

RADIATION SAFETY TRAINING MANUAL

University of Notre Dame

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University of Notre Dame
Notre Dame, Indiana



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I. INTRODUCTION

All employees, graduate students and undergraduate students working in or frequenting a radioisotope laboratory should understand the hazards of radiation and follow the procedures necessary for working safely around them. This training manual and associated training session is designed to provide principles, procedures and practices which new radioisotope users should know. Hopefully, this training program will correct any misconceptions you may have about radiation and safety and prepare you for routine use of radionuclides and for certain emergencies that may arise in the laboratory.

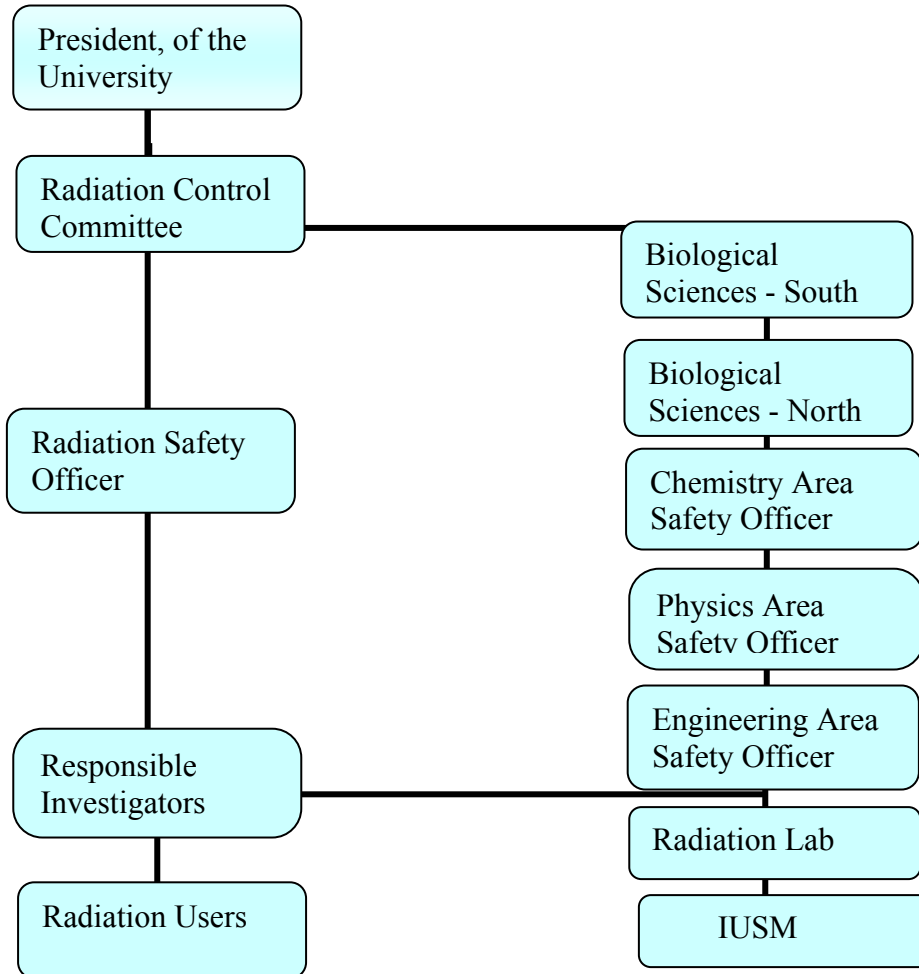
The organization structure of the University of Notre Dame's Radiation Safety Program is outlined on the following page. The duties and responsibilities of each group indicated are listed in the University of Notre Dame's **Radiation Safety Manual**. Specific procedures for radionuclide procurement and use are also included in the University's **Radiation Safety Manual**.

The Risk Management and Safety Staff is concerned with your understanding of radiation, proper evaluation of radiation hazards, and keeping radiation exposures As Low As Reasonable Achievable (ALARA). Do not hesitate to call the Risk Management and Safety Department at 631-5037 if you have any questions concerning radiation protection.

The University of Notre Dame is authorized to use radioactive material by the United States Nuclear Regulatory Commission under broad scope license number, 13-01983-15.

Figure 1. Organizational Structure

Radiation Safety Program Chart of Organization



What is Radiation?

Radiation consists of energy or particles, emitted from a source, that travel in wave-like motions. You are familiar with many kinds of radiation. Heat, light, and sound are kinds of radiation. The kind of radiation that we work with at most laboratories is called ionizing radiation. We cannot feel, see, hear, taste, nor smell this radiation. It is capable of producing small electrically charged particles called ions as it passes through matter. Such ions, produced in the cells of our body in sufficient quantities, can cause malfunctioning or damage in varying degrees.

Man is being continuously bombarded by ionizing radiation. This radiation comes from outer space and from natural radioactive elements in the earth. The amount of such radiation varies but usually it is not sufficient to produce harmful effects. This radiation in man's natural environment is called BACKGROUND or NATURAL radiation.

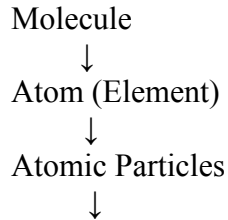
Only recently (since 1895) man has learned to produce large amounts of ionizing radiation. This has been done by concentrating natural radioactive materials, by using certain electrical operation devices (e.g. X-ray machines), and synthesizing material through the use of nuclear reactors and accelerators (e.g. radioisotopes).

There are 106 different kinds of unique atoms, called elements. All atoms of an element behave the same chemically, even though they may vary in weight. Atoms which vary in weight but behave the same chemically are said to be isotopes of the same element. Isotopes which emit radiation because they are too heavy compared to their neighbors are called radioactive isotopes. Many of these radioactive isotopes are used in research laboratories at Notre Dame.

The types of ionizing radiation with which we are mainly concerned are alphas, betas, gammas, X-rays and neutrons and each of these will be defined in the following chapters.

II. ATOMIC STRUCTURE AND RADIATION

A. Atomic Structure and Particles

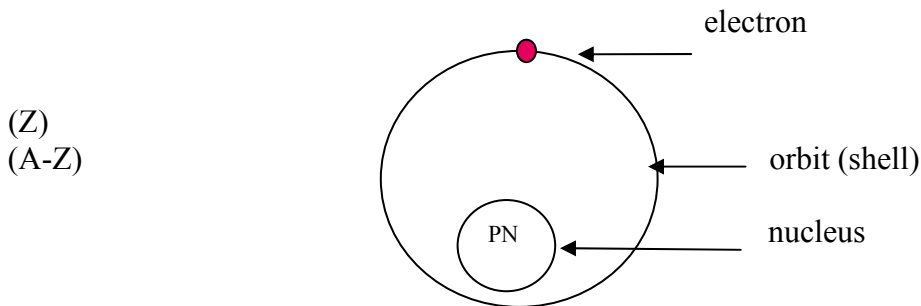


Molecule: Smallest quantity of a compound which can exist by itself and retain all the properties of the original substance.

Element: A category of atoms all of the same atomic number.

Atom: Smallest individual part of a molecule.

Atomic Particles: Basic components of an atom including the nucleus (protons and neutrons) and the orbiting electrons.



Atomic Notation:



Where

A = atomic weight = number of protons and neutrons

X = element symbol

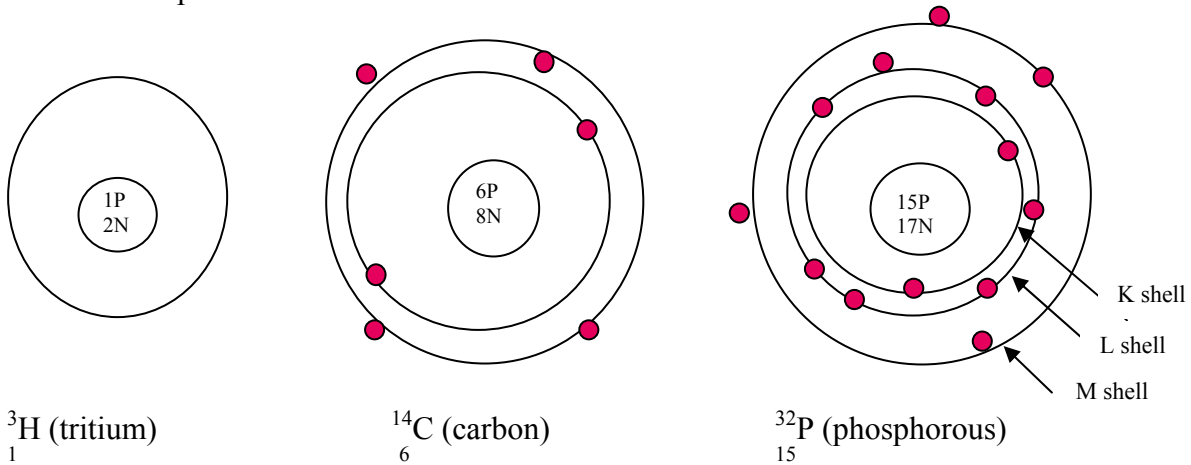
Z = atomic number

Atomic Mass: The actual mass of the atom.

1 Proton 1 neutron 1 atomic mass unit (a.m.u.) = 1 1/2 the mass of Carbon 12.

Atomic Number: The number of electrons orbiting the nucleus (also equals the number of protons in the nucleus). electron = 0.0006 a.m.u.

Example:



Nuclide: A species of atom having specified numbers of neutrons and protons in its nucleus. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time.

Isotopes: Nuclides all having the same atomic number. (equal number of protons, different number of neutrons.)

${}^1_1\text{H}$ hydrogen-stable isotope (non-radioactive)

${}^2_1\text{H}$ deuterium - stable isotope (non-radioactive)

${}^3_1\text{H}$ tritium - radioactive isotope

Atomic number determines chemical properties of an atom.

example: 1 proton = hydrogen ${}^1_1\text{H}$
6 proton = carbon ${}^6_6\text{C}$
8 proton = oxygen ${}^8_8\text{O}$

Isobars: Nuclides all having the same atomic weight.

example: ${}^3_1\text{H}$ ${}^3_2\text{H}$

Isotones: Nuclides all have the same number of neutrons.

Figure 2. Chart of Nuclides

Periodic Table of the Elements

1a																	0
1 H Hydrogen 1.0079																	2 He Helium 4.0026
											V						
IIa												IIIa	IVa	Va	VIa	VIIa	
3 Li Lithium 6.941	4 Be Beryllium 9.0122											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984	10 Ne Neon 20.179
11 Na Sodium 22.9898	12 Mg Magnesium 24.305											13 Al Aluminum 26.9815	14 Si Silicon 28.086	15 P Phosphorus 30.9738	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
IIIb			IVb	Vb	VIb	VIIb	_VIII_		Ib	IIb							
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.90	23 V Vanadium 50.941	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.933	28 Ni Nickel 58.71	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.22	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.4	47 Ag Silver 107.868	48 Cd Cadmium 112.40	49 In Indium 114.82	50 Sn Tin 118.69	51 Sb Antimony 121.75	52 Te Tellurium 127.60	53 I Iodine 126.905	54 Xe Xenon 131.30
55 Cs Cesium 132.905	56 Ba Barium 137.34	57 La Lanthanum 138.906	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.22	78 Pt Platinum 195.09	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.37	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium 226.03	89 Ac Actinium 227.03	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Ro Roentgenium							
58-71 lanthanides			58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium	62 Sm Samarium 150.4	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97	
90-103 actinides			90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium	

B. Radioactivity and Types of Radiation

Radioactivity: An atom having an unstable nucleus thereby emitting a part of the nucleus (called corpuscular radiation) in order to go to a more stable state. This action is often accompanied by release of electromagnetic radiation called gamma rays.

