

## 37. Commonly Used Radioactive Sources

Table 37.1. Revised September 2019 by D.E. Groom (LBNL).

Nuclide	Half-life	Type of decay	Particle		Photon	
			Energy (MeV)	Emission prob.	Energy (MeV)	Emission prob.
$^{22}_{11}\text{Na}$	2.603 y	$\beta^+$ , EC	0.546	90%	0.511 1.275	Annih. 100%
$^{51}_{24}\text{Cr}$	27.70 d	EC			0.320 V K x rays	10% 100%
Neutrino calibration source						
$^{54}_{25}\text{Mn}$	0.855 y	EC			0.835 Cr K x rays	100% 26%
$^{55}_{26}\text{Fe}$	2.747 y	EC			Mn K x rays: 0.00590 0.00649	24.4% 2.86%
$^{57}_{27}\text{Co}$	271.8 d	EC			0.014 0.122 0.136	9% 86% 11%
					Fe K x rays	58%
$^{60}_{27}\text{Co}$	5.271 y	$\beta^-$	0.317	99.9%	1.173 1.333	99.9% 99.9%
$^{68}_{32}\text{Ge}$	271.0 d	EC			Ga K x rays	42%
$\rightarrow ^{68}_{31}\text{Ga}$	67.8 m	$\beta^+$ , EC	1.899	90%	0.511 1.077	Annih. 3%
$^{90}_{38}\text{Sr}$	28.8 y	$\beta^-$	0.546	100%		
$\rightarrow ^{90}_{39}\text{Y}$	2.67 d	$\beta^-$	2.279	100%		
$^{106}_{44}\text{Ru}$	371.5 d	$\beta^-$	0.039	100%		
$\rightarrow ^{106}_{45}\text{Rh}$	30.1 s	$\beta^-$	3.546	79%	0.512 0.622	21% 10%
$^{109}_{48}\text{Cd}$	1.265 y	EC	0.063 0.084	$e^-$ 42% $e^-$ 44%	0.088	3.7% Ag K x rays 100%
$^{113}_{50}\text{Sn}$	115.1 d	EC	0.364 0.388	$e^-$ 28% $e^-$ 6%	0.392	65% In K x rays 97%
$^{137}_{55}\text{Cs}$	30.0 y	$\beta^-$	0.514 1.176	94% 6%	0.662	85%
$^{133}_{56}\text{Ba}$	10.55 y	EC	0.045 0.075	$e^-$ 50% $e^-$ 6%	0.081 0.356	33% 62% Cs K x rays 121%
$^{152}_{63}\text{Eu}$	13.537 y	EC $\beta^-$		72.1% 27.9%	Many $\gamma$ 's 0.1218–1.408 MeV	
$^{207}_{83}\text{Bi}$	32.9 y	EC	0.481 0.975 1.047	$e^-$ 2% $e^-$ 7% $e^-$ 2%	0.569 1.063 1.770	98% 75% 7% Pb K x rays 78%
$^{228}_{90}\text{Th}$	1.912 y	$6\alpha$ : $3\beta^-$ :	5.341 to 8.785 0.334 to 2.246		0.239 0.583 2.614	44% 31% 36%
$(\rightarrow ^{224}_{88}\text{Ra} \rightarrow ^{220}_{86}\text{Rn} \rightarrow ^{216}_{84}\text{Po} \rightarrow ^{212}_{82}\text{Pb} \rightarrow ^{212}_{83}\text{Bi} \rightarrow ^{212}_{84}\text{Po})$ ( 361 d    55.8 s    0.148 s    10.64 h    60.54 m    300 ns)						
$^{241}_{95}\text{Am}$	432.6 y	$\alpha$	5.443 5.486	13% 84%	0.060	36% Np L x rays 38%
$^{241}_{95}\text{Am/Be}$	432.6 y	$6 \times 10^{-5}$ neutrons ( $\langle E \rangle = 4$ MeV) and $4 \times 10^{-5} \gamma$ 's (4.43 MeV from $^9_4\text{Be}(\alpha, n)$ )				
$^{244}_{96}\text{Cm}$	18.11 y	$\alpha$	5.763 5.805	24% 76%		Pu L x rays $\sim$ 9%
$^{252}_{98}\text{Cf}$	2.645 y	$\alpha$ (97%)	6.076 6.118	15% 82%		
		Fission (3.1%): Average 7.8 $\gamma$ 's/fission; $\langle E_\gamma \rangle = 0.88$ MeV $\approx 4$ 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  $\gamma$ -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](http://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](http://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).

$^{51}\text{Cr}$  calibration of neutrino detectors is discussed in *e.g.* J.N. Abdurashitov *et al.* [SAGE Collaboration], Phys. Rev. **C59**, 2246 (1999). The use of  $^{75}_{34}\text{Se}$  and other isotopes has also been proposed.