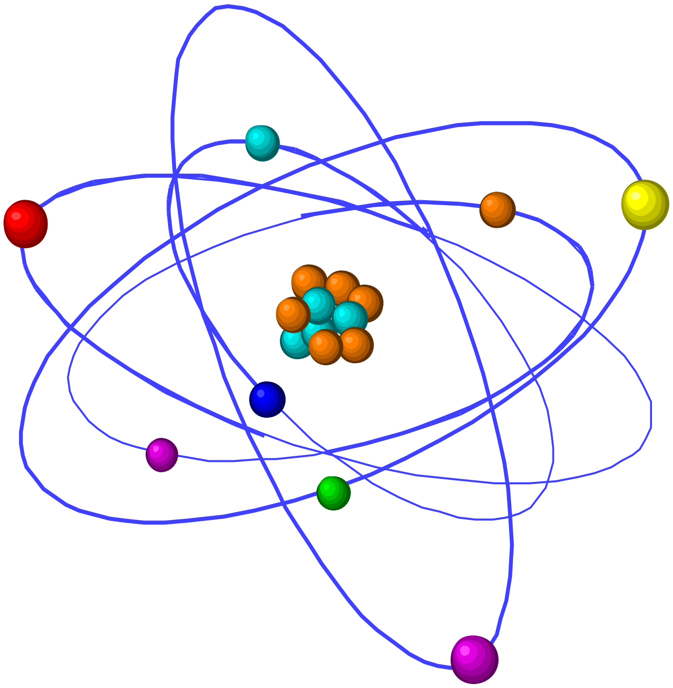
Radiation Worker Guide



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Contents

INTRODUCTION

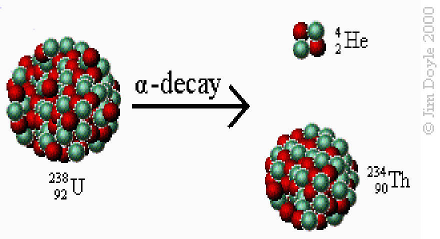
This manual provides an introduction to the various types of radiation, interaction of radiation with matter, radiation risk, dose limits, and the different types of monitoring equipment used in the research laboratory. This should be read along with the companion document"Radiation Safety Procedures for Laboratory Personnel".

1.0 NATURE OF RADIOACTIVITY

Radioactivity is a spontaneous process characteristic of atoms with unstable nuclei in which the nucleus releases energy either as a particle with kinetic energy or as electromagnetic energy or both. Upon release of this energy, the nucleus may be stable or it may still be unstable and will acquire stability through an additional transformation(s). The original species prior to radioactive disintegration is often termed the 'parent', with the species after the transformation called the 'daughter' or 'progeny'. A given transformation (one parent/daughter transition) is termed'disintegration' or a 'decay'. Only a limited number of types of transformation have been observed in the disintegration of radionuclides. The names of the 4 most common types of radioactive disintegration are:

- Alpha disintegration
- Beta disintegration
- Electron capture
- Isomeric transition

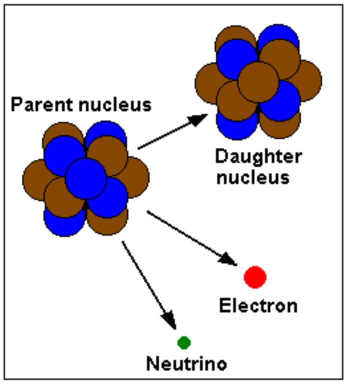
Prior to discussing these types of radioactive disintegration it is helpful to introduce a unit of energy - the 'Electron Volt' (eV). This unit is used to denote particle and photon energies in atomic physics, and it represents the energy change experienced by an electron while undergoing a potential energy change of one volt. It is common to express certain energies in kilo electron volts (keV = one thousand electron volts), mega electron volts (MeV = one million eV), etc. For comparative purposes, the kinetic energy of an air molecule at typical room temperature is about 0.025 eV and diagnostic x-rays average about 50 keV.



Alpha Disintegration

Alpha emission is generally limited to isotopes of the heavy elements. (Isotopes are different nuclear varieties of an element, same atomic number (Z) but different mass numbers (A). In alpha emission, a particle consisting of 2 protons and 2 neutrons (a Helium nucleus) is ejected from the parent nucleus with high kinetic energy - typically, about 4 MeV. The alpha particle, although its initial energy is great, is stopped by a few centimeters of air or by a few micrometers of tissue. After the emission of the alpha particle, the daughter atom may be in an excited level of that particular species. The resulting transition to the ground state is generally accompanied by the emission of a gamma ray, a photon of electromagnetic energy that is emitted from the nucleus of the excited atom.

Common alpha-emitting isotopes are Polonium-210, Radium-226, thorium and uranium compounds.



