Los Alamos
Radiation Monitoring Notebook

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ABBREVIATIONS

ampere	A, or amp
angstrom unit	D, or A
atmosphere	atm
atomic weight	at. wt.
cubic foot	ft^3, or cu. Ft.
cubic feet per minute	ft^3/min, or cfm
cubic inch	in^3, or cu. in.
cubic meter	m^3, or cu. m.
curie	Ci
day	day, or d
degree	deg, or ^{0}
disintegrations per minute	dpm
foot	ft.
gallon	gal.
gallons per minute	gpm
hour	h, or hr
inch	in.
liter	L
meter	m
micron	μ, μm, or mu
minute	min, or m
pounds per square inch	lb/in^2, or psi
roentgen	R
second	sec, or s
square centimeter	cm^2, or sq cm
square foot	ft^2, sq ft
square meter	m^2, or sq m
volt	V, or v
watt	W, or w
year	yr, or y

CONVERSION OF UNITS

Multiply	**®**	**by**	**®**	**To Obtain**
To Obtain	**®**	**by**	**®**	**Divide**
		Length		
Angstroms		1 E-8		centimeters
Inches		2.54		centimeters
meters		3.2808		feet
kilometers		0.6214		miles
miles		5280		feet
microns (µm)		1 E-6		meters
mils		1 E-3		inches
		Area		
Acres		43,560		square feet
Barns		1 E-24		square centimeters
Square centimeters		0.1550		square inches
Square meters		10.764		square feet
Square meters		3.861 E-7		square miles
Square miles		640		acres
		Volume		
Cubic centimeters		3.531 E-5		cubic feet
Cubic centimeters		1 E-6		cubic meters
Cubic feet		28.316		liters
Cubic feet		7.481		gallons
Liters		1.057		quarts
Liters		0.2642		gallons
Cubic meters		35.315		cubic feet
Cubic meters		1,000		liters
Milliliters		1		cubic centimeters

CONVERSION OF UNITS

Multiply	®	by	®	To Obtain
To Obtain	**®**	**by**	**®**	**Divide**
		Time		
days		1440		minutes
days		86,400		seconds
work week		1.44 E5		seconds
work month		4.33		work weeks
work month		173.3		work hours
years (calendar)		365		days
years		8,760		hours
years		5.256 E5		minutes
years		3.1536 E7		seconds
		Density		
grams / cm^3		62.428		pounds / cubic foot
grams / cm^3		8.345		pounds / gallon
		Pressure		
atmospheres		1.0133		bars
atmospheres		1,033		grams / cm^2
atmospheres		14.70		pounds / $in.^2$
atmospheres		760		mm Hg @ 0 ^{0}C
atmospheres		29.921		inches Hg @ 32 ^{0}F
atmospheres		33.90		feet H_2O @ 39.2 ^{0}F
bars		1 E6		dynes / cm^2
dynes / cm^2		1.0197 E-3		grams / cm^2
grams / cm^2		0.01422		pounds / square inch
Torr		1		mm Hg @ 0 ^{0}C
		Energy		
ergs		6.242 E11		electron volts
ergs		2.390 E-8		gram calories
electron volts		1.602 E-12		ergs

CONVERSION OF UNITS

Multiply	®	by	®	To Obtain
To Obtain	**®**	**by**	**®**	**Divide**
		Mass		
grams		0.03527		ounces
kilograms		2.2046		pounds
pounds		16		ounces
pounds		453.59		grams
		Others		
amperes		2.998 E9		electrostatic units / sec
amperes		6.242 E18		electronic charges / sec
coulombs		6.242 E18		electronic charges
radians		57.296		degrees
		Radiological		
rads		100		ergs / gram
rads		6.242 E13		electron volts / gram
roentgens		87.7		ergs / gram of air
roentgens		1.61 E12		ion pairs / gram of air
roentgens		5.47 E13		electron volts / gm of air
sievert		100		rem
curies		3.7 E10		dps
curies		2.22 E12		dpm
µcuries / sq. meter		220		dpm / cm^2
megacuries / sq. mile		0.386		curies / square meter
dpm/m^3		4.5 E-13		microcuries / cm^3
bequerels		2.7027 E-11		curies
bequerels		1		dps
BTU		1.28 E-8		grams ^{235}U fissioned
BTU		1.53 E-8		grams ^{235}U destroyed
BTU		3.29 E13		fissions
fission of 1 g ^{235}U		1		megawatt-days
fissions		8.9058 E-18		kilowatt-hours
fissions		3.204 E-4		ergs

CONVERSION OF UNITS

Multiply	®	by	®	To Obtain
To Obtain	**®**	**by**	**®**	**Divide**
		Power		
joules/sec		1 E7		ergs / second
watts		1 E7		ergs / second
watts		0.001341		horsepower
watts		3.1 E10		fissions / second

MULTIPLES AND SUBMULTIPLES

10^{12}	tera	T	10^{-1}	deci	d
10^{9}	giga	G	10^{-2}	centi	c
10^{6}	mega	M	10^{-3}	milli	m
10^{3}	kilo	k	10^{-6}	micro	µ
10^{2}	hecto	h	10^{-9}	nano	n
10^{1}	deka	da	10^{-12}	pico	p
10^{0}	1	1	10^{-15}	femto	f
			10^{-18}	atto	a

GREEK ALPHABET

Α	α	Alpha	Ν	ν	Nu
Β	β	Beta	Ξ	ξ	Xi
Γ	γ	Gamma	Ο	ο	Omicron
Δ	δ	Delta	Π	π	Pi
Ε	ε	Epsilon	Ρ	ρ	Rho
Ζ	ζ	Zeta	Σ	σ	Sigma
Η	η	Eta	Τ	τ	Tau
Θ	θ	Theta	Υ	υ	Upsilon
Ι	ι	Iota	Φ	φ	Phi
Κ	κ	Kappa	Χ	χ	Chi
Λ	λ	Lambda	Ψ	ψ	Psi
Μ	μ	Mu	Ω	ω	Omega

CONSTANTS

Avogadro's number (N_0)	6.02252 E23
electron charge (e)	4.80298 E-10 esu
electron rest mass (m_e)	9.1091 E-28 g
acceleration gravity (g)	32.1725 ft / sec^2
@ sea level & 45^0 latitude	980.621 cm / sec^2
Planck's constant (h)	6.625 E-27 erg-sec
velocity of light (c)	2.9979 E10 cm / sec
velocity of light (c)	186,280 miles / sec
ideal gas volume (V_0)	22,414 cm^3 / mole (STP)
neutron mass	1.67482 E-24 g
proton mass	1.67252 E-24 g
ratio of proton to electron mass	1,836.13
natural base of logarithms (e)	2.71828
π	3.14159

A gram-molecular weight of any gas contains (Avogadro's number), N_0 (6.02252 E23) atoms and occupies a volume of 22,414 cm^3 at STP.

Temperature

$^0C = (^0F - 32)(5/9)$	$^0F = 1.8\ ^0C + 32$
$^0K = {}^0C + 273.1$	$^0R = {}^0F + 459.58$

Conversion Equations

grams/sq. cm	=	density (g/cm^3) x thickness (cm)
Photon energy (keV)	=	12.4/wavelength (A)

RULES OF THUMB FOR ALPHA PARTICLES

1. An alpha particle of at least 7.5 MeV energy is needed to penetrate the nominal protective layer of the skin (7 mg / cm^2 or 0.07 mm).

2. The alpha emissions and energies of the predominant particles from 1 µg of several common materials are:

	DPM per µg	**Alpha Energy (MeV)**
^{238}Pu	39,000,000	5.50 (72%)
^{239}Pu	140,000	5.15 (72.5%)
^{240}Pu	500,000	5.16 (76%)
^{242}Pu	8,700	4.90 (76%)
[a]Natural U	1.5	4.20 (37%), 4.77 (36%)
Oralloy (93% ^{235}U)	160	4.77 (~ 80%)
[b]Natural Th	0.5	4.01 (38%), 5.43 (36%)
D-38 (DU, tuballoy)	1	4.20 (~ 60%)

[a] Includes ^{234}U in equilibrium.

[b] Includes ^{228}Th in equilibrium. Depending upon the time since chemical separation, ^{228}Th can decrease to give a net disintegration rate lower than 0.5.

[c.] With 2π (50%) geometry, the surface of a thick uranium metal (tuballoy) source gives ~ 2400 alpha counts/min per cm^2. Depleted uranium (D-38) gives ~ 800 alpha cpm/cm^2.

3. Alpha particle range in cm of air at 1 atmosphere

$R_a = 0.56\ E\ (E < 4\ MeV)$

$R_a = 1.24\ E - 2.62\ (E > 4\ MeV)$

Alpha particles lose about 60KeV of energy per mm of air at 1 atmosphere.

RULES OF THUMB FOR ALPHA PARTICLES

4. Detector window thicknesses cause alpha particles to lose energy at about 1 MeV per mg/cm^2 of window thickness. Therefore, a detector with a window thickness of 3 mg/cm^2 (such as sealed gas-proportional pancake alpha/beta detectors and pancake GM detectors) will not detect alpha emitters of less than 3 MeV . These detectors will have very low efficiency for low energy alpha particles or attenuated alpha particles.

5. Air proportional alpha particles have a flatter energy vs efficiency response than gas-proportional or GM detectors.

6. **Half-value thickness vs alpha energy**

A. For surface alpha contamination first determine an unshielded net count rate (subtract background) with your instrument.

B. Place a sheet of mylar between the source and the detector and take another net reading. Some typical thickness of mylar are 0.29, 0.45, 0.85, and 0.9 mg/cm^2.

C. Calculate the half-value density thickness by using this formula.

$$mg / cm^2 = \frac{mg / cm^2 \text{ of the mylar } \times -0.693}{\ln(\text{shielded net count rate / unshielded net count rate})}$$

Note: make sure to take the natural log of the count rates

D. Approximate the alpha energy in MeV by using this formula.

$MeV = 4.5 \times \sqrt{\text{thickness from 'C'}}$

RULES OF THUMB FOR BETA PARTICLES

1. Beta particles of at least 70 keV energy are required to penetrate the nominal protective layer of the skin (7 mg / cm^2 or 0.07mm).
2. The average energy of a beta-ray spectrum is approximately one-third the maximum energy.
3. The range of beta particles in air is ~ 12 ft / MeV.
4. The range of beta particles (or electrons) in grams / cm^2 (thickness in cm multiplied by the density in grams / cm^3) is approximately half the maximum energy in MeV. This rule overestimates the range for low energies (0.5 MeV) and low atomic numbers, and underestimates for high energies and high atomic numbers.
5. The dose rate in rads per hour in an infinite medium uniformly contaminated by a beta emitter is 2.12 EC / ρ where E is the average beta energy per disintegration in MeV, C is the concentration in μCi / cm^3, and ρ is the density of the medium in grams/cm^3. The dose rate at the surface of the mass is one half the value given by this relation. In such a large mass, the relative beta and gamma dose rates are in the ratio of the average energies released per disintegration.
6. The surface dose rate through 7 mg / cm^2 from a uniform thin deposition of 1 μCi / cm^2 is about 9 rads / h for energies above about 0.6 MeV. Note that in a thin layer, the beta dose rate exceeds the gamma dose rate, for equal energies released, by about a factor of 100.
7. The bremsstrahlung from a 1 Ci P^{32} aqueous solution in a glass bottle is ~ 3 mrad / h at 1 m.
8. For a Sr^{90} / Y^{90} source greater than 10 cm in diameter, a reading of 0.1 mR / h on a portable Geiger counter with the window open corresponds to a contamination level of 3.5 E-5 μCi / cm^2 (6.9 E-2 μCi total). For a small source with a diameter of 0.75 cm, the same reading corresponds to 3.5 E-3 μCi / cm^2 (1.5 E-3 μCi total).

RULES OF THUMB FOR BETA PARTICLES

9. Half-value thickness vs beta energy

Isotope	ß max energy (KeV)	Half-Value Thickness
Tc^{99}	292	7.5 mg / cm^2
Cl^{36}	714	15 mg / cm^2
Sr^{90} / Y^{90}	546 / 2270	50 mg / cm^2
U^{238} Betas from short lived progeny	191 / 2290	130 mg / cm^2

A. For surface beta contamination first determine an unshielded net count rate (subtract background) with your instrument.

B. Place one sheet of this notebook paper between the source and the detector and take another net reading.

(1) A single sheet of paper will stop all alpha particles and some low energy beta particles. If the new net count rate is zero, then the contamination is alpha only and/or a very low energy beta such as C^{14}.

(2) The single sheet of paper will reduce the count rate from a 400 KeV beta particle by approximately one-half.

C. Continue adding layers of paper between the source of contamination and the detector until the net count rate is less than one-half of the unshielded net count rate.

D. Multiply the number of pages used for shielding by 7.5. This is the total half-value thickness in mg / cm^2.

E. If you are unable to decrease the net count rate to one-half, then use this formula to estimate the half-value thickness.

$$\text{mg / cm}^2 = \frac{7.5 \times \#\text{ of sheets of paper} \times -0.693}{\ln(\text{shielded net count rate / unshielded net count rate})}$$

F. Approximate the beta energy in KeV by using this formula.

$$\text{KeV} = 250 \times \sqrt{\text{thickness from ‘D’ or “E’ above}} - 300$$

RULES OF THUMB FOR GAMMA RAYS

1. For point sources with energies between 0.07 and 4 MeV, the exposure rate in roentgens per hour at 1 ft is given within 20% by 6 CEN, where C is the number of curies, E is the average gamma energy per disintegration in MeV, & N is the γ abundance.

2. The dose rate 1 m above a flat, infinite plane contaminated with a thin layer (1 Ci / m^2) of gamma emitters is:

Energy (MeV)	Dose rate (Rads / h)
0.4	7.2
0.6	10
0.8	13
1.0	16
1.2	19

3. The dose rate to tissue in rads per hour in an infinite medium uniformly contaminated by a gamma emitter is 2.12 EC / ρ, where C is the number of microcuries per cubic centimeter, E is the average gamma energy per disintegration in MeV, and ρ is the density of the medium. At the surface of a large body, the dose rate is about half of this. At ground level (one-half of an infinite cloud), the dose rate from a uniformly contaminated atmosphere is 1600 EC rads/h per μCi / cm^3.

4. The radiation scattered from the air (skyshine) from a 100 Ci ^{60}Co source 1 ft behind a 4-ft-high shield is ~ 100 mR / h at 6 in. from the outside of the shield.

RULES OF THUMB FOR NEUTRONS

The number of neutrons per square centimeter per second at a distance R from a small source emitting Q neutrons per second without shielding is given by;

$$\frac{n}{cm^2\text{-sec}} = \frac{Q}{4\pi R^2} = \frac{0.08Q}{R^2}$$

For α, η neutron sources:

Q (neutrons per million alpha particles) = $0.152E^{3.65}$

Where E is the alpha particle energy in MeV

This holds true for Be targets; multiply by 0.16 for B targets, multiply by 0.05 for F targets.

APPROXIMATE NEUTRON ENERGIES

cold neutrons	0 - 0.025 eV
thermal neutrons	0.025 eV
epithermal neutrons	0.025 - 0.4 eV
cadmium neutrons	0.4 - 0.6 eV
epicadmium neutrons	0.6 - 1 eV
slow neutrons	1 eV - 10 eV
resonance neutrons	10 eV - 300 eV
intermediate neutrons	300 eV - 1 MeV
fast neutrons	1 MeV - 20 MeV
relativistic neutrons	>20 MeV

Note: A thermal neutron is one which has the same energy and moves at the same velocity as a gas molecule does at a temperature of 20 degrees C. The velocity of a thermal neutron is 2200 m/sec (~5,000 mph).

CRITICALITY BADGE NEUTRON RESPONSE

Indium	$\Rightarrow$	thermal & 1.5 eV
Gold	$\Rightarrow$	thermal & 5 eV
Indium	$\Rightarrow$	1 MeV threshold
Sulphur	$\Rightarrow$	2.9 MeV threshold
Copper	$\Rightarrow$	11.4 MeV threshold

RULES OF THUMB FOR NEUTRONS

a, h sources	h energy in MeV	neutrons per million a decays
$Pu^{239}Be$	4.5	61
$Po^{210}Be$	4.2	71
$Pu^{238}Be$	4.5	79
$Am^{241}Be$	4.5	76
$Cm^{244}Be$	4	100
$Cm^{242}Be$	4	112
$Ra^{226}Be$	spectrum, 4, 5	502
$Ac^{227}Be$	multiple, 4.6	702
$Am^{241}B$		13
$Am^{241}F$		4.1
$Am^{241}Li$	0.7	1.4
$Po^{210}Li$	0.48	1.2
$Po^{210}B$	2.5	10
$Po^{210}F$	0.42	3
$Pu^{238}C^{13}$		11
$Ra^{226}B$	3.0	80

neutron yield is the average of calculated and experimental

$Cm^{244}Be$ does not include neutrons from spontaneous fission

Ra^{226} and Ac^{227} include progeny effects

Spontaneous fission	h/sec/g
Cm^{244}	1.2E7
Cf^{252}	2.3E12
Pu^{239}	0.03
Am^{241}	0.6
Bk^{249}	2.7E5

MISCELLANEOUS RULES OF THUMB

1. One watt of power in a reactor requires 3.1 E10 fissions per second. In a reactor operating for more than 4 days, the total fission products are about 3 Ci / watt at 1.5 min after shutdown. At 2 yr after shutdown, the fission products are approximately 75 Ci / MW-day.

2. The quantity of a short-lived fission product in a reactor which has been operated about four times as long as the half-life is given by;

$$Ci = 3.7\ E10\ (FY)(PL) / 3.7\ E10 \approx (FY)(PL),$$

where FY is the fission yield (%/100) and PL is the power level in watts.

3. The correction factor for unsealed ion chambers to standard temperatures and pressures (0^0C and 760 mm of Hg) is;

$$f = (t + 273) / (273) \times (760 / P) = 2.78(t + 273) / P,$$

where t is the temperature in degrees C and P is the barometric pressure in mm of Hg.