Unit of measure of radioactivity is the Curie
(Ci) Curie = 3.7×10^{10} dps = 2.22×10^{12} dpm
(mCi) millicurie = 3.7×10^7 dps = 2.22×10^9 dpm
(uCi) microcurie = 3.7×10^4 dps = 2.22×10^6 dpm
dps = disintegrations per second

International unit of measurement: Becquerel

Becquerel (Bq) = (sec^{-1}) reciprocal second
1 Curie = $3.7 \times 10^{10} \text{ sec}^{-1}$

Example: $600 \text{ dpm} = \frac{600 \text{ events}}{\text{min}} \times \frac{1 \text{ min}}{60 \text{ sec}} = \frac{10 \text{ events}}{\text{sec}} = 10 \text{ Bq}$

Energy: 1 electron volt (eV) = 1.6×10^{-19} joules
1 keV = 10^3 eV
1 MeV = 10^6 eV

<u>Major Types of Radiation</u>	<u>Symbol</u>
alpha (stripped helium nucleus - He^{2+})	α
beta (electron)	B-
beta (positron) - positively charged electron	B+
gamma	δ
x-ray	x
neutron	n

Alpha radiation:

Particles - two protons and two neutrons (a helium nucleus) are ejected as a single particle from the nucleus. These particles usually carry high amounts of energy and are too heavily ionizing to travel farther than a few inches in air. An alpha particle is easily stopped by such materials as a sheet of paper or the cells on the outside of our skin. However, if alpha particles get inside the body, they can produce greater damage than any other kind of radiation. Laboratories at Notre Dame seldom use alpha-emitting materials and thus such a hazard as this would not ordinarily be

encountered. The recent alarm concerning ^{210}Po in tobacco smoke is due to the fact that ^{210}Po is an alpha emitter. The same is true for radon.

Beta radiation

An electron or positron emitted from the nucleus of an atom. Beta particles travel at very high speeds and may have a range in air of 12 to 15 feet, depending upon their energy. This energy and speed may cause them to penetrate several layers of the skin. You can usually shield out or greatly reduce exposure with a thin piece of aluminum, glass or plastic. Positrons will annihilate with electrons forming (usually) two 511 keV photons.

Gamma radiation:

Electromagnetic (waves) - energy is released from the nucleus in the form of radiant energy, not as particles. Gamma rays, like visible light and x-rays, are small bits of energy called photons traveling in straight lines in the form of waves. They are more energetic than visible light. X-rays and gamma rays have enough energy to go completely through the body where visible light is stopped by the body. Gamma rays are usually attenuated with thick sheets of lead or concrete.

Neutron radiation:

Neutrons are particles, about 1/4 the mass of alpha particles, and are difficult to stop. Neutrons are electrically neutral, as opposed to alpha and beta particles, which are electrically charged. Therefore, neutrons are more difficult to stop and have a very good chance of passing through materials without interacting or striking anything. Neutrons are usually attenuated with such materials as paraffin, cadmium, or water.

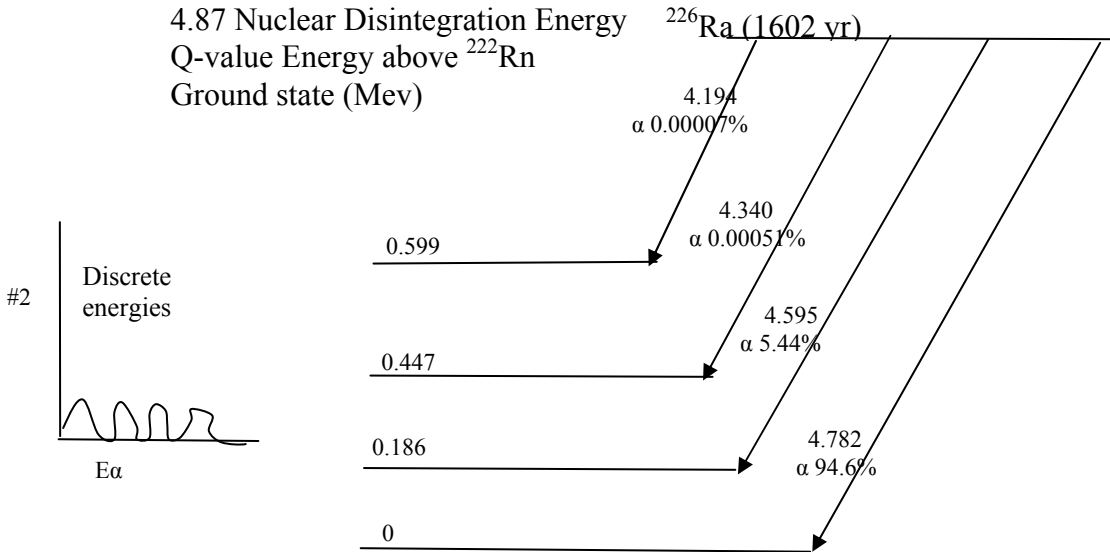
Bremsstrahlung radiation:

X-radiation produced as high energy beta particle slows down quickly as it passes through matter. Bremsstrahlung radiation is German for "Braking Radiation"

example: To prevent bremsstrahlung production by ^{32}P , plexiglass (low atomic number) shielding is used.

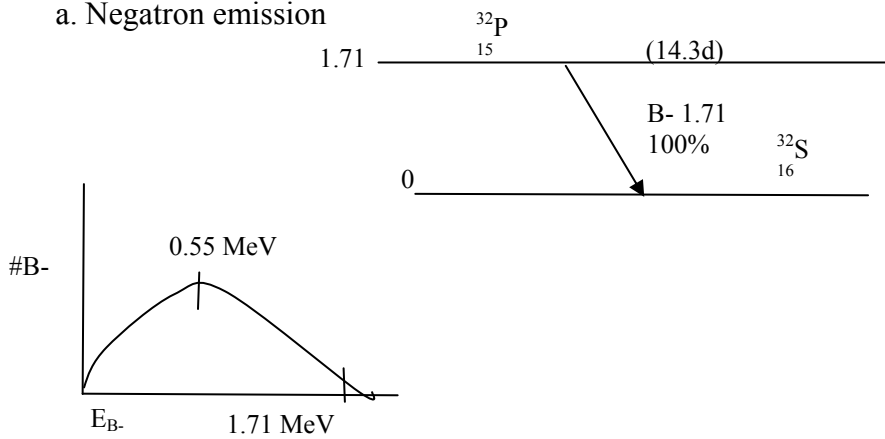
Decay Schemes:

Alpha decay

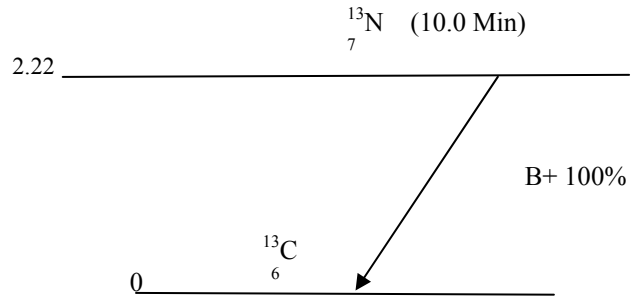
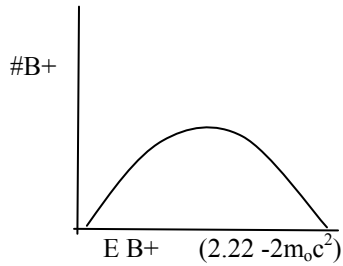


Beta decay

a. Negatron emission

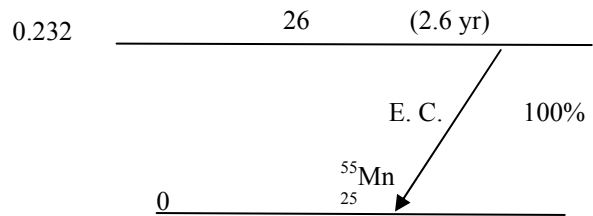


b. Positron emission



c. Electron capture

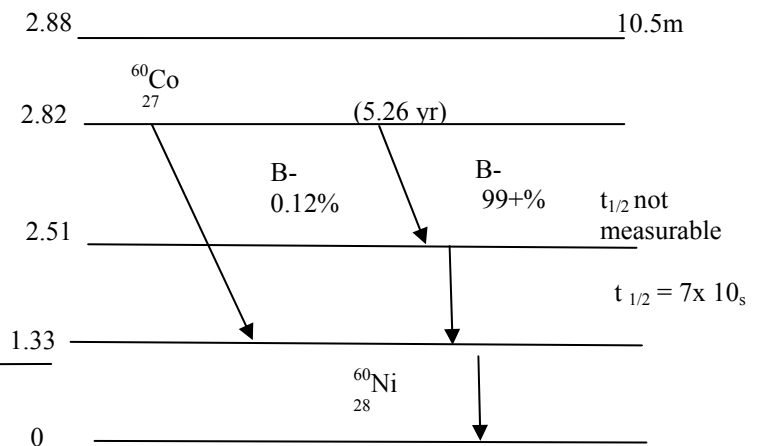
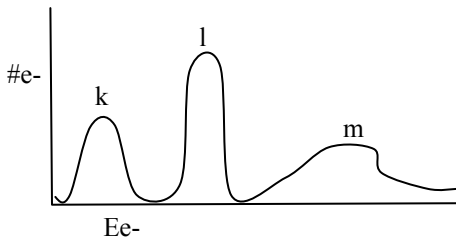
(X-rays of Mn are observed)



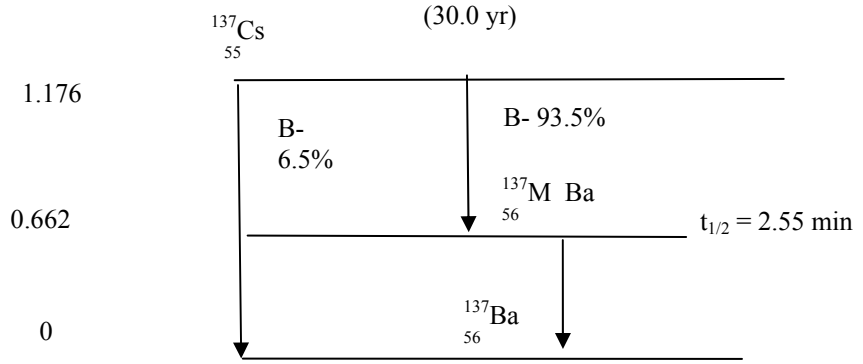
Gamma decay - radiative transition

a. Isomeric transition

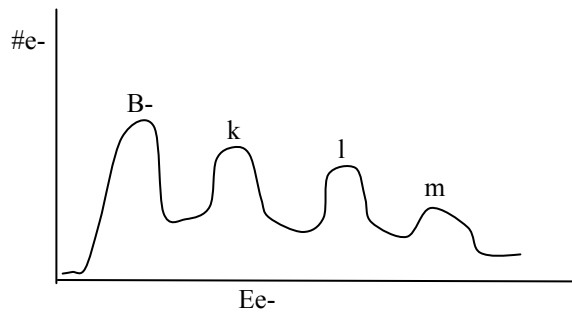
I. T. proceeds by mainly internal conversion



b. Internal conversion

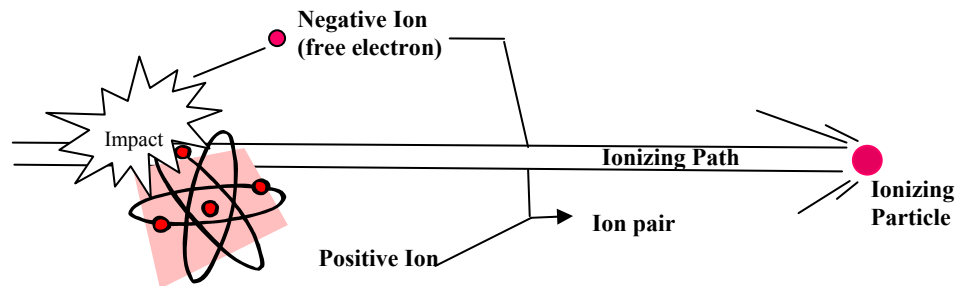


0.662 MeV state in ^{137}Ba can decay via several alternate Modes, including gamma rays, ejection of K,L, M, N, etc, electrons from the atomic shells.



