ)

Gamma radiation is a form of electromagnetic radiation, and may also be called a photon. It is extremely penetrating and depending on the activity and energy it may require significant thicknesses of lead or other materials to reduce the radiation level to a safe and acceptable exposure rate. External exposure to gamma radiation is considered to be both an internal and external hazard due to its ability to penetrate dense materials.

A radionuclide may emit gamma radiation after it has decayed by one of the processes previously discussed if the resulting nucleus is left in an excited energy state. The energy of the gamma radiation(s) emitted is characteristic of the particular radioisotope.

X-Ray radiation is comparable to gamma radiation, however, it tends to be lower in energy and differs in origin; X-ray radiation is emitted from the electron shell.

BASIC PRINCIPLES OF RADIATION PROTECTION

When working with radioactive materials, it is important to follow the *ALARA* principle, which refers to keeping your radiation dose **A**s **L**ow **A**s **R**easonably **A**chievable.

A.L.A.R.A.

Maintaining *ALARA* incorporates many factors, but the most notable methods are to limit your exposure time, increase your distance from the source and to use proper shielding for the radionuclide(s).

Exposure Time
The total absorbed dose is proportional to the duration of the exposure. Experiments should be carefully planned to minimize exposure time. Often, practicing the procedure using simulated sources ("dry runs") may be useful.

Distance from the Source
Since the exposure rate varies by the 'inverse square law," it increases dramatically as the distance from the radiation source decreases and, therefore, it is important to minimize time spent in close proximity to large sources. The inverse square law is defined by;

$$I_1 d_1^2 = I_2 d_2^2 \qquad I_2 = I_1\left(\frac{d_1}{d_2}\right)^2$$

I_1 = exposure at distance d_1 from radiation source

I_2 = exposure at distance d_2

Shielding
Proper radiation shielding can dramatically reduce your radiation dose. Information on shielding radiation can be found on the following page.

Containment of Radioactivity

The factors discussed above pertain to protection against sources which are external to the body (the external hazard). Containment of radioactivity concerns minimizing the contamination from a source, thereby providing protection against intake of radioactivity (the internal hazard). Sources in the form of liquid, gas, or finely divided solid may be easily dispersed and result in contamination of the environment and/or of the individual. Special care must be taken to avoid contamination from ingestion or inhalation of such non-sealed sources.

Protection against internal exposure is primarily a matter of good housekeeping and cleanliness. When radioactive liquids are being used great care should be taken to avoid spilling or smearing them. Experiments using liquid sources should be confined to a single location, and should be set up on washable metal or plastic trays lined with absorbent paper so that spills will be easy to clean up. Containers and contaminated materials should be kept well to the rear of the work area. Bench coverings should be monitored and changed frequently. Protective clothing such as lab coat and gloves should always be worn and changed or washed frequently. And of course no food or beverages may be in the lab.

SHIELDING OF RADIATION SOURCES

Radiation sources must be shielded so that personnel exposures are kept as low as reasonably achievable (ALARA). In addition to being ALARA, the radiation dose levels must be maintained at or below the specified Maximum Permissible Dose Levels for unrestricted areas. Unrestricted areas are areas in which members of the public and non-radiation workers have access; these areas must be maintained at or below 20 μSv/hr (2 mrem/hr).

Beta Shielding

Β-emitting radionuclides emit beta particles with kinetic energies specific to the nuclide. The range of a beta particle is dependent on its energy; the greater the energy is the greater the particle will traverse.

When shielding beta particles, it is important to note that as the electron travels and interacts through matter it may produce bremsstrahlung x-rays. The amount of bremsstrahlung produced is proportional to both the beta-particle's energy and to the atomic number of the shielding material.

The fraction, *F*, of Beta energy converted to Bremsstrahlung can be calculated by:

$$F = 3.5 \times 10^{-4} ZE$$

where *Z* is the atomic number of the absorbing material, and *E* is the Max Beta Energy, in MeV.

The most effective shielding arrangement for large quantities of high energy β emitting radionuclides is displayed in Figure 1, and some recommended shielding arrangements for commonly used beta-emitting radionuclides are listed in Table 1.

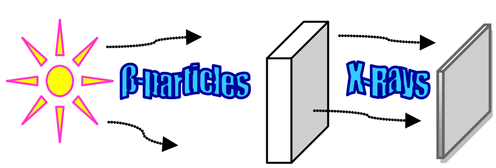


Figure 1. *Shielding arrangement for large quantities of high energy β-emitting radionuclides to eliminate exposure due to Bremsstrahlung radiation by first using a low-Z material immediately followed by a high-Z material.*

Table 1. Recommended Shielding Arrangements for commonly used β-emitting radionuclides

β-emitters	Recommended Shielding
^{3}H, ^{14}C, ^{33}P, ^{35}S, ^{45}Ca, ^{55}Fe	None required - mCi quantities not an external radiation hazard
^{32}P	3.4 mm glass, 6.3 mm plastic
^{36}Cl	1.1 mm glass, 2.0 mm plastic
^{63}Ni	< 0.1 mm glass, 0.1 mm plastic
^{90}Sr, ^{90}Y	4.9 mm glass, 9.2 mm plastic

Photon (X & γ Ray) Shielding

As previously mentioned X-rays and gamma rays are ionizing electromagnetic radiation, or photons; the two types of radiation differ in origin. Shielding methods and calculations will be consistent for radionuclides producing either X or gamma rays, dependent on the radionuclides energy and other forms of radiation produced.

Photons are highly penetrating and cannot be completely attenuated by a certain thickness of shielding material. Instead, a certain thickness of material attenuates the radiation by a fixed fractional amount. The half value layer (HVL) and tenth value layer (TVL) are commonly used in photon shielding calculations for determining the shielded or unshielded intensity of the radiation exposure rate or dose rate. The half value layer is the thickness of a particular material that will attenuate the radiation intensity in half; the tenth value layer is the thickness of a particular material that will attenuate the radiation to one tenth of the original intensity. HVL and TVL may be determined as;

$$HVL = \frac{\ln(2)}{\mu} = \frac{0.693}{\mu}$$

$$TVL = \frac{\ln(10)}{\mu} = \frac{2.3026}{\mu}$$

$$TVL = 3.32 \times HVL$$

where μ is the linear attenuation coefficient for the shielding material.

Shielding materials of high density and high atomic number, such as lead, are the most effective shields for x- and gamma rays since they require less thickness and weight to attain a given attenuation factor. However, high density concrete, steel or other materials can provide the same degree of protection if used in appropriately greater thicknesses.

If a particular radiation exposure rate must be met, the thickness, x, of shielding material can be solved for using the intensity equation for monoenergetic electromagnetic radiation;

$$I = I_o e^{-\mu x}$$

where I_0 is the unshielded intensity, I, is the shielded intensity, I.

The intensity may also be calculated using the value for TVL or HVL:

$$I = I_o e^{-.693x/HVL}$$

or

$$I = I_o e^{-2.3x/TVL}$$

The HVL and TVL for shielding material are dependent on the radionuclide, but more specifically it is characteristic of the photon energy the radionuclide produces. Table 2 provides the HVL and TVL for shielding commonly used gamma emitting radionuclides with lead as the shield.