4. The activity of an isotope (without radioactive daughter) is reduced to less than 1% after seven half-lives.

5. Uranium Enrichment by % by Weight

	Typical		Enriched		
	Natural	Commercial	10%	20%	Depleted
U^{238}	99.2739	97.01	89.87	79.68	99.75
U^{235}	0.7204	2.96	10.0	20.0	0.25
U^{234}	0.0057	0.03	0.13	0.32	0.0005

Uranium Enrichment by % by Activity

	Typical		Enriched		
	Natural	Commercial	10%	20%	Depleted
U^{238}	48.72	14.92	3.57	1.31	90.33
U^{235}	2.32	3.02	2.55	2.09	1.49
U^{234}	48.96	82.06	93.88	96.60	8.18

UNITS AND TERMINOLOGY

	"Special Units"	SI Units
Exposure	Roentgen	Coulombs / kg
Dose	rad (0.01 Gy)	Gray (100 rad)
Dose Equiv	rem (0.01 Sv)	Sievert (100 rem)
Activity	Curie (2.22 E12dpm)	Becquerel(1dps)

1 Roentgen	=	2.58 E-4 coulomb / kg in air
	=	1 esu / cm^3 in air
1 rad	=	100 ergs / gm in any absorber
1 Gray	=	10,000 ergs / gm in any absorber
1 rem	=	1 rad x QF = 0.01 Sv
H	=	DQN (from ICRP 26)
H (Dose Equiv.)	=	D (absorbed dose) x Q (quality factor) x N (any other modifying factors)

DEFINITIONS

Acute	any dose in a short period of time
Chronic	any dose in a long period of time
Somatic	effects in the exposed individual
Genetic	effects in the offspring of the exposed individual
Teratogenic	effects in the exposed unborn embryo/fetus
Stochastic	effects for which a probability exists and increases with increasing dose
Non-Stochastic (deterministic)	effects for which a threshold exists – effects do not occur below the threshold (examples; cataracts, erythema, epilation, acute radiation syndrome)

RADIATION INTERACTIONS

Charged Particles

Ionization, Excitation, *Bremsstrahlung* (β^-), Annihilation (β^+)

Neutrons

Scattering (E > 0.025 eV)

Elastic (energy and momentum are conserved)

Inelastic (photon emitted)

Absorption ($E \leq 0.025$ eV)

Radiative Capture (n, γ)

Particle Emission (n, a) (n, p) (n, n)

Fission (n, f)

Gamma or X-ray photons

Photoelectric Effect (generally $\leq$ 1 MeV)

Compton Scattering (generally 200 keV - 5 MeV)

Pair Production (minimum 1.022 MeV)

Scattered Photon

$T' = T / [1 + T(1 - \cos\theta) / m_0c^2]$

where c^2 = 931.5 MeV / amu

Energy Calculation

m = mass of electron = 5.4858 E-4 amu

Fraction of Energy Lost by Electrons through *Bremsstrahlung* in a medium

$f = 0.0007\ Z\ T_e$

where; T_e = K. E. of electron, Z = atomic #

Photon Attenuation: $I_x = I_0 e^{\mu x}$

Interaction Probability per gram:

Photoelectric $\propto$ Z^3 / E^3

Compton independent of Z

Pair Production $\propto$ Z^1

$\mu_{Total} = \mu_{pe} + \mu_{cs} + \mu_{cc}$

W_{Air} = 33.9 eV per ion pair

Specific Ionization = S/W (i.p. / cm)

PUBLIC RADIATION DOSES

Average per capita US Dose	200 mrem / yr
Living in Los Alamos	327 mrem / yr
Flying from NY to LA	2.5 mrem / trip
Chest x-ray	10 mrem / exam
Full mouth dental x-ray	9 mrem / exam

The external dose rate for cosmic rays doubles for each mile increase in elevation.

BACKGROUND RADIATION

Cosmic	=	28 mrem / yr
Rocks	=	28 mrem / yr
Internal	=	36 mrem / yr
Medical x-rays	=	20 to 30 mrem / yr
Nuclear medicine	=	2 mrem / yr
TOTAL US Ave	≈	120 mrem / yr
US Ave H_E from radon	=	200 mrem / yr

Ave H_E from medical x-ray procedures (in mrem per exam):

Skull 20, Upper GI 245, Hip 65, Chest 6, Kidney 55, Dental 54.5

NATURALLY OCCURRING RADIONUCLIDES

Primordial	Cosmogenic
K^{40}	Tritium
Rb^{87}	Be^{7}
Natural U and Th	C^{14}

Comparative Risks of Radiation Exposure

Health Risk		Estimated Days of Life Lost
Smoking 1 pack of cigarettes / day		2370 days
20% overweight		985 days
Average US alcohol consumption		130 days
Home accidents		95 days
Occupational exposure	• 5.0 rem / year	32 days
	• 0.5 rem / year	3 days

RADON FACTS

1 working level	=	3 DAC Rn^{222} (including progeny)
	=	1.3 E5 MeV / liter of air a energy
	=	100 pCi / liter (1 E-7 µCi / ml)
1 working level-month	=	1 rem CEDE

EPA ACTION LEVELS FOR RESIDENCES

Concentration (pCi/L)	Sampling frequency
0 - 4	initial & no follow-up
4 - 20	one year & follow-up
20 - 200	3 month & follow-up
>200	implement radon reduction methods

Wells > 25 residences,

must implement radon reduction method at water concentrations > 300 pCi / L

4 pCi / L in typical living area ≈ 1.03 working level-month ≈ 1 rem

10,000 pCi / L in water ≈ 1pCi / L in air thru evaporation

BIOLOGICAL EFFECTS OF RADIATION

Radiosensitivity Criteria	Rate of Reproduction
	Age
	Degree of Specialization

Acute Radiation Effects

25 - 100 rad	Subclinical range, minor blood chemistry changes
100 - 200 rad	White blood cell (leukocyte) loss
> 250 rad	Acute Radiation Syndrome (Nausea, Chills, Epilation, Erythema)
> 350 rad	Hematopoietic Syndrome (Decrease in red blood cell production)
450 rad	LD 50 / 60
> 600 rad	Gastrointestinal Syndrome (Death of epithelial cells, Blood infection, Fluid loss)
1000 rad	LD 100 / 60
> 1000 rad	Central Nervous System Syndrome

Radiation Dose Risk

Report	Additional Cancer Deaths
BEIR III, 1980 (also Reg Guide 8.29)	3 in 10,000 per 1 rem
BEIR V, 1990	800 in 100,000 per 10 rad

RADIATION BIOLOGY

Relative Biological Effect $= \dfrac{\text{Dose of 250 kVp x-rays}}{\text{Dose of other radiation}}$

Maximum survivable dose ≈ 1000 rem

Cancer mortality rate ≈ 900 excess deaths per 100,000 persons at 0.1 Sv

DOSIMETRY

1 Bq	=	1 dps	=	2.7 E-11 Ci
1 Gy	=	1 joule / kg	=	100 rads
H_T(Sv)	=	D(Gy) x Q (Sv / Gy)		

Quality Factors (Q) values:

x-rays, beta, gamma		=	1
neutrons:	thermal	=	2
	fast	=	10
alpha		=	20

Effective Dose Equivalent EDE = H_E = $\Sigma W_T H_T$

W_T values: gonads 2.5, breast 0.15, red marrow 0.12, lung 0.12, thyroid 0.03, bone surface 0.03, remainder 0.3

D.E. rate (Sv / hr)= 0.15 A(TBq)E / r^2

Neutron flux to dose rate conversion:

Fast: 1 mrem / hr per 6 n / cm^2-sec

Slow: 1 mrem / hr per 272 n / cm^2-sec

DOSE EQUIVALENT CALCULATIONS

1 Roentgen	=	2.58E-4C / kg	or	1 esu / cm^3
	=	87 ergs / g	or	2.082 E9 ip / cm^3
	=	7.02 E4 MeV / cm^3 in air @ STP		
or	=	98 ergs / g in tissue		
1 R/hr	~	1 E-13 Amperes / cm^3		
1 rad	=	100 ergs / g in any absorber		
ρ_{air}	=	0.001293 g / cm^3		
W_{air}	=	33.7 eV		
1 Ampere	=	1Coulomb / sec		
STP_{air}	=	760mm Hg @ 0^0C	or	14.7lb / in^2 @ 32^0 F

INTERNAL DOSIMETRY

Calculating CDE ICRP 26/30

CDE	=	I / nALI x 50 rem
CDE	=	50 yr committed dose equivalent to irradiated tissue
I	=	Intake
nALI	=	non-stochastic ALI = 50 rem / h_{max}
h_{max}	=	greatest dose equivalent found in the exposure-to-dose conversion tables

Calculating CEDE

CEDE	=	I / sALI x 5 rem
CEDE	=	50 yr committed effective dose equivalent
I	=	Intake
OR CEDE	=	$\Sigma^{n}_{i=1} W_T$
CEDE	=	50 yr committed effective dose equivalent to individual tissue
W_T	=	tissue weighting factor

Calculating DAC

DAC	=	ALI / 2000 hr x 1.2 E6 ml / hr
1 DAC	=	2.5 mrem CEDE if based on sALI **OR** 25 mrem (ICRP 26) CDE to an organ or tissue if based on nALI

Calculating DAC-hours

DAC Fraction	=	Σ_i(concentration / DAC) / PF
DAC fraction x time (hours)	=	DAC-hours

INTERNAL DOSIMETRY

Intake I(Bq)	=	A_t(Bq) / IRF_t
Body burden q_t	=	$q_0 e^{-\lambda_{eff} t}$
CEDE or H_{50}	=	50 mSv x I / ALI
TEDE	=	CEDE + Deep Dose Equivalent

INTERNAL DOSIMETRY

Effective Half-Life

$t_{eff} = t_r \times t_b / (t_r + t_b)$

where; t_r = radioactive half-life

t_b = biological half-life

Effective Removal Constant

$\lambda_{eff} = \lambda_r + \lambda_b$

where; λ_r = decay constant = 0.693 / $t_{½}$

λ_b = biological removal constant - 0.693 / t_b

Calculating Internal Dose (ICRP 30)

$H_{50}(T \leftarrow S) = (1.6E\text{-}10) U_S \, SEE(T \leftarrow S)$

H_{50} = 50 year dose equivalent commitment in sieverts

Where; SEE is the Specific Effective Energy modified by a quality factor for radiation absorbed in the target organ (T) for each transformation in the source organ (S) expressed in MeV/g.

$SEE = \Sigma Y \bullet E \bullet AF \bullet Q / M_T$

Where;

Y	=	yield of radiations per transformation
E	=	average energy of the radiation
AF	=	absorbed fraction of energy absorbed in the target organ (T) per emission of radiation in the source organ (S)
Q	=	quality factor
M_T	=	mass of the target organ
U_S	=	number of nuclear transformations in the source organ (S) during the time interval for which the dose is to be calculated

EQUIVALENT DOSE, EFFECTIVE DOSE, AND COMMITTED EFFECTIVE DOSE

ICRP 60 Equivalent Dose

$H_T = \Sigma_R W_R D_{T,R}$

H_T = equivalent dose in tissue T

W_R = radiation weighting factor

$D_{T,R}$ = absorbed dose averaged over tissue T due to radiation R

ICRP 60 Effective Dose

$E = \Sigma_T W_T H_T$

E = effective dose to the individual

W_T = tissue weighting factor

H_T = equivalent dose in tissue(s) T

ICRP 60 Committed Effective Dose

$$E(50) = \Sigma^{T=j}_{T=I} W_T H_T(50) + W_{remainder} \frac{\Sigma^{T=1}_{T=K} m_T H_T(50)}{\Sigma^{T=1}_{T=K} m_T}$$

E(50) = committed effective dose

W_T = tissue weighting factor for tissues and organs T_i to T_j

m_T = mass of the remainder tissues T_K to T_1

$W_{remainder}$ = 0.05 (the W_T assigned to the remainder tissues)

ICRP 23 REFERENCE MAN

Daily Water Intake = 2.2 liters / day

Breathing Rate = 2 E4 ml / min

There are approximately 10^{13} cells in the human body.

There are 140 g of potassium in standard man, 125 nCi is K^{40} which results in 0.25 mrem/wk (13 mrem/yr) to the whole body. An additional 15 mrem/yr will occur when using a salt substitute.

RADIATION WEIGHTING FACTORS[1] (ICRP 60)

Type and Energy Range[2]	Radiation Weighting Factor, W_R
Photons, all energies	1
Electrons and muons, all energies[3]	1
Neutrons, <10 keV	5
10 keV to 100 kev	10
100 keV to 2 MeV	20
2 MeV to 20 MeV	10
> 20 MeV	5
Protons, other than recoil protons, energy >2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

[1] All values relate to the radiation incident on the body or, for internal sources, emitted from the source.

[2] The choice of values for other radiation is discussed in Annex A of Publication 60.

[3] Excluding Auger electrons emitted from nuclei bound to DNA.

ICRP 60 Tissue Weighting Factors

Tissue or organ	Tissue weighting factor, W_T
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05

CALCULATING TODE AND TEDE

$$TEDE = DDE + CEDE$$

$$TODE = DDE + CDE$$

TEDE	=	total effective dose equivalent
TODE	=	total organ dose equivalent
DDE	=	deep dose equivalent
CDE	=	50 year committed dose equivalent to a tissue or organ
CEDE	=	50 year committed effective dose equivalent

DOSE EQUIVALENT LIMITS & POSTING REQUIREMENTS (10CFR20 & 10CFR835)

Dose Equivalent	Annual Limit (rem)
TEDE	5
TODE	50
LDE	15
SDE,WB	50
SDE, ME	50
TEDE (general public)	0.1

DOSE EQUIVALENT MEASUREMENT

Abbreviations from USNRC Reg. Guide 8.7

	Measurement Depth for External Sources (cm)	Density Thickness (mg / cm^2)
TEDE	1	1000
TODE	1	1000
LDE	0.3	300
SDE, WB[1]	0.007	7
SDE, ME[2]	0.007	7

[1] SDE, WB is the shallow dose equivalent to the skin of the whole body.

[2] SDE, ME the shallow dose equivalent to a major extremity.

EFFECTS OF RADIATION EXPOSURE

Gastro-Intestinal radiation syndrome: pathophysiology from gastro-intestinal syndrome is of greater consequence from exposure to neutron radiation fields than the hematopoetic syndrome.

Note: RBE (GI syndrome, neutron rad) = 2.4

The sooner the onset of vomiting and/or diarrhea the higher the expected dose.

γ, x-ray absorbed dose LD_{50} (rad)	acute effects	approximate time to onset
10,000 - 15,000	neuro-vascular	hours
500 - 1,200	GI	days
250 - 500	hematopoetic	weeks

Plutonium Exposure – Acute Effects

0.1 to 0.9 μCi/g Pu^{239} in lung tissue caused acute-fatal effects in dogs 55 to 412 days post-exposure. Lung doses were on the order of 4,000 to 14,000 rad.

Table of the Elements

Z#	Element	Symbol	Z#	Element	Symbol
89	Actinium	Ac	63	Europium	Eu
13	Aluminum	Al	100	Fermium	Fm
95	Americium	Am	9	Fluorine	F
51	Antimony	Sb	87	Francium	Fr
18	Argon	Ar	64	Gadolinium	Gd
33	Arsenic	As	31	Gallium	Ga
85	Astatine	At	32	Germanium	Ge
56	Barium	Ba	79	Gold	Au
97	Berkelium	Bk	72	Hafnium	Hf
4	Beryllium	Be	105	Hahnium	Ha
83	Bismuth	Bi	2	Helium	He
5	Boron	B	67	Holmium	Ho
35	Bromine	Br	1	Hydrogen	H
48	Cadmium	Cd	49	Indium	In
20	Calcium	Ca	53	Iodine	I
98	Californium	Cf	77	Iridium	Ir
6	Carbon	C	26	Iron	Fe
58	Cerium	Ce	36	Krypton	Kr
55	Cesium	Cs	57	Lanthanum	La
17	Chlorine	Cl	103	Lawrencium	Lr
24	Chromium	Cr	82	Lead	Pb
27	Cobalt	Co	3	Lithium	Li
29	Copper	Cu	71	Lutetium	Lu
96	Curium	Cm	12	Magnesium	Mg
66	Dysprosium	Dy	25	Manganese	Mn
99	Einsteinium	Es	101	Mendelevium	Mv
68	Erbium	Er			

Table of the Elements

Z#	Element	Symbol	Z#	Element	Symbol
80	Mercury	Hg	62	Samarium	Sm
42	Molybdenum	Mo	21	Scandium	Sc
60	Neodymium	Nd	106	Seaborgium	Sg
10	Neon	Ne	34	Selenium	Se
93	Neptunium	Np	14	Silicon	Si
28	Nickel	Ni	47	Silver	Ag
41	Niobium	Nb	11	Sodium	Na
7	Nitrogen	N	38	Strontium	Sr
102	Nobelium	No	16	Sulfur	S
76	Osmium	Os	73	Tantalum	Ta
8	Oxygen	O	43	Technetium	Tc
46	Palladium	Pd	52	Tellurium	Te
15	Phosphorus	P	65	Terbium	Tb
78	Platinum	Pt	81	Thallium	Tl
94	Plutonium	Pu	90	Thorium	Th
84	Polonium	Po	69	Thulium	Tm
19	Potassium	K	50	Tin	Sn
59	Praseodymium	Pr	22	Titanium	Ti
61	Promethium	Pm	74	Tungsten	W
91	Protactinium	Pa	92	Uranium	U
88	Radium	Ra	23	Vanadium	V
86	Radon	Rn	54	Xenon	Xe
75	Rhenium	Re	70	Ytterbium	Yb
45	Rhodium	Rh	39	Yttrium	Y
37	Rubidium	Rb	30	Zinc	Zn
44	Ruthenium	Ru	40	Zirconium	Zr
104	Rutherfordium	Rf			

Relative locations of the Products of Various Nuclear Processes

			He^3 in	α in
	β^- out	p in	d in	t in
	η out	Original Nucleus	η in	
t out	d out	p out	β^+ ε out	
α out	He^3 out			

η neutron
p proton
d deuteron
t triton
α alpha
β^- beta
β^+ positron
ε electron capture

Use this chart along with the Table of the Elements to determine the progeny (and ancestor) of an isotope.

