Appendix A

RADIATION SAFETY REFERENCE MANUAL

Table of Contents

GLOSSARY

Activity: The number of nuclear disintegrations occurring per unit time in a radioactive material. The units of activity are the curie and the becquerel.

Acute: An adjective indicating a short and relatively severe course, such as acute radiation effects. It is also used to indicate brief irradiation at high dose rates, as distinguished from irradiation at low dose rates over long periods of time (chronic irradiation).

Acute radiation syndrome: The set of symptoms of acute illness caused by a high dose of whole-body radiation.

Adult: An individual 18 or more years of age.

Agreement State: A state which has entered into an agreement with the U.S. Nuclear Regulatory Commission to assume regulatory responsibility for by-product materials and certain fissionable materials. Tennessee is one of 29 such states.

ALARA: Making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical consistent with the purpose for which the activity is undertaken and taking into account:

(a) The state of technology;
(b) The economics of improvements in relation to;

1. The state of technology;
2. Benefits to public health and safety, and other societal and socioeconomic considerations; and
3. Utilization of radiation and radioactive materials in the public interest.

Annual limit on intake (ALI): The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given committed effective dose equivalent of 5 rems (0.05 Sv) or a committed dose equivalent of 50 rems (0.05 Sv) to any individual organ or tissue. ALI values for intake by ingestion and by inhalation of selected radionuclides are given in Schedule RHS 8-30.

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

Background radiation: The radiation in the natural environment, including cosmic rays and the radiation from the naturally radioactive elements, both outside and inside the body.

Bioassay (radiobioassay): The determination of kinds, quantities or concentrations, and, in some cases, the locations of radioactive material in the human body, whether by direct measurement (in vivo counting) or by analysis and evaluations of materials excreted or removed from the human body.

Bremsstrahlung radiation: Electromagnetic radiation (x-rays) 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.

Committed dose equivalent (CDE) ($H_{T,50}$): The dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by an individual during the 50 year period following the intake.

Committed effective dose equivalent (CEDE) ($H_{E,50}$): 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 $H_{\sum,50}=\sum W_T H_{T,50}$).

Carcinogenesis: The induction of cancer.

Committed Dose Equivalent (CDE): Internal dose as measured with respect to an organ.

Committed Effective Dose Equivalent (CEDE): Dose to the whole body from the internal uptake of radioisotopes.

Cosmic rays: High energy radiations originating outside the earth's atmosphere.

Daughter products: Isotopes that are formed by the radioactive decay of another isotope. For example, following the decay of radium-226 there are 9 successive radioactive daughter products, ending in the stable isotope lead-206.

Declared Pregnant Woman (DPW): A woman who has voluntarily informed her employer, *in writing*, of her pregnancy and the estimated date of conception.

Disintegration, nuclear (radioactive decay): A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus. When large numbers of nuclei are involved, the process is characterized by a definite half-life.

Deep Dose Equivalent (DDE): Dose to the whole body due to external radiation.

Dose Equivalent (H_T): The product of the absorbed dose in tissue, the quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv).

Doubling dose, genetic: Amount of radiation needed to double the natural incidence of a genetic anomaly

Effective whole body dose equivalent (EDE or H_E): 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 ($H_{\sum}=\sum W_T H_T$).

Electromagnetic radiation: Radiation consisting of interacting electric and magnetic waves that travel at the speed of light. Examples are radio waves, TV waves, ultraviolet radiation, light waves, x-rays and gamma rays.

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: A unit of energy. One eV is equivalent to the energy gained by an electron when accelerated by a potential difference of one volt. Multiples of this unit are commonly used for ionizing radiation, namely the kilo electron volt (keV) and mega electron volt (MeV).

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

External radiation: Radiation originating from radiation sources located outside the body. Compare to internal radiation.

Extremity: Hand, elbow, arm below the elbow, foot, knee or leg below the knee.

Eye dose equivalent: Applies to the external exposures of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeter (300 mg/cm^2).

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

Geiger-Mueller counter: A radiation detection instrument named for H. Geiger and W. Mueller, also called a Geiger counter or G-M counter. When ionizing radiation passes through the gas in the tube, a pulse of electrons is created which passes through an external electrical circuit and is counted.

Halflife, biological: The time required for the body to eliminate half of an administered dosage of any substance by regular processes of elimination.

Halflife, 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.

Halflife, radioactive: Time for the activity of any particular radionuclide to be reduced to one-half of its initial value.

Health Physicist: A person professionally engaged in radiation protection.

High radiation area: An area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 mSv) in 1 hour at 30 centimeters from the source of radiation or from any surface that the radiation penetrates.

Hot spot: A region in a contaminated area where the level of contamination is noticeably greater than in neighboring regions.

Induced radioactivity: Radioactivity that is created when stable substances are bombarded by neutrons. For example, the stable isotope P-31 becomes radioactive P-32 when irradiated by neutrons.

Internal radiation: Radiation emitted by radioactive substances in the body.

Ionization chamber: An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber.

Ionizing radiation: Radiation capable of ionizing neutral atoms, i.e. displacing electrons from atoms or molecules, thereby producing ions.

Isomeric transition: Change of a radioactive nucleus from a higher energy state to a lower energy state of the same isotope, accompanied by the emission of gamma rays.

Latent period: The period of time between exposure to a damaging agent such as radiation, and the detection of a specified biological effect.

$LD_{50/30}$: The radiation absorbed dose expected to cause death within 30 days to 50 percent of those exposed. Believed to be within the range of 300 to 500 rads in humans for whole body irradiation.

Lens Dose Equivalent (LDE): Dose equivalent to the lens of the eye due to external radiation sources.

Linear Energy Transfer (LET): The radiation energy lost per unit length (and thus the density of ionization produced) measured along the track of an ionizing particle. Gamma rays and x-rays are low-LET radiations; alpha particles and neutrons give high-LET tracks. In general, the higher the LET value, the greater is the relative biological effectiveness of the radiation.

Maximum Permissible Doses (MPD): Refers to the maximum radiation doses allowed by State of Tennessee regulations.

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 effect: Health effects, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect (also called a deterministic effect).

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. Occupational dose does not include dose received from background radiation, as a patient from medical practices, or as a member of the general public.

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

Pig: A container (usually lead) used to store radioactive material.

Prefixes for fractions or multiples of the basic units:

pico = p = 10^{-12}
nano = n = 10^{-9}
micro = u = 10^{-6}
milli = m = 10^{-3}

kilo = k = 10^{3}
mega = M = 10^{6}
giga = G = 10^{9}
tera = T = 10^{12}

Ex. 1 MeV = 1000 keV 1 mR = 0.001 R
25 uCi = 0.025 mCi 16 rads = 16,000 mrads

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. It does not include occupational dose or doses received from background radiation or a patient from medical practices.

Quality factor: A factor which represents the effectiveness of different types of ionizing radiation in producing harmful effects at low doses, as compared to the effect produced by x-rays or gamma rays. The dose equivalent (in rems) is obtained by multiplying the absorbed dose (in rads) by the quality factor.

Radioactivity: The spontaneous emission of radiation from the nucleus of an unstable atom, as it transmutes into a more stable form. The amount of radioactivity is measured in curies or becquerels.

