Abbreviations	2
Activity vs Exposure Rate	63
Activity vs Particle Size	79
Acute Radiation Effects	28
Air Pollution	26
Airborne Radioactivity	46
Characteristic Radiations	67
Composition of Air	98
Contamination Limits	60
Conversions	3
Dosimetry	30
Elevation vs Air Pressure	97
Emergency Response	99
Ingestion and Inhalation ALIs	82
Instrument Selection	61
Public Radiation Doses	23
Radiation Biology	27
Radiation Interactions	22
Radiation Shielding	54
Radioactive Decay Chains	90
Radon	25
Rules of Thumb	10
SI & US Units	1
Statistics	38
Surface and Volume Calculations	8
Table of the Elements	36
Units and Terminology	21

Author's notes

Over my career in health physics starting with a US Army CBR unit at Dugway Proving Grounds in 1965 I have needed to quickly find that elusive data point that I just couldn't remember, even though I knew the information was in one of my several hundred reference books.

My early attempts to develop a reference book began in 1967 during my Army career, then I added to the material as I gained experience in the commercial nuclear power industry and later the Department of Energy. Finally in 1998 the first of these radiation reference books were published.

So, here it is today, the product of my work to assemble useful field information from a wide range of sources. I must give credit to those individuals who put their efforts into creating the original data. Without their work, this document could not have been assembled.

I must give further credit to those special individuals who have encouraged and helped me over these many past years. Morgan Cox, Mark Hoover, Mike McNaughton, and Chuan-Fu Wu have been outstanding companions who have urged me to attempt ever more challenging projects and have always been there to help me along.

Finally, my family has given me their unlimited support in my development of this reference book and in my projects all through my career. Sandy my wife of 30 some years and our two daughters Susan and Sarah and their excellent husbands, Bill Gilson and Rolfe Bergstrom, my son-in-laws, continue to provide me with a steady foundation that allows me to try out new concepts.

James T. (Tom) Voss, NRRPT, CHP
Fellow of the Health Physics Society
New Mexico, 2007

Send your orrections, additions, deletions, and comments to:
TVOSS@NEWMEXICO.COM

SI and US "Traditional" Units

Activity

1 TBq	=	27 Ci
1 GBq	=	27 mCi
1 Mbq	=	27 µCi
1 kBq	=	27 nCi
1 Bq	=	27 pCi
1 Bq	=	1 dps
1 Bq	=	60 dpm
1 kCi	=	37 TBq
1 Ci	=	37 Gbq
1 mCi	=	37 MBq
1 µCi	=	37 kBq
1 nCi	=	37 Bq
1 nCi	=	37 dps
1 nCi	=	2220 dpm
1 pCi	=	0.037 Bq
1 pCi	=	2.22 dpm

Dose Equivalent

1 Sv	=	100 rem
1 mSv	=	100 mrem
1 mSv	=	0.10 rem
1 µSv	=	100 µrem
1 µSv	=	0.10 mrem
1 nSv	=	0.10 µrem
1 krem	=	10 Sv
1 rem	=	10 mSv
1 mrem	=	10 µSv
1 mrem	=	0.01 mSv
1 µrem	=	0.01 µSv
1 µrem	=	10 nSv

Absorbed Dose

1 kGy	=	100 krad
1 Gy	=	100 rad
1 mGy	=	100 mrad
1 µGy	=	100 µrad
1 krad	=	10 Gy
1 rad	=	10 mGy
1 mrad	=	10 µGy
1 µrad	=	10 nGy

Dose Rate

1 Sv/h	=	100 rem/h
1 mSv/h	=	100 mrem/h
1 mSv/h	=	0.10 rem/h
1 µSv/h	=	100 µrem/h
1 µSv/h	=	0.1 mrem/h
1 krem/h	=	10 Sv/h
1 rem/h	=	10 mSv/h
1 mrem/h	=	10 µSv/h
1 mrem/h	=	0.01 mSv/h
1 µrem/h	=	0.01 µSv/h

ABBREVIATIONS

ampere	A, or amp
angstrom unit	A, or Å
atmosphere	atm
atomic weight	at. wt.
becquerel	Bq
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
gram	g or gm
hour	h, or hr
inch	in.
liter	liter, or 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
	Length	
angstroms	1E-8	centimeters
inches	2.54	centimeters
meters	3.2808	feet
kilometers	0.6214	miles
miles	5,280	feet
microns (µm)	1E-6	meters
mils	1E-3	inches
thousands of an inch (0.001")	2.54E-2	mm
yard	0.9144	meters
	Area	
acres	43,560	square feet
barns	1E-24	square cm
square centimeters	0.1550	square inches
square meters	10.764	square feet
square meters	3.861E-7	square miles
square miles	640	acres
	Volume	
cubic centimeters	3.531E-5	cubic feet
cubic centimeters	1E-6	cubic meters
cubic centimeters	0.03381	fluid ounces
cubic feet	28.316	liters
cubic feet	7.481	gallons
liters	1.057	quarts
liters	0.2642	gallons
liters	61.0237	cubic inches
cubic meters	35.315	cubic feet
cubic meters	1,000	liters
milliliters	1	cm^3

Multiply	by	To Obtain
	Mass	
grams	0.03527	ounces
kilograms	2.2046	pounds
pounds	16	ounces
pounds	453.59	grams
	Density	
grams / cm^3	62.428	pounds / cu ft
grams / cm^3	8.345	pounds / gallon
	Concentration	
µCi / cc	2.22E12	DPM / M^3
Bq / M^3	60	DPM / M^3
pCi / L	37	Bq / M^3
µCi / cc	3.7E10	Bq / M^3
pCi / Ft^3	3.53E-11	µCi / cc
pCi / L	1E-9	µCi / cc
DPM / M^3	4.5E-13	µCi / cc
DPM / M^3	1.67E-2	Bq / M^3
	Pressure	
atmospheres	1.01325	bars
atmospheres	101.325	kPa (kilopascals)
atmospheres	14.696	pounds / in^2
atmospheres	760	mm Hg
atmospheres	29.9213	inches of Hg
atmospheres	33.8995	feet H_2O
bars	1E6	dynes / cm^2
dynes / cm^2	1.0197E-3	grams / cm^2
dynes / cm^2	0.1	Pascals
Torr	1	mm Hg

Radiological

rads	100	ergs / gram
rads	6.242E13	electron volts / gram
roentgens	87.7	ergs / gram of air
roentgens	1.61E12	ion pairs/gram of air
roentgens	5.47E13	electron volts/gm air
roentgens	0.98	rads (in soft tissue)
rem	100	ergs / g in tissue
sievert	100	rem
sievert	1	J / kg
curie	3.7E10	dps
curie	2.22E12	dpm
μcuries / sq. meter	220	dpm / cm^2
megacuries / sq mile	0.386	curies / sq meter
dpm / m^3	4.5E-13	microcuries / cm^3
becquerel	2.7027E-11	curies
becquerel	1	dps
BTU	1.28E-8	grams ^{235}U fissioned
BTU	3.29E13	fissions
fission of 1 g ^{235}U	1	megawatt-days
fission of 1 g ^{235}U	1.8E-2	kilotons TNT
fissions	8.9058E-18	kilowatt-hours
fissions	3.204E-4	ergs
fissions	6.9E-21	Megatons TNT
gray	100	rads
joule	6.24E18	eV

Others

amperes	2.998 E9	electrostatic units/sec
amperes	6.242 E18	electronic charges/sec
coulombs	6.242 E18	electronic charges

Multiply	by	To Obtain
	Power	
joules/sec	1E7	ergs / second
watts	1E7	ergs / second
watts	1	joules / second
watts	0.001341	horsepower
watts	3.1E10	fissions / second
BTU/min	0.01757	kW
BTU/min	0.023575	hp
hp	0.7457	kW
joules	9.478E-4	BTU
joules	1E7	ergs
calories, g	0.003971	BTU

MULTIPLES AND SUBMULTIPLES

1E18	Exa	E	1E2	hecto	h	1E-6	micro	μ
1E15	Peta	P	1E1	deka	da	1E-9	nano	n
1E12	tera	T	1E0	1	1	1E-12	pico	p
1E9	giga	G	1E-1	deci	d	1E-15	femto	f
1E6	mega	M	1E-2	centi	c	1E-18	atto	a
1E3	kilo	k	1E-3	milli	m			

GREEK ALPHABET

A	α	Alpha	I	ι	Iota	R	ρ	Rho
B	β	Beta	K	κ	Kappa	S	σ	Sigma
G	γ	Gamma	L	λ	Lambda	T	τ	Tau
D	δ	Delta	M	μ	Mu	U	υ	Upsilon
E	ϵ	Epsilon	N	ν	Nu	F	ϕ	Phi
Z	ζ	Zeta	X	ξ	Xi	C	χ	Chi
H	η	Eta	O	ο	Omicron	Y	ψ	Psi
Q	θ	Theta	P	π	Pi	Ω	ω	Omega

CONSTANTS

Avogadro's number (N_0)	6.02252E23
electron charge (e)	4.80298E-10 esu
electron rest mass (m_e)	9.1091 E-28 g
acceleration of gravity (g)	32.1725 ft / sec^2
@ sea level & 45^0 latitude	980.621 cm / sec^2
Planck's constant (h)	6.625E-27 erg-sec
velocity of light (c)	2.9979E10 cm / sec
	186,280 miles / sec
ideal gas volume (V_0)	22,414 cm^3 / mole (STP)
neutron mass	1.67482E-24 g
proton mass	1.67252E-24 g
ratio of proton to electron mass	1836.13
natural base of logarithms (e)	2.71828
p	3.14159
1C	6.2418E18 esus
1A	1 C/sec
1 barn (b)	1E-24 cm^2
charge (e^{-1})	1.6E-19 C
W for air	33.7 eV / ion pair
Universal gas constant (R)	8.32E7 ergs/^{0}C gram mol

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

$^0C = (^0F - 32)(5/9)$ $^0F = ^0C \times 1.8 + 32$

$^0K = ^0C + 273.1$ $^0R = ^0F + 459.58$

Conversion Equations

grams/sq. cm = density (g/cm^3) x thickness (cm)

Photon energy (keV) = 12.4 / wavelength (Å)

$P_1 V_1 / T_1 = P_2 V_2 / T_2$

SURFACE AREA CALCULATIONS

Triangle A (area) = ½ x b x h;
where b is the base and h is the height of the triangle

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 Q;
where a and b are the length of the sides, h is the altitude (or vertical height), and Q 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 height

Regular polygon of *n* sides
A (area) = 1/4 x n x a^2 x cotangent (180^0 / n);
where a is the length of a side and n is the number of sides

Circle A (area) = p x r^2; or 1/4 x p x d^2;
where r is the radius and d is the diameter

Cube A (area) = 6 x a^2;
where a is the length of a side

Cylinder A (area) = 2 x p x r x h;
where r is the radius and h is the length of the height

Sphere A (area) = 4 x p x r^2; or p x 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) = p x r^2 x h;
where r is the radius and h is the length of the height
Sphere V (volume) = 4/3 x p x r^3 **or** 1/6 x p x d^3
where r is the radius and 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

1 CFM sample for 1 week equals 10,080 CF (285.4 M^3)
2 CFM sample for 1 week equals 20,160 CF (571 M^3)

Ventilation Rates
Ventilation rates of work areas for health physics and industrial hygiene requirements is typically 6 to 7 volume turnovers per hour.
Calculate the ventilation rate in CFM to ventilate a room at 7 volume turnovers per hour given room dimensions of 30 feet by 30 feet by 10 feet. Volume of the room is 30 x 30 x 10 = 9,000 cubic feet. Seven volume turnovers per hour would be 7 times 9,000 cubic feet or 63,000 cubic feet per hour (1,050 CFM) room ventilation rate.

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	4.39 (~ 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 2p (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 60 KeV of energy per mm of air at 1 atmosphere STP.

4. Detector window thicknesses cause alpha particles to lose energy at about 0.8 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 detectors have a flatter energy vs efficiency response than gas-proportional or GM detectors.

6. Alpha particle energy transfer to air
6 MeV alpha particles produce 40,000 Ion Pairs per cm
4 MeV alpha particles produce 55,000 Ion Pairs per cm

ω for air is 34 eV per Ion Pair
therefore;

6 MeV alpha particles lose 1.18 MeV per cm of air
4 MeV alpha particles lose 1.87 MeV per cm of air

7. Alpha particles lose about 0.8 MeV per mg/cm^2 density thickness of the attenuating material.

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.
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 (3.6 m) / MeV.
4. The range of beta particles (or electrons) in grams / cm^2 (thickness in cm multiplied by the density in g / 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 exposure rate in rads per hour in an infinite medium uniformly contaminated by a beta emitter is 2.12 EC / r where E is the average beta energy per disintegration in MeV, C is the concentration in µCi / cm^3, and r 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 mCi / cm^2 is about 9 rads/h (90 mGy/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 ~100.
7. The bremsstrahlung from a 1 Ci P^{32} aqueous solution in a glass bottle is ~ 3 mrad/h (30 µGy/h) at 1 m.
8. The range of beta particles from 0.01 to 2.5 MeV can be estimated using the following relationship

   R in mg/cm^2 ~ $412E^{(1.265 - 0.0954 \ln E)}$

   Where E is max beta energy

9. Half-value thickness vs beta energy

Isotope	β max energy (KeV)	Half-Value Thickness
Tc^{99}	292	7.5 mg / cm^2
Cl^{36}	714	15 mg / cm^2
Sr/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 20 pound 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 sheets 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 1/2, then use this formula to estimate the half-value thickness.