For example; we know Pu-238 is an alpha emitter. The alpha decay mode tells us the mass # decreases by 4 (238 goes to 234) and the Z # decreases by two (94 goes to 92). The element with a Z # of 92 is Uranium. Pu-238 decays to U-234.

As another example; we know Cl-36 is a beta emitter. The beta decay mode tells us the mass # stays the same and the Z # increases by one (16 goes to 17). The element with a Z # of 17 is Argon. Cl-36 decays to Ar-36.

RADIOACTIVITY

$_{Z}X^{A}$	Z	=	atomic # (number of protons)
	X	=	element
	A	=	mass # (number of protons and neutrons)

Decay Modes

Alpha	$_{Z}X^{A}$	$\rightarrow$	$_{Z-2}X^{A-4} + \alpha$
Beta Minus	$_{Z}X^{A}$	$\rightarrow$	$_{Z+1}X^{A} + \beta^{-}$
Beta Plus (Positron)	$_{Z}X^{A}$	$\rightarrow$	$_{Z-1}X^{A} + \beta^{+}$
Electron Capture	$_{Z}X^{A}$	$\rightarrow$	$_{Z-1}X^{A}$

Radioactive Decay Equation is; $A_t = A_o e^{-\lambda t}$

Where; A_t is the activity at the end of time 't'

A_o is the activity at the beginning

λ is 0.693 divided by the half-life

t is the decay time

REPORTING RADIOLOGICAL DATA

For Minimum Detectable Activity (MDA)

$$MDA = \frac{k^2 + 2k\sqrt{R_B \times t_{S+B} \times Eff \times (1 + t_{S+B} / t_B)}}{t_{S+B} \times Eff}$$

k (for 95%)	=	1.645
t_{S+B}	=	sample count time
t_B	=	background count time
R_B	=	background count rate
Eff	=	efficiency of the detector (expressed as a decimal)
R_{S+B}	=	sample count rate

MDA when background and sample count times are one minute and background is displayed in DPM.

$$MDA = \frac{2.71 + 4.65\sqrt{R_B \times Eff}}{Eff}$$

MDA when background count time is ten minutes and sample count time is one minute and background is displayed in DPM.

$$MDA = \frac{2.71 + 3.45\sqrt{R_B \times Eff}}{Eff}$$

MDA when background and sample count times are one minute and background is displayed in CPM.

$$MDA = \frac{2.71 + 4.65\sqrt{R_B}}{Eff}$$

MDA when background count time is ten minutes and sample count time is one minute and background is displayed in CPM.

$$MDA = \frac{2.71 + 3.45\sqrt{R_B}}{Eff}$$

Surface Contamination Correction Factors for Probe Area

The contamination reporting requirements in 10CFR835 call for survey results to be stated as dpm/100cm^2 **or as dpm per surface area** for items or spots smaller than 100cm^2.

Detector surface areas may be; 1) smaller than 100cm^2, 2) exactly 100cm^2, or 3) larger than 100cm^2. Areas of contamination may be smaller than 100cm^2 , or exactly 100cm^2, or larger than 100cm^2. Use the following matrix to determine how to perform the probe surface area and contamination surface area correction factors.

1) Detector surface area smaller than 100 cm^2

A. For a probe with a surface area smaller than 100cm^2, no correction factor is needed for areas of contamination equal to the probe surface area (report the contamination as dpm per the probe surface area).

$$\text{DPM/probe cm}^2 = \text{Indicated DPM}$$

B. If the item or spot of contamination is smaller than the probe surface area, then report the contamination as the measured dpm per that surface area.

$$\text{DPM/spot cm}^2 = \frac{\text{Indicated DPM}}{\text{spot surface area}}$$

C. If the item or spot of contamination is equal to or greater than 100cm^2, then correct the measured dpm for probe surface area vs 100cm^2 and report the contamination as the corrected dpm per 100cm^2.

$$\text{DPM/100cm}^2 = \text{Indicated DPM} \times \frac{100\text{cm}^2}{\text{detector surface area}}$$

D. If the item or spot of contamination is larger than the probe surface area, but smaller than 100cm^2, then average the contamination over the surface area and report the contamination as the summed measured dpm per that surface area.

$$\text{DPM/spot cm}^2 = \text{Average DPM} \times \frac{\text{Spot Surface Area}}{\text{Detector Surface Area}}$$

Surface Contamination Correction Factors for Probe Area

2) Detector surface area exactly 100 cm^2

A. For a probe with a surface area of 100cm^2, no correction factor is needed for areas of contamination equal to or larger than 100cm^2.

$$DPM/100cm^2 = \text{Indicated DPM}$$

B. If the item or spot of contamination is smaller than 100cm^2, then report the contamination as the measured dpm per that surface area.

$$DPM/spot\ cm^2 = \frac{\text{Indicated DPM}}{\text{spot surface area}}$$

3) Detector surface area larger than 100 cm^2

A. For a probe with a surface area greater than 100cm^2, no correction factor is needed for areas of contamination of exactly 100cm^2.

$$DPM/100cm^2 = \text{Indicated DPM}$$

B. If the item or spot of contamination is smaller than 100cm^2, then report the contamination as the measured dpm per that surface area.

$$DPM/spot\ cm^2 = \frac{\text{Indicated DPM}}{\text{spot surface area}}$$

C. If the item or spot of contamination is greater than 100cm^2, then correct the measured dpm for probe surface area as 100cm^2 and report the contamination as the corrected dpm per 100cm^2.

$$DPM/100cm^2 = \text{Indicated DPM} \times \frac{100\ cm^2}{\text{Detector Surface Area}}$$

Detector Efficiency

Calculate the efficiency of a detector as follows.

Efficiency = CPM / DPM

Alpha to Beta Crosstalk

Alpha to beta crosstalk is that portion of counts from alpha particles that are detected as beta particles by a detector. It is usually expressed as a percentage.

Using an alpha source;

$$\alpha \text{ to } \beta \text{ crosstalk} = \frac{\text{counts detected as beta particles}}{\text{counts detected as alpha particles}}$$

Multiply by 100 to express the crosstalk as percent.

Beta to Alpha Crosstalk

Beta to alpha crosstalk is that portion of counts from beta particles that are detected as alpha particles by a detector. It is usually expressed as a percentage.

Using an alpha source;

$$\beta \text{ to } \alpha \text{ crosstalk} = \frac{\text{counts detected as alpha particles}}{\text{counts detected as beta particles}}$$

Multiply by 100 to express the crosstalk as percent.

Correction Factor for Alpha and Beta Energy vs Efficiency

If you are surveying for an isotope whose energy is different than what the instrument was calibrated with, then use a calibrated source with an energy similar to that being surveyed for;

CF (**C**orrection **F**actor) $= \frac{\text{Calibrated Source DPM}}{\text{DPM indicated by instrument}}$

Multiply your instrument indication by the calculated CF.

Inverse Square Law Calculation

The inverse square law provides a simple way to calculate the exposure from a point gamma source at different distances.

$\text{Exposure Rate}_1 \times D_1^2 \quad = \quad \text{Exposure Rate}_2 \times D_2^2$

where;

Exposure Rate_1	=	Measured (or known) exposure rate
D_1^2	=	Distance from source for the measured or known exposure rate
Exposure Rate_2	=	Exposure rate to be calculated
D_2^2	=	New distance from the source

Shallow Dose Correction Factor

In accordance with 10CFR835 deep dose equivalent will be used for posting. Shallow dose equivalent will be reported separate from deep dose equivalent. Deep dose equivalent is the sum of the gamma and neutron deep dose equivalents. Shallow dose includes low-energy photons and beta particles. Alpha particles are not included in shallow dose.

The need to report a shallow dose for a survey is determined by this equation;

If the Open Window Reading divided by the Closed Window Reading is equal to or greater than 1.2, then perform a shallow dose survey.

Calculate the shallow dose rate using this equation;

(Open Window Reading - Closed Window Reading) x **C**orrection **F**actor

Stay Time Calculation

Stay-time calculations are typically used to determine how long an individual can remain in an area with elevated radiation fields until they reach some pre-determined dose limit.

	Stay-time	=	Allowable exposure/exposure rate		
Example:	Stay-time	=	100 mR / 25 mR/hr	=	4 hours

Calculating Exposure Rate in an Air-Filled Ionization Chamber

$X = I / m[1 / (2.58E-4\ C / kg\text{-}R)]$

X = exposure rate R / sec)

I = current (amperes)

m = mass of air in chamber (kg)

Note: 1 ampere = 1 Coulomb / second

Calculating Percent Resolution of a Gamma Spectroscopy Detector

% R = FWHM / peak energy x 100 = percent resolution

where;

FWHM = peak width at full width half-max peak height (keV)

peak energy = photopeak energy of interest (keV)

Calculating True Count Rate Based on Resolving Time of a Gas-Filled Detector

$R_C = R_0 / (1 - R_0 Y)$

where;

R_C = true count rate

R_0 = observed count rate

Y = resolving time

CALCULATING SPECIFIC GAMMA-RAY CONSTANT (G) FOR SOURCE ACTIVITY (A)

$\Gamma = \varphi E\gamma(\mu_{en} / \rho)_{air} e / W$

where;

Γ = specific gamma constant (R-cm^2 / hr-A)

φ = photon fluence rate (γ / cm^2-hr)

$E\gamma$ = gamma photon energy (MeV)

(μ_{en} / ρ) = density thickness of air (g / cm^2)

e = electron charge (Coulombs)

W = average amount of energy to produce an ion pair in air (eV)

CALCULATING PHOTON FLUENCE RATE (j) FROM A POINT SOURCE

$\varphi = AY / 4\pi r^2$

where;

φ = photon fluence rate (γ / cm^2-hr)

A = source activity (decay per hr)

Y = photon yield (γ / decay)

r = distance from point source (cm)

CALCULATING EXPOSURE RATE (X) FROM A POINT SOURCE

X (R/hr) = $\Gamma A / r^2$

where;

Γ = specific gamma ray constant (R/hr @ 1 meter per Ci)

A = activity of source in curies

r = distance from source in meters

CALCULATING DOSE RATE TO AIR (D) FROM A POINT BETA SOURCE

$D = 300\ A / d^2$

where;

D = dose rate (rad / hr)

A = source activity in curies

d = distance from source in feet

CALCULATING EXPOSURE RATE (X) FROM A LINE SOURCE

Inside L / 2:	$X_1 (d_1)$	=	$X_2 (d_2)$
Outside L / 2:	$X_1 (d_1)^2$	=	$X_2 (d_2)^2$

where; d_1 = distance from source at location 1

d_2 = distance from source at location 2

L = length of line

Note that outside of L / 2 the equation is the same as the inverse square law.

OR

X (R/hr) = ΓA_L / R x $\tan^{-1}$(L / R)

where;

Γ	=	R/hr @ 1 meter per Ci
A_L	=	activity per unit length (curies per meter)
R	=	distance from line in meters
L	=	length of line in meters

CALCULATING EXPOSURE RATE (X) FROM A DISK SOURCE

X (R/hr) = $\pi A_a \Gamma$ x $\ln[(L^2 + R^2) / R^2]$

where;

Γ	=	R/hr @ 1 meter per Ci
A_a	=	activity per unit area (curies per sq. cm)
L	=	diameter of source surface in centimeters
R	=	distance from source surface in centimeters

6CEN

The 6CEN equation can be used to calculate the exposure rate in R/hr at one foot for x-ray and gamma radiation point sources with energies between 70 KeV and 2 MeV.

R/hr at 1 foot = 6CEN

where;

C	=	curies of radioactive material
E	=	photon energy in MeV
N	=	abundance of that photon (expressed as a decimal)

Calculating Airborne Radioactivity (long-lived)

C_S = R_N / (V x ε x SA x CE x CF)

where;

C_S	=	activity concentration at end of sample run time
R_N	=	net counting rate
V	=	sample volume
ε	=	detector efficiency
SA	=	self-absorption factor
CE	=	collection efficiency
CF	=	conversion from disintegrations per unit time to activity

Calculating Airborne Radioactivity (short-lived)

C_S = R_N / [V x ε x SA x CE x CF x (1-$e^{-\lambda ts}$) x ($e^{-\lambda td}$)

where;

t_s	=	sample count time
t_d	=	time elapsed between end of sample run time and start of sample count time

RESPIRATORY PROTECTION FACTORS (PF) 10CFR20

Device	Mode	Particulates	Vapors	PF
Air-purifying half-mask	D	Y	N	10
Air-purifying full-face	D	Y	N	50
Air-purifying full-face	PP	Y	N	1000
Supplied-air hood	PP	Y	Y	1000*
Supplied-air full-face	PP	Y	Y	2000
SCBA	D	Y	N	50
SCBA	PD	Y	Y	10,000

* 2000 for supplied-air hood if run at max flow rate with calibrated flow gauge.

Lung Deposition from ICRP 30

AMAD (μ)	NP (Naso-pharanx)	TB (Trachea-bronchus)	P (Lungs) Pulmonary
0.1	0.01	0.08	0.61
1	0.3	0.08	0.25
10	0.9	0.08	0.04

Air Monitoring

Concentration

Concentration is activity per volume of air and may be stated as dpm / cubic meter, µCi / ml, or Bq / cubic meter. DAC (**D**erived **A**ir **C**oncentration) is another way to express airborne radioactivity concentrations as relative hazards.

$$\text{DPM} = \frac{\text{Sample CPM}}{\text{Eff (CPM / DPM)}}$$

$$\mu\text{Ci} = 2.22\text{ E6 DPM}$$

$$1\text{ DPM / M}^3 = 4.5\text{ E-13 } \mu\text{Ci / ml}$$

$$1\ \mu\text{Ci / ml} = 2.22\text{ E12 DPM / M}^3$$

$$\text{Becquerel (Bq)} = \text{DPS}$$

$$\text{DPM / M}^3 = \frac{\text{CPM}}{\text{Eff (CPM / DPM) x total sample volume in M}^3}$$

$$\mu\text{Ci / ml} = \frac{\text{CPM}}{\text{Eff x 2.22 E6 DPM / } \mu\text{Ci x total sample volume in ml}}$$

$$\text{Bq / M}^3 = \frac{\text{CPM}}{\text{Eff x 60 DPM / Bq x total sample volume in M}^3}$$

$$\text{DAC} = \frac{\mu\text{Ci / ml}}{\mu\text{Ci / ml per DAC (DAC Factor)}}$$

CONCENTRATION, DAC, AND DAC-HR

To calculate concentration you need the CPM (or DPM) and the total air sample volume.

1. Divide the CPM by the efficiency (expressed as a decimal) to get DPM.

2. Divide the DPM by 2.22 E6 DPM / µCi to get µCi.

3. Multiply the air sampling rate by the sampling time to get the total air sample volume.

- **A.** For a FAS running for 1 week the total air sample volume is 168 hours times 2 CFM (cubic feet per minute).
- **B.** Multiply 168 hours times 60 minutes per hour times 2 CFM. This equals 20,160 cubic feet.
- **C.** Multiply the 20,160 cubic feet by 28,316 ml / cubic foot to get the total milliliters. This equals 5.7 E8 milliliters.
- **D.** Use a similar set of calculations for a Giraffe covering a job for a short period of time, obviously it would not be sampling for a full week, so the sample time might be 2 or 4 hours.

4. Divide the µCi by the sample volume to get concentration in µCi / ml.

5. Divide the µCi / ml by the DAC factor from 10CFR835 to get the concentration in numbers of DACs.

6. Multiply the numbers of DACs by the exposure time (how long a worker was in the area in hours) to get the DAC-HRs.

Example Calculations for Airborne Radioactivity

A Giraffe sampled the working area for 2 hours, sampling at 2 CFM. At the end of the job you sent the filter to the count lab and they identified 36 DPM of Pu^{239}. What was the concentration in µCi / ml, DPM / M^3, and DACs, and what are the DAC-HRs?

