EXPOSURE RATE CONSTANTS AND LEAD SHIELDING VALUES FOR OVER 1,100 RADIONUCLIDES

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Abstract—**The authors have assembled a compilation of exposure rate constants, *f*-factors, and lead shielding thicknesses for more than 1,100 radionuclides described in ICRP Publication 107. Physical data were taken from well established reference sources for mass-energy absorption coefficients in air, attenuation coefficients, and buildup factors in lead and other variables. The data agreed favorably for the most part with those of other investigators; thus this compilation provides an up-to-date and sizeable database of these data, which are of interest to many for routine calculations. Emissions were also segregated by emitting nuclide, and decay product emissions were emitted from the calculated coefficients, thus for the first time providing for the calculation of exposure rates from arbitrary mixtures of nuclides in arbitrary equilibrium states.**
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Key words: gamma radiation, radiation protection, radionuclide, shielding

INTRODUCTION

EXPOSURE RATE constants and lead shielding thicknesses are needed by many for routine calculations in radiation safety, medical uses of radionuclides, and other applications. A number of compilations have been found to be useful, including the Radiological Health Handbook (USDHEW 1970), which included exposure rate constants from Jaeger et al. (1968), an article by Unger and Trubey (1982), and others. The goal of this work was to provide an updated and comprehensive list of such values, using data from the recent ICRP Publication 107 (ICRP 2009). Comparisons of the calculated values with those of other investigators are also provided. This compilation uses newly released decay data for many radionuclides and traditional definitions of exposure rate constants, which can be related to absorbed dose or equivalent dose via well known relationships. Nuclide-specific *f*-factors for conversion between exposure rate in air and dose rate to tissue are also presented.

METHODS

The exposure rate constant Γ relates the activity of a point isotropic radiation source to the exposure rate in air at a given distance:

$$\dot{X} = \Gamma_\delta \frac{A}{d^2}, \qquad (1)$$

where A is the source activity, d is distance to the source, and δ is a minimum cutoff energy, which determines the minimum energy photon that can contribute to the exposure. In this work, δ = 15 keV is used. In terms of the decay spectrum of a nuclide, the exposure rate constant can be written as

$$\Gamma_\delta = \frac{1}{4\pi}\sum_i \left(\frac{\mu_{en}}{\rho}\right)_i Y_i E_i, \qquad (2)$$

where $(\mu_{en}/\rho)_i$ is the mass-energy absorption coefficient in air for photons of energy E_i emitted by the nuclide with yield Y_i. This equation will have units of exposure rate per unit activity at distance d when appropriate unit conversions and assumptions (e.g., about the amount of energy needed to produce an ion pair in air) are applied, as in this example from Stabin (2007) for ^{60}Co (considering just the two principal photons for demonstration purposes):

$$\Gamma = \left[\left(1.17\frac{MeV}{\gamma}\right)\left(1.0\frac{\gamma}{dis}\right)(0.0035\,m^{-1}) + \left(1.33\frac{MeV}{\gamma}\right)\left(1.0\frac{\gamma}{dis}\right)(0.0034\,m^{-1})\right]$$
$$\times\ \frac{1}{4\pi}\frac{10^6\,eV}{MeV}\frac{i.p.}{34\,eV}\frac{1.6\times10^{-19}\,C}{i.p.}\frac{m^3}{1.293\,kg}\frac{10^6\,dis}{s-MBq} = 2.5\times10^{-12}\frac{(C/kg)m^2}{MBq\,s} \qquad (3)$$

$$2.5\times10^{-12}\frac{(C/kg)m^2}{MBq\,s}\frac{37\,MBq}{mCi}\frac{3{,}600\,s}{h}\frac{R}{2.58\times10^{-4}\,C/kg}\frac{10^4\,cm^2}{m^2} = 12.9\frac{R\,cm^2}{mCi\,h}. \qquad (4)$$

The nuclear decay data from ICRP Publication 107 were taken in electronic form and used to find the yield Y_i and

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energy E_i of all photon emissions of each nuclide. The authors included only gamma rays, x-rays, annihilation photons, and prompt and delayed photons of spontaneous fission given in ICRP 107 with energies of at least 15 keV and yields of at least 10^{-4}. Bremsstrahlung was neglected. All mass-energy absorption coefficients were obtained by log-log interpolation of Hubbell and Seltzer (1996).

Additionally, for nuclides that have no photon emissions themselves but are in secular equilibrium with photon-emitting products (e.g., ^{137}Cs/^{137m}Ba), the decay schemes have been combined in selected cases with this being noted. In general the authors did NOT combine emissions for parent/progeny situations. This segregation of the emissions by the actual emitting nuclide allows more accurate determination of the exposure due to a complex mixture of nuclides. If the decay equilibrium of a mixture is known, the resulting exposure rate can be found by simple linear combination of the appropriate nuclides from Table 1 below. However, the lead shielding thicknesses cannot be combined easily for mixtures of nuclides.

The shielding requirements were calculated by energy-dependent attenuation of the exposure rates calculated here through varying thickness of pure lead. The broad-beam transmission, $T(E,x)$, for photons of energy E through lead thickness x was modeled as exponential attenuation modified by an energy- and depth-dependent buildup factor:

$$T(E,x) = B(E,x)\ \exp[-\mu(E)x]. \tag{5}$$

Two recent works have calculated in detail the buildup curves for monoenergetic photons in lead (Shimizu et al. 2004; Kharrati et al. 2007), albeit in different energy ranges. Shimizu et al. (2004) present data for energies from 30 keV to 15 MeV; Kharrati et al. (2007) include data for 15 to 150 keV. (The lower limit of 15 keV for the buildup factors is the reason for the 15 keV lower cutoff on photon emissions in this effort.) Since the energy coverage overlaps between 30 and 150 keV between these two works, transmission values in the overlap region were averaged:

$$B(E,x) = \begin{cases} B_K(E,x) & : \ 15\,\text{keV} \le E < 30\,\text{keV} \\ \dfrac{B_K(E,x) + B_S(E,x)}{2} & : \ 30\,\text{keV} \le E \le 150\,\text{keV} \\ B_S(E,x) & : \ E > 150\,\text{keV} \end{cases}, \tag{6}$$

where the subscript K denotes data taken from Kharrati et al. and S denotes Shimizu et al. For the Shimizu et al. (2004) data, the buildup factors were taken directly from Table 4. For the Kharrati et al. (2007) data, the empirical fit given in their eqn (6) was used:

$$B_K(E_i,x)=\{[1+\beta(E)/\alpha(E)]e^{\alpha(E)\gamma(E)x}-\beta(E)/\alpha(E)\}^{-1/\gamma(E)}, \tag{7}$$

where x is depth in units of 0.1 mm. The coefficients α, β, and γ were taken from the columns for dose from Table I of Kharrati et al.

Finally, the nuclide-specific *f*-factors (cGy/R) in Table 1 were calculated as spectrally averaged tissue-to-air stopping power ratios. The tissue model was based on the ICRU-44 soft tissue model, and the mass-energy absorption coefficients for it were obtained from Hubbell and Seltzer (1996).

RESULTS

A listing of the results for all nuclides is given in Table 1. The complete list in electronic form will be made available from the web site maintained by the RAdiation Dose Assessment Resource (RADAR) Task Group of the Society of Nuclear Medicine (www.doseinfo-radar.com).

DISCUSSION

Tables 2–4 show comparisons of the values in this report to those reported in the original Radiological Health Handbook (RHH; U.S. DHEW 1970), Unger and Trubey (1982), and Tschurlovits et al. (1992) for selected radionuclides. In converting the current values for comparison to dose rate, as in Tables 3 and 4, the calculated nuclide-specific *f*-factors in Table 1 were applied. Table 2 shows a comparison between these results and those of the RHH. The authors find good agreement except for ^{125}I, for which the value is listed as "$\sim$0.7," but the nature of this difference is unknown due to the approximate nature of the RHH value provided and the age of the publication.

A comparison between the exposure rate constants calculated here and values of equivalent dose constants given in Unger and Trubey (1982) is given in Table 3. The current values are systematically lower than those of Unger and Trubey. This is likely due to differences in methodology. Unger and Trubey included emissions down to 10 keV and used a fitted function of dose rate per unit flux density to obtain their constants instead of using absorption coefficients directly. Contributions from emissions in the 10–15 keV range were neglected, as in practice these emissions almost never contribute to dose due to the rapid attenuation of photons at these energies and the frequent presence of encapsulating materials.

Table 4 shows comparisons of the current values to those of Tschurlovits et al. (1992). Agreement is quite good in many cases, but the current values are notably lower in several cases (^{133}Ba, ^{67}Ga, ^{166}Ho, ^{123}I, ^{125}I, ^{111}In, ^{99m}Tc, ^{201}Tl, and ^{65}Zn). As agreement is very good for most cases, and agreement with the RHH is good for all nuclides except for ^{125}I, some error in calculation or reporting in the Tschurlovits et al. work for these particular nuclides is suspected.

