

Attachment 1; Table 1 - Four Classifications of Radioactive Material ¹

1. Primordial Radioisotopes (abundance) (decay mode)	Half-Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	NORM	Notes; e.g., Use of Material
U-238 Decay Series (99.27%) long-lived isotopes:							
U-238 (α) (Th-234; 24 days, β)	4.47x10 ⁹	Yes	Yes		Yes	Yes	Radiation shield; Penetrator
U-234 (α)	2.46x10 ⁵	Yes			Yes	Yes	
Th-230 (thorium) (α)	7.54x10 ⁴				Yes	Yes	
Ra-226 (radium) (α) (Radon-222; 3.8 days, α)	1.6x10 ³				Yes	Yes	
Pb-210 (lead) (β) (Bi-210; 5 days, β)	22.3				Yes	Yes	
Po-210 (polonium) (α)	138 days					Yes	Static eliminator
Pb-206 (lead)	Stable						
U-235 Decay Series (0.7%) Daughters no significant dose	7.1x10 ⁸	Yes		Yes	Yes	Yes	Becomes SNM if enriched
Th-232 Decay Series long-lived isotopes:							
Th-232 (thorium) (α) (100%)	1.405x10 ¹⁰	Yes	Yes		Yes	Yes	Th-Mg Alloy; Welding
Ra-228 (radium) (β)	5.75				Yes	Yes	
Th-228 (thorium) (α) (Ra-224; 3.66 days, α)	1.91				Yes	Yes	
Pb-208 (lead)	Stable						

1. Primordial Radioisotopes, continued (decay mode)	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	NORM	Notes; e.g., Use of Material
K-40 (potassium) (β decay) (0.0117%)	1.28×10^9					Yes	major internal body burden
V-50 (vanadium) (electron capture) (0.25%)	1.4×10^{17}					Yes	
Rb-87 (rubidium) (β) (28%)	4.75×10^{10}					Yes	earth mantle heat flux
In-115 (indium) (β) (95.71%)	4.41×10^{14}					Yes	
Te-123 (tellurium) (e) (0.91%)	1.0×10^{13}					Yes	
La-138 (lanthanum) (e & β) (.09%)	1.05×10^{11}					Yes	
Ce-142 (cerium) (β) (11%)	5.0×10^{16}					Yes	
Nd-144 (neodymium) (α)(24%)	2.29×10^{15}					Yes	
Sm-147 (samarium) (α) (15%)	1.06×10^{11}					Yes	
Sm-148 (α) (11%)	7×10^{15}					Yes	
Sm-149 (α) (14%)	2.0×10^{15}					Yes	
Gd-152 (gadolinium) (α)(0.2%)	1.08×10^{14}					Yes	
Hf-174 (hafnium) (α) (0.16%)	2.0×10^{15}					Yes	
Lu-176 (lutetium) (β) (2.6%)	3.78×10^{10}					Yes	meteorite dating
Os-186 (osmium) (α) (1.58%)	2.0×10^{15}					Yes	
Re-187 (rhenium) (β) (62.6%)	4.35×10^{10}					Yes	
Pt-190 (platinum) (α) (0.01%)	6.5×10^{11}					Yes	
Pb-204 (lead) (α) (1.4%)	1.4×10^{17}					Yes	
Pa-231 (protactinium) (α)	3.27×10^4					Yes	

1. Primordial Radioisotopes, decay chain missing from the earth due to short half-lives	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	NORM	Notes; e.g., Use of Material
Am-241 (americium) (α)	432.2						
Np-237 (neptunium) (α)	2.14×10^6						
U-233 (uranium) (α)	1.59×10^5						
Th-229 (thorium) (α)	7880						
Ra-225 (radium) (β) (Ac-225)	15 days						
Rn-221 (radon) (α)	25 minutes						
Rn-217 (α)	0.54 millisecond						
Po-213 (polonium) (α)	4.2μ second						
Bi-209 (bismuth) (stable)	$> 2 \times 10^{18}$						