1. We divide the DPM from the count lab by 2.22 E6 DPM / µCi to get µCi.

36 DPM / 2.22 E6 DPM / mCi = 1.6 E-5 mCi

2. Multiply the air sampling rate by the sampling time to get the total air sample volume.

A. The Giraffe ran for 2 hours at 2 CFM. Multiply 2 hours times 60 minutes per hour times 2 CFM.

2 hours x 60 min / hr x 2 CFM = 240 cubic feet

B. Multiply the 240 cubic feet by 28,316 ml / cubic foot to get the total milliliters.

240 cubic feet x 28,316 ml / cubic foot = 6.8 E6 ml

C. Or, multiply the 240 cubic feet (CF) by 0.028316 cubic meters / cubic foot to get the total cubic meters (M^3).

240 cubic feet x 0.028316 M^3 / CF = 6.8 M^3

3. Divide the µCi by the sample volume to get concentration in µCi / ml.

1.6 E-5 mCi / 6.8 E6 ml = 2.4 E-12 mCi / ml

4. Or, divide the DPM by the sample volume in M^3 to get DPM / M^3.

36 DPM / 6.8M^3 = 5.3 DPM / M^3

5. Divide the µCi / ml by the DAC factor from 10CFR835 to get the concentration in numbers of DACs.

2.4 E-12 mCi / ml divided by 2 E-12 mCi / ml per DAC = 1.2 DAC

6. Multiply the numbers of DACs by the exposure time (how long a worker was in the area in hours) to get the DAC-HRs.

1.2 DAC times 2 hours = 2.4 DAC-HRs

SURFACE AREA CALCULATIONS

Triangle A (area) = ½ x b x h;

where b is the base and h is the height of the triangle (you don't need to know the length of the sides, just the base and the height)

Rectangle A (area) = a x b;

where a and b are the lengths of the sides

Parallelogram (a 4-sided figure with opposite sides parallel)

A (area) = a x h; or a x b x sin θ;

where a and b are the length of the sides, h is the altitude (or vertical height), and θ is the angle between the sides

Trapezoid (a 4-sided figure with two sides parallel)

A (area) = ½ x h (a + b);

where a and b are the length of the sides and h is the altitude

Regular polygon of *n* sides

A (area) = $1/4 \times n \times a^2 \times$ cotangent $(180^0 / n)$;

where a is the length of a side and *n* is the number of sides

Circle A (area) = $\pi \times r^2$; or $1/4 \times \pi \times d^2$;

where r is the radius and d is the diameter

Cube A (area) = $6 \times a^2$;

where a is the length of a side

Cylinder A (area) = $2 \times \pi \times r \times h$;

where r is the radius and h is the length of the height

Sphere A (area) = $4 \times \pi \times r^2$; or $\pi \times d^2$;

where r is the radius and d is the diameter

VOLUME CALCULATIONS

Cube V (volume) = a^3;
where a is the length of a side

Box V (volume) = w x l x h;
where w is the width, l is the length, and h is the height

Cylinder V (volume) = $\pi \times r^2 \times h$;
where r is the radius and h is the length of the height

Sphere V (volume) = $4/3 \times \pi \times r^3$;
where r is the radius
or V (volume) = $1/6 \times \pi \times d^3$;
where d is the diameter

Conversions

1 ml (milliliter)	=	1 cc (cubic centimeter or cm^3)
1000 ml	=	1 liter
1000 liters	=	1 cubic meter (M^3)
1 cubic foot (CF)	=	28.316 liters or 0.028316 M^3
1 M^3	=	35.315 CF

GAMMA AND NEUTRON HALF-VALUE LAYERS

Half-Value Layers in cm for Varying Photon Energies for Various Materials

	10 to 100 KeV	100 to 500 KeV	1 MeV
Concrete	6.56	10.83	12.05
Lead	0.03	0.50	1.31
DU	0.02	0.22	0.65
Tungsten	0.02	0.38	0.87
Steel / Iron	0.36	2.73	3.45
Tin	0.08	1.92	3.27
Aluminum	0.44	9.78	10.94
Water	23.83	26.15	28.71

	1 to 1.5 MeV	1.5 to 2 MeV	> 2 MeV
Concrete	13.64	14.41	19.65
Lead	1.88	2.12	2.62
DU	0.98	1.12	1.17
Tungsten	1.15	1.39	1.62
Steel / Iron	3.78	4.10	4.41
Tin	3.68	4.17	4.88
Aluminum	12.32	13.13	17.50
Water	31.07	31.88	57.75

These numbers were generated using NIST mass attenuation coefficients. Buildup is included.

HVL in centimeters for fast neutrons

Energy in MeV	1	5	10	15
Polyethylene	3.7	6.1	7.7	8.8
Water	4.3	6.9	8.8	10.1
Concrete	6.8	11	14	16
Damp soil	8.8	14.3	18.2	20.8

SHIELDING CALCULATIONS

CALCULATING NEUTRON SHIELD THICKNESSES

$$I = I_0 e^{-\sigma N x}$$

where; I = final neutron flux rate

I_0 = initial neutron flux rate

σ = shield cross section in square centimeters

N = number of atoms per cm^3 in the shield

x = shield thickness in centimeters

CALCULATING GAMMA SHIELD THICKNESSES

"Good Geometry" (narrow beam)

$$I = I_0 e^{-\mu x}$$

I = shielded exposure rate

I_0 = unshielded exposure rate

μ = linear attenuation coefficient

x = shield thickness

"Poor Geometry" (broad beam)

$$I = B \times I_0 e^{-\mu x} \quad \textbf{OR} \quad I_0 e^{-\mu en x}$$

B = buildup factor

μen = linear energy absorption coefficient

Half-Value Layer (HVL) = $\ln 2 / \mu$

Tenth-Value Layer (TVL) = $\ln 10 / \mu$

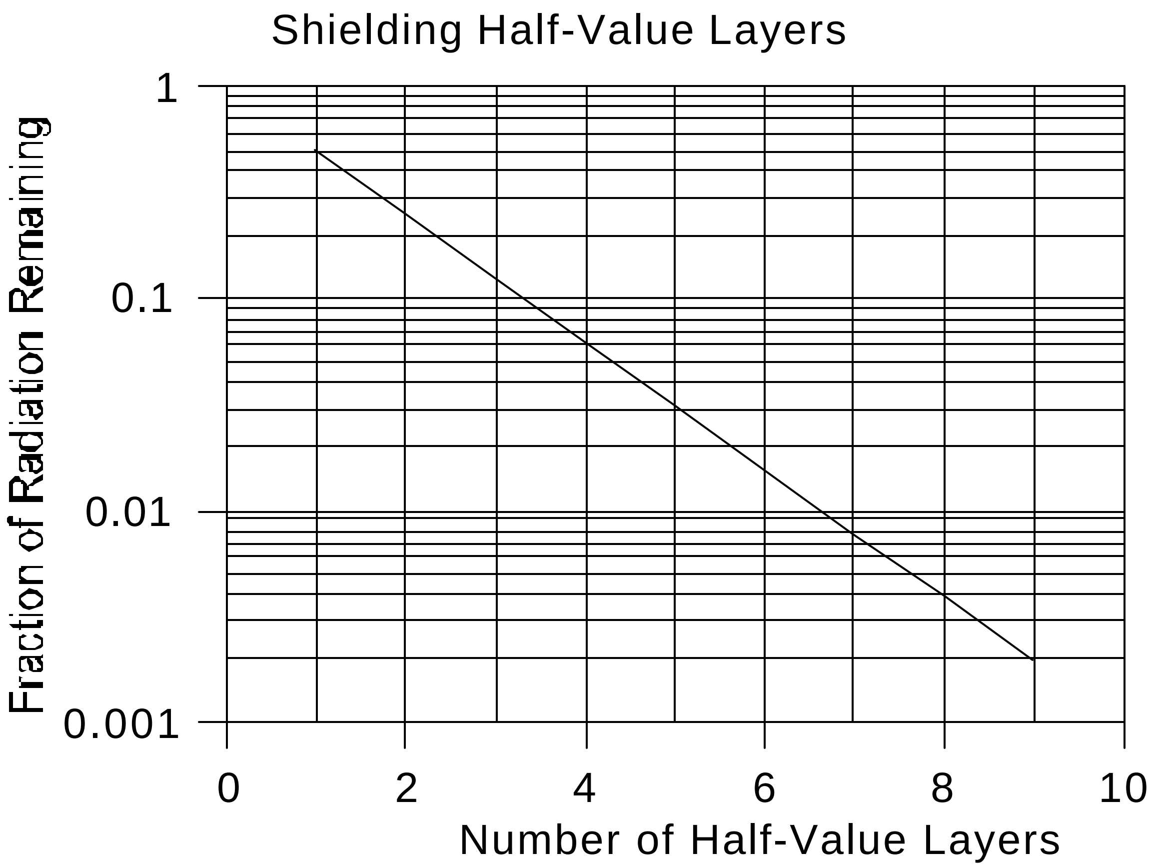
Transmission Factor (F) = I / I_0 **OR** $F = e^{-\mu x}$

BETA SHIELDING

Bremsstrahlung Fraction:

f = 3.5 (low Z) or 5 (high Z) $\times 10^{-4} Z E_{max}$

$Activity_{gamma}$ = $f \times Activity_{beta}$


Shielding Half-Value Layers
Fraction of Radiation Remaining
1
0.1
0.01
0.001
0
2
4
6
8
10
Number of Half-Value Layers

Gamma Shielding

How to use the graph.

Given: A Co^{60} source reading 120 mrem/hr at 30 cm
Find: the number of half-value layers to reduce the exposure rate to 5 mrem/hr at 30 cm

Divide 5 mrem/hr by 120 mrem/hr = 0.042

Locate 0.042 on the vertical axis and move across to where the slanted line crosses 0.042, then move vertically down to the “Number of Half-Value Layers” horizontal axis, this value is approximately 4.6

Pick a shielding material from page 47 and multiply the number of half-value layers by the cm thickness in the shielding table to obtain the thickness required.

Neutron Shielding

How to use the graph.
Given: A 5 MeV neutron source reading 12,000 n/cm^2-sec at 30 cm
Find: the number of half-value layers to reduce the flux rate to 200 n/cm^2-sec at 30 cm

Divide 200 n/cm^2-sec by 12,000 n/cm^2-sec = 0.0167

Locate 0.0167 on the vertical axis and move across to where the slanted line crosses 0.0167, then move vertically down to the “Number of Half-Value Layers” horizontal axis, this value is approximately 5.9

Pick a shielding material from page 47 and multiply the number of half-value layers by the cm thickness in the shielding table to obtain the thickness required.

Shielding Materials

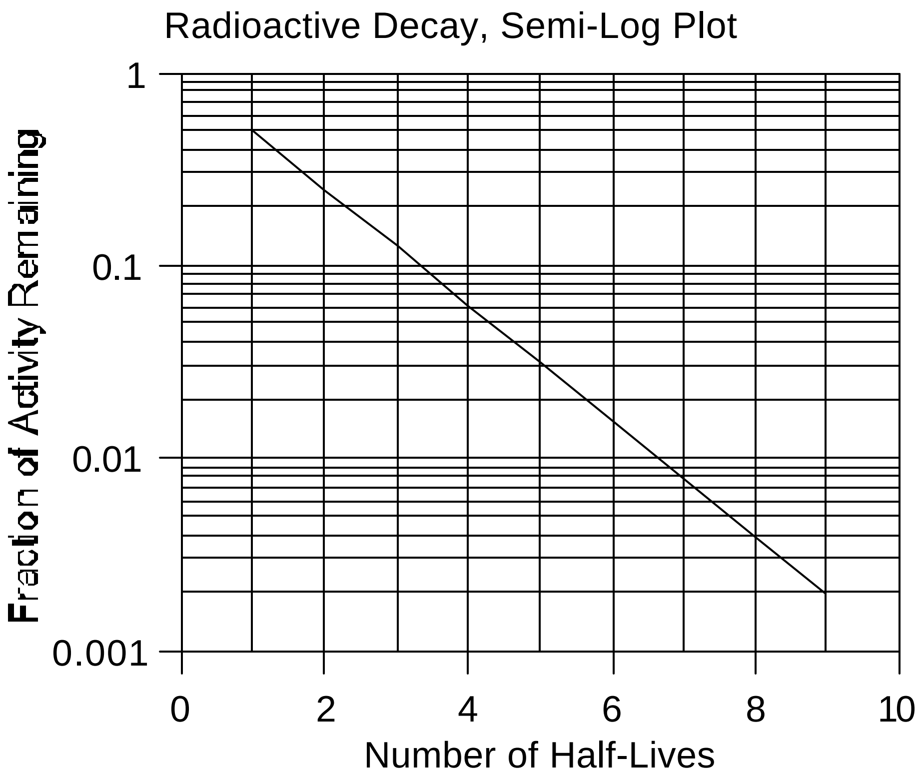
α	N/A
β^-	low Z, such as plastic or aluminum
γ	high Z, such as lead
mixed β^-/γ	low Z, then high Z
neutron	hydrogenous material to thermalize (such as polyethylene) then neutron absorber (such as Cd, B, Li, Hf), then high Z to absorb "capture gammas"

CALCULATING TRANSMISSION FACTOR (F) FOR SHIELDING AN X-RAY DEVICE

F	=	Pd^2/WUT (BCF)
P	=	permissible dose rate (mrem/wk)
d	=	distance to point of interest
W	=	workload (mA-min / wk)
U	=	use factor
T	=	occupancy factor
BCF	=	beam conversion factor R / $mA\text{-}m^2$)

DENSITY OF VARIOUS MATERIALS IN GRAMS PER CUBIC CENTIMETER

Snow (fresh)	0.2
Wood (cedar)	0.4
Wood (pine)	0.5
Wood (oak)	0.7
Paper	0.9
Polyethylene	0.9
Water	1.0
Rubber	1.1
Linoleum	1.2
Polycarbonate	1.2
PVC	1.3
Earth (packed)	1.5
Sandstone	2.2
Concrete	2.4
Aluminum	2.6
Glass	2.6
Granite	2.7
Limestone	2.7
Marble	2.7
Titanium	3.5
Iron	7.8
Steel	7.8
Bronze	8.2
Brass	8.4
Copper	8.8
Lead	11.4
Tungsten	19.6



Radioactive Decay Equation is; $A_t = A_o e^{-\lambda t}$

Example of how to use this graph.

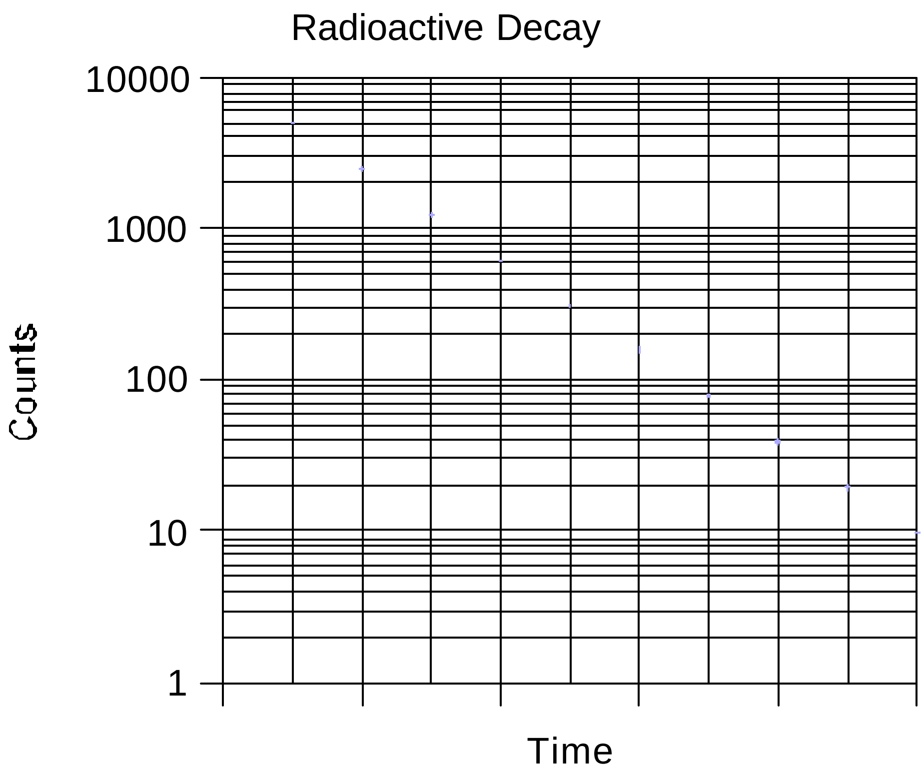
Given: 10 mCi of P^{32} with a half-life of 14.3 days

Find: the activity remaining after 125 days

Determine the number of half-lives during the decay by dividing 125 by 14.3 = 8.74

Locate 8.74 on the horizontal axis and move up to where the radioactive decay line crosses 8.74, then move horizontally to the “Fraction of Activity Remaining” vertical axis, this value is approximately 0.002

Multiply the original activity, 10 mCi, by 0.002; the activity remaining after 125 days is 0.02 mCi (20 µCi)



Example of how to use this graph.

Given: An unknown isotope

Find: the half-life of the isotope

Perform an initial net sample count, then recount the sample at regular intervals, perhaps every 10 minutes for a short-lived isotope.

Plot the sample counts on the vertical axis.

Draw a line connecting the sample counts. It should be a straight line, if it is not then it may be due to counting errors.

Find where the line crosses half the initial count and then go down to the horizontal axis, this is the half-life.

Table 1 of DOE 5400.5 and Appendix A of the LANL RPP

Surface Activity Guidelines

Allowable Total Residual Surface Contamination (dpm/100cm^2)

Radionuclides	Average	Maximum	Removable
Group 1: Transuranics, ^{125}I, ^{129}I, ^{227}Ac, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, ^{231}Pa	100	300	20
Group 2: Th-natural, ^{90}Sr, ^{126}I, ^{131}I, ^{133}I, ^{223}Ra, ^{224}Ra, ^{232}U, ^{232}Th	1,000	3,000	200
Group 3: U-natural, ^{235}U, ^{238}U, and associated decay products, alpha emitters	5,000	15,000	1,000
Group 4: Beta/gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr and others noted above	5,000	15,000	1,000
Tritium (applicable to surface and subsurface)	N/A	N/A	10,000

Appendix D of 10CFR835

Nuclide	Removable	Total (fixed + removable)
Natural U, ^{235}U, ^{238}U, and associated decay Products	1,000 alpha dpm/100 cm^2	5,000 alpha dpm/100 cm^2
Transuranics, ^{226}Ra, ^{228}Ra, ^{230}Th, ^{228}Th, ^{231}Pa, ^{227}Ac, ^{125}I, ^{129}I	20 dpm/100 cm^2	500 dpm/100 cm^2
Natural Th, ^{232}Th, ^{90}Sr, ^{223}Ra, ^{224}Ra, ^{232}U, ^{126}I, ^{131}I, ^{133}I	200 dpm/100 cm^2	1,000 dpm/100 cm^2
Beta/gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr and others noted above	1,000 beta/gamma dpm/100 cm^2	5,000 beta/gamma dpm/100 cm^2
Tritium organic compounds, surfaces contaminated by HT, HTO, and metal tritide aerosols	10,000 dpm/100 cm^2	10,000 dpm/100 cm^2

POSTING

Radiological Controlled Area (RCA)

Note: For areas where the potential exists for both internal dose and external dose, area designation must consider the total effective dose equivalent (TEDE).

RCA for external radiation - An individual is not expected to receive more than 0.1 rem during a year from external radiation.

RCA for contamination - A reasonable potential exists for contamination to occur at levels in excess of those specified in Appendix A,

or

An individual is not expected to receive more than 0.1 rem committed effective dose equivalent (CEDE) during a year from intakes.

RCA for DU shrapnel - DU exists as a result of explosive testing.

RCA for volume contamination - A reasonable potential exists for the presence of volume-contaminated materials that are not individually labeled.

Radiation Area

Any area where an individual could exceed a deep dose equivalent of 5 mrem in one hour at 30 cm from the source or the surface the radiation penetrates.

High Radiation Area

Any area where an individual could exceed a deep dose equivalent of 100 mrem in one hour at 30 cm from the source or the surface the radiation penetrates.

