Radiation Safety Awareness Guide

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INTRODUCTION

We hope the following information provides essential understanding and some useful tools for lab staff that don't utilize ionizing radiation in their research projects but work nearby.

To begin, defining the word 'radiation' should be informative.

A physics related definition from Oxford Dictionaries on the web is:

> *The emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles that cause ionization. The energy transmitted by radiation, as heat, light, electricity, etc..*

Regarding origin, Oxford Dictionaries also offers:

> *Late Middle English (denoting the action of sending out rays of light): from Latin radiatio(n-), from radiare 'emit rays' (see radiate).*

Also, Oak Ridge Institute for Science and Education (a key resource for ionizing radiation safety training) offers the following description on their web pages.

> *Radiation is energy that comes from a source and travels through some material or through space. Light, heat and sound are types of radiation. The kind of radiation discussed in this presentation is called ionizing radiation because it can produce charged particles (ions) in matter.*

In summary, the broad definition of radiation includes radio waves, microwaves, infrared light, visible light, ultraviolet light, X-Rays, gamma rays, and cosmic radiation. However for various reasons, we've come to directly associate the word radiation with just the ionizing radiation range of the full spectrum. So, in keeping with general public perception this guide will rely on the word radiation to refer to the ionizing radiation range of energies.

Now for some understanding of ionizing radiation.

From a U.S. NRC web blog, *NRC Science 101*:

> *Ionizing radiation is radiation with enough energy to create ion pairs in atoms.*

From the same source a perspective on ion pairs is offered.

> *... if an orbiting electron is pushed out of its orbit (due to absorbing energy from an outside source), the charges are now unequal. The result? An "ion pair" has been formed. The creation of an "ion pair" is called . . . ionization.*

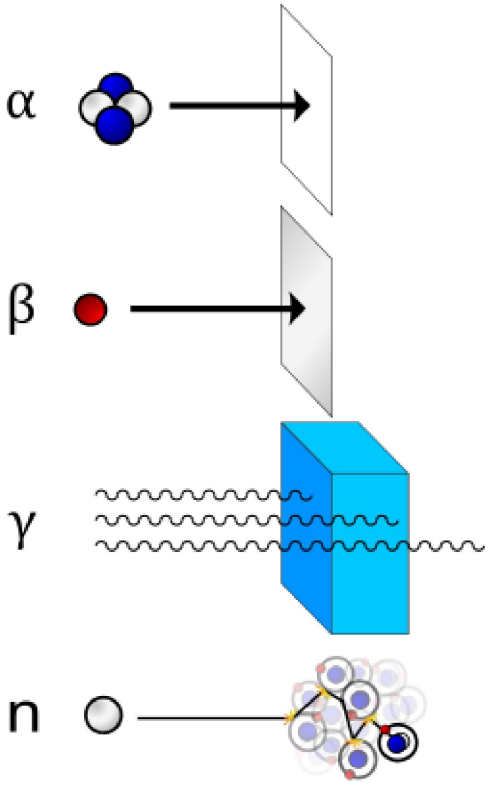
TYPES OF RADIATION

A basic understanding of major types of ionizing radiation and their characteristics is useful for understanding the purposes and values of protection techniques presented later.

Some isotopes of chemical elements are radioactive because their atoms are unstable. Instability of atoms tends to be due to an imbalance in the numbers of neutrons and protons in the nucleus.

Unstable atoms decay randomly over time, and the products of decay are relatively high energy emissions (ionizing radiation). Most emissions can be characterized into 4 key types: alpha, beta, gamma or X-Ray (photons), and neutron.

A) Alpha (α^{2+}) radiation emissions are particles comprised of 2 protons and 2 neutrons. They are equivalent to helium nuclei and lack orbiting electrons, at least temporarily.



Alpha emissions are highly energetic, relatively large physically, and doubly charged. Nearly all have energies of 3.5 to 10 MeV (Mega or million electron volts).

Sources of alpha emissions are common in nature, and include isotopes of thorium, uranium and radium. Alpha emitting isotopes tend to have atomic numbers greater than 82. One exception is ^{147}Sm.

Alpha radiation can be produced by sources other than natural decay of unstable nuclei, such as by linear accelerators.

Research utilizing Alpha emitters or heavy radioactive elements is very limited at USU.

As long as alpha emitting material remains external to the human body their emissions present minimal health concerns. The emissions are easily stopped by a thin absorber, such as a sheet of paper, or about 2 cm of air. Consequently, dead layers of skin protect deep tissue from impact.

However, a sufficient quantity of alpha emitting material inside the body can present significant concern. Because of their charge and mass they tend to have many interactions with surrounding atoms and deposit all their energy in a very small volume. Energy deposition of this magnitude within a cell nucleus will virtually guarantee cell destruction. Consequently, preventing sources of alpha

emissions from entering the body is very important.

Note: Humans commonly take in small amounts of radioactive material, including alpha emitters, from food and other environmental interactions. Because of this we develop standard body burdens of at least a few ubiquitous radioactive isotopes. Carbon dating of human remains is based on our understanding of such body burdens. And our bodies appear to tolerate these relatively low levels of radio-isotopes.

