Quick Reference Information – Radiation

Activity: Radioactive materials aren't quantified by units we are normally familiar with, units such as pound, ounce, kilogram, cc, handful, etc. We must use units of activity to quantify radioactive materials. The activity is a way of expressing how many atoms are disintegrating in a unit of time (disintegrations per second or minute, for instance)

- Curie (Ci): A curie is equivalent to 3.7×10^{10} disintegrations per second (dps) or 2.22×10^{12} disintegrations per minute. Commonly used divisions are the millicurie (mCi, 0.001 Ci) and the µCi (0.000001 Ci). One µCi = 2.22×10^{6} (2.22 million) dpm. This unit is most commonly used in the US.
- Becquerel (Bq): The international unit of activity. A becquerel equals one disintegration per second.

ALARA: A system of dose limitation based on keeping radiation doses As Low As Reasonably Achievable taking into account social and economic 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 Am-241, Pu-239, and U-235. Alpha particles can be shielded by a business card and only travel a couple of inches in air.

Annual Limit on Intake (ALI): The ALI is a regulatory limit for internal contamination. It is that amount of radioactive material, that if taken into the body, results in an annual regulatory dose limit being met. Both inhalation and ingestion ALIs for the various radionuclides can be found in EPA Federal Guidance Report No. 11. The ALI is a handy benchmark when trying to rapidly assess the magnitude of potentially internalized contamination.

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Oak Ridge Institute for Science and Education (ORISE)
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24-hour: (865)576-1005

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Beta Particle (β): Beta particles are negatively charged particles emitted from the nuclei of various radionuclides. A beta particle is identical to an electron. Examples of beta emitters include Sr-90, P-32, and H-3. Beta particles can travel a couple of meters in air, depending on their energies, and can be shielded by a couple sheets of aluminum foil or thin plastic.

Clinical Decision Guide: From NCRP Report 161, the CDG is intended to provide a measure that physicians can use when considering the need for medical treatment of internally contaminated patients. It is not regulatory in nature.

Contamination: Deposition of radioactive material on a surface. A person can be externally contaminated (radioactive material on clothes/skin) or internally contaminated (radioactive material inside the body). Note that you are not contaminated by the alpha particles or gamma rays that are emitted from the radioactive material, but by the material itself. Obviously, if you have the radioactive material on/in you, you are being exposed to the ionizing radiation emitted from the radioactive contamination and will continue to be exposed until the radioactive material is removed.

Criticality: A term used to describe the state of a given fission system when the conditions are such that the number of neutrons produced equals the number of neutrons that escape from the system.

- Sub-critical: The number if neutrons produced is less than the number of neutrons that escape the system.
- Super-critical: The number of neutrons produced exceeds the number of neutrons that escape the system.

Decontamination: The removal or reduction of radioactive contaminants.

Derived Reference Level (DRL) – REAC/TS term (not regulatory). Amount of contamination in a wound that would likely result in a regulatory dose limit being met (see http://orise.orau.gov/reacts/resources/radiation-accident-management.aspx)

Deterministic Effects: Also called non-stochastic effects. They are based on a threshold radiation dose, below which there is no effect. An example of a deterministic, or non-stochastic, effect is skin erythema. The threshold for erythema is approximately 600 rads (6 Gy). Higher doses can result in other effects.

~300 mrem	5 rem		300 rads	600 rads
stochastic concerns		>>	*deterministic concerns*	→
Background	Annual Whole Body Dose Limit		Epilation Threshold	Erythema Threshold

Dose: Dose describes the amount of energy deposited into a specified mass of material (Absorbed Dose). Although not a perfect analogy, this is analogous to someone punching you in the arm. Energy has been deposited and an acute biological response may occur where that energy has been deposited. With regard to Absorbed Dose, one is measuring the amount of energy that's deposited via ionizing radiation. Dose is usually what one is concerned with when evaluating potential early deterministic effects.

- 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. One rad is equal to 0.01 Gy.
- Gray: The unit of radiation dose primarily used everywhere else! One Gy is equal to 1 joule of energy deposited into 1 kg of material. 1 Gy is equal to 100 rads. For points of reference, one joule is equal to 6.2415×10^{18} electron volts (all of the gamma energy available from about 2.5 trillion Co-60 decays!) and one kilowatt-hour is equal to 3.6 million joules.