Finally, comparison of shielding values shows good agreement for many commonly used nuclides, but it is hard to make an extensive comparison because such data

Table 1. Exposure rate constants, *f*-factors, and lead shielding data developed in this work for all photon-emitting nuclides in the ICRP 107 nuclear decay data set.

Nuclide	Exposure rate constant		*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Ac-223	2.33×10^{-14}	0.12	0.956	0.639	2.3	5.86	16.9	28.8
Ac-224	3.57×10^{-13}	1.84	0.955	0.168	0.631	1.42	3.71	6.09
Ac-225	2.45×10^{-14}	0.126	0.952	0.0698	0.459	1.21	9.26	22.1
Ac-226	2.04×10^{-13}	1.05	0.957	0.284	0.932	1.92	4.95	13.2
Ac-227	1.23×10^{-14}	0.0635	0.921	0.00676	0.0135	0.0225	0.048	0.0982
Ac-228	1.03×10^{-12}	5.31	0.958	7.86	18.6	32.7	69.4	109
Ac-230	5.97×10^{-13}	3.08	0.957	11.1	25.3	44.1	91.1	138
Ac-231	5.23×10^{-13}	2.7	0.960	0.894	2.36	4.6	11.1	18.5
Ac-232	1.18×10^{-12}	6.11	0.959	14.1	29.1	48.7	97.7	145
Ac-233	5.58×10^{-13}	2.88	0.965	5.19	9.93	15.9	30.5	44.7
Ag-100m	2.95×10^{-12}	15.3	0.965	8.41	17.6	32.7	78.5	125
Ag-101	1.76×10^{-12}	9.1	0.962	5.48	12.2	23.3	62.7	108
Ag-102m	1.90×10^{-12}	9.83	0.962	11.8	26.6	47.8	101	152
Ag-102	3.55×10^{-12}	18.3	0.963	8.89	19.1	35.4	82.6	131
Ag-103	1.09×10^{-12}	5.65	0.953	3.91	11.4	24.4	63.4	104
Ag-104	3.07×10^{-12}	15.8	0.959	8.38	17.7	31	69.2	111
Ag-104m	1.94×10^{-12}	10	0.961	7.05	15.2	30.6	81.6	133
Ag-105	8.48×10^{-13}	4.38	0.947	1.19	4.37	10.8	36	66.3
Ag-105m	1.75×10^{-15}	0.00904	0.942	0.178	2.3	5.71	26.9	56.5
Ag-106	8.79×10^{-13}	4.54	0.958	4.12	8.69	14.5	28.8	44.6
Ag-106m	3.21×10^{-12}	16.6	0.958	7.66	17	30.8	69	109
Ag-108	2.68×10^{-14}	0.138	0.949	3.6	9.34	16.7	35.2	54.1
Ag-108m	2.02×10^{-12}	10.4	0.956	5.08	11.1	19.2	39.7	60.2
Ag-109m	1.25×10^{-13}	0.644	0.924	0.0111	0.022	0.0372	0.205	1.15
Ag-110	3.39×10^{-14}	0.175	0.963	7.11	13.6	21.8	41.7	61.8
Ag-110m	2.91×10^{-12}	15	0.965	10.3	20	33	69.2	109
Ag-111	2.91×10^{-14}	0.15	0.964	1.93	3.89	6.49	13.1	20.2
Ag-111m	7.00×10^{-14}	0.361	0.923	0.0118	0.0241	0.0459	7.63	27
Ag-112	6.95×10^{-13}	3.59	0.965	10.8	22.2	39.4	87.4	135
Ag-113m	2.56×10^{-13}	1.32	0.960	2.56	6.05	12.3	32.2	53.1
Ag-113	7.83×10^{-14}	0.404	0.964	3.04	7.56	18.5	50.7	85.2
Ag-114	2.62×10^{-13}	1.35	0.965	9.27	19.7	37	86.3	136
Ag-115	4.71×10^{-13}	2.43	0.964	10.6	25.5	45.4	95	144
Ag-116	2.00×10^{-12}	10.3	0.964	13.3	28.2	49	101	153
Ag-117	1.20×10^{-12}	6.18	0.962	14.9	31.8	53.1	105	155
Ag-99	2.43×10^{-12}	12.6	0.964	7.22	16.3	31.4	76.9	125
Al-26	2.60×10^{-12}	13.4	0.965	11.9	26.6	47	96.3	144
Al-28	1.62×10^{-12}	8.37	0.876	19.8	35.9	56.4	105	152
Al-29	1.34×10^{-12}	6.93	0.965	16.6	30.5	48.2	91.2	135
Am-237	5.57×10^{-13}	2.87	0.955	0.508	2.52	7.01	28.5	55.6
Am-238	1.09×10^{-12}	5.65	0.956	7.29	17.8	31.6	67.4	106
Am-239	4.91×10^{-13}	2.53	0.951	0.0306	0.334	1.09	4.53	8.47
Am-240	1.30×10^{-12}	6.73	0.954	7.89	18.6	31.6	62.7	92.9
Am-241	1.45×10^{-13}	0.749	0.932	0.00974	0.0235	0.106	0.528	0.948
Am-242	9.22×10^{-14}	0.476	0.937	0.01	0.0227	0.1	0.779	1.55
Am-242m	7.60×10^{-14}	0.392	0.921	0.00758	0.0151	0.0252	0.0532	0.249
Am-243	1.16×10^{-13}	0.597	0.944	0.0234	0.193	0.49	1.24	2.01
Am-244	1.12×10^{-12}	5.78	0.950	5.24	13.8	24.3	49.9	75.4
Am-244m	5.09×10^{-14}	0.263	0.930	0.0174	3.57	18.3	52.5	85.1
Am-245	5.28×10^{-14}	0.273	0.953	0.138	0.683	1.85	5.14	8.53
Am-246	1.17×10^{-12}	6.02	0.949	2.21	9.09	18.4	40.9	63.1
Am-246m	1.09×10^{-12}	5.6	0.959	11	21.8	35.6	69.8	104
Am-247	1.98×10^{-13}	1.02	0.955	0.267	1.08	2.71	7.01	11.3
Ar-41	1.27×10^{-12}	6.58	0.965	16.1	29.6	46.6	86.8	126
Ar-43	1.47×10^{-12}	7.6	0.965	15	28.9	47.2	94.9	144
Ar-44	1.80×10^{-12}	9.29	0.965	16.8	32.9	53	101	148
As-68	3.78×10^{-12}	19.5	0.965	9.93	20.9	37.2	82.5	129
As-69	1.24×10^{-12}	6.42	0.965	5.28	10.5	18.1	51.2	98.7
As-70	4.35×10^{-12}	22.5	0.965	10.5	21.8	37.9	81.2	126
As-71	6.07×10^{-13}	3.13	0.965	3.76	9.27	17.5	46.3	81.3
As-72	1.92×10^{-12}	9.9	0.965	7.11	14.2	24.7	58.1	102
As-73	7.80×10^{-15}	0.0403	0.876	0.101	0.196	0.319	0.631	0.944
As-74	8.38×10^{-13}	4.33	0.965	5.87	11.2	18	35.4	54
As-76	4.46×10^{-13}	2.3	0.965	7.37	14.7	26.1	64.6	108
As-77	8.75×10^{-15}	0.0452	0.964	1.64	3.94	9.24	23.6	37.6

(Continued on next page)