B) Beta (β^- or β^+) radiation emissions are particles that are essentially unpaired singly charged electrons. Their energies range from a few keV (kilo or thousand electron volts) to a few 10's of MeV (Mega or million electron volts). Beta mass is about 0.000125 of alpha mass.

There are many naturally occurring sources of beta emissions as well as those produced artificially by man. Beta emitting radioactive isotopes range from light to heavy elements. Accelerators and electron microscopes also emit high-energy electrons.

Negatron (β^-) emitting isotopes are commonly used in research, and include ^{3}H, ^{14}C, ^{35}S and ^{32}P. Positron (β^+) emitters are more commonly used in medical diagnostics or research, and include ^{18}F and ^{64}Cu.

The ability of beta emissions to penetrate matter is a function of their energy. A one MeV beta emission will travel about 3.3 meters in air, 1 millimeter in Lucite, or 1 to 3 millimeters in skin. Low-energy beta emissions (less than 0.2 MeV) are easily absorbed in the outer layer of skin.

Beta sources external to the body present a somewhat greater threat of penetration than alpha emissions. Similar to alpha radiation, sufficient quantities of beta emitters inside the body may produce significant doses, which may disable and kill cells.

C) Gamma (γ) and X-Ray radiation emissions are electromagnetic (photons). They can traverse matter because they lack mass and charge. They create ionization in materials through which they pass by causing excited electrons to be ejected from struck atoms. And their interactions per unit volume are fewer than alpha or beta emissions, which allows them to be vastly more penetrating.

X and gamma rays have identical physical characteristics, and differ only in method of production. Gamma rays result from emission of energy as an excited nucleus drops from one energy level to a lower energy state. X-Rays result from transitions within the electron cloud of an atom, or they are emitted when a charged particle is decelerated quickly by interacting with dense material.

Unique safety controls may need to be established for research using X or gamma radiation. The ability of X and gamma rays to penetrate makes them

biological hazards regardless of whether they are external or internal to the body.

D) Neutron (n^0) radiation emissions are particles that are unpaired neutrons without charge. And they tend to have relatively high emission energies.

Of the four major types of ionizing radiation, neutron radiation is least commonly encountered in university research laboratories.

Alpha emitters, such as ^{241}Am, can be mixed with beryllium and formed into a sealed source, that then produces neutron emissions from the interactions of alpha emissions with the beryllium. These neutron emitting sealed sources can be used to study the composition of and effects on materials.

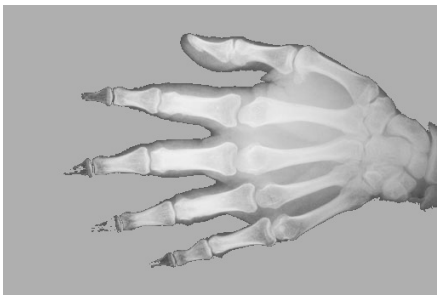
Although we can speak of the absorption or penetrating ability of alpha, beta, and X or gamma emissions fairly easily, that is not the case for neutron emissions. Their absorption properties are complex functions of the absorber's atomic weight, neutron to proton ratio, and interaction probabilities with various nuclei.

Unique safety controls may need to be established for research using neutron emissions. Exposure to neutron radiation is of considerable concern because biological damage from such sources is considerably greater than equivalent amounts of beta, X, or gamma radiation.

DISPENSABLE ISOTOPES COMMONLY USED at USU

Isotope	Emission Key Type	Emission Peak. Energy (MeV)	Physical 1/2 Life
$^{3}_{1}H$ (Tritium)	$^{-}$ beta	0.019	12.3 years
$^{14}_{6}C$	$^{-}$ beta	0.156	5,730 years
$^{18}_{9}F$	$^{+}$ beta (positron)	0.634 also 0.511 photon	1.83 hours or 109.8 minutes
$^{32}_{15}P$	$^{-}$ beta	1.71	14.3 days
$^{35}_{16}S$	$^{-}$ beta	0.167	87.4 days
$^{45}_{20}Ca$	$^{-}$ beta	0.257	163 days
$^{64}_{29}Cu$	$^{+}$ beta (positron)	0.578 and 0.653 also 0.511 photon also 0.007 gamma	12.7 hours
$^{125}_{53}I$	gamma	0.035 also 0.027 and 0.031 X-Rays	60.1 days

MEASUREMENT UNITS



In 1895 Wilhelm Conrad Roentgen (or Röntgen) discovered that energetic electrons impinging on a target of high atomic number (dense material) produces rays (X-Rays), that easily penetrate matter and can expose photographic film. Since this discovery the scientific community has relied on special measurement units to describe the amount and nature of ionizing radiation.

The International Commission on Radiological Units (ICRU) is responsible for a standardized system of units and nomenclature that supports physicians and others working with not only X-Rays but other types of radiation found in nature or produced by man. Pioneers in radiation research (Roentgen, Curie, Becquerel, ...) have been a source for naming these units, though some units began as descriptive terms that turned into acronyms (Rad - radiation absorbed dose, rem - Roentgen or radiation equivalent man or mammal).

A) The Curie (Ci) and Becquerel (Bq) are measures of activity (radioactivity or numbers of emissions). The ICRU associated these units with quantities of emissions.