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

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

$$KeV = 250 \times \sqrt{\text{thickness from 'D' or "E' above}} - 300$$

RULES OF THUMB FOR GAMMA RADIATION

1. The range of gamma rays (any photon) for energies from eV to 10 MeV in air is from a few mm to 100 meters. The range of those photons in water is from a few mm to several cm.

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

	Dose Rate	
Energy (MeV)	**rem/h**	**mSv/h**
0.4	7.2	72
0.6	10	100
0.8	13	130
1.0	16	160
1.2	19	190

3. The dose rate in rem/h per hour in an infinite medium uniformly contaminated by a gamma emitter is 2.12 EC / r, where C is the number of microcuries per cubic centimeter, E is the average gamma energy per disintegration in MeV, and r 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 1,600 EC rem/h per mCi / cm^3.

4. The radiation scattered from the air (skyshine) from a 100 Ci ^{60}Co source 30 cm behind a 1 m high shield is ~ 100 mR/h (1 mSv/h) at 15 cm from the outside of the shield.

RULES OF THUMB FOR NEUTRONS

1. Use the following equation to approximate the number of neutrons per second per Ci.

   neutrons / s / Ci = 5.624E3 x (alpha particle MeV)$^{3.65}$
   This is approximate for Be, multiply by 0.16 for B, by 0.05 for F, by 0.015 for Li, and 0.003 for O targets.

2. Use the following equation to calculate the number of neutrons per sec per cm^2.

   $0.08Q / R^2$
   Q is neutrons per second and R is the distance in cm.

3. For neutron energies from 1 to 10 MeV the neutron exposure rate is 1 mrem per hour at 1 meter for each 1E6 neutrons per second emission rate. Multiply the neutron mrem per hour at 1 meter by 11.1 to calculate the neutron exposure rate for the same source at a distance of 30 cm.
4. For spontaneous fission the gamma exposure rate for an unshielded source is twice the neutron exposure rate. The gamma exposure rate includes the “prompt” gammas and the gamma decay from the short-lived progeny of the fission fragments.
5. The range of neutrons in air for neutron energies from 0 to 10 MeV is from a few centimeters to 100 meters.
6. The range of neutrons in water (or tissue) for neutron energies from 0 to 10 MeV is from a few millimeters to 1 meter.

RULES OF THUMB FOR NEUTRONS

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).

Neutron Fluence per mrem (10CFR20)

MeV	n/cm^2 per mrem	$n/cm^2/s$ per mrem/hr	MeV	n/cm^2 per mrem	$n/cm^2/s$ per mrem/hr
thermal	....	......	10	2.4E4	6.7
to	9E5	250	14	1.7E4	4.7
1E-2	....	....	20	1.6E4	4.4
1E-1	1.7E5	47	40	1.4E4	6.7
5E-1	3.9E4	11	60	1.6E4	4.4
1	2.7E4	7.5	100	2E4	5.6
2.5	2.9E4	8	200	1.9E4	5.3
5	2.3E4	6.4	300	1.6E4	4.4
7	2.4E4	6.7	400	1.4E4	6.7

Spontaneous Fission Neutron Yields

	SF (years) half-life	n/s/Ci	n/s/GBq	mrem / hr per Ci @ 30 cm neutron	gamma
Es^{253}	6.7E5	7.14E3	1.92E2	0.1	0.2
Cf^{252}	85	2.64E9	7.14E7	2.93R4	6E4
Bk^{249}	6E8	1.25E2	3.38	<0.1	<0.1
Cm^{244}	1.38E7	1.11E5	3.0E3	1.2	2.4
Cm^{242}	7.2E6	5.28E3	1.43E2	<0.1	0.1
Am^{241}	2E14	0.18	4.86E-3	<0.1	<0.1
Pu^{242}	7E10	4.56E5	1.23E4	5.0	10.0
Pu^{240}	1.39E11	4.01E3	1.08E2	<0.1	0.1
Pu^{239}	5.5E15	0.37	1.0E-2	<0.1	<0.1
Pu^{238}	4.9E10	1.52E2	4.1	<0.1	<0.1
Pu^{236}	3.5E9	69.7	1.88	<0.1	<0.1
Np^{237}	1E18	0.18	4.86E-3	<0.1	<0.1
U^{238}	7E15	5.44E4	1.47E3	0.6	1.2
U^{235}	1.9E17	3.15E2	8.51	<0.1	<0.1
U^{234}	2E16	1.05	2.84E-2	<0.1	<0.1
U^{232}	8E13	0.07	1.89E-3	<0.1	<0.1
Th^{232}	1E21	1.18	3.19E-2	<0.1	<0.1

These neutron and gamma exposure rates are approximate values for the spontaneous fission process. When you are making exposure rate measurements you should take into account shielding of the source (including self-shielding), individual instrument response to both neutron and gamma radiation, isotopic mixtures, age of the material (for both decay and ingrowth), homogeneity of the material, and impurities. Refer to the Specific Activity and Characteristic Radiations of Commonly Encountered Radionuclides sections for information on gamma exposure rates and radiations from primary decay modes of these isotopes.

Energy & Yield of neutrons from the alpha, n reaction

	η energy MeV	**n/s/GBq**	**n/s/Ci**	**mrem/hr per Ci @ 30 cm**
$Cf^{252}O$	4.5	8.73E6	3.23E8	3,600
$Cm^{244}Be$	4	1.0E5	3.7E6	41.1
$Cm^{244}O$	1.9	1.0E5	3.7E6	41.1
$Cm^{242}Be$	4	1.12E5	4.1E6	45.5
$Cm^{242}O$	1.9	1.12E5	4.1E6	45.5
$Am^{241}Be$	4.5	7.6E4	2.8E6	34.7
$Am^{241}B$	2.8	1.3E4	4.8E5	5.9
$Am^{241}F$	1.3	4.1E3	1.5E4	0.17
$Am^{241}Li$	0.7	1.4E3	5.2E4	0.29
$Am^{241}O$	1.9	250	9.23E3	0.1
$Pu^{242}O$	1.7	2.13E-4	7.88E-3	8.7E-8
$Pu^{240}O$	1.9	0.86	32	3.6E-4
$Pu^{239}Be$	4.5	6.1E4	2.3E6	28.5
$Pu^{239}O$	1.9	0.06	2.36	2.6E-5
$Pu^{238}Be$	4.5	7.9E4	2.9E6	32.2
$Pu^{238}O$	1.9	6.19E3	2.29E5	2.5
$Pu^{239}F$	1.4	5.4E3	2E5	2.2
$Pu^{238}Li$	0.6	38	1.4E3	0.008
$Pu^{238}C^{13}$	3.6	1.1E4	4.1E4	0.46
$Pu^{236}O$	2.0	54	2E3	0.02
$Np^{237}O$	1.2	54	2E3	0.02
$U^{238}O$, $U^{235}O$, $U^{234}O$, $U^{233}O$, and $U^{232}O$ have similar alpha particle energies, therefore the energy and yield of the neutrons from the uranium oxide alpha, n reactions are similar.	1.2	54	2E3	0.02
$Th^{232}O$	1.2	54	2E3	0.02

Energy & Yield of neutrons from the alpha, n reaction

	η energy MeV	n/s/GBq	n/s/Ci	mrem/hr per Ci @ 30 cm
$Ac^{227}Be$	av 5	7.02E5	2.6E7	289
$Ra^{226}Be$	av 4.5	5.02E5	1.9E7	211
$Ra^{226}B$	3.0	8.0E4	3.0E5	3.3
$Po^{210}Be$	4.2	7.1E4	2.6E6	28.9
$Po^{210}Li$	0.48	1.2E3	4.4E4	0.49
$Po^{210}B$	2.5	1.0E3	3.7E5	4.1
$Po^{210}F$	0.42	3E3	1.1E5	1.2

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

Energy & Yield for 5.2 MeV alpha particles for various elements

α, η sources	η energy (MeV)	n/s/GBq	n/s/Ci
Li	0.3	1.13E3	4.2E4
Be	4.2	6.5E4	2.4E6
B	2.9	1.75E4	6.5E5
C	4.4	7.8E1	2.9E3
O	1.9	5.9E1	2.2E3
F	1.2	5.9E3	2.2E5
Na	?	1.1E3	4.1E4
Mg	2.7	8.9E2	3.3E4
Al	1.0	4.1E2	1.5E4
Si	1.2	7.6E1	2.8E3
Cl	?	7E1	2.6E3

MISCELLANEOUS RULES OF THUMB

1. One watt of power in a reactor requires 3.1E10 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 » (FY)(PL) ,
   where FY is the fission yield (%/100) and PL is the power level in watts.
3. Correction factor for unsealed ion chambers to STP (0^0C and 760 mm of Hg) is f = (t + 273)/(273) x (760 / P) where t is the ambient temperature in degrees C and P is the ambient 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. Isotopic Mix of U by % Weight

	Natural	Commercial	Enriched 10%	Enriched 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

6. Isotopic Mix of U by % Activity

	Natural	Commercial	Enriched 10%	Enriched 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

7. Uranium Specific Activity
   natural U is 6.8 E-7 Ci/g — U^{235} 2.16 E-6 Ci/g
   U^{238} 3.36 E-7 Ci/g — U^{234} 6.22 E-3 Ci/g

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 E12 dpm)	Becquerel (1dps)

1 Roentgen	= 2.58 E-4 coulomb / kg in air
	= 1 esu / cm^3 in air
	= 87.7 ergs / gm in air
	= 98 ergs / gm in soft tissue
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, α) (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
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 #
    emitted energy is ~ 1/3 of the electron energy
Photon Attenuation: $I_x = I_0e^{\mu x}$
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 (2 mSv) / yr
Living in Los Alamos (7000' elev)	327 mrem (3.27 mSv)/yr
Flying from NY to LA	2.5 mrem (25 μSv) / trip
Chest x-ray	10 mrem (0.1mSv)/exam
Full mouth dental x-ray	9 mrem (90 μSv) / exam

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

BACKGROUND RADIATION

Cosmic	=	28 mrem (0.28 mSv) / yr
Rocks	=	28 mrem (0.28 mSv) / yr
Internal	=	36 mrem (0.36 mSv) / yr
Medical x-rays	=	20 to 30 mrem (0.2 to 0.3 mSv)/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:

Skull 20 mrem (0.2 mSv),
Upper GI 245 mrem (2.45 mSv),
Hip 65 mrem (0.65 mSv),
Chest 6 mrem (60 μSv),
Kidney 55 mrem (0.55 mSv),
Dental 55 mrem (0.55 mSv)

Comparison of Occupational Doses

Occupation	mrem /yr	mSv/yr
airline flight crew	1,000	10
nuclear power plant	700	7
Grand Central Station workers	120	1.2
medical personnel	70	0.7
DOE employees	44	0.44

NATURALLY OCCURRING RADIONUCLIDES

Primordial	Cosmogonic
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	2,370
20% overweight	985
Average US alcohol consumption	130
Home accidents	95
Occupational exposure	
• 5.0 rem (50 mSv) / year	32
• 0.5 rem (5 mSv) / year	3

COMPARISON OF OCCUPATIONAL RISKS

Occupation	Estimated Days of Life Lost
demolition	1,500
mining	1,100
firefighting	800
railroad	500
farming	300
construction	200
transportation & public utilities	160
average of all occupations	**60**
government	55
radiation dose of 1 rem (10 mSv) per year	50
service	45
trade	30
single radiation dose of 1 rem (10 mSv)	1.5

RADON FACTS

1 working level	= 3 DAC Rn^{222} (including progeny)
	= 1.3 E5 MeV / liter of air α energy
	= 100 pCi / liter (1 E-7 μCi / ml)
	= 20.8 μJoules / m^3
1 working level-month	= 1 rem CEDE

EPA ACTION LEVELS FOR RADON GAS IN HOMES

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

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

PROPOSED EPA ACTION LEVELS FOR RADON IN DRINKING WATER

Maximum Contaminant Level - MCL is 300 pCi / L of radon in water of community water systems.
Alternative Maximum Contaminant Level - AMCL is 4,000 pCi / L of radon in water of community water systems.

To comply with the AMCL limit the state or the CWS must implement a Multi-Media Mitigation plan to address the radon in the air of residences.

The proposed rule would not apply to CWSs that use soley surface water.

The proposed rule requires monitoring for radon in drinking water. The monitoring frequency varies from once per quarter to once in 9 years based on radon concentrations.
10,000 pCi / l in water ≈ 1pCi / l in air thru evaporation

AIR POLLUTION SAFE LIMITS (mg / m^3)

Pollutant	Limit	Pollutant	Limit
Benzene **	0.3	Iron oxide (fume)	5
Bromine	0.66	Isopropyl alcohol	980
Cadmium *	0.002	Lead (dust & fume)	0.2
CO_2	9,000	Manganese	0.2
Carbon disulfide	31	Mercury	0.01
CO	29	Methanol	0.2
Carbon tetrachloride ***	31	Nitric oxide	30
Chlorine	1.5	NO_2	5.6
Chloroform *	49	Selenium	0.2
Cresol	22	SO_2	5.2
Ethanol	1,880	Sulfuric acid	1
Fluorine	1.6	Tellurium	0.1
Formaldehyde *	0.37	Tetraethyl lead	0.1
Gasoline	890	Toluene	188
Hydrogen cyanide	11	Turpentine	560
Iodine	1	Vinyl chloride **	13
		Zinc oxide (fume)	5

Asbestos ** 0.2 fibers / cc

* Suspected human carcinogen
** Animal carcinogen
*** Confirmed human carcinogen

RADIATION BIOLOGY

Maximum survivable dose: 1000 rem (10 Sv)

Cancer mortality rate ≈ 900 excess deaths per 100,000 persons at 0.1 Sv (10 rem)

Radiation Dose Risk

Report	Additional Cancer Deaths
BEIR III 1980 (also Reg Guide 8.29)	3 in 10,000 per 1 rem (10 mSv)
BEIR V 1990	800 in 100,000 per 10 rad (0.1 Gy)

Hiroshima Survivors Incidence of Cancer

4,000 Hiroshima survivors who received doses greater than 50 rem showed an extra 300 incidences of cancer.