Beta decay

1.2 Beta Disintegration

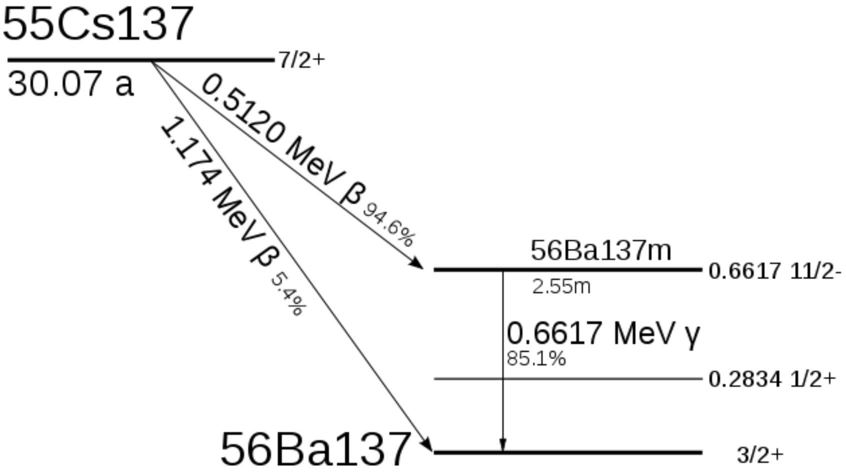
Beta emission is the name of a transition that results in the emission of a positron or an electron from the nucleus. The emitted particle may be positively charged (a positron) or negatively charged (an electron). The disintegration process also results in the emission of an accompanying particle - a neutrino for positron emission, an anti-neutrino for electron emission. The sum of the kinetic energies of the two particles, electron and anti-neutrino or positron and neutrino, is characteristic for each beta-emitting radionuclide. As examples, this sum is 1.71 MeV for P-32 and 0.156 MeV for C-14. The sum represents the maximum kinetic energy ever associated with the emitted beta particle. As an example, the betas emitted by P-32 are polyenergetic with individual kinetic energies from 0 to 1.71 MeV. In every disintegration, a sum of 1.71 MeV of kinetic energy is shared by the beta and the anti-neutrino. The mean or average beta-particle energy is approximately 1/3 of the characteristic maximum or ‘end-point’ energy.

Although the neutrino or anti-neutrino carries the other 2/3 of the total kinetic energy, on average, it has no practical interaction with matter and, consequently, produces no biological effects. There are about 25 cases of nuclides that decay by simple beta disintegration. Examples of such radionuclides are H-3 (Tritium), C-14 (Carbon-14), P-32 (Phosphorous-32), S-35 (Sulfur-35), and Ca-45 (Calcium-45). In these cases, the only emissions are the beta-particle and the neutrino.

However, the two common processes of beta disintegration is for the daughter to be in an 'Excited Isomeric State' of the nuclide with the subsequent emission (usually promptly) of a photon of electromagnetic radiation from the nucleus that is called a 'gamma-ray'. These two processes are termed isomeric transition and electron capture.

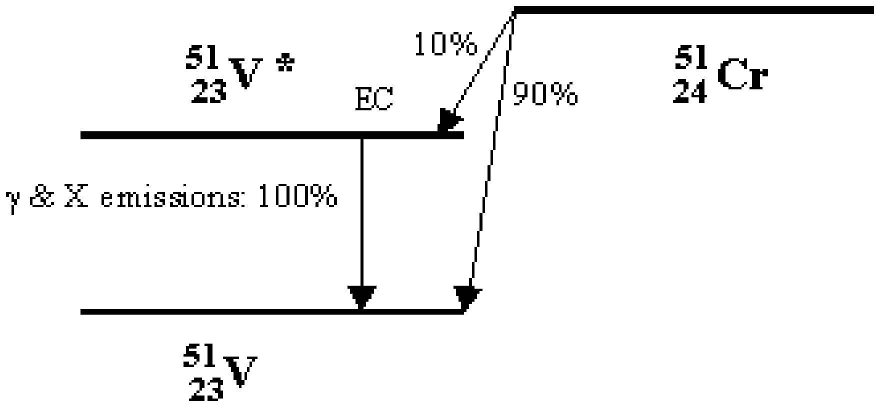
1.1 Isomeric Transition

Because the excited levels and the ground state level of a radionuclide differ only in nuclear energy content, the various levels are called nuclear 'isomers' and the transitions between them are called "isomeric transitions" . These transitions normally occur promptly after formation of the excited level. 'Promptly' usually implies de-excitation times on the order of nanoseconds) and generally result in x-rays of energy equal to the difference of the energies of the two isomeric levels involved in the transition. Cs-137 decays by beta decay to Ba-137 by two different pathways. In the first pathway which occurs 6.5% of the time, the resulting betas have an endpoint energy of 1.174 MeV and the daughter is at its ground state. For the other pathway, occurring 93.5% of the time, the endpoint energy is 0.5120 MeV; this suggests an average beta particle kinetic energy of about 1/3 x 0.512 = 0.171 MeV. This pathway leaves the daughter of the decay at an excited level, approximately 0.662 MeV above the ground state. A prompt de-excitation change takes the nucleus to the ground state and results in the emission of a gamma ray of 0.662 MeV from the nucleus.