Very High Radiation Area

Any area where an individual could exceed a deep dose equivalent of 500 rad in one hour at 1 meter from the source or the surface the radiation penetrates.

POSTING

Contamination Area

Any area where removable contamination levels exceed or are likely to exceed those specified in Appendix A.

High Contamination Area

Any area where removable contamination levels exceed or are likely to exceed100 x those specified in Appendix A..

Airborne Radioactivity Area

Any area where airborne concentrations:

1) are > (or likely to exceed) the applicable DAC values,
   or
2) would result in an individual (without respiratory protection) being exposed to > 12 DAC-hours in a week.

Radioactive Materials Area

Accessible areas where items or containers of radioactive materials in quantities exceeding the values provided in Appendix 4A are used, handled, or stored.

INSTRUMENT USE

1. Select an instrument and / or detector appropriate for the isotope(s) to be surveyed for.
2. Check instrument and detector for a valid calibration sticker and for damage that would prevent it (them) from operating acceptably.
3. Check the battery condition.
4. Perform an operational (or performance) check.
5. Determine the isotope(s) correction factor to be applied to the detector.
6. Calculate the instrument's MDA.
7. Compare the instrument's MDA to the survey criteria.
8. If the instrument or detector do not meet all of the above criteria, then replace the instrument or detector (or change/charge the batteries) or change your survey technique so that the instrument's MDA will meet the survey criteria.
9. Perform and document the survey.

INSTRUMENT SELECTION

Exposure/Absorbed Dose Rates (photon)

Ion Chamber, Energy Compensated GM (above 40 keV), Tissue-Equivalent Plastic

Dose Equivalent Rates (neutron)

Boron Trifluoride Counter with polyethylene moderator, Neutron-Proton Recoil (Rossi Detector, Liquid Plastic Scintillator, Plastic/ZnS Scintillator) , $LiGdBO_3$-loaded Plastic

Beta/gamma activity

Proportional Counter, GM, Plastic Scintillator

Alpha activity

Proportional Counter, ZnS Scintillator, Air Proportional, Solid-state Silicon, Plastic Scintillator

Alpha + beta activity

Proportional Counter, Plastic/ZnS Scintillator, Plastic Scintillator, Solid-state Silicon

Gross gamma activity.......... NaI, CsI

X-ray spectroscopy .... Si(Li)

Gamma spectroscopy.......... HPGe, CZT, HgI, CsI

Alpha spectroscopy .... Frisch Grid, Solid-state Silicon

Beta spectroscopy .... BGO, Plastic Scintillator, Solid state Silicon

DOT 49CFR173

Non-exclusive use (on package)

200 contact and 10 mrem / hr @ 1 m

Exclusive use (open transport)

200 contact and 10 mrem / hr @ 2 m from sides of vehicle, 2 mrem / hr in cab

Exclusive use (closed transport)

1,000 contact, 200 @ vehicle sides, & 10 mrem / hr @ 2 m, 2 mrem / hr in cab

Label	**Surface Radiation Level**	**TI**
White I	$\leq$ 0.5 mrem / hr	0
Yellow II	0.5 < RL $\leq$ 50 mrem / hr	$\leq$ 1.0
Yellow III	> 50 mrem / hr	> 1.0

Note: Packages are exempt from specification labeling if shipped Exclusive-Use LSA, or contain Limited Quantities of radioactive materials.

Removable External Radioactive Contamination - Wipe Limits

	Max Permissible Limits	
Contaminant	μCi/cm^2	dpm/cm^2
Beta/gamma emitting radionuclides; all radionuclides with half-lives less than 1o days; natural uranium; natural thorium; U^{235}; U^{238}; Th^{228}; Th^{230} and Th^{232} when contained in ores or physical concentrates	10^{-5}	22
All other alpha-emitting radionuclides	10^{-6}	2.2

Activity Limits for Limited Quantities, Instruments & Articles

	Instruments and Articles		**Materials**
	Instrument & Article Limits	Package Limits	Package Limits
Solids			
Special form	10^{-2} A_1	A_1	10^{-3} A_1
Other forms	10^{-2} A_2	A_2	10^{-3} A_2
Liquids			
Tritiated water			
< 0.1 Ci/L	–	–	1,000 curies
0.1 to 1.0 Ci/L	–	–	100 curies
> 1.0 Ci/L	–	–	1 curie
Other liquids	10^{-3} A_2	10^{-1} A_2	10^{-4} A_2
Gases			
Tritium*	20 curies	200 curies	20 curies
Special form	10^{-3} A_1	10^{-2} A_1	10^{-3} A_1
Other forms	10^{-3} A_2	10^{-2} A_2	10^{-3} A_2

* These tritium values also apply to tritium in activated luminous paint and tritium absorbed on solid carriers.

Examples of A_1 and A_2 Values

	A_1 Ci	A_2 Ci		A_1 Ci	A_2 Ci
C^{14}	1,000	60	Cs^{137}	30	10
Mo^{99}	100	20	U^{235}	100	0.2
Ra^{226}	10	0.05	Pu^{239}	2	0.002
S^{35}	1,000	60	Co^{60}	7	7
Sr^{90}	10	0.4	Am^{241}	8	0.008
Ir^{192}	20	10			

A_1 means the maximum amount of *special form* (encapsulated or massive solid metal) material allowed in a *Type A package*, such that its escape from the packaging would cause only a direct radiation hazard. A_2 means the maximum amount of *normal form* or *non-special* form material allowed in a *Type A package*, such that its escape from the packaging would present both a radiation and a contamination hazard. Quantities exceeding A_1 or A_2 values require *Type B packaging.*

SPECIFIC ACTIVITY (Ci / g)

Specific Acitivity = 3.578 E5 / ($T_{1/2}$ x atomic mass) if $T_{1/2}$ is in years

multiply the above by		365	8760	5.25 E5	3.15 E7	
if $T_{1/2}$ is in		days	hours	minutes	seconds	

	Half-Life	Ci/g		Half-Life	Ci/g
H^{3}	12.3 y	9.70 E3	Ni^{59}	7.60E4 y	0.0798
Be^{7}	53.28 d	3.50 E5	Fe^{59}	44.51 d	4.97 E4
C^{14}	5730 y	4.46	Co^{60}	5.271 y	1.13 E3
O^{15}	122.2 s	6.15 E9	Cu^{62}	9.74 m	3.11 E8
N^{16}	7.13 s	9.88 E10	Ni^{65}	2.52 h	1.91 E7
F^{18}	1.830 h	9.52 E7	Zn^{65}	243.8 d	8.24 E3
Na^{22}	2.605 y	6.24 E3	Ge^{68}	270.8 d	7.09 E3
Na^{24}	14.96 h	8.73 E6	As^{74}	127.8 d	1.38 E4
Al^{26}	7.3 E5 y	1.89 E-2	Se^{75}	119.78 d	1.45 E4
P^{32}	14.28 d	2.86 E5	Kr^{85}	10.73 y	392
Cl^{36}	3.01 E5 y	3.30 E-2	Rb^{88}	17.7 m	1.21 E8
K^{40}	1.28 E9 y	6.99 E-6	Rb^{89}	15.4 m	1.37 E8
Ar^{41}	1.82 h	4.20 E7	Sr^{89}	50.52 d	2.90 E4
K^{42}	12.36 h	6.04 E6	Sr^{90}	29.1 y	137
K^{43}	22.3 h	3.27 E6	Y^{90}	64.1 h	5.43 E5
Sc^{46}	83.81 d	3.39 E4	Zr^{95}	64.02 d	2.15 E4
Sc^{47}	3.349 d	8.30 E5	Nb^{95}	35.06 d	3.92 E4
Sc^{48}	43.7 h	1.49 E6	Tc^{99}	2.13 E5 y	1.70 E-2
V^{48}	15.98 d	1.70 E5	Mo^{99}	67 h	4.80 E5
Cr^{51}	27.70 d	9.24 E4	Tc^{99m}	6.01 h	5.27 E6
Mn^{52}	5.591 d	4.49 E5	Ru^{106}	1.02 y	3.31 E3
Mn^{54}	312.2 d	7.75 E3	I^{125}	60.1 d	1.74 E4
Fe^{55}	2.73 y	2.38 E3	I^{126}	12.93 d	7.97 E4
Mn^{56}	2.578 h	2.17 E7	I^{129}	1.57 E7 y	1.77 E-4
Co^{56}	77.3 d	3.02 E4	I^{131}	8.040 d	1.24 E5
Co^{57}	271.8 d	8.43 E3	I^{133}	20.8 h	1.13 E6
Ni^{57}	35.6 h	1.54 E6	I^{134}	52.6 m	2.67 E7
Co^{58}	70.88 d	3.18 E4	I^{135}	6.57 h	3.53 E6

SPECIFIC ACTIVITY (Ci / g)

	Half-Life	Ci/g		Half-Life	Ci/g
Cs^{137}	30.17 y	86.6	Th^{228}	1.913 y	820
Ba^{137m}	2.552 m	5.37 E8	Th^{229}	7300 y	0.214
Ba^{140}	12.75 d	7.32 E4	Th^{230}	7.54 E4 y	2.06 E-2
La^{140}	1.678 d	5.56 E5	U^{230}	20.8 d	2.73 E4
Gd^{148}	75 y	32.2	Pa^{231}	3.28 E4 y	4.72 E-2
Ir^{192}	73.83 d	9.21 E3	Th^{232}	1.40 E10 y	1.10 E-7
Tl^{204}	3.78 y	464	U^{232}	70 y	22.0
Tl^{206}	4.20 m	2.17 E8	U^{233}	1.592E5 y	9.65 E-3
Tl^{208}	3.053 m	2.96 E8	U^{234}	2.46 E5 y	6.22 E3
Pb^{210}	22.3y	76.4	Pa^{234m}	1.17 m	6.86 E8
Po^{210}	138.38 d	4.49 E3	Pa^{234}	6.69 h	2.00 E6
Bi^{210}	5.01 d	1.24 E5	Th^{234}	24.10 d	2.32E4
Tl^{210}	1.30 m	6.88 E8	U^{235}	7.04 E8 y	2.16 E-6
Po^{212}	298 ns	1.78 E17	Pu^{236}	2.87 y	528
Bi^{212}	60.6 m	1.47 E7	Np^{237}	2.14 E 6 y	7.05 E-4
Pb^{212}	10.64 h	1.39 E6	U^{238}	4.47 E9 y	3.36 E-7
Po^{214}	163.7 us	3.22 E14	Pu^{238}	87.7 y	17.1
Bi^{214}	19.9 m	4.41 E7	Pu^{239}	2.410 E4 y	6.21 E-2
Pb^{214}	27 m	3.25 E7	Np^{239}	2.355 d	2.32 E5
Po^{216}	145 ms	3.60 E11	Pu^{240}	6560 y	0.227
At^{218}	1.6 s	3.23 E10	Pu^{241}	14.4 y	103
Po^{218}	3.10 m	2.78 E8	Am^{241}	432.7 y	3.43
Rn^{220}	55.6 s	9.21 E8	Pu^{242}	3.75E5 y	3.94 E-3
Rn^{222}	3.8235 d	1.54 E5	Cm^{242}	162.8 d	3.31 E3
Ra^{223}	11.435 d	5.12 E4	Am^{243}	7370 y	0.200
Ra^{224}	3.66 d	1.59 E5	Cm^{244}	18.1 y	81.0
Ra^{225}	14.9 d	3.90 E4	Cf^{249}	351 y	4.09
Ra^{226}	1600 y	0.989	Bk^{249}	320 d	1.64 E3
Ac^{227}	21.77 y	72.4	Cf^{252}	2.638 y	538
Th^{227}	18.72 d	3.07 E4	Es^{253}	20.47 d	2.52 E4
Ac^{228}	6.15 h	2.24 E6			
Ra^{228}	5.76 y	2.72 E2			

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

These tables show the first progeny with the type of radiation, its energy in keV, and the % abundance of that energy. Only the most abundant energies are listed if the decay has more than three energy levels unless the additional energy levels are typically used in identifying the radionuclide. The energies are rounded to the nearest keV.

	1st Daughter	Radiation	keV	(% abundance)
H^3	He^3	β^-	18.6	(100)
Be^7	Li^7	EC γ	478	(10.42)
C^{14}	N^{14}	β^-	157	(100)
O^{15}	N^{15}	β^+	1732	(99.9)
N^{16}	O^{16}	β^-	3302	(4.9), 4288 (68), 10418 (26);
		γ	6129	(69), 7115 (5)
F^{18}	O^{18}	β^+	634	(96.73)
Na^{22}	Ne^{22}	β^+	546	(89.84);
		γ	1275	(99.94);
		Ne x-rays	1	(0.12)
Na^{24}	Mg^{24}	β^-	1390	(99.935);
		γ	1369	(99.9991), 2754 (99.862)
Al^{26}	Mg^{26}	β^+	1174	(81.81);
		γ	130	(2.5), 1809 (99.96), 2938 (0.24);
		Mg x-rays	1	(0.44)
P^{32}	S^{32}	β^-	1710	(100)
Cl^{36}	Ar^{36}	β^-	710	(99.0)
K^{40}	Ca^{40}	β^-	1312	(89.33)
	Ar^{40}	EC γ	1461	(10.67);
		Ar x-rays	3	(0.94)
Ar^{41}	K^{41}	β^-	1198	(99.17), 2492 (0.78);
		γ	1294	(99.16)
K^{42}	Ca^{42}	β^-	1684	(0.319), 1996 (17.5), 3521 (82.1);
		γ	313	(0.319), 1525 (17.9)
K^{43}	Ca^{43}	β^-	422	(2.24), 827 (92.2), 1224 (3.6);
		γ	373	(87.3), 397 (11.43), 593 (11.0), 617 (80.5)
Sc^{46}	Ti^{46}	β^-	357	(99.996);
		γ	889	(99.983), 1121 (99.987)
	IT	γ	143	(62.7);
		Sc x-rays	0.4	(0.11), 4 (6.26)
Sc^{47}	Ti^{47}	β^-	441	(68), 601 (32);
		γ	159	(68)
Sc^{48}	Ti^{48}	β^-	482	(10.01), 657 (89.99);
		γ	984	(100), 1037 (97.5), 1312 (100)

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

	1^{st} Daughter	Radiation	keV	(% abundance)
V^{48}	Ti^{48}	β^+	697	(50.1);
		γ	944	(7.76), 984 (100), 1312 (97.5);
		Ti x-rays	0.45	(0.15), 5 (9.74)
Cr^{51}	V^{51}	EC γ	320	(9.83);
		V x-rays	1	(0.33), 5 (22.31)
Mn^{52}	Cr^{54}	IT γ	378	(1.68);
		EC + β^+	905	(0.164), 2633 (96.4);
		γ	1434	(98.2), 1727 (0.216);
		Cr x-rays	5	(0.37)
		β^+	575	(29.4);
		γ	744	(90.0), 848 (3.32), 836 (94.5), 1246 (4.21), 1434 (5.07);
		Cr x-rays	1	(0.26), 5 (15.5), 6 (2.06)
Mn^{54}	Cr^{54}	EC γ	835	(99.975);
		Cr x-rays	1	(0.37), 5 (22.13), 6 (2.94)
Fe^{55}	Mn^{55}	EC Mn x-rays	1	(0.42), 6 (24.5), 6 (3.29)
Mn^{56}	Fe^{56}	β^-	736	(14.6), 1038 (27.8), 2849 (56.2);
		γ	847	(98.9), 1811 (27.2), 2113 (14.3)
Co^{56}	Fe^{56}	β^+	423	(1.05), 1461 (18.7);
		γ	847	(99.958), 1038 (14.03), 1238 (67.0), 1771 (15.51), 2598 (16.9);
		Fe x-rays	1	(0.34), 6 (21.83), 7 (2.92)
Co^{57}	Fe^{57}	EC γ	14	(9.54), 122 (85.51), 136 (10.6);
		Fe x-rays	1	(0.8), 6 (49.4), 7 (6.62)
Ni^{57}	Co^{57}	β^+	463	(0.87), 716 (5.7), 843 (33.1);
		γ	127	(12.9), 1378 (77.9), 1919(14.7);
		Co x-rays	1	(0.29), 7 (18.1), 8 (2.46)
Co^{58}	Fe^{58}	β^+	475	(14.93);
		γ	811	(99.4), 864 (0.74), 1675 (0.54);
		Fe x-rays	0.7	(0.36), 6 (23.18), 7 (3.1)
Ni^{59}	Co^{59}	EC Co x-rays	1	(0.47), 7 (29.8),
Fe^{59}	Co^{59}	β^-	131	(1.37), 273 (45.2), 466 (53.1);
		γ	192	(3.11), 1099 (56.5), 1292 (43.2)
Co^{60}	Ni^{60}	β^-	318	(100);
		γ	1173	(100), 1332 (100)
Cu^{62}	Ni^{62}	β^+	1754	(0.132), 2927 (97.59);
		γ	876	(0.148), 1173 (0.336);
		Ni x-rays	7	(0.7)
Zn^{65}	Cu^{65}	EC β^+	330	(1.415);
		γ	1116	(50.75);
		Cu x-rays	1	(0.57), 8 (34.1), 9 (4.61)