Table 2 is based on the ideal situation where the beam of radiation is narrow and the total shield thickness is small. When a thick shield is required and the radiation beam is broad, the actual attenuation will be somewhat less due to the presence of additional radiation scattered backward (known as "buildup"). If accurate calculations are necessary, dose buildup factors must be used.

Table 2. HVL and TVL values of Lead for commonly used γ-emitting radionuclides[12]

γ-emitters	γ-Energy (keV)	HVL(mm)	TVL(mm)
^{18}F	511	6	17
^{22}Na	1275	10	37
^{51}Cr	320	2	7
^{60}Co	1333	16	46
^{99m}Tc	141	<1	1
^{124}I	1691	8	31
^{137}Cs	662	8	24

RADIATION SURVEYS AND DETECTION

When a laboratory uses gamma or high energy beta emitting sources, area exposure rates should be measured to determine radiation levels in both restricted and unrestricted areas. An ion chamber is a high accuracy portable survey meter which is recommended when relatively high exposure rates must be measured (such as in a nuclear medicine department). The most commonly used portable survey meter is the Geiger-Mueller (GM) pancake probe. The GM can effectively detect low levels of radiation and is economically practical.

Detection of Surface Contamination

Instrument Survey

Contamination on surfaces can be detected by using an appropriate instrument to scan suspect surfaces. A thin window Geiger counter can be used in surveys for most radioisotopes, although it has poor detection efficiency for weak beta emitters such as ^{14}C and cannot detect ^{3}H. As a GM detector is very inefficient for photon emitters, a sodium iodide scintillation crystal detector is recommended for users of ^{125}I or other low energy gamma emitters.

When performing a survey to detect contamination, the detector should be held as close as possible to the surface to be scanned without actually touching the surface (approximately 1 cm), and moved slowly to give the instrument a chance to respond to any radiation source present. An instrument with an audible signal is helpful because it will give an immediate indication of a radiation source, whereas the needle on the meter requires several seconds to respond. Note that contamination has the greatest tendency to be found on horizontal surfaces (where dust also collects) and on items that people frequently touch, i.e. door knobs, telephones, pencils, etc.

It is best to *keep probes covered during work*, which could result in splash contamination of the probe's surface. When surveying work areas for beta emitters, all plastic caps and/or film, should be removed from the probe for optimal efficiency.

Removable Contamination Survey

These surveys are conducted to determine the presence of loose surface contamination; radioactivity which could potentially become airborne or transferred to personnel through direct contact. A removable contamination survey, or wipe test, is conducted by rubbing a piece of filter paper or Q-tip on the surface to be tested and analyzed for radioactivity in an appropriate counter. Wipe testing is the only commonly available method for detecting ^{3}H contamination.

Efficiency of a Radiation Detector for Measurement of Radioactivity

$$\text{Eff} = \frac{\text{CPM}}{\text{DPM}}$$

Where;

Eff = efficiency of the radiation detector (count/disintegration)

CPM = counts per minute registered by the detector

DPM = actual number of disintegrations per minute of the radionuclide source

GUIDLINES FOR SELECTING PORTABLE RADIATION SURVEY METERS

Personnel needing radiation detection equipment should consult with VEHS Radiation Safety to ensure the instrument selected provides the optimal combination of detection capability for the radiation being measured, ease of use, reliability, and the availability of calibration and maintenance support. All meters will not detect all radionuclides. The following guidelines are designed to assist in selecting meters that are appropriate for detecting various types of radiation:

1. For detecting beta emitters with a maximum beta energy greater than or equal to 150 keV such as ^{14}C, ^{35}S, or ^{32}P, either of the following are recommended:

   a) A Geiger-Mueller (GM) detector with a maximum window thickness of 1.7 mg/cm^2. Pancake style GM's are recommended over end window GM's because pancake style GM's are generally more efficient for low energy beta emitters (^{14}C or ^{35}S) and the pancake's larger window surface area makes it easier to monitor large areas for contamination.

   b) A beta scintillator with a plastic scintillation detector. The cost of a GM is significantly lower than a beta scintillator, but the scintillator is generally more efficient.

      Note: A side window GM will not be approved for use as a detector for beta emitting radionuclides, since this type of probe will not detect ^{14}C or ^{35}S and is significantly less efficient than either end window or pancake GM's.

2. For surveying radiation sources that generate x- or gamma rays with energy greater than 30 keV, a GM pancake, GM end window, or a GM side window is usually adequate. As mentioned above, the pancake style is preferable since it has a larger window surface area that assists in monitoring large areas for contamination. However, solid detectors (i.e. NaI) are much more efficient and may be more appropriate if very low levels of radiation need to be detected.

3. For PI's approved for ^{125}I or other radiation sources that generate x- or gamma rays with energies less than 30 keV, a low energy 1" x 1 mm NaI(Tl) gamma scintillation detector is recommended.

4. For PI's approved for both beta and low energy gamma emitters (i.e. less than 30 keV), one of the following should be purchased: (1) two meters (one with a GM probe and one with a NaI probe), (2) two probes for one meter (a GM probe and a NaI probe), or (3) a beta-gamma sandwich scintillation detector. The beta-gamma scintillation detector is a combination of two scintillation probes previously described.

5. Ion chambers are used to detect x- and gamma radiation fields. They have an energy independent response and are therefore recommended for any dose rate measurements that are made to demonstrate compliance with Vanderbilt's license and/or State regulations. Ion chambers are not practical for the detection of contamination.

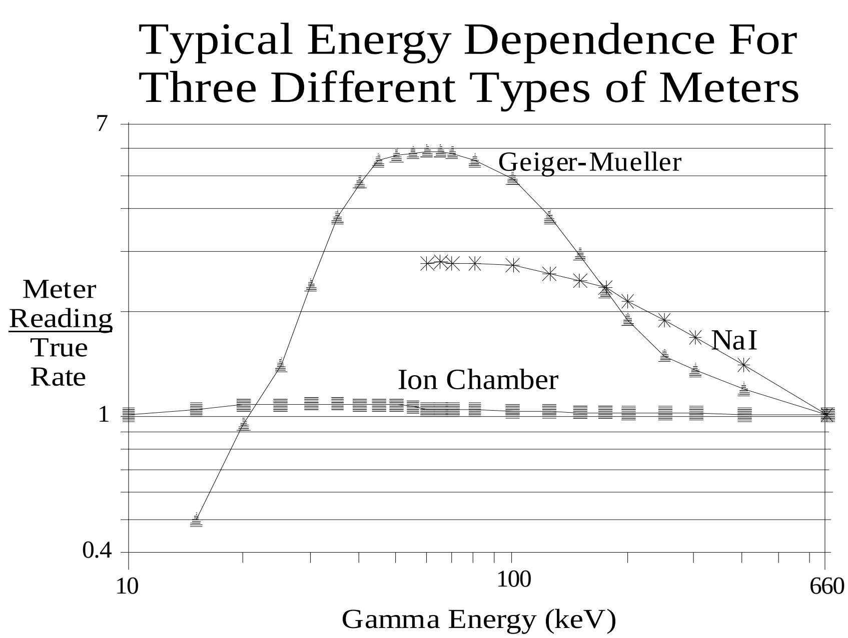
Probes that are separate from the body of the meter are preferable. Built-in probes are often difficult to repair or replace without sending them back to the manufacturer. Separate probes can usually be readily replaced or repaired.