COMPOSITION OF THE HUMAN BODY

O	65 %	Rb	0.00046 %	I	1.6E-5 %
C	18	Sr	0.00046	Au	1.4E-5
H	10	Br	0.00029	Ni	1.4E-5
N	3	Pb	0.00017	Mo	1.3E-5
Ca	1.5	Nb	0.00016	Ti	1.3E-5
P	1.0	Cu	0.00010	Te	1.2E-5
S	0.25	Al	0.000087	Sb	1.1E-5
K	0.20	Cd	0.000072	Li	3.11E-6
Cl	0.15	B	0.000069	Cr	2.4E-6
Na	0.15	Ba	0.000031	Cs	2.1E-6
Mg	0.05	As	0.000026	Co	2.1E-6
Fe	0.006	V	0.000026	Ag	1.0E-6
F	0.0037	Sn	0.000024	U	1.3E-7
Zn	0.0032	Hg	0.000019	Be	5E-8
Si	0.0020	Se	0.000019	Ra	1E-13
Zr	0.0006	Mn	0.000017		

ACUTE RADIATION EFFECTS

Phase of Syndrome	Feature	Effects of whole-body radiation exposure		
		0-1 Gy	1-2 Gy	2-8 Gy
Promordal	Nausea, vomiting	None	5-50%	50-100%
	Time of onset		3-6 hr	2-4 hr
	Duration		<24 hr	<24 gr
	Lymphocyte Count	None	Minimally decreased	<1,000 at 24 hr
	CNS function	None	None	Routine task performance Cognitive impairment for 6-20 hr
Latent	No symptoms	>2 wk	7-15 d	0-7 d
Manifest Illness	Signs, symptoms	None	Moderate leukopenia	Severe leukopenia, purpura, hemmorhage, penumonia, hair loss after 3 Gy
	Time of onset		> 2 wk	2 d - 2 wk
	Critical period		None	4-6 wk, greatest potential for effective medical intervention
	Organ system	None		Hematopoietic, respiratory (mucosal) systems
	Hospital duration	0%	<5% 45-60 d	90% 60-90 d
	Mortality	None	Minimal	Low with aggressive therapy

Phase of Syndrome		Effects of whole-body radiation exposure		
	Feature	6-8 Gy	8-30 Gy	>30 Gy
Promordal	Nausea, vomiting	75-100%	90-100%	100%
	Time of onset	1-2 hr	<1 hr	Minutes
	Duration	<48 hr	<48 hr	N/A
	Lymphocyte Count	<500 at 24 hr	Decreases within hrs	Decreases within hrs
	CNS function	Simple, routine task performance Cognitive impairment for >24 hr	Rapid incapacitation May have a lucid interval of several hours	
Latent	No symptoms	0-2 d	None	
Manifest Illness	Signs, symptoms	Severe leukopenia, purpura, hemorrhage, pneumonia, hair loss	Diarrhea, fever, electrolyte disturbance	Convulsions ataxia, tremor, lethargy
	Time of onset	2 d - 2 wk	1-3 d	
	Critical period	4-6 wk, greatest potential for effective medical intervention	2-14 d	1-48 hr
	Organ system	Hematopoietic, respiratory (mucosal) systems	GI tract Mucosal systems	CNS
	Hospital duration	100% 90+ d	100% wks to months	100% days to weeks
	Mortality	High	Very high, significant neurological symptoms indicate lethal dose	

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 = $\sum W_T H_T$

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 (0.01 mSv) / hr per 6 n / cm^2-sec

Slow: 1 mrem (0.01 mSv) / 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	= 1 Coulomb / sec
STP_{air}	= 760mm Hg @ 0^0C or 14.7lb / in^2 @ 32^0 F

INTERNAL DOSIMETRY

Calculating CDE and CEDE ICRP 26/30

CDE = I / nALI x 50 rem (0.5 Sv) nALI is the non-stochastic ALI

CDE = 50 yr committed dose equivalent to irradiated tissue

I = Intake

nALI = non-stochastic ALI = 50 rem (0.5 Sv)/ h_{max}

h_{max} = greatest dose equivalent found in the exposure-to-dose conversion tables

CEDE = I / sALI x 5 rem (50 mSv) sALI is the stochastic ALI

CEDE = 50 yr committed effective dose equivalent

OR CEDE = $\sum_{i=1}^{n} W_T$

CEDE = 50 yr committed effective dose equivalent to individual tissue

W_T = tissue weighting factor

Calculating DAC

DAC = ALI / 2000 hr at 1.2 E6 ml / hr

1 DAC-h = 2.5 mrem (25 µSv) CEDE if based on sALI **OR** 25 mrem (0.25 mSv) ref ICRP 26 CDE to an organ or tissue if based on nALI

Calculating DAC-hours

DAC Fraction = $\sum_i$(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 (5 rem) x I / ALI

TEDE = CEDE + Deep Dose Equivalent

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.

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

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

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

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

$E = \sum_T W_T H_T$

E = effective dose to the individual

W_T = tissue weighting factor

H_T = equivalent dose in tissue(s) T

ICRP 60 Committed Effective Dose

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

E(50) = committed effective dose

W_T = tissue weighting factor for tissues & 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

Skin surface area = 18,000 cm^2

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

There are 140 g of potassium in standard man, 125 nCi (4.625kBq) is K^{40} which results in 0.25 mrem/wk or13 mrem/yr (2.5 µSv/wk or 0.13 mSv/yr) to the whole body. An additional 15 mrem/yr (0.15 mSv/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 > 2MeV	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	
TEDE	5 rem	50 mSv
TODE	50 rem	0.5 Sv
LDE	15 rem	0.15 Sv
SDE,WB	50 rem	0.5 Sv
SDE, ME	50 rem	0.5 Sv
TEDE (general public)	0.1 rem	1 mSv

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.

TABLE OF THE ELEMENTS

Z			Density	Z			Density
89	Actinium	Ac	10.07	64	Gadolinium	Gd	7.90
13	Aluminum	Al	2.6989	31	Gallium	Ga	5.9
95	Americium	Am	13.67	32	Germanium	Ge	5.32
51	Antimony	Sb	6.618	79	Gold	Au	19.32
18	Argon	Ar	0.0018	72	Hafnium	Hf	13.31
33	Arsenic	As	5.727	105	Hahnium	Ha	~ 18
85	Astatine	At	~ 15	2	Helium	He	1.8E-3
56	Barium	Ba	3.51	67	Holmium	Ho	8.795
97	Berkelium	Bk	14	1	Hydrogen	H	9E-5
4	Beryllium	Be	1.848	49	Indium	In	7.31
83	Bismuth	Bi	9.747	53	Iodine	I	4.93
5	Boron	B	2.37	77	Iridium	Ir	22.42
35	Bromine	Br	3.12	26	Iron	Fe	7.87
48	Cadmium	Cd	8.65	36	Krypton	Kr	0.0037
20	Calcium	Ca	1.55	57	Lanthanum	La	6.15
98	Californium	Cf	~ 18	103	Lawrencium	Lr	~ 18
6	Carbon	C	2.05	82	Lead	Pb	11.35
58	Cerium	Ce	6.67	3	Lithium	Li	0.534
55	Cesium	Cs	1.873	71	Lutetium	Lu	9.84
17	Chlorine	Cl	0.0031	12	Magnesium	Mg	1.738
24	Chromium	Cr	7.19	25	Manganese	Mn	7.43
27	Cobalt	Co	8.9	101	Mendelevium	Mv	~ 18
29	Copper	Cu	8.96	80	Mercury	Hg	13.546
96	Curium	Cm	13.51	42	Molybdenum	Mo	10.22
66	Dysprosium	Dy	8.54	60	Neodymium	Nd	7.008
99	Einsteinium	Es	~ 18	10	Neon	Ne	0.0009
68	Erbium	Er	9.066	93	Neptunium	Np	20.25
63	Europium	Eu	5.244	28	Nickel	Ni	8.9
100	Fermium	Fm	~ 18	41	Niobium	Nb	8.57
9	Fluorine	F	0.0017	7	Nitrogen	N	0.00125
87	Francium	Fr	~ 15	102	Nobelium	No	~ 18

Z			Density	Z			Density
76	Osmium	Os	22.57	14	Silicon	Si	2.33
8	Oxygen	O	0.00143	47	Silver	Ag	10.5
46	Palladium	Pd	12.02	11	Sodium	Na	0.97
15	Phosphorus	P	2.2	38	Strontium	Sr	2.54
78	Platinum	Pt	21.45	16	Sulfur	S	2.0
94	Plutonium	Pu	19.84	73	Tantalum	Ta	16.6
84	Polonium	Po	9.32	43	Technetium	Tc	11.5
19	Potassium	K	0.862	52	Tellurium	Te	6.24
59	Praseodymium	Pr	6.773	65	Terbium	Tb	8.27
61	Promethium	Pm	7.264	81	Thallium	Tl	11.85
91	Protactinium	Pa	15.37	90	Thorium	Th	11.70
88	Radium	Ra	5.5	69	Thulium	Tm	9.321
86	Radon	Rn	0.0097	50	Tin	Sn	6.5
75	Rhenium	Re	21.02	22	Titanium	Ti	4.54
45	Rhodium	Rh	12.41	74	Tungsten	W	19.3
37	Rubidium	Rb	1.532	92	Uranium	U	16.95
44	Ruthenium	Ru	12.41	23	Vanadium	V	6.11
104	Rutherfordium	Rf	~18	54	Xenon	Xe	0.0059
62	Samarium	Sm	7.54	70	Ytterbium	Yb	6.98
21	Scandium	Sc	2.989	39	Yttrium	Y	4.47
106	Seaborgium	Sg	~18	30	Zinc	Zn	7.13
34	Selenium	Se	4.5	40	Zirconium	Zr	6.06

RADIOACTIVITY

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

Decay Modes

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

Relative Locations of Products of 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^+ out ϵ	
α out	He^3 out			

η neutron p proton d deuteron
t triton (H^3) 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 ^{238}Pu 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. ^{238}Pu decays to ^{234}U.
As another example; we know ^{36}Cl 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. ^{36}Cl decays to ^{36}Ar.

COUNTING STATISTICS

Minimum Detectable Activity

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

Minimum Detectable Count Rate

LLD = L_D = MDCR $\dfrac{k^2 + 2k\sqrt{R_B \times t_{S+B} \times (1+t_{S+B}/t_B)}}{t_{S+B}}$

L_C = $k \times \sqrt{R_B \times t_{S+B} + R_B \times t_B}$

k = 1.645 (for 95% Confidence Level)
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
LLD is Lower Limit of Detection
L_D is the Decision Level
L_C is the Critical Level and generally expressed as counts (or signal level) above background

K	0.674	1	1.645	1.96	2.58	3.00
% C.L.	50	68.3	90	95	99	99.7

If R_B is in DPM it must be converted to CPM before using the above equations.
A 'k' of 1.645 is used as the 95% confidence level for a two-tailed distribution.
Gaussian statistics should be used for $\geq$ 30 counts and Poisson statistics for < 30 counts. The typical formulas such as those above are an attempt to blend the two statistics methods.

MDA when background and sample count times are one minute and k is 1.645. $\frac{3 + 4.65 \sqrt{R_B}}{Eff}$

MDA when background count time is ten minutes and sample count time is one minute and k is 1.645. $\frac{3 + 3.45 \sqrt{R_B}}{Eff}$

POISSON STATISTICS

For Poisson distributions the following logic applies.

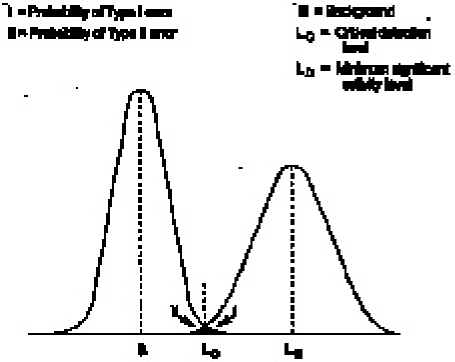
P_n is the probability of getting count "n"

$$P_n = \frac{\mu^n e^{-\mu}}{n!}$$

n = the hypothetical count

μ = true mean counts

If the true mean, μ, is 3, then there is a 5% probability that we will get a zero count and a 95% probability that we will get greater than zero counts. There is a 65% probability that we will get 3 or more counts.



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 following applies to air ionization chambers with a window thickness of 7 mg/cm^2.

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

Obtain the **CF** from experimental or published data for the specific detector and radiation source(s).

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. The principles can also be applied to airborne areas.