Table 1. *(Continued)*

Nuclide	Exposure rate constant C m² / kg MBq s	Exposure rate constant R cm² / mCi h	*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb) HVL	QVL	TVL	CVL	MVL
As-78	1.32×10^{-12}	6.83	0.965	11.2	22.7	39.2	84.5	131
As-79	3.67×10^{-14}	0.19	0.965	5.44	12	22.3	49.9	77.3
At-204	2.56×10^{-12}	13.2	0.963	5.72	11.6	19.5	41.1	64.7
At-205	1.21×10^{-12}	6.24	0.960	7.72	16.6	29.9	70.3	115
At-206	2.67×10^{-12}	13.8	0.963	6.54	13.9	24.9	59.5	102
At-207	2.06×10^{-12}	10.6	0.961	9.81	20.9	36.7	81.2	128
At-208	3.18×10^{-12}	16.4	0.962	8.88	18.2	31.5	71.4	117
At-209	2.46×10^{-12}	12.7	0.961	7.67	15.9	27	57.8	93.6
At-210	2.95×10^{-12}	15.2	0.962	13.8	27.8	45.2	87.3	129
At-211	4.15×10^{-14}	0.214	0.951	0.175	0.461	0.96	16.1	37.1
At-215	1.83×10^{-16}	0.000946	0.876	3.22	6.19	9.97	19.3	28.4
At-216	2.57×10^{-15}	0.0133	0.953	0.338	0.849	2.12	6.9	12
At-217	2.43×10^{-16}	0.00126	0.962	1.75	4.17	10.4	28	45
At-220	4.85×10^{-13}	2.5	0.964	1.95	4.62	10.2	28.3	47.6
Au-186	1.58×10^{-12}	8.15	0.962	5.69	13.2	25.8	66.8	112
Au-187	1.05×10^{-12}	5.44	0.956	10.8	24.3	42.7	89.1	135
Au-190	2.18×10^{-12}	11.3	0.960	12	28.5	50	103	155
Au-191	6.36×10^{-13}	3.28	0.956	3.17	8.07	15.8	39.3	68.7
Au-192	1.83×10^{-12}	9.43	0.959	12.2	28.2	48.8	99.3	149
Au-193	1.69×10^{-13}	0.871	0.950	0.505	1.54	4.29	17	35.9
Au-193m	2.03×10^{-13}	1.05	0.960	1.02	2.04	3.37	6.68	9.99
Au-194	1.03×10^{-12}	5.31	0.958	8.23	22.4	41.4	88.4	135
Au-195	7.93×10^{-14}	0.409	0.947	0.19	0.375	0.623	1.3	1.95
Au-195m	2.07×10^{-13}	1.07	0.960	1.06	2.12	3.5	6.95	10.4
Au-196	5.11×10^{-13}	2.64	0.957	2.04	4.31	7.28	15.3	28
Au-196m	2.34×10^{-13}	1.21	0.955	0.447	0.927	1.73	5.35	10.4
Au-198	4.46×10^{-13}	2.3	0.965	3.35	6.47	10.5	21.2	35.9
Au-198m	5.25×10^{-13}	2.71	0.959	0.634	1.36	2.53	7.23	13.3
Au-199	9.13×10^{-14}	0.471	0.959	0.483	0.9	1.47	3.18	5.22
Au-200	2.80×10^{-13}	1.45	0.965	9.66	22.8	39.5	79.6	118
Au-200m	2.15×10^{-12}	11.1	0.964	4.32	9.96	18.1	40.1	63.3
Au-201	3.77×10^{-14}	0.195	0.960	4.74	9.87	16.6	33.8	51.7
Au-202	1.80×10^{-13}	0.93	0.965	8.73	19.4	34.6	72.8	111
Ba-124	7.09×10^{-13}	3.66	0.947	4.11	11	22.2	56.6	93.2
Ba-126	7.13×10^{-13}	3.68	0.946	4.45	13.5	26.8	61.5	96.9
Ba-127	8.49×10^{-13}	4.38	0.953	4.7	10.2	18.8	56.7	105
Ba-128	1.68×10^{-13}	0.868	0.929	0.0436	0.24	1.83	5.99	10.6
Ba-129	4.38×10^{-13}	2.26	0.943	3	8.82	18.5	60.1	107
Ba-129m	1.75×10^{-12}	9.06	0.954	7.26	17.6	32.6	72.4	113
Ba-131	6.38×10^{-13}	3.29	0.946	1.8	5.78	11.8	30	56.2
Ba-131m	1.28×10^{-13}	0.659	0.942	0.0644	0.202	0.465	1.16	1.82
Ba-133	5.89×10^{-13}	3.04	0.943	0.819	2.84	5.65	12.7	19.9
Ba-133m	1.37×10^{-13}	0.707	0.932	0.0693	0.849	2.5	6.49	10.4
Ba-135m	1.28×10^{-13}	0.663	0.931	0.0605	0.637	2.15	5.85	9.51
Ba-137m	6.64×10^{-13}	3.43	0.962	7.19	13.7	21.8	41.5	60.7
Ba-139	4.91×10^{-14}	0.254	0.957	0.496	1.04	2.44	46.1	88.9
Ba-140	2.21×10^{-13}	1.14	0.953	3.46	8.01	13.9	28.6	43
Ba-141	9.67×10^{-13}	4.99	0.963	5.72	15.7	31.6	74.4	118
Ba-142	1.11×10^{-12}	5.75	0.959	9.43	20.8	35.1	70.3	105
Be-7	5.54×10^{-14}	0.286	0.876	4.35	8.33	13.4	25.6	37.7
Bi-197	1.76×10^{-12}	9.07	0.961	10.4	21.5	36.4	75.6	116
Bi-200	2.60×10^{-12}	13.4	0.962	6.06	14	26.4	59.1	90.9
Bi-201	1.73×10^{-12}	8.92	0.960	12.8	25.5	42.2	85.5	130
Bi-202	2.90×10^{-12}	15	0.962	8.41	17.9	31.3	67.9	109
Bi-203	2.35×10^{-12}	12.1	0.961	13.5	26.8	44.5	90.4	137
Bi-204	3.02×10^{-12}	15.6	0.962	9.99	20.8	35.1	73.1	114
Bi-205	1.66×10^{-12}	8.58	0.960	13.1	26.6	44.7	91.2	137
Bi-206	3.41×10^{-12}	17.6	0.962	9.35	19.5	33.7	73.6	117
Bi-207	1.61×10^{-12}	8.33	0.961	9.28	19.1	32.9	69.7	108
Bi-208	2.15×10^{-12}	11.1	0.959	21.4	39.5	62.5	117	170
Bi-210m	2.77×10^{-13}	1.43	0.963	1.56	3.23	6.09	21.7	40.8
Bi-211	5.13×10^{-14}	0.265	0.962	2.19	4.35	7.12	14	20.7
Bi-212	1.08×10^{-13}	0.556	0.961	10.3	20.6	34.8	76.2	120
Bi-213	1.41×10^{-13}	0.728	0.963	3.75	7.42	12.4	29.4	59.6
Bi-214	1.45×10^{-12}	7.48	0.965	13.4	26.9	45.1	91.8	138
Bi-215	2.69×10^{-13}	1.39	0.962	3.62	10.6	24.3	60.6	97.7
Bi-216	8.20×10^{-13}	4.23	0.965	4.88	9.48	15.4	30.4	45.3
Bk-245	3.88×10^{-13}	2	0.953	0.0927	0.515	1.58	6.33	13.8