Be wary of purchasing a meter if a vendor cannot or will not provide the above information. If necessary, VEHS can provide vendor information.

RADIATION SURVEY METER CHARACTERISTICS

Meter Type	**Geiger-Mueller (GM) Counter**		**NaI Crystal Scintillator Probe**	**Ion Chamber**
Radiation detection method	CPM, CPS and/or Radiation levels [mR/h]		CPM or CPS	Radiation levels [mR/h]
Detectors available	-Thin end window, 2-5 cm^2 area -Thin window pancake, 20 cm^2 area (better for finding small areas of contamination)		-1 mm thick crystal covered with plastic -1 inch thick with metal cover (has higher background but better for detecting high energy γ 's)	-A variety of chamber sizes is available for measurement of very low, medium level, or very high radiation levels
Radiations detected	Low & high energy β's Low & high energy γ's α's		High energy ß's (with 1 mm crystal) Low & high energy γ's	Low & high energy γ's
Radioisotopes and radiation not detected	^{3}H, ^{63}Ni, ^{125}I		^{3}H, ^{14}C, ^{63}Ni Low energy ß's α's	^{3}H, ^{14}C, ^{63}Ni Low energy ß's α's
Typical efficiencies	<u>pancake</u>	<u>thin window</u>	<u>1 mm crystal</u>	
^{14}C	6%	4%	0%	
^{32}P	38%	26%	60%	
^{125}I	0.01%	0.01%	14%	
^{137}Cs	1%	1%	5%	
Typical "background"	80-100 cpm		2,500 cpm	0.03 mR/h
Features & Characteristics	-Versatile -Relatively inexpensive -Audible signal -Sensitive for ß's		-Very sensitive for γ's -Available with single channel analyzer (SCA) to reduce background levels -Audible signal	-Energy independent response (most accurate for measuring radiation levels) -Can measure high radiation levels
Disadvantages	-Energy dependent -Loses counts and may jam at high count rates -Window is breakable		-Energy dependent -High background levels -Affected by magnetic fields such as the earth's	-Slow response; not ideal for contamination detection -Very expensive

Energy Dependence: Radiation detection instruments are not equally accurate at measuring all radiation energies, as shown by the graph. All instruments were calibrated to be accurate at 660 keV.



RADIATION WARNING SIGNS AND LABELS

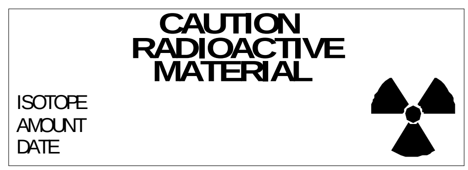
Radiation workers must ensure that appropriate radiation warning signs are posted in all areas, and on all containers, where significant levels of radiation or significant amounts of radioactive materials are present. The signs and labels will be initially supplied by Vanderbilt Environmental Health & Safety (VEHS); however, each investigator must purchase his or her own if there is a continuing need for new labels.

General Requirements

1. Signs and labels must describe the actual situation. For example, do not post a "Caution - Radiation Area" sign unless a Radiation Area (i.e. radiation source capable of producing a dose of 5 mrem in an hour at 30 cm from the source) actually exists. Do not use a radiation warning sign as a "scare tactic" to keep outsiders away from items or areas where there is no radiation hazard.
2. Radiation signs and labels must be removed when the reason for posting no longer exists. Radioactive labels must be removed and obliterated from containers that are empty and verified to be uncontaminated prior to being placed in the regular, nonradioactive trash.
3. More than one sign may be required in some situations. For example, a Radiation Area may also require a "Caution-Radioactive Materials" sign.

Types of Signs and Labels

1. **RADIOACTIVE MATERIAL label -** must be posted on containers when activities exceed the Container Posting Level (CPL). The label should also identify the isotope and give the activity & date.

   Exception: Containers which contain radioactive materials on a temporary basis and which are being attended to by an individual who will assure that no one will be exposed in excess of regulatory limits.
   Comments: Radioactive material and potentially contaminated items must be identified for the benefit of non-involved personnel who may be in the lab in the absence of laboratory staff, such as janitors and emergency personnel.

2. **RADIOACTIVE MATERIAL sign -** must be posted on storage cabinets, fume hoods, refrigerators, room doors, etc, which contain **10 times** the Container Posting Level. However these signs are also used institutionally to indicate rooms where radioactive material use or storage is authorized, regardless of whether any radioactive material is present.
   Exception: The radioactive material is present for less than 8 hours and there is someone in attendance to ensure that no one will be exposed in excess of the regulatory limits.

3. **RADIATION AREA -** required in areas where the dose rate to the whole body can exceed 0.05 mSv (5 mrem) in 1 hour at 30 centimeters from the source of radiation or 1 mSv/5days (100 mrem/5 days).

4. **HIGH RADIATION AREA -** required if the dose rate to the whole body can exceed 1 mSv (100 mrem) in 1 hour at 30 centimeters from the source of radiation. Personnel monitoring equipment must be used in these areas. In addition, each entrance to the area must have visible or audible warning signals, or control devices must reduce exposure upon entry into the area.

5. **Shipping labels -** Various shipping labels are required to ship packages of radioactive materials. The diamond-shaped label shown at the right indicates the radiation dose rates emitted from the package:

Radioactive Package; Label	Max Surface Dose Rate (mrem/hr)	Max Dose Rate at 1 meter (mrem/hr)
Type A; White-I	0.5	N/A
Type A; Yellow-II	50	1.0
Type A; Yellow-III	200	10.0

*The dose rate at 1 m is known as the "transport index."

A package with a Type III label emits significant levels of radiation; it should not be left unshielded in occupied areas.

Contact VEHS to ship any amount of radioactive material

6. **RADIOACTIVE HOT SINK -** sinks designated for disposal of radioactive wastes must be marked with this sign.

7. **RADIOACTIVE WASTE -** containers used for solid radioactive wastes must be marked on at least two sides with this sign. In addition, the cans must be lined with the yellow, specially-marked radioactive waste bags.

8. **RADIATION-PRODUCING EQUIPMENT** must be posted with this warning at a location near the energizing switch on each control panel.

9. **HIGH INTENSITY X-RAY BEAM -** This warning must be posted near analytical x-ray machine tube housings, clearly visible to any individual who may be working in close proximity to the primary beam path.