Dose Equivalent (and Equivalent Dose – slightly different, but very similar): This is a biologically weighted way to relate radiation dose through the use of quality or weighting factors which are based on the risk of stochastic effects from various 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 risk management, for instance the risk of future cancer induction. (The threshold doses for deterministic effects are well above regulatory occupational limits.) Rem = rads x Q; Sv = Gy x W_R

- The Quality Factor (Q) and the Radiation Weighting Factor (W_R) relate the radiation dose to its relative biological effectiveness. It is a dimensionless unit that communicates a specific type of radiation's potential efficiency of depositing energy and creating the stochastic effect in question. For gammas Q = 1.

Dose Rate: Absorbed dose delivered per unit time.

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.

Electron: Negatively charged particles orbiting the atomic nucleus.

Fission: The splitting of the atom into two unequal pieces (fission fragments/products) accompanied by a large release of energy, most of which is due to the kinetic energy of the fission fragments.

Half-life: The half-life ($T_{1/2}$) of a radioactive material is the amount of time it takes for the activity to decrease to ½ of its original amount.

- Physical Half-life: The amount if time it take for a radioactive sample to decay to one-half of its original value
- Biological Half-life: The amount of time it takes for the body to eliminate one-half of an internally deposited radioactive material without regard to physical decay.

- Effective Half-life: The combination of physical and biological half-life. It can be calculated by the product of the physical and biological half-lives divided by the sum of the physical and biological half-lives.

Gamma Rays (γ): Gamma rays are electromagnetic radiation emitted from the nuclei of various radionuclides. Examples include Ir-192, Cs-137, and Co-60. Gamma rays are shielded using dense materials such as lead and can travel many meters in air. The primary difference between gamma rays and x-rays is that gamma rays originate inside the nucleus and x-rays originate outside the nucleus. For basic radiation protection purposes they are essentially the same.

Inverse Square Law: The intensity of the radiation dose decreases inversely with the square of the distance ($1/R^2$).

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 (Exposure): Irradiation, or exposure (used colloquially), is a term used to say that you "are in the presence of" ionizing radiation. You are exposed to ionizing radiation just as you are exposed to light. Just like when you are exposed to light, when you are irradiated (exposed) it doesn't mean that you have "particles" on you and that you can transfer them to other people or things. You are exposed to radiation 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 particles found in atomic nuclei. They can be emitted from the nuclei of various unstable radioisotopes. They can also be significant contributors to dose in a criticality event. Neutrons have the ability to make something else radioactive. This is called 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.

Radiation Energy: Each disintegration results in a release of energy which can be deposited into an absorber. The energy available to be deposited is measured in electron-volts (eV). If you were to accelerate one electron across the electrodes of a nine volt battery it would have 9 eV of energy available to deposit into a target. Various radioisotopes emit varying types of radiation. For instance, Co-60 emits 2 gamma rays, one having ~1.17 million eV (1.17 megaelectron-volts, or MeV) and one having ~1.33 MeV. Am-241 emits an alpha particle of about 5.5 MeV and a gamma ray of 60,000 electron-volts (60 kiloelectron-volts, or keV). Each of these emissions is capable of depositing some, or all, of their energy.

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.

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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 (9.64×10^3) Ci of activity; for every gram of U-235 there is only 2.1×10^{-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: A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state or when a metal target is bombarded with high-speed electrons (x-ray machine). X-rays are always non-nuclear in origin.

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Conversions

Activity

1 terabecquerel	1 TBq	27 curies
1 gigabecquerel	1 GBq	27 millicuries
1 megabecquerel	1 MBq	27 microcuries
1 kilobecquerel	1 kBq	27 nanocuries
1 becquerel	1 Bq	27 picocuries
1 kilocurie	1 kCi	37 terabecquerels
1 curie	1 Ci	37 gigabecquerels
1 millicurie	1 mCi	37 megabecquerels
1 microcurie	1 µCi	37 kilobecquerels
1 nanocurie	1 nCi	37 becquerels

Dose Equivalent (1 Sv = 100 rem, 1 rem = 0.01 Sv)

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 kilorem	1 krem	10 sieverts
1 rem	1 rem	10 millisieverts
1 millirem	1 mrem	10 microsieverts
1 microrem	1 µrem	10 nanosieverts

Dose (1 Gy = 100 rads, 1 rad = 0.01 Gy)