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

	1st Daughter	Radiation	keV	(% abundance)
Ge^{68}	Ga^{68}	EC Ga x-rays	1	(0.67), 9 (38.7), 10 (5.46)
As^{74}	Se^{74}	β^-	718	(15.5), 1353 (18.8);
		γ	634	(15.4)
	Ge^{74}	EC + β^+	945	(26.6), 1540 (3.0);
		γ	596	(59.9), 608 (0.55), 1204 (0.287);
		Ge x-rays	1	(0.26), 10 (15), 11 (2.22)
Se^{75}	As^{75}	EC γ	136	(59.2), 265 (59.8), 280 (25.2),
		As x-rays	1	(0.9), 11 (47.5), 12 (7.3)
Kr^{85}	Rb^{85}	β^-	173	(0.437), 687 (99.563);
		γ	514	(0.434)
Rb^{88}	Sr^{88}	β^-	2581	(13.3), 3479 (4.1), 5315 (78);
		γ	898	(14), 1836 (21.4), 2678 (1.96)
Rb^{89}	Sr^{89}	β^-	1275	(33), 2223 (34), 4503 (25);
		γ	1031	(58), 1248 (42), 2196 (13.3)
Sr^{89}	Y^{89}	β^-	1491	(99.985);
		γ	av.909	(0.02)
Sr^{90}	Y^{90}	β^-	546	(100)
Y^{90}	Zr^{90}	β^-	2284	(99.988)
Nb^{94}	Mo^{94}	β^-	471	(100);
		γ	703	(100), 871 (100)
Zr^{95}	Nb^{95}	β^-	366	(55.4), 399 (43.7), 887 (0.78);
		γ	724	(43.7), 757 (55.3)
Tc^{99}	Ru^{99}	β^-	294	(99.998)
Mo^{99}	Tc^{99}	β^-	436	(17.3), 848 (1.36), 1214 (82.7);
		γ	181	(6.2), 740 (12.8), 778 (4.5);
		Tc x-rays	2	(0.2), 18 (2.63), 21 (0.52)
Tc^{99m}	Tc^{99}	IT γ	141	(89.07);
		Tc x-rays	2	(0.48), 18 (6.12), 21 (1.21)
Ru^{106}	Rh^{106}	β^-	39	(100)
I^{125}	Te^{125}	EC γ	35	(6.49);
		Te x-rays	4	(15), 27 (112.2), 31 (25.4)
I^{126}	Xe^{126}	β^-	371	(3.1), 862 (27.2), 1251 (9);
		γ	389	(29.1), 491 (2.43), 880 (0.64);
		Xe x-rays	29	(0.115), 30 (0.213)
	Te^{126}	EC + β^+	468	(0.244), 1134 (0.83);
		γ	666	(40.2), 754 (5.1), 1420 (0.358);
		Te x-rays	4	(4.8), 27 (36.4), 31 (8.2)

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

	1st Daughter	Radiation	keV	(% abundance)
I^{129}	Xe^{129}	β^-	152	(100);
		γ	40	(7.52);
		Xe x-rays	4	(12), 29 (29.7), 30 (55), 34 (19.6)
I^{131}	Xe^{131}	β^-	247	(2.12), 334 (7.36), 606 (89.3);
		γ	284	(6.05), 364 (81.2), 637 (7.26);
		Xe x-rays	4	(0.55), 29 (1.35), 30 (2.5), 34 (0.89)
I^{133}	Xe^{133}	β^-	460	(3.75), 520 (3.13), 880 (4.16), 1230 (83.5);
		γ	530	(86.3), 875 (4.47), 1298 (2.33);
		Xe x-rays	29	(0.151), 30 (0.281)
I^{134}	Xe^{134}	β^-	1280	(32.5), 1560 (16.3), 1800 (11.2), 2420 (11.5);
		γ	847	(95.41), 884 (65.3),1073 (15.3);
		Xe x-rays	4	(0.17), 29 (0.432), 30 (0.8), 34 (0.285)
I^{135}	Xe^{135}	β^-	920	(8.7), 1030 (21.8), 1450 (23.6);
		γ	1132	(22.5), 1260 (28.6), 1678 (9.5);
		Xe x-rays	30	(0.127)
Cs^{137}	Ba^{137m}	β^-	512	(94.6), 1173 (5.4)
Ba^{137m}	Ba^{137}	IT γ	662	(89.98);
		Ba x-rays	5	(1), 32 (5.89), 36 (1.39)
Ba^{140}	La^{140}	β^-	454	(26), 991 (37.4), 1005 (22);
		γ	30	(14), 163 (6.7), 537 (25);
		La x-rays	5	(15), 33 (1.51), 38 (0.36)
La^{140}	Ce^{140}	β^-	1239	(11.11), 1348 (44.5), 1677 (20.7);
		γ	329	(20.5), 487 (45.5), 816 (23.5);
		Ce x-rays	5	(0.25), 34 (0.472), 35 (0.87), 39 (0.87)
Gd^{148}	Sm^{144}	a	3.180	(100)
Ir^{192}	Pt^{192}	β^-	256	(5.65), 536 (41.4), 672 (48.3);
		γ	296	(29.02), 308 (29.68), 317 (82.85), 468 (48.1);
		Pt x-rays	9	(4.1), 65 (2.63), 67 (4.52), 76 (1.97)
	Os^{192}	EC (4.69%); γ	206	(3.29), 374 (0.73), 485 (3.16);
		Os x-rays	9	(1.46), 61 (1.13), 63 (1.96), 71 (0.84)

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

	1st Daughter	Radiation	keV	(% abundance)
Tl^{204}	Pb^{204}	β^-	763	(97.42);
	Hg^{204}	EC (2.58);		
		Hg x-rays	10	(0.76), 69 (0.425), 71 (0.723), 80 (0.318)
Tl^{206}	Pb^{206}	β^-	1520	(100)
Tl^{208}	Pb^{208}	β^-	1283	(23.2), 1517 (22.7), 1794 (49.3);
		γ	511	(21.6), 583 (84.2), 860 (12.46);
		Pb x-rays	11	(2.9), 73 (2.03), 75 (3.43), 85 (1.52)
Pb^{210}	Bi^{210}	β^-	17	(80.2), 63 (19.8);
		γ	47	(4.05);
		Bi x-rays	11	(24.3)
Po^{210}	Pb^{206}	α	5305	(99.9989)
Bi^{210}	Po^{210}	β^-	1161	(99.9998)
Tl^{210}	Pb^{210}	β^-	1320	(25), 1870 (56), 2340 (19);
		γ	298	(79), 800 (99), 1310 (21);
		Pb x-rays	11	(13), 73 (2.5), 75 (4.3), 85 (1.9)
Po^{212}	Pb^{208}	α	8785	(100)
Bi^{212}	Tl^{208}	α	5767	(0.6), 6050 (25.2), 6090 (9.6);
		β^-	625	(3.4), 1519 (8), 2246 (48.4);
		γ	727	(11.8), 785 (1.97), 1621 (2.75);
		Tl x-rays	10	(7.7)
Pb^{212}	Bi^{212}	β^-	158	(5.22), 334 (85.1), 573 (9.9);
		γ	115	(0.6), 239 (44.6), 300 (3.4);
		Bi x-rays	11	(15.5), 75 (10.7), 77 (18), 87 (8)
Po^{214}	Pb^{210}	α	7687	(99.989), 6892 (0.01);
		γ	av 797	(0.013)
Bi^{214}	Po^{214}	β^-	1505	(17.7), 1540 (17.9), 3270 (17.2);
		γ	609	(46.3), 1120 (15.1), 1764 (15.8);
		Po x-rays	11	(0.52), 77 (0.36), 79 (0.6), 90 (0.27)
Pb^{214}	Bi^{214}	β^-	672	(48), 729 (42.5), 1024 (6.3);
		γ	242	(7.49), 295 (19.2), 352 (37.2);
		Bi x-rays	11	(13.5), 75 (6.21), 77 (10.5), 87 (4.67)
Po^{216}	Pb^{212}	α	6779	(99.998)
At^{218}	Bi^{214}	α	6650	(6), 6700 (94)
Po^{218}	Pb^{214}	α	6003	(99.978)

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

	1^{st} Daughter	Radiation	keV	(% abundance)
Rn^{220}	Po^{216}	α	6288	(99.9), 5747 (0.1);
		γ	av 550	(0.1)
Rn^{222}	Po^{218}	γ	5490	(99.92), 4986 (0.08);
		γ	av 512	(0.08)
Ra^{223}	Rn^{219}	α	5606	(24.2), 5715 (52.5), 5745 (9.5);
		γ	154	(5.58), 269 (13.6), 324 (3.88);
		Rn x-rays	12	(25), 81 (14.9), 84 (24.7), 95 (11.2)
Ra^{224}	Rn^{220}	α	5449	(4.9), 5686 (95.1);
		γ	241	(3.95);
		Rn x-rays	12	(0.4), 81 (0.126), 84 (0.209)
Ra^{225}	Ac^{225}	β^-	322	(72), 362 (28);
		γ	40	(31);
		Ac x-rays	13	(15.8)
Ra^{226}	Rn^{222}	α	4602	(5.6), 4785 (94.4);
		γ	186	(3.28);
		Rn x-rays	12	(0.8), 81 (0.18), 84 (0.299), 95 (0.136)
Ac^{227}	Th^{227}	β^-	19	(10), 34 (35), 44 (54);
		α	4938	(0.5), 4951 (0.68);
		γ	av 17	(0.04), av 115 (0.1);
		Th x-rays	13	(1.15)
Th^{227}	Ra^{223}	α	5757	(20.3), 5978 (23.4), 6038 (24.5);
		γ	50	(8.4), 236 (11.5), 256 (6.3);
		Ra x-rays	12	(42), 85 (1.41), 88 (2.32), 100 (1.06)
Ac^{228}	Th^{228}	β^-	606	(8), 1168 (32), 1741 (12);
		γ	338	(11.4), 911 (27.7), 969 (16.6);
		Th x-rays	13	(39), 90 (2.1), 93 (3.5), 105 (1.6)
Ra^{228}	Ac^{228}	β^-	39	(100)
Th^{228}	Ra^{224}	α	5212	(0.4), 5341 (26.7), 5423 (72.7);
		γ	84	(1.2), 132 (0.12), 216 (0.24);
		Ra x-rays	12	(9.6)
Th^{229}	Ra^{225}	α	4815	(9.3), 4845 (56.2), 4901 (10.2);
		γ	31	(4), 194 (4.6), 211 (3.3);
		Ra x-rays	12	(81), 85 (16.5), 88 (27.1), 100 (12.4)
Th^{230}	Ra^{226}	α	4476	(0.12), 4621 (23.4), 4688 (76.3);
		γ	68	(0.4), 168 (0.07);
		Ra x-rays	12	(8.4)
U^{230}	Th^{226}	α	5667	(0.4), 5818 (32), 5889 (67.4);
		γ	72	(0.6), 154 (0.13), 230 (0.12);
		Th x-rays	13	(12.2)
Pa^{231}	Ac^{227}	α	4950	(22.8), 5011 (25.4), 5028 (20);
		γ	27	(9.3), 300 (2.3), 303 (2.3);
		Ac x-rays	13	(43), 88 (0.62), 91 (1.02), 102 (0.47)

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

	1st Daughter	Radiation	keV	(% abundance)
Th^{232}	Ra^{228}	α	3830	(0.2), 3953 (23), 4010 (77);
		γ	59	(0.19), 125 (0.04);
		Ra x-rays	12	(8.4)
U^{232}	Th^{228}	α	5139	(0.3), 5264 (31.2), 5320 (68.6),
		γ	58	(0.2), 129 (0.082), 270 (0.0038), 328 (0.0034);
		Th x-rays	13	(12)
U^{233}	Th^{229}	α	4729	(1.6), 4784 (13.2), 4824 (84.4);
		γ	115	(0.18);
		Th x-rays	13	(3.9)
U^{234}	Th^{230}	α	4605	(0.2), 4724 (27.4), 4776 (72.4);
		γ	53	(0.118), 121 (0.04);
		Th x-rays	13	(10.5)
Pa^{234}	U^{234}	β^-	484	(35), 654 (16), 1183 (10);
		γ	131	(20.4), 882 (24), 946 (12);
		U x-rays	14	(114), 95 (15.7), 98 (25.4), 111(11.8)
Pa^{234m}	U^{234}	β^-	1236	(0.7), 1471 (0.6), 2281 (98.6);
		γ	766	(0.2), 1001 (0.6);
		U x-rays	14	(0.44), 95 (0.115), 98 (0.187)
Th^{234}	Pa^{234}	β^-	76	(2), 96 (25.3), 189 (72.5);
		γ	63	(3.8), 92 (2.7), 93 (2.7);
		Pa x-rays	13	(9.6)
U^{235}	Th^{231}	α	4364	(11), 4370 (6), 4396 (55);
		γ	144	(10.5), 163 (4.7), 186 (54);
		Th x-rays	13	(31), 90 (2.7), 93 (4.5), 105 (2.1)
Pu^{236}	U^{232}	α	5614	(0.2), 5722 (31.8), 5770 (68.1);
		γ	av 61	(0.08);
		U x-rays	14	(13)
Np^{237}	Pa^{233}	α	4766	(8), 4771 (25), 4788 (47);
		γ	29	(14), 87 (12.6), 95 (0.8);
		Pa x-rays	13	(59), 92 (1.58), 96 (2.6), 108 (1.6)
U^{238}	Th^{234}	α	4039	(0.2), 4147 (23.4), 4196 (77.4);
		γ	av 66	(0.1);
		Th x-rays	13	(8.8)
Pu^{238}	U^{234}	α	5358	(0.1), 5456 (28.3), 5499 (71.6);
		γ	44	(0.039), 100 (0.0075), 153 (0.0013);
		U x-rays	14	(11.6)

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

	1st Daughter	Radiation	keV	(% abundance)
Pu^{239}	U^{235}	α	5105	(11.5), 5143 (15.1), 5155 (73.3);
		γ	52	(0.02), 129 (0.0062), 375 (0.0015), 414 (0.0015);
		U x-rays	14	(4.4)
Np^{239}	Pu^{239}	β^-	330	(35.7), 391 (7.1), 436 (52);
		γ	106	(22.7), 228 (10.7), 278 (14.1);
		Pu x-rays	14	(62), 100 (14.7), 104 (23.7), 117 (11.1)
Pu^{240}	U^{236}	α	5123	(26.4), 5168 (73.5);
		γ	av 54	(0.05);
		U x-rays	14	(11)
Pu^{241}	Am^{241}	β^-	21	(99.99755);
		α	4900	(0.00245)
Am^{241}	Np^{237}	α	5388	(1.4), 5443 (12.8), 5486 (85.2);
		γ	26	(2.4), 33 (0.1), 60 (35.9);
		Np x-rays	14	(43)
Pu^{242}	U^{238}	α	4856	(22.4), 4901 (78);
		U x-rays	14	(9.1)
Cm^{242}	Pu^{238}	α	6070	(25.9), 6113 (74.1);
		γ	av 59	(0.04);
		Pu x-rays	14	(11.5)
Am^{243}	Np^{239}	α	5181	(1), 5234 (10.6), 5275 (87.9);
		γ	43	(5.5), 75 (66), 118 (0.55);
		Np x-rays	14	(39)
Cm^{244}	Pu^{240}	α	5763	(23.6), 5805 (76.4);
		γ	av 57	(0.03);
		Pu x-rays	14	(10.3)
Cf^{249}	Cm^{245}	α	5760	(3.66), 5814 (84.4), 5946 (4);
		γ	253	(2.7), 333 (15.5), 388 (66);
		Cm x-rays	15	(30), 105 (2.19), 109 (3.5), 123 (1.66)
Bk^{249}	Cf^{249}	β^-	126	(100)
Cf^{252}	Cm^{248}	α	5977	(0.2), 6076 (15.2), 6118 (81.6);
		γ	av 68	(0.03);
		Cm x-rays	15	(7.3);
		spontaneous fission		(3)
Es^{253}	Bk^{249}	α	6540	(0.9), 6592 (6.6), 6633 (89.8);
		γ	av 203	(0.14);
		Bk x-rays	15	(4.6)

See the note at the beginning of these tables.

SPECIFIC ACTIVITY AND RADIATION LEVELS OF COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	Ci/gram	gram/Ci	R/hr per Ci at 30 cm	R/hr per gram at 30 cm
H^{3}	9.70E+3	1.03E-4	N/A	N/A
Be^{7}	3.50E+5	2.86E-6	0.38	1.33E+5
C^{14}	4.46	0.224	N/A	N/A
O^{15}	6.15E+9	1.63E-10	7.98	4.91E+10
N^{16}	9.88E+10	1.01E-11	16.35	1.62E+12
F^{18}	9.52E+7	1.05E-8	7.72	7.35E+8
Na^{22}	6.24E+3	1.60E-4	14.85	9.27E+4
Na^{24}	8.73E+6	1.15E-7	20.55	1.79E+8
Al^{26}	1.89E-2	53	16.6	0.313
P^{32}	2.86E+5	3.50E-6	N/A	N/A
Cl^{36}	3.30E-2	30.3	N/A	N/A
K^{40}	6.99E-6	1.43E+5	0.91	6.36E-6
Ar^{41}	4.20E+7	2.38E-8	7.73	3.25E+8
K^{42}	6.04E+6	1.66E-7	1.4	8.45E+6
K^{43}	3.27E+6	3.06E-7	5.6	1.83E+7
Sc^{46}	3.39E+4	2.95E-5	10.9	3.69E+5
Sc^{47}	8.30E+5	1.21E-6	0.56	4.65E+5
Sc^{48}	1.49E+6	6.69E-7	21	3.14E+7
V^{48}	1.70E+5	5.87E-6	15.6	2.66E+6
Cr^{51}	9.24E+4	1.08E-5	0.16	1.48E+4
Mn^{52}	4.49E+5	2.23E-6	18.6	8.36E+6
Mn^{54}	7.75E+3	1.29E-4	5.67	4.39E+4
Fe^{55}	2.38E+3	4.20E-4	N/A	N/A
Mn^{56}	2.17E+7	4.61E-8	10.24	2.22E+8
Co^{56}	3.02E+4	3.31E-5	21.36	6.44E+5
Co^{57}	8.43E+3	1.19E-4	1.68	1.42E+4
Ni^{57}	1.54E+6	6.47E-7	12	1.85E+7
Co^{58}	3.18E+4	3.15E-5	6.81	2.16E+5
Ni^{59}	7.98E-2	12.5	N/A	N/A