BIOLOGICAL EFFECTS OF RADIATION

Soon after Wilhelm Konrad Roentgen announced his discovery of X-rays on January 4, 1896, it was discovered that ionizing radiation can produce harmful biologic effects. One of the first reports in the scientific literature appeared in Science (N.S. Vol III, No. 67, excerpt):

> TO THE EDITOR OF SCIENCE:
> *As opportunity offered, experiments have been made in our laboratory with the X-rays since a few days after the appearance of Prof. Roentgen's paper....*
>
> *The most interesting observation is a physiological effect of the X-rays. A month ago we were asked to undertake the location of a bullet in the head of a child that had been accidentally shot. On the 29th of February, Dr. William L. Dudley and I decided to make a preliminary test of photographing through the head with our rather weak apparatus before undertaking the surgical case. Accordingly, Dr. Dudley, with his characteristic devotion to the cause of science, lent himself to the experiment.*
>
> *The tube was about one-half inch distant from his hair, and the exposure was one hour. The plate developed nothing; but yesterday, 21 days after the experiment, all the hair came out over the space under the X-ray discharge. The spot is now perfectly bald. We, and especially Dr. Dudley, shall watch with interest the ultimate effect.*
>
> *John Daniel*
> *Physical Laboratory*
> *Vanderbilt University*
> *March 23, 1896*

Acute Radiation Injury

Acute injuries are those which appear within a month or two after exposure to radiation. All short term effects require large doses of radiation. The degree of injury depends on the magnitude of the dose as well as other factors such as the type of radiation, the body area which is exposed, the exposure rate, and the time duration between fractionated exposures.

The acute radiation syndrome results from the exposure of a large portion of the body to large amounts of radiation. Clinical manifestations of large doses include general toxic symptoms such as weakness, nausea, fatigue and vomiting, and specific symptoms caused by damage to the GI tract, the blood-forming organs and the central nervous system. Sensitivity to the effects of radiation exposure varies; the $LD_{50/60}$ is the whole body dose which is lethal to 50% of those exposed within a period of 60 days. Estimated values for humans:

$LD_{50/60}$	= 3-4 Gy (340 rads)	*With minimal treatment*
	= 5 Gy (510 rads)	*With careful supportive treatment*
	= 10 Gy (1050 rads)	*With "heroic" clinical treatments such as marrow transplants*

Radiation injuries to the skin include:

<u>Epilation</u> (loss of hair) may occur for skin doses exceeding 3 Gy (300 rads).

<u>Erythema</u>, equivalent to a mild sunburn (first degree burn), may occur after several gray (if received in a brief exposure). It can appear as late as 2-3 weeks after exposure if the exposure is relatively low.

<u>Transepidermal injury</u> is equivalent to a second degree burn. Erythema develops, followed by blisters that break open leaving painful wounds subject to infection. Requires 10-20 Gy (1000-2000 rads).

<u>Dermal radionecrosis</u> (skin death) requires doses in excess of 20 Gy (2000 rads). The lesions resemble those caused by a severe scalding or chemical burn.

<u>Chronic radiation dermatitis</u>, an eczema-like condition, may be caused by frequently repeated skin exposures over a period of years. Skin cancer may also occur. The effective dose for skin cancer for x-ray workers is thought to be of the order of several hundred gray if accumulated at the rate of about 0.01 gray per day.

Latent Effects of Radiation Exposure

Stochastic Effects: Cancer

The long-term or latent effects of radiation exposure are ordinarily of more concern than the acute effects since it is assumed that they can be induced by low levels of radiation. Risk data for the induction of cancer by radiation comes primarily from follow up studies on human population groups that received rather large doses of radiation, generally more than 100 rad. Data has been analyzed for groups such as the Japanese survivors in Hiroshima and Nagasaki and patients treated therapeutically for various conditions (thymic enlargement, cervical cancer, tinea capitis, hyperthyroidism, ankylosing spondylitis, etc). A great deal of data has been collected and analyzed by national and international agencies such as the ICRP (International Council on Radiological Protection) and the National Academy of Sciences (BEIR reports).

If a malignancy appears it follows a **latent period** which ranges from 2 to 10 years for leukemia and 10-35 years for solid tumors. The table below presents cancer risk in various organs of the body following an organ dose of one rem.

Cancer Site	Fatal Cancers per Million Persons per 1 rem	
Leukemia	20	
Breast	50	(females)
Lung	25	
Thyroid	5	(males)
	10	(females)
Bone	5	
Large intestines	10	
Stomach	10	
Brain	10	
Liver	10	
Other organs	10	(total for all)

The overall risk to the ***population*** of a fatal cancer from **whole body radiation** is approximately **4 in 10,000 per rem** of absorbed dose. (This should be compared to the "natural" incidence of cancer death in the United States: One in six deaths is a cancer death.) Although the risk estimates are derived from populations receiving large doses of radiation, the **linearity hypothesis** states that the risk per rad is the same at low doses as at high doses. This is probably an over simplification which results in an overestimate of the risk at low doses since it does not take into account the greater efficiency of cellular repair processes at low doses and low dose rates. For lack of any definitive data from low dose studies, however, these estimates are assumed to apply to low doses. Another conservative assumption is that there is **no threshold** for the induction of cancer, that is, any dose of radiation, no matter how small, carries with it some risk. This is the underlying rationale behind a basic operating principle in radiation protection, the **ALARA** philosophy, which states that all radiation exposures should be kept As Low As Reasonably Achievable.

Example: A radiation worker receives an average dose equivalent of 0.25 rem/yr for 40 years, or 0.25 x 40 = 10 rem. The increased risk of a fatal cancer is therefore 10 rem x 0.0004 fatal cancers/rem = 0.004. Since the natural risk of a fatal cancer is 1 in 6, or 0.167, the worker's total probability of a fatal cancer is 0.004 + 0.167 = 0.171.

Effects of Fetal Exposure

Developing mammals, including man, are particularly sensitive to radiation during the intrauterine and early postnatal periods of life. At moderate to high doses a close correspondence has been demonstrated between man and various experimental species. It is therefore possible to fill in gaps in the human exposure data, especially at low exposure levels where it is very difficult to obtain direct evidence of effects in human populations.

Radiation during preimplantation stages probably produces no abnormalities in survivors, owing to the great developmental plasticity of mammalian embryos. The major risk at this stage is implantation failure.

Radiation at later stages, however, may produce developmental abnormalities, growth retardation or functional impairments, if doses are sufficient. Obvious malformations are particularly associated with irradiation during the period of major organogenesis, which in man extends from approximately week 2 to week 9 after conception. Functional abnormalities and growth retardation may be produced during the fetal and early postnatal periods. Data from the Japanese survivors indicates that the period of 15-18 weeks is important with respect to development of the brain and intelligence, with radiation damage being produced by acute doses below 10 rad.

However, it is likely that there are threshold doses for most mal developments, and lowering the dose rate, reduces the damage. Until an exposure has been clearly established below which even subtle damage does not occur, it is prudent not to subject the abdominal area for women of child-bearing age to quantities of radiation appreciably above background, unless a clear health benefit to the mother or child can be demonstrated (BEIR III, 1980). For pregnant radiation workers, the maximum permissible dose to the fetus for the entire gestation period has been established as 5 mSv (500 mrem).