C. Interaction with Matter

Charged Particles: The primary mode is via ionization of the atoms in the material. Ionization is the process of producing ions. Ions are electrons, atoms or groups of atoms carrying an electric charge - positive or negative.



Neutrons: The primary mode (in hydrogenous material) is by collisions with protons. The recoiling protons can then produce ionization (say in tissue).

Photons: Must interact with the atoms in the stopper by either

- A. Photoelectric effect, an ionization of the atoms.
- B. Compton effect, an inelastic scattering of the photon by a free electron.
- C. Pair production, conversion of a photon into an electron positron pair. Threshold is 1.022 Mev.

Radioactive Decay: If the activity of a source is measured over a period of time, it can be observed that the disintegration rate, and thus the number of radioactive atoms present, decreases with time. When half of the radioactive atoms in the source have decayed, the disintegration rate is also cut in half. The time in which the source activity decreases to half its original value is called half life ($t_{1/2}$) for that particular radionuclide. The half-lives of commonly used radionuclides cover a wide range, e.g. the half-life for ^{32}P is 14.3 days, for ^3H is 12.3 years, and for ^{14}C is 5570 years.

The equation for radioactive decay is:

$$A = A_0 e^{-n(t)}$$

Where:

A_0	=	activity before decay
A	=	activity remaining after decay
e	=	base of natural log
t	=	decay time
n	=	decay constant $\frac{=0.693}{t^{1/2}}$
$t^{1/2}$	=	half life of the radionuclide

See Appendix A = Exponential Functions

III. UNITS OF RADIATION MEASUREMENTS, BIOLOGICAL EFFECTS OF RADIATION AND EXPOSURE LIMITS

A. Exposure Units

1. Roentgen (R) - Unit of External Radiation Exposure

The Roentgen is a unit of external radiation exposure for x-ray and gamma radiation only. It measures that amount of ionization produced by photon radiation in a given sample of air at STP (1cc). The Roentgen measures TOTAL EXPOSURE in a given field. One Roentgen equals 2.58×10^{-4} coulomb per kilogram of air.

2. Rad (r) - Unit of Radiation Absorbed Dose

The rad is a measure of LOCAL ENERGY deposited per unit mass of absorber by ionizing radiation. The rad is used to express dose from alpha, beta or gamma radiation.

$$1 \text{ rad} = \frac{100 \text{ ergs absorbed energy}}{1 \text{ gm of absorber}} = \frac{0.01 \text{ Joules}}{\text{Kg}}$$

The rad depends upon:

- A. Type of radiation (alpha, beta, gamma).
- B. Type of absorber (density)
- C. Intensity of radiation field (mR).

New S.I. Unit - Gray which is equal to 100 rads or 1 Joule/kg

3. Rem (rem) - Roentgen Equivalent Man

The rem is related to the rad by the relative biological effectiveness (RBE) of the radiation.....also know as Quality Factor (QF).

Number of rem = QF x rads

example: 0.05 rad of alpha radiation produces the same biological effect as 1.0 rad of x or gamma radiation.

$$\text{RBE or QF for alphas} = \frac{1.0 \text{ rad gamma}}{0.05 \text{ rad alpha}} = 20$$

Quality Factors (QF) for various types of radiation are:

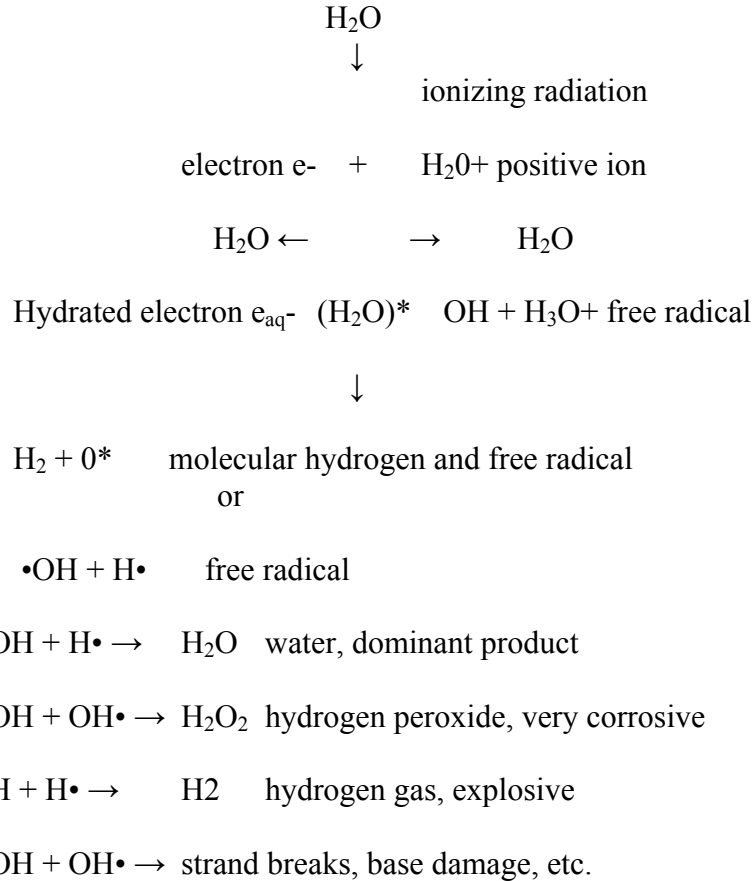
Alpha Particles	20
Protons	10
Fast Neutrons	10
Thermal Neutrons	5
Gamma Rays	1
Beta Particles	1

International S. I. Unit - Sievert which is equal to 1 Joule/Kg = 100Rems

B. Biological Effects of Radiation

1. Effect of Ionizing Radiation on Biological Tissue.

example: Water molecules (80 percent body composition).



2. Sources of Radiation Exposure to Man

<u>Earth</u>		<u>Man-Made</u>	
Cosmic Ray	40 mrem/yr	Medical	100 mrem/yr
Earth	260 mrem/yr	Occupational	1 mrem/yr
Internal Man	<u>25 mrem/yr</u>	Fallout	<u><1 mrem/yr</u>
Total Natural \approx 325 mrem/yr		Total Man-Made \approx 102 mrem/yr	

Local Dose from Medical Diagnostic Procedures

Radiology

Chest x-ray 50 mrad
Mammogram 1 rad
G. I Series 1-5 rad

Nuclear Medicine

Liver Scan 1 rad
Lung Scan 1 rad
Bone Scan 0.5 rad

3. Risk vs. Benefit

Benefits:

Medical diagnosis and therapy
Research
Nuclear Power
Household convenience
Employment (radiation workers)

Risks:

Risk can be defined in general as the probability (chance) of injury, illness, or death resulting from some radiation exposure. The effects of radiation are categorized as either somatic or genetic.

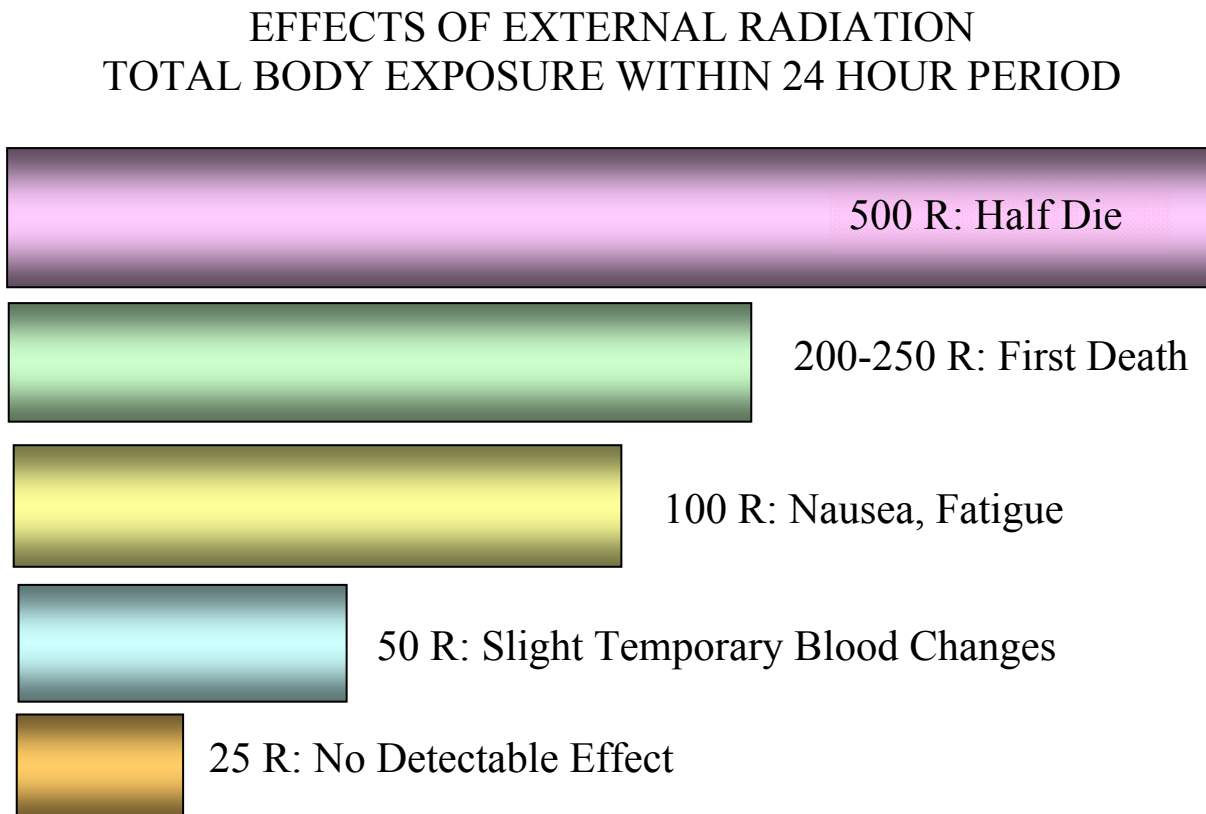
Somatic effects:

Directly affect the health of the person exposed.