Stay-time = Allowable exposure/exposure rate

example:

Stay-time = 100 mR / 25 mR/hr = 4 hours

Exposure Rate in an Air-Filled Ion Chamber

X = I / m[1 / (2.58E-4 C / kg-R)]
X = exposure rate R / sec)
I = current (amperes)
m = mass of air in chamber (kg)

% Resolution of a Gamma Spec System

% R = FWHM / peak energy x 100 = % resolution
FWHM = peak energy width at full width half-max height
peak energy = photopeak energy of interest

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

R_C = $R_0 / (1 - R_0 Y)$ = true count rate
R_0 = observed count rate
Y = resolving time

Specific Gamma-Ray Constant (Γ) for Source Activity (A)

Γ = $\phi E_\gamma (\mu_{en} / \rho)_{air} e / W$
Γ = specific gamma constant ($R\text{-}cm^2$ / hr-A)
ϕ = photon fluence rate (γ / cm^2-hr)
E_γ = 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)

Dose Rate (D) to Air from a Point Beta Source

D = $300\ A / d^2$ = rad /hr
A = source activity in curies
d = distance from source in feet

Photon Fluence Rate ϕ from a Point Source

ϕ = $AY / 4\pi r^2$ = photon fluence rate (γ / cm^2-hr)

A = source activity (decay per hr)

Y = photon yield (γ / decay)

r = distance from point source (cm)

Exposure Rate (X) from a Point Source

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

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

A = activity of source in curies

r = distance from source in meters

Exposure Rate (X) from a Line Source

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

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

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) = $\Gamma A_L / R \times \tan^{-1}(L / R)$

Γ = R/hr @ 1 meter per Ci

A_L = activity per unit length (curies per meter)

R = distance from line in meters

Exposure Rate (X) from a Disk Source

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

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

Inverse Square Law

$$X_1 (D_1)^2 = X_2 (D_2)^2$$

X_1 = Measured exposure rate
D_1^2 = Distance from source for the measured exposure rate
X_2 = Exposure rate to be calculated
D_2^2 = New distance from the source

Applying the Inverse Square Law to Dose Reduction

Given: A high activity source at an unknown distance.
Find: Exposure rate from the source at 30 cm without approaching closer to the source.
X_2 is measured exposure rate at distance Y
X_3 is measured exposure rate at distance Y + 100 cm

$X_2 (Y)^2 = X_3 (Y + 100 \text{ cm})^2$
$Y^2 = X_3 (Y + 100 \text{ cm})^2 / X_2$

Set up this equation by entering the exposure rates you measured at distances Y and Y + 100 cm
Let us assume 100 mr/hr and 50 mr/hr for those two points.
$Y^2 = 50 (Y + 100 \text{ cm})^2 / 100 = 0.5Y^2 + 100Y + 5{,}000$
simplify this to $Y^2 - 200Y - 10{,}000 = 0$
This quadratic equation can be factored into two answers.
The positive answer for Y is 241.42 cm.
Now we know the distance for exposure rate X_2 and we can calculate the exposure rate at any distance.
The exposure rate at 30 cm would be 6,476 mR/hr but we were able to calculate that exposure rate without entering the High Radiation Area. A simpler method without having to factor a quadratic equation is to back AWAY from the source until the exposure rate is 1/4 of the initial rate. The distance you moved away is equal to the original distance to the source. Now you can use the inverse square law to calculate the 30 cm exposure rate.

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

2.22TBqEN

The same formula in Sv/h is given by 2.22 TBqEN, where TBq is the number of terabecquels.

Sv/hr at 30 cm = 2.22TBqEN

where; TBq = quantity of radioactive material

Airborne Activity General Dispersion Model

Assume a 1 µCi (37 kBq) release of respirable Pu^{239} inside a large room measuring 12 x 12 x 3 meters with a ventilation turnover rate of 7 volumes per hour. The General Dispersion Model uses this 2π formula for volume.

$V = 2/3 \times \pi \times R^3$

Volume in cm^3	30 cm	1 M	10 M
@ distance R	5.65E4	2.09E6	2.09E9
Concentration @ R			
in µCi / cc	1.77E-5	4.78E-7	4.78E-10
in Bq / M^3	6.55E5	1.77E4	17.7
in DAC	8.85E6	2.39E5	239
Time for airborne			
wave front to reach R	13 sec	43 sec	7.15 min

Airborne Radioactivity (long-lived)

C_S = R_N / (V x ϵ x SA x CE x CF)
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

Airborne Radioactivity (short-lived)

C_S = $R_N / [V \times \epsilon \times SA \times CE \times CF \times (1-e^{-\lambda t_s}) \times (e^{-\lambda t_d})]$
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

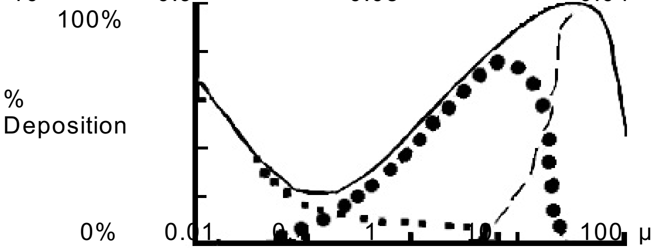
** Current regulations may allow a PF of 100 but plan on 50 for the future.

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

Bubble suits have been used in Pu atmospheres as high as 1,000,000 DAC. Supplied-air respirators are worn inside the bubble suits and real-time air monitoring INSIDE the bubble suits is performed.

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



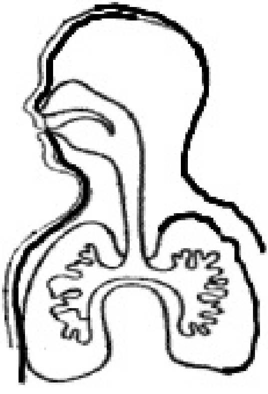
● ● ● ● T-B tracheobronchial
■ ■ ■ ■ Alveolar
▬ ▬ ▬ ▬ N-P nasopharyngeal
▬▬▬▬▬▬ Total Deposition

Regions of Deposition

Naso-Pharyngeal

Tracheobronchial

Alveolar



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.

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

1 µCi = 2.22 E6 DPM

1 DPM / M^3 = 4.5 E-13 µCi / ml

1 µCi / ml = 2.22 E12 DPM / M^3

1 Bq = 1 DPS

DPM / M^3 = CPM/(Eff x total sample volume in M^3)

µCi / ml = CPM/(Eff x 2.22 E6 DPM / µCi x total sample volume in ml)

Bq / M^3 = CPM / (Eff x 60 DPM / Bq x total sample volume in M^3)

DAC = µCi / ml (µCi / ml per DAC {DAC Factor})

1 DAC-h = 1 DAC exposure for 1 hour

1 DAC-h = 2.5 mrem = 25 µSv

1 DAC for Pu239 is 4.44 DPM / M^3

Calculate the number of DAC-h on a filter by this formula

DAC-h = $\frac{\text{\# of DPM on filter}}{\text{(Sample flow rate in LPM x 1.332E11 x DAC factor)}}$

Calculate the DPM on a filter to reach 8 DAC-h

DPM = 8 DAC-h x flow rate in LPM x 1.33E11 x DAC factor

Calculate the DAC level on a filter from the # of DPM

DAC = $\frac{\text{\# of DPM}}{\text{(DAC factor x LPM x time in minutes x 2.22E9)}}$

AIR FLOW METER CORRECTIONS

Mass Flow Meters

Q_s = Q_A $(P_A/P_s \times T_s/T_A)$

Q_A = Q_S $(P_S/P_A \times T_A/T_S)$

where; Q_s is the STP flow rate

Q_A is the ambient flow rate

P_A is STP pressure

P_s is the ambient pressure

T_s is STP temperature

T_A is the ambient temperature

Rotameter Corrections

Q_s = $Q_I \sqrt{(P_A/P_s \times T_s/T_A)}$

Q_I = $Q_S \sqrt{(P_S/P_A \times T_A/T_S)}$

Q_A = Q_S $(P_S/P_A \times T_A/T_S)$

where; Q_I is the rotameter flow indication

P_s is the pressure inside the rotameter

T_A is the ambient temperature

If the rotameter is downstream from the sampling head then the ambient pressure inside the rotameter will be less than the local atmospheric pressure. The ambient pressure inside the rotameter should be used in the calculations.

For personnel protection against particulate airborne radioactivity ambient sample volumes instead of volumes corrected to STP should be used for calculations. The ambient respiratory rate will remain the same as atmospheric pressure changes from STP up to an elevation of approximately 12,000 feet (3,660 Meters).

SHIELDING MATERIALS

α	N/A
β^-	low Z, such as plastic or aluminum
γ	high Z, such as tungsten
mixed B^-/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"

Photon Half-Value Layers in CM

	100 KeV	600 KeV	1 MeV	2 MeV
U	0.005	0.25	0.48	0.78
W	0.008	0.35	0.58	0.82
Pb	0.012	0.52	0.90	1.35
Sn	0.06	1.20	1.38	1.80
Cu	0.18	1.01	1.70	1.65
Fe	0.25	1.15	1.32	1.55
Al	1.12	3.30	4.45	5.90
Concrete	1.8	3.8	4.6	6.2
Water	4.20	7.80	9.60	14.2

This table applies to a thin shield and no provision is made for buildup factor. Always perform a radiation measurement to confirm adequacy of shield.

Fast Neutron Half-Value Layes in CM

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

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) $I = B \times I_0 e^{-\mu x}$ **OR** $I_0 e^{-\mu_{en} x}$

- 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** $F = e^{-\mu x}$

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-m^2)

BETA SHIELDING

Bremsstrahlung Fraction:

f	=	3.5 (low Z) or 5 (high Z) x 1E-4 Z E_{max}
$Activity_{gamma}$	=	f x $Activity_{beta}$

SHIELD RATIO RULE OF THUMB

Estimate the effectiveness for an unlisted shield material by comparing that material's Z number and Specific Gravity with lead HVLs listed for iron. A higher Z and S.G. make a more effective gamma shield.

DENSITY OF VARIOUS MATERIALS (G / CM^3)

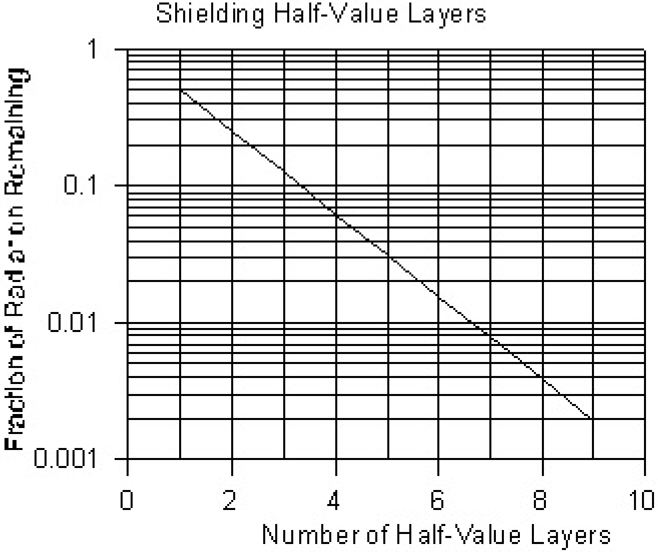
Air	0.0012928	Rubber	1.52
Snow (fresh)	0.16	Earth (packed)	1.52
Wood (cedar)	0.38	Sand	1.60
Snow (compacted)	0.48	Bricks	2.16
Wood (pine)	0.54	Sandstone	2.32
Wood (oak)	0.71	Concrete	2.48
Fat	0.80	Marble	2.56
Bone	0.88	Glass	2.58
Muscle	0.95	Limestone	2.61
Polyethylene	0.98	Granite	2.69
Water	1.00	Steel	7.85
Paper	1.20	Bronze	8.16
Linoleum	1.20	Brass	8.56
Polycarbonate	1.20		
PVC	1.30		

See the Table of Elements for element densities

SIMPLIFIED SHIELD THICKNESS CALCULATION

perform radiation measurements to verify these calculations

- I = shielded exposure rate
- I_0 = unshielded exposure rate
- n = number of shielding layers (tenth or half)
- $I = I_0 \times 0.1^n$ for tenth value thickness
- $I = I_0 \times 0.5^n$ for half value thickness



Neutron and Gamma Shielding

Using the graph for neutron or gamma shielding estimation.

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 neutron flux rate to 200 n/cm^2-sec at 30 cm

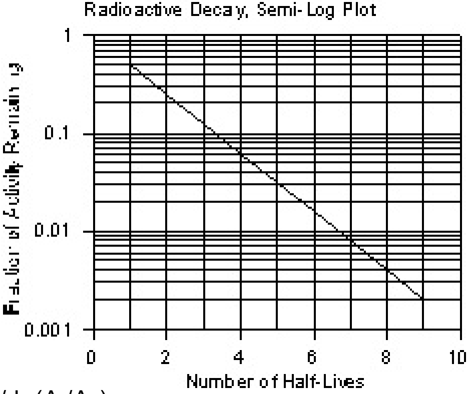
1. Divide 200 n/cm^2-sec by 12,000 n/cm^2-sec = 0.0167
2. Locate 0.0167 on the vertical axis and move across to where the slanted line crosses 0.0167, then move vertically down to the "Number of Half-Value Layers" horizontal axis, this value is approximately 5.9

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

1. Divide 5 mrem/hr by 120 mrem/hr = 0.042
2. Locate 0.042 on the vertical axis and see where it crosses the slanted line, then move vertically down to the "Number of Half-Value Layers" horizontal axis, this is approximately 4.6

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

Radioactive Decay



$A_t = A_o e^{-\lambda t}$
$A_o = A_t / e^{-\lambda t}$
$t = \ln(A_t / A_0) / -\lambda$
$\text{half-life} = -t \times 0.693 / \ln(A_t/A_0)$

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

Given: 10 mCi of P^{32} with a half-life of 14.3 days
Find: the activity remaining after 125 days

1. Determine the number of half-lives during the decay by dividing 125 by 14.3 = 8.74
2. 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
3. Multiply the original activity, 10 mCi, by 0.002; the activity remaining after 125 days is 0.02 mCi (20 µCi).