1.4 Electron Capture

An unstable nucleus of certain species can convert a proton to a neutron by a process termed “Electron Capture”. An orbital electron is ‘captured’ while passing through the nucleus of these unstable nuclides. The captured electron combines with a nuclear proton to yield a neutron; a reaction product, a neutrino, is emitted from the nucleus. A rearrangement of the orbital electrons then results to fill the vacancy due to the captured electron. This rearrangement of orbital electrons is generally accompanied by the emission of characteristic x-rays. In addition, if the disintegration leaves the daughter at an excited level, then gamma rays are likely to be emitted in the subsequent transition(s) to the ground state of the daughter nucleus. Cr-51 decays via Electron Capture to the ground state of the daughter, Vanadium-51, 91% of the time. These transformations result in neutrinos and vanadium -characteristic x-rays. However, the electron capture transformation leaves the daughter in an excited state (0.32 MeV above the ground state) about 9% of the time. The subsequent isomeric transitions to the ground state yield 0.32 MeV gamma rays.



2.0 UNITS AND CALCULATIONS FOR MEASURING RADIATION AND RADIATION DOSE

2.1 Activity

The rate of radioactive disintegration is often used to indicate the ‘radioactivity’ of a sample and is termed the activity. Two different definitions of activity are used. The older definition of activity defines the Curie (Ci) as the amount of radioactive material (RAM) having a disintegration rate of 3.7×10^9(37 billion) per second. It is common to express activities in Curies (Ci), milliCuries (1 thousand mCi = 1 Ci), microCuries (1 million µCi = 1 Ci), nanoCuries (1 billion nCi = 1 Ci), picoCuries (1 trillion pCi = 1 Ci), etc. It is important to note that activity denotes only the rate of disintegration; it provides no information regarding the kind of radiation emitted during the radioactive disintegration. The newer definition of activity defines its basic unit as the Becquerel (Bq); a Becquerel corresponds to a disintegration rate of one disintegration per second (dps). It is common to express activities in kilobecquerels (kBq - one thousand dps), megaBecquerels (MBq - one million dps), etc.

2.2 Half-Life

An important characteristic of any radionuclide is its half-life. The half-life corresponds to the time necessary for one-half of the radioactive atoms of a sample to disintegrate. The mathematical description of exponential decay is given as follows and can be used to determine the amount of activity remaining in a particular sample after a certain time (t) has elapsed:

$A_t=A_0e^{-\lambda t}$

Where:

A_t=the activity of the isotope after an elapsed time (t)

A_0=the initial activity of the isotope

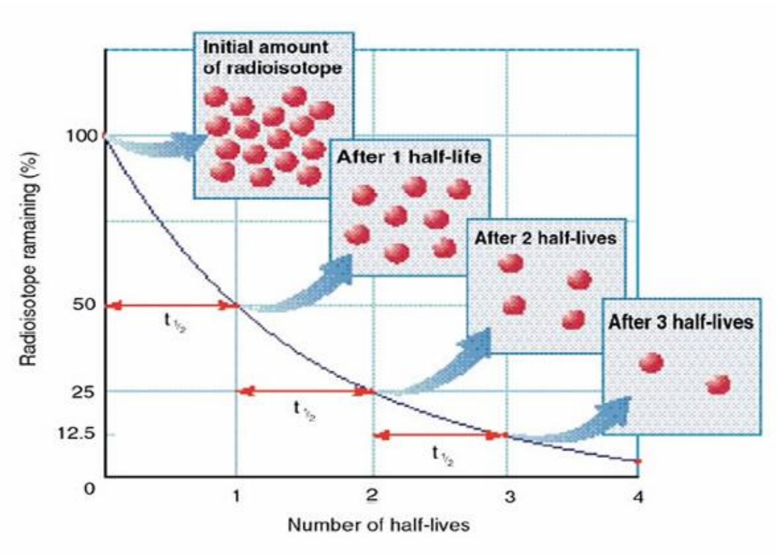
t= elapsed time since the initial activity was measured (days, years, etc)

$t_{1/2}$=the half-life of the isotope in days, years (available in reference tables)

λ=the radioactive decay constant=$0.693/t_{1/2}$

In general, the fraction remaining is expressed by the relationship fraction remaining = $(1/2)^n$ where n = number of half-lives.

The fraction of atoms (or activity) remaining as a function of the number of selected elapsed half-lives is as follows:



It is interesting that of the approximately 1300 different radionuclides the most frequently found half-life is about 1 hour. Approximately 24% have a half-life of 1 hour to 1 day, and 20% have a half-life of 1 day to 1 year. The half-lives of the most commonly used radionuclides at UCR are as follows:

Radionuclide	Half-life
Hydrogen-3	12.3 years
Carbon-14	5700 years
Phosphorus-32	14.3 days
Phosphorus-33	25.3 days
Sulfur-35	88 days
Chromium-51	28 days
Iodine-125	60 days
Calcium-45	165 days
Cesium 137	30.1 years

2.3 Effective half-Life

In biological systems, the physical half-lives tell only part of the story. The rate of biological removal or elimination can often be expressed as a biological half-life. If a radioactive element with a physical half-life (Tp) is incorporated in a compound that is eliminated with a biological half-life (Tb), the effective half-life (Teff) can be expressed as:

Teff = (Tp x Tb)/ (Tp + Tb)

As an example, the biological half-life of radioiodine in a human thyroid is about 60 days. Since the physical half-life of I-125 is 60 days, the effective half-life is given by:

Teff = (60 x 60)/(60 + 60) = 30 days

It should be noted that Teff is less than either Tb or Tp provided they are finite.

