BASIC RAD INFORMATION

Introduction:

Regulations and **standards** are in place to help minimize exposures to many sources of ionizing radiation. However, it is not possible to avoid all exposures. Radioactive materials are all around us. Terrestrial sources, such as radon, and cosmic radiation are contributors to our natural background radiation levels. Brick and concrete contain small amounts of naturally occurring radioactive materials such as uranium and thorium. Many of the foods that we eat contain naturally occurring radioactive materials – for instance, potassium-40 is found in bananas and Brazil nuts. Radioactive materials are routinely used in medicine for both diagnostic purposes (nuclear medicine) and therapeutic purposes (brachytherapy for the treatment of cancer, for example).

According to the National Council on Radiation Protection and Measurements (NCRP) Report No. 160: Ionizing Radiation Exposure of the Population of the United States (**https://ncrponline.org/publications/reports/ncrp-report-160/**), the average annual dose to a member of the US population from all sources is about 6.25 mSv (625 mrem). Furthermore, NCRP 160 states that approximately 2.5 million Americans receive annual doses from ubiquitous background in excess of 20 mSv (2000 mrem). The lowest annual doses are just over 0.5 mSv (50 mrem). The arithmetic mean is 3.11 mSv (311 mrem), of which 68%, or about 2.1 mSv (210 mrem), is from radon.

Ionizing radiation emitted from radioactive materials can pose a health risk. The risk of a future adverse effect such as cancer induction (a stochastic effect) is largely dependent upon the radiation dose received, but the severity of the potential effect is independent of the dose received. For deterministic effects (non-stochastic or threshold effects such as skin reddening), both the risk of occurrence and the severity of the effect are largely dependent upon the radiation dose and the rate at which it was received. Fortunately, ionizing radiation is easy to detect with proper instrumentation, and its effects have been studied for well over 100 years. Regulations are in place to minimize the health risks associated with exposure to ionizing radiation for both radiation workers and the public.

The intent of this document is to briefly explain various radiation-related terms and concepts in an easy to read format and to provide additional information for those that may find it useful. Although organizationally different among the states, each has a radiation health department that can help with further questions and concerns. The Health Physics Society (Health Physicists – or HPs – specialize in radiation protection) has resources available to help answer questions (**http://hps.org/publicinformation/ate/**). The Radiation Emergency Assistance Center/Training Site (REAC/TS: **https://orise.orau.gov/reacts/**) employs subject matter experts on the medical management of radiation incidents. The Centers for Disease Control and Prevention (CDC) Radiation Studies Branch has a lot of good information available about radiation protection and incident response available on its website (**https://www.cdc.gov/nceh/radiation/default.htm**). The US Department of Homeland Security/FEMA, and the US Department of Energy are also good resources for more information.

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Definitions of Selected Terms:

Activity: As opposed to traditional units such as ounces, pounds, grams, or kilograms; radioactive materials are quantified by units reflecting their activities. Activity describes the number if disintegrations that occur per unit time (disintegrations per second – dps, or disintegrations per minute – dpm). Just as 5,280 feet make 1 mile, a certain number of dps or dpm define standard units of activity.

- A curie (Ci), commonly used in the United States, is equivalent to $3.7x10^{10}$ disintegrations per second (dps) or $2.22x10^{12}$ disintegrations per minute. A Ci can be subdivided into what may be more useful units such as the millicurie (mCi, 0.001 Ci, $2.22x10^{9}$ dpm) or microcurie (µCi, 0.000001 Ci, $2.22x10^{6}$ dpm).
- The Becquerel (Bq) is the international unit of activity. A becquerel equals one disintegration per second. There are 3.7x1010 Bq in one Ci. Commonly used multiples of the Bq include the megabecquerel (MBq, $1.00x10^{6}$ Bq, 27 µCi), the gigabecquerel (GBq, $1.00x10^{9}$ Bq, 27 mCi), and the terabecquerel (TBq, $1.00x10^{12}$ Bq, 27 Ci).