   One Ci was defined as the number of disintegrations (emissions) per unit of time from 1 gram of ^{226}Ra. Marie Curie discovered and named the element radium. The agreed value for one Ci is 3.7×10^{10} DPS (disintegrations per second) or 2.22×10^{12} DPM (disintegrations per minute). The mass of an isotope needed for 1 Ci of activity varies with specific activity of the isotope. Curie units are still somewhat in use in the United States.

   The Bq is the newer international unit for activity and is somewhat comparable to the Ci. Henri Becquerel was the researcher associated with this unit. Its basis is very simple in that 1 Bq is equal to 1 DPS or 60 DPM.

   With time 1 Ci of activity of any radioisotope has become a relatively large amount. As research has progressed efficiencies have been found that gradually reduced the activity of material needed to produce reliable results from standardized experiments. Currently most tracer studies utilize only micro-Ci (μCi, 1×10^{-6} Ci) quantities for each experiment, although it is not unusual to find milli-Ci (mCi, 1×10^{-3} Ci) quantities on-hand in labs.

   It is essential that the symbols for micro and milli not be confused. The 1,000 fold error that results may mean the difference between an almost inconsequential problem and a significant concern. Useful expressions to remember are 2.22×10^{6} DPM equals 1 μCi and 2.22×10^{9} DPM equals 1 mCi. Alternatively, 1 μCi is equal to 37 kBq (kilo-Becquerels) and 1 mCi is equal to 37 MBq (mega-Becquerels).

B) The Roentgen (R) unit is a special measure of exposure or impact of emissions in air. It was developed as a replacement for a more crude measure (erythema dose) that involved exposure of human tissue until it started to become red. The R is associated with numbers of ion pairs produced in air by X or gamma radiation. It has been superceded by measures of absorbed dose, in part because R doesn't measure effects of alpha, beta, or neutron emissions. One R equals 2.58×10^{-4} Coulombs/kg of air.

R values can be translated to approximate absorbed dose values if weighting factors relative to air of other substances are known. It is relatively easy and inexpensive to measure ionization in air, which allows us to measure R directly. It isn't as easy to measure energy absorbed in a material directly.

Measurement of absorbed dose (see below) is more useful for indicating potential for biological damage.

C) The Rad unit is a measure of absorbed energy (impact, or dose). This term is generally considered an acronym, possibly for Radiation or Roentgen Absorbed Dose. One Rad is defined as the amount of ionizing radiation that imparts 87 ergs (energy deposited) to 1 gram of matter. This value is often rounded to 100 ergs/gram to simplify calculations because the consequences of rounding are generally considered insignificant. The comparable international unit is the Gray (Gy). One Gy equals 100 Rad, or 1 Rad equals 0.01 Gy.

The Rad is applicable for all types of ionizing radiation, yet is difficult to measure directly. Ionization in air or another gas is normally measured and the absorbed dose in a particular material calculated. If muscle tissue is impacted then 1 R in air equals about 95 ergs/gram in muscle. When X and gamma rays are being measured it is reasonable to assume that 1 R = 1 Rad.

Since 1 Rad is a relatively large value we often find measurements reported in mRad (milli-Rad) or uRad (micro-Rad) values.

D) The rem unit is a measure that indicates the potential for emissions to impact deep human tissue (e.g. muscle, heart, lung, etc..,) not just skin. This term is also considered an acronym, possibly for radiation or Rad equivalent man or mammal. Rem values account for differences in biological effectiveness of the types of radiation and provide dose equivalent measures.

COMMON RADIATION MEASUREMENT UNITS

UNIT	MEASURE OF	EXPRESSION / DESCRIPTION
Curie (Ci)	Activity (Radioactivity)	= 3.7 x 10^{10} disintegrations/second (DPS); 37 GBq; or 2.22 x 10^{12} disintegrations/minute (DPM) (The amount of a substance that yields essentially the same number of disintegrations per unit time as 1 g of ^{226}Ra.)
Becquerel (Bq)*	Activity (Radioactivity)	= 1 DPS; 60 DPM; 27 pico-Ci's
Roentgen (R)	Exposure (Dose)	= 2.58 x 10^{-4} Coulombs/kg of air (Ionization per mass unit of air from X or gamma radiation.)
Rad	Absorbed Dose	= 1 x 10^{-2} joules/kg; 100 ergs/g; 0.01 Gy (Energy deposited in a unit of mass by any type of radiation.)
Gray (Gy)*	Absorbed Dose	= 1 joule/kg; 10^{3} ergs/g; 100 Rad (Energy deposited in a unit of mass by any type of radiation.)
rem	Dose Equivalent	= 0.01 Sv (Measure of impact on human or mammalian tissue. The product of the Rad and a quality factor for the type of emission.)
Sievert (Sv)*	Dose Equivalent	= 100 rem (Measure of impact on human or mammalian tissue. The product of the Gray and a quality factor for the type of emission.)
Q or W_R	Relative quality, or affect, of types of radiation on human tissue.	Type of Radiation / Q (if internalized) X, gamma, and beta: 1 neutron: 2-12 (or 15) alpha: 20

[* SI Unit (ICRU)]

Roughly, rem is the product of absorbed dose (Rad) and a quality factor (Q) or weighting factor (W_R) for the type of radiation. Since the weighting factor for X, gamma, and beta radiation is essentially one, a 1 Rad measurement for these types of emissions is essentially equal to 1 rem. For alpha emissions W_R is 0 if the source of emissions is outside the body and 20 if the source is inside. W_R for neutron radiation varies with emission energies and ranges from 2 to 12, or 2 to 15 depending on the reference table used.