- Acute Exposure

Acute radiation exposures, which causes prompt effects and may cause delayed effects, refers to a large dose of radiation received in a short period of time, e.g., exposure following a nuclear bomb explosion. (See figure 3.)

Figure 3. Effects of Acute Radiation Exposure



- Chronic Exposure

Chronic radiation exposure, which may cause delayed effects but not prompt effects, refers to small doses received repeatedly over long time periods, e.g. 20-100 mrem per month for several years. Concern with occupational risk is primarily focused on chronic exposure to low levels of radiation over long time periods.

Genetic Effects:

Occur in the genes of reproductive cells of the exposure individual. These effects may show up as birth defects in future offspring. This has been demonstrated in animal studies, but never observed in human populations.

Table 1. Cancer Risk Estimates From Exposure to Low-Level Radiation

<u>Source</u>	<u>Number of additional cancers estimated to occur in 1 million people after exposure of each to 1 rem of radiation</u>
BEIR 1979	268-399
ICRP 1977	300*
UNSCEAR 1977	300*

*Only one-third of excess cancer causes would be fatal. That is, 100 excess delayed cancer deaths per 1 million people after 1 rem exposure.

BEIR - Biological Effects of Ionizing Radiation, Report of the Science Work Group of the Interagency Task Force on Radiation, DHEW, June 1979.

ICRP - International Commission on Radiation Protection, ICRP, Publication 26, Pergamon Press January 1977.

UNSCEAR - Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, 1977.

Table 2. Estimated Loss of Life Expectancy from Health Risks

<u>Health Risk</u>	<u>Estimates of Days of Life Expectancy Lost, Average</u>	
Smoking 20 cigarettes/day	2370	(6.5 years)
Overweight (by 20%)	985	(2.7 years)
All accidents combined	435	(1.2 years)
Auto Accidents	200	
Alcohol consumption (U.S. average)	130	
Home accidents	95	
Drowning	41	
Safest jobs (such as teaching)	30	
Natural background radiation, calculated	8	
Medical x-rays (U.S. average), calculated	6	
All catastrophes (earthquake, etc).	3.5	
1 rem occupational radiation dose, calculated (industry average is 0.34 rme/yr)	1	
1 rem/yr for 30 years, calculated	30	
5 rems/yr for 30 years, calculated	150	

These estimates indicate that the health risks from occupational radiation exposure are not greater than the risks associated with many other events or activities we encounter in normal day to day activities

Table 3. Permissible Occupational Exposure Limits -External Radiation

	<u>ANNUAL</u>
* Whole Body (W.B.)	5 rem
Lens of the eye	15 rem
Skin of W.B.	50 rem
Extremities (hands, etc.)	50 rem

* Minors are limited to 0.5 rem/yr W.B. and the unborn child to 0.5rem/gestation period. Dose to the whole body includes a dose to head and trunk; active blood forming organs; gonads. This is the sum of both external and internal radiation doses.

Monitoring must be provided for any individual who might receive a dose from external radiation which exceeds the following:

Over 18 years of age

500 mrem/yr W.B.
 1500 mrem/yr eye
 5000 mrem/yr extremities
 5000 mrem/yr skin of W.B.

Under 18 years of age

50 mrem/yr W.B.
 150 mrem/yr eye dose
 500 mrem/yr extremities
 500 mrem/yr skin of W.B.

As a general rule at the University of Notre Dame, film badges must be worn by personnel working in the following instances:

- a. When working with 1 MeV or greater beta emitters.
- b. When working with gamma emitters of any energy.
- c. When working with neutron sources or neutron generating devices.
- d. When working with x-ray producing devices.

Internal Radiation

Bioassays for determining the dose from internal radiation exposure are required for all personnel likely to receive 10% of the maximum permissible dose. Reference NRC Regulatory Guide 8.34 for further information.

ALARA Principle (As Low As Reasonably Achievable)

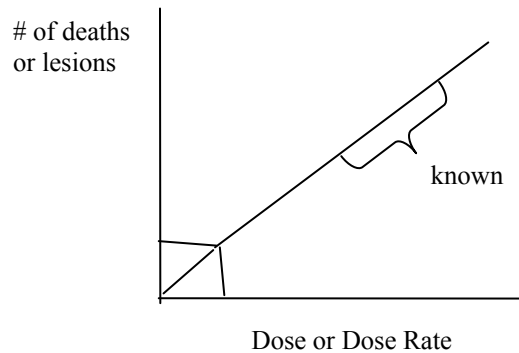
The ALARA Principle is the Philosophy in which radiation exposures are kept as low as reasonably achievable. Any unnecessary radiation exposure to employees should be eliminated by careful planning of laboratory procedures and by employing common radiation safety techniques.

1. Problems in Establishing Permissible Doses.
 - a. Non-uniformity of ionizing radiation
 1. probability of interacting with tissue
 2. energy transfer

example: If an H₂O molecule is hit by a large particle, there is much disruption but the probability of reassociation is great.

If an H₂O molecule is exposed to a gamma ray, there is a low probability of interaction. But if the molecule is hit, the products are scattered farther and the probability of reassociation is reduced.
 - b. Non-uniformity of tissue response
 1. Depends on tissue age, type, activity, etc.
 - c. Species differences
 1. Most data is from species other than man. Data on man is very sparse.
 - d. Susceptibility varies with age
 1. Young are much more susceptible to radiation effects
 - e. Extrapolation to Low Doses
 1. Data for low doses not available
 2. Becomes a measurement of probabilities
 3. Extrapolation assumes either
 - a. linear relationship
 - b. threshold level

4. dose rate dependency



IV. Principles of Radiation Film Badges and Detection Instruments

All radiation detection devices rely on the production of ions or deposition of energy in matter.

alphas - ionize and excite atoms → ion pairs

betas - ionize and excite atoms → ion pairs
(also deposit energy by bremsstrahlung process → x-rays)

x-rays & gamma rays - give energy to electrons via:

1. photoelectric effect
2. compton effect
3. pair production

Electrons then lose energy → ion pairs

neutrons - collisions with protons in nuclei result in recoiling protons that deposit energy and produce ion pairs.

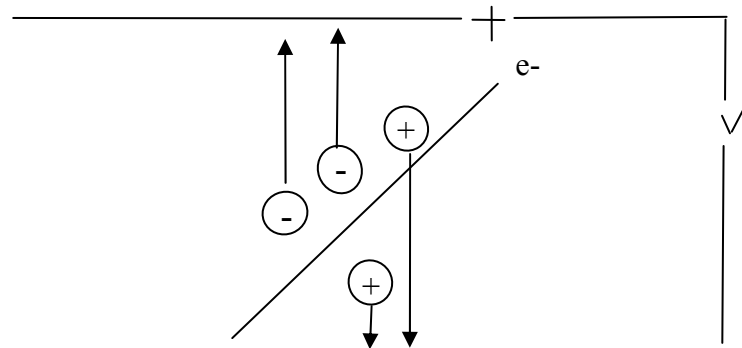
A. Radiation Film Badges

Photographic film is one of the first radiation detectors used after the discovery of x-rays. Photographic emulsions in the film are divided into 2 major categories according to the intended use. They are x-ray film, usually in dental packet size which can be calibrated for x- or gamma- ray exposures in terms of blackening and nuclear emulsions on film or glass plates, which are used in studying ionizing particle tracks.

The radiation sensing element in these emulsions is a silver halide, most often silver bromide. Small crystals of silver bromide, ranging in size from less than 0.5 microns in nuclear emulsion to a few microns in the most sensitive x-ray emulsions, are suspended in a gelatin which is generally deposited on a cellulose acetate film or on a glass plate. Electrons traversing the emulsion become trapped in the crystal lattice, causing the reduction of silver ions to atomic silver. These silver atoms, in turn, result in deeper traps, which capture electrons, reducing more silver ions, eventually forming microscopic aggregates of silver atoms which constitute the latent image. Upon development, the latent images are reduced to metallic silver which appears to the eye as the blackening of x-ray or gamma-ray film or microscopic tracks in the nuclear emulsions.

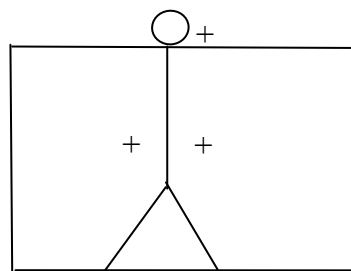
B. Ionization Detectors - Gas Filled

Principle- As radiation traverses a gas, ions are produced and in an electric field will migrate toward the appropriate electrode. If the voltage is large enough, ion pairs will not recombine before collection.



1. Electroscope Discharge Type

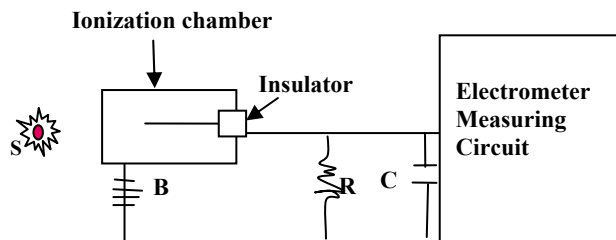
Ions cause discharge of electroscope by neutralizing some of the charges.



Separation of "leaves" indicates amount of radiation passing through.

2. Ionization Chamber (Air Filled)

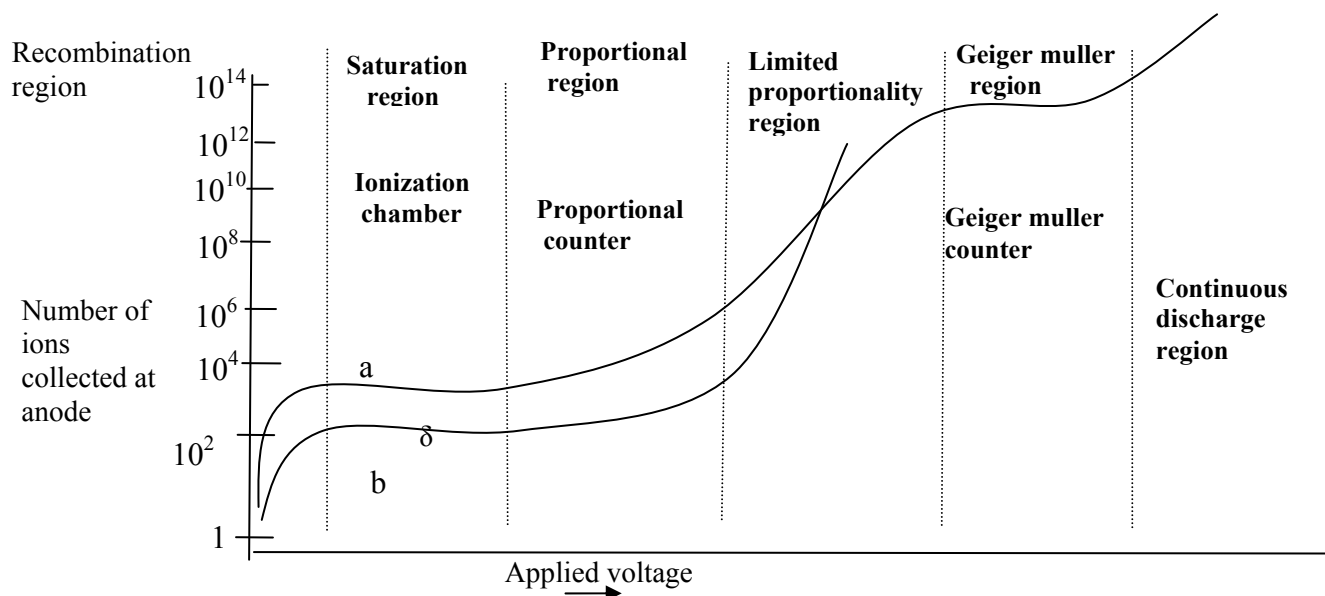
This chamber operates in the saturation region. (see figure 4) all of the ions formed by the radiation are collected. This collection results in what is called a saturation current in the external circuit.