Radiation area: An area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.0055 mSv) in 1 hour at 30 centimeters from the source of radiation or from any surface that the radiation or from any surface that the radiation penetrates.

Restricted area: An area, access to which is limited by the licensee or registrant for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. Restricted area does not include areas used as residential quarters, but separate rooms in a residential building may be set apart by the licensee.

Sealed source: A radioactive source sealed in a container or having a bonded cover, in which the container or cover has sufficient mechanical strength to prevent contact with or dispersion of the radioactive material. Radiation is emitted through the walls of the source.

Shallow Dose Equivalent, Maximal Extremities (SDE,ME): Dose to the extremities (ie. fingers, hands, feet, etc.) due to external radiation sources.

Shallow Dose Equivalent, Whole Body (SDE, WB): Shallow dose to the whole body due to external radiation sources.

Somatic effects of radiation: Effects of radiation limited to the exposed individual, as opposed to genetic effects.

Specific gamma-ray constant: 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. Often expressed in units of R/hr per mCi at 1 cm.

Stochastic effects: Health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

Total Effective Dose Equivalent (TEDE): CEDE + DDE

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, accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess if 500 rads (5 grays) in 1 hour at 1 meter from a source radiation or from any surface that the radiation penetrates.

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

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

RADIATION UNITS

<table>
<tr><th><u>UNIT</u></th><th><u>DEFINITION</u></th><th><u>SI UNIT</u>*</th></tr>
<tr><td>keV</td><td>The keV (kilo electron volt) and MeV (mega electron volt) are units of radiation energy. 1 MeV = 1000 keV.</td><td>joule (J), keV, MeV
1 J = 6.25 x 10^{12} MeV</td></tr>
<tr><td>curie
(Ci)</td><td>The curie is the unit of activity, the number of nuclear disintegrations occurring per unit time.

1 Ci = $3.7\text{x}10^{10}$ dis/sec = $2.22\text{x}10^{12}$ dis/min (dpm) = 1000 mCi
1 mCi = .001 Ci = 1000 uCi
1 uCi = .001 mCi
1 uCi = 3.7 x 10^{4} dis/sec = 2.22 x 10^{6} dis/min</td><td>becquerel (Bq)
1 Bq = 1 dis/sec
1 Ci = $3.7\text{x}10^{10}$ Bq
= 37 GBq
1 mCi = 37 MBq
1 μCi = 37 kBq</td></tr>
<tr><td>rad</td><td>The rad is the unit of absorbed dose and is a measure of the radiation energy absorbed per unit mass of irradiated material.

1 rad = the absorption of 0.01 joules/kg of material</td><td>gray (Gy)
1 Gy = 1 J/kg

1 rad = 10 mGy</td></tr>
<tr><td>rem</td><td>The rem is the unit of dose equivalence, which equates the absorbed dose from various radiations to the dose from gamma rays which would produce the same biologic effect. It is the product of the absorbed dose (D) and the quality factor (Q):

H(rems) = D (rads) x Q (rems/rad)

The quality factor accounts for the relative effectiveness of different radiations in producing biologic damage from low doses
<table>
<tr><th><i><u>Type of Radiation</u></i></th><th><i><u>Q</u></i></th></tr>
<tr><td><i>Gamma rays, x-rays, betas, electrons</i></td><td><i>1</i></td></tr>
<tr><td><i>Thermal neutrons</i></td><td><i>2.3</i></td></tr>
<tr><td><i>Protons</i></td><td><i>10</i></td></tr>
<tr><td><i>Alpha particles, fast neutrons</i></td><td><i>20</i></td></tr>
</table></td><td>sievert (Sv)
Sv = Gy x Q(Sv/Gy)

1 Sv = 100 rem

1 rem = 0.01 Sv
= 10 mSv</td></tr>
<tr><td>roentgen
(R)</td><td>The roentgen is the unit of exposure, a measure of the ionization produced by x- or gamma radiation in a unit mass of air. An exposure of 1 R produces 2.58 x 10^{-4} coulombs of electrical charge per kg of air (about 1.6 x 10^{15} ion pairs).

1 R = 1000 mR   1 mR = 0.001 R

Note: For beta radiation, gamma rays, and x-rays:

1 R   1 rad = 1 rem for water or soft tissues in the body</td><td>coulombs/kg(air)</td></tr>
</table>

The Standard International (SI), or metric, units are scheduled to supersede the older units in the near future.

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 such a disintegration, the nuclide is often transformed from one element to another. About 80% of the more than 1500 different isotopes are radioactive. The rate at which the radioactive disintegrations occur is characteristic of each radionuclide. For example, if the activity (number of decays per unit time) is reduced to one-half of its original level in 4 days, it will be reduced by one-half again in another 4 days, i.e. to one-fourth of its original level. This radionuclide is then said to have a halflife of 4 days. Halflives for radionuclides range from less than a second (e.g. 0.16 msec for ^{214}Po) to billions of years (e.g. 4.5 x 10^9 years for ^{238}U). There are two units of activity, the curie (1 Ci = 3.7 x 10^{10} disintegrations per second) and the becquerel (1 Bq = 1 disintegration per second).

The Properties of Radiation

The radiation emitted from radioactive materials differs from other types of radiation such as heat, light, or radio waves 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*.

<u>Alpha (α) particles</u> are slow, heavy particles having a positive electrical charge. They consist of 2 neutrons and 2 protons and are identical with the nucleus of the helium-4 atom. Alpha radiation penetrates poorly, usually being stopped by a sheet of paper, and travels only a few centimeters in air. Consequently, alpha-emitting material outside the body, even 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. When an atom emits an alpha particle, its atomic number decreases by two and its mass number by four.

<u>Beta (ß) radiation</u> consists of very light particles, each carrying an electrical charge. Negatively charged beta particles are identical with electrons except that they have a nuclear origin. Positively charged beta particles are referred to as positrons and are the antimatter equivalent of the electron. Beta particle energies, and therefore their penetrating power, depend on the particular radionuclide from which they are emitted. Typically the range could be a few meters in air or a few millimeters in tissue. They are therefore 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. Negatively charged beta particles are emitted by nuclei with too many neutrons in the nucleus. The beta particle is given off when the neutron is transformed into a proton: $n \quad p^+ + e^-$. Similarly, for nuclei with too many protons, a proton may change into a neutron, emitting a positron in the process: $p^+ \quad n + e^+$.

During each beta decay a massless particle known as a neutrino is also emitted. The neutrino shares in the total energy released during the nuclear transformation (E_{max}). 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}.

<u>Gamma (γ) radiation</u> is a form of electromagnetic radiation (visible light and radio waves are also forms of electromagnetic radiation). It is very penetrating and may require significant thicknesses of lead or other materials to reduce the radiation level to a safe rate. The energy of the gamma radiation(s) emitted following radioactive decay depends on the particular isotope. It is both an internal and external hazard. A radionuclide may emit gamma radiation after it has decayed by one of the processes previously discussed if the resulting nucleus is in an excited energy state (i.e. above the ground level).

In addition to the radiations originating in the nucleus of the atom, radiation may also be emitted from the atomic shell of the atom during a radioactive decay. These radiations include high energy electrons (known as Auger and Internal Conversion electrons) and x-rays (high energy electromagnetic radiations identical to gamma rays, except for their origin).