Other Somatic Effects: Sterility, Cataracts, and Life Shortening

Acute exposure (dose received in a single short exposure) of the testes to radiation at high doses - much higher than 400 rads - could result in permanent sterility. Acute exposure of the ovaries to about 400 rads could result in impaired fertility. Little is known about the effects of prolonged low-dose exposure of the gonads.

Cataract formation is considered to be a threshold phenomenon, with doses of at least 200 rads being required to produce a minimal clinically significant cataract. At or above a threshold of 500 rads may yield more serious progressive cataracts; the latent period varies from 0.5 to 35 years.

Although life shortening of a population group is a consequence of high radiation exposure, a very large body of evidence indicates that this effect is due to the induction of specific cancers. (UNSCEAR, 1982)

Genetic Effects

Exposure of cells to ionizing radiation may produce gene mutations and chromosome aberrations. Irradiation of the gonads and the germ cells are believed to cause harmful mutations transmitted to the descendants of the irradiated individual. Due to lack of data in radiation-induced genetic effects in humans, laboratory mouse data provides the basis for estimating the genetic risks to human populations.

It is assumed that there is **no radiation threshold** for the induction of genetic effects. From mouse studies it is known that the female is significantly less sensitive to genetic effects from radiation exposure than the male. Exposure at high dose rates are found to produce more damage per rad than exposure at low dose rates; evidence that **repair mechanisms** in the cell nucleus repair much of the radiation induced damage.

The National Council on Radiation Protection (1987) has estimated that the average ***population*** risk of a serious genetic defect appearing in the first two generations (i.e., in children or grandchildren of the exposed individual) as **0.8 in 10,000 per rem** of gonadal exposure. This is the average risk for males and females; as noted above, the risk for females is less than for males, the risk being in the range of 0-0.2 genetic defects per rem exposure to 10,000 women parents.

This risk should be compared with the estimate of the overall incidence of serious human disorders of genetic origin, which occur in roughly 10% of live born offspring, or 1,000 serious genetic disorders per 10,000 live births.

Example of risk calculation: If a radiation worker received the limit of 5 rem/yr for 20 years prior to giving conception, the risk to the population of having a child or (later) a grandchild with a serious genetic defect caused by the radiation is expected to be:

$$100 \text{ rem} \times (0.8 \times 10^{-4} \text{ defects/rem}) = 0.008$$
(or 1 in 125)

Since the normal incidence is 10%, or 0.100 (or 12.5 in 125), the total probability would be 0.108 (or 13.5 in 125).

DECONTAMINATION

Personnel Decontamination

Contamination of the skin with beta-emitting radionuclides can result in very high dose rates to the skin. Thus, prompt removal of skin contamination is important, both to minimize skin exposure and to prevent transfer of radioactive material into the body by absorption through the skin or through cuts in the skin.

Skin should be monitored with an appropriate survey meter during use of radioactive materials. Be sure to pay attention to any folds or crevices in the skin. If any contamination is found on the skin, the following steps should be followed:

- Decontaminate body surface immediately by washing the affected area with water and a mild soap or detergent, checking the intensity of the contamination with a survey meter periodically.
    - The skin acts as protective layer to prevent radioactivity from entering the body, however, skin penetration could occur if excessive washing persists and irritates the skin.
- If washing the radioactivity does not effectively remove all contamination, notify the Radiation Safety Officer to obtain assistance.
- Individuals who have punctured the skin with a contaminated object should induce the wound to bleed and wash the wound under running water.
- *<u>Report all radiation incidents involving intake of radioactivity or personnel contamination to Institutional Safety.</u>*

Decontamination of Equipment and Facilities

1. Monitor to determine level and location of contamination.
2. Confine the contamination as much as possible. Mark off contaminated areas with masking tape, chalk, etc. Care must be taken not to track contamination out of the contaminated area; frequently monitor hands and shoes. If lab equipment is contaminated, label it with radiation warning tape until it has been decontaminated or decayed to background.
3. Wear protective clothing such as; lab coats, rubber or plastic gloves, and shoe covers when appropriate.
4. Cleaning spills: First remove hot spots, and then work from the perimeter toward the center. Do not use excessive amounts of water as this may allow the contamination to run off. If a large amount of gamma or high energy beta emitter has been spilled, manipulate the cleaning rags with forceps or tongs.
5. Dry spills should be removed by wet methods, using wet absorbent paper to prevent dispersion. This will reduce the inhalation hazard.
6. Decontamination of equipment can usually be accomplished by using conventional cleaning methods, such as soap and water, scouring powder, or chromic or nitric acid cleaning solutions for glassware. If the item is inexpensive it may be simpler to dispose of such equipment as radioactive waste.
7. Decontamination agents include; soap, detergent and water. A number of commercial decontamination agents are readily available and generally effective. Solutions of sodium thiosulfate should be maintained if the laboratory uses radioiodine. Many other chemical and physical agents, such as those listed in the table below, may also be used.
8. Isolate rags, brushes, etc., used in the cleanup until they can be monitored. Dispose of contaminated waste material properly.
9. Contaminated areas and items must be decontaminated to the levels specified in the Radiation Safety Manual. If contamination levels cannot be sufficiently reduced, the surface should be stripped or covered.
10. Responsibility for decontamination rests with each individual user. In no case should Housekeeping or other untrained personnel be involved in the handling or cleanup of radioactive contamination without the specific approval of the Radiation Safety Officer.
11. Items suggested for a radioactivity decontamination kit:
    a. Radiation signs & warning tape
    b. Small plastic bags or shoe covers
    c. Large plastic bag for waste
    d. Small paper bags for sharp & broken objects
    e. Gauze sponges and/or paper towels
    f. Masking tape or grease pencil
    g. Filter paper for wipes
    h. Disposable gloves
    i. Scissors
    j. Forceps or tongs
    k. Large absorbent pads
    l. Scouring powder
    m. Detergent/emulsifier
    n. Tags for waste bags