ALARA (As Low As Reasonably Possible): A radiation protection philosophy based on keeping radiation doses As Low As Reasonably Achievable taking into account social, economic, and other factors.

Alpha Particle (α): An alpha particle is a positively charged particle consisting of two protons and two neutrons emitted from the nuclei of various radionuclides. Examples of alpha emitters include U-235, Pu-239, and Am-241. Alpha particles travel only travel a few centimeters in air and can be shielded by a piece of paper.

Annual Limit on Intake (ALI): The amount of radioactive material taken into the body via inhalation or ingestion that would result in an annual regulatory dose limit being met. ALIs are found in EPA Federal Guidance Report No. 11.

Beta Particle (β): Beta particles are negatively charged particles (comparable to an electron) emitted from the nuclei of various radioisotopes. Examples of beta emitters include H-3, P-32, and Sr-90. Beta particles, depending on their energies, can travel several meters in air. They can be shielded by relatively thin piece of plastic such as the facepiece of a full-face respirator or the lenses of reading glasses.

Clinical Decision Guide (CDG): The CDG, defined in NCRP Report 161, is an operational quantity intended to assist physicians who are evaluating if a patient needs treatment for internal contamination.

Contamination: Deposition of radioactive material, or the spread of radioactive materials from point A to point B. People can be externally contaminated (when radioactive material is deposited on the skin) or internally contaminated (when the radioactive material is taken into the body).

Criticality: The word “criticality” is usually associated with an uncontrolled fission chain reaction of uranium or plutonium atoms (see Fission).

Decontamination: The removal of radioactive material from an object.

Derived Reference Level (DRL): Amount of contamination in a wound that would likely result in a regulatory dose limit being met. This is a tool developed by REAC/TS to assess wounds and is not a regulatory unit. (see **https://orise.orau.gov/reacts/documents/medical-aspects-of-radiation-incidents.pdf**)

Deterministic Effects: Radiation effects that are based on a radiation dose threshold, below which there is no effect. Deterministic effects are also called non-stochastic effects.

Disintegration: A transformation within the atom resulting in the emission of ionizing radiation. Typical units are disintegrations per minute (dpm) and disintegrations per second (dps).

Dose: Radiation energy deposited into a unit mass of absorber.

- Rad: The unit of radiation dose primarily used in the United States. It is equal to 100 ergs of energy deposited into 1 gram of material. An erg is equal to 10^{-7} joules (6.2415×10^{11} electronvolts). One rad is equal to 0.01 Gy.
- Gray: The unit of radiation dose primarily used outside of the US. One Gy is equal to 1 joule (6.2415×10^{18} electronvolts) of energy deposited into 1 kg of material. One Gy is equal to 100 rads.

Dose Equivalent (and Equivalent Dose): Radiation dose multiplied times a quality or weighting factor, which are based on the risk of a stochastic effect due to differing radiations. Units of dose equivalent (and equivalent dose) are rem (US) and its international unit counterpart, Seivert (Sv). Rem and Sv are used primarily in occupational settings where the regulatory concern is management of stochastic risk (primarily cancer).

- Rem = rads x Q
- Sv = Gy x WR
- Quality Factors (Q) and Radiation Weighting Factors (WR) are dimensionless units that relate the radiation dose to its relative biological effectiveness.

Radiation Type and Energy Range	W_R
Photons, electrons, and muons - all energies	1
Neutrons - energy < 10 keV	5
Neutrons - energy 10 keV to 100 keV	10
Neutrons - energy > 100 keV to 2 MeV	20
Neutrons - energy > 2 MeV to 20 MeV	10
Neutrons - energy > 20 MeV	5
Protons - other than recoil protons, energy > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Dose Rate: Absorbed dose (rad or gray) delivered per unit time (i.e.: rads/hr or Gy/hr).

Electron: Negatively charged particles orbiting the atomic nucleus.