Exposure Time

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

Distance from the Source

Since the exposure rate varies as the square of the distance from the source ("inverse square law"), it increases dramatically as the distance to the radiation source becomes small. Thus it is very important to minimize time spent in close proximity to large sources. For example, if the distance increases from 1 cm to 10 cm, the exposure rate will decrease by a factor of $(10/1)^2=100$! Conversely, if the distance decreases from 20 cm to 5 cm, the exposure rate will increase by a factor of $(20\text{cm}/5\text{cm})^2= 4^2= 16$.

Shielding

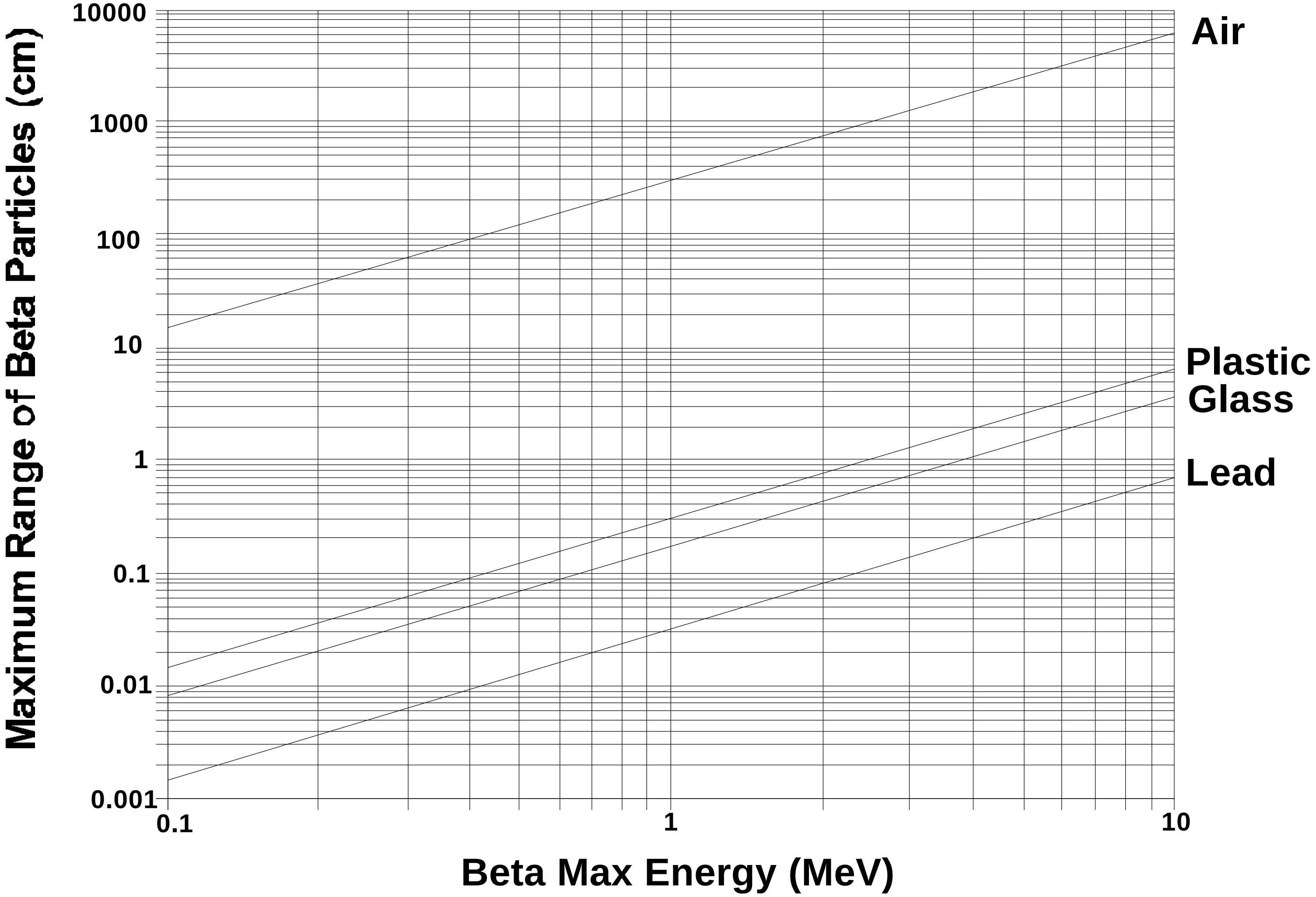
Beta particles have a maximum range which depends on the medium through which they are passing. Therefore beta radiation may be completely absorbed. Gamma rays, on the other hand, have no maximum range, but are attenuated exponentially. A given thickness of absorber will attenuate the radiation by a certain factor; for example, every 6.3 mm of lead reduces the exposure rate from Cr-51 by a factor of 10. Theoretically it is not possible to absorb gamma rays (or x-rays) completely, but the exposure rate can be reduced by any desired factor if sufficient shielding is used. It is recommended that primary consideration be given to fixed shielding. Reliance should ordinarily not be placed on protective aprons and other shielding worn on the person.

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 liquid, gaseous, or finely divided form may be easily dispersed and result in contamination of the environment or of the individual. Special care must be taken to avoid contamination from 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; gloves should be changed or washed frequently.

Penetration Ability of Beta Particles



SHIELDING OF RADIATION SOURCES

Shielding Requirements

Radiation sources must be shielded so that personnel exposures are as low as reasonably achievable (ALARA), and always below these Maximum Permissible Dose Levels:

1. For restricted areas (radiation work areas) the maximum permissible dose is 5000 mrem/year for the whole body. This is equivalent, for a 40 hour work week, to a steady dose rate of

   2.5 mrem/hr

2. An unrestricted area (areas to which the public or non-radiation workers have access) must not be exposed to radiation in excess of

   2 mrem in 1 hour
   100 mrem in 1 year

   The maximum permissible dose rate will depend on the duration of the radiation exposure. For example, 0.6 mrem/hr is the maximum permissible dose rate if this radiation level exists for an entire week, since
   0.6 mrem/hr x 168 hr/wk = 100 mrem/wk.

Beta Shielding

Beta emitters give off betas (electrons) with kinetic energies ranging from zero up to a specific maximum energy. For example, P-32 gives off electrons with kinetic energies between 0 and 1.7 MeV. The electrons of maximum energy penetrate farther into a material than electrons of lower energy. Therefore if you pick a shield thick enough to stop the maximum energy betas, then all lower energy betas will be completely stopped also.

The graph entitled "Range of Beta Rays" shows that a 1.7 MeV beta has a maximum penetration (or range) of 0.6 cm (0.25") in plastic. Thus a piece of plastic 1/4" thick provides good shielding for P-32. C-14 has a maximum beta energy of 0.15 MeV and is stopped by 30 cm of air or 0.25 mm of plastic. No shielding other than the containment vessel is needed for C-14.

