38. Commonly Used Radioactive Sources

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Table 38.1: Radioactive sources

Nuclide	Half-life	Type of Decay	Particle Energy (MeV)	Particle Emission prob.	Photon Energy (MeV)	Photon Emission prob.
$^{22}_{11}$Na	2.603 y	β^+,	0.546	90%	0.511	Annih.
		EC			1.275	100%
$^{51}_{24}$Cr	27.70 d	EC			0.320	10%
					V K x rays	100%
			Neutrino calibration source			
$^{54}_{25}$Mn	0.855 y	EC			0.835	100%
					Cr K x rays	26%
$^{55}_{26}$Fe	2.747 y	EC			Mn K x rays:	
					0.00590	24.4%
					0.00649	2.86%
$^{57}_{27}$Co	271.8 d	EC			0.014	9%
					0.122	86%
					0.136	11%
					Fe K x rays	58%
$^{60}_{27}$Co	5.271 y	β^-	0.317	99.9%	1.173	99.9%
					1.333	99.9%
$^{68}_{32}$Ge	271.0 d	EC			Ga K x rays	42%
$\rightarrow ^{68}_{31}$Ga						
	67.8 m	β^+,	1.899	90%	0.511	Annih.
		EC			1.077	3%
$^{90}_{38}$Sr	28.8 y	β^-	0.546	100%		
$\rightarrow ^{90}_{39}$Y	2.67 d	β^-	2.279	100%		
$^{106}_{44}$Ru	371.5 d	β^-	0.039	100%		
$\rightarrow ^{106}_{45}$Rh						
	30.1 s	β^-	3.546	79%	0.512	21%
					0.622	10%
$^{109}_{48}$Cd	1.265 y	EC	0.063 e^-	42%	0.088	3.7%
			0.084 e^-	44%	Ag K x rays	100%
$^{113}_{50}$Sn	115.1 d	EC	0.364 e^-	28%	0.392	65%
			0.388 e^-	6%	In K x rays	97
$^{137}_{55}$Cs	30.0 y	β^-	0.514	94%	0.662	85%
			1.176	6%		

Nuclide	Half-life	Type of Decay	Particle Energy (MeV)	Particle Emission prob.	Photon Energy (MeV)	Photon Emission prob.
$^{133}_{56}$Ba	10.55 y	EC	0.045 e^-	50%	0.081	33%
			0.075 e^-	6%	0.356	62%
					Cs K x rays	121%
$^{152}_{63}$Eu	13.537 y	EC		72.1%	Many γ's	
		β^-		27.9%	0.1218–1.408 MeV	
$^{207}_{83}$Bi	32.9 y	EC	0.481 e^-	2%	0.569	98%
			0.975 e^-	7%	1.063	75%
			1.047 e^-	2%	1.770	7%
					Pb K x rays	78%
$^{228}_{90}$Th	1.912 y	6α:	5.341 – 8.785		0.239	44%
		3β^-:	0.334 – 2.246		0.583	31%
					2.614	36%
($\rightarrow {}^{224}_{88}$Ra 361 d	$\rightarrow {}^{220}_{86}$Rn 55.8 s	$\rightarrow {}^{216}_{84}$Po 0.148 s	$\rightarrow {}^{212}_{82}$Pb 10.64 h	$\rightarrow {}^{212}_{83}$Bi 60.54 m	$\rightarrow {}^{212}_{84}$Po 300 ns)	
$^{241}_{95}$Am	432.6 y	α	5.433	13%	0.0595409	36%
			5.486	85%	Np L x rays	38%
$^{241}_{95}$Am/Be	432.6 y	neutrons ($\langle E\rangle = 4$ MeV) and γ's (4.43 MeV from $^9_4$Be(α, n))				
$^{244}_{96}$Cm	18.11 y	α	5.763	24%	Pu L x rays	$\sim 9\%$
			5.805	76%		
$^{252}_{98}$Cf	2.645 y	α	6.076	15%		
		(97%)	6.118	82%		
Fission (3.1%): Average 7.8 γ's/fission; $\langle E_\gamma\rangle = 0.88$ MeV; ≈ 4 neutrons/fission; $\langle E_n\rangle = 2.14$ MeV						

"Emission probability" is the probability per decay of a given emission; because of cascades these may total more than 100%. Only principal emissions are listed. EC means electron capture, and e^- means monoenergetic internal conversion (Auger) electron. The intensity of 0.511 MeV e^+e^- annihilation photons depends upon the number of stopped positrons. Endpoint $\beta^\pm$ energies are listed. In some cases when energies are closely spaced, the γ-ray values are approximate weighted averages. Radiation from short-lived daughter isotopes is included where relevant.

Isotopic data may be found at `https://physics.nist.gov/cgi-bin/Compositions/stand_alone.pl`.

Neutron sources: See *e.g.* J. Liu *et al.*, "Neutron Calibration Sources in the Daya Bay Experiment" [1]. $^{51}_{24}$Cr calibration of neutrino detectors is discussed in *e.g.* J.N. Abdurashitov *et al.*, "Measurement of the response of a gallium metal solar neutrino experiment to neutrinos from a ^{51}Cr source" [2]. The use of $^{75}_{34}$Se and other isotopes has also been proposed.

References

[1] J. Liu *et al.*, Nucl. Instrum. Meth. A **797**, 260 (2015), [arXiv:1504.07911].

[2] J. N. Abdurashitov *et al.* (SAGE), Phys. Rev. C **59**, 2246 (1999), [hep-ph/9803418].