Electronvolt: The amount of energy gained (or lost) by the charge of a single electron moving across an electric potential difference of one volt. Radiation energies are measured in electronvolts (eV). Common multiples of the eV are keV (1,000 electronvolts) and MeV (1,000,000 electronvolts).

Energy: The energy available to be deposited into an absorber that results from the decay of a radioactive atom. It is measured in electronvolts (eV). Energies associated with common isotopes are: Co-60 (1.17 MeV and 1.33 MeV gammas), Cs-137 (0.512 MeV beta to Ba-137m that decays with a 0.662 MeV gamma), Sr-90 (0.546 MeV beta to Y-90 that decays with a 2.28 MeV beta).

Exposure: A measure of the amount of ionization produced in air. The unit used in the United States is the Roentgen (2.58×10^{-4} Coulombs per kilogram). The international unit is expressed in terms of Coulombs per kilogram.

Fission: The splitting of the atom into two unequal pieces (fission products/fragments). This is accompanied by a large release of energy, most of which is due to the kinetic energy of the fission fragments. Fission is the process used in the production of nuclear power (a controlled chain reaction).

Half-life: The time it takes for an activity to decrease to ½ of its original value.

- Biological Half-life: The amount of time it takes for the body to eliminate one-half of an internally deposited material without regard to radioactive decay.
- Effective Half-life: The combination of the radiological half-life (rad decay) and biological half-life (physical elimination).
    - $T_{1/2\text{-Eff}} = (T_{1/2\text{-Rad}} \times T_{1/2\text{-Bio}}) / (T_{1/2\text{-Rad}} + T_{1/2\text{-Bio}})$

Gamma Rays (γ): Gamma rays are electromagnetic radiation emitted from the nuclei of various radioisotopes. Examples include Ir-192 and Co-60. Gamma rays can travel many meters in air and are shielded using dense materials such as lead.

Inverse Square Law: Primarily intended for physically small sources, it says that the intensity of the radiation dose decreases inversely with the square of the distance from the source ($1/R^2$). It's generally applicable at distances greater than 3x the largest dimension of the source.

Ionizing Radiation: Radiation that has the ability to remove orbital electrons from an atom (ionization). Not all radiation is ionizing (visible light, radio waves, and microwaves, for example).

Irradiation: Irradiation (often referred to as exposure) is a term used to indicate that something is "in the presence of" of a radioactive source. Think of it as someone shining a flashlight on you – you are being exposed to light. Irradiation does not cause contamination. When the source of radiation is removed (for instance, the flashlight is turned off) the exposure stops and there is no material left behind. You are irradiated every time you have a CT scan or a chest x-ray.

Isotope: Atoms having the same number of protons, but different numbers of neutrons. Since the number of protons defines the element, isotopes can also be defined as atoms of the same element with differing numbers of neutrons (if the isotope is radioactive it is called a radioisotope, Cs-134 and Cs-137, for instance).

$LD_{50/60}$: The dose of ionizing radiation that would kill 50% of a group receiving that dose within 60 days without medical treatment. The $LD_{50/60}$ is about 400 rads.

Neutrons: Neutrons are neutral (non-charged) particles found in the nucleus of atoms. They can be emitted from the nuclei of various unstable radioisotopes and are produced when fission occurs. Unlike other ionizing radiations, neutrons have the ability to make something else radioactive (neutron activation).

Photon: An energy quantum of electromagnetic radiation. Gamma and x-rays are photons.

Protons: Positively charged elementary particles found in atomic nuclei.

Radiation: The propagation of energy through space, or some other medium, in the form of electromagnetic waves or particles.

Radioactive Decay: Reduction in activity of a quantity of radioactive material by disintegration of its atoms. Elements that undergo radioactive decay are said to be radioactive.

Radioactive Materials: Radioactive materials are materials that emit ionizing radiation.