3.0 MEASUREMENT OF RADIATION DOSE

It is important to know the ‘Radiation Level’ to which workers are exposed. There are 3 different concepts of determining personnel radiation levels:

- Radiation Exposure
- Absorbed Dose
- Dose Equivalent

3.1 Radiation Exposure

The concept of ‘exposure’ is based on the ability of x-rays and gamma-radiation to ionize matter. Specifically, the amount of electrical charge liberated in air is used to measure radiation level. The unit of radiation exposure is the Roentgen. Electronic devices called Ionization Chambers are designed to monitor x-ray and gamma-radiation exposure levels.

3.2. Absorbed Dose

Absorbed Dose is a computed quantity that denotes the energy imparted to matter by ionizing radiation per unit mass of irradiated material at a place of interest. The unit of Absorbed Dose is the ‘Rad’, and it is defined as the energy absorption of 100 ergs per gram of material.

3.3. Dose Equivalent

Dose equivalent is a computed quantity that denotes the potential biological effect of the ionizing radiation. It is defined as the product of the absorbed dose and certain modifying factors. The unit of the product (the unit of dose equivalent) is the rem. Although several modifying factors have been proposed, only the Quality Factor (QF) has been used extensively. The Quality Factor is a subjective measure of the 'relative hazard or biological effect' of a given type of radiation. Examples of the quality factors for common types of radiation are as follows:

Radiation Type	***QF***
X, Beta, Gamma	1
Thermal neutron	2
Fast neutron	10
Alpha	20

An estimate of biological effect (the dose equivalent in Rems) is computed by simply multiplying the absorbed dose in 'rads' by the appropriate QF. Example: If an individual received a fast neutron absorbed dose of 2 Rads, then the calculated dose equivalent is 20 Rem. The relationships among the rad, the rem, and the quality factor are complicated. However, the following simplification is helpful: a dose equivalent of approximately of 1 Rem or an absorbed dose of approximately 1 Rad is imparted to human tissues at a location where a survey instrument indicates an exposure of 1 Roentgen due to x- or gamma-radiation.

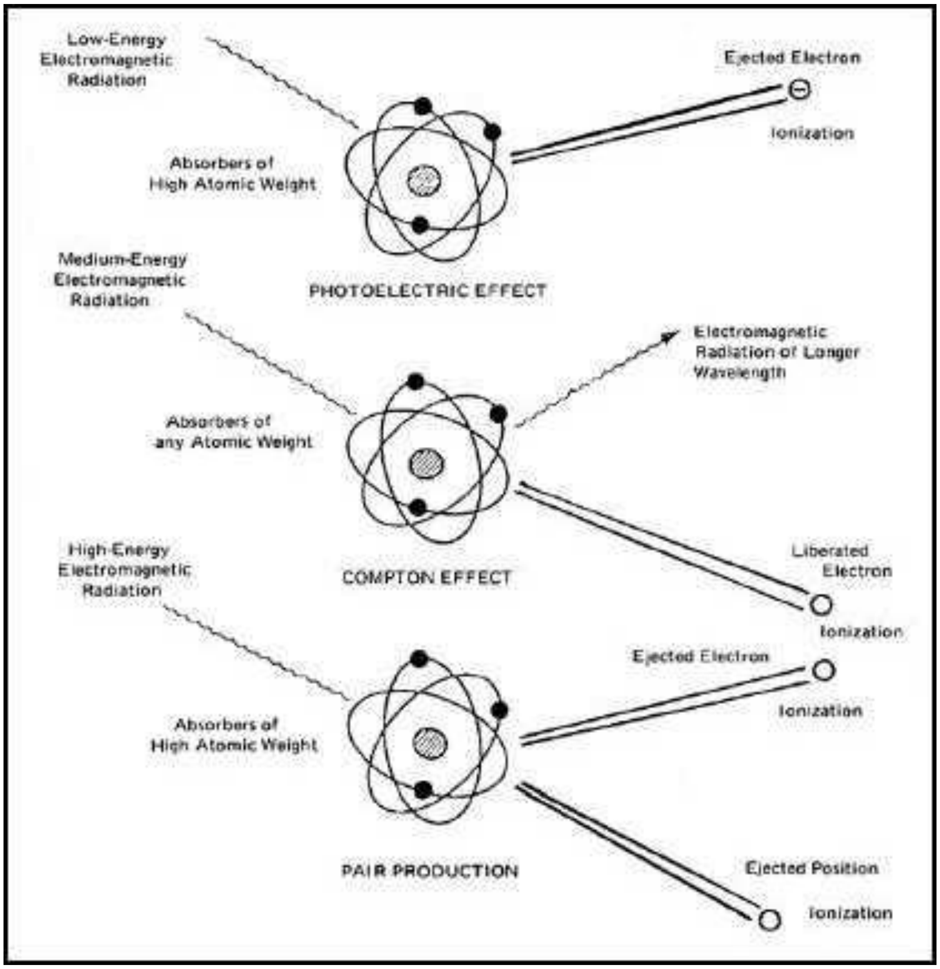
4.0 INTERACTION OF RADIATION WITH MATTER

