38. Commonly Used Radioactive Sources

Table 38.1. Revised August 2017 by D.E. Groom (LBNL) and R.B. Firestone (LBNL).

			Particle		Photon	
Nuclide	Half-life	Type of decay	Energy (MeV)	Emission prob.	Energy (MeV)	Emission prob.
${}^{22}_{11}$Na	2.603 y	β^+, EC	0.546	90%	0.511	Annih.
					1.275	100%
${}^{51}_{24}$Cr	27.70 d	EC			0.340	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^+, EC	1.899	90%	0.511	Annih.
					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%		
${}^{133}_{56}$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 to 8.785		0.239	44%
		$3\beta^-$:	0.334 to 2.246		0.583	31%
					2.614	36%
($\rightarrow {}^{224}_{88}$Ra	$\rightarrow {}^{220}_{86}$Rn	$\rightarrow {}^{216}_{84}$Po	$\rightarrow {}^{212}_{82}$Pb		$\rightarrow {}^{212}_{83}$Bi	$\rightarrow {}^{212}_{84}$Po)
(361 d	55.8 s	0.148 s	10.64 h		60.54 m	300 ns)
${}^{241}_{95}$Am	432.6 y	α	5.443	13%	0.060	36%
			5.486	84%	Np L x rays	38%
${}^{241}_{95}$Am/Be	432.6 y	6×10^{-5} neutrons ($\langle E\rangle = 4$ MeV) and $4\times10^{-5}\gamma$'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 (97%)	6.076	15%		
			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.

Half-lives, energies, and intensities may be found in `www-pub.iaea.org/books/IAEABooks/7551/Update-of-X-Ray-and-Gamma-Ray-Decay-Data-Standards-for-Detector-Calibration-and-Other-Applications` `IAEA` (2007)
or Nuclear Data Sheets (`www.journals.elsevier.com/nuclear-data-sheets`) (2007).

Neutron sources: See *e.g.* "Neutron Calibration Sources in the Daya Bay Experiment," J. Liu *et al.*, Nuclear Instrum. Methods **A797,** 260 (2005) (arXiv.1504.07911).

${}^{51}_{24}$Cr calibration of neutrino detectors is discussed in *e.g.* Phys. Rev. **B114** (1998). The use of ${}^{75}_{34}$Se and other isotopes has been proposed.