Specific Activity: The reason traditional units of measure such as pound and kilogram can't be used is the concept of specific activity. It relates an activity per unit mass of material, i.e.: Ci/kg, MBq/g, etc. For every gram of Ir-192, for instance, there are 9640 ($9.64x10^{3}$) Ci of activity; for every gram of U-235 there is only $2.1x10^{-6}$ Ci.

Stochastic Effects: An effect where the probability of that effect, rather than its severity, is a function of dose. An example would be cancer induction. The probability of cancer induction increases with dose, yet the effects of the cancer are not better or worse because of the radiation dose that caused it.

X-rays: Electromagnetic radiation emitted either when an inner orbital electron of an excited atom returns to its normal state. X-rays can be machine generated and result from energetic electrons "slowing down" when interacting with a metal target (x-ray machine).

Radiological Terrorism Terms:

The use of radioactive materials for malevolent purpose is typically divided into three basic categories: IND, RED, or RDD. The hazards posed by these devices share various commonalities but are also quite different.

Improvised Nuclear Device (IND): An IND incorporates nuclear materials designed to produce a nuclear explosion. It may be fabricated in an improvised manner or may be a modification to an existing nuclear weapon. Thermal and blast injuries accompanied by radiation concerns affecting large populations must be considered.

Radiation Exposure Device (RED): An RED is radioactive material, either as a sealed source or within some type of container, intended to expose people to radiation. With an RED, there is no spread of contamination, so the primary hazard is radiation exposure. An example of an RED is the placement of an industrial radiography source in a subway car in order to expose the occupants.

Radiological Dispersal Device (RDD): An RDD uses conventional explosives to spread radioactive contamination, or does so via some other mechanism. An RDD poses both exposure and contamination concerns of varying degrees. Introduction of a radioactive material into a ventilation system with the intent of spreading the material throughout the building is an example of an RDD.

Good Sources for Further Radiological Terrorism Information:

- NCRP Report 138: Management of Terrorist Events Involving Radioactive Material
- NCRP Commentary 19: Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism
- NCRP Report 165: Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers
- Department of Homeland Security: Radiological Dispersal Device (RDD) Response Guidance Planning for the First 100 Minutes (**https://www.dhs.gov/publication/st-frg-rdd-response-guidance-planning-first-100-minutes**)
- Department of Homeland Security: Health and Safety Planning Guide for Planners, Safety Officers, and Supervisors for Protecting Responders Following a Nuclear Detonation (**https://www.dhs.gov/publication/ind-health-and-safety-planning-guide**)
- National Council on Radiation Protection and Measurements (NCRP) Report No. 179 – Guidance for Emergency Response Dosimetry (**https://ncrponline.org/shop/reports/report-no-179-guidance-for-emergency-response-dosimetry-2017/**)
- Radiation Emergency Medical Management: Radiological Dispersal Devices (**https://www.remm.nlm.gov/rdd.htm**)

Note: these documents contain references that may also be useful

Other Useful Reference Sites:

- US Federal Standards for Protection Against Radiation: **https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/**
- US EPA Radiation Information: **https://www.epa.gov/radiation**
- Recommendations of the International Commission on Radiological Protection: **http://www.icrp.org/publication.asp?id=ICRP%20Publication%20103**
- The Radiation Emergency Assistance Center/Training Site (REAC/TS): **http://orise.orau.gov/reacts**
- Rapid Internal and External Dose Estimation (REAC/TS): **http://orise.orau.gov/files/reacts/rapid-internal-external-dose-magnitude-estimation.pdf**
- Medical Aspects of Radiation Incidents (REAC/TS): **https://orise.orau.gov/reacts/documents/medical-aspects-of-radiation-incidents.pdf**
- Package Inserts (DTPA and Prussian Blue): **http://orise.orau.gov/reacts/resources/package-inserts.aspx**
- Radiation Emergency Medical Management: **http://www.remm.nlm.gov/**
- The Nuclear Regulatory Commission (NRC): **https://www.nrc.gov/**
- Environmental Protection Agency Protective Action Guides and Planning Guidance for Radiological Incidents (2017 PAG Manual): **https://www.epa.gov/sites/production/files/2017-01/documents/epa_pag_manual_final_revisions_01-11-2017_cover_disclaimer_8.pdf**
- National Council on Radiation Protection and Measurement (NCRP) Report No. 161 – Management of Persons Contaminated with Radionuclides: **https://ncrponline.org/publications/reports/ncrp-report-161/**
- The Virtual Nuclear Tourist: **http://www.nucleartourist.com/**