2. Cosmic-Ray-Induced Radioisotopes (decay mode)	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	NORM	Notes; e.g., Use of Material
H-3 (tritium) (β)	12.33					Yes	thickness gauge
Be-7 (beryllium) (e capture)	53 days					Yes	
Be-10 (β)	1.51×10^6					Yes	
C-14 (carbon) (β)	5.73×10^3					Yes	thickness gauge, tracer, determination of age
Na-22 (sodium) (e)	2.6					Yes	
Si-32 (silicon) (β)	172					Yes	
P-32 (phosphorus) (β)	14 days					Yes	
P-33 (β)	25 days					Yes	
S-35 (sulfur) (β)	87 days					Yes	
Cl-36 (chlorine) (β)	3.01×10^5					Yes	thickness gauge
Cl-39 (β)	55 minutes					Yes	

3a. Reactor-Produced Radioisotopes; Activation Products Used in Medicine (decay mode)	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	NORM	Notes; e.g., Use of Material
C-14 (carbon) (β)	5.73x10 ³						urea halobacter pylori test
P-32 (phosphorus) (β)	14 days						medical procedures, inter-vascular brachytherapy
Co-60 (cobalt) (β)	5.27						teletherapy, brachytherapy, interstitial and intracavitary cancer therapy
Sr-89 (strontium) (β)	50.5 Days						palliative treatment
Sr-90 (β)	28.8						brachytherapy, treatment of superficial eye conditions
Y-90 (yttrium) (β)	64.1 hours						micro-sphere brachytherapy
Tc-99m (technetium) (IT, β)	6 hours						imaging
Pd-103 (palladium) (e)	17 days						brachytherapy, interstitial cancer therapy
I-125 (iodine) (e)	59.4 days						brachytherapy, interstitial cancer therapy
I-131 (β)	8.02 days						hyperthyroidism, thyroid cancer
Xe-133 (xenon) (β)	5.2 days						lung studies
Cs-137 (cesium) (β)	30.1						brachytherapy, interstitial and intracavitary cancer therapy
Ir-192 (iridium) (β)	73.8 days						brachytherapy, interstitial cancer therapy
Au-198 (gold) (β)	2.7 days						brachytherapy, interstitial cancer therapy

3b. Reactor-Produced Radioisotopes; (% remaining 20 years post irradiation)	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	NORM	Notes; e.g., Use of Material
H-3 (tritium) (β) (0.09%)	12.33						tracer
Co-60 (cobalt) (β , β) (0.23%)	5.27						density gauge, β radiography
Ni-63 (nickel) (β) (0.13%)	100.1						thickness gauge
Kr-85 (krypton) (β) (0.83%)	10.8						
Sr-90 (strontium) (β) (14.65%)	28.8						
Y-90 (yttrium) (β) (14.65%)	64.1 hours						
Sb-125 (antimony) (β) (0.04%)	2.76						
Cs-134 (cesium) (β) (0.08%)	2.06						
Cs-137 (β) (23.15%)	30.1						
Ba-137m (barium) (β) (21.90%)	2.5 minutes						
Pm-147(promethium)(β)(0.18%)	2.62						
Sm-151 (samarium) (β) (0.12%)	90.0						
Eu-154 (europium) (β) (0.84%)	8.59						
Eu-155 (β) (0.17%)	4.76						
Pu-238 (plutonium) (α) (1.26%)	87.7						
Pu-239 (α) (0.12%)	2.41×10^4			Yes			
Pu-240 (α) (0.18%)	6.56×10^3						
Pu-241 (β) (19.25%)	14.35			Yes			
Am-241 (americium) (α)(1.08%)	432.2						x-ray fluorescence analysis
Cm-244(curium) (α) (0.96%)	18.1						