When beta particles are absorbed, x-rays (called bremsstrahlung) may be produced, the amount being proportional to the energy of the beta which is absorbed. Bremsstrahlung production is therefore much greater for a high energy beta-emitter such as P-32 than for a low energy beta-emitter such as C-14. In many cases, when source intensities are small, this secondary radiation can be ignored. However, for large amounts of high energy beta-emitters, additional shielding will be needed for the x-rays. Since bremsstrahlung production is also proportional to the atomic number of the absorber, the procedure is to place l uCi or other low atomic number material close to the emitter (to minimize production of x-rays) and then place lead (or other high atomic number material) on the outside of the l uCi to attenuate the x-rays which are produced in the l uCi.

Gamma Shielding

Gamma rays cannot be completely attenuated by a certain thickness of shield material. Instead, a certain thickness of material attenuates the radiation by a fixed fractional amount (this is called exponential attenuation). For example, one inch of lead attenuates 0.9 MeV gamma radiation by a factor of ten; this thickness is known as the tenth value layer (TVL) for 0.9 MeV gamma radiation. If the radiation exposure rate is originally 100 mR/hr, 1" of lead will reduce the rate to 10 mR/hr. Adding another inch of lead (2" total now) will reduce the exposure rate by another factor of ten:

1/10 x 1/10 x 100 mR/hr = 1 mR/hr.

The foregoing example 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.

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, concrete, steel or other materials can provide the same degree of protection if used in appropriately greater thicknesses.

GAMMA RAY SHIELDING

FORMULAS(strictly applicable to monoenergetic radiations, i.e., radiations with a single energy

$$I = I_0 e^{\frac{-2.3x}{TVL}}$$

I_o = exposure (or exposure rate) with no shielding

I = exposure (or exposure rate) with shielding present

x = thickness of shield

TVL = Tenth Value Layer = thickness of a material which will reduce exposure rate to 1/10 (same units as x)

$$I = I_0 \left(\frac{1}{10}\right)^n$$

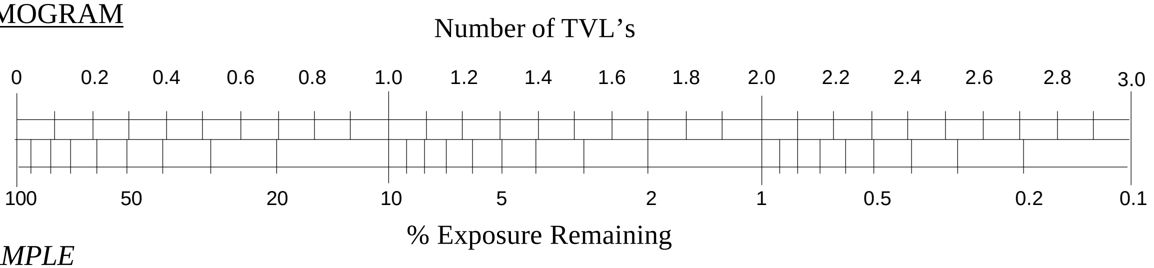
$$n = \log_{10}\left(I_0 / I\right)$$

n = number of TVL's = x/*TVL*

1 TVL = 3.32 HVL

HVL = Half Value Layer = thickness of a material which will reduce the exposure rate to one-half its unshielded value

NOMOGRAM



EXAMPLE

How much Pb shielding is required to reduce the exposure rate from 68 mR/h to 5 mR/h for a ^{95}Nb source? TVL for niobium-95 = 22.5 mm Pb

Method 1, Nomogram

The exposure rate is to be reduced to this fraction: (5 mR/h) / (68 mR/h) = 0.074, or 7.4%

From the nomogram it is seen that approximately 1.15 TVLs are needed: 1.15 TVLs x 22.5 mm/TVL = 25.9 mm Pb

Method 2, Formula

The number of TVLs required is: n = log(68/5) = log 13.6 = 1.13 TVLs. 1.13 TVLs x 22.5 mm/TVL = 25.4 mm Pb

---

RULES OF THUMB FOR BETA PARTICLES

1. The average energy of the beta ray spectrum is approximately **1/3 the maximum** beta energy.
   Examples: ^{32}P = 41%, ^{35}S = 29%, ^{14}C = 31%
2. Beta particle range in air: **d(ft) = 12 E**, where E = energy in MeV
   Example: For ^{32}P (1.71 MeV max energy), d= 20 feet (max)
3. Dose rate in air at 1 cm from a point source of beta radiation of *A millicurie* is approximately
   D(rads/h) = 200 A (varies only slowly with beta energy)
4. Beta particles with energies less than 70 keV will not penetrate the nominal protective layer of the skin (7 mg/cm^2, or 0.07 mm).
5. Dose rate to skin thru nominal protective layer of skin, from a uniform thin deposition of *B μCi/cm^2* is, for energies above about 0.6 MeV, **D(rads/h) = 9 B**
   (For gamma emitters, the dose rate is less by a factor of about 100, for equal energies released.)
6. Dose rate at the surface of a solution of *concentration C μCi/cm^3*:
   D(rads/h) = 1.06 EC/ϱ, where E = average beta energy, ϱ = density of medium (g/cm^3)
   Example: For 1 Ci/cm^3 of ^{32}P (0.69 MeV avg. energy) in H_2O, D = 0.7 rads/h

RADIATION PROTECTION FORMULAS

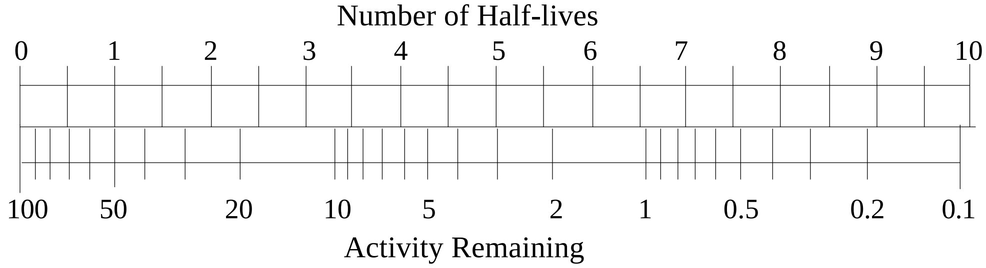
RADIOACTIVE DECAY

$$A = A_0 e^{\frac{-0.693t}{T_{1/2}}} = A_0 (1/2)^N$$

A = activity at time t, A_0= initial activity at t= 0

$T_{½}$ = halflife (in same units as t), N = # halflives = t/$T_{½}$

Half-Life Decay Chart



Rule of Thumb: Activity is reduced to less than 1% after 7 halflives.