1 kilogray	1 kGy	100 kilorads
1 gray	1 Gy	100 rads
1 milligray	1 mGy	100 millirads
1 microgray	1 µGy	100 microrads
1 kilorad	1 krad	10 grays
1 rad	1 rad	10 milligrays
1 millirad	1 mrad	10 micrograys
1 microrad	1 µrad	10 nanograys

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Conversions

Standard Prefixes for Units of Measurements

Multiple	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
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
10^{-18}	atto	a

U.S. ALIs for Assumed Radionuclides

Emission	Assumed Nuclide	Inh. ALI (µCi)	dpm
alpha	Am-241	0.006 - W	1.3×10^4
beta	Sr-90	4 - Y	8.9×10^6
gamma	Cs-137	200 - D	4.4×10^8

Most restrictive ALI values in FGR-11 are listed (solubility class also listed).

U.S. ALIs for Selected Specific Radionuclides

Nuclide	Inh. ALI (µCi)	dpm
H-3	80,000 (H_20 Vapor)	1.8×10^{11}
Co-60	30 - Y	6.7×10^7
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
Cf-252	0.02 - W	4.4×10^4

Most restrictive ALI values in FGR-11 are listed (solubility class also listed).

Selected 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

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Approximate Dose Rates from Common Gamma Emitters (U.S. Units)

Radionuclide/ Half-Life	Exposure Rate Constant* (R-cm^2/hr- mCi)	*f* – factor*	Surface** (R/min-Ci)	Dose Rate at 1 cm Tissue Depth*** (R/min-Ci)	Dose Rate at 3 cm Tissue Depth*** (R/min-Ci)
Co-60/5.26y	12.9	0.965	609	114	16.0
Cs-137/30.17y	3.43	0.962	113	28	3.7
Ir-192/74d	4.60	0.964	180	43	5.5

*Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides (Smith, Stabin – Health Physics – 2012)
**Primarily due to electron buildup in the capsule wall. From Waller, et.al, IRPA 13 poster (abstract 2350443)
***From NCRP Report No. 40, Appendix B, Table 6

Notes:
f-factor: conversion between exposure rate in air and dose rate to tissue
Assumes point source geometry

Approximate Doses from Common Gamma Emitters (SI Units)

Radionuclide/ Half-Life	Exposure Rate Constant* (mSv-cm^2/hr-MBq)	*f* – factor*	Surface** (mSv/min-GBq)	Dose Rate at 1 cm Tissue Depth*** (mSv/min-GBq)	Dose Rate at 3 cm Tissue Depth*** (mSv/min-GBq)
Co-60/5.26y	3.48	0.965	164.6	30.8	4.3
Cs-137/30.17y	0.927	0.962	30.5	7.6	1
Ir-192/74d	1.24	0.964	48.7	11.6	1.5

*Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides (Smith, Stabin – Health Physics – 2012)
**Primarily due to electron buildup in the capsule wall. From Waller, et.al, IRPA 13 poster (abstract 2350443)
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Of Particular Interest to Physicians

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	Wet 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.

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Recommended Treatment Points – Potassium Iodide*

Adults >40 y of age with thyroid exposure ≥ 5 Gy (500 rad)	130 mg/day
Adults 18 – 40 y of age with thyroid exposure ≥ 0.1 Gy (10 rad	130 mg/day
Pregnant or lactating women with thyroid exposure ≥ 0.05 Gy (5 rad)	130 mg/day
Children and adolescents 3 – 18 y of age with thyroid exposure ≥ 0.05 Gy (5 rad)	65 mg/day
Infants 1 month – 3 y of age with thyroid exposure ≥ 0.05 Gy (5 rad)	32 mg/day
Neonates from birth – 1 month with thyroid exposure ≥ 0.05 Gy (5 rad)	16 mg/day

* See NCRP Report 161 for a more detailed discussion on use and side effects. Further guidance can be found on the Food and Drug Administration's website at: http://www.fda.gov/downloads/Drugs/GuidanceComplianceRegulatoryInformation/Guidances/ucm080542.pdf

Other Useful Reference Sites

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):
http://orise.orau.gov/reacts/resources/radiation-accident-management.aspx

Package Inserts (DTPA and Prussian Blue):
http://orise.orau.gov/reacts/resources/package-inserts.aspx

Radiation Emergency Medical Management: http://www.remm.nlm.gov/