SPECIFIC ACTIVITY AND RADIATION LEVELS OF COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	Ci/gram	gram/Ci	R/hr per Ci at 30 cm	R/hr per gram at 30 cm
Fe^{59}	4.97E+4	2.01E-5	7.34	3.65E+5
Co^{60}	1.13E+3	8.84E-4	15.19	1.72E+4
Cu^{62}	3.11E+8	3.21E-9	7.85	2.44E+9
Zn^{65}	8.24E+3	1.21E-4	3.66	3.02E+4
Ge^{68}	7.09E+3	1.41E-4	0.67	4.75E+3
Se^{75}	1.45E+4	6.88E-5	9.53	1.39E+5
Kr^{85}	392	2.55E-3	0.02	7.85
Rb^{88}	1.21E+8	8.29E-9	3.58	4.32E+8
Rb^{89}	1.37E+8	7.3E-9	2.17	1.67E+9
Sr^{89}	2.90E+4	3.44E-5	9.00E-4	26.1
Sr^{90}	137	7.32E-3	N/A	N/A
Y^{90}	5.43E+5	1.84E-6	N/A	N/A
Nb^{94}	0.19	5.25	10.89	2.07
Zr^{95}	2.15E+4	4.66E-5	5.16	1.11E+5
Tc^{99}	0.017	58.8	N/A	N/A
Mo^{99}	4.80E+5	2.08E-6	1.25	6.00E+5
Tc^{99m}	5.27E+6	1.90E-7	1.36	7.16E+6
Ru^{106}	3.31E+3	3.02E-4	N/A	N/A
I^{125}	1.74E+4	5.75E-5	3.055	5.31E+4
I^{126}	7.97E+4	1.25E-5	4.34	3.46E+5
I^{129}	1.77E-4	5.66E+3	1.4	2.47E-4
I^{131}	1.24E+5	8.06E-6	3.14	3.89E+5
I^{133}	1.13E+6	8.83E-7	4.54	5.14E+6
I^{134}	2.67E+7	3.75E-8	17.47	4.66E+8
I^{135}	3.53E+6	2.83E-7	9.57	3.38E+7
Cs^{137}	86.6	0.0116	N/A	N/A
Ba^{137m}	5.37E+8	1.86E-9	4.44	2.39E+9
Ba^{140}	7.32E+4	1.37E-5	1.81	1.32E+5
La^{140}	5.56E+5	1.80E-6	12.42	6.90E+6
Gd^{148}	32.2	0.031	N/A	N/A

SPECIFIC ACTIVITY AND RADIATION LEVELS OF COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	Ci/gram	gram/Ci	R/hr per Ci at 30 cm	R/hr per gram at 30 cm
Ir^{192}	9.21E+3	1.09E-4	6.56	6.04E+4
Tl^{204}	464	2.16E-3	0.0124	5.75
Tl^{206}	2.17E+8	4.61E-9	N/A	N/A
Tl^{208}	2.96E+8	3.38E-9	18.89	5.59E+9
Pb^{210}	76.4	0.0131	2.79	213
Po^{210}	4.49E+3	2.23E-4	5.84E-5	0.262
Bi^{210}	1.24E+5	8.06E-6	N/A	N/A
Tl^{210}	6.88E+8	1.45E-9	18.88	1.30E+10
Po^{212}	1.78E+17	5.61E-18	N/A	N/A
Bi^{212}	1.47E+7	6.82E-8	2.16	3.16E+7
Pb^{212}	1.39E+6	7.20E-7	3.03	4.21E+6
Po^{214}	3.22E+14	3.11E-15	5.74E-4	1.85E+11
Bi^{214}	4.41E+7	2.27E-8	9.31	4.11E+8
Pb^{214}	3.25E+7	3.08E-8	3.59	1.17E+8
Po^{216}	3.60E+11	2.78E-12	9.95E-5	3.58E+7
At^{218}	3.23E+10	3.09E-11	N/A	N/A
Po^{218}	2.78E+8	3.60E-9	N/A	N/A
Rn^{220}	9.21E+8	1.09E-9	3.99E-3	3.68E+6
Rn^{222}	1.54E+5	6.50E-6	3.03E-3	466
Ra^{223}	5.12E+4	1.95E-5	3.61	1.85E+5
Ra^{224}	1.59E+5	6.28E-6	0.12	1.91E+4
Ra^{225}	3.90E+4	2.57E-5	1.71	6.66E+4
Ra^{226}	0.989	1.01	0.13	0.129
Ac^{227}	72.4	0.0138	0.1	7.24
Th^{227}	3.07E+4	3.25E-5	4.7	1.44E+5
Ac^{228}	2.24E+6	4.47E-7	9.36	2.09E+7
Ra^{228}	272	3.67E-3	5.1	1.39E+3
Th^{228}	820	1.22E-3	0.88	722
Th^{229}	0.213	4.67	8.16	1.75
Th^{230}	0.0206	48.5	0.76	0.0157

SPECIFIC ACTIVITY AND RADIATION LEVELS OF COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	Ci/gram	gram/Ci	R/hr per Ci at 30 cm	R/hr per gram at 30 cm
U^{230}	2.73E+4	3.66E-5	1.01	2.76E+4
Pa^{231}	0.0472	21.2	4.15	0.196
Th^{232}	1.10E-7	9.08E+6	0.76	8.37E-8
U^{232}	22.0	0.0454	0.99	21.8
U^{233}	9.65E-3	104	0.32	3.09E-3
U^{234}	6.22E-3	161	0.86	5.35E-3
Pa^{234}	6.86E+8	1.46E-9	21.98	1.51E+10
Pa^{234m}	2.00E+6	4.99E-7	0.11	2.20E+5
Th^{234}	2.32E+4	4.32E-5	0.84	1.95E+4
U^{235}	2.16E-6	4.62E+5	3.76	8.13E-6
Pu^{236}	528	1.89E-3	0.99	523
Np^{237}	7.05E-4	1.42E+3	5.13	3.62E-3
U^{238}	3.36E-7	2.97E+6	0.72	2.42E-7
Pu^{238}	17.1	0.0583	0.87	14.9
Pu^{239}	0.0621	16.1	0.33	0.0205
Np^{239}	2.32E+5	4.31E-6	5.69	1.32E+6
Pu^{240}	0.227	4.40	0.83	0.189
Pu^{241}	103	9.70E-3	N/A	N/A
Am^{241}	3.43	0.291	0.17	0.58
Pu^{242}	3.94E-3	254	0.69	2.72E-3
Cm^{242}	3.31E+3	3.02E-4	0.8	2.65E+3
Am^{243}	0.200	5.01	1.13	0.235
Cm^{244}	81.0	0.0123	0.71	57.5
Cf^{249}	4.09	0.244	4.59	18.8
Bk^{249}	1.64E+3	6.10E-4	N/A	N/A
Cf^{252}	538	1.86E-3	0.46	248
Es^{253}	2.52E+4	3.97E-5	0.28	7.06E+3

These tables may also be expressed in units of mCi/mg, mg/Ci, mR/hr per mCi and mR/hr per mg simply by changing **all headings** to those values.

Gamma exposure in mR/hr at 30 cm vs Particle Size in microns for commonly encountered radionuclides

Isotope	1µ	10µ	100µ	1,000µ
Be^{7}	1.3E-4	1.3E-1	1.3E2	1.3E5
Na^{22}	4.7E-5	4.7E-2	4.7E1	4.7E4
Na^{24}	9.5E-2	9.5E1	9.5E4	9.5E7
Al^{26}	4.5E-10	4.5E-7	4.5E-4	4.5E-1
Mg^{28}	4.8E-2	4.8E1	4.8E4	4.8E7
Sc^{46}	6.9E-4	6.9E-1	6.9E2	6.9E5
V^{48}	1E-2	1E1	1E4	1E7
Cr^{51}	9E-5	9E-2	9E1	9E4
Mn^{52}	3.8E-2	3.8E1	3.8E4	3.8E7
Mn^{54}	1.7E-4	1.7E-1	1.7E2	1.7E5
Mn^{56}	8.3E-1	8.3E2	8.3E5	8.3E8
Co^{56}	2.9E-3	2.9	2.9E3	2.9E6
Co^{57}	6.6E-5	6.6E-2	6.6E1	6.6E4
Co^{58}	1E-3	1	1E3	1E6
Fe^{59}	1.5E-3	1.5	1.5E3	1.5E6
Co^{60}	8E-5	8E-2	8E1	8E4
Zn^{65}	1.1E-4	1.1E-1	1.1E2	1.1E5
Se^{75}	3.5E-4	3.5E-1	3.5E2	3.5E5

Gamma exposure in mR/hr at 30 cm vs Particle Size in microns for commonly encountered radionuclides

Isotope	1µ	10µ	100µ	1,000µ
Y^{88}	6.3E-4	6.3E-1	6.3E2	6.3E5
Zr^{95}	3.8E-4	3.8E-1	3.8E2	3.8E5
Mo^{99}	3.2E-3	3.2	3.2E3	3.2E6
Cd^{109}	2.4E-5	2.4E-2	2.4E1	2.4E4
Cs^{137}	3.6E-7	3.6E-4	3.6E-1	3.6E2
Ba^{140}	2.4E-4	2.4E-1	2.4E2	2.4E5
W^{187}	1.1E-3	1.1	1.1E3	1.1E6
Os^{191}	3.9E-4	3.9E-1	3.9E2	3.9E5
Ir^{192}	7.1E-4	7.1E-1	7.1E2	7.1E5
Au^{198}	8E-3	8	8E3	8E6
Ra^{226}	3.5E-10	3.5E-7	3.5E-4	3.5E-1
U^{234}	5.4E-11	5.4E-8	5.4E-5	5.4E-2
U^{235}	8.1E-14	8.1E-11	8.1E-8	8.1E-5
Np^{237}	3.9E-11	3.9E-8	3.9E-5	3.9E-2
Pu^{238}	1.6E-7	1.6E-4	1.6E-1	1.6E2
Pu^{239}	2.2E-10	2.2E-7	2.2E-4	2.2E-1
Pu^{240}	2E-9	2E-6	2E-3	2
Am^{241}	1.3E-7	1.3E-4	1.3E-1	1.3E2

1000 µ = 1 mm (millimeter) = 0.03937 inches
100 µ is easily discernible with the naked eye
50 µ is not easily discernible with the naked eye

INGESTION ALIs OF
COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI
H^{3}	80	8.25E-3	1.78E+11
Be^{7}	40	1.14E-4	8.88E+10
C^{14}	2	0.448	4.44E+9
O^{15}	N/A	N/A	N/A
N^{16}	N/A	N/A	N/A
F^{18}	50	5.25E-7	1.11E+11
Na^{22}	0.4	6.41E-5	8.88E+8
Na^{24}	4	4.58E-7	8.88E+9
Al^{26}	0.4	21.2	8.88E+8
P^{32}	0.6	2.1E-6	1.33E+9
Cl^{36}	2	60.6	4.44E+9
K^{40}	0.3	4.29E+4	6.66E+8
Ar^{41}	N/A	N/A	N/A
K^{42}	5	8.28E-7	1.11E+10
K^{43}	5	1.84E-6	1.33E+10
Sc^{46}	0.9	2.66E-5	2.00E+9
Sc^{47}	2	2.41E-6	4.44E+9
Sc^{48}	0.8	5.35E-7	1.78E+9
V^{48}	0.6	3.52E-6	1.33E+9
Cr^{51}	40	4.33E-4	8.88E+10
Mn^{52}	0.7	1.56E-6	1.55E+9
Mn^{54}	2	2.58E-4	4.44E+9
Fe^{55}	9	3.78E-3	2.00E+10
Mn^{56}	5	2.30E-7	1.11E+10
Co^{56}	0.4	1.33E-5	8.88E+8
Co^{57}	4	4.75E-4	8.88E+9
Ni^{57}	2	1.29E-6	4.44E+9
Co^{58}	1	3.15E-5	2.22E+9
Ni^{59}	20	251	4.44E+10

INGESTION ALIs OF COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI
Fe^{59}	0.8	1.61E-5	1.78E+9
Co^{60}	0.2	1.77E-4	4.44E+8
Cu^{62}	1	3.21E-9	2.22E+9
Zn^{65}	0.4	4.85E-5	8.88E+8
Ge^{68}	5	7.05E-4	1.11E+10
Se^{75}	0.5	3.44E-5	1.11E+9
Kr^{85}	N/A	N/A	N/A
Rb^{88}	20	1.66E-7	4.44E+10
Rb^{89}	40	2.92E-7	8.88E+10
Sr^{89}	0.5	1.72E-5	1.11E+9
Sr^{90}	0.03	2.20E-4	6.66E+7
Y^{90}	0.4	7.36E-7	8.88E+8
Nb^{94}	0.9	4.37	2.00E+9
Zr^{95}	1	4.66E-5	2.22E+9
Tc^{99}	4	236	8.88E+9
Mo^{99}	1	2.08E-6	2.22E+9
Tc^{99m}	80	1.52E-5	1.78E+11
Ru^{106}	0.2	6.04E-5	4.44E+8
I^{125}	0.04	2.30E-6	8.88E+7
I^{126}	0.02	2.51E-7	4.44E+7
I^{129}	5E-3	28.3	1.11E+7
I^{131}	0.03	2.42E-7	6.66E+7
I^{133}	0.1	8.83E-8	2.22E+8
I^{134}	20	7.50E-7	4.44E+10
I^{135}	0.8	2.26E-7	1.78E+9
Cs^{137}	0.1	1.16E-3	2.22E+8
Ba^{137m}	N/A	N/A	N/A
Ba^{140}	0.5	6.83E-6	1.11E+9
La^{140}	0.6	1.08E-6	1.33E+9

INGESTION ALIs OF
COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI
Gd^{148}	0.01	3.10E-4	2.22E+7
Ir^{192}	0.9	9.77E-5	2.00E+9
Tl^{204}	2	4.31E-3	4.44E+9
Tl^{206}	*	*	*
Tl^{208}	*	*	*
Pb^{210}	6E-4	7.85E-6	1.33E+6
Po^{210}	3E-3	6.68E-7	6.66E+6
Bi^{210}	0.8	6.44E-6	1.78E+9
Tl^{210}	*	*	*
Po^{212}	*	*	*
Bi^{212}	5	3.41E-7	1.11E+10
Pb^{212}	0.08	5.76E-8	1.78E+10
Po^{214}	*	*	*
Bi^{214}	20	4.53E-7	4.44E+10
Pb^{214}	9	2.77E-7	2.00E+10
Po^{216}	*	*	*
At^{218}	*	*	*
Po^{218}	*	*	*
Rn^{220}	N/A	N/A	N/A
Rn^{222}	N/A	N/A	N/A
Ra^{223}	5E-3	9.76E-8	1.11E+7
Ra^{224}	8E-3	5.02E-8	1.78E+7
Ra^{225}	8E-3	2.05E-7	1.78E+7
Ra^{226}	2E-3	2.02E-3	4.44E+6
Ac^{227}	2E-4	2.76E-6	4.44E+5
Th^{227}	0.1	3.25E-6	2.22E+8
Ac^{228}	2	8.95E-7	4.44E+9
Ac^{228}	0.02	7.34E-5	4.44E+7
Th^{228}	6E-3	7.31E-6	1.33E+7

INGESTION ALIs OF
COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI
Th^{229}	6E-3	0.028	1.33E+7
Th^{230}	4E-3	0.194	8.88E+6
U^{230}	4E-3	1.47E-7	8.88E+6
Pa^{231}	2E-4	4.24E-3	4.44E+5
Th^{232}	7E-4	6.35E+3	1.55E+6
U^{232}	2E-3	9.08E-5	4.44E+6
U^{233}	0.01	1.04	2.22E+7
U^{234}	0.01	1.61	2.22E+7
Pa^{234m}	2	2.91E-9	4.44E+9
Pa^{234}	2	9.99E-7	4.44E+9
Th^{234}	0.3	1.30E-5	6.66E+8
U^{235}	0.01	4.62E+3	2.22E+7
Pu^{236}	2E-3	3.79E-6	4.44E+6
Np^{237}	5E-4	0.709	1.11E+6
U^{238}	0.01	2.97E+4	2.22E+7
Pu^{238}	9E-4	5.25E-5	2.00E+6
Pu^{239}	8E-4	0.0129	1.78E+6
Np^{239}	2	8.62E-6	4.44E+9
Pu^{240}	8E-4	3.52E-3	1.78E+6
Pu^{241}	0.04	3.88E-4	8.88E+7
Am^{241}	8E-4	2.33E-4	1.78E+6
Pu^{242}	8E-4	0.203	1.78E+6
Cm^{242}	0.03	9.05E-6	6.66E+7
Am^{243}	8E-4	4.00E-3	1.78E+6
Cm^{244}	1E-3	1.23E-5	2.22E+6
Cf^{249}	5E-4	1.22E-4	1.11E+6
Bk^{249}	0.2	1.22E-4	4.44E+8
Cf^{252}	2E-3	3.72E-6	4.44E+6
Es^{253}	0.2	7.93E-6	4.44E+8

INHALATION ALIs OF
COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI	DAC (μCi/ml)
H^{3}	80	8.25E-3	1.78E+11	2E-5
Be^{7}	20	5.71E-5	4.44E+10	8E-6
C^{14}	2	0.448	4.44E+9	1E-6
F^{18}	70	7.36E-7	1.55E+11	3E-5
Na^{22}	0.6	9.61E-5	1.33E+9	3E-7
Na^{24}	5	5.73E-7	1.11E+10	2E-6
Al^{26}	0.06	3.18	1.33E+8	3E-8
P^{32}	0.4	1.40E-6	8.88E+8	2E-7
Cl^{36}	0.2	6.1	4.44E+8	1E-7
K^{40}	0.4	5.72E+4	8.88E+8	2E-7
K^{42}	5	8.28E-7	1.11E+10	2E-6
K^{43}	9	2.75E-6	2.00E+10	4E-6
Sc^{46}	0.2	5.90E-6	4.44E+8	1E-7
Sc^{47}	3	3.62E-6	6.66E+9	1E-6
Sc^{48}	1	6.69E-7	2.22E+9	6E-7
V^{48}	0.6	3.52E-6	1.33E+9	3E-7
Cr^{51}	20	2.16E-4	4.44E+10	8E-6
Mn^{52}	0.9	2.00E-6	2.00E+9	4E-7
Mn^{54}	0.8	1.03E-4	1.78E+9	3E-7
Fe^{55}	2	8.39E-4	4.44E+9	8E-7
Mn^{56}	20	9.21E-7	4.44E+10	6E-6
Co^{56}	0.2	6.63E-6	4.44E+8	8E-8
Co^{57}	0.7	8.30E-5	1.55E+9	3E-7
Ni^{57}	3	1.94E-6	6.66E+9	1E-6
Co^{58}	0.7	2.20E-5	1.55E+9	3E-7
Ni^{59}	2	25.1	4.44E+9	8E-7
Fe^{59}	0.3	6.03E-6	6.66E+8	1E-7