Table 1 of DOE 5400.5 Surface Activity Guidelines

Radionuclides	**Ave**	**Max**	**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 emiters[1]	5,000	15,000	1,000
Tritium[2]	N/A	N/A	10,000

[1] radionuclides with decay modes other than alpha emission or spontaneous fission except ^{90}Sr and others noted above
[2] applicable to surface and subsurface

Appendix D of 10CFR835

Nuclide	**Removable**	**Total (fixed + removable)**
Natural U, ^{235}U, ^{238}U, and associated decay products	1,000 alpha	5,000 alpha
Transuranics, ^{226}Ra, ^{228}Ra, ^{230}Th, ^{228}Th, ^{231}Pa, ^{227}Ac, ^{125}I, ^{129}I	20	500
Natural Th, ^{232}Th, ^{90}Sr, ^{223}Ra, ^{224}Ra, ^{232}U, ^{126}I, ^{131}I, ^{133}I	200	1,000
Beta/gamma emitters[1]	1,000	5,000
Tritium[2]	10,000	10,000

[1] nuclides with decay modes other than alpha emission or spontaneous fission except ^{90}Sr and others noted above
[2] Tritium organic compounds, surfaces contaminated by HT, HTO, and metal tritide aerosols
Contamination levels in dpm/100 cm^2

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 and 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

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 then document the survey.

SPECIFIC ACTIVITY

$$Ci / g = \frac{3.578\ E5}{(T_{1/2} \times \text{atomic mass})} \qquad GBq / g) = \frac{1.324\ E7}{(T_{1/2} \times \text{atomic mass})}$$

where $T_{1/2}$ is in years

	Half-Life	Ci / g	Rem/hr per Ci @ 30 cm	GBq/g	Sv/hr per GBq @ 30cm
H^3	12.3 y	9.70E3	N/A	3.59E5	N/A
Be^7	53.28 d	3.50E5	0.38	1.30E7	1.03E-4
C^{14}	5730 y	4.46	N/A	1.65E2	N/A
O^{15}	122.2 s	6.15E9	7.98	2.29E11	2.16E-3
N^{16}	7.13 s	9.88E10	16.35	3.66E12	4.42E-3
F^{18}	1.830 h	9.52E7	7.72	3.52E9	2.09E-3
Na^{22}	2.605 y	6.24E3	14.85	2.31E5	4.01E-3
Na^{24}	14.96 h	8.73E6	20.55	3.23E8	5.55E-3
Al^{26}	7.3 E5 y	1.89E-2	16.6	0.699	4.49E-3
P^{32}	14.28 d	2.86E5	N/A	1.06E7	N/A
Cl^{36}	3.01 E5 y	3.30E-2	N/A	1.22	N/A
K^{40}	1.28 E9 y	6.99E-6	0.91	2.59E-4	2.46E-4
Ar^{41}	1.82 h	4.20E7	7.73	1,55E9	2.09E-3
K^{42}	12.36 h	6.04E6	1.4	2.23E8	3.78E-4
K^{43}	22.3 h	3.27E6	5.6	1.21E8	1.51E-3
Sc^{46}	83.81 d	3.39E4	10.9	1.25E6	2.95E-3
Sc^{47}	3.349 d	8.30E5	0.56	3.07E7	1.51E-4
Sc^{48}	43.7 h	1.49E6	21	5.51E7	5.68E-3
V^{48}	15.98 d	1.70E5	15.6	6.29E6	4.22E-3
Cr^{51}	27.70 d	9.24E4	0.16	3.42E6	4.32E-5
Mn^{52}	5.591 d	4.49E5	18.6	1.66E7	5.03E-3
Mn^{54}	312.2 d	7.75E3	5.67	2.87E5	1.53E-3
Fe^{55}	2.73 y	2.38E3	N/A	8.81E4	N/A

	Half-Life	Ci / g	Rem/h per Ci @ 30 cm	GBq/g	Sv/h per GBq @ 30cm
Mn^{56}	2.578 h	2.17E7	10.24	8.03E8	2.77E-3
Co^{56}	77.3 d	3.02E4	21.36	1.12E6	5.77E-3
Co^{57}	271.8 d	8.43E3	1.68	3.12E5	4.54E-4
Ni^{57}	35.6 h	1.54E6	12	5.70E7	3.24E-3
Co^{58}	70.88 d	3.18E4	6.81	1.18E6	1.84E-3
Ni^{59}	7.60E4 y	0.0798	12.5	2.95	3.38E-3
Fe^{59}	44.51 d	4.97E4	7.34	1.84E6	1.98E-3
Co^{60}	5.271 y	1.13E3	15.19	4.18E4	4.11E-3
Cu^{62}	9.74 m	3.11E8	7.85	3.39E7	2.12E-3
Ni^{65}	2.52 h	1.91E7	3.40	7.07E8	9.19E-4
Zn^{65}	243.8 d	8.24E3	3.66	3.05E5	9.89E-4
Ge^{68}	270.8 d	7.09E3	N/A	2.62E5	N/A
As^{74}	17.8 d	9.91E4	0.586	3.67E6	1.58E-4
Se^{75}	119.78 d	1.45E4	9.53	5.37E5	2.58E-3
Kr^{85}	10.73 y	392	0.02	1.45E4	5.40E-6
Rb^{88}	17.7 m	1.21E8	3.58	4.48E9	9.68E-4
Rb^{89}	15.4 m	1.37E8	12.17	5.07E9	3.29E-3
Sr^{89}	50.52 d	2.90E4	9.00E-4	1.07E6	2.43E-7
Sr^{90}	29.1 y	137	N/A	5.07E3	N/A
Y^{90}	64.1 h	5.43E5	N/A	2.01E7	N/A
Nb^{94}	2.0 E4 y	0.19	10.89	7.03	2.94E-3
Zr^{95}	64.02 d	2.15E4	5.16	7.96E5	1.39E-3
Nb^{95}	35.06 d	3.92E4	4.59	1.45E6	1.24E-3
Tc^{99}	2.13 E5 y	1.70E-2	N/A	0.629	N/A
Mo^{99}	67 h	4.80E5	1.25	1.78E7	3.38E-4
Tc^{99m}	6.01 h	5.27E6	1.36	1.95E8	3.68E-4
Ru^{106}	1.02 y	3.31E3	N/A	1.22E5	N/A

I^{125}	60.1 d	1.74E4	3.055	6.44E5	8.26E-4
I^{126}	12.93 d	7.97E4	4.34	2.95E6	1.17E-3
I^{129}	1.57 E7 y	1.77E-4	1.4	6.55E-3	3.78E-4
I^{131}	8.040 d	1.24E5	3.14	4.59E6	8.49E-4
I^{133}	20.8 h	1.13E6	4.54	4.18E7	1.23E-3
I^{134}	52.6 m	2.67E7	17.47	9.88E8	4.72E-3
I^{135}	6.57 h	3.53E6	9.57	1.31E8	2.59E-3
Cs^{137}	30.17 y	86.6	See Ba^{137m}	3.20E3	N/A
Ba^{137m}	2.552 m	5.37E8	4.44	1.99E10	1.20E-3
Ba^{140}	12.75 d	7.32E4	1.81	2.71E6	4.89E-4
La^{140}	1.678 d	5.56E5	12.42	2.06E7	3.36E-3
Gd^{148}	75 y	32.2	N/A	1.19E3	N/A
Ir^{192}	73.83 d	9.21E3	6.56	3.41E5	1.77E-3
Tl^{204}	3.78 y	464	0.0124	1.72E4	3.35E-6
Tl^{206}	4.20 m	2.17E8	N/A	8.03E9	N/A
Tl^{208}	3.053 m	2.96E8	18.89	1.10E10	5.11E-3
Pb^{210}	22.3y	76.4	N/A	2.83E3	N/A
Po^{210}	138.38 d	4.49E3	N/A	1.66E5	N/A
Bi^{210}	5.01 d	1.24E5	N/A	4.59E6	N/A
Tl^{210}	1.30 m	6.88E8	7.82	2.55E10	2.11E-3
Po^{212}	304 ns	1.78E17	N/A	6.59E18	N/A
Bi^{212}	60.6 m	1.47E7	N/A	5.44E8	N/A
Pb^{212}	10.64 h	1.39E6	0.732	5.14E7	1.98E-4
Po^{214}	164 µs	3.22E14	6.71E-4	1.19E16	1.81E-7
Bi^{214}	19.9 m	4.41E7	9.31	1.63E9	2.52E-3
Pb^{214}	27 m	3.25E7	1.155	1.20E9	3.12E-4
Po^{216}	145 ms	3.60E11	9.95E-5	1.33E13	2.69E-9
At^{218}	1.6 s	3.23E10	N/A	1.20E12	N/A
Po^{218}	3.10 m	2.78E8	N/A	1.03E10	N/A

	Half-Life	Ci/g	Rem/hr per Ci @30 cm	GBq/g	Sv/hr per GBq @30 cm
Rn^{220}	55.6 s	9.21E8	3.99E-3	3.41E10	1.08E-6
Rn^{222}	3.8235 d	1.54E5	3.03E-3	5.70E6	8.19E-7
Ra^{223}	11.435 d	5.12E4	0.370	1.89E6	1.00E-4
Ra^{224}	3.66 d	1.59E5	0.054	5.88E6	1.46E-5
Ra^{225}	14.9 d	3.90E4	0.070	1.44E6	1.89E-5
Ra^{226}	1600 y	0.989	0.045	36.6	1.22E-5
Ac^{227}	21.77 y	72.4	N/A	2.68E3	N/A
Th^{227}	18.72 d	3.07E4	0.39	1.14E6	1.05E-4
Ac^{228}	6.15 h	2.24E6	2.82	8.29E7	7.62E-4
Ra^{228}	5.76 y	2.72E2	N/A	1.01E4	N/A
Th^{228}	1.913 y	820	0.014	3.03E4	3.78E-6
Th^{229}	7300 y	0.214	0.145	7.92	3.92E-5
Th^{230}	7.54 E4 y	2.06E-2	N/A	0.762	N/A
Th^{231}	25.55 h	5.32E5	4.80E-2	1.97E7	1.30E-5
U^{230}	20.8 d	2.73E4	N/A	1.01E6	N/A
Pa^{231}	3.28 E4 y	4.72E-2	0.104	1.75	2.81E-5
Th^{232}	1.40E10y	1.10E-7	N/A	4.07E-6	N/A
U^{232}	70 y	22.0	N/A	814	N/A
U^{233}	1.592E5 y	9.65E-3	N/A	0.357	N/A
U^{234}	2.46 E5 y	6.22E-3	N/A	0.230	N/A
Pa^{234m}	1.17 m	6.86E8	0.050	2.54E10	1.35E-5
Pa^{234}	6.69 h	2.00E6	7.03	7.40E7	1.90E-3
Th^{234}	24.10 d	2.32E4	0.0356	8.58E5	9.62E-6
U^{235}	7.04 E8 y	2.16E-6	0.755	7.99E-5	2.04E-4
Pu^{236}	2.87 y	528	N/A	1.95E4	N/A
Np^{237}	2.14 E 6 y	7.05E-4	0.184	2.61E-2	4.97E-5
U^{238}	4.47 E9 y	3.36E-7	N/A	1.24E-5	N/A

Pu^{238}	87.7 y	17.1	N/A	6.33E2	N/A
Pu^{239}	2.410E4y	6.21E-2	N/A	2.30	N/A
Np^{239}	2.355 d	2.32E5	0.594	8.58E6	1.61E-4
Pu^{240}	6560 y	0.227	N/A	8.40	N/A
Pu^{241}	14.4 y	103	N/A	3.81E3	N/A
Am^{241}	432.7 y	3.43	0.17	1.27E2	4.59E-5
Pu^{242}	3.75E5 y	3.94E-3	N/A	0.146	N/A
Cm^{242}	162.8 d	3.31E3	N/A	1.22E5	N/A
Am^{243}	7370 y	0.200	0.23	7.40	6.22E-5
Cm^{244}	18.1 y	81.0	N/A	3.00E3	N/A
Cf^{249}	351 y	4.09	1.98	1.51E2	5.35E-4
Bk^{249}	320 d	1.64E3	N/A	6.07 E4	N/A
Cf^{252}	2.638 y	538	N/A	1.99 E4	N/A
Es^{253}	20.47 d	2.52E4	N/A	9.32 E5	N/A

The exposure rate from these radionuclides do not include that from their short-lived progeny. Spontaneous fission, isotopic mixtures, and impurities in mixtures should also be taken into account when estimating exposure rates.

Isotopic Mix of WG Pu

	Pu^{238}	Pu^{239}	Pu^{240}	Pu^{241}	Pu^{242}
% Weight	0.02	92.8	6.4	0.33	0.06
% Activity	0.82	13.87	3.49	81.82	0.0006

Isotopic Mix of Heat Source (RTG) Pu^{238}

	Pu^{238}	Pu^{239}	Pu^{240}	Pu^{241}	Pu^{242}
% Weight	90.0	9.1	0.6	0.3	<0.01
% Activity	97.99	0.036	0.009	1.972	<0.0000036

Isotopic Mix of Reactor Grade Pu

	Pu^{238}	Pu^{239}	Pu^{240}	Pu^{241}	Pu^{242}
% Weight	1.5	58.1	24.1	11.4	4.9
% Activity	2.12	0.3	0.45	97.13	0.0016

CHARACTERISTIC RADIATIONS OF COMMONLY ENCOUNTERED RADIONUCLIDES

These tables show the type of radiation, its energy in keV, and the % abundance of that energy for the parent. Only the most abundant energies are listed.