INTERNATIONAL SYSTEM (SI) of MEASUREMENTS

Basic SI Units

UNIT	MEASURE OF	SYMBOL
meter	distance	m
gram	mass	g
seconds, minutes, hours	time	s, m, hr (h)
volt	electrical energy	V
amp	electric current	A

SI Prefixes

FACTOR	PREFIX	SYMBOL
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da

FACTOR	PREFIX	SYMBOL
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	u
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

PROTECTION STANDARDS

Radiation protection (safety) standards apply to radiation workers and the general population (public). Protection standards for the public are of importance since they serve as a basis for many of the considerations applicable to design of nuclear power facilities, as well as design and implementation of environmental surveillance programs.

Included in this section is a brief history of the development of radiation protection standards, a review of goals and objectives sought, and a description of the approach used for basing such standards on associated risk.

A) Basis for Protection - Shortly after the discovery of X-Rays in 1895, and of natural radioactive material in 1896, reports of radiation injury began to appear in published literature[1]. Recognizing the need for protection of researchers, dose limits were informally recommended, with the initial concern being to avoid direct physical symptoms.

As early as 1902 it was suggested that radiation exposures might result in delayed effects, such as development of cancer. Between 1925 and 1930 bone cancers among Radium Dial Painters (Radium Girls) provided early evidence of delayed effects from internalization of radioactive material. Radium Girls painted watch dials and watch hands with radium laden paint so the items would glow continuously and the watches would be readable in the dark . Radium was ingested by a common practice of 'tipping' brushes (forming bristles into a fine tip) with their tongue and lips.

Delayed effects from radiation exposures were subsequently confirmed for external sources as well.

With publication in 1927 of H. J. Muller's research with Drosophila[2], concern began to be expressed regarding the possibility of genetic effects from radiation exposures to humans. This concern grew and dominated the basis for radiation protection from the end of World War II until about 1960. It also led to recommendations for dose limits to the public.

With observance of excess leukemia among survivors of World War II's atomic bombings in Japan, and failure to observe previously anticipated genetic effects, the radiation protection community gradually shifted to a position in which somatic effects, primarily leukemia, were judged to be the critical (or governing) effects of radiation exposures. This belief continued until about 1970 when it was concluded that, although somatic effects were the dominant effects, the most important such effects were solid tumors, such as cancer of the lung, breast, bone, and thyroid, rather than leukemia.[3]

In 1977, the International Commission on Radiological Protection (ICRP) initiated action to base protection standards on acceptable levels of associated risk.[4] This effort was supported by the National Council on Radiation Protection and Measurements (NCRP) with issuance of updated "Recommendations on Limits for Exposure to Ionizing Radiation" in 1987.[5]

B) Basic Standards - The primary source of recommendations for radiation protection standards within the United States is the NCRP. Many of the recommendations of this group have been given legislative authority through the Code of Federal Regulations[6] (CFR's) by the U.S. Nuclear Regulatory Commission.

i) Philosophy - Roughly, the main purpose for control of radiation exposures is to ensure that no exposure is unjustified in relation to its overall benefit. Consequently, necessary exposures are to be kept as low as is reasonably achievable (ALARA), they are not allowed to exceed specified limits, and future concerns need to be considered when allowing dose in the near term.

ii) Objective - In general, the goal of radiation protection, and the associated standards, is to limit the probability of radiation induced diseases (somatic effects) in exposed persons and in their progeny (genetic effects) to a degree that is reasonable and acceptable in relation to the benefits of the activities that involve such exposures. In other words, to reduce dose to ALARA levels.

C) Dose Limits

i) Occupational - Government regulations establish an upper effective dose equivalent (EDE) limit for trained (informed) radiation workers of 5,000 mrem/year (50 mSv/year).

Regulations express limits as EDE values, which permits, on a mathematical basis, summation of partial and whole body exposures. Summation of EDE's received from both external and internal exposures, as well as focused and distributed exposures, are used to determine compliance with the worker's dose limit.

DOSE LIMITS for RADIATION WORKERS

Target Tissue	Regulatory Limit
Whole Body (trunk, deep tissue impact)	5,000 mrem (50 mSv) / year
Extremities (lower arms, lower legs)	50,000 mrem (500 mSv) / year
Skin (shallow tissue impact)	50,000 mrem (500 mSv) / year
Eye	15,000 mrem (150 mSv) / year
Fetus (of radiation worker)	500 mrem (5 mSv) / gestation
Radiation worker under the age of 18	1/10th of adult worker limits

ii) Public - The public are generally defined as individuals who aren't trained (not informed) in radioactive material use for the lab they work in. So, a radiation worker from one lab could be a member of the public in other labs.