EFFECTIVE HALFLIFE

$$T_{eff} = \frac{T_{1/2}T_b}{T_{1/2} + T_b}$$

$T_{½}$= physical (radiological) halflife

T_b= biological halflife (same units as $T_{½}$)

INVERSE SQUARE LAW

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

I_1 = exposure (or exposure rate) at distance d_1 from radiation source
I_2 = exposure at distance d_2

EXPOSURE RATE FROM POINT SOURCE OF GAMMA RAYS

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

I = exposure rate (R/h) @ d *cm* from A *mCi*

Γ= specific gamma ray constant = R/h *1 cm* from *1 mCi* for a specific radionuclide

BREMSSTRAHLUNG PRODUCTION

Fraction of beta energy converted to bremsstrahlung (F): $F = 3.5 \times 10^{-4} ZE$

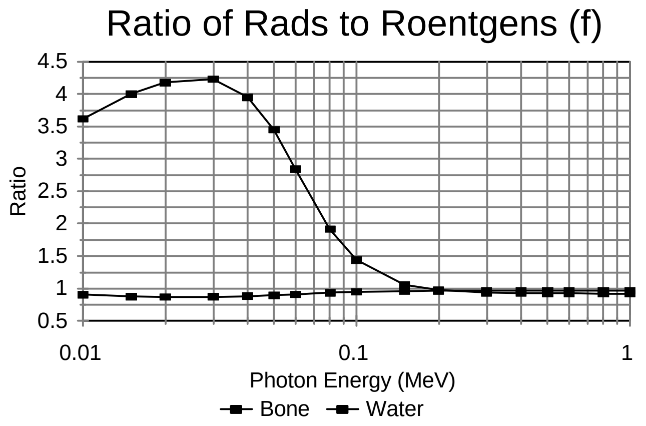
Z = atomic number of absorbing material
E = beta (max) energy in MeV

RELATIVE RADIOTOXICITY RATING OF RADIONUCLIDES

Toxicity	ALI of Nuclide
Low	5000
Moderate	500
High	50
Very High	50

ROENTGEN TO RAD CONVERSION

D*(rads)* = f x I*(roentgens)*



RADIATION SURVEYS

Measurement of External Radiation Levels

When a laboratory uses gamma or high energy beta ray sources, exposure rate measurements should be made to determine radiation levels in the vicinity of storage and work areas, around waste containers, and in nearby unrestricted areas. An ion chamber survey instrument is used when it is desired to make a high accuracy measurement, or when relatively high exposure rates must be measured (such as in a nuclear medicine department). More commonly, a Geiger-Mueller (GM) counter is used. A GM counter has the advantage of being able to measure lower radiation levels and is also much less expensive than an ion chamber.

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 a poor detection efficiency for weak beta emitters such as ^{14}C and cannot detect tritium. As a G-M detector is very inefficient for ^{125}I, a sodium iodide scintillation crystal detector is recommended for users of ^{125}I or other low energy gamma emitters. (See next page for more information on different meter types.)

When performing a contamination survey the detector should be held as close as possible to the surface to be scanned without actually touching the surface. The probe should be 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 - 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, especially low energy beta emitters, all plastic caps, plastic film, and/or parafilm should be removed from the probe for optimal efficiency.

Smear survey:

These surveys are conducted to determine the presence of loose surface contamination - radioactivity which potentially could become airborne or be transferred to personnel through direct contact. A smear test (wipe test) is conducted by rubbing a piece of paper or Q-tip on the surface to be tested and then counting it for radioactivity in a suitable counter. Smear testing is the only commonly available method for detecting tritium contamination.

Efficiency of a Radiation Detector for Measurement of Radioactivity

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

where

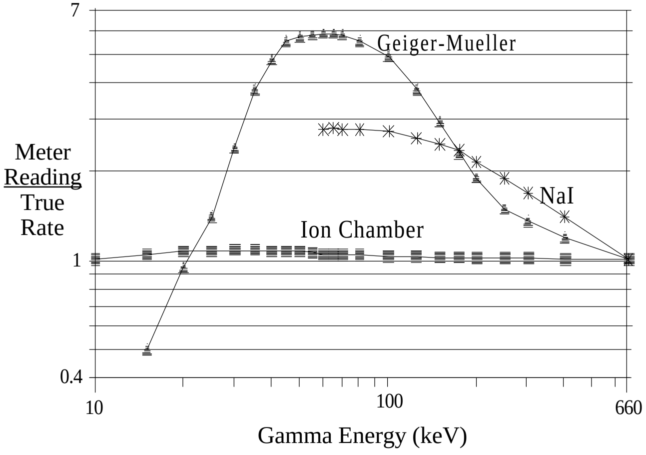
CPM = counts per minute registered by the detector

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

RADIATION SURVEY METER CHARACTERISTICS

Meter Type	Geiger-Mueller Counter (GM Counter)	NaI Crystal Scintillation Detector	Ion Chamber
Radiation measured as counts or levels:	CPM, CPS and/or Radiation levels [mR/h]	CPM, CPS only	Radiation levels [mR/h] only
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 '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 radiations 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 ^{14}C ^{32}P ^{125}I ^{137}Cs	<u>pancake</u> / <u>thin window</u> 6% / 4% 38% / 26% 0.01% / 0.01% 1% / 1%	<u>1 mm crystal</u> 0% 60% 14% 5%	
Typical "background"	80-100 cpm	2,500 cpm	
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 good for detection of contamination; 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.



Typical Energy Dependence For Three Different Types of Meters

RADIATION WARNING SIGNS AND LABELS

Radiation workers have the responsibility of posting appropriate radiation warning signs 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 Institutional Safety; however, each investigator must purchase his or her own if there is a continuing need for new labels.

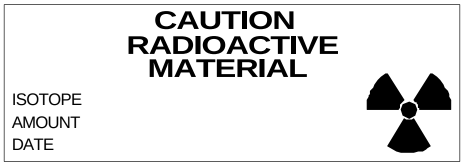
General Requirements

1. Signs and labels must describe the actual situation. For example, do not post a "Caution - Radiation Area" sign unless a Radiation Area 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 from empty, uncontaminated containers when they are 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 materials need to 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. Any item which is contaminated also needs to be labeled.



2. **RADIOACTIVE MATERIAL sign -** must be posted on storage cabinets, fume hoods, refrigerators, room doors, etc, which contain **10 times** the Container Posting Level.
   Exception: The radioactive material is present for less than 8 hours and there is someone in attendance to assure 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 5 mrem in 1 hour or 100 mrem/5 days. This sign serves as a warning that the average weekly MPD (maximum permissible dose) of 100 mrem can be exceeded in the area. *Exception*: Same as for #2.

4. **HIGH RADIATION AREA -** required if the dose rate to the whole body can exceed 100 mrem in 1 hour. 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.

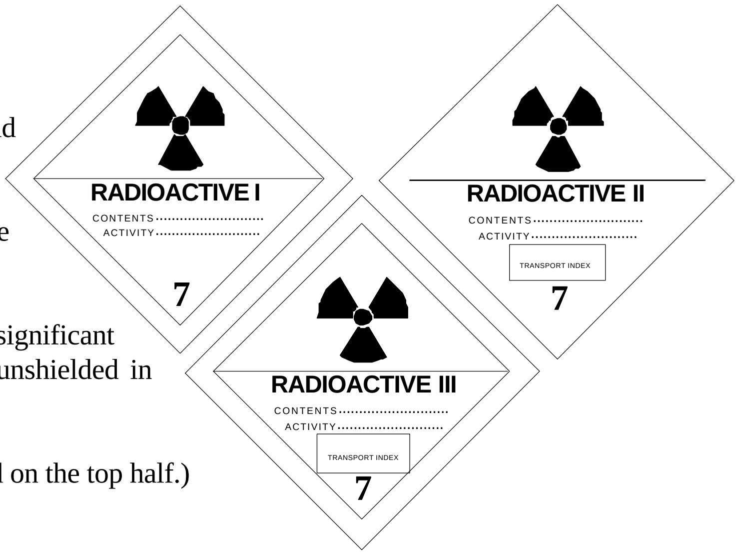
5. **Shipping labels -** Various shipping labels are required to ship packages of radioactive materials. The diamond-shaped label shown at the right indicates the radiation dose rates emitted from the package:

   I 0.5 mrem/h @ surface of package
   II 50 mrem/h @ surface of package, and
   1.0 mrem/h @1 m from package*
   III : 200 mrem/h @ surface of package, and
   10 mrem/h @ 1 m from package*

   *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.