Table 1. *(Continued)*

	Exposure rate constant			Lead attenuation thicknesses (mm Pb)				
Nuclide	C m^2 / kg MBq s	R cm^2 / mCi h	*f*-factor (cGy/R)	HVL	QVL	TVL	CVL	MVL
Bk-246	1.10×10^{-12}	5.66	0.953	6.47	16.1	27.9	57.5	87.8
Bk-247	1.88×10^{-13}	0.969	0.956	0.377	1.15	2.51	6.08	9.62
Bk-248m	1.40×10^{-13}	0.723	0.944	0.0219	0.585	6.17	22.2	37.4
Bk-250	1.04×10^{-12}	5.39	0.957	10.8	21.8	35.3	67.6	98.9
Bk-251	3.46×10^{-13}	1.78	0.944	0.0117	0.0382	0.334	1.25	2.39
Br-72	3.09×10^{-12}	15.9	0.965	8.73	18.4	33.2	75.6	121
Br-73	1.57×10^{-12}	8.12	0.963	5.29	10.7	18.3	42.5	73.9
Br-74	4.10×10^{-12}	21.2	0.964	12.2	27.2	49	104	159
Br-74m	4.01×10^{-12}	20.7	0.965	10.1	21.7	40.3	92.6	145
Br-75	1.31×10^{-12}	6.77	0.965	3.9	8.4	14.8	34.2	63.4
Br-76	2.70×10^{-12}	14	0.965	10.3	22.8	42.6	94.8	146
Br-76m	5.76×10^{-14}	0.297	0.930	0.0917	0.214	2.84	22.4	43.9
Br-77	3.41×10^{-13}	1.76	0.965	3.61	8.64	15.8	36.4	61.1
Br-77m	1.29×10^{-14}	0.0665	0.876	0.248	0.442	0.697	1.48	1.74
Br-78	1.15×10^{-12}	5.93	0.965	5.09	9.73	15.6	30.5	47.5
Br-80	8.36×10^{-14}	0.431	0.965	6.28	12	19.4	38.4	60
Br-80m	4.97×10^{-14}	0.257	0.923	0.0386	0.0741	0.121	0.239	0.364
Br-82m	2.94×10^{-15}	0.0152	0.949	8.72	17.4	28.7	59.4	95.3
Br-82	2.80×10^{-12}	14.4	0.965	9.56	18.8	31.7	67.9	107
Br-83	7.61×10^{-15}	0.0393	0.965	5.26	10	16	30.7	45.1
Br-84m	2.82×10^{-12}	14.5	0.965	11.5	24.1	40.8	83	125
Br-84	1.56×10^{-12}	8.07	0.964	16.6	31.8	52.1	105	157
Br-85	6.87×10^{-14}	0.355	0.965	11.4	21.9	35.5	72.8	114
C-10	1.92×10^{-12}	9.94	0.965	6.08	11.8	19.4	39.5	60.7
C-11	1.13×10^{-12}	5.86	0.876	4.95	9.46	15.1	28.9	42.5
Ca-47	1.05×10^{-12}	5.43	0.965	15.1	28.5	45.2	85.5	124
Ca-49	2.41×10^{-12}	12.4	0.961	22.4	40.9	64.5	121	176
Cd-101	2.64×10^{-12}	13.6	0.959	8.8	20.6	38.7	86	133
Cd-102	1.13×10^{-12}	5.84	0.951	3.94	10	20.3	55.8	94.3
Cd-103	2.23×10^{-12}	11.5	0.954	10.7	25	44.7	94.1	143
Cd-104	5.94×10^{-13}	3.07	0.937	0.0395	3.8	12.8	33.9	54.6
Cd-105	1.47×10^{-12}	7.57	0.952	8.77	21.6	40.4	88.7	136
Cd-107	3.94×10^{-13}	2.03	0.922	0.0112	0.0222	0.038	2	23.5
Cd-109	3.66×10^{-13}	1.89	0.922	0.0109	0.0213	0.0353	0.0805	0.74
Cd-111m	4.16×10^{-13}	2.15	0.954	0.455	1.29	2.46	5.43	8.38
Cd-113m	2.11×10^{-16}	0.00109	0.936	0.0227	0.419	1.86	5.41	8.9
Cd-115	2.24×10^{-13}	1.16	0.961	4.52	9.14	15	29.2	43.2
Cd-115m	3.40×10^{-14}	0.175	0.965	12.5	23.8	38.2	74.2	111
Cd-117	1.10×10^{-12}	5.68	0.963	11.2	24.9	42.2	84.9	127
Cd-117m	1.96×10^{-12}	10.1	0.965	15.3	29.8	48.8	97	145
Cd-119	1.57×10^{-12}	8.1	0.964	14.1	29.5	49	97.2	145
Cd-119m	2.22×10^{-12}	11.5	0.964	15	29.3	47.9	95.2	143
Ce-130	6.31×10^{-13}	3.26	0.945	2.51	9.57	22	55.9	90.8
Ce-131	1.79×10^{-12}	9.25	0.957	6.35	14.6	28.8	71	115
Ce-132	3.69×10^{-13}	1.91	0.947	0.407	1.21	3.04	14.7	30.2
Ce-133	7.21×10^{-13}	3.72	0.944	2.51	7.16	13	27.3	41.2
Ce-133m	1.89×10^{-12}	9.78	0.951	7.86	18.8	35.5	80.1	125
Ce-134	1.12×10^{-13}	0.579	0.923	0.0316	0.0609	0.102	0.322	3.71
Ce-135	9.83×10^{-13}	5.08	0.951	3.72	9.97	19.3	45.7	76.8
Ce-137	1.25×10^{-13}	0.645	0.923	0.0366	0.0775	0.361	13.3	31.6
Ce-137m	1.14×10^{-13}	0.59	0.930	0.0697	0.615	2.6	23.2	49.6
Ce-139	2.46×10^{-13}	1.27	0.943	0.141	0.532	1.05	2.3	3.53
Ce-141	8.78×10^{-14}	0.453	0.953	0.249	0.577	0.981	1.96	2.93
Ce-143	3.58×10^{-13}	1.85	0.944	1.78	5.16	12.9	36.4	61.6
Ce-144	2.61×10^{-14}	0.135	0.945	0.123	0.372	0.709	1.53	2.36
Ce-145	9.57×10^{-13}	4.94	0.946	6.22	14.3	25.2	54.5	86.9
Cf-244	2.66×10^{-14}	0.137	0.921	0.00779	0.0155	0.0259	0.0527	0.0818
Cf-246	1.83×10^{-14}	0.0947	0.921	0.0078	0.0156	0.026	0.0536	0.094
Cf-247	5.74×10^{-13}	2.96	0.938	0.00948	0.0224	0.16	1.8	11
Cf-248	2.20×10^{-14}	0.114	0.921	0.00781	0.0156	0.026	0.0539	0.101
Cf-249	4.15×10^{-13}	2.14	0.959	2.02	4.61	7.97	16.4	25.1
Cf-250	2.50×10^{-14}	0.129	0.929	0.0205	4.94	20.8	67.4	116
Cf-251	2.36×10^{-13}	1.22	0.951	0.0425	0.366	0.965	3.44	6.99
Cf-252	4.48×10^{-13}	2.31	0.960	11.5	25.5	44.7	94.9	146
Cf-253	1.01×10^{-13}	0.522	0.921	0.00761	0.0154	0.0261	0.0582	0.147
Cf-254	1.59×10^{-11}	82.3	0.963	12.3	26.4	45.7	96	147

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Table 1. *(Continued)*

	Exposure rate constant			Lead attenuation thicknesses (mm Pb)				
Nuclide	C m^2 / kg MBq s	R cm^2 / mCi h	*f*-factor (cGy/R)	HVL	QVL	TVL	CVL	MVL
Cl-34	1.14×10^{-12}	5.87	0.876	4.95	9.46	15.1	28.9	42.5
Cl-34m	1.94×10^{-12}	10	0.965	12.3	27.9	49.5	103	155
Cl-36	1.58×10^{-16}	0.000816	0.876	4.95	9.46	15.1	28.9	42.5
Cl-38	1.28×10^{-12}	6.6	0.965	20.4	37.1	58.2	109	158
Cl-39	1.43×10^{-12}	7.37	0.965	14.8	29.1	46.9	89.3	131
Cl-40	3.42×10^{-12}	17.7	0.964	19.6	36.4	57.7	110	163
Cm-238	1.69×10^{-13}	0.87	0.951	0.0252	0.179	0.452	1.15	1.78
Cm-239	3.74×10^{-13}	1.93	0.956	0.191	0.585	1.18	2.88	5.32
Cm-240	3.48×10^{-14}	0.179	0.921	0.00732	0.0146	0.0242	0.0489	0.0776
Cm-241	7.61×10^{-13}	3.93	0.953	1.18	4.9	10.1	22.7	35.9
Cm-242	3.12×10^{-14}	0.161	0.921	0.00732	0.0146	0.0242	0.0488	0.077
Cm-243	2.64×10^{-13}	1.36	0.951	0.042	0.527	1.69	5.37	9.3
Cm-244	2.67×10^{-14}	0.138	0.921	0.00732	0.0146	0.0241	0.0487	0.076
Cm-245	2.39×10^{-13}	1.23	0.950	0.0219	0.182	0.507	1.55	2.79
Cm-246	2.28×10^{-14}	0.118	0.922	0.00833	0.0176	0.0376	30.9	73.6
Cm-247	3.50×10^{-13}	1.81	0.964	2.95	5.85	9.58	18.8	27.9
Cm-248	1.26×10^{-12}	6.51	0.962	12	26	45.3	95.6	146
Cm-249	2.26×10^{-14}	0.117	0.961	5.14	10.9	18.3	36.4	54.3
Cm-250	1.26×10^{-11}	65	0.963	12.3	26.5	45.8	96.1	147
Cm-251	1.54×10^{-13}	0.797	0.956	3.01	8.16	15.2	36.2	63.3
Co-54m	4.07×10^{-12}	21	0.965	9.46	20.9	37.2	77.8	117
Co-55	2.12×10^{-12}	11	0.965	8.06	16.8	29.9	66.4	105
Co-56	3.46×10^{-12}	17.9	0.965	14.5	28.2	46.7	95.5	146
Co-57	1.09×10^{-13}	0.563	0.961	0.298	0.533	0.85	2.39	24
Co-58	1.05×10^{-12}	5.44	0.965	8.85	17	27.5	53.7	80.3
Co-58m	1.23×10^{-16}	0.000636	0.876	0.0161	0.0299	0.0473	0.09	0.133
Co-60	2.50×10^{-12}	12.9	0.965	15.6	28.8	45.3	84.7	123
Co-60m	4.59×10^{-15}	0.0237	0.942	8.27	23.2	40.7	82.1	122
Co-61	1.02×10^{-13}	0.525	0.946	0.69	8.35	21	50.2	78
Co-62	1.54×10^{-12}	7.94	0.965	16.3	30.2	48	93.2	140
Co-62m	2.63×10^{-12}	13.6	0.965	15.9	29.4	46.7	89.9	135
Cr-48	4.50×10^{-13}	2.32	0.963	1.26	3.05	5.47	12.6	23.6
Cr-49	1.15×10^{-12}	5.95	0.962	4.39	8.92	14.6	28.6	43.1
Cr-51	3.44×10^{-14}	0.178	0.876	1.92	3.74	6.07	11.8	17.5
Cr-55	5.38×10^{-16}	0.00278	0.876	18.3	33.4	52.5	97.5	141
Cr-56	1.97×10^{-13}	1.02	0.943	0.0331	0.17	0.576	1.58	2.58
Cs-121	1.31×10^{-12}	6.76	0.962	4.78	9.75	16.6	40.3	77.6
Cs-121m	1.33×10^{-12}	6.86	0.961	4.27	9.34	16.6	42	78.4
Cs-123	1.25×10^{-12}	6.47	0.957	4.85	10.2	17.7	43.8	79.9
Cs-124	1.28×10^{-12}	6.59	0.964	5.06	10.1	17.3	47.6	95.1
Cs-125	8.92×10^{-13}	4.61	0.953	4.79	10.2	18.2	52	99.8
Cs-126	1.29×10^{-12}	6.64	0.963	4.87	9.72	16.7	43.9	88
Cs-127	5.84×10^{-13}	3.01	0.945	2.24	5.93	11.3	33.4	70.7
Cs-128	1.02×10^{-12}	5.24	0.960	4.7	9.34	15.6	35.7	74.9
Cs-129	4.61×10^{-13}	2.38	0.937	0.915	3.69	7.62	19	35.3
Cs-130m	1.87×10^{-13}	0.963	0.932	0.0369	0.0905	0.391	5.13	20.5
Cs-130	6.15×10^{-13}	3.18	0.952	4.3	9.06	15.3	34.9	74.7
Cs-131	1.31×10^{-13}	0.679	0.921	0.0262	0.0481	0.0765	0.15	0.226
Cs-132	8.90×10^{-13}	4.6	0.947	5.9	12.6	21.1	42.5	66.6
Cs-134	1.70×10^{-12}	8.76	0.965	8.04	15.4	25.1	50.9	79.5
Cs-134m	6.55×10^{-14}	0.338	0.933	0.0392	0.0941	0.345	1.11	1.88
Cs-135m	1.73×10^{-12}	8.91	0.965	9.82	18.5	29.2	55	80.2
Cs-136	2.25×10^{-12}	11.6	0.963	10.1	20.5	33.8	66.7	99.9
Cs-137†	6.64×10^{-13}	3.43	0.962	7.19	13.7	21.8	41.5	60.7
Cs-138m	4.72×10^{-13}	2.44	0.946	7.32	20.6	39	82.8	125
Cs-138	2.27×10^{-12}	11.7	0.965	14.9	29.5	48.3	95.2	142
Cs-139	2.79×10^{-13}	1.44	0.965	17	32.2	51.8	101	150
Cs-140	1.64×10^{-12}	8.45	0.965	14.6	29.7	50.1	102	153
Cu-57	1.26×10^{-12}	6.48	0.965	5.4	10.5	17.6	43.1	82.5
Cu-59	1.57×10^{-12}	8.1	0.965	6.08	12.3	22.3	58.2	98.4
Cu-60	3.83×10^{-12}	19.8	0.965	12.1	25.8	44.6	92.2	140
Cu-61	9.06×10^{-13}	4.68	0.965	5.2	10.3	17.4	40.7	74.7
Cu-62	1.12×10^{-12}	5.78	0.965	4.98	9.52	15.3	29.7	46.3
Cu-64	2.04×10^{-13}	1.05	0.965	5.11	9.81	16	34.5	68.3
Cu-66	1.02×10^{-13}	0.525	0.965	12.9	24.1	37.9	71	103
Cu-67	1.11×10^{-13}	0.574	0.962	0.544	1.06	1.76	4.16	10.1
Cu-69	5.53×10^{-13}	2.86	0.965	11.4	22	35.8	70.8	107
Dy-148	8.17×10^{-13}	4.22	0.950	6.08	12.3	20.3	42.1	70.5