Limits to public dose are lower than those of radiation workers for a variety of reasons, including:

a) They might have an increased risk factor.

b) They didn't choose to be exposed.

c) They may be exposed continuously for their lifetime, when workers are only exposed during work periods.

d) They may receive no direct benefit (e.g. research progress) from exposures.

e) They are exposed to other risks in their occupations.

f) They are not subject to the selection, supervision, and monitoring afforded radiation workers.

g) Even if individual exposures are relatively low, the sum of risks as represented by a total burden from somatic and genetic doses may justify further efforts to limit exposures.

E) Effective Dose Equivalent (EDE)[4,5]

i) EDE values incorporate tissue weighting factors in order to reflect realistic risks of exposure. For example, exposure of hands or feet would have lower EDE values than the same exposure level to the chest or abdomen, because tissues in the hands and feet are generally less sensitive.

The objective in developing EDE was to provide a measurement unit for radiation protection that could express, on an equal risk basis, both whole body and partial body exposures. The ICRP sought to:

a) Base limits on total risk to all tissues as well as hereditary detriment in immediate offspring (the first two generations).

b) Consider not only the dose occurring during the year of exposure but also the committed dose for future years in cases of internalized radionuclides.

ii) Risk - The next goal of the ICRP was to set occupational dose limits at such levels that risk to the average worker from exposures would not exceed risk of accidental death to the average worker in a relatively "safe" (non-nuclear) industry.

Based on review of world-wide data (see table below), the ICRP concluded that in a "safe" industry an average of about 100 workers or less die accidentally each year for every million workers employed.

ANNUAL ACCIDENT FATALITIES for DIFFERENT OCCUPATIONS

CATEGORY	OCCUPATION	per 10 K workers	per 1 M workers
Safe	Trade	0.5	50
	Manufacturing	0.6	60
	Service	0.7	70
	Government	0.9	90
Less Safe	Transportation & Utilities	2.7	270
	Construction	3.9	390
	Agriculture	4.6	460
	Mining, Quarrying	6.0	600
Least Safe	Sports (auto, racing, etc.)	10-20	1,000 - 2,000
	Deep Sea Fishing	30	3,000
	High-rise Steelworkers	50	5,000
	Farm Machinery Workers	80	8,000

Risk of accidental death to the average worker in a "safe" industry would be about:

100 accidental deaths / 1,000,000 workers / year
or, risk of accidental death is 10^{-4} / worker / year

From epidemiological studies with human populations and biological studies in animals, estimates can also be made of the risk of fatality from cancer or genetic death for given levels of EDE to various body organs. Examples below illustrate formulation of risk factors.

a) Studies of survivors of World War II atomic bombings in Japan indicate that for a collective dose of 1,000,000 person-rem (10,000 person-Sv's) exposure to bone marrow there will be, after a latency period, an average of 1 excess case of leukemia occurring in the population each year.

Assuming that each case ultimately results in death, and that the excess continues for a period of 20 years, there is assumed a total of 20 excess cases of leukemia, and therefore 20 excess deaths, due to such exposure. Thus, the risk of death due to leukemia resulting from radiation exposure can be estimated to be:

20 leukemia deaths / 10,000 person-Sv's
= 2×10^{-3} risk of leukemia death / Sv

b) Studies among uranium miners have shown that there are approximately 20 excess cases of lung cancer, and consequently 20 excess deaths (assuming all cases of lung cancer are fatal) for each 10,000 person-Sv's exposure to the lungs. Thus the risk of death from lung cancer resulting from radiation exposure can be estimated to be:

20 lung cancer deaths / 10,000 person-Sv's
= 2×10^{-3} risk of lung cancer death / Sv

c) Epidemiological data for breast cancer have shown that there are about 100 excess breast cancers per 10,000 person-Sv's exposure to female breasts. Assuming that breast cancer is fatal 50% of the time, and assuming that the those being exposed consist of 50% men and 50% women, then the risk of excess deaths due to exposure to female breasts can be estimated to be:

100 excess cancers / 10,000 person-Sv's x 0.5 fatality rate
x 0.5 of population being female
= 2.5×10^{-3} risk of breast cancer death / Sv

d) Epidemiological data for thyroid cancer have shown that there are about 100 excess thyroid cancers per 10,000 person-Sv's exposure to the thyroid. However, the fatality rate for thyroid cancer is only about 5%, so the risk of death due to cancer of the thyroid from exposure to radiation is:

100 excess thyroid cancers / 10,000 person-Sv's x 0.05 fatality rate
= 5×10^{-4} risk of thyroid cancer death / Sv

Similar calculations can be made to estimate excess deaths due to exposures to other body organs.

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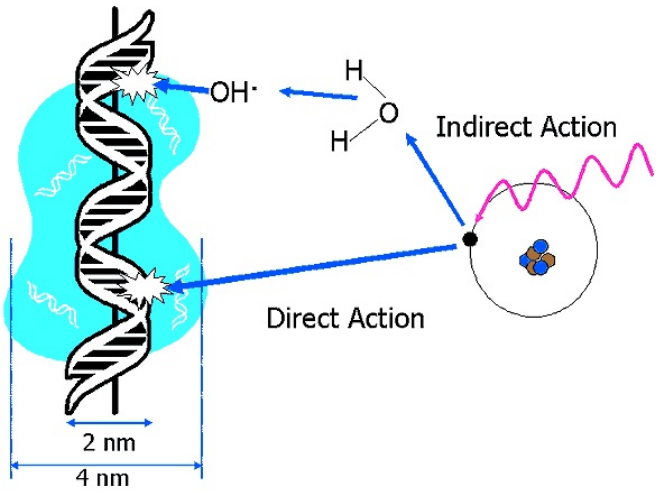
BIOLOGICAL EFFECTS

A) Physical and Chemical Effects - Ionizing radiation is so named because its initial interaction with matter is ejection of an orbital electron from an atom, forming a pair of ions with opposite charges.