   (II and III labels have a yellow background on the top half.)



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

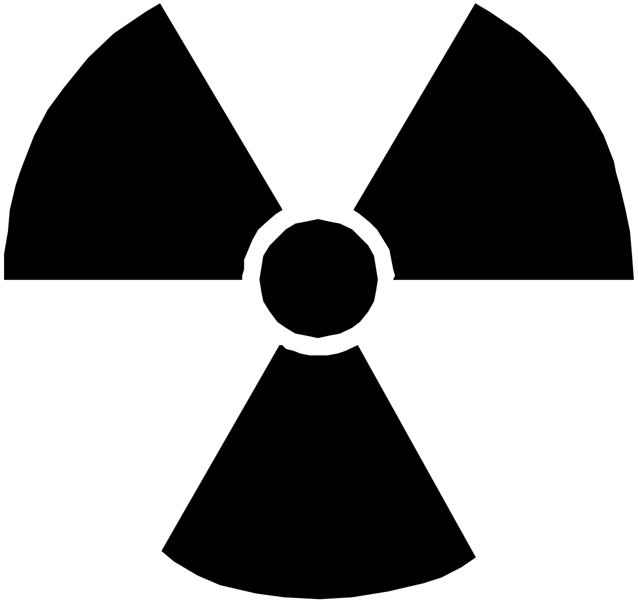
7. **RADIOACTIVE WASTE -** containers used for solid radioactive wastes must be marked on at least two sides with this sign. In addition, the cans must be lined with the yellow, specially-marked radioactive waste bags.

8. **Radiation-producing equipment** must be posted with this warning at a location near the energizing switch on the 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.

10. **RADIOACTIVE MATERIALS AREA -** this sign must be posted at the main entrance to each radioisotope laboratory or storage room. The sign indicates the radionuclides which are used or stored at the location, assigns a hazard rating of Slight, Low, Medium or High to this location, and gives emergency phone numbers for Institutional Safety and lab supervisor. (See next page for example.)

CAUTION



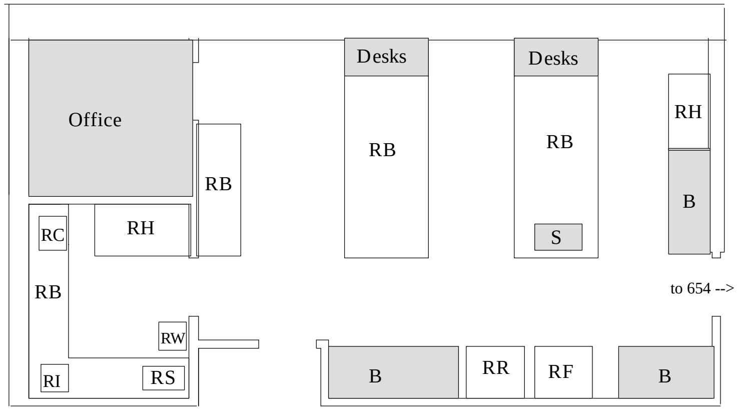
RADIOACTIVE MATERIALS AREA

RADIONUCLIDES USED: ^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{125}I

RADIATION HAZARD RATING OF LABORATORY:

LOW - Casual entry discouraged

▨ **Indicates location(s) in the lab where radioisotopes may NOT be used.**



IN CASE OF EMERGENCY CONTACT:

1. **Dr. Jane Doe ext: 5-5555**
2. **Institutional Safety ext: 2-2057,
VU operator after hours**

Posted on: March 20, 1996

BIOLOGICAL EFFECTS OF RADIATION

Soon after 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:

$LD_{50/60}$ = 340 rads (if minimal treatment is available)
= 510 rads (with careful supportive treatment)
= 1050 rads ("heroic" treatments such as marrow transplants)

Radiation injury to the skin

Epilation (loss of hair) may occur for skin doses exceeding 300 rads.

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

Transepidermal injury is equivalent to a second degree burn. Erythema develops, followed by blisters that break open leaving painful wounds subject to infection. Requires 1000-2000 rads.

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

Chronic radiation dermatitis, 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 thousand rads if accumulated at the rate of about one rad per day.

LONG-TERM EFFECTS OF RADIATION EXPOSURE

Somatic Effects: Cancer

The long-term or late 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 rads. Data has been analyzed for groups such as the Japanese survivors in Hiroshima and Nagasaki and patients treated therapeutically for various conditions (thymic enlargement, tinea capitis, hyperthyroidism, cervical cancer, 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 leukemias 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 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 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.

Somatic Effects: Fetus and Embryo

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 rads. However, it is likely that there are threshold doses for most maldevelopments, 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 of 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 has been established as 0.5 rem.

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 protracted 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. 500 rads or more may produce more serious progressive cataracts. The latent period varies from 0.5 to 35 years.

There appear to be no nonspecific effects from low doses of radiation that result in a shortening of the life span. Although life shortening of a population group is a consequence of exposure to significant levels of radiation, 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 may cause harmful mutations to be transmitted to the descendants of the irradiated individual. Due to a lack of data of 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** which is necessary for the induction of genetic effects. From mouse studies it is known that the female is much less sensitive to transmission of genetic damage from radiation than is the male. Exposure at high dose rates produces more damage per rad than exposure at low dose rates, which is 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 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 parent received the limit of 5 rem/yr for 20 years prior to giving conception, the risk of having a child or (later) a grandchild with a serious genetic defect caused by the radiation exposure would 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).

A COMPARISON OF RADIATION RISKS TO OTHER KINDS OF HEALTH RISK

Perhaps the most useful unit for comparison among risks is the average number of days of life expectancy lost per unit of exposure to each particular health risk. Estimates are calculated by looking at a large number of persons, recording the age when death occurs from apparent causes, and estimating the number of days of life lost as a result of these early deaths. The total number of days of life lost is then averaged over the total group observed.

Several studies have compared the projected loss of life expectancy resulting from exposure to radiation with other health risks. Some representative numbers are presented in Table 2.

These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in normal day-to-day activities.

A second useful comparison is to look at estimates of the average number of days of life expectancy lost from exposure to radiation and from common industrial accidents at radiation-related facilities and to compare this number with days lost from other occupational accidents. Table 3 shows average days of life expectancy lost as a result of fatal work-related accidents. Note that the data for occupations other than radiation related do not include death risks from other possible hazards such as exposure to toxic chemicals, dusts, or unusual temperatures. Note also that the unlikely occupational exposure at 5 rems per year for 50 years, the maximum allowable risk level, may result in a risk comparable to the average risks in mining and heavy construction.