4.1. X-ray-and Gamma Radiation

X-rays and gamma rays are electromagnetic radiation. The terms x-ray and gamma ray refer to the origin of the radiation; x-rays are generated by electrons whereas gamma rays are emitted by nuclei involved in radioactive disintegration. Hence, x-rays and gamma rays of the same energy are identical in every respect except origin. They are known to interact with matter by more than 10 different processes. However, there are only three important interactions:

- Photoelectric Absorption
- Compton Effect
- Pair Production

In some interactions the radiation behaves like particles called photons. They travel with the speed of light and are characterized by their energy. The following summarizes the important photon interactions with matter.



4.1.1 Photoelectric Absorption

In this process the incident photon is absorbed by a bound electron and ceases to exist. The electron is ejected from its previously bound state and carries away most of the absorbed energy as Kinetic Energy. A rearrangement of orbital electrons to fill the vacancy caused by the ejected electron results in the emission of characteristic x-rays and the products of a competing process, Auger Electrons.

The probability of Photoelectric Absorption occurring is very dependent upon the energy of the radiation and upon the atomic number of the absorption material. In general, Photoelectric Absorption is the dominant absorption process at low radiation energies, and it occurs, for a given energy, much more in materials of high atomic number than in materials with low atomic number. Thus, Lead with an atomic number of 82 is an excellent material for absorbing radiation by the photoelectric process.

4.1.2 Compton Effect

In this interaction the incident photon undergoes a billiard-ball type collision with an electron of the interacting material. The photon is deflected or scattered by the collision and continues with reduced energy. Compton interactions occur to about the same degree in unit masses of different materials (a gram of wood is about as effective as a gram of Lead) if the attenuation process is Compton Scattering. The probability of Compton Scattering in any material steadily decreases as the energy of the radiation increases.

4.1.3 Pair Production

In this attenuation process, the incident photon materializes into a pair of particles (an electron and a positron) in the vicinity of a nucleus. The minimum or threshold energy for this interaction is 1.02 MeV. This corresponds to the rest mass energy-equivalence of the two created particles. Pair Production occurs more in matter with high atomic number constituents than matter of low atomic number. In general, photoelectric absorption is the dominant interaction at low energies while Pair Production is the dominant interaction at very high energies. Compton Scatter is the important mechanism for intermediate energies.

4.2 Particle Interactions

Every swiftly moving, charged particle, such as an alpha particle or beta particle (electron), ionizes some of the atoms that lie along its path as it traverses matter. It is this ionization that is responsible for the radiobiological effects of radiation and also that makes possible the detection of radiation with various types of instruments. In passing through air, a typical particle will produce on the order of thirty thousand ionizations along its path before being brought to rest. The density of ionization along the path of a charged particle is approximately proportional to the square of the charge on the particle. Hence, for alpha particles it is four times as great as for protons or electrons having the same velocity.

Also, the ionization per unit path length is approximately inversely proportional to the square of the velocity of the particle. Thus, slow-moving particles ionize much more densely than swift particles. Typical values of the specific ionization along the path of an alpha particle are about 5,000 ion pairs per millimeter of air or per micron of water or tissue while typical values for electrons are in the order of 5-10 ion pairs per millimeter of air or per micron of tissue. As a charged particle passes among the atoms of an absorbing material it may:

- Dislodge electrons from atoms to form positive and negative ions (ionization)
- Excite electrons to higher energy levels in atoms
- Set up vibrations of molecules in the path
- Break molecular bonds
- Produce electromagnetic radiation subsequent to a sudden change in its course (Bremsstrahlung).

Of the 34 eV dissipated on average per ion produced in air, only about 16% goes into the production of ions, the remaining 84% going into the other dissipating processes. The energy that a particle loses to its surroundings for each unit of path length is called the “Linear Energy Transfer” (LET) and is usually expressed in keV/ micron. The net distance that a charged particle travels from its point of origin to its end point (Rest Point) is its range. As an example, the range of a 1 MeV electron is 4.2 mm in water (tissue). The paths of heavy particles are essentially straight with few drastic deflections. However, for electrons the paths are very tortuous and the average path length is about twice as great as the range.

5.0 BIOLOGICAL EFFECTS OF LOW LEVEL RADIATION

RAM emits ionizing radiation, the interaction of which with human tissues can result in biological damage. The biological damage to tissues is primarily due to secondary charged particles that result when the tissues are exposed to the ionizing radiation. The energetic secondary particles yield highly reactive free radicals that interact with molecules in the tissues, breaking chemical bonds and causing other chemical changes. Some of the resulting damage is repairable, and some is not. Biological effects of low- level radiation (low level radiation means acute whole body doses of 10 rems or less, or substantially larger doses if received over an extended length of time) can be classified into three categories; somatic effects, developmental effects, and genetic effects.