3. Proportional Counter

This detector operates in the proportional region. The radiation produces ionization as it passes through the gas. This is called primary ionization. Primary ions are formed. The electrons from these primary ions are then accelerated by the applied voltage. They acquire enough kinetic energy to produce further ionization of the gas. This is called secondary ionization. Secondary ions are formed. The production of secondary ion pairs is called gas multiplications or gas amplification.

Figure 4. Effect of varying the voltage applied across the electrodes of an ionization chamber.



Specific ionization (air)

a	≈	10 ⁴ - 10 ⁵	ion pairs/cm
b	≈	50 - 100	ion pairs/cm
δ	≈	1 - 10	ion pairs/cm but actually about the same as beta because of electrons formed.

Number of ion pairs collected = $mN\emptyset$

Where m = multiplication factor which is dependent on V
 N = initial number of primary ions produced
 \emptyset = efficiency of ion collection

The primary ionization produced by an alpha particle is large compared to the primary ionization produced by either a beta particle or a gamma ray. Therefore, the total number of ion pairs collected from an alpha particle is large compared to the number collected from a beta particles and gamma rays.

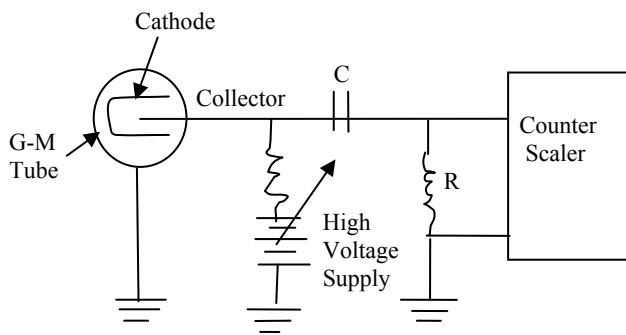
Limited Proportionality Region

The gas multiplication factor begins to become dependent on the primary ionization.

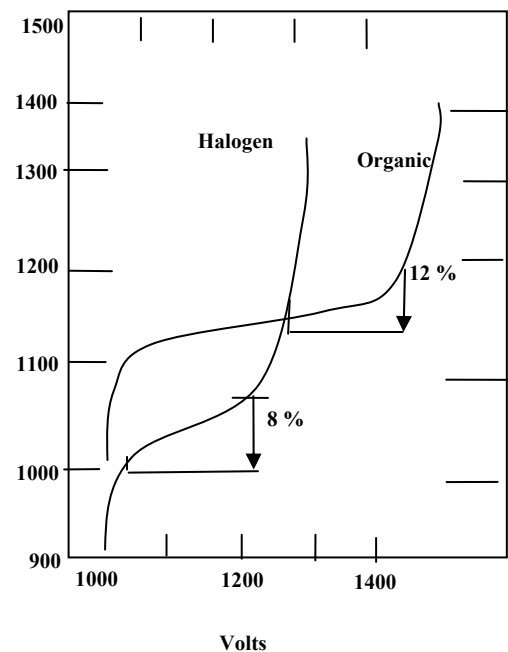
4. "Geiger-Muller" Counters

These counters operate in the Geiger Muller region where the total number of ion pairs collected at a given voltage is independent of primary ionization. Therefore, the total number of ion pairs collected is the same for all ionizing radiations and one cannot distinguish between different kinds. At any given voltage, the total numbers depend only on the voltage and the construction of the ionization chamber.

G-M tubes are very sensitive and little amplification of the pulse is necessary to drive a counting circuit. G-M tubes are also relatively inexpensive.



Typical plateau slopes of organic-halogen quenched G-M counters



If the count rate is greater than 1000 counts per minute in a G-M tube, a correction factor is necessary to reflect the lost of counts due to the "dead time or resolving time" in each system. Resolving time is defined as the minimum time interval between two distinct events which will permit both to be counted. Resolving time for most G-M tubes is usually between 100 to 300 usec. To determine the true counting rate of a system, the following equation is used:

$$R_{\text{true}} = \frac{R_{\text{obs}}}{1 - R_{\text{obs}} \tau}$$

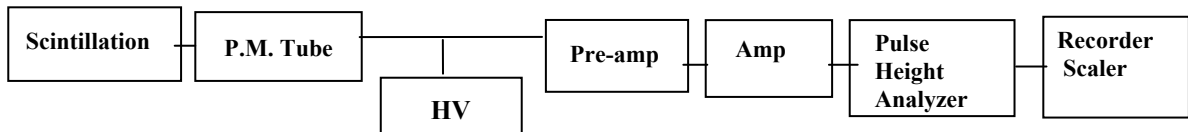
Where;

- R_{true} = True counting rate
- R_{obs} = Observed counting rate
- τ = Resolving time

Organic molecules or halogen molecules are added to the gas in the G-M tubes are sensitive to quench or reduce the resolving time in a system. Though G-M tubes are sensitive to gamma radiation their efficiency for gamma detection is low (approximately 1%).

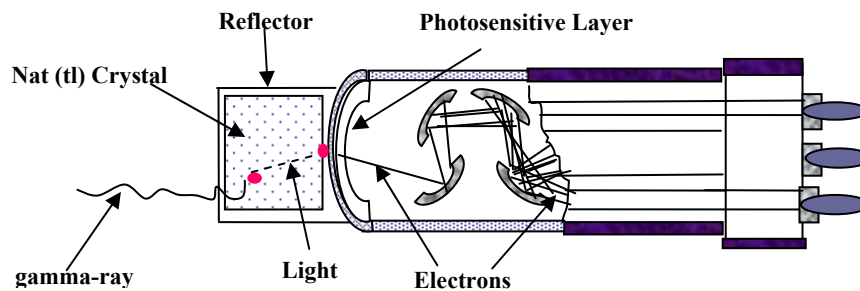
C. Scintillation Detectors

System:



Scintillation detectors consist of:

1. A scintillation; usually an inorganic solid (NaI), an organic plastic or organic liquid.
2. A photomultiplier tube
3. High Voltage power supply (700-2000 volts)
4. Preamplifier
5. Amplifier
6. Pulse height analyzer
7. Recorder-Scaler, etc.



A sodium iodide crystal and photomultiplier

Sequence of Events in a Scintillation System:

1. Radiation enters the scintillator
2. The radiation deposits its energy and then
3. Excites the atoms or molecules in the scintillator
4. Light is emitted with the number of light photons proportional
5. Light photons strike the photocathode photosensitive layer in the photomultiplier tube and electrons are produced.
6. The electrons are accelerated to the electrode and electron multiplication occurs.
7. Electrons are finally collected at the anode. (Multiplication = 10^6)

The output pulse size is proportional to the energy deposited in the scintillator.

Types of Scintillation counters

1. NaI (Tl): High efficiency for gamma rays and allows for energy selection.
2. Plastic: Low efficiency for gamma rays. Little energy selection. High efficiency for betas.
3. Liquid (organic): High efficiency for beta. Low efficiency for gamma and alphas.

Advantages of Scintillation counters over G-M counters

1. Energy selection is provided
2. Very short resolving time.
3. NaI provides high efficiency for gamma ray detection

A. Survey Meters

Survey meters are used to determine the extent of possible external radiation hazards and/or to detect contamination.

1. G-M Survey Meter: G-M survey meters are the most common meters used. They are battery operated with a rate meter readout and have an end window or side window on the G-M tube.

G-M meters are:

- a. Very sensitive for relative low levels of radiation
- b. Best used for detection of radiation, not the measurement of radiation dose rate.
- c. Capable of detecting betas and alphas if the radiation can get into the sensitive part of the counter. The window thickness of the tube is extremely important for detecting alphas and betas.

G-M meters can be calibrated for dose rate (mR/hr) for a particular gamma ray energy by using a source of known activity (mCi) and the following equation:

$$I = \frac{1000 \Gamma A}{d^2}$$

where I = Intensity (mr/hr)
 A = Activity (mCi)
 Γ = Specific gamma ray constant
 R-cm²/mCi-hr)
 d = distance in cm

example: What is the exposure rate at 60 cm of a 100 mCi ¹³⁷Cs source?
 (Γ for Cs is 3.3)

$$\frac{1000 \text{ mR/hr} (3.3 \text{ R-cm}^2/\text{mCi-hr}) (100 \text{ mCi})}{(60 \text{ cm})^2} = 91.6 \text{ mR/hr}$$

Exposure rate will vary according to the inverse square law. All meters should be calibrated on several scales; x 0.1; x 1.0, x 100 mR/hr.

This equation is used to convert between radioactivity (mCi) and exposure intensity (mR/hr). Any user can determine the exposure rate from a source they are using by using this equation and the gamma constant for the particular source. Gamma constants for many common radionuclides are listed in Table 4.

Operation of a G-M meter

1. Check to make sure the meter has been calibrated in past 12 months.
2. Check batteries - most meters have a battery check setting.
3. Check against a source of known dose rate.
4. Start reading at the highest scale, e.g. x 100, and work down to lowest scale when entering a radiation area.
5. Some G-M tubes have a beta shield (end cap or side shield). Readings with and without the shield allow one to measure the relative number of high-energy betas and gamma vs. number of low energy betas.

Caution - When interpreting mR/hr readings for betas, the meter reading will be incorrect or lower than the real exposure due to window absorption.

2. Ion Chamber Survey Meters

"Cutie Pie" or "Juno" are two popular styles of ion chambers. Most ion chambers are air-filled and directly measure exposure rate (R/hr or mR/hr) over a wide range of photon energies. These instruments are reliable and hold their calibration well.