	1st Progeny	Radiation type	kev and % 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)
		γ	511 (200)
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)
		γ	511 (194)
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 (0.32), 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)
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)	

1st Progeny			kev and % abundance
Mn^{52}	Cr^{52}	β^+	575 (29.4)
		γ	511 (67), 744 (82), 935 (84), 1434 (100)
		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 (15.5), 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)	
Ni^{65}	Cu^{65}	β^-	2130 (100)
		γ	368 (4.5), 1115 (16), 1481 (25)
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)

	1st Progeny		kev and % abundance
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)
Nb^{95}	Mo^{95}	β^-	160 (100)
		γ	765 (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 (6.1), 21 (1.2)	
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)
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 (0.6), 29 (1.3), 30 (2.5), 34 (0.9)
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)
Ba^{133}	Cs^{133}	γ	276 (7), 302 (14), 356 (69), 382 (8)
		Cs x-rays	80 (36)
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 (0.43), 30 (0.8), 34 (0.3)
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)

	1st Progeny		kev and % abundance
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 (0.47), 35 (0.9), 39 (0.9)
Gd^{148}	Sm^{144}	α	3180 (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 (2.6), 67 (4.5), 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 (1.1), 63 (1.96), 71 (0.8)
Tl^{204}	Pb^{204}	β^-	763 (97.42)
	Hg^{204}	EC (2.58)	
		Hg x-rays	10 (0.8), 69 (0.4), 71 (0.7), 80 (0.3)
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), 2614 (99.8)
		Pb x-rays	11 (2.9), 73 (2.0), 75 (3.4), 85 (1.5)
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)

1^{st} Progeny			kev and % abundance
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 (0.5), 77 (0.36), 79 (0.6), 90 (0.3)
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 (6.2), 77 (10.5), 87 (4.7)
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)
Rn^{220}	Po^{216}	α	6288 (99.9), 5747 (0.1)
		γ	av. 550 (0.1)
Rn^{222}	Po^{218}	α	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 (0.3), 95 (0.14)

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 (1.4), 88 (2.3), 100 (1.1)
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), 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)

1st Progeny			kev and % abundance
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)
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), 926 (0.4), 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)

	1st Progeny		kev and % abundance
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 (1.6), 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 (0.008), 153 (0.001)
		U x-rays	14 (11.6)
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)

Parent	1st Progeny		kev and % abundance
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)
		γ	av. 4753 (0.1)
		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^-	26 (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)	

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

	mRem/hr			mSv/hr		
	1μ	**10**μ	**100**μ	**1**μ	**10**μ	**100**μ
Be^{7}	1.3E-4	1.3E-1	1.3E2	1.3E-6	1.3E-3	1.3
Na^{22}	4.7E-5	4.7E-2	4.7E1	4.7E-7	4.7E-4	0.47
Na^{24}	9.5E-2	9.5E1	9.5E4	9.5E-4	0.95	9.5E2
Al^{26}	4.5E-10	4.5E-7	4.5E-4	4.5E-12	4.5E-9	4.5E-7
Mg^{28}	4.8E-2	4.8E1	4.8E4	4.8E-4	0.48	4.8E2
Sc^{46}	6.9E-4	6.9E-1	6.9E2	6.9E-6	6.9E-4	6.9
V^{48}	1E-2	1E1	1E4	1E-4	0.10	1E2
Cr^{51}	9E-5	9E-2	9E1	9E-7	9E-4	0.9
Mn^{52}	3.8E-2	3.8E1	3.8E4	3.8E-4	0.38	3.8E2
Mn^{54}	1.7E-4	1.7E-1	1.7E2	1.7E-6	1.7E-3	1.7
Mn^{56}	8.3E-1	8.3E2	8.3E5	8.3E-3	8.3	8.3E3
Co^{56}	2.9E-3	2.9	2.9E3	2.9E-5	2.9E-2	29
Co^{57}	6.6E-5	6.6E-2	6.6E1	6.6E-7	6.6E-4	0.66
Co^{58}	1E-3	1	1E3	1E-5	1E-2	10
Fe^{59}	1.5E-3	1.5	1.5E3	1.5E-5	1.5E-2	15
Co^{60}	8E-5	8E-2	8E1	8E-7	8E-4	0.8
Zn^{65}	1.1E-4	1.1E-1	1.1E2	1.1E-6	1.1E-3	1.1
Se^{75}	3.5E-4	3.5E-1	3.5E2	3.5E-6	3.5E-3	3.5
Y^{88}	6.3E-4	6.3E-1	6.3E2	6.3E-6	6.3E-3	6.3
Sr/Y^{90}	N/A	N/A	N/A	N/A	N/A	N/A
Zr^{95}	3.8E-4	3.8E-1	3.8E2	3.8E-6	3.8E-3	3.8
Mo^{99}	3.2E-3	3.2	3.2E3	3.2E-5	3.2E-2	32
Cd^{109}	2.4E-5	2.4E-2	2.4E1	2.4E-7	2.4E-4	0.24
Cs^{137}	3.6E-7	3.6E-4	3.6E-1	3.6E-9	3.6E-6	3.6E-3
Ba^{140}	2.4E-4	2.4E-1	2.4E2	2.4E-6	2.4E-3	2.4

	mRem/hr			mSv/hr		
	1μ	**10**μ	**100**μ	**1**μ	**10**μ	**100**μ
W^{187}	1.1E-3	1.1	1.1E3	1.1E-5	1.1E-2	11
Os^{191}	3.9E-4	3.9E-1	3.9E2	3.9E-6	3.9E-3	3.9
Ir^{192}	7.1E-4	7.1E-1	7.1E2	7.1E-6	7.1E-3	7.1
Au^{198}	8E-3	8	8E3	8E-5	8E-2	80
Ra^{226}	3.5E-10	3.5E-7	3.5E-4	3.5E-12	3.5E-9	3.5E-6
U^{234}	5.4E-11	5.4E-8	5.4E-5	5.4E-13	5.4E-10	5.4E-7
U^{235}	8.1E-14	8.1E-11	8.1E-8	8.1E-16	8.1E-13	8.1E-10
Np^{237}	3.9E-11	3.9E-8	3.9E-5	3.9E-13	3.9E-10	3.9E-7
Pu^{238}	1.6E-7	1.6E-4	1.6E-1	1.6E-9	1.6E-6	1.6E-3
Pu^{239}	2.2E-10	2.2E-7	2.2E-4	2.2E-12	2.2E-9	2.2E-6
Pu^{240}	2E-9	2E-6	2E-3	2E-11	2E-8	2E-5
Am^{241}	1.3E-7	1.3E-4	1.3E-1	1.3E-9	1.3E-6	1.3E-3

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
< 10 μ is typical size for airborne particles

Activity in DPM vs Particle Size in microns for oxide form of various isotopes

	0.5µ	**1**µ	**5**µ	**10**µ	**50**µ
U^{234}	8.7E-3	0.07	9	69.7	8700
U^{235}	3.0E-6	2.4E-5	3E-3	0.02	3
U^{238}	4.7E-7	3.8E-6	5E-4	3.8E-3	0.47
Np^{237}	1.0E-3	8.0E-3	1.0	8	1000
Pu^{238}	25	201	2.5E4	2E5	2.5E7
Pu^{239}	0.09	0.73	91	730	9.1E4
Pu^{240}	0.33	2.7	333	2670	3.3E5
Pu^{241}	151	1210	1.5E5	1.2E6	1.5E8
Am^{241}	5.1	41.1	5140	4.1E4	5.14E6

Calculating Activity vs Particle Size

1. Volume of the particle is $V = 1/6\pi d^3$.
2. Use the density of the isotope listed in this reference.
3. Mass of the particle is M = V x density.
4. Activity of the particle is A = M x specific activity.

Correct the activity of the particle for the oxide form if you need that; 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.

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.

INGESTION ALIs
OF COMMONLY ENCOUNTERED RADIONUCLIDES
Quantities to equal 1 ALI

	mCi	mg	DPM	MBq
H^{3}	80	8.25E-3	1.78E+11	2960
Be^{7}	40	1.14E-4	8.88E+10	1480
C^{14}	2	0.448	4.44E+9	74
O^{15}	N/A	N/A	N/A	N/A
N^{16}	N/A	N/A	N/A	N/A
F^{18}	50	5.25E-7	1.11E+11	1850
Na^{22}	0.4	6.41E-5	8.88E+8	14.8
Na^{24}	4	4.58E-7	8.88E+9	148
Al^{26}	0.4	21.2	8.88E+8	14.8
P^{32}	0.6	2.1E-6	1.33E+9	22.2
Cl^{36}	2	60.6	4.44E+9	74
K^{40}	0.3	4.29E+4	6.66E+8	11.1
Ar^{41}	N/A	N/A	N/A	N/A
K^{42}	5	8.28E-7	1.11E+10	185
K^{43}	5	1.84E-6	1.33E+10	185
Sc^{46}	0.9	2.66E-5	2.00E+9	33.3
Sc^{47}	2	2.41E-6	4.44E+9	74
Sc^{48}	0.8	5.35E-7	1.78E+9	29.6
V^{48}	0.6	3.52E-6	1.33E+9	22.2
Cr^{51}	40	4.33E-4	8.88E+10	1480
Mn^{52}	0.7	1.56E-6	1.55E+9	25.9
Mn^{54}	2	2.58E-4	4.44E+9	74
Fe^{55}	9	3.78E-3	2.00E+10	333
Mn^{56}	5	2.30E-7	1.11E+10	185
Co^{56}	0.4	1.33E-5	8.88E+8	14.8
Co^{57}	4	4.75E-4	8.88E+9	148
Ni^{57}	2	1.29E-6	4.44E+9	74
Co^{58}	1	3.15E-5	2.22E+9	37
Ni^{59}	20	251	4.44E+10	740

Fe^{59}	0.8	1.61E-5	1.78E+9	29.6
Co^{60}	0.2	1.77E-4	4.44E+8	7.4
Cu^{62}	1	3.21E-9	2.22E+9	37
Zn^{65}	0.4	4.85E-5	8.88E+8	14.8
Ge^{68}	5	7.05E-4	1.11E+10	185
Se^{75}	0.5	3.44E-5	1.11E+9	18.5
Kr^{85}	N/A	N/A	N/A	N/A
Rb^{88}	20	1.66E-7	4.44E+10	740
Rb^{89}	40	2.92E-7	8.88E+10	1480
Sr^{89}	0.5	1.72E-5	1.11E+9	18.5
Sr^{90}	0.03	2.20E-4	6.66E+7	1.11
Y^{90}	0.4	7.36E-7	8.88E+8	14.8
Nb^{94}	0.9	4.37	2.00E+9	33.3
Zr^{95}	1	4.66E-5	2.22E+9	37
Tc^{99}	4	236	8.88E+9	148
Mo^{99}	1	2.08E-6	2.22E+9	37
Tc^{99m}	80	1.52E-5	1.78E+11	2960
Ru^{106}	0.2	6.04E-5	4.44E+8	7.4
I^{125}	0.04	2.30E-6	8.88E+7	1.48
I^{126}	0.02	2.51E-7	4.44E+7	0.74
I^{129}	5E-3	28.3	1.11E+7	0.185
I^{131}	0.03	2.42E-7	6.66E+7	1.11
I^{133}	0.1	8.83E-8	2.22E+8	3.7
I^{134}	20	7.50E-7	4.44E+10	74
I^{135}	0.8	2.26E-7	1.78E+9	29.6
Cs^{137}	0.1	1.16E-3	2.22E+8	3.7
Ba^{137m}	N/A	N/A	N/A	N/A
Ba^{140}	0.5	6.83E-6	1.11E+9	18.5
La^{140}	0.6	1.08E-6	1.33E+9	22.2

INGESTION ALIs

	mCi	mg	DPM	MBq
Gd^{148}	0.01	3.10E-4	2.22E+7	0.37
Ir^{192}	0.9	9.77E-5	2.00E+9	33.3
Tl^{204}	2	4.31E-3	4.44E+9	74
Tl^{206}	*	*	*	*
Tl^{208}	*	*	*	*
Pb^{210}	6E-4	7.85E-6	1.33E+6	2.22E-2
Po^{210}	3E-3	6.68E-7	6.66E+6	0.111
Bi^{210}	0.8	6.44E-6	1.78E+9	29.6
Tl^{210}	*	*	*	*
Po^{212}	*	*	*	*
Bi^{212}	5	3.41E-7	1.11E+10	185
Pb^{212}	0.08	5.76E-8	1.78E+10	2.96
Po^{214}	*	*	*	*
Bi^{214}	20	4.53E-7	4.44E+10	740
Pb^{214}	9	2.77E-7	2.00E+10	333
Po^{216}	*	*	*	*
At^{218}	*	*	*	*
Po^{218}	*	*	*	*
Rn^{220}	N/A	N/A	N/A	N/A
Rn^{222}	N/A	N/A	N/A	N/A
Ra^{223}	5E-3	9.76E-8	1.11E+7	0.185
Ra^{224}	8E-3	5.02E-8	1.78E+7	0.296
Ra^{225}	8E-3	2.05E-7	1.78E+7	0.296
Ra^{226}	2E-3	2.02E-3	4.44E+6	7.4E-2
Ac^{227}	2E-4	2.76E-6	4.44E+5	7.4E-3
Th^{227}	0.1	3.25E-6	2.22E+8	3.7
Ac^{228}	2	8.95E-7	4.44E+9	74
Ra^{228}	0.02	7.34E-5	4.44E+7	0.74
Th^{228}	6E-3	7.31E-6	1.33E+7	0.222