5.1 Somatic Effects

These are effects occurring in the exposed person. The somatic effect thought to be associated with low-level radiation doses is cancer induction. The following is known regarding radiation-induced cancers: The manifestation is delayed after exposure to radiation - a few years for leukemia development and perhaps as many as 20 years for solid tumor formation. The resultant forms of cancer are indistinguishable from the cancers spontaneously occurring in people.

The probability of fatal radiation- induced cancer, based on the linear no-threshold model, is very conservatively estimated to be 120×10^{-6} per rem (about one chance in 8,000 per rem) of whole- body radiation. This means that, according to the linear no-threshold model, if you are exposed to a whole- body dose equivalent of 1 rem, your radiation-induced fatal cancer risk is 0.0125%. Since your fatal cancer risk based on national life expectancy statistics is 25%, your fatal cancer risk due to the 1 rem of radiation dose would be increased to 25.0125% rather than 25.0000%. The linear no-threshold model has no supporting data. In fact, there is much to show it grossly over-predicts the effects of radiation exposure. Again based on the linear no-threshold model, the fatal risk of 1 rem of whole body dose is calculated to be equivalent to the fatal risks of the following

- Traveling 7000 miles by car
- Smoking approximately 200 cigarettes
- Working three years in a typical factory

Thus, while the only known ‘Somatic Effect’ of low-level radiation exposure is cancer induction, the chance of occurrence is small.

5.2. Developmental Effects

These are effects occurring due to exposure of the unborn. The risks of in-utero exposure of the developing child are summarized as follows:

Radiation exposure during the first 2 weeks of pregnancy is thought to result in an ‘All or Nothing’ response. If a response occurs, the embryo is spontaneously reabsorbed and the pregnancy is terminated. Otherwise, the pregnancy continues in normal fashion with no deleterious effects. It is estimated that a radiation dose of 10 rem during the first 2 weeks of pregnancy results in a 0.1% increase in the embryonic re-absorption rate that occurs naturally.

The most critical period occurs between approximately the second and eighth week. The organ systems of the fetus are developing and radiation disturbances can result in congenital abnormalities - skeletal abnormalities tend to occur due to early exposure while neurologic abnormalities occur later in the 2 to 8 week organogenesis period. It is estimated that a dose of 10 rem to the fetus will increase the frequency of congenital abnormalities by 1% above the normally occurring level.

The induction of childhood cancer occurs following irradiation at any time in the gestation period. It is estimated that the dose of 1 rem to the unborn will result in two to fifteen cases of radiation-induced cancer per 100,000 live births.

5.3. Genetic Effects

Current knowledge of radiation-induced genetic effects suggests that at genetic equilibrium there would be a risk of serious genetic disorders in offspring of about 120×10^{-6} per rem of paternal radiation, with the understanding that the risk may be nearly twice that large for paternal and smaller for maternal exposure. To date all radiation genetic risk estimates have been derived from mouse data. The susceptibly of humans has been assumed to be equal to that of mice in development of the risk factors, although evidence from the Japanese A-bomb survivors has indicated that humans are probably less susceptible. No evidence of radiation-induced genetic effects in human beings exists. The incidence of serious genetic disease among live-born children in the United States are estimated to be about 3.1%. Using the risk parameter derived from mouse data each of the children of male radiation workers exposed to 0.1 rem/ year for 11 years prior to conception (29 years is the average age of fathers at time of birth in the U.S. 18 years is the minimum age for occupational exposure) has a risk of about $11 \times 0.1 \times 2 \times 120 \times 10^{-6} = 2.6 \times 10^{-4}$ (one chance in 3,800) of a serious birth defect (applies to a population at genetic equilibrium consisting of radiation workers; only about one-tenth of this rate would apply to the first generation). This represents an added risk that is about 1% of the spontaneous serious genetic disorder rate. It is well known that chromosomal abnormalities in offspring increase in frequency with both maternal and paternal age, with Down's Syndrome Trisomy 21, associated with maternal age the most familiar. It has been shown that the risk of an average U.S. radiation worker (0.6 rem/ year; 20 times our institutional average) to have children with serious genetic disease is roughly equal to that of delaying conception of his younger children by one year.

6.0 EXTERNAL AND INTERNAL RADIATION CONTROLS

6.1 Protection From External Radiation

6.11 Time

Reduce the amount of time you spend in close proximity to a radioactive source by working quickly and efficiently, without working so fast that you will compromise your results or cause spills. Take time to plan your work and perform dry runs.

Exposure (mrem) = exposure rate (mrem/hr) x exposure time (time in hours)

6.12 Distance

Whenever possible, increase the distance between you and the source of radiation. The intensity of radiation exposure decreases with the square of the distance from the source according to the relationship:

$$I_1 \times D_1^2 = I_2 \times D_2^2$$

$I_{1=}$ the intensity at an initial distance

I_2= the intensity at a new distance

D_1= the initial distance

D_2=the final distance

Therefore, if you double your distance from a source of radiation the exposure rate will be decreased to one-fourth of the initial value

6.13 Shielding

6.131 Beta emitters

If you are using high-energy beta emitters such as P-32, 1cm of Plexiglass can provide adequate shielding, since Bremsstrahlung radiation(x-rays) is also produced. For electrons of a given energy (E) (MeV), the fraction of energy that appears as Bremsstrahlung is given by the expression:

$f=ZE/1400$

where Z = the absorber atomic number. That is the reason that you should shield a pure beta emitter of high energy such as P-32 with a low atomic number such as Plexiglass, in order to minimize the production of the penetrating x-rays. High skin and eye radiation doses can be incurred while handling P-32.