The ion chamber's major use is in measuring x- or x-ray dose rates at moderate to high radiation levels

Table 4. Specific Gamma Ray Constants (R-cm²/mCi-hr)

Nuclide	rt	Nuclide	rt	Nuclide	rt
Actinium-227	2.2	Gold-198	2.3	Potassium-43	5.6
Antimony-122	2.4	Gold-199	0.9	Radium-226	8.25
Antimony-124	9.8	Hafnium-175	2.1	Radium-228	5.1
Antimony-125	2.7	Hafnium-181	3.1	Rhenium-186	0.2
Arsenic-72	10.1	Indium-114m	0.2	Rubidium-86	0.5
Arsenic-74	4.4	Iodine-124	7.2	Ruthenium-106	1.7
Arsenic-76	2.4	Iodine-125	0.7	Scandium-46	10.9
Barium-131	3.0	Iodine-126	2.5	Scandium-47	0.56
Barium-133	2.4	Iodine-130	12.2	Selenium-75	2.0
Barium-140	12.4	Iodine-131	2.2	Silver-110m	14.3
Beryllium-7	0.3	Iodine-132	11.8	Silver-111	0.2
Bromine-82	14.6	Iridium-192	4.8	Sodium-22	12.0
Cadmium-115m	0.2	Iridium-194	1.5	Sodium-24	18.4
Calcium-47	5.7	Iron-59	6.4	Strontium-85	3.0
Carbon-11	5.9	Krypton-85	0.04	Tantalum-182	6.8
Cerium-141	0.35	Lanthanum-140	11.3	Tellurium-121	3.3
Cerium-144	0.4	Lutecium-177	0.09	Tellurium-132	2.2
Cesium-134	8.7	Magnesium-28	15.7	Thulium-170	0.025
Cesium-137	3.3	Manganese-52	18.6	Tin-113	1.7
Chlorine-38	8.8	Manganese-54	4.7	Tungsten-185	0.5
Chromium-51	0.16	Manganese-56	8.3	Tungsten-187	3.0
Cobalt-56	17.6	Mercury-197	0.4	Uranium-234	0.1
Cobalt-57	0.9	Mercury-203	1.3	Vanadium-48	15.6
Cobalt-58	5.5	Molybdenum-99	1.8	Xenon-133	0.1
Cobalt-60	13.2	Neodymium-147	0.8	Ytterbium-175	0.4
Copper-64	1.2	Nickel-65	3.1	Yttrium-88	14.1
Europium-152	5.8	Niobium-95	4.2	Yttrium-91	0.01
Europium-154	6.2	Osmium-191	0.6	Zinc-65	2.7
Europium-155	0.3	Palladium-109	0.03	Zirconium-95	4.1
Gallium-67	1.1	Platinum-197	0.5	Technetium-99m	0.78
Gallium-72	11.6	Potassium-42	1.4		

Jaeger, R.G., et al., Engineering compendium on Radiation Shielding, Vol. 1, (New York: Springer-Verlag, 1968), pp. 21-30. $\Gamma = R \cdot d^2 / \text{hr} \cdot \text{mCi}$ or $\Gamma/10 = R/\text{hr}$ at 1 mCi A Manual of Radioactivity Procedures (National Bureau of Standards Handbook No. 80 [Washington, D.C.: Supt. Of Docs., U. S. Government Printing Office, Nov. 1961]), Appendix A, pp. 137-140.

B. Personnel Monitoring Devices

1. Film badges - As mentioned in Section A, radiation badges are typically composed of 2 pieces of dental film covered by light-tight paper in a compact plastic container. Various filters in the badge holder allows areas to be restricted to x and gamma, hard gamma, and B+ gamma, which allows for determination of the energy level and type of external radiation exposure.

Typically, the sensitivity of film badges are as follows:

Gamma ray - 10-1800 mrem

Beta - 50-1000 mrem

The disadvantages of film badges are that they take 3 to 6 weeks for exposure records to be returned to the user and that they are not effective in measuring ^3H and ^{14}C .

2. Pocket Dosimeters (Ion Chambers - Electroscope type) - Fountain pen size dosimeter that measures total exposure over time from charging to time reading. This is considered an active device in that radiation exposure measurement can be read immediately as opposed to the passive film badge which cannot be read immediately as mentioned previously.

C. Liquid Scintillation Detectors

Liquid Scintillation detectors are used mainly to measure low energy beta emitters such as ^3H and ^{14}C . Radioactive samples are placed in scintillation cocktail mix which contains a fluor in an organic media. When radiation interacts with the fluor, the fluor emits light photons. These light photons must reach the photomultiplier tube in order to be detected.

A major problem associated with liquid scintillation counting is called "quenching". This refers to the absorption of light pulses by the sample. The absorbed light pulses do not reach the photomultiplier tubes to be counted are, therefore, "lost". As more counts are lost, the instruments counting efficiency decreases. A correction factor must, therefore, be used to determine the actual total count.

The most accurate method of determining the correction factor for quenching is called "internal standardization". An accurately measured activity, called a standard, is added to the sample vial which contains the unknown activity. The counting efficiency is then given by the ratio of the observed count rate to the theoretical activity of the standard. The observed count rate is obtained by subtracting the cpm of the unknown sample (CPM_u) before the standard (μCi) is added, from the cpm of the unknown sample plus standard ($\text{CPM}_u + \text{std}$).

$$\text{Then, Efficiency (cpm-uCi)} = \frac{(\text{CPM}_u + \text{std}) - \text{CPM}_u}{\text{Activity of std. (uCi)}}$$

Once the efficiency has been determined, the activity of the original unknown sample is calculated:

$$\text{Unknown sample (uCi)} = \frac{\text{CPM}_u - \text{CPM BKG}}{\text{Efficiency (CPM/uCi)}}$$

V. Basic Principles of Radiation Protection

A. Time, Distance, Shielding

1. Time Exposure dose is a direct proportion of the amount of radiation you are exposed to and the amount of time you are being exposed.

$$\text{Exposed Dose (mR)} = \text{Exposure rate (mR/hr)} \times \text{Time (hr)}$$

General Rule: Work as fast as possible without jeopardizing safety by being careless.

2. Decay Time As the radioactivity (millicuries) of a source decreases with time, according to the half life ($t^{1/2}$), so dose the exposure rate (mR/hr) decrease. After one half-life, only half the activity remains and, therefore, only half the radiation intensity is present.
3. Distance Inverse Square Law (gamma radiation) Radiation intensity (I) from a point varies inversely as the square of distance from the source.

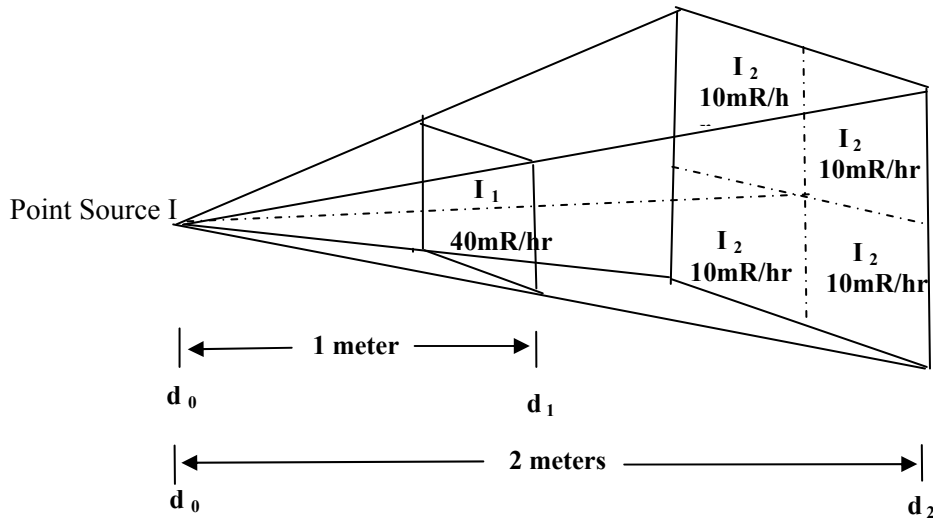
The equation for inverse square is law is:

$$\frac{I_1}{I_2} = \frac{(d_2)^2}{(d_1)^2} \quad \text{or} \quad I^2 = \frac{I_1 (d_1)^2}{(d_2)^2}$$

Where

$$\begin{aligned} I_1 &= \text{Radiation intensity (mR/hr) at distance } d_1 \text{ from the source} \\ I_2 &= \text{Radiation intensity (mR/hr) at distance } d_2 \text{ from the source} \end{aligned}$$

Figure 5. The Inverse Square Law



As radiations are emitted from a point source, at 1 meter the radiation intensity is 40 mR/hr. At 2 meters (twice the distance from the point) source that same radiation field of 40mR/hr has expanded to an area four times the size of the original area. Consequently, the original area (I_1) now receives only one-fourth of the entire radiation, i.e., 10mR/hr.

4. Shielding - Gamma Radiation

Shielding is one of the most important principles for gamma radiation protection. It may be defined as absorption of energy (radiation) in an absorbing material (shielding). The absorption of energy by matter depends upon:

- a. Energy of radiation
- b. Density of absorbing medium
- c. Thickness of the absorber transversed.

General rule at the University is that any containers of radioactive material that exceed 5.0mR/hr at the surface of the container must be shielded with material to sufficiently reduce the dose rate below 5.0 mR/hr.

- Beta Radiation

Beta particles are very small and light weight (9.1086×10^{-28} grams) with maximum range dependent upon the maximum beta energy.

TABLE 5. MAXIMUM BETA ENERGY

<u>Radionuclide</u>	<u>Max. energy (MeV)</u>
^3H	0.018
^{14}C	0.158
^{32}P	1.709
^{35}S	0.167
^{45}Ca	0.254
^{59}Fe	1.560
^{60}Co	1.478
^{63}Ni	0.066
^{90}Sr	0.554

The absorbing thickness or range of beta particles in any material depends upon the density and thickness of the shielding material and the maximum energy of the beta particle.

In general applications at Notre Dame, shielding for ^3H and ^{14}C solutions will not be necessary or required. For higher energy beta emitters such as ^{32}P , lucite or plexiglass shielding should be used. High energy beta emitters will produce bremsstrahlung radiation when passing through high density shielding material.

- Alpha radiation

Alpha particles are very large and heavy (6.642×10^{-24} gms), and usually easily shielded by a piece of paper.

B. Reducing Internal Radiation Exposure

It is extremely important to prevent radionuclides from being taken into the body. This is because there is no quick and easy way of speeding up the natural processes of removing the radioactivity from the body. It is also, in many cases, more difficult to measure how much radioactivity a person has ingested then to measure his external exposure. There are many situations, through, when radionuclides are taken into the body, either by accident or by controlled exposures of radiation workers or medical patients.

The routes by which radionuclides can enter the body and their control measures are listed below:

1. Inhalation - An example of this is the inhalation of tritium around certain accelerators or when using tritiated water in synthesizing compounds.

Control - Work with radioactive material in a fume hood when possible. If not, work in a well-ventilated area and wear an appropriate respirator.

2. Swallowing - This is probably the most common way in which radioactivity gets into the body. Usually these results are from contaminated hands or mouth pipetting.

Control - Never mouth pipette radioactive materials. When working with radioactive materials, always use protective gloves. After working with radioactive materials, wash hands, and then monitor them before eating or smoking.

3. Absorption through the skin - A labeled chemical which can penetrate the skin will, of course, carry the radioactive materials.

Control - Wear protective clothing such as lab coat and gloves. Immediately wash away any radioactive material spilled on the skin.

4. Absorption through wounds - This is a rare but easy way for radioactivity to enter the body.

Control - Wear protective clothing and in some cases wear extra protective material.

5. Injection - This is again a rare route of entry but several individuals have accidentally injected themselves with radioactive material when attempting to inject research animals or nuclear medicine patients.

Control - Be extra careful when performing injections.