Th^{229}	6E-3	0.028	1.33E+7	0.222
Th^{230}	4E-3	0.194	8.88E+6	0.148
U^{230}	4E-3	1.47E-7	8.88E+6	0.148
Pa^{231}	2E-4	4.24E-3	4.44E+5	7.4E-3
Th^{232}	7E-4	6.35E+3	1.55E+6	2.59E-2
U^{232}	2E-3	9.08E-5	4.44E+6	7.4E-1
U^{233}	0.01	1.04	2.22E+7	0.37
U^{234}	0.01	1.61	2.22E+7	0.37
Pa^{234m}	2	2.91E-9	4.44E+9	74
Pa^{234}	2	9.99E-7	4.44E+9	74
Th^{234}	0.3	1.30E-5	6.66E+8	11.1
U^{235}	0.01	4.62E+3	2.22E+7	0.37
Pu^{236}	2E-3	3.79E-6	4.44E+6	7.4E-1
Np^{237}	5E-4	0.709	1.11E+6	1.85E-2
U^{238}	0.01	2.97E+4	2.22E+7	0.37
Pu^{238}	9E-4	5.25E-5	2.00E+6	3.33E-2
Pu^{239}	8E-4	0.0129	1.78E+6	2.96E-2
Np^{239}	2	8.62E-6	4.44E+9	74
Pu^{240}	8E-4	3.52E-3	1.78E+6	2.96E-2
Pu^{241}	0.04	3.88E-4	8.88E+7	1.48
Am^{241}	8E-4	2.33E-4	1.78E+6	2.96E-2
Pu^{242}	8E-4	0.203	1.78E+6	2.96E-2
Cm^{242}	0.03	9.05E-6	6.66E+7	1.11
Am^{243}	8E-4	4.00E-3	1.78E+6	2.96E-2
Cm^{244}	1E-3	1.23E-5	2.22E+6	3.7E-2
Cf^{249}	5E-4	1.22E-4	1.11E+6	1.85E-2
Bk^{249}	0.2	1.22E-4	4.44E+8	7.4
Cf^{252}	2E-3	3.72E-6	4.44E+6	7.4E-2
Es^{253}	0.2	7.93E-6	4.44E+8	7.4

INHALATION ALIs

	Quantity needed to equal 1 ALI				DAC	
	mCi	mg	DPM	MBq	µCi/ml	Bq/M^3
H^{3}	80	8.25E-3	1.78E11	2960	2E-5	7.4E5
Be^{7}	20	5.71E-5	4.44E10	740	8E-6	2.96E5
C^{14}	2	0.448	4.44E9	74	1E-6	3.7E4
F^{18}	70	7.36E-7	1.55E11	2590	3E-5	1.11E6
Na^{22}	0.6	9.61E-5	1.33E9	22.2	3E-7	1.11E4
Na^{24}	5	5.73E-7	1.11E10	185	2E-6	7.4E4
Al^{26}	0.06	3.18	1.33E8	2.22	3E-8	1.11E3
P^{32}	0.4	1.40E-6	8.88E8	14.8	2E-7	7.4E3
Cl^{36}	0.2	6.1	4.44E8	7.4	1E-7	3.7E3
K^{40}	0.4	5.72E4	8.88E8	14.8	2E-7	7.4E3
K^{42}	5	8.28E-7	1.11E10	185	2E-6	7.4E4
K^{43}	9	2.75E-6	2.00E10	333	4E-6	1.48E5
Sc^{46}	0.2	5.90E-6	4.44E8	7.4	1E-7	3.7E3
Sc^{47}	3	3.62E-6	6.66E9	111	1E-6	3.7E4
Sc^{48}	1	6.69E-7	2.22E9	37	6E-7	2.22E4
V^{48}	0.6	3.52E-6	1.33E9	22.2	3E-7	1.11E4
Cr^{51}	20	2.16E-4	4.44E10	740	8E-6	2.96E5
Mn^{52}	0.9	2.00E-6	2.00E9	33.3	4E-7	1.48E4
Mn^{54}	0.8	1.03E-4	1.78E9	296	3E-7	1.11E4
Fe^{55}	2	8.39E-4	4.44E9	74	8E-7	2.96E4
Mn^{56}	20	9.21E-7	4.44E10	740	6E-6	2.22E5
Co^{56}	0.2	6.63E-6	4.44E8	7.4	8E-8	2.96E3
Co^{57}	0.7	8.30E-5	1.55E9	25.9	3E-7	1.11E4
Ni^{57}	3	1.94E-6	6.66E9	111	1E-6	3.7E4
Co^{58}	0.7	2.20E-5	1.55E9	25.9	3E-7	1.11E4
Ni^{59}	2	25.1	4.44E9	74	8E-7	2.96E4
Fe^{59}	0.3	6.03E-6	6.66E8	11.1	1E-7	3.7E3

Co^{60}	0.03	2.65E-5	6.66E7	1.11	1E-8	370
Cu^{62}	3	9.64E-9	6.66E9	111	1E-6	3.7E4
Zn^{65}	0.3	3.64E-5	6.66E8	11.1	1E-7	3.7E3
Ge^{68}	0.1	1.41E-5	2.22E8	3.7	4E-8	1.48E3
Se^{75}	0.6	4.13E-5	1.33E9	22.2	3E-7	1.11E4
Rb^{88}	60	4.98E-7	1.33E11	2220	3E-5	1.11E6
Rb^{89}	100	7.30E-7	2.22E11	3700	6E-5	2.22E6
Sr^{89}	0.1	3.44E-6	2.22E8	3.7	6E-8	2.22E3
Sr^{90}	0.02	1.46E-4	4.44E7	0.74	2E-9	74
Y^{90}	0.6	1.10E-6	1.33E9	22.2	2E-7	7.4E3
Nb^{94}	0.02	0.105	4.44E7	0.74	6E-9	222
Zr^{95}	0.1	4.68E-6	2.22E8	3.7	6E-8	2.22E3
Tc^{99}	0.7	41.3	1.55E9	25.9	3E-7	1.11E4
Mo^{99}	1	2.08E-6	2.22E9	37	6E-7	2.22E4
Tc^{99m}	200	3.80E-5	4.44E11	7400	6E-5	2.22E6
Ru^{106}	0.01	3.02E-6	2.22E7	0.37	5E-9	185
I^{125}	0.06	3.45E-6	1.33E8	2.22	3E-8	1.11E3
I^{126}	0.04	5.02E-7	8.88E7	1.48	1E-8	370
I^{129}	9E-3	50.	2.00E7	0.333	4E-9	148
I^{131}	0.05	4.03E-7	1.11E8	1.85	2E-8	740
I^{133}	0.3	2.65E-7	6.66E8	11.1	1E-7	3.7E3
I^{134}	50	1.88E-6	1.11E11	1850	2E-5	7.4E5
I^{135}	2	5.66E-7	4.44E9	7	7E-7	2.59E4
Cs^{137}	0.2	2.31E-3	4.44E8	7.4	7E-8	2.59E3
Ba^{137m}	N/A	N/A	N/A	N/A	N/A	N/A
Ba^{140}	1	1.37E-5	2.22E9	3	6E-7	2.22E4

INHALATION ALIs

	Quantity needed to equal 1 ALI				DAC	
	mCi	mg	DPM	MBq	μCi/ml	Bq/M^3
La^{140}	1	1.80E-6	2.22E9	37	5E-7	1.85E4
Gd^{148}	8E-6	2.48E-7	1.78E4	2.96E-4	3E-12	0.111
Ir^{192}	0.2	2.71E-5	4.44E8	7.4	9E-8	3.33E3
Tl^{204}	2	4.31E-3	4.44E9	74	9E-7	3.33E4
Pb^{210}	2E-4	2.62E-6	4.44E5	7.4E-3	1E-10	3.7
Po^{210}	6E-4	1.33E-7	1.33E6	0.0222	3E-10	11.1
Bi^{210}	0.03	2.42E-7	6.66E7	1.11	1E-8	370
Bi^{212}	0.2	1.36E-8	4.44E8	7.4	1E-7	3.7E3
Pb^{212}	0.03	2.16E-8	6.66E7	1.11	1E-8	370
Bi^{214}	0.8	1.81E-8	1.78E9	29.	3E-7	1.11E4
Pb^{214}	0.8	2.46E-8	1.78E9	29.	3E-7	1.11E4
Rn^{220}	0.02	2.17E-11	4.44E7	0.74	8E-9	296
Rn^{222}	0.1	6.50E-7	2.22E8	3.7	3E-8	1.11E3

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}

	mCi	mg	DPM	MBq	μCi/ml	Bq/M^3
Ra^{223}	7E-4	1.37E-8	1.55E6	0.0259	3E-10	11.1
Ra^{224}	2E-3	1.26E-8	4.44E6	0.074	7E-10	25.9
Ra^{225}	7E-4	1.80E-8	1.55E6	0.0259	3E-10	11.1
Ra^{226}	6E-4	6.06E-4	1.33E6	0.0222	3E-10	11.1
Ac^{227}	4E-7	5.52E-9	888	1.48E-5	2E-13	7.4E-3
Th^{227}	3E-4	9.76E-9	6.66E5	0.0111	1E-10	3.7
Ac^{228}	9E-3	4.03E-9	2.00E7	0.333	4E-9	148
Ra^{228}	0.001	3.67E-6	2.22E6	0.037	5E-10	18.5
Th^{228}	1E-5	1.22E-8	2.22E4	3.7E-4	4E-12	0.148
Th^{229}	9E-7	4.20E-6	2.00E3	3.33E-5	4E-13	0.0148
Th^{230}	6E-6	2.91E-4	1.33E4	2.22E-4	3E-12	0.111
U^{230}	3E-4	1.10E-8	6.66E5	0.0111	1E-10	3.7
Pa^{231}	2E-6	4.24E-5	4.44E3	7.4E-5	7E-13	0.0259
Th^{232}	1E-6	9.08	2.22E3	3.7E-5	5E-13	0.0185

U^{232}	8E-6	3.63E-7	1.78E4	2.96E-4	3E-1	0.111
U^{233}	4E-5	4.15E-3	8.88E4	1.48E-3	2E-1	0.74
U^{234}	4E-5	6.44E-3	8.88E4	1.48E-3	2E-11	0.74
Pa^{234}	7	1.02E-8	1.55E10	259	3E-6	1.11E5
Pa^{234m}	7	3.50E-6	1.55E10	259	3E-6	1.11E5
Th^{234}	0.2	8.64E-6	4.44E8	7.4	6E-8	2.22E3
U^{235}	4E-5	18.5	8.88E4	1.48E-3	2E-11	0.74
Pu^{236}	2E-5	3.79E-8	4.44E4	7.4E-4	7E-12	0.259
Np^{237}	4E-6	5.67E-3	8.88E3	1.48E-4	2E-12	0.074
U^{238}	4E-5	119	8.88E4	1.48E-3	2E-11	0.74
Pu^{238}	7E-6	4.08E-7	1.55E4	2.59E-4	3E-12	0.111
Pu^{239}	6E-6	9.66E-5	1.33E4	2.22E-4	2E-12	0.074
Np^{239}	2	8.62E-6	4.44E9	74	1E-6	3.7E4
Pu^{240}	6E-6	2.64E-5	1.33E4	2.22E-4	2E-12	0.074
Pu^{241}	3E-4	2.91E-6	6.66E5	0.0111	1E-10	3.7
Am^{241}	6E-6	1.75E-6	1.33E4	2.22E-4	2E-12	0.074
Pu^{242}	7E-6	1.78E-3	1.55E4	2.59E-4	2E-12	0.074
Cm^{242}	3E-4	9.05E-8	6.66E5	0.0111	1E-10	3.7
Am^{243}	6E-6	3.00E-5	1.33E4	2.22E-4	2E-1	0.074
Cm^{244}	1E-5	1.23E-7	2.22E4	3.7E-4	4E-12	0.148
Cf^{249}	4E-6	9.77E-7	8.88E3	1.48E-4	2E-12	0.074
Bk^{249}	2E-3	1.22E-6	4.44E6	0.074	9E-10	33.3
Cf^{252}	2E-5	3.72E-8	4.44E4	7.4E-4	1E-11	0.37
Es^{253}	1E-3	3.97E-8	2.22E6	0.037	6E-10	22.2

Thorium-232 Decay Chain including thoron

1st Progeny kev and % abundance

Th^{232} 1.41E10y	Ra^{228}	α 3830 (0.2), 3953 (23), 4010 (77) γ 59 (0.19), 125 (0.04) Ra x-rays 12 (8.4)
Ra^{228} 5.75y	Ac^{228}	β^- 39 (100)
Ac^{228} 6.13h	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)
Th^{228} 1.91y	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)
Ra^{224} 3.62d	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)

Rn^{220} is "thoron" gas, usually included with "radon" gas

Rn^{220} 56s	Po^{216}	α 6288 (99.9), 5747 (0.1) γ av. 550 (0.1)

Po^{216} 0.15s	Pb^{212}	α 6779 (99.998)

Pb^{212} 10.64h	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)

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

Bi^{212} 60.6m	Tl^{208} Po^{212}	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)

Po^{212} 304ns	Pb^{208}	α 8785 (100)

Tl^{208} 3.05m	Pb^{208}	β^- 1283 (23.2), 1517 (22.7), 1794 (49.3) γ 511 (21.6), 583 (84.2), 860 (12.46), 2614 (99.8) Pb x-rays 11 (2.9), 73 (2.0), 75 (3.4), 85 (1.5)

Pb^{208} is stable

Uranium-238 Decay (including Radon progeny)

	1st Progeny	kev and % abundance
U^{238} 4.47E9y	Th^{234}	α 4039 (0.2), 4147 (23.4), 4196 (77.4) γ av. 66 (0.1) Th x-rays 13 (8.8)
Th^{234} 24.1d	Pa^{234m}	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)