Shielding is not required for low energy beta emitters such as S-35 or C-14 since these betas have very limited range, even in air.

6.132 Gamma Emitters

Attenuation refers to the reduction in the intensity of radiation (e.g. gammas and x-rays) as they pass through an absorbing material. The relationship is as follows:

$I_x=I_0e^{-\mu x}$

Where:

I_0=the intensity of the radiation with no absorbing material

I_x=the intensity of the radiation after passing through an absorber with thickness

x=absorber thickness

μ=Attenuation Coefficient= $0.693/x_{1/2}$

$x_{1/2}$= Half value layer(HVL)= Thickness of absorber that will reduce radiation intensity to one half of its original value. Thus 1/2 (50%) of the incident radiation is transmitted through one HVL, 1/4 (25%) through 2 HVL's. 1/8 (12.5%) through 3 HVL's, and so on. Values can be found in reference tables. Lead is the shielding of choice for gamma emitters.

6.133 Mixed Gamma and Beta Emitters

For mixed gamma and beta emitters, first shield with Plexiglas, then lead.

6.2. Protection from Internal Radiation

Internal deposition of radioactive materials within the body may cause high doses to body organs. This is most significant when a radioisotope has a long residence time (effective half-life) in the body and/or selectively accumulates in specific body organs. There are four primary routes of entry into the body: inhalation, ingestion, absorption (through the skin), and injection via cuts and abrasions.

Efforts to minimize internal contamination are important. To provide some perspective regarding tolerable internal contamination level, The California Code of Regulations uses 10CFR Part 20 Appendix B tables to specify maximum ‘annual limits on intake’ (ALI). The concept of the ALI is that it represents the quantity of a given radionuclide that, if ingested or inhaled by an individual, will result in the same cancer risk as that attributed to 5 Rem of whole- body dose. The ALI's for some commonly employed radionuclides as per 10CFR Part 20 Appendix B are listed below.

Radionuclide	**Oral Ingestion (uCi)**	**Inhalation (uCi)**
Tritium (H-3)	80,000	80,000
Carbon-14	2,000	2,000
Phosphorus-32	600	900
Calcium-45	2,000	800
Chromium-51	6,000	10,000
Iodine-125	40	60

Most of the radionuclides used at UCR are considered only slightly toxic with regard to internal contamination. However, I-125 is considered highly toxic because of it’s specificity for the thyroid gland. Internal contamination via ingestion, inhalation, or skin absorption can result in a high thyroid dose. (The computed thyroid dose for I-125 is 3.2 rem/ uCi.)

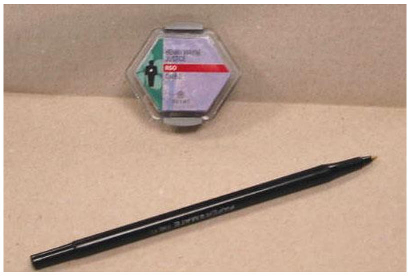
7.0 RADIATION MONITORING DEVICES

7.1 Personnel Monitors

The use of personnel monitoring devices or ‘dosimeters’ permits evaluation and documentation of the radiation levels incurred by individuals working with radioactive material. Personnel monitoring of external radiation usually employs one of the following types of dosimeters:

7.1.1Thermoluminescent Dosimeters

The Thermoluminescent Dosimeter (TLD) utilizes several ‘chips’ of special material (typically lithium fluoride) that have the unique property of emitting a quantity of light (luminescence) when heated (thermo) that is proportional to the dosimeter's prior radiation dose. The monitors generally contain two chips and two filters for monitoring skin dose (penetrating plus non-penetrating radiation) and whole- body dose (penetrating radiation). In addition, ring monitors containing a single chip are used to measure doses to the fingers of selected personnel. TLD body and ring monitors have minimum sensitivities of 10 and 30 mRem respectively.



Thermoluminescent Dosimeter

7.2. Portable and Non-Portable Survey Instruments

Portable survey instruments used at our institution are of two types; Geiger-Mueller (G-M) Survey Instrument and the Ionization Chamber Survey Instrument.