Note: Many of the documents/websites listed above were used as references for Basic Radiation Information. Please consult them as they contain a wealth of information.

Biological Effects, Dose Information, and Conversions:

Absorbed Dose

1 gray	1 Gy	100 rads
1 milligray	1 mGy	100 millirads
1 microgray	1 µGy	100 microrads
1 rad	1 rad	10 milligrays
1 millirad	1 mrad	10 micrograys
1 microrad	1 µrad	10 nanograys

Dose Equivalent

1 Sievert	1 Sv	100 rem
1 millisievert	1 mSv	100 millirem
1 microsievert	1 µSv	100 microrem
1 nanosievert	1 nSv	100 nanorem
1 rem	1 rem	10 millisieverts
1 millirem	1 mrem	10 microsieverts
1 microrem	1 µrem	10 nanosieverts

Activity

1 terabecquerel	1 TBq	27 curies	6.0E+13 dpm*
1 gigabecquerel	1 GBq	27 millicuries	6.0E+10 dpm*
1 megabecquerel	1 MBq	27 microcuries	6.0E+7 dpm*
1 kilobecquerel	1 kBq	27 nanocuries	60,000 dpm*
1 becquerel	1 Bq	27 picocuries	60 dpm*
1 kilocurie	1 kCi	37 terabecquerels	2.22E+15 dpm
1 curie	1 Ci	37 gigabecquerels	2.22E+12 dpm
1 millicurie	1 mCi	37 megabecquerels	2.22E+9 dpm
1 microcurie	1 µCi	37 kilobecquerels	2,200,000 dpm
1 nanocurie	1 nCi	37 becquerels	2,200 dpm
*Slightly rounded			

Skin Injury Thresholds vs. Acute Doses

Dose	Effect	Timing* (time post exposure)
300 rads, 3 Gy	Epilation	14-21 days
600 rads, 6 Gy	Erythema	Early, then 14-21 days later
1000-1500 rads, 10-15 Gy	Dry Desquamation	2-3 Weeks
1500 - 2500 rads, 15-25 Gy	Moist Desquamation	2-3 Weeks
> 2500 rads, > 25 Gy	Deep Ulceration/Necrosis	Dependent upon dose
* At higher doses the time to onset of signs/symptoms may be compressed.		

Thresholds for Acute Radiation Syndromes

Dose	Syndrome	Signs/Symptoms*
0-100 rads, 0-1 Gy	NA	Generally asymptomatic, potential slight drop in lymphocytes later (near 1 Gy)
> 100 rads, > 1 Gy	Hematopoietic	Anorexia, nausea, vomiting, initial granulocytosis and lymphocytopenia
> 6-800 rads, >6-8 Gy	Gastrointestinal	Early severe nausea, vomiting, watery diarrhea, pancytopenia
> 2000 rads, > 20 Gy	Neurovascular	Nausea/vomiting within first hour, prostration, ataxia, confusion
*At higher doses the time to onset of signs/symptoms may be compressed		

Derived Reference Levels (DRL) to Assess Wound Contamination (dpm)