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

Pa^{234m} 1.17m	U^{234}	β^- 1236 (0.7), 1471 (0.6), 2281 (98.6) γ 766 (0.2), 926 (0.4), 1001 (0.6) U x-rays 14 (0.44), 95 (0.115), 98 (0.187)
	Pa^{234}	IT
Pa^{234} 6.70h	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)
U^{234} 2.45E5y	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)
Th^{230} 7.7E4y	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)
Ra^{226} 1600y	Rn^{222}	α 4602 (5.6), 4785 (94.4) γ 186 (3.28) Rn x-rays 12 (0.8), 81 (0.18), 84 (0.3), 95 (0.14)

Rn^{222} is "radon" gas

Rn^{222} Po^{218} α 5490 (99.92), 4986 (0.08)
3.82d γ av. 512 (0.08)

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

Po^{218} Pb^{214} α 6003 (99.98)
3.05m At^{218} β^- 330 (0.02)

At^{218} Bi^{214} α^- 6650 (6), 6700 (94)
2s

Pb^{214} Bi^{214} β^- 672 (48), 729 (42.5), 1024 (6.3)
26.8m γ 242 (7.49), 295 (19.2), 352 (37.2)
Bi x-rays 11 (13.5), 75 (6.2), 77 (10.5), 87 (4.7)

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

Bi^{214} Po^{214} β^- 1505 (17.7), 1540 (17.9), 3270 (17.2)
19.9m γ 609 (46.3), 1120 (15.1), 1764 (15.8)
Po x-rays 11 (o.5), 77 (0.36), 79 (0.6), 90 (0.3)
Tl^{210} α 5450 (0.012), 5510 (0.008)

Uranium-238 Decay (including Radon progeny)

1^{st} Progeny **kev and % abundance**

Po^{214}	Pb^{210}	α 7687 (99.989), 6892 (0.01)
164 μs		γ 797 (0.013

Tl^{210}	Pb^{210}	β^- 1320 (25), 1870 (56), 2340 (19)
1.30m		γ 298 (79), 800 (99), 1310 (21)
		Pb x-rays 11 (13), 73 (2.5), 75 (4.3), 85 (1.9)

Pb^{210}	Bi^{210}	β^- 17 (80.2), 63 (19.8)
22.3 y		γ 47 (4.05)
		Bi x-rays 11 (24.3)

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

Bi^{210}	Po^{210}	β^- 1161 (99.9998)
5.01d	Tl^{206}	α 4650 (0.00007), 4690 (0.00005)

Po^{210}	Pb^{206}	α 5305 (99.9989)
138.4d		

Tl^{206}	Pb^{206}	β^- 1520 (100)
4.19m		

Pb^{206} is stable

Neptunium Decay Chain (4n + 1)

1^{st} Progeny **kev and % abundance**

Pu^{241} decays ~100 % of the time by β^- to Am^{241} & 0.0023 % of the time by α to U^{237}

Pu^{241}	Am^{241}	β^- 21 (~100.0)
14.4y	U^{237}	α 4850 (0.0003), 4900 (0.0019)
Am^{241}	Np^{237}	α 5440 (13), 5490 (85)
432.2y		γ 26 (2.4), 33 (0.1), 59.5 (36)
		Np x-rays 14 (43)
U^{237}	Np^{237}	β^- 248 (96)
6.75d		γ 26 (2.3), 59.5 (34), 208 (22)
		Np x-rays 4 (71), 97 (16), 101 (26), 114 (12)
Np^{237}	Pa^{233}	α 4650 (12), 4780 (75)
2.14E6y		γ 30 (14), 86 (14), 145 (1)
		Pa x-rays 13.3 (59), 92 (1.58), 96 (2.6), 108 (1.2)
Pa^{233}	U^{233}	β^- 145 (37), 257 (58), 568 (5)
27.0d		γ 75 (1.2), 87 (1.9), 311 (49)
		U x-rays 14 (49), 96 (28), 111 (8)
U^{233}	Th^{229}	α 4780 (15), 4820 (83)
1.592E5y		Th x-rays 13 (3.9)
Th^{229}	Ra^{225}	α 4840 (58), 4900 (11), 5050 (7)
7.34E3y		γ 31 (4), 137 (2), 211 (3.3)
		Ra x-rays 12 (81), 85 (16), 100 (12)
Ra^{225}	Ac^{225}	β^- 320 (100.0)
14.8d		γ 40 (31)
		Ac x-rays 13 (16)

Neptunium Decay Chain (4n + 1)

	1st Progeny	kev and % abundance
Ac^{225}	Fr^{221}	β^- 21 (~100.0)
10.0d		γ 63 (0.6), 100 (3), 150 (1)
		Fr x-rays 12 (21), 85 (3), 98 (0.8)
Fr^{221}	At^{217}	α 6126 (15), 6242 (1.4), 6340 (83.4)
4.8m		γ 100 (0.2), 218 (12.5), 412 (0.1)
		At x-rays 11 (2.3), 80 (2), 92 (0.6)
At^{217}	Bi^{213}	α 7066 (99.9)
0.0323s		γ 595 (0.04)

Bi^{213} decays 97.8% of the time by β^- to Po^{213} & 2.2% of the time by α to Tl^{209}

Bi^{213}	Po^{213}	β^- 320 (1.06), 980 (32), 1420 (64)
45.65m		γ 293 (0.7), 440 (28), 1100 (0.5)
		Po x-rays 11 (1.8), 78 (3.4), 90 (1)
	Tl^{209}	α 5549 (0.16), 5870 (2)
Po^{213}	Pb^{209}	α 8377 (~ 100.0)
4.2E-6s		
Tl^{209}	Pb^{209}	β^- 1825 (100.0)
2.20m		γ 117 (77), 465 (96.6), 1567 (99.7)
		Pb x-rays 10.6 (8.7), 74 (16), 85 (4.4)
Pb^{209}	Bi^{209}	β^- 645 (100)
3.253h		

Bi^{209} is stable

Actinium Decay Chain (4n + 3)

1st Progeny **kev and % abundance**

U^{235}	Th^{231}	α	4370 (18), 4400 (57), 4580 (8)
7.08E8y		γ	143 (11), 185 (54), 204 (5)
Th^{231}	Pa^{231}	β^-	140 (45), 220 (15), 305 (40)
25.55h		γ	26 (2), 84 (10)
Pa^{231}	Ac^{227}	α	4950 (22), 5010 (24), 5020 (23)
3.48E4y		γ	27 (6), 29 (6)

Ac^{227} decays 98.6% of the time by β^- to Th^{227} & 1.4% of the time by α to Fr^{223}

Ac^{227}	Th^{227}	β^-	43 (98.6)
21.77y		γ	70 (0.08)
	Fr^{223}	α	4860 (0.18), 4950 (1.2)
Th^{227}	Ra^{223}	α	5760 (21), 5980 (24), 6040 (23)
18.72d		γ	50 (8), 237 (15), 31 (8)
Fr^{223}	Ra^{223}	β^-	1150 (~100)
21.8m		γ	50 (8), 80 (13), 234 (4)
Ra^{223}	Rn^{219}	α	5610 (26), 5710 (54), 5750 (9)
11.435d		γ	33 (6), 149 (10), 270 (10)

Actinium Decay Chain (4n + 3)

	1^{st} Progeny		kev and % abundance
Rn^{219}	Po^{215}	α	6420 (8), 6550 (11), 6820 (81)
3.96s		γ	272 (9), 401 (5)

Po^{215} decays ~100 % of the time by α to Pb^{211} & 0.00023 % of the time by β^- to At^{215}

Po^{215}	Pb^{211}	α	7380 (~100)
1.778ms			
	At^{215}	β^-	740 (0.00023)
At^{215}	Bi^{211}	α	8010 (100)
0.1ms			
Pb^{211}	Bi^{211}	β^-	290 (1.4), 560 (9.4), 1390 (87.5)
36.1m		γ	405 (3.4), 427 (1.8), 832 (3.4)

Bi^{211} decays 99.7 % of the time by α to Tl^{207} & 0.28 % of the time by β^- to Po^{211}

Bi^{211}	Tl^{207}	α	6280 (16), 6620 (84)
2.13m		γ	351 (14)
	Po^{211}	β^-	600 (0.28)
Po^{211}	Pb^{207}	α	7450 (99)
0.516s			
		γ	570 (0.5), 900 (0.5)
Tl^{207}	Pb^{207}	β^-	1440 (99.8)
4.77m		γ	897 (0.16)

Pb^{207} is stable

ELEVATION VS AIR PRESSURE

Elevation		Barometric Pressure		Boiling Point of Water		Speed of Sound	
FT	M	mm Hg	kPa	^{0}C	^{0}F	M/S	MPH
-500	-152	774	103.2	100.5	212.9	340.9	763
0	0	760	101.3	100	212.0	340.3	761
500	152	746	99.5	99.5	211.1	339.7	760
1,000	305	732	97.6	99.0	210.2	339.1	759
1,500	457	720	96.0	98.4	209.2	338.6	757
2,000	610	707	94.3	97.9	208.3	338.0	756
2,500	762	694	92.5	97.4	207.4	337.4	755
3,000	914	681	90.8	97.0	206.6	336.7	753
3,500	1,067	668	89.1	96.4	205.6	336.2	752
4,000	1,219	656	87.5	95.9	204.6	335.6	751
4,500	1,372	644	85.9	95.4	203.7	334.8	749
5,000	1,524	632	84.3	94.9	202.9	334.4	748
5,500	1,676	619	82.5	94.4	202.0	333.8	747
6,000	1,829	609	81.2	93.9	201.1	333.2	745
6,500	1,981	597	79.6	93.3	200.0	332.6	744
7,000	2,134	586	78.1	92.8	199.1	332.2	743
7,500	2,286	575	76.7	92.4	198.3	331.4	741
8,000	2,438	564	75.2	91.8	197.4	330.8	740
9,000	2,743	543	72.4	90.9	195.6	330.1	738
10,000	3,048	523	69.7	89.8	193.7	328.5	735
11,000	3,353	504	67.1	88.8	191.4	327.3	732
12,000	3,658	484	64.5	87.8	190.1	326.0	729
13,000	3,962	464	62.0	86.8	188.2	324.6	726
14,000	4,267	444	59.5	85.8	186.4	323.2	723
15,000	4,572	424	57.0	84.8	184.6	321.8	720
16,000	4,877	404	54.6	83.7	182.7	320.4	717

COMPOSITION OF AIR

	Symbol	% Volume	Density of the Gases g / l
Air	-	100.00	1.2928
Nitrogen	N_2	78.084	1.2506
Oxygen	O_2	20.947	1.4290
Argon	Ar	0.934	1.7840
Carbon Dioxide	CO_2	0.033	1.9770
Neon	Ne	18.2 PPM	0.9002
Helium	He	5.2 PPM	0.1785
Methane	CH_4	2.0 PPM	-
Krypton	Kr	1.1 PPM	3.7
Sulfur Dioxide	SO_2	1.0 PPM	2.927
Hydrogen	H_2	0.5 PPM	0.0899
Nitrous Oxide	N_2O	0.5 PPM	1.977
Xenon	Xe	0.09 PPM	5.9
Ozone	O_3	0.0 to 0.07 PPM	2.144
Ozone - winter	O_3	0.0 to 0.02 PPM	2.144
Nitrogen Dioxide	NO_2	0.02 PPM	1.4494
Iodine	I_2	0.01 PPM	-
Carbon Monoxide	CO	0.0 to trace	1.2500
Ammonia	NH_3	0.0 to trace	0.7710

RADIOLOGICAL EMERGENCY RESPONSE

Write in Your Emergency Phone Numbers

Supervisor:

Team Office:

Group Office:

Division Office:

Emergency Response Team:

Fire Department:

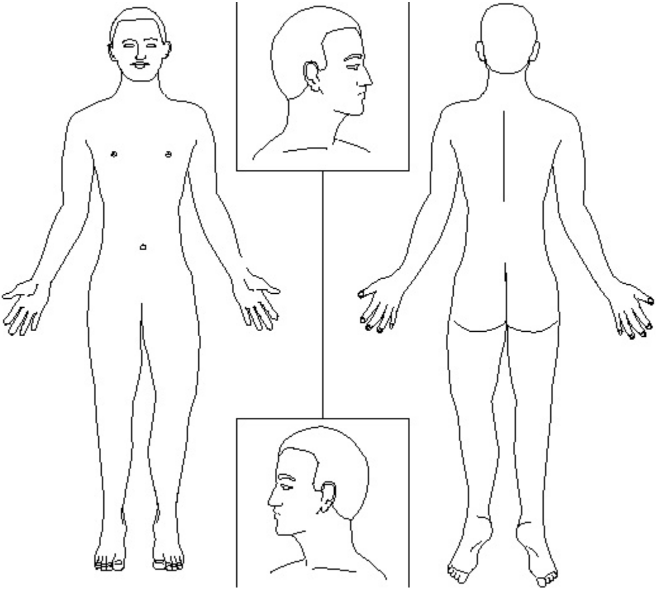
Hospital:

Guidelines for Control of Emergency Exposures

Use a dose limit of:

5 rem (50 mSv)	for all emergency procedures
10 rem (100 mSv)	only for protecting major property
25 rem (250 mSv)	for lifesaving or protection of large populations
> 25 rem (250 mSv)	for lifesaving or protection of large populations only by volunteers and where the risks have been evaluated

CONTAMINATED / INJURED PERSON FORM



Indicate on this form any injuries or contamination and the extent of the injury or contamination.