Table 1. *(Continued)*

Nuclide	Exposure rate constant C m² / kg MBq s	R cm² / mCi h	*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb) HVL	QVL	TVL	CVL	MVL
Dy-149	1.67×10^{-12}	8.63	0.951	11.1	23.6	40.6	85.4	131
Dy-150	3.27×10^{-13}	1.69	0.949	2.48	5.38	9.06	18.1	27
Dy-151	1.45×10^{-12}	7.5	0.953	8.84	20	35.7	77.4	120
Dy-152	3.32×10^{-13}	1.71	0.949	0.792	1.83	3.16	6.46	9.73
Dy-153	9.68×10^{-13}	5	0.945	5.36	15.6	31.3	72.4	114
Dy-155	7.25×10^{-13}	3.74	0.949	5	15.8	31	69.9	110
Dy-157	4.09×10^{-13}	2.11	0.948	1.41	3.31	5.78	12.2	20.8
Dy-159	8.58×10^{-14}	0.443	0.929	0.066	0.128	0.213	0.439	0.697
Dy-165m	2.23×10^{-14}	0.115	0.941	0.672	4.21	9.78	23.7	37.4
Dy-165	3.06×10^{-14}	0.158	0.944	2.25	7.65	16.3	40.4	68.1
Dy-166	6.09×10^{-14}	0.315	0.936	0.105	0.255	0.823	8.9	18.3
Dy-167	5.86×10^{-13}	3.03	0.959	3.46	8.6	16.2	37.7	65.3
Dy-168	4.40×10^{-13}	2.27	0.955	3.02	7.43	13.4	29.1	46
Er-154	1.77×10^{-13}	0.914	0.930	0.0479	0.199	4.16	18.6	32.3
Er-156	1.25×10^{-13}	0.647	0.930	0.0653	0.156	0.452	6.69	14.7
Er-159	1.03×10^{-12}	5.31	0.952	7.57	16.8	31	74.1	120
Er-161	1.07×10^{-12}	5.52	0.950	9.12	19.1	31.9	65.7	102
Er-163	6.52×10^{-14}	0.336	0.931	0.0795	0.157	0.266	3.78	38.2
Er-165	6.19×10^{-14}	0.319	0.931	0.0776	0.151	0.25	0.508	0.788
Er-167m	1.02×10^{-13}	0.526	0.955	0.651	1.33	2.2	4.39	6.57
Er-171	4.03×10^{-13}	2.08	0.956	1.42	3.28	5.99	21.6	48
Er-172	5.80×10^{-13}	3	0.952	4.14	8.95	15.5	32.9	50.3
Er-173	8.75×10^{-13}	4.52	0.957	5.25	15.2	27	55.2	82.5
Es-249	7.26×10^{-13}	3.75	0.951	0.474	4.01	11.6	40.3	71.1
Es-250	2.54×10^{-12}	13.1	0.944	0.259	5.16	16.4	43.3	69
Es-250m	8.56×10^{-13}	4.42	0.949	3.5	14.5	29.2	65.3	102
Es-251	4.86×10^{-13}	2.51	0.941	0.0101	0.0253	0.209	0.998	1.89
Es-253	1.33×10^{-14}	0.0686	0.922	0.0073	0.0148	0.0258	1.61	10.4
Es-254	4.42×10^{-13}	2.28	0.921	0.00709	0.0143	0.0242	0.0608	2.87
Es-254m	6.68×10^{-13}	3.45	0.951	4.74	11.6	20	40.7	62.1
Es-256	6.45×10^{-14}	0.333	0.921	0.00813	0.0164	0.0278	0.0598	0.101
Eu-142	1.30×10^{-12}	6.71	0.964	5.85	11.6	20.4	58.6	107
Eu-142m	3.70×10^{-12}	19.1	0.964	7.95	16	27.3	59	93.3
Eu-143	1.20×10^{-12}	6.21	0.961	6.59	13.7	26.6	71.7	119
Eu-144	1.18×10^{-12}	6.11	0.963	5.84	11.6	21.1	63	110
Eu-145	1.33×10^{-12}	6.89	0.950	11.4	23.3	39.4	83.9	130
Eu-146	2.54×10^{-12}	13.1	0.957	9.31	18.8	32.6	74.3	120
Eu-147	5.50×10^{-13}	2.84	0.944	4.85	14.1	26.5	58.6	92
Eu-148	2.44×10^{-12}	12.6	0.958	7.14	14.6	25.9	62.1	104
Eu-149	1.21×10^{-13}	0.626	0.930	0.0844	0.546	3.08	12.7	26.2
Eu-150	1.73×10^{-12}	8.92	0.957	4.68	10.6	20.7	53.9	91.7
Eu-150m	5.73×10^{-14}	0.296	0.947	3.41	8.44	19.3	58.4	101
Eu-152	1.25×10^{-12}	6.44	0.952	9.52	21.5	36.7	75.1	114
Eu-152m	3.26×10^{-13}	1.68	0.949	9.31	19.4	32	63.4	95.7
Eu-152n	8.52×10^{-14}	0.44	0.948	0.133	0.294	0.537	1.2	1.2
Eu-154	1.30×10^{-12}	6.69	0.959	11.2	22.5	37.1	74.3	112
Eu-154m	1.02×10^{-13}	0.524	0.940	0.0809	0.214	0.439	1.08	1.61
Eu-155	6.80×10^{-14}	0.351	0.947	0.162	0.396	0.764	1.75	2.87
Eu-156	1.20×10^{-12}	6.21	0.961	14.6	28.4	46.5	93.1	140
Eu-157	3.49×10^{-13}	1.8	0.944	2.53	6.34	12.1	30.3	52.5
Eu-158	1.33×10^{-12}	6.87	0.959	12.4	23.9	38.9	78.5	121
Eu-159	3.69×10^{-13}	1.9	0.940	3.77	12.5	24.5	57.9	95
F-17	1.14×10^{-12}	5.86	0.965	4.96	9.46	15.1	29	42.5
F-18	1.10×10^{-12}	5.68	0.876	4.95	9.46	15.1	28.9	42.5
Fe-52	7.97×10^{-13}	4.12	0.965	3.5	8.1	13.9	28.8	48.9
Fe-53	1.30×10^{-12}	6.72	0.965	4.67	9.09	15	32.6	72.1
Fe-53m	3.09×10^{-12}	16	0.965	13	25	40.9	82.4	125
Fe-59	1.20×10^{-12}	6.2	0.965	14.7	27.3	43.1	80.9	118
Fe-61	1.39×10^{-12}	7.18	0.965	13.7	26.7	43.1	84.4	127
Fe-62	5.63×10^{-13}	2.91	0.876	4.88	9.33	14.9	28.6	41.9
Fm-251	3.97×10^{-13}	2.05	0.946	0.0213	0.388	4.78	32.7	63.3
Fm-252	3.63×10^{-14}	0.187	0.921	0.00744	0.0149	0.0251	0.0535	0.103
Fm-253	4.37×10^{-13}	2.25	0.935	0.00947	0.0216	0.104	1.44	5.43
Fm-254	4.22×10^{-14}	0.218	0.924	0.00998	0.0243	4.87	47.6	95
Fm-255	3.85×10^{-13}	1.99	0.921	0.00718	0.0144	0.0243	0.0551	0.45
Fm-256	1.18×10^{-11}	60.9	0.963	12.2	26.2	45.5	95.6	146