Isotope	Based on*	Weak	Moderate	Strong	Avid
Co-60	ED	1.54E+08	1.54E+08	1.65E+08	2.01E+08
Sr-90	BS	2.20E+07	2.20E+07	2.25E+07	2.38E+07
Tc-99m	ED	2.00E+11	2.56E+11	9.33E+11	8.78E+11
I-131	Thy	7.06E+07	8.01E+07	1.26E+08	3.46E+08
Cs-137	ED	2.20E+08	2.20E+08	2.23E+08	2.34E+08
Ir-192	ED	4.49E+08	4.66E+08	6.21E+08	1.69E+09
U-235	BS	8.23E+05	8.23E+05	8.29E+05	8.46E+05
U-238	BS	8.55E+05	8.55E+05	8.63E+05	8.78E+05
Pu-239	BS	1.81E+03	1.81E+03	1.85E+03	1.92E+03
Am-241	BS	1.65E+03	1.65E+03	1.68E+03	1.74E+03
Cf-252	BS	5.14E+03	5.15E+03	5.75E+03	7.96E+03
ED reference point = 5 rem (committed) Organ dose reference point = 50 rem (committed) *ED = Effective Dose, BS = Bone Surface, Thy = Thyroid					

U.S. ALIs for Selected Specific Radionuclides

Nuclide	Inh. ALI (µCi)	dpm
H-3	80,000 (H_2O Vapor)	1.8×10^{11}
Co-60	30 - Y	6.7×10^{7}
Sr-90	4 - Y	8.9×10^{6}
Cs-137	200 - D	4.4×10^{8}
U-235, 238	0.04 - Y	8.9×10^{4}
Pu-238	0.007 - W	1.6×10^{4}
Pu-239	0.006 - W	1.3×10^{4}
Am-241	0.006 - W	1.3×10^{4}
Most restrictive ALI values in Fed. Guidance Rpt. #11 are listed (solubility class also listed).		

Dose Information for Selected Radioisotopes

Approximate dose rates to the skin for 1 MBq in a sealed source - PHITS Simulations									
		Dose to first 0.07mm			Dose to first 1mm				
Nuclide	Gamma Constant (mSv-cm2/	Dose Rate Photon Only (mSv/h)	Dose Rate due to secondary electron buildup in encapsulation (mSv/h)	Dose Rate Total (mSv/h)	Dose Rate Photon Only (mSv/h)	Dose Rate due to secondary electron buildup in encapsulation (mSv/h)	Dose Rate Total (mSv/h)	Dose rate at 1cm tissue depth (mSv/h)	Dose rate at 3cm tissue depth (mSv/h)
Cs-137	0.927	0.95	3.99	4.94	2.90	1.28	4.18	0.48	0.065
Co-60	3.48	1.60	14.00	15.60	5.42	8.20	13.62	1.74	0.262
Ir-192	1.24	2.65	6.80	9.45	5.12	1.04	6.16	0.59	0.092
Ra-226	2.23*	2.15	11.30	13.45	5.30	4.80	10.10	1.28	0.157
Se-75	0.548	1.95	4.61	6.56	2.43	0.47	2.90	0.21	0.022

- 0.7 and 1 mm data from Improved Contact Dose Rate Conversion Factors and Secondary Electron Correction Factors for Encapsulated Gamma Sources: Presented by Ed Waller on 07/12/17 - Raleigh, NC - Health Physics Society Annual Meeting - Session WAM-A.10 (Primary Author: Eric Heritage, University of Ontario Institute of Technology)
- 1 cm and 3 cm data was provided by Ed Waller on 03/02/2016 via personal correspondence.
- Cs, Co, Ir, Ra 1 cm and 3 cm data closely resembles that published in NCRP 40.
- No data available in NCRP 40 for Se.
- Gamma constant information from Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides (Smith, Stabin – Health Physics – 2012) – converted from conventional US units listed in the reference
- *Converted from NCRP 40 (includes daughter contributions

Note: Multiply mSv/hr/MBq by 3.7 to get R/hr/mCi

Table data compiled from references above by Steve Sugarman

Standard Prefixes for Units of Measurements

Multiple	Prefix	Symbol
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
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f