Performing a survey with a GM Survey Instrument

7.2.1. Geiger-Mueller (G-M) Survey Instrument

G-M instruments are widely used for radiation survey work because they are reliable and inexpensive. The instruments are compact, lightweight units with rugged electronics. These units utilize a gas detector that is capable of detecting beta, gamma, and x-radiation. Usually, a detector called a “pancake probe” is enclosed in a metal shield that precludes beta-particle detection except through a thin portion of the shield that is called the ‘window’. When the window is open, the probe can detect beta, gamma, and x-radiation. With the window closed, the device can detect only x-ray and gamma radiation. The exposure rate scale of a G-M device with a pancake probe will yield a fairly accurate indication of the true exposure rate only when exposed to x or gamma radiation. When the device is used to detect beta-particle radiation the exposure rate (in mRem/ hr) should not be used. Only counts per minute (cpm) scale are appropriate for particle detection. Thin-window G-M's monitor low energy beta emitters with low efficiency (3% for C-14 and S-35) and they do not respond at all to the betas from Tritium (H-3). Another detector that can be used with G-M instrument is called a Sodium Iodide (NaI) probe. The NaI scintillator was developed specifically to detect gamma radiation. The thallium doped NaI crystal has the property of producing light when energy is deposited into it by radiation. The detector is very light sensitive so even a tiny scratch on its thin end window will cause a very high spurious count rate.

7.2.2. Ionization Chamber Survey Instruments

Survey instruments utilizing an air ionization chamber are designed to measure exposure in mRems. They exhibit much less ‘energy-dependence’ of response than

G-M devices and can be used at much higher rate levels.

7.2.3. Scintillation Survey Instruments (Liquid scintillation Counter)

The liquid scintillation counter is a non- portable survey instrument and is the instrument most commonly used to detect H-3. A sample is mixed with liquid scintillation fluid in a small vial and placed in the counter. The light emitted by the interaction between the sample and the liquid scintillation fluid is collected by two photo-cathodes and their associated photomultiplier tubes. Only signals allowed to pass through the circuit and arrive at a point of coincidence in the circuitry by a certain time are considered a valid count. All other signals are rejected as noise. This allows accurate counting of very low activity samples such as used in cell tagging for biomedical research.

8.0 RULES AND REGULATIONS AFFECTING THE USE OF RADIOACTIVE MATERIAL

8.1 Dose Limits

Radiation exposure shall be “As Low As Reasonably Achievable (ALARA)”, but cannot exceed the limits specified below when exposures for external and internal sources are added together.

Occupational Dose Limits*

Exposure Area	Limit
Whole Body	5 rem/year
Lens of the eye	15 rem/year
Skin of the whole body or extremities	50 rem/year
Embryo/fetus of declared pregnant woman	0.5 rem during pregnancy
Minors (<18 years of age)	0.5 rem/year
Members of the public (long term)	100 mrem/year
Member of the public (short term)	2 mrem/hour

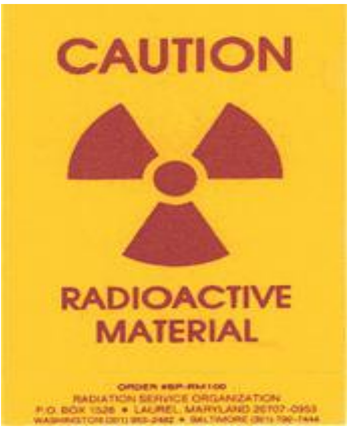
* Reference: 10CFR Part 20.1201,1207,1208,1301

8.2 Classification of Areas

8.2.1. Restricted Areas

A restricted area is one the access to which is controlled by the licensee to protect individuals from undue risks from exposure to radiation and RAM. Restricted areas are posted with warning signs and have limited access. The signs may be any of the following:

‘Caution Radioactive Materials’ Signifies that significant amounts of radioactive material are used or stored in the area.



‘Caution Radiation Area’ - Denotes areas accessible to personnel in which the dose rate may exceed 5 mrem per hour.

‘Caution Airborne Radioactivity Area’ - Used to warn individuals that airborne activity concentration exceeds of state limit for airborne activity in a restricted area or may exceed 25% of the state limit when the activity is averaged over the hours that any individual is in the area.

Each of the signs bears the three-bladed trefoil used as the universal symbol for radiation. The symbol is usually magenta or purple on a yellow background.

8.2.2 Unrestricted Areas

An area is unrestricted (access to the area is not limited or controlled for radiation protection purposes) if the radiation dose in the area is less than 2 mrem per hour or 100 mrem per year.

Radiation Safety Facts

Alphas and betas

It requires an alpha particle of at least 7.5MeV or a beta particle of at least 70KeV to penetrate the dead layer of skin 0.07mm thick.

The range of beta particles in air is about 12 feet per MeV.

The Bremsstrahlung x-rays from 10mCi of P-32 in aqueous solution in a glass bottle causes and exposure ate of about 0.1-0.2 mrem/hr at 1 foot.

The dose rate to fingers in contact with the sides of a small glass vial of P-32 is about 400 mRem/ hour/ mCi.

For a point source of beta radiation that can travel at least 1 foot in air, the beta skin dose can be determined by multiplying the activity in mCi by 300. The result is the beta skin dose at 1 foot from the source in mrem/hr.

For P-32, 8300cpm is approximately equal to 1mrem/hr beta skin exposure when using a Geiger-Mueller survey instrument with a pancake probe.

Gamma and X-rays

For a point source gamma emitter with an energy between 0.07 and 3MeV, the exposure rate in mrem/hr at 1 foot = 6CEn

Where:

C= the activity of the source in millicuries

E=the gamma energy in MeV

n= the number of gammas per disintegration