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Table 1. *(Continued)*

Nuclide	Exposure rate constant		*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Fm-257	4.87×10^{-13}	2.51	0.943	0.0141	0.119	1.06	32.8	81.9
Fr-212	1.17×10^{-12}	6.06	0.961	10.4	23.3	39.4	78.4	116
Fr-219	3.83×10^{-15}	0.0198	0.963	2.67	5.7	10.1	22.7	36.2
Fr-220	1.39×10^{-14}	0.0719	0.951	0.1	0.404	0.889	3.84	11.2
Fr-221	3.06×10^{-14}	0.158	0.962	0.769	1.52	2.57	6.14	14.1
Fr-222	2.92×10^{-13}	1.51	0.956	0.356	1.54	7.97	45.8	82.7
Fr-223	1.53×10^{-13}	0.788	0.937	0.0172	0.158	1.13	20.2	45.4
Fr-224	6.12×10^{-13}	3.16	0.960	7.55	20.4	37.1	79.5	122
Fr-227	5.55×10^{-13}	2.86	0.956	2.78	8.37	16.9	46.1	84.7
Ga-64	3.23×10^{-12}	16.7	0.965	10.9	23.8	43	94.6	147
Ga-65	1.26×10^{-12}	6.53	0.963	4.95	10.1	17.1	39.9	75.6
Ga-66	2.24×10^{-12}	11.6	0.965	12.8	27.7	48.7	103	156
Ga-67	1.55×10^{-13}	0.803	0.961	0.861	2.23	4.8	13.9	34
Ga-68	1.05×10^{-12}	5.43	0.965	5.12	9.84	16	33.8	61.7
Ga-70	7.52×10^{-15}	0.0388	0.965	11.9	23.1	37.1	70.2	102
Ga-72	2.60×10^{-12}	13.4	0.965	14	27.4	46	96.2	147
Ga-73	3.75×10^{-13}	1.94	0.962	2.14	4.54	9.6	35.5	64
Ga-74	2.93×10^{-12}	15.1	0.965	14.3	29.4	50.1	102	153
Gd-142	1.13×10^{-12}	5.83	0.958	6.14	13.3	25.8	68.3	113
Gd-143m	2.27×10^{-12}	11.7	0.958	6.54	15.1	29.2	71.6	116
Gd-144	9.43×10^{-13}	4.87	0.955	7.13	15.9	33	85.1	137
Gd-145m	7.58×10^{-13}	3.91	0.960	7.34	14.4	23.4	45.2	66.5
Gd-145	2.27×10^{-12}	11.7	0.956	14.8	30.5	51.1	101	151
Gd-146	3.36×10^{-13}	1.73	0.941	0.128	0.328	0.692	1.79	6.12
Gd-147	1.53×10^{-12}	7.92	0.954	5.89	14.8	27.5	61	96.9
Gd-149	6.16×10^{-13}	3.18	0.948	2.23	6.84	16	41.3	67.1
Gd-151	1.24×10^{-13}	0.639	0.932	0.0839	0.257	1.09	4.54	9.27
Gd-153	1.64×10^{-13}	0.847	0.936	0.0783	0.172	0.349	1.01	1.58
Gd-159	6.62×10^{-14}	0.342	0.942	1.38	3.73	6.79	14.6	23.5
Gd-162	4.65×10^{-13}	2.4	0.963	3.37	6.58	10.7	20.9	31
Ge-66	7.50×10^{-13}	3.87	0.958	3.62	8.2	15.3	42.5	82
Ge-67	1.52×10^{-12}	7.84	0.965	5.37	11.4	21.1	59.5	106
Ge-69	9.98×10^{-13}	5.15	0.965	9.4	19.4	33.4	70.1	108
Ge-75	3.71×10^{-14}	0.192	0.965	1.27	2.49	4.29	12.8	28
Ge-77	1.13×10^{-12}	5.82	0.965	4.92	13.2	26.9	66.5	109
Ge-78	2.96×10^{-13}	1.53	0.965	1.37	2.64	4.27	8.35	12.4
Hf-167	6.84×10^{-13}	3.53	0.957	3.2	7.02	12.4	26.2	39.8
Hf-169	7.19×10^{-13}	3.71	0.954	3.99	8.22	13.6	26.8	39.8
Hf-170	4.83×10^{-13}	2.49	0.950	2.58	7.91	15.1	32.9	50.9
Hf-172	1.83×10^{-13}	0.943	0.938	0.0552	0.178	0.368	0.977	1.75
Hf-173	4.15×10^{-13}	2.14	0.952	0.639	2.35	6.03	32.9	64.7
Hf-175	3.94×10^{-13}	2.04	0.950	1.62	3.73	6.43	13.2	20.1
Hf-177m	2.44×10^{-12}	12.6	0.959	1.5	3.5	7.12	21.7	39.4
Hf-178m	2.43×10^{-12}	12.5	0.961	2.78	6.57	12.1	26.7	41.7
Hf-179m	9.92×10^{-13}	5.12	0.957	1.79	4.52	8.53	19	29.7
Hf-180m	1.07×10^{-12}	5.54	0.959	2.08	4.81	8.84	19.7	31.1
Hf-181	5.78×10^{-13}	2.98	0.960	3.22	7.13	12.2	24.7	37
Hf-182	2.53×10^{-13}	1.3	0.961	1.13	2.29	3.8	7.55	11.3
Hf-182m	9.85×10^{-13}	5.08	0.956	3.59	9.28	18.9	46.5	74.7
Hf-183	8.36×10^{-13}	4.32	0.957	7.31	15.2	25.9	54.1	86.9
Hf-184	2.50×10^{-13}	1.29	0.954	0.817	2.44	5.13	11.8	18.3
Hg-190	1.91×10^{-13}	0.985	0.954	0.323	0.644	1.16	9.36	27.9
Hg-191m	1.54×10^{-12}	7.97	0.960	5.96	15.4	30.6	72.9	116
Hg-192	2.79×10^{-13}	1.44	0.954	0.722	1.84	3.52	8.05	13.9
Hg-193	8.43×10^{-13}	4.35	0.956	8.92	21.1	37.4	80.3	125
Hg-193m	1.06×10^{-12}	5.46	0.958	7.99	18.8	34.5	76	118
Hg-195	2.04×10^{-13}	1.05	0.950	4.25	13	24.8	55.4	87.6
Hg-195m	2.10×10^{-13}	1.08	0.955	1.66	4.69	11.9	37.4	71.4
Hg-197	6.76×10^{-14}	0.349	0.947	0.216	0.431	0.727	1.59	2.88
Hg-197m	8.94×10^{-14}	0.461	0.955	0.359	0.746	1.6	5.57	9.65
Hg-199m	1.79×10^{-13}	0.926	0.956	0.602	1.5	4.32	12.2	20
Hg-203	2.52×10^{-13}	1.3	0.963	1.32	2.6	4.25	8.35	12.4
Hg-205	5.04×10^{-15}	0.026	0.961	0.719	1.37	2.25	4.81	11.1
Hg-206	1.30×10^{-13}	0.672	0.961	1.96	4.11	7.72	24.5	43.7
Hg-207	2.58×10^{-12}	13.3	0.964	14	28.6	47.3	93.9	140
Ho-150	2.07×10^{-12}	10.7	0.964	6.8	13.4	22.5	47	72.5
Ho-153	1.13×10^{-12}	5.84	0.957	4.61	10.7	20.5	52.9	89.3
Ho-153m	1.18×10^{-12}	6.08	0.957	4.22	9.43	17	41.6	73.8