INHALATION ALIs OF
COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI	DAC (μCi/ml)
Co^{60}	0.03	2.65E-5	6.66E+7	1E-8
Cu^{62}	3	9.64E-9	6.66E+9	1E-6
Zn^{65}	0.3	3.64E-5	6.66E+8	1E-7
Ge^{68}	0.1	1.41E-5	2.22E+8	4E-8
Se^{75}	0.6	4.13E-5	1.33E+9	3E-7
Rb^{88}	60	4.98E-7	1.33E+11	3E-5
Rb^{89}	100	7.30E-7	2.22E+11	6E-5
Sr^{89}	0.1	3.44E-6	2.22E+8	6E-8
Sr^{90}	0.02	1.46E-4	4.44E+7	2E-9
Y^{90}	0.6	1.10E-6	1.33E+9	2E-7
Nb^{94}	0.02	0.105	4.44E+7	6E-9
Zr^{95}	0.1	4.66E-6	2.22E+8	6E-8
Tc^{99}	0.7	41.3	1.55E+9	3E-7
Mo^{99}	1	2.08E-6	2.22E+9	6E-7
Tc^{99m}	200	3.80E-5	4.44E+11	6E-5
Ru^{106}	0.01	3.02E-6	2.22E+7	5E-9
I^{125}	0.06	3.45E-6	1.33E+8	3E-8
I^{126}	0.04	5.02E-7	8.88E+7	1E-8
I^{129}	9E-3	50.9	2.00E+7	4E-9
I^{131}	0.05	4.03E-7	1.11E+8	2E-8
I^{133}	0.3	2.65E-7	6.66E+8	1E-7
I^{134}	50	1.88E-6	1.11E+11	2E-5
I^{135}	2	5.66E-7	4.44E+9	7E-7
Cs^{137}	0.2	2.31E-3	4.44E+8	7E-8
Ba^{137m}	N/A	N/A	N/A	N/A
Ba^{140}	1	1.37E-5	2.22E+9	6E-7

INHALATION ALIs OF
COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI	DAC (µCi/ml)
La^{140}	1	1.80E-6	2.22E+9	5E-7
Gd^{148}	8E-6	2.48E-7	1.78E+4	3E-12
Ir^{192}	0.2	2.71E-5	4.44E+8	9E-8
Tl^{204}	2	4.31E-3	4.44E+9	9E-7
Pb^{210}	2E-4	2.62E-6	4.44E+5	1E-10
Po^{210}	6E-4	1.34E-7	1.33E+6	3E-10
Bi^{210}	0.03	2.42E-7	6.66E+7	1E-8
Bi^{212}	0.2	1.36E-8	4.44E+8	1E-7
Pb^{212}	0.03	2.16E-8	6.66E+7	1E-8
Bi^{214}	0.8	1.81E-8	1.78E+9	3E-7
Pb^{214}	0.8	2.46E-8	1.78E+9	3E-7
Rn^{220}	0.02	2.17E-11	4.44E+7	8E-9
Rn^{222}	0.1	6.5E-7	2.22E+8	3E-8
Ra^{223}	7E-4	1.37E-8	1.55E+6	3E-10
Ra^{224}	2E-3	1.26E-8	4.44E+6	7E-10
Ra^{225}	7E-4	1.80E-8	1.55E+6	3E-10
Ra^{226}	6E-4	6.06E-4	1.33E+6	3E-10
Ac^{227}	4E-7	5.52E-9	888	2E-13
Th^{227}	3E-4	9.76E-9	6.66E+5	1E-10
Ac^{228}	9E-3	4.03E-9	2.00E+7	4E-9
Ra^{228}	0.001	3.67E-6	2.22E+6	5E-10
Th^{228}	1E-5	1.22E-8	2.22E+4	4E-12
Th^{229}	9E-7	4.20E-6	2.00E+3	4E-13
Th^{230}	6E-6	2.91E-4	1.33E+4	3E-12
U^{230}	3E-4	1.10E-8	6.66E+5	1E-10
Pa^{231}	2E-6	4.24E-5	4.44E+3	7E-13
Th^{232}	1E-6	9.08	2.22E+3	5E-13

INHALATION ALIs OF COMMONLY ENCOUNTERED RADIONUCLIDES

Isotope	mCi/ALI	mg/ALI	DPM/ALI	DAC (μCi/ml)
U^{232}	8E-6	3.63E-7	1.78E+4	3E-12
U^{233}	4E-5	4.15E-3	8.88E+4	2E-11
U^{234}	4E-5	6.44E-3	8.88E+4	2E-11
Pa^{234}	7	1.02E-8	1.55E+10	3E-6
Pa^{234M}	7	3.50E-6	1.55E+10	3E-6
Th^{234}	0.2	8.64E-6	4.44E+8	6E-8
U^{235}	4E-5	18.5	8.88E+4	2E-11
Pu^{236}	2E-5	3.79E-8	4.44E+4	7E-12
Np^{237}	4E-6	5.67E-3	8.88E+3	2E-12
U^{238}	4E-5	119	8.88E+4	2E-11
Pu^{238}	7E-6	4.08E-7	1.55E+4	3E-12
Pu^{239}	6E-6	9.66E-5	1.33E+4	2E-12
Np^{239}	2	8.62E-6	4.44E+9	1E-6
Pu^{240}	6E-6	2.64E-5	1.33E+4	2E-12
Pu^{241}	3E-4	2.91E-6	6.66E+5	1E-10
Am^{241}	6E-6	1.75E-6	1.33E+4	2E-12
Pu^{242}	7E-6	1.78E-3	1.55E+4	2E-12
Cm^{242}	3E-4	9.05E-8	6.66E+5	1E-10
Am^{243}	6E-6	3.00E-5	1.33E+4	2E-12
Cm^{244}	1E-5	1.23E-7	2.22E+4	4E-12
Cf^{249}	4E-6	9.77E-7	8.88E+3	2E-12
Bk^{249}	2E-3	1.22E-6	4.44E+6	9E-10
Cf^{252}	2E-5	3.72E-8	4.44E+4	1E-11
Es^{253}	1E-3	3.97E-8	2.22E+6	6E-10

The values stated for Rn^{220} and Rn^{222} include their progeny; Tl^{206}, Tl^{208}, Tl^{210}, Po^{212}, Po^{214}, Po^{216}, Po^{218} and At^{218}

Activity (in DPM) vs Particle Size (in microns)
For oxide form of various isotopes

Isotope	0.1µ DPM	0.3µ DPM	0.5µ DPM	1µ DPM	3µ DPM
U^{234}	7.0E-5	1.88E-3	8.7E-3	0.07	1.9
U^{235}	2.4E-8	6.5E-7	3.0E-6	2.4E-5	6.5E-4
U^{238}	3.8E-9	1.0E-7	4.7E-7	3.8E-6	1.0E-4
Np^{237}	8.0E-5	2.2E-4	1.0E-3	8.0E-3	0.22
Pu^{238}	0.2	5.4	25	201	5420
Pu^{239}	7.3E-4	0.02	0.09	0.73	19.7
Pu^{240}	2.7E-3	0.07	0.33	2.7	72
Pu^{241}	1.2	32.7	151	1210	3.3E4
Am^{241}	0.04	1.1	5.1	41.1	1110

Isotope	5µ DPM	10µ DPM	30µ DPM	50µ DPM	100µ DPM
U^{234}	8.7	69.7	1900	8700	7.0E4
U^{235}	3.0E-3	0.02	0.7	3.0	24.2
U^{238}	4.7E-4	3.8E-3	0.1	0.47	3.8
Np^{237}	1.0	8.0	217	1000	8020
Pu^{238}	2.5E4	2.0E5	5.4E6	2.5E7	2.0E8
Pu^{239}	91	730	2.0E4	9.1E4	7.3E5
Pu^{240}	333	2670	7.2E4	3.3E5	2.7E6
Pu^{241}	1.5E5	1.2E6	3.3E7	1.5E8	1.2E9
Am^{241}	5140	4.1E4	1.1E6	5.14E6	4.1E7

Note: The measured activity will be less than calculated due to self-shielding.

Calculating Activity in DPM for the Oxide Form of Isotopes

1. Volume of the particle is V = $1/6\pi d^3$.

2. Use the stated density of the isotope's dioxide form from a reference such as the Handbook of Chemistry and Physics.

3. Mass of the particle is M = V x density.

4. Activity of the particle is A = M x specific activity.

5. Correct the activity of the particle for the oxide; the molecular weight of Pu^{238} is 238, the activity of the dioxide form must be reduced by the ratio of the molecular weight of the dioxide form to the molecular weight of Pu^{238}. Multiply the calculated activity by 238/270 to get the activity of the dioxide form.

6. Change the activity to dpm by multiplying the activity in curies by 2.22E12.

Example: For a 10µ diameter Pu^{238} dioxide form particle

DPM	=	V x M x A x ratio x 2.22E12		
V	=	$1/6\pi d^3$ (d of 10µ is 0.001 cm)	=	5.236E-10 cm^3
M	=	V x density (11.46 g/cm^3)	=	6E-9 g/cm^3
A	=	M x specific activity (17.1 Ci/g)	=	1.03E-7 Ci
A x ratio =		1.03E-7 Ci x 238/270	=	9E-8 Ci
DPM	=	9E-8 Ci x 2.22E12 dpm/Ci	=	200,777 DPM

For particles larger than about 1µ the aerodynamic diameter is approximately equal to the physical diameter times the square root of the density. The 10µ diameter particle in our example would have an equivalent aerodynamic diameter of 34µ (10µ x the square root of 11.46). This must be taken into account in air sampling/monitoring situations.

EMERGENCY RESPONSE

Write in Your Emergency Phone Numbers

Supervisor:

Team Office:

Group Office:

Division Office:

Emergency Response Team:

Fire Department:

Hospital:

Guidelines for Control of Emergency Exposures

Use a dose limit of 5 rem for all emergency procedures

Use a dose limit of 10 rem only for protecting major property

Use a dose limit of 25 rem for lifesaving or protection of large populations

Use a dose limit > 25 rem for lifesaving or protection of large populations only by volunteers and where the risks have been evaluated

RADIOLOGICAL EMERGENCY RESPONSE

SWIMS for Radiological Emergencies

Only under extreme radiological conditions such as external radiation greater than 100 rem / hr or airborne radioactivity concentrations greater than 100,000 DAC would the radiological emergency take precedence over serious personnel injuries. Therefore, you would not attempt to move a seriously injured person before medical personnel arrived unless the radiological conditions presented a greater danger to that person and yourself.

Stop or **S**ecure operations in the area. If applicable, secure the operation causing the emergency.

Warn others in the area as you are evacuating. Do not search for potentially missing personnel at this stage of the emergency.

Isolate the source of the radiation or radioactivity if you understand the operation and are qualified to isolate the source.

Minimize individual exposure and contamination. Control the entry points to the area if possible.

Secure unfiltered ventilation. Evaluate the radiological conditions and advise facility personnel on ventilation control.

RADIOLOGICAL CONTROL PRIORITIES DURING MEDICAL EMERGENCIES

Immediate treatment by trained medical personnel should be sought for any serious injuries such as those involving profuse bleeding or broken bones. The order of priority should be to protect lives, protect property, and then to control the spread of contamination.

Identifying a Major Injury
Consider the following points in determining if the injury should be handled as a major injury.

Any head injury (from base of neck to top of head)

Any loss of consciousness

Any disorientation

Any convulsion

Any loss of sensation

Any loss of motor function

Limbs at abnormal angles

Amputations

Any burn of the face, hands, feet, or genitals (chemical, thermal, or radiation)

Any burn larger than the palm of your hand

Any inhalation of any abnormal substance

Profuse bleeding

Abnormal breathing patterns

Major Injuries Occurring in Radiological Areas

Protect yourself - consider the magnitude of any radiation field or airborne radioactivity

Stay with the victim

Don’t move the victim unless there is a danger from some environmental emergency such as fire, explosion, hazardous material spill, or radiation field

If you must move the victim, drag them by either the hands or the feet to a safe area

Apply First Aid Only if you are trained to do so

Secure help - yell or phone, but don’t leave the victim unless necessary

Send someone to meet the ambulance to guide the medical personnel to the victim

Prepare the area for access by the medical team

Begin a gross radiological survey of the immediate area near the victim, beginning with the victim

Be sure to survey any object that caused the injury

Provide information to medical personnel about the victim (what happened, how, when, location of phone and exits, indicate which areas on the victim are contaminated and include contamination values)

FACILITY HAZARDS

Power Reactors

Fission Products (β^-, γ), Activation Products (β^-, γ), Neutrons (during operation)

Production Reactors

Fission Products (β^-, γ), Activation Products (β^-, γ), Transuranics (α, β^-, γ), Neutrons (during operation)

Accelerators

Prompt Radiations: *Bremsstrahlung*, Photoneutrons, Photons, Protons
Induced Radiations: Activation Products (β^-, γ)
Highest Dose Equivalent Rate at Target

X-ray Devices

Primary Beam (unscattered X-rays)
Secondary (scattered X-rays, mostly from patient)
Leakage (X-rays at locations other than primary beam)

Nuclear Medicine

Highest dose received while eluting radioisotope generator and working near patients (γ)

Radioactive Waste Disposal Sites

Contamination of potable water supply (α, β^-), Occupational dose during off-loading and handling (γ)

Thorium-232 Decay Chain (including Thoron progeny)

Isotope and half-life	Energy (MeV) and abundance (%)		
	a	b	g
^{232}Th / 1.41E10 y	3.95 @ 24% 4.01 @ 76%	No	negligible
^{228}Ra / 6.7 y	No	0.055 @ 100%	negligible
^{228}Ac / 6.13 h	No	1.118 @ 35% 1.75 @ 12% 2.09 @ 12%	0.340 @ 15% 0.908 @ 25% 0.960 @ 20%
^{228}Th / 1.91 y	5.34 @ 28% 5.43 @ 71%	No	0.084 @ 1.6% 0.214 @ 0.3%
^{224}Ra / 3.64 d	5.45 @ 6% 5.68 @ 94%	No	0.241 @ 3.7%
^{220}Rn (Thoron) / 55 s	6.29 @ 100%	No	0.550@0.07%
^{216}Po / 0.15 s	6.78 @ 100%	No	negligible
^{212}Pb / 10.64 h	No	0.346 @ 81% 0.586 @ 14%	0.239 @ 47% 0.300 @ 3.2%
^{212}Bi / 60.6 m	6.05 @ 25% 6.09 @ 10%	1.55 @ 5% 2.26 @ 55%	0.040 @ 2% 0.727 @ 7% 1.62 @ 1.8%
^{212}Po / 304 ns	8.78 @ 100%	No	negligible
^{208}Tl / 3.10 m	No	1.28 @ 25% 1.52 @ 21% 1.80 @ 50%	0.511 @ 23% 0.583 @ 86% 2.614@ 100%

^{212}Bi decays 64% of the time to ^{212}Po and 36% of the time to ^{208}Tl

Uranium-238 Decay Chain (down to Polonium-218

Isotope and half-life	Energy (MeV) and abundance (%)		
	a	**b**	**g**
^{238}U / 4.451E9 y	4.15 @ 25% 4.20 @ 75%	No	negligible
^{234}Th / 24.1 d	No	0.103 @ 21% 0.193 @ 79%	0.063 @ 3.5% 0.093 @ 4%
^{234m}Pa / 1.17m	No	2.29 @ 98%	0.765 @ 0.3% 1.001 @ 0.6%
^{234}U / 2.47E5y	4.72 @ 28% 4.77 @ 72%	No	0.053 @ 0.2%
^{230}Th / 8.0E4 y	4.62 @ 24% 4.68 @ 76%	No	0.068 @ 0.6% 0.142@0.07%
^{226}Ra / 1602 y	4.60 @ 6% 4.78 @ 95%	No	0.186 @ 4%
^{222}Rn (Radon) / 3.823 d	5.49 @ 100%	No	0.510@0.07%
^{218}Po / 3.05 m	6.00 @ 100%	0.33 @ 0.019%	negligible
↓	↓	↓	↓

^{234m}Pa decays 99.87% of the time to ^{234}U & 0.13% of the time to ^{234}Pa

Radon Decay Chain (from Uranium-238 decay)

Isotope and half-life	Energy (MeV) and abundance (%)		
	a	b	g
^{222}Rn (Radon) / 3.823 d	5.49 @ 100%	No	0.510@0.07%
^{218}Po / 3.05 m	6.00 @ 100%	0.33 @ 0.019%	negligible
^{214}Pb / 26.8 m	No	0.65 @ 50% 0.71 @ 40% 0.98 @ 6%	0.295 @ 19% 0.352 @ 36%
^{214}Bi / 19.7 m	negligible	1.00 @ 23% 1.51 @ 40% 3.26 @ 19%	0.609 @ 47% 1.120 @ 17% 1.764 @ 17%
^{214}Po / 164 us	7.69 @ 100%	No	0.799@0.014%
^{210}Tl / 1.3 m	No	1.3 @ 25% 1.9 @ 56% 2.3 @ 19%	0.296 @ 80% 0.795 @100% 1.31 @ 21%
^{210}Pb / 21 y	negligible	0.016 @ 85% 0.061 @ 15%	0.047 @ 4%
^{210}Bi / 5.01 d	negligible	1.161 @ 100%	negligible
^{210}Po / 138.4 d	5.305 @ 100%	No	negligible
^{206}Tl / 4.19 m	No	1.571 @ 100%	negligible

^{218}Po decays 99.98% of the time to ^{214}Pb & 0.02% of the time to ^{218}At

^{214}Bi decays 99.98% of the time to ^{214}Po & 0.02% of the time to ^{210}Tl

^{210}Bi decays ~ 100% of the time to ^{210}Po & 0.00013% of the time to ^{206}Tl