C. Personnel Protection Rules

The following rules should be observed when handling or storing radioactive materials;

1. Become familiar with the requirements of the University of Notre Dame's Radiation Safety Manual.
2. Work Carefully.
3. Observe Time, Distance and Shielding principles while working with radioactive materials or while in a radiation area.
4. Film badges (when required) must be worn at all times when an individual is in a radioactive materials area.
5. Protective gloves should be worn when working with radioactive materials.
6. Do not touch clean areas such as bench tops, water faucets, door knobs and light switches with contaminated gloves. Remove the gloves or use a tissue between the glove and item to be touched.
7. A laboratory coat should be worn while you are in the isotope laboratory and removed when you leave for lunch, etc.
8. Monitor yourself for contamination at frequent intervals when working with high energy beta or gamma emitting materials. Monitoring should include hands, body, shoes and protective clothing.
9. A radiation contamination survey must be conducted at least once in every calendar month in which unsealed radioactive material is used. More frequent surveys may be required; you will be notified by the Radiation Safety Officer if this is required for the isotopes and quantity that your lab is using. A survey is required every time that more than one millicurie of P-32, I-125, or I-131 is used.
10. Prior to leaving the laboratory, wash your hands thoroughly.
11. No **mouth pipetting** of radioactive material is permitted.
12. Eating, drinking, smoking or application of cosmetics is prohibited in the radioisotope laboratory.

13. Procedures involving loose (particulate) or volatile radioactive material should be conducted in an approved glove box or fume hood. All work and storage of iodine must be conducted in a properly working fume hood.
14. Clean up after yourself. Don not leave the laboratory contaminated or in a mess. Check all work areas for contamination.
15. Be familiar with and abide by information concerning the increased risks of prenatal radiation exposures.
16. Report immediately to your Responsible Investigator the details of spills or accidents involving radioactivity.
17. Conduct decontamination procedures as outlined in this manual (Section V.F.).
18. Know what steps to take in the event of an emergency. See emergency procedures in Section V.F. of this manual.

D. Laboratory Facilities

1. The laboratory must be properly posted.
2. All containers of radioactive material should be identified by radionuclide, compound, radioactivity and date of assay.
3. Absorbent paper should cover bench tops where radioactive materials are handled or stored. Whenever possible, place a tray between the lined bench top and container of radioactive material.
4. Radioisotope areas should be maintained in clean and orderly conditions.
5. Storage of food or beverage is prohibited in radioisotope laboratories.
6. Radioactive material must be secured (locked) against unauthorized removal when left unattended.
7. Conduct surveys at required frequencies, and record data, including counting instruments used, on appropriate reporting form. Refer to the Radiation Safety Manual for frequency of surveys and contamination levels for respective radionuclides.

E. Emergency Procedures

An emergency is any incident resulting from the use of radioactive substances that presents or threatens to present an internal or external radiation hazard to personnel. In an emergency, the primary concern must always be the protection of human life and health. The secondary concern is the confinement of the contamination to the local area of the accident if possible and the protection of personnel from radiation hazards.

1. Procedures

In the event of an emergency or suspected emergency, e.g. major spill, overexposure, etc., the Radiation Safety Officer and the Responsible Investigator shall be notified immediately without such action as to cause excessive spread of contamination. **See page 47 for telephone numbers and additional emergency information.**

The user and Responsible Investigator shall be responsible for the decontamination procedures necessary and shall carry out these procedures under the direction of the Radiation Safety Officer or persons designated by him.

a. Minor spills - Spills involving no significant radiation hazard to personnel.

1. Notify all other persons in the area at once.

2. Permit only the minimum number of persons necessary to deal with the spill into the area.

3. Confine the spill **immediately**.

a) Liquid spills - Don protective gloves
- Drop absorbent paper on spill
- Wipe up and dispose of contaminated paper in solid radioactive trash.
- Smear area and count smear to determine if decontaminated.

b) Dry spills - Don protective gloves
- Gently, dampen area thoroughly and cover it with absorbent paper taking care not to spread contamination.

- Wipe up and dispose of paper properly
 - Smear area and count smear to determine if area is decontaminated.
4. Notify the Radiation Safety Officer and Responsible Investigator as soon as possible, giving all details of the spill.
- b. Major spills - Spills involving radiation hazard to personnel:
1. Notify all persons not involved in the spill to vacate the room **at once**.
 2. Make no immediate attempt to clean up the spill.
 - a) If the spill is liquid and the hands are protected, right the overturned container.
 - b) If the spill is on the skin, flush thoroughly with water. Do not scrub or use strong detergents.
 - c) If spill is on clothing, discard outer or protective clothing at once.
 3. Switch off all fans and air conditioners.
 4. Vacate the room and prohibit unauthorized entrance to contaminated area.
 5. Notify the Radiation Safety Officer and Responsible Investigator at once and give all details of the accident.
 6. The spread of radioactive contamination can be diminished by restricting the movements of potentially contaminated persons to a local zone just outside of the spill area until the extent of shoe and clothing contamination is ascertained.
 7. Anyone who might have been contaminated should be monitored for radioactivity and if contaminated, you should discard that clothing and be decontaminated. If no means are available for monitoring, it should be assumed that the person is contaminated.

8. Immediately take the necessary steps to decontaminate personnel involved. Under no circumstances should an untrained person attempt to examine or clean up the radioactive material.
 9. Decontaminate the area under the supervision of the Radiation Safety Officer or his designate.
 10. Monitor all persons involved in the spill and cleaning to determine the effectiveness of decontamination.
 11. Permit no person to resume work in the area until a survey is made and approval of the Risk Management and Safety Office is secured.
- c. Accidents involving radioactive dusts, mites, fumes, organic vapors and gases
1. Notify all other persons to vacate the room immediately.
 2. Hold breath and close escape valves. Switch off air-circulating devices if possible and if time permits.
 3. Vacate the room.
 4. Notify the Radiation Safety Officer and Responsible Investigator at once giving all details of the accident.
 5. Ascertain that all doors giving access to the room are closed and sealed by the use of wide masking tape or adhesive tape and heavy paper. Post conspicuous warning signs or guards to prevent accidental opening of doors.
 6. Report at once all known or suspected inhalations of radioactive materials.
 7. Decontaminate the area under the supervision of the Radiation Safety Officer or designate.
 8. Monitor all persons suspected of contamination.
- d. Injuries to personnel involving radiation hazards
1. Wash minor wounds immediately under running water while spreading the edges of the wound.

2. Report all radiation accidents (wounds, over exposures, ingestion, inhalation, etc.) to the Radiation Safety Officer A.S.A.P. @ 631-5037.
3. Permit no person involved in a radiation injury to return to work without the approval of the Radiation Safety Officer and the attending physician.
4. Have appropriate bioassay performed as specified.

e. Fires involving radioactive material

1. Notify all persons in the room and building at once.
2. Notify the Fire Department and Radiation Safety Officer of the emergency.
3. Attempt to put out minor fires if radiation hazard is not immediately present.
4. Following the emergency, monitor the area and determine the protective devices necessary for safe decontamination.
5. Decontaminate under the supervision of the Radiation Safety Officer or his designate.
6. Monitor all persons involved in combating the emergency.
7. Permit no person to resume work without approval of the Radiation Safety Officer.

F. Decontamination Procedures

1. Personal Contamination - External
The recommended procedures for removing contamination on the body are as follows;
 - a. Hands, Arms, and Face - Wash for not less than two minutes, nor more than three minutes with mild soap in warm water. Clean the entire affected area thoroughly. Give special attention to areas between the fingers and around the fingernails. The outer edges of the hands are readily contaminated and often neglected in the washing.

Do not use highly alkaline soaps or abrasives. Rinse thoroughly and monitor for contamination. If monitor indicates contamination still present, repeat washing until decontamination is achieved. However, washings should not be repeated more than four times as the skin may become sensitive following repeated application of detergents to the same area. In any case, one must avoid the use of organic solvents that may increase the probability of the radioactive material penetrating through the pores of the skin.

After each decontamination operation, the treated area should be dried with a fresh non-contaminated towel or swab and then monitored. All materials used in decontamination should be disposed of in the approved manner.

2. Personnel Contamination - Wounds

When the skin is lacerated by glassware, hypodermic needles, or other instruments containing radioactive material, the wounded area must be washed immediately under a stream of cold water. If the radioactive material is extremely toxic, a tourniquet should be applied and emergency procedures followed as outlined in Section V.E.

3. Personnel Contamination - Internal

Internal contamination is essentially a medical problem, similar in some ways to the absorption of chemical toxins. Special corrective procedures should therefore be carried out only with medical advice and supervision.

The aims of the corrective procedures are:

- a) Try to eliminate as much of the internally introduced contaminant still remaining in the mouth, gastrointestinal or respiratory tract, as quickly as possible, and try to prevent or reduce its uptake into the bloodstream and tissues.
- b) Try to prevent the fixation of the contaminant in the body or try to increase its excretion from the body.

For the first of these aims, it is sometimes necessary that the contaminated person or another non-medical person takes immediate action, for instance, to promote the mechanical elimination of the contaminant by vomiting or expectoration.

For the second of these aims, more complicated chemical or physicochemical methods are required. Hence, treatment is a medical matter and should be undertaken as soon as possible and the emergency procedures as listed in Section V.E. followed.

4. Non-Human Contamination

Procedure for the decontamination of equipment and facilities are listed in the University's Radiation Safety Manual. These steps should be reviewed before decontamination of equipment and facilities are listed in the University's Radiation Safety Manual. These steps should be reviewed before decontamination of equipment is attempted.

APPENDIX A Exponential Functions

x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value
0.00	1.00000	0.50	.60653	1.00	.36788	1.50	.22313	2.00	.13534
0.01	.99005	0.51	.60050	1.01	.36422	1.51	.22091	2.01	.13399
0.02	.98020	0.52	.59452	1.02	.36060	1.52	.21871	2.02	.13266
0.03	.97045	0.53	.58860	1.03	.35701	1.53	.21654	2.03	.13134
0.04	.96079	0.54	.58275	1.04	.35345	1.54	.21438	2.04	.13003
0.05	.95123	0.55	.57695	1.05	.34994	1.55	.21225	2.05	.12873
0.06	.94176	0.56	.57121	1.06	.34646	1.56	.21024	2.06	.12745
0.07	.93239	0.57	.56553	1.07	.34301	1.57	.20805	2.07	.12619
0.08	.92312	0.58	.55990	1.08	.33960	1.58	.20598	2.08	.12493
0.09	.91393	0.59	.55433	1.09	.33622	1.59	.20393	2.09	.12369
0.10	.90484	0.60	.54881	1.10	.33287	1.60	.20190	2.10	.12246
0.11	.89583	0.61	.54335	1.11	.32956	1.61	.19989	2.11	.12124
0.12	.88692	0.62	.53794	1.12	.32628	1.62	.19790	2.12	.12003
0.13	.87809	0.63	.53259	1.13	.32303	1.63	.19593	2.13	.11884
0.14	.86936	0.64	.52729	1.14	.31982	1.64	.19398	2.14	.11765
0.15	.86071	0.65	.52205	1.15	.31664	1.65	.19205	2.15	.11648
0.16	.85214	0.66	.51685	1.16	.31349	1.66	.19014	2.16	.11533
0.17	.84366	0.67	.51171	1.17	.31037	1.67	.18825	2.17	.11418
0.18	.83527	0.68	.50662	1.18	.30728	1.68	.18637	2.18	.11304
0.19	.82696	0.69	.50158	1.19	.30422	1.69	.18452	2.19	.11192
0.20	.81873	0.70	.49659	1.20	.30119	1.70	.18268	2.20	.11080
0.21	.81058	0.71	.49164	1.21	.29820	1.71	.18087	2.21	.10970
0.22	.80252	0.72	.48675	1.22	.29523	1.72	.17907	2.22	.10861
0.23	.79453	0.73	.48191	1.23	.29229	1.73	.17728	2.23	.10753
0.24	.78663	0.74	.47711	1.24	.28938	1.74	.17552	2.24	.10646
0.25	.77880	0.75	.47237	1.25	.28650	1.75	.17377	2.25	.10540
0.26	.77105	0.76	.46767	1.26	.28365	1.76	.17204	2.26	.10435
0.27	.76338	0.77	.46301	1.27	.28083	1.77	.17033	2.27	.10331
0.28	.75578	0.78	.45841	1.28	.27804	1.78	.16864	2.28	.10228
0.29	.74826	0.79	.45384	1.29	.27527	1.79	.16696	2.29	.10127