Table 1. *(Continued)*

Nuclide	Exposure rate constant C m^2 / kg MBq s	R cm^2 / mCi h	*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb) HVL	QVL	TVL	CVL	MVL
Ho-154m	2.68×10^{-12}	13.8	0.962	4.68	10	18.9	49.8	85.3
Ho-154	2.02×10^{-12}	10.4	0.962	5.78	12.9	25.2	64.8	108
Ho-155	6.74×10^{-13}	3.48	0.949	4.22	11.1	24	68.5	116
Ho-156	2.16×10^{-12}	11.2	0.958	7.79	18.8	35.7	81.8	129
Ho-157	6.69×10^{-13}	3.45	0.946	2.6	8.13	19.3	53.1	89.8
Ho-159	4.49×10^{-13}	2.32	0.945	0.604	3.04	11.4	40.6	69.9
Ho-160	1.84×10^{-12}	9.52	0.954	8.79	17.7	29.3	58.5	88.3
Ho-161	1.62×10^{-13}	0.837	0.929	0.0335	0.0841	0.187	0.675	6.71
Ho-162	2.00×10^{-13}	1.03	0.936	3.18	12.3	28.1	69.7	110
Ho-162m	6.07×10^{-13}	3.14	0.946	7.25	19.9	35.2	72.3	109
Ho-164	4.88×10^{-14}	0.252	0.931	0.0764	0.151	0.257	0.631	1.25
Ho-164m	7.87×10^{-14}	0.406	0.930	0.0701	0.141	0.24	0.514	0.825
Ho-166	3.10×10^{-14}	0.16	0.942	5.68	20.6	39.3	83.4	126
Ho-166m	1.75×10^{-12}	9.05	0.961	6.42	14.2	24.3	49.8	76.6
Ho-167	4.02×10^{-13}	2.08	0.959	1.99	4.13	7.03	15.1	26.2
Ho-168	9.38×10^{-13}	4.84	0.961	9.16	17.8	29.1	59.1	95.2
Ho-168m	1.03×10^{-14}	0.0531	0.931	0.0777	0.152	0.25	0.51	0.792
Ho-170	1.80×10^{-12}	9.28	0.959	9.45	19.8	32.8	64.5	96.3
I-118m	4.09×10^{-12}	21.1	0.964	7.31	14.8	25.7	59.2	96.5
I-118	2.19×10^{-12}	11.3	0.964	6.6	13.2	23.7	61.6	106
I-119	1.08×10^{-12}	5.56	0.958	3.1	7.76	14.6	37.3	74
I-120	2.65×10^{-12}	13.7	0.962	9.31	20.9	40.3	92.3	144
I-120m	3.75×10^{-12}	19.4	0.963	7.74	16	29.6	73.8	121
I-121	5.69×10^{-13}	2.94	0.948	1	3.73	10.5	32.3	64.8
I-122	1.09×10^{-12}	5.65	0.962	5.01	9.86	16.3	36.2	76.2
I-123	3.46×10^{-13}	1.78	0.942	0.0667	0.442	1.12	11.1	27.1
I-124	1.28×10^{-12}	6.59	0.953	7.2	15.9	30.5	76.5	124
I-125	3.38×10^{-13}	1.75	0.921	0.0211	0.039	0.0623	0.124	0.193
I-126	5.57×10^{-13}	2.88	0.950	3.98	9.57	17.5	39	62.7
I-128	8.53×10^{-14}	0.44	0.953	3.24	7.07	12.2	28.2	53.9
I-129	1.34×10^{-13}	0.692	0.922	0.0269	0.0499	0.0805	0.166	0.272
I-130m	1.48×10^{-13}	0.766	0.943	3.87	9.47	17.5	49.4	95.3
I-130	2.34×10^{-12}	12.1	0.965	7.01	13.7	22.8	47.8	77.4
I-131	4.26×10^{-13}	2.2	0.963	2.74	5.59	9.93	25.9	45.3
I-132	2.42×10^{-12}	12.5	0.965	8.93	17.4	28.9	62.3	102
I-132m	4.42×10^{-13}	2.28	0.949	4.94	11.9	20.6	42.3	64
I-133	6.71×10^{-13}	3.47	0.965	6.05	11.9	20.3	48.5	84.1
I-134m	4.48×10^{-13}	2.31	0.943	0.595	2.16	4.99	30.6	58
I-134	2.73×10^{-12}	14.1	0.965	10.6	20.6	33.8	69.5	109
I-135	1.56×10^{-12}	8.04	0.965	14.9	28.6	46.1	89.4	133
In-103	2.81×10^{-12}	14.5	0.964	8.32	18.4	35	83.3	134
In-105	2.09×10^{-12}	10.8	0.961	6.82	15.3	29.7	75.3	124
In-106	3.88×10^{-12}	20	0.964	7.92	16	27.3	59	93.8
In-106m	2.84×10^{-12}	14.7	0.964	8.84	19.1	37.1	89	140
In-107	1.68×10^{-12}	8.67	0.957	7.46	18.9	37.5	86.8	136
In-108	4.25×10^{-12}	22	0.961	9.44	19.8	34.1	73.1	115
In-108m	2.69×10^{-12}	13.9	0.960	10.4	23.8	44.3	98.1	151
In-109	8.95×10^{-13}	4.62	0.949	2.6	10.7	24.8	64.8	107
In-109m	6.83×10^{-13}	3.53	0.963	6.99	13.4	21.3	40.6	59.4
In-110	3.55×10^{-12}	18.3	0.958	8.58	17.3	28.7	58.4	90.4
In-110m	1.76×10^{-12}	9.08	0.961	6.55	13.4	24.2	67.1	119
In-111	6.70×10^{-13}	3.46	0.951	0.257	0.95	1.96	4.82	7.77
In-111m	5.49×10^{-13}	2.83	0.961	4.99	9.84	15.9	30.8	45.3
In-112	3.74×10^{-13}	1.93	0.950	3.46	8.34	14.6	31.7	56.4
In-112m	1.97×10^{-13}	1.02	0.929	0.018	0.0371	0.114	1.29	2.4
In-113m	3.59×10^{-13}	1.85	0.953	1.98	4.8	8.36	17.1	25.6
In-114	3.40×10^{-15}	0.0175	0.937	5.86	18.3	35.2	76.1	115
In-114m	1.89×10^{-13}	0.977	0.937	0.0473	1.6	8.81	29.7	50.5
In-115m	2.74×10^{-13}	1.42	0.946	0.74	2.69	5.29	11.6	18
In-116m	2.45×10^{-12}	12.6	0.965	14.6	28.1	45.3	88	131
In-117	7.76×10^{-13}	4.01	0.962	3.87	9.02	15.4	31	46.1
In-117m	1.54×10^{-13}	0.793	0.948	0.334	1.57	3.82	9.61	16.2
In-118m	2.85×10^{-12}	14.7	0.965	12.9	24.7	40	78.1	117
In-118	7.82×10^{-14}	0.404	0.965	14.6	27.6	44	83.9	123
In-119	8.85×10^{-13}	4.57	0.959	8.31	16.3	26.1	50.1	73.7
In-119m	9.16×10^{-14}	0.473	0.942	6.12	18.6	34.1	71.3	108