Radiation passing through living cells can ionize or excite atoms and molecules in or around cells. This produces ions and radicals mostly from water molecules. Damage can result when these radicals and ions interact with cellular material. Some cell damage can be effectively repaired by cellular mechanisms. Extensive damage can result in cell death or alteration.

i) Direct effects from radiation may damage biologically important molecules in cells. Damage to DNA molecules or chemical changes to other cellular material are the primary results. Such damage can result in somatic mutations that may show up years after exposure, or genetic mutations that require several life spans to appear.

ii) Indirect effects may initiate a chain of chemical reactions, mediated through cellular water, leading to ultimate biologic damage. A hydroxyl poisoning effect on the cell membrane results in a change in its permeability. Inactivation and release of enzymes is the primary result.



iii) Biological effects from all types of ionizing radiation

are similar. However, some radiation emissions are more efficient than others and produce more biological damage per unit of exposure.

B) Cell death from intense radiation exposure is responsible for acute somatic effects. It occurs by two mechanisms:

i) Inhibition of mitosis results from moderate doses and leads to delayed cell death.

ii) Immediate cellular death results from very high doses.

Alteration of cellular genetic material consistent with continued cell proliferation usually manifests no visible change in cellular appearance but a point (recessive) mutation is formed, which may not be passed to future generations.

C) Systemic Biological Effects

i) Somatic Effects - Abnormality may become manifest only after many generations of cell replication. This is the proposed mechanism for long-term (somatic) effects of radiation (e.g. carcinogenesis, nonspecific life shortening). These are non-stochastic effects.

ii) Genetic Effects - Reproductive cell mutations may allow transfer to offspring. Increase in number of “recessive” mutations in a population pool leads to increased probability of abnormalities in offspring due to chance mating of individuals carrying the same mutation. These are stochastic effects.

D) Acute somatic effects are related to killing of cells, generally in tissues where cells are rapidly proliferating. Observed effects from intense radiation exposure usually occur in 1-3 weeks.

Relationships between dose range and symptoms include:

Dose Range	Symptoms
50,000 - 150,000 mrem (500 - 1,500 mSv)	None to minimal. Possible delayed onset long-term effects.
150,000 - 400,000 mrem (1,500 - 4,000 mSv)	Moderate to severe illness due to hematopoietic derangement
400,000 - 800,000 mrem (4,000 - 8,000 mSv)	Severe illness. LD 50/30 in humans is probably about 450,000 mrem (~4,500 mSv). Gastrointestinal damage occurs at higher doses in this range.
Above 800,000 mrem (> 8,000 mSv)	Fatal, even with the best available treatment.

Effects of partial body exposure depend on tissues or organs involved. Significant acute changes are usually seen only after a fairly large radiation dose (> 1,000,000 mrem; > 10,000 mSv).

COMMON EXPOSURES from NATURAL & MANUFACTURED SOURCES

Source of Exposure	Common Dose
Coast-to-Coast Airline Flight	3 mrem/flight (0.03 mSv)
Natural Background Radiation (U.S.A.)	150 - 300 mrem/year (1.5 - 3 mSv)
Chest Radiograph (A/P view)	15 - 25 mrem/view (0.15 - 0.25 mSv)
Chest Radiograph (Lateral view)	50 - 65 mrem/view (0.5 - 0.65 mSv)
Screening Mammography (film/screen combination)	60 - 135 mrem/view (0.6 - 1.35 mSv)
Computerized Tomography (CT) of brain (13 slice)	2,000 - 3,000 mrem/scan (20 - 30 mSv)
Computerized Tomography (CT) of brain (20 slice)	3,000 - 6,000 mrem/scan (30 - 60 mSv)

E) Long-term effects may occur many years after acute or chronic radiation exposure. Our understanding of long-term biological effects includes:

i) Biological effects may occur below 50,000 mrem (500 mSv) doses. However, such low doses are generally insufficient to cause acute somatic effects.

ii) Biological effects are probably related to irreparable damage to genetic material in cells which are capable of continued cell division.

iii) Large doses can be an effective carcinogenic agent. However, carcinogenesis generally requires many years to develop.

iv) Temporary sterility can be induced at approximately 150,000 mrem (1,500 mSv), and permanent sterility at approximately 250,000 mrem (2,500 mSv). Females are more often permanently affected than males.

v) Cataracts can develop from exposures of 200,000 - 600,000 mrem (2,000 - 6,000 mSv).

vi) The aging process can be accelerated. Nutrition to cells appear to be impaired. Total cell numbers are decreased and composition of cellular material is modified.

vii) The fetus is highly radiosensitive due to rapid division of cells. However, measurable fetal damage has not been seen at exposures less than 1,000 mrem (10 mSv). Consequently, exposure to the fetus of a radiation worker is limited to 500 mrem (5 mSv), if pregnancy is declared.

viii) Detection of chromosomal damage requires many generations. An Oak Ridge National Laboratory study suggests that low intensity (1,000 - 10,000 mrem, 10 - 100 mSv, per day) continuous exposure has only 0.25 to 0.1 the mutagenic efficiency of acute exposure.