4. Accelerator-Produced Radioisotopes (decay mode)	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	ARM	Notes; e.g., Use of Material
C-11 (carbon) (positron)	20 minutes					Yes	lung uptake & metabolism, prostate tumor localization, positron tomography
N-13 (nitrogen) (positron)	10 minutes					Yes	pancreatic scan, brain scan, positron tomography
O-15 (oxygen) (positron)	2 minutes					Yes	brain scan, shunt detection, positron tomography
F-18 (fluorine) (positron)	110 minutes					Yes	bone uptake, brain scan, chemotherapy, metabolism, positron tomography
Na-22 (sodium) (positron)	2.60					Yes	extra-cellular water
Mg-28 (magnesium) (β)	20.9 hours					Yes	
P-32 (phosphorus) (β)	14 days					Yes	medical procedures
P-33 (β)	25 days					Yes	palliative treatment
Ar-37 (argon) (e)	35 days					Yes	total calcium measurement
K-43 (potassium) (β)	22 hours					Yes	myocardial imaging
Sc-49 (scandium) (β)	57 minutes					Yes	
Mn-52 (manganese) (e)	5.6 days					Yes	
Fe-52 (iron) (positron)	8.3 hours					Yes	
Co-56 (cobalt) (e)	77.3 days					Yes	tumor localization
Co-57 (e)	272 days					Yes	vitamin B-12 measurement, tumor imaging calibration, x-ray fluorescence analysis, simulated tumors

4. Accelerator-Produced Radioisotopes , continued	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	ARM	Notes; e.g., Use of Material
Co-58 (cobalt) (e)	71 days					Yes	intestinal absorption studies
Cu-62 (copper) (positron)	9.7 minutes					Yes	radiopharmaceuticals
Cu-67 (β)	61.8 hours					Yes	studies of Wilson's disease
Ga-67 (gallium) (e)	3.26 days					Yes	lung scan, bowel scan, parotid gland uptake (Sjogren's syndrome), cardiac scanning
Ga-68 (e)	68 minutes					Yes	brain scan, positron emission tomography for cerebral hemodynamics
As-74 (arsenic) (e)	18 days					Yes	brain tumor localization
Br-77 (bromine) (e)	57 hours					Yes	
Kr-77 (krypton) (positron)	74 minutes					Yes	brain scan, positron tomography
Rb-81 (rubidium) (e)	4.6 hours					Yes	myocardial imaging
Rb-82 (positron)	1.3 minutes					Yes	imaging, positron tomography
Rb-84 (e)	33 days					Yes	radiopharmaceuticals
Sr-87m (strontium) (isomeric transition)	2.8 hours					Yes	bone scan, index of bone growth
Y-87 (yttrium) (e)	80 hours					Yes	parent of Sr-87m
Tc-97m (technetium) (IT)	91 days					Yes	imaging
Pd-103 (palladium) (e)	17 days						brachytherapy, interstitial cancer therapy
In-111 (indium) (e)	2.8 days					Yes	cisternography, tomography, tagged platelets, tagged lymphocytes

4. Accelerator-Produced Radioisotopes , continued	Half Life (yrs)	Source Material	Fertile	SNM	Mill Tailings [11.e(2)]	ARM	Notes; e.g., Use of Material
I-123 (iodine) (e)	13 hours					Yes	thyroid studies, imaging, labeled fibrinogen for in-vivo identification of thrombophlebitis
I-125 (e)	59 days					Yes	bone mineral analysis, interstitial treatment of cancer, uptake studies
Xe-127 (xenon) (e)	36 days					Yes	cardiac studies, blood-flow studies, pulmonary function studies
Cs-129 (cesium) (e)	32 hours					Yes	myocardial imaging
Cs-131 (e)	9.7 days					Yes	thyroid scanning
Dy-157 (dysprosium) (e)	8 hours					Yes	bone tumor localization
Ir-190 (iridium) (e)	11.8 days					Yes	
Au-195 (gold) (e)	186 days					Yes	
Hg-197 (mercury) (e)	64 hours					Yes	brain and kidney scanning
Tl-199 (thallium) (e)	7.4 hours					Yes	cardiac scanning
Tl-201 (e)	73 hours					Yes	cardiac scanning
Pb-203 (lead) (e)	52 hours					Yes	detection of malignant melanoma
Bi-204 (bismuth) (e)	11 hours					Yes	soft tissue scanning
Bi-206 (e)	6.24 days					Yes	soft tissue scanning

¹Data from online data base, Table of the Nuclides, linked to web site for Brookhaven National Laboratory at <http://www.dne.bnl.gov/CoN/index.html>