Reference: NRC Regulatory Guide 8.29, as adapted from Cohen and Lee, "A Catalogue of Risks," Health Physics, Vol. 36, June 1979; and World Health Organization, "Health Implications of Nuclear Power Production," December 1975.

Table 2
Estimated Loss of Life Expectancy from Health Risks

Health Risk	Estimated Loss of Life Expectancy, Average
Smoking 20 cigarettes/day	6.5 years
Overweight by 20%	2.7 years
All accidents combined	435 days
Auto accidents	200 days
Alcohol consumption (U.S. avg.)	130 days
Home accidents	95 days
Drowning	41 days
Natural background radiation, calculated	8 days
Medical diagnostic x-rays (U.S. avg.), calculated	6 days
All catastrophes (earthquakes, etc)	3.5 days
1 rem radiation dose, calculated (industry average for higher-dose jobs is 0.65 rem/year)	1 day
1 rem/year for 30 yrs, calculated	30 days

Table 3
Estimated Loss of Life Expectancy from Industrial Hazards

Industry Type	Estimated Loss of Life Expectancy, Average
All industry	74 days
Trade	30 days
Manufacturing	43 days
Service	47 days
Transportation & utilities	164 days
Agriculture	277 days
Construction	302 days
Mining & quarrying	328 days
Radiation dose of 0.65 rem/yr (industry average) for 30 yrs, calculated	20 days
Radiation dose of 5 rems/yr for 50 years	250 days
Industrial accidents at nuclear facilities (nonradiation)	58 days

DECONTAMINATION

Personnel Decontamination

1. Contamination of the skin with beta-emitting radionuclides can result in very high dose rates to the skin, about 9 rads/hr for every microcurie per sq. cm deposited on the skin (see Rules of Thumb for Beta Particles). 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.

2. Skin should be monitored with a survey meter. Pay particular attention to folds and crevices in the skin. Any "hot spots" which are located should be cleaned first to prevent the spread of the contamination to other areas of the body.

3. Decontamination of body surfaces may be carried out by washing the affected area with a mild soap or detergent and water. A specialized, commercially available skin decontamination agent may also be used. Wash 2-3 minutes and then monitor; repeat if necessary. Do not wash more than 3 or 4 times as continued washing will defat the skin. A soft brush may be used to lightly scrub the area, but care must be taken not to allow the skin to become irritated or abraded. In no case should decontamination continue to the point where the effectiveness of the skin as a protective barrier is destroyed.

4. If a suitable solvent for the material is known which is not injurious to the skin, it may he helpful to try this also. Organic solvents should not be used, as they may increase the probability of radioactive material penetrating the skin.

5. If the above procedures are not effective, notify the Radiation Safety Officer to obtain assistance.

6. Individuals who have been cut by contaminated glassware or whose skin has been punctured by a hypodermic needle should induce the wound to bleed and should wash the wound under running water.

7. Persons who have swallowed large amounts of radioactive material can be treated as for poisoning. Vomiting should be induced or a stomach pump used to remove some of the ingested material. See also following section entitled "Methods for Reducing Absorption of Radionuclides."

8. Report all radiation incidents involving intake of radioactivity or personnel contamination to Institutional Safety.

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; monitor persons leaving the area, especially hands and shoes. If labware is contaminated, label it with warning tape if it is not going to be immediately decontaminated.

3. Wear protective clothing such as lab coat, rubber or plastic gloves, and shoe covers (if floor is contaminated).

4. Cleaning spills: First remove hot spots, 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. Plasticware is very

difficult to decontaminate; if the item is inexpensive it may be simpler to dispose of such equipment.

6. Decontamination agents. Soap or detergent and water are often sufficient. 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. The Radiation Safety Section may be consulted for more information.

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 are Housekeeping or other untrained personnel to 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:
    1) Radiation signs & warning tape
    2) Small plastic bags or shoe covers
    3) Large plastic bag for waste
    4) Small paper bags for sharp &broken objects
    5) Gauze sponges and/or paper towels
    6) Masking tape or grease pencil
    7) Filter paper for wipes
    8) Disposable gloves
    9) Scissors
    10) Forceps or tongs
    11) Large absorbent pads
    12) Scouring powder
    13) Detergent/emulsifier
    14) Tags for waste bags
    15) Container to hold these items

HINTS FOR DECONTAMINATION OF VARIOUS 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	Monitor wash water and dispose of properly
	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

METHODS FOR REDUCING ABSORPTION OF RADIONUCLIDES

Following internal contamination there is usually a period of time (up to 3 hours following intake) before the radionuclide has been absorbed, transported and taken up by tissue cells. Absorption can be reduced by:

1. Alkalizing the stomach - reduces solubility of metal salts (Fe, Cu, Pu).
2. Administration of a cathartic to shorten intestinal transit time, thereby reducing absorption (and radiation exposure to gut wall).
3. Chelating agents, which bind metals into complexes and thus prevent tissue uptake.
4. Blocking agents or isotopic dilution to saturate tissue with a non radioactive element.

Once uptake of a radionuclide has occurred, there is often little one can do but wait for metabolism and excretion as well as physical decay to occur.

DIETARY MANIPULATIONS

ISOTOPE	DIETARY MANIPULATION	MECHANISM OF ACTION
^{51}Cr	Avoid antacid; increase acidity of stomach	Hexavalent chromium is better absorbed than trivalent chromium. Gastric acid reduces hexavalent Cr to trivalent Cr.
^{57}Co, ^{60}Co	Vitamin B-12	Isotopic dilution.
^{59}Fe	Raise pH of stomach with vigorous antacid therapy	Inorganic Fe forms complexes with normal gastric juice at low pH which remain soluble in higher pH of duodenum where iron is absorbed.
^{65}Zn	Copper	Interferes with zinc uptake.

MEDICATIONS

ISOTOPE	MEDICATION	DOSE (ORAL ADMIN.)	EFFECTIVENESS
^{3}H	Water	1-2 liters initially. Continue to force fluids (5-10 liters per day) for 7-14 days.	^{3}H rapidly incorporated into body water. Isotopic dilution. Excretion can be increased 10-20 times by prompt treatment.
Iodine	Potassium iodide saturated solution	100 mg. 2-3 drops in glass of water.	Reduces uptake by thyroid by 90% if given within 2 hours. Limited benefit after 10 hrs.
^{32}P	Phosphorus	2 capsules in glass of water.	Isotopic dilution. 4 capsules supply 1 gram of phosphorus.
^{99m}Tc	Potassium iodide (Lugol's solution)	100 mg. 2-3 drops in glass of water	Reduces uptake by thyroid.

American Industrial Hygiene Association Journal

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 1. Summary of Average Whole Body Dose Rates in the U.S.

Rates in the U.S.	mrem/yr)
Natural Sources	300
Medical radiation exams	53
Occupational exposure	1
Consumer products	5-13
Equivalent Whole Body Dose	360

NCRP Report 93, 1987

Natural Background Radiation. External sources include cosmic radiation and naturally-occurring radionuclides present in rocks, soil, and water.