F) Law of Bergonie and Tribondeau - In 1906 Jean A. Bergonie and Louis F.A. Tribondeau established that ionizing radiation affects cell types differently. From

their efforts as well as subsequent research we understand that cells are generally more sensitive to radiation if they:

Divide more rapidly,
Divide for longer time periods,
Are less specialized,
Are well nourished.

Radio-Sensitivity	CELL TYPE
Least	Mature Red Blood Corpuscles
|	Liver
|	Nerve
|	Pituitary
|	Thyroid
|	Muscle
|	Bone and Cartilage
|	Skin Epithelium
|	Cornea
|	Squamous Mucous Epithelium
|	Renal Tubules
|	Lung
|	Lens
|	Gonadal Germ
|	Bone Marrow
Most	Lymphocytes

G) Severity of absorbed dose depends in part on the location of the emission source relative to the human body.

i) Factors that influence dose when the source is inside the body.
Isotope/Element
Amount of Activity (Radioactivity)
Type of Emissions (alpha, beta, gamma, neutron)
Critical Organ
Physical Half-Life (T_P)
Biological Half-Life (T_B)
Effective Half-Life ($T_E = [T_B \times T_P] / [T_B + T_P]$)
Age, Weight, Gender

ii) Factors that influence dose when the source is external to the body.
Amount of Activity (Radioactivity)
Type of Emissions (alpha, beta, gamma, neutron)
Emission Energy
Area/Region of Body
Time, Distance, Shielding
Age, Weight, Gender

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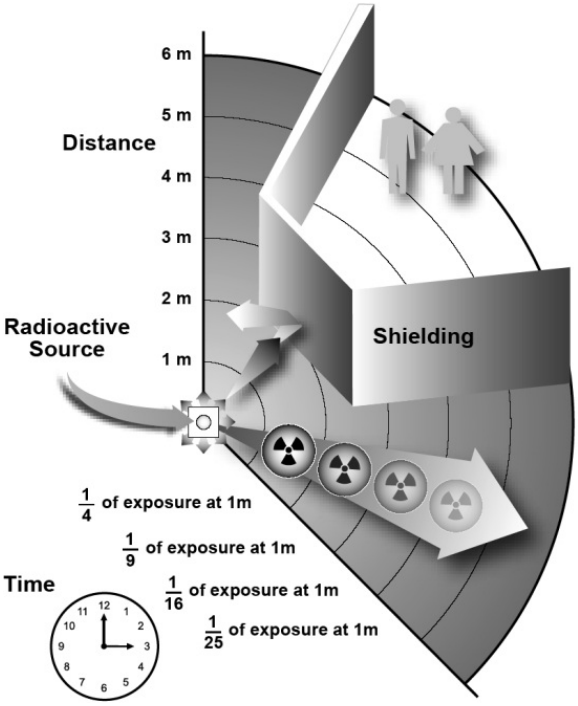
FUNDAMENTALS OF PROTECTION

A) Time - Reducing the amount of time we are exposed to licensed sources of radiation is a very practical method of protection. Changing exposure time essentially has a linear effect because it doesn't affect dose rate.

i) Radiation workers are limited to 5,000 mrem (50 mSv) per year total EDE from licensed sources of radiation.

Full-time workers tend to work 8 hours a day, 5 days a week, and 50 weeks a year. This equals 2,000 hours of potential exposure per year.

A constant exposure rate of 2.5 mrem (0.025 mSv) per hour through a year would accumulate 5,000 mrem (50 mSv) of individual dose. In this case, exceeding the hourly



rate, even slightly, should result in reduction in radiological work hours. Exceeding a dose limit is generally reportable, and is likely a violation.

ii) Members of the public are limited to 2 mrem (0.02 mSv) per hour maximum exposure rate, and 100 mrem (1 mSv) per year.

The maximum continuous rate for a member of the public working full-time in conditions that expose them to licensed sources of radiation would be 0.05 mrem (0.0005 mSv) per hour.

B) Distance - Increasing distance from sources can be very effective for dose reduction, and is often the least expensive as well as most generally applicable method. Changing distance from a source of radiation changes dose values by the inverse square of the distance factor. The inverse square formula is expressed as follows.

$I_1 \times d_1^2 = I_2 \times d_2^2$
where I_1 = intensity at a distance (d_1) from a point source,
and I_2 = intensity at a second distance (d_2) from the same point source.

Examples:

What is the dose rate 15 cm from a source when 5 mrem (0.05 mSv) / hr is measured 30 cm from the source?

$5 \text{ mrem/hr} \times (30 \text{ cm})^2 = I_2 \times (15 \text{ cm})^2$
$5 \times 900 / 225 = I_2$
$20 \text{ mrem/hr} = I_2$ {at 15 cm}

At what distance should 5 mrem (0.05 mSv) / hr be measured when 10 mrem (0.1 mSv) / hr is measured at 15 cm?