Guidelines for Decontamination of Materials

CONTAMINATED ITEM	DECONTAMINATION AGENT	REMARKS
Glassware	Soap or detergent and water	Monitor wash water and dispose of properly
	Chromic acid cleaning solution or concentrated nitric acid	
	Suggested agents for specific elements:	
	Versene (EDTA) 5% conc, 3% NH_4OH, HCl 10% by volume	Alkali earth metals: Mg, Ca, Sr, Ba, Ra, P as PO_4 Alkali metals: Na, K, Rb, Cs and strongly absorbed metals like Po
	Solution of (dissolve in order): (1) Versene (EDTA) 5% (2) Conc. NH_4OH 3% by volume (3) Glacial acetic acid %5 (vol)	Trivalent metals: Al, Se, Y, Eu, Nd, Ce Rare earths: Ga, In, Tl, B, Ac Transition metals: Cu, Zn, Fe, Co, Ni, Cd, Sn, Hg, Pb, Th, U, Ag
Laboratory tools	Detergents & water; steam cleaning	Use mechanical scrubbing action
Metal tools	Dilute nitric acid, 10% solution of sodium citrate or ammonium bifluoride	As a last resort, use HCl on stainless steel
	Metal polish, abrasives, sand blasting	Such as brass polish on brass. Use caution as these procedures may spread contamination.
Plastic tools	Ammonium citrate, dilute acids, organic solvents	
Walls, floors, and benches	Detergents and water with mechanical action	
	Vacuum cleaning	The exhaust of the cleaner must be filtered to prevent escape of contamination
Rubber, glass, plastic	Washing or dilute HNO_3	Short-lived contamination may be covered up to await decay
Leather		Very difficult to decontaminate
Linoleum	Ammonium citrate, dilute mineral acids, CCl_4	
Ceramic tile	Mineral acids, ammonium citrate, trisodium phosphate	Scrub hot 10% solution into surface and flush thoroughly with hot water
Paint	10% HCl acid, CCl_4	Usually best to remove paint and then repaint
Brick, concrete	32% HCl acid	If this is not successful, concrete must be removed
Wood	Hot citric acid	Remove the wood with a plane or floor chippers and grinders
Traps & drains	(1) Flush with water (2) Scour with rust remover (3) Soak in a solution of citric acid (4) Flush again	Follow all 4 steps

Ref: IAEA Technical Report No. 152

AVERAGE ANNUAL WHOLE-BODY DOSE RATES IN THE U.S.

Mankind has always been exposed to radiation from a variety of natural sources, and this "natural background radiation" is still the largest contributor to the average population dose. Man-made sources include medical radiation, occupational radiation exposure, radiation from various consumer products, and fallout from nuclear tests.

TABLE 2. Summary of Average Whole Body Dose

Rates in the U.S.	(mrem/yr)
Natural Sources	311
Medical radiation exams	300
Occupational exposure	0.5
Industrial	0.3
Consumer products	13
Equivalent Whole Body Dose	620

NCRP Report 160, 2009

Natural Background Radiation. Subcategories include internal inhalation and ingestion and external space and terrestrial exposures. The main contribution to background dose due to inhalation of radon and thoron. Residential studies show that the average residential radon concentrations over the U.S. were calculated to be 43.3 Bq/m^3. In TN, the radon concentrations average just below the U.S. average at 42.2 Bq/m^3.

Miscellaneous Sources such as environmental exposure from; nuclear power plants, television sets, wristwatches, and tobacco smoking. The average annual effective dose to an individual from consumer products is estimated to be 100 mrem. Table 3 shows typical doses to the *exposed populations* from various consumer products.

TABLE 3. Effective Whole Body Dose Equivalent to the Exposed Groups from Consumer Products
NCRP Report 160, 2009

	mrem/yr
Highway and road construction materials	4
Mining and agriculture	1
Building materials	7
Cigarette Smoking	30
Natural Gas cooking	0.1

Medical Radiation is the most important manmade source of radiation exposure, although not everyone receives exposure from this source each year. The value given in Table 2 is the average for the U.S. population.

TABLE 4. Typical Patient Doses from Medical Exams

Exam	Effective Dose (mrem)
Chest X-Ray	10
Mammography*	42*
Chest CT	200
Upper GI (including Fluoroscopy)	600
Head CT	700
Whole Body CT	1000
Breast, External Beam	33,700
Nuclear Medicine Exams:	
^{18}F [PET]	703
^{131}I [MIBG]	740
^{99m}Tc [bone scan]	422
^{99m}Tc [MUGA/RVG]	523
^{133}Xe [Lung Scintigraphy]	45

NCRP Report 160, 2009
www.doseinfo-radar.com/RADARHome.html
**Uses the ICRP 2007 weighting factor w_T=0.12*

Occupational Exposure
In 2006, the average annual dose to the occupationally exposed individual from all monitored U.S. workers was 113 mrem. Occupational exposure in the medical industry represents 39 % of the U.S. total in 2006, with an average annual dose of 75 mrem. Monitored individuals in Aviation represented 38% of the U.S. totals and had the highest average annual dose of 307 mrem.

TABLE OF RADIOISOTOPES

Isotope	Half Life	Decay Mode	Internal Toxicity Class	ALI (μCi)	Container Posting Level (μCi)	Γ [R/h @ 1 cm per mCi]	TVL mm Pb	Radiation Types KeV (% per decay)
^{3}H	12.35 Y	β	Low	80,000	1000	-	-	Betas: 19 (100%)
^{11}C	20.38 M	β+, EC	Low	400,000	1000	5.97	13.7	Positrons: 960 (99.7%) Gammas: 511 (199.5%)
^{13}N	9.97 M	β+	Low		1000	5.97	13.7	Positrons: 1199 (99.8%) Gammas: 511 (199.6%)
^{14}C	5730 Y	β	Moderate	2,000	1000	-	-	Betas: 156 (100%)
^{15}O	122.24 S	β+	Low			5.97	13.7	Positrons: 1732 (99.9%) Gammas: 511 (199.8%)
^{18}F	109.77 M	β+	Low	70,000	1000	5.8	13.7	Positrons: 634 (96.7%) Gammas: 511 (193.4%)
^{22}Na	2.6 Y	β+, EC	High	400	10	12	26.6	Positrons: 545 (89.8%) Gammas: 511 (180%) 1275 (99.9%)
^{24}Na	15 H	β	Moderate	4,000	100	18.4	52	Betas: 1390 (99.9%) Gammas: 1386 (100%) 2754 (100%)
^{32}P	14.29 D	β	High	400	10	-	-	Betas: 1710 (100%)
^{33}P	25.4 D	β	Moderate	3000	100	-	-	Betas: 250 (100%)
^{35}S	87.44 D	β	Moderate	2000	100	-	-	Betas: 167 (100%)
^{36}Cl	301,000 Y	β	High	200	10	-	-	Betas: 714 (98%)
^{40}K	1.3 x 10^{9}Y	β, EC	High	300	100	0.7	38.7	Betas: 1312 (89.3%) Gammas: 1460 (10.7%)
^{42}K	12.36 H	β	Moderate	5000	1000	1.4	39.8	Betas: 1996 (17.5%) 3521 (82%) Gammas: 1525 (18%)
^{45}Ca	163 D		Moderate	800	100	-	-	Betas: 257 (100%)
^{46}Sc	83.83 D	β	High	200	10	10.9	29.1	Betas: 357 (100%) Electrons: 140 (38%) Gammas: 889 (100%) 1121 (100%) 143 (62%)
^{47}Ca	4.53 D	β	Moderate	800	100	5.7	34.4	Betas: 691 (81.7%) 1988 (18%) Gammas: 489 (7.0%) 808 (6.9%) 1297 (74.9%)

DECAY MODES: α = Alpha Decay, β = Beta Decay, β+ = Positron Decay, EC = Electron Capture, IT = Isomeric Transition (gamma) Decay, SF = Spontaneous Fission ALI = ANNUAL LIMIT ON INTAKE, Γ = SPECIFIC GAMMA RAY CONSTANT, TVL = TENTH VALUE LAYER