TABLE 2. Radioactivity/Acre in Typical Soils

Radionuclide	Amt. per 1 ft depth	
Potassium 40	28 mCi	(9 lbs)
Thorium 232 series	25 mCi	(49 lbs)
Uranium 238 series	21 mCi	(10 lbs)

Radionuclides, the most important of which is potassium-40, are also ingested with our food and drink and result in internal exposure. External plus internal sources result in an annual dose equivalent of about **100 mrem per year**.

Radon gas is created by the radioactive decay of radium. Radon is also radioactive and after it decays a series of radioactive daughter products are created, some of which are hazardous alpha emitters. The dose equivalent to the bronchial epithelium from the Rn daughter products is about 2,500 mrem/year, equal to an effective whole body dose of about **200 mrem per year**.

TABLE 3. Effective Whole Body Dose Rates from Natural Sources of Radiation

	mrem/yr)
Cosmic rays	27
Terrestrial radioactivity (U, Th, K-40)	28
Internal emitters (K-40, C-14...)	39
Inhaled radon daughters	200
TOTAL	300

NCRP Report 93, 1987

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 1 is the average for the U.S. population.

TABLE 4. TYPICAL DOSES FROM MEDICAL EXAMS

X-Ray Exams (Typical Dose Values)

Exam	mrad (Organ)	EDE(mrem)
Chest, PA	20 (skin)	6
Dental, full mouth	87 (pharynx)	9
Abdomen, KUB	221 (ovaries)	56
Lumbar spine	240 (marrow)	127
CT lung	6030 (lungs)	1210
Mammography	580 (skin)	n/a
Fluoroscopy	1000-10000/min(skin)	

Nuclear Medicine Exams

Test	mrad(Organ)	EDE(mrem)
125I Iothalamate GFR	10 (bladder)	1.1
51Cr Blood volume	36 (blood)	21
131I Renal exam	890 (bladder)	61
99mTc Cardiac imaging	2100 (kidneys)	350
18F FDG-Brain	800 (spleen)	480
99mTc Ventriculography	710 (marrow)	590
111In Thrombi	15000 (spleen)	1200
131I Thyroid scan	33000 (thyroid)	1600

Note: EDE = Effective Dose Equivalent, the equivalent whole body dose which would produce the same biologic risk as the actual organ doses.

Radiotherapy

Typically 6000 rads to site of cancer, delivered in fractionated treatments.

Occupational Exposure. The average radiation dose received by radiation workers, including those at nuclear power plants, in medicine and in industry, is about 220 mrem/year, or 0.9 mrem/year averaged over the U.S. population.

Miscellaneous Sources, such as environmental exposure from nuclear power production, television sets, wristwatches, and tobacco smoking (dose to a segment of the bronchial epithelium of an average smoker is estimated to be 16,000 mrem/yr). Table 5 shows typical doses to the *exposed populations* from various consumer products.

TABLE 5. Effective Whole Body Dose Equivalent to the Exposed Groups from Consumer Products

	mrem/yr
TV + smoke detectors + airport x-ray	1
Mantles for gas lanterns (Th)	0.2
Ophthalmic glass (Th)	0.4
Rn from natural gas heaters	1.8
Rn from water supplies	1-6
Highway materials	4
Building materials	7
Tobacco (Po-210 & Pb-210)	*

*Greatest source from consumer products, but it is difficult to estimate effective whole body dose.

NCRP Report 93, 1987

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%)

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)
^{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%)
^{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%)

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)
^{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%)
^{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%)

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)
^{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 x 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%)

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)
^{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%)

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)
^{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%)
^{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%)

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)
^{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	4.5×10^9 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%)
^{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%)

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)
^{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%)

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

REFERENCES

General References

1. The Health Physics and Radiological Health Handbook, Nucleon Lectern Associates, Olney, MD, 1984, 1986.
2. Hurley, Patrick M, Living with Nuclear Radiation, U. Mich. Press, 1982.
3. Management of Persons Accidentally Contaminated with Radionuclides, NCRP Report No. 65, 1980.
4. Protection of the Thyroid Gland in the Event of Release of Radioiodine, NCRP Report No. 55, 1977.
5. Norwood, W. D., Health Protection of Radiation Workers, Charles C. Thomas, Springfield, IL, 1975.
6. Faires, R.A. and Boswell, G.G.J., Radioisotope Laboratory Techniques, Fourth Edition, Butterworth & Co.(Publishers) Ltd., London, 1981.
7. Shapiro, J., Radiation Protection, A Guide for Scientists and Physicians, Harvard University Press, Mass., 1981.
8. Radionuclide Transformations: Energy and Intensity of Emissions, ICRP Publication 38, 1983.
9. The Handling, Storage, Use and Disposal of Unsealed Radionuclides in Hospitals and Medical Research Establishments, ICRP Publication 25, 1977.
10. Evaluation of Radiation Emergencies and Accidents: Selected Criteria and Data, IAEA Technical Reports Series No. 152, 1974.

Biological Effects and Radiation Doses

1. Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V, National Academy of Sciences - National Research Council, Washington, DC, 1990
2. Health Risks of Radon and Other Internally Deposited Alpha-Emitters, BEIR IV, National Research Council, Washington DC, 1988.
3. Ionizing Radiation: Sources and Biological Effects, United Nations Scientific Committee on the Effects of Atomic Radiation, New York, 1982.
4. Limitations of Exposure to Ionizing Radiation, NCRP Report No. 116, Washington, D.C., 1993.
5. Genetic Effects of Internally Deposited Radionuclides, NCRP Report No. 88,1987
6. Comparative Carcinogenesis of Ionizing Radiation and Chemicals, NCRP Report No. 96, 1989.
7. Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, 1981, 1982.
8. Developmental Effects of Irradiation on the Brain of the Embryo and Fetus, ICRP Pub. 49, 1986.
9. Radiation Protection, ICRP Publication 26, Oxford, England, 1977.
10. Radiation Dose to Patients from Radiopharmaceuticals, ICRP Pub. 53, 1988.
11. Recommendations of the International Commision on Radiological Protection, ICRP Pub 60, 1990
12. Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimation, MIRD, 1975.
13. Instruction Concerning Prenatal Radiation Exposure, NRC Regulatory Guide 8.13, 1975.
14. Instruction Concerning Risks from Occupational Radiation Exposure, NRC Regulatory Guide 8.29, 1981.

Regulations

1. State Regulations for Protection Against Radiation, Department Environment and Conservation, Division of Radiological Health, Nashville, Tenn.
2. Vanderbilt Univ. Radiation Safety Manual, Dept. of Institutional Safety., U-0202 Med Center N., Nashville, TN
3. A Compendium of Major U.S. Radiation Protection Standards and Guides: Legal and Technical Facts, ORAU.
4. Transportation, Title 49 Code of Federal Regulations, Parts 100 to 199, 1986.

Radiation Measurement

1. Instrumentation and Monitoring Methods for Radiation Protection, NCRP Report No. 57, 1978.
2. Kobayashi,Y and Maudsley,D, Biological Applications of Liquid Scintillation Counting, Academic Press, NY,1974
3. Tritium Measurement Techniques, NCRP Report No. 47, 1976.
4. A Handbook of Radioactivity Measurement Procedures, NCRP Report No. 58, 1978.
5. Instrumentation and Monitoring Methods for Radiation Protection, NCRP Report No. 57, 1978.

References available from the Department of Institutional Safety.