$10 \text{ mrem/hr} \times (15 \text{ cm})^2 = 5 \text{ mrem/hr} \times (d_2)^2$
$\sqrt{(10 \times 225 / 5)} = d_2$
approx. 21 cm $= d_2$ {5 mrem/hr}

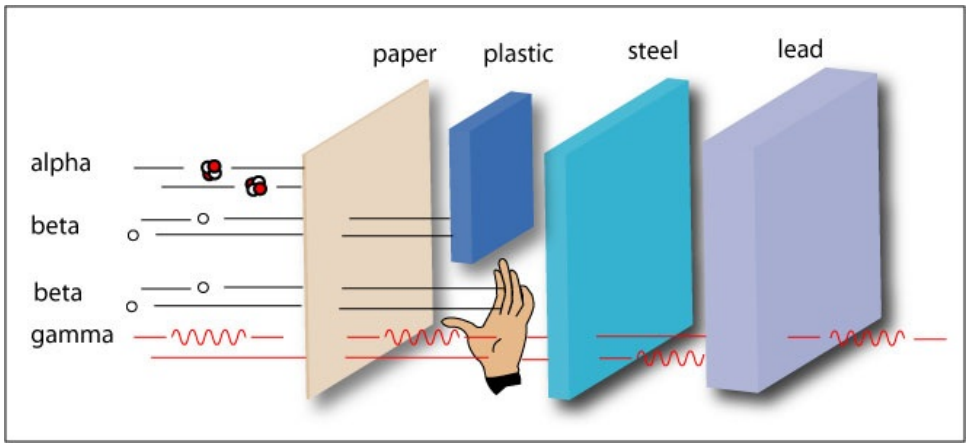
The inverse square law is easily demonstrated using a survey meter and a point source. Place the point source 15 cm from the detector and note the reading. Move the detector or source to 30 cm and the intensity will be reduced to about 25 percent of the first reading.

However, this law fails when the source of emissions is distributed (e.g. smeared, large area, rod, ...) and the distance between the source and the survey meter is less than 3 times the largest dimension of the source.

C) Shielding - Shielding can be practical means of radiation protection. For alpha and beta radiation very little shielding is required to absorb emissions completely.

Alpha (α) emissions are stopped by standard paper sheets. Beta (β) emissions are stopped by 1" wood, ¼" plexiglass, and varied thicknesses of other compounds.

Low energy beta emissions need very little if any shielding. Short distances or low density substances (lab coats, gloves, ...) may shield most or all emissions.



For mid and high energy beta emissions it's best to shield with lower density substances initially. If more shielding is needed then higher density substances may be used as outer shielding. This shielding arrangement reduces Bremsstrahlung (incidental photon) radiation production associated with higher energy beta emissions and their interaction with more dense substances.

Neutron emissions are generally more difficult to shield because they lack charge. However substances that contain atoms with nuclei that are comparable in size to neutrons can be very effective. Neutron (n) emissions are best resolved by hydrogen rich substances (water, borated cement, HDPE plastic, ...). Distance can also be very effective.

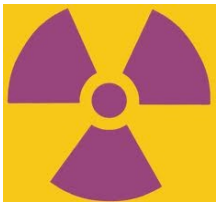
Because gamma and X-Ray emissions are photons, without charge or mass, the best we can do is attenuate them with dense substances such as lead (Pb) or concrete. Consequently, adjustments to time and distance can be more cost effective and functional for limiting exposure than adding shielding.

In general, as the density and/or thickness of substances increase absorption of radioactive emissions also increase.

RECOGNIZING RAD' WORK AREAS

Labs authorized for work with radioactive material or radiation producing machines are required to maintain caution or warning signs and markings. The exterior of each door into a Rad' lab should have a "Caution - Radioactive" sign. Active work areas must also be outlined with "Caution - Radioactive" tape. Dedicated tools and supplies must be marked with "Caution - Radioactive" tape or possibly tags or stickers with the trefoil

graphic similar to those on the signs and tape.



Some labs only use sealed radioactive sources. Such labs generally do not need caution signs or tape. Equipment that includes a sealed source, or the sealed source itself, should be marked with the trefoil graphic and possibly some cautionary words. Sealed sources generally present fewer concerns because of durable construction, limited content, and isotope properties.

RESPONSIBILITIES OF NON-RAD' WORKERS

Non-Rad' workers are those that lack current qualified radiation safety training and/or lab specific radiological training. Radiation safety training is conducted by USU's Radiation Safety Program and must be relative to the current calendar year. Lab training is conducted by the PI for the lab.

Without adequate training simply avoid Rad' work areas, Rad' source containers, Rad' waste, and any other radiological item.

The Principal investigator (PI) and trained lab staff are responsible for controlling and managing radiological items and work in their labs.

If spills, waste, or other concerns might involve radiological items or work areas, inform and defer to the PI and trained staff.

If the PI or trained staff are not available, report radiological concerns to USU's Radiation Safety Program.

Radiation Safety Officer	John Jones 435-797-3514 john.p.jones@usu.edu
Environmental Health and Safety	435-797-2892