TABLE OF RADIOISOTOPES

Isotope	Half Life	Decay Mode	Internal Toxicity Class	ALI (μCi)	Container Posting Level (μCi)	Γ [R/h @ 1 cm per mCi]	TVL mm Pb	Radiation Types KeV (% per decay)
^{48}V	16.24 D	β+	Moderate	600	100	15.6	30.1	Positrons: 698 (50%) Gammas: 983 (100%) 1312 (97.5%) 2240 (2.4%) 511 (100%) 944 (7.7%)
^{51}Cr	27.7 D	EC	Low	20,000	1000	0.2	6.3	Gammas: 320 (9.8%)
^{54}Mn	312.5 D	EC	Moderate	800	100	4.7	24.6	Gammas: 835 (100%)
^{55}Fe	2.7 Y	EC	Moderate	2,000	100	-	-	X-rays: 6 (28%)
^{57}Co	270.9 D	EC	Moderate	700	100	0.9	0.7	Gammas: 122 (85.5%) 136 (10.6%)
^{59}Fe	44.53 D	β	High	300	10	6.4	33.6	Betas: 273 (45.2%) 465 (53.1%) Gammas: 192 (3.0%) 1099 (56.5%) 1292 (43.2%)
^{60}Co	5.27 Y	β	High	30	1	13.2	34.8	Betas: 318 (100%) Gammas: 1173 (100%) 1332 (100%)
^{63}Ni	96 Y	β	Moderate	800	100	-	-	Betas: 66 (100%)
^{67}Ga	3.26 D	EC	Low	7,000	1000	1.1	4.7	Electrons: 84 (26.8%) Gammas: 93 (36%) 185 (19.7%) 300 (15.9%) 394 (4.5%)
^{68}Ge	288 D	EC	High	100	10	5.51	14.4	Positrons: 836 (84%) Gammas: 511 (178%) 1077 (3.3%) 1883 (0.1%) X-rays: 9 (39%) 10 (5.5%)
^{74}As	17.76 D	β+	Moderate	800	100	4.4	16.8	Betas: 718 (16%) 1353 (19%) Positrons: 944 (27%) 944 (27%) 945 (27%) Gammas: 10 (5.1%) 511 (59%) 596 (60%) 608 (5.5%)
^{75}Se	119.8 D	EC	Moderate	500	100	2.1	4.6	Gammas: 121 (16.7%) 136 (59.2%) 265 (59.8%) 280 (25.2%) 401 (11.4%)
^{85}Kr	10.72 Y	β			1000	0.4	2.8	Betas: 687 (99.6%) Gammas: 51.4 (43.4%)
^{85}Sr	64.84 D	EC	Moderate	2,000	100	3.0	13.9	Gammas: 514 (99.2%) 15 (8.7%)
^{86}Rb	18.66 D	β	Moderate	500	100	0.5	31.3	Betas: 698 (8.8%) 1774 (94%) Gammas: 1076 (8.8%)
^{89}Sr	50.5 D	β	High	100	0	-	26.8	Betas: 1491 (100%)
$^{90}Sr/Y$	29.12 Y	β	Very High	4	0.1	-	-	Betas: 546 (100%) 2284 (100%)

DECAY MODES: α = Alpha Decay, β = Beta Decay, β+ = Positron Decay, EC = Electron Capture, IT = Isomeric Transition (gamma) Decay, SF = Spontaneous Fission ALI = ANNUAL LIMIT ON INTAKE, Γ = SPECIFIC GAMMA RAY CONSTANT, TVL = TENTH VALUE LAYER

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Isotope	Half Life	Decay Mode	Internal Toxicity Class	ALI (μCi)	Container Posting Level (μCi)	Γ [R/h @ 1 cm per mCi]	TVL mm Pb	Radiation Types KeV (% per decay)
^{90}Y	64.0 H	β	High	400	10	-	-	Betas: 2,284 (100%)
^{95}Nb	35.15 D	β	Moderate	1,000	100	4.3	22.5	Betas: 160 (100%) Gammas: 766 (100%)
^{99}Mo	2.75 D	β	Moderate	1,000	100	1.8	20.5	Betas: 436 (17.3%) 1214 (82.7%) Gammas: 181 (6.2%) 740 (12.8%)
^{99m}Tc	6.02 H	IT	Low	80,000	1000	0.6	0.9	Electrons: 119 (8.8%) 137 (1.1%) Gammas: 140 (89%)
^{103}Pd	16.96 D	EC	Low	6,000	100	1.48	0.02	X-Rays: 20.1 (28.7%) 20.2 (54.4%) 22.7 (16.9%)
^{109}Cd	464 D	EC	High	40	1	1.8	-	Electrons: 63 (42%) 84 (44%) 88 (10%) X-rays: 22 (84%) 25 (18%)
^{110m}Ag	249.9 D	IT, β	High	90	10	-	-	Betas: 22 (67.3%) 531 (30.5%) Gammas: 658 (94.4%) 678 (10.7%) 687 (6.5%) 707 (16.7%) 764 (22.4%) 818 (7.3%) 885 (72.6%) 938 (34.3%) 1384 (24.3%) 1505 (13.1%)
^{111}In	2.83 D	EC	Moderate	4,000	100	3.4	2.2	Electrons: 145 (8.4%) 219 (4.9%) Gammas: 171 (90.2%) 245 (94%) X-rays: 23 (68%) 26 (15%)
^{113}Sn	115.1 D	IT	Moderate	500	100	1.7	0.05	Electrons: 20 (13%) X-rays: 24 (60%) 27 (13%)
^{115m}Cd	44.6 D	β	High	50	10	0.2	30.1	Betas: 616 (98%) 1621 (98%)
^{123}I	13.2 H	EC	Moderate	3,000	100	1.3	1	Electrons: 127 (13.6%) Gammas: 159 (83%) X-rays: 27 (70.6%) 31 (16%)
^{125}I	60.14 D	EC	High	40	1	0.7	0.06	Electrons: 23 (19.7%) 31 (12.3%) Gammas: 35 (6.5%) X-rays: 27 (112%) 31 (25.4%)
^{129}I	1.6×10^7 Y	β	High	5	1	0.6	0.08	Betas: 152 (100%) Electrons: 34 (11%) Gammas: 40 (7.5%) X-rays: 30 (57%) 34 (13%)
^{131}I	8.04 D	β	High	30	1	2.1	9.6	Betas: 334 (7.4%) 606 (89.3%) Gammas: 284 (6.2%) 364 (81.2%) 637 (7.3%)