APPENDIX A Exponential Functions

x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value
0.30	.74802	0.80	.44933	1.30	.27253	1.80	.16530	2.30	.10026
0.31	.73345	0.81	.44486	1.31	.26982	1.81	.16365	2.31	.09926
0.32	.72615	0.82	.44043	1.32	.26714	1.82	.16203	2.32	0.9827
0.33	.71892	0.83	.43605	1.33	.26448	1.83	.16041	2.33	.09730
0.34	.71177	0.84	.43171	1.34	.26185	1.84	.15882	2.34	.09633
0.35	.70469	0.85	.42741	1.35	.25924	1.85	.15724	2.35	.09537
0.36	.69768	0.86	.42316	1.36	.25666	1.86	.15567	2.36	.09442
0.37	.69073	0.87	.41895	1.37	.25411	1.87	.15412	2.37	.09348
0.38	.68386	0.88	.41478	1.38	.25158	1.88	.15259	2.38	.09255
0.39	.67706	0.89	.41066	1.39	.24908	1.89	.15107	2.39	.09163
0.40	.67032	0.90	.40657	1.40	.24660	1.90	.14957	2.40	.09072
0.41	.66365	0.91	.40252	1.41	.24414	1.91	.14808	2.41	.08982
0.42	.65705	0.92	.39852	1.42	.24171	1.92	.14661	2.42	.08892
0.43	.65051	0.93	.39455	1.43	.23931	1.93	.14515	2.43	.08804
0.44	.64404	0.94	.39063	1.44	.23693	1.94	.14370	2.44	.08716
0.45	.63763	0.95	.38674	1.45	.23457	1.95	.14227	2.45	.08629
0.46	.63128	0.96	.38289	1.46	.23224	1.96	.14086	2.46	.08543
0.47	.62500	0.97	.37908	1.47	.22993	1.97	.13946	2.47	.08458
0.48	.61878	0.98	.37531	1.48	.22764	1.98	.13807	2.48	.08374
0.49	.61263	0.99	.37158	1.49	.22537	1.99	.13670	2.49	.08208
0.50	.60653	1.00	.36788	1.50	.22313	2.00	.13534	2.50	.08208

APPENDIX A Exponential Functions

x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value
2.50	.08208	3.00	.04979	3.50	.03020	4.00	.01832	4.50	.01111
2.51	0.8127	3.01	.04929	3.51	.02990	4.01	.01813	4.51	.01100
2.52	0.8046	3.02	.04880	3.52	.02960	4.02	.01795	4.52	.01089
2.53	.07966	3.03	.04832	3.53	.02931	4.03	.01777	4.53	.01078
2.54	.07887	3.04	.04784	3.54	.02901	4.04	.01760	4.54	.01067
2.55	.07808	3.05	.04736	3.55	.02873	4.05	.01742	4.55	.01057
2.56	.07730	3.06	.04689	3.56	.02844	4.06	.01725	4.56	.01046
2.57	.07654	3.07	.04642	3.57	.02816	4.07	.01708	4.57	.01036
2.58	.07577	3.08	.04596	3.58	.02788	4.08	.01691	4.58	.01026
2.59	.07502	3.09	.04550	3.59	.02760	4.09	.01674	4.59	.01015
2.60	.07427	3.10	.04505	3.60	.02732	4.10	.01657	4.60	.01005
2.61	.07353	3.11	.04460	3.61	.02705	4.11	.01641	4.61	.00995
2.62	.07280	3.12	.04416	3.62	.02678	4.12	.01625	4.62	.00985
2.63	.07208	3.13	.04372	3.63	.02652	4.13	.01608	4.63	.00976
2.64	.07136	3.14	.04328	3.64	.02625	4.14	.01592	4.64	.00966
2.65	.07065	3.15	.04285	3.65	.02599	4.15	.01576	4.65	.00956
2.66	.06995	3.16	.04243	3.66	.02573	4.16	.01561	4.66	.00947
2.67	.06925	3.17	.04200	3.67	.02548	4.16	.01545	4.67	.00937
2.68	.06856	3.18	.04159	3.68	.02522	4.18	.01530	4.68	.00928
2.69	.06788	3.19	.04117	3.69	.02497	4.19	.01515	4.69	.00919
2.70	.06721	3.20	.04076	3.70	.02472	4.20	.01500	4.70	.00910
2.71	.06654	3.21	.04036	3.71	.02448	4.21	.01485	4.71	.00901
2.72	.06587	3.22	.03996	3.72	.02423	4.22	.01470	4.72	.00892
2.73	.06522	3.23	.03956	3.73	.02399	4.23	.01455	4.73	.00883
2.74	.06457	3.24	.03916	3.74	.02375	4.24	.01441	4.74	.00874
2.75	.06393	3.25	.03877	3.75	.02352	4.25	.01426	4.75	.00865
2.76	.06329	3.26	.03839	3.76	.02328	4.26	.01412	4.76	.00857

APPENDIX A Exponential Functions

x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value	x	e ^{-x} value
2.77	.06266	3.27	.03801	3.77	.02305	4.27	.01398	4.77	.00848
2.78	.06204	3.28	.03763	3.78	.02282	4.28	.01384	4.78	.00840
2.79	.06142	3.29	.03725	3.79	.02260	4.29	.01371	4.79	.00831
2.80	.06081	3.30	.03688	3.80	.02237	4.30	.01357	4.80	.00823
2.81	.06020	3.31	.03652	3.81	.02215	4.31	.01343	4.81	.00815
2.82	.05961	3.32	.03615	3.82	.02193	4.32	.01330	4.82	.00807
2.83	.05901	3.33	.03579	3.83	.02171	4.33	.01317	4.83	.00799
2.84	.05843	3.34	.03544	3.84	.02149	4.34	.01304	4.84	.00791
2.85	.05784	3.35	.03508	3.85	.02128	4.35	.01291	4.85	.00783
2.86	.05727	3.36	.03474	3.86	.02107	4.36	.01278	4.86	.00775
2.87	.05670	3.37	.03439	3.87	.02086	4.37	.01265	4.87	.00767
2.88	.05613	3.38	.03405	3.88	.02065	4.38	.01253	4.88	.00760
2.89	.05558	3.39	.03371	3.89	.02045	4.39	.01240	4.89	.00752
2.90	.05502	3.40	.03337	3.90	.02024	4.40	.01228	4.90	.00745
2.91	.05448	3.41	.03304	3.91	.02004	4.41	.01216	4.91	.00737
2.92	.05393	3.42	.03271	3.92	.01984	4.42	.01203	4.92	.00730
2.93	.05340	3.43	.03239	3.93	.01964	4.43	.01196	4.93	.00723
2.94	.05287	3.44	.03207	3.94	.01945	4.44	.01180	4.94	.00716
2.95	.05234	3.45	.03175	3.95	.01926	4.45	.01168	4.95	.00708
2.96	.05182	3.46	.03143	3.96	.01906	4.46	.01156	4.96	.00701
2.97	.05130	3.47	.03112	3.97	.01887	4.47	.01145	4.97	.00694
2.98	.05079	3.48	.03081	3.98	.01869	4.47	.01133	4.98	.00687

APPENDIX A Exponential Functions

	e^{-x} value	x	e^{-x} value		x	e^{-x} value	x	e^{-x} value
5.00	.00674	7.50	.000553		6.30	.00184	8.80	.000151
5.05	.00641	7.55	.000526		6.35	.00175	8.85	.000143
5.10	.00610	7.60	.000501		6.40	.00166	8.90	.000136
5.15	.00580	7.65	.000476		6.45	.00158	8.95	.000130
5.20	.00552	7.70	.000453		6.50	.00150	9.00	.000123
5.25	.00525	7.75	.000431		6.55	.00143	9.05	.000117
5.30	.00499	7.80	.000410		6.60	.00136	9.10	.000112
5.35	.00475	7.85	.000390		6.65	.00129	9.15	.000106
5.40	.00452	7.90	.000371		6.70	.00123	9.20	.000101
5.45	.00430	7.95	.000353		6.75	.00117	9.25	.000096
5.50	.00409	8.00	.000336		6.80	.00111	9.30	.000091
5.55	.00389	8.05	.000319		6.85	.00106	9.35	.000087
5.60	.00370	8.10	.000304		6.90	.00101	9.40	.000083
5.65	.00352	8.15	.000289		6.95	.00096	9.45	.000079
5.70	.00335	8.20	.000275		7.00	.00091	9.50	.000075
5.75	.00319	8.25	.000261		7.05	.00087	9.55	.000071
5.80	.00303	8.30	.000249		7.10	.00083	9.60	.000068
5.85	.00288	8.35	.000236		7.15	.00078	9.65	.000064
5.90	.00274	8.40	.000225		7.20	.00075	9.70	.000061
5.95	.00261	8.45	.000214		7.25	.00071	9.75	.000058
6.00	.00248	8.50	.000204		7.30	.00068	9.80	.000056
6.05	.00236	8.55	.000194		7.35	.00064	9.85	.000053
6.10	.00224	8.60	.000184		7.40	.00061	9.90	.000050
6.15	.00213	8.65	.000175		7.45	.00058	9.95	.000048
6.20	.00203	8.70	.000167		7.50	.00055	10.00	.000045
6.25	.00193	8.75	.000159					

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Instruction Concerning Risk From Occupational Radiation Exposure,
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EMERGENCY INFORMATION

1. **Campus Security Emergency Number**

EMERGENCY # 9 1 1 (fire, explosion, personal injury)

Security Dispatch 1-5555(after hours spill, non injury accidents)

(This number is open 24 hours and should be called to arrange for an ambulance.)

2. **Risk Management and Safety Department** 8:00 am to 5:00 pm

Radiation Safety Officer / Director - Robert Zerr	1-5037
After Hours	674-4154
Radiation Safety Specialist - Andrew Welding	1-5037
After Hours	272-0450
Assistant Director - Michael McCauslin	1-5037
After Hours	(269) 683-2494
Chemical Safety Specialist - Lisa Bognar-Phillips	1-5037
After Hours	287-2407
Industrial Hygienist - Scott Knight	1-5037
After Hours	(269) 435-2200
General Safety Specialist – Kirk Flickinger	1-5037
After Hours	(574)344-0798

3. **Radiation Control Committee**

Chairman - Dr. Peter Burns	1-7852
After Hours	258-9034

4. **Notre Dame Fire Department** 1-6200

5. **Memorial Hospital** 284-6800

Memorial Hospital of South Bend is the designated Treatment center for radiation ingestion or injury due to the "Poison Control Center" facilities located there and the existence of radioisotope treatment program at the hospital.

6. **University Health Services**

Days	1-7567	Nights	1-7154
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