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TABLE OF RADIOISOTOPES

Isotope	Half Life	Decay Mode	Internal Toxicity Class	ALI (μCi)	Container Posting Level (μCi)	Γ [R/h @ 1 cm per mCi]	TVL mm Pb	Radiation Types KeV (% per decay)
^{133}Ba	10.74 Y	EC	Moderate	700	100	2.4	5.8	Electrons: 45 (48%) 75 (7.4%) Gammas: 81 (33%) 276 (6.9%) 303 (17.8%) 356 (60%) 383 (8.7%) X-rays: 31 (97%) 35 (22.8%)
^{133}Xe	5.25 D	β	-		1000	0.1	0.4	Betas: 346 (99.3%) Electrons: 45 (53.3%) Gammas: 81 (36.5%) X-rays: 31 (38.9%)
^{137}Cs	30.0 Y	β	High	100	10	3.5	18.9	Betas: 512 (94.6%) 1173 (5.4%) Electrons: 624 (8.1%) Gammas: 662 (90%)
^{141}Ce	32.5 D	β	Moderate	700	100	0.4	0.9	Betas: 435 (71%) 580 (29.5%) Electrons: 103 (18.8%) Gammas: 145 (48.4%) X-rays: 36 (13.8%)
^{150}Eu	34.2 Y	EC	High	20	1	-	-	Electrons: 5 (45.9%) 5 (45.9%) 6 (27.1%) 1 (150%) Gammas: 334 (94%) 584 (51.5%) 737 (9.4%) 748 (5.1%) 1049 (5.2%) X-rays: 40 (65.4%) 45 (8.3%)
^{152}Eu	13.33 Y	β, EC	High	20	1	-	-	Betas: 696 (13.6%) 1475 (8.4%) Electrons: 5 (73.4%) 33 (5.7%) 75 (19.5%) 114 (10.6%)
^{153}Gd	242 D	EC	High	100	10	0.8	0.2	Electrons: 55 (32.2%) 49 (8.1%) 95 (5.1%) Gammas: 70 (2.6%) 97 (32%) 103 (22.2%) X-rays: 41 (100.5%) 47 (25.3%)
^{154}Eu	8.8 Y	β, EC	High	20	1	6.3	29.1	Betas: 247 (27.9%) 569 (36.5%) 839 (17.4%) 1844 (11.4%) Gammas: 723 (19.7%) 873 (11.5%) 1005 (17.9%) 127 (35.5%)
^{169}Yb	32.01 D	EC	Moderate	700	100	1.8	1.6	Electrons: 50 (34.9%) 100 (5.6%) 118 (10.3%) 120 (51.6%) 139 (12.4%) Gammas: 63 (42%) 110 (17%) 131 (12%) 177 (22%) 197 (36%) 307 (10%) X-rays: 50 (147%) 58 (39%)
^{186}Re	3.78 D	β	Moderate	2,000	100	0.2	0.8	Betas: 1070 (94%) 1076 (71%) Gammas: 137 (9.5%)

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TABLE OF RADIOISOTOPES

Isotope	Half Life	Decay Mode	Internal Toxicity Class	ALI (μCi)	Container Posting Level (μCi)	Γ [R/h @ 1 cm per mCi]	TVL mm Pb	Radiation Types KeV (% per decay)
^{188}Re	16.98 H	β	Moderate	2,000	100	0.3	16.8	Betas: 2120 (71.4%) Gammas: 155 (15%)
^{192}Ir	74.02 D	β, EC	High	200	1	4.8	20	Betas: 536 (41.4%) 672 (48.3%) Gammas: 296 (29%) 308 (29.7%) 317 (82.8%) 468 (48%) 604 (8.2%) 612 (5.3%)
^{198}Au	2.7 D	β	Moderate	1,000	100	2.4	10.1	Betas: 961 (98.6%) Gammas: 412 (95.5%)
^{201}Tl	3.04 D	EC	Low	20,000	1000	0.4	0.9	Electrons: 84 (15.4%) Gammas: 167 (10%) X-rays: 69 (27.4%) 71 (46.5%) 80 (20.5%)
^{203}Hg	46.6 D	β	Moderate	500	100	1.3	4.7	Betas: 212 (100%) Electrons: 194 (16.9%) 264 (4.4%) Gammas: 279 (77.3%) X-rays: 71 (4.7%) 73 (8.0%)
^{206}Bi	6.24 D	EC	Moderate	600	100	17.2	26	Electrons: 96 (22.2%) 256 (5.6%) Gammas: 516 (40%) 803 (98.9%) 881 (66.2%) 1719 (32%)
^{207}Bi	38 Y	EC	High	400	10	8.3	25.8	Electrons: 976 (7.0%) Gammas: 570 (97.7%) 1064 (75%) 1770 (6.8%)
^{208}Po	2.93 Y	α	High	14	0.001	-	-	Alphas: 5110 (100%)
^{210}Pb	22.3 Y	β	Very High	0.2	0.01	0.0	0.2	Betas: 17 (80.2%) 63 (19.8%) Electrons: 8 (33.6%) 30 (57.9%) 43 (18.1%) Gammas: 11 (24%)
^{210}Po	138.38 D	α	Very High	0.6	0.1	-	-	Alphas: 5305 (100%)
^{222}Rn	3.82 D	α	High	100	1	-	-	Alphas: 5490 (99.9%)
^{226}Ra	1600 Y	α	Very High	0.6	0.1	-	-	Alphas: 4602 (5.6%) 4785 (94.6%)
^{228}Th	1.91 Y	α	Very High	0.01	0.001	-	-	Alphas: 5341 (26.7%) 5423 (72.7%) Electrons: 9 (9.6%) 65 (19.1%) 80 (5.2%) X-rays: 12 (9.6%)
^{238}Pu	87.74 Y	α, SF	Very High	0.007	0.001	-	-	Alphas: 5457 (28.3%) 5499 (71.6%) Electrons: 10 (9.1%) 22 (20.7%) 38 (7.6%) X-rays: 14 (11.6%)
^{238}U	4.5E+9 Y	α, SF	Very High	0.04	100	-	-	Alphas: 4147 (23%) 4196 (77%) Electrons: 10 (8.2%) 29 (16.8%) 44 (6.1%) X-rays: 13 (9%)

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TABLE OF RADIOISOTOPES

Isotope	Half Life	Decay Mode	Internal Toxicity Class	ALI (μCi)	Container Posting Level (μCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{239}Pu	24,065 Y	α	Very High	0.006	0.001	-	-	Alphas: 5105 (11.5%) 5143 (15.1%) 5155 (73.3%) Electrons: 7 (19%)
^{241}Am	432.2 Y	α	Very High	0.006	0.001	0.1	0.4	Alphas: 5443 (12.8%) 5486 (85.2%) Gammas: 60 (35.9%)
^{244}Cm	18.11 Y	α, SF	Very High	0.01	0.001	-	-	Alphas: 5763 (23.6%) 5805 (76.4%) Electrons: 10 (6.9%) 20 (17.2%) 37 (6.3%) X-rays: 14 (10.3%)
^{250}Cf	13.08 Y	α	Very High	0.009	0.001	-	-	Alphas: 5989 (16.2%) 6031 (83.4%) Electrons: 18 (12%) X-rays: 15 (7.8%)
^{252}Cf	2.638 Y	α, SF	Very High	0.02	0.001	-	-	Alphas: 6076 (15.2%) 6118 (81.6%) Electrons: 19 (11.2%) X-rays: 15 (7.3%)

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