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Table 1. *(Continued)*

Nuclide	Exposure rate constant: C m^2 / kg MBq s	Exposure rate constant: R cm^2 / mCi h	*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb): HVL	QVL	TVL	CVL	MVL
In-121	9.85×10^{-13}	5.09	0.965	10.8	20.5	32.7	62	90.4
In-121m	1.62×10^{-13}	0.839	0.930	0.0375	2.35	18.1	60.1	106
Ir-180	1.73×10^{-12}	8.92	0.962	5.32	11.7	20.9	47.4	76.8
Ir-182	1.50×10^{-12}	7.77	0.961	5.3	12.4	23.7	58.5	96.9
Ir-183	1.18×10^{-12}	6.11	0.955	8.93	21.9	40.2	87.7	135
Ir-184	2.01×10^{-12}	10.4	0.960	7.64	18.5	34.5	77.6	123
Ir-185	8.29×10^{-13}	4.28	0.952	10.7	26	45.6	93.4	140
Ir-186	1.69×10^{-12}	8.73	0.959	7	17.6	34.1	80.1	128
Ir-186m	1.26×10^{-12}	6.52	0.958	9.83	21	37	82.9	131
Ir-187	3.52×10^{-13}	1.82	0.950	4.85	12.7	24	53.9	83.8
Ir-188	1.95×10^{-12}	10.1	0.958	14.9	30.7	51.2	102	151
Ir-189	8.02×10^{-14}	0.414	0.945	0.243	0.569	1.42	4.45	7.76
Ir-190	1.61×10^{-12}	8.3	0.960	4.26	9.43	16.7	38	65.3
Ir-190n	6.04×10^{-14}	0.312	0.943	0.166	0.345	0.609	1.68	3.67
Ir-191m	7.04×10^{-14}	0.364	0.950	0.227	0.438	0.715	1.44	2.19
Ir-192	8.91×10^{-13}	4.6	0.964	2.67	5.68	10.5	25.3	42.1
Ir-192m	2.45×10^{-17}	0.000127	0.876	0.117	0.228	0.374	0.739	1.11
Ir-192n	5.90×10^{-16}	0.00305	0.946	0.221	0.447	0.776	1.75	2.8
Ir-193m	3.03×10^{-16}	0.00156	0.944	0.172	0.341	0.565	1.15	1.79
Ir-194	9.55×10^{-14}	0.493	0.964	3.7	9.28	22.5	60.3	99.5
Ir-194m	2.57×10^{-12}	13.3	0.965	4.47	9.38	16.3	35.2	56.1
Ir-195	5.73×10^{-14}	0.296	0.948	0.211	0.43	0.775	2.33	4.55
Ir-195m	4.05×10^{-13}	2.09	0.958	2.69	6.45	12.6	31.7	52.4
Ir-196	2.49×10^{-13}	1.28	0.964	5.49	13	25.3	60	98.6
Ir-196m	2.71×10^{-12}	14	0.964	4.43	9.09	15.9	36.8	65.3
K-38	2.99×10^{-12}	15.5	0.965	12.1	27.7	49.6	103	153
K-40	1.51×10^{-13}	0.779	0.965	17.6	32.3	50.8	94.7	137
K-42	2.65×10^{-13}	1.37	0.965	18.2	33.3	52.3	97.4	141
K-43	1.06×10^{-12}	5.48	0.965	4.62	9.62	16.8	36.5	58.8
K-44	2.17×10^{-12}	11.2	0.965	17.2	32.4	52	102	152
K-45	1.68×10^{-12}	8.68	0.965	16.8	32.9	53.1	102	150
K-46	2.48×10^{-12}	12.8	0.964	18.7	34.5	54.7	105	157
Kr-74	1.15×10^{-12}	5.94	0.963	3.95	8.5	14.5	29.9	48.1
Kr-75	1.39×10^{-12}	7.15	0.964	4.72	9.9	17.3	45.4	87
Kr-76	4.61×10^{-13}	2.38	0.960	2.15	4.79	9.34	27.8	54.6
Kr-77	1.12×10^{-12}	5.78	0.964	3.99	8.59	14.5	30	52.1
Kr-79	2.71×10^{-13}	1.4	0.965	3.9	8.8	16.2	40.3	72.4
Kr-81	8.71×10^{-16}	0.0045	0.876	1.35	2.58	4.18	8.15	12.1
Kr-81m	1.28×10^{-13}	0.658	0.876	0.675	1.22	1.93	3.68	5.43
Kr-83m	8.00×10^{-17}	0.000413	0.876	0.0271	0.0515	0.0833	0.163	0.244
Kr-85	2.48×10^{-15}	0.0128	0.876	5	9.54	15.3	29.2	42.8
Kr-85m	1.53×10^{-13}	0.79	0.964	0.626	1.27	2.81	8.17	13.5
Kr-87	7.38×10^{-13}	3.81	0.965	10.9	26.7	48.1	101	154
Kr-88	1.74×10^{-12}	8.97	0.964	18.1	34.8	56.1	108	159
Kr-89	1.79×10^{-12}	9.25	0.965	13.8	28.4	48.2	99.1	150
La-128	3.03×10^{-12}	15.7	0.964	6.55	14.5	27.5	66.7	109
La-129	1.06×10^{-12}	5.48	0.957	3.91	8.74	15.7	41.1	81.1
La-130	2.39×10^{-12}	12.3	0.962	6.44	14.2	27.5	70.1	117
La-131	8.11×10^{-13}	4.19	0.950	2.95	7.35	14	40.3	83
La-132	2.08×10^{-12}	10.7	0.959	7.72	17.3	34.7	84.6	135
La-132m	7.77×10^{-13}	4.01	0.953	4.42	10.9	20.6	49.1	79.5
La-133	2.57×10^{-13}	1.33	0.933	1.32	5.88	13.1	34.9	64.6
La-134	8.25×10^{-13}	4.26	0.958	4.84	9.64	16	36.7	77.9
La-135	1.30×10^{-13}	0.672	0.923	0.0329	0.0685	0.19	15.6	36.7
La-136	5.09×10^{-13}	2.63	0.948	4.08	8.9	15.2	33.5	62.1
La-137	1.15×10^{-13}	0.593	0.922	0.0283	0.054	0.0881	0.177	0.272
La-138	1.27×10^{-12}	6.55	0.953	14.2	27.7	45.1	87.8	129
La-140	2.26×10^{-12}	11.7	0.965	13.7	28.1	46.8	93.2	138
La-141	2.51×10^{-14}	0.13	0.965	17	31.2	49.3	92.4	135
La-142	2.12×10^{-12}	10.9	0.964	16.5	32.6	53.8	107	158
La-143	2.53×10^{-13}	1.31	0.965	14.2	28.2	47	95.4	144
Lu-165	1.16×10^{-12}	5.98	0.953	6.43	16	32.5	78.3	124
Lu-167	1.69×10^{-12}	8.74	0.952	11.6	26.3	45.5	93.2	140
Lu-169	1.34×10^{-12}	6.91	0.951	11.8	24.8	41.5	83.4	126
Lu-170	2.36×10^{-12}	12.2	0.954	16.8	32.3	52.2	102	152
Lu-171m	3.56×10^{-16}	0.00184	0.940	0.137	0.28	0.487	1.08	1.73
Lu-171	7.80×10^{-13}	4.03	0.945	5.87	13.7	23.3	46.9	70.8
Lu-172	2.04×10^{-12}	10.5	0.955	10.5	21.6	35.9	72.1	110

Table 1. *(Continued)*

Nuclide	Exposure rate constant		f-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Lu-173	2.15×10^{-13}	1.11	0.941	0.262	1.09	3.2	16.4	34.8
Lu-174	1.30×10^{-13}	0.673	0.937	2.81	15.4	32.7	72.5	110
Lu-174m	7.66×10^{-14}	0.395	0.936	0.128	0.289	1.18	33	65.4
Lu-176	5.05×10^{-13}	2.61	0.960	1.16	2.54	4.58	9.97	15.4
Lu-176m	1.41×10^{-14}	0.073	0.946	0.145	0.294	0.527	1.16	1.16
Lu-177	3.52×10^{-14}	0.181	0.957	0.542	1.19	2.11	4.7	8.46
Lu-177m	1.06×10^{-12}	5.47	0.957	1.15	2.88	5.93	14.7	23.9
Lu-178	1.23×10^{-13}	0.635	0.955	14.5	28.6	46.1	87.8	128
Lu-178m	1.12×10^{-12}	5.8	0.959	1.82	4.24	7.79	17.3	27.1
Lu-179	3.00×10^{-14}	0.155	0.962	0.907	1.82	3.5	27.7	57.1
Lu-180	1.54×10^{-12}	7.95	0.962	11	23.9	40.3	80.1	119
Lu-181	6.24×10^{-13}	3.22	0.957	5.09	11.8	20.7	43.8	67.5
Mg-27	9.48×10^{-13}	4.89	0.965	11	20.5	32.6	61.8	90.8
Mg-28	1.48×10^{-12}	7.64	0.951	11.3	24.2	40.7	81	120
Mn-50m	4.80×10^{-12}	24.8	0.965	10.5	21.5	36.9	77.4	119
Mn-51	1.11×10^{-12}	5.73	0.965	4.97	9.5	15.2	29.4	44.8
Mn-52	3.56×10^{-12}	18.4	0.965	11.9	23.4	38.8	79	119
Mn-52m	2.47×10^{-12}	12.8	0.965	9.6	21.3	38.9	82.6	125
Mn-54	8.97×10^{-13}	4.63	0.876	10.1	19	29.9	56.3	81.9
Mn-56	1.65×10^{-12}	8.54	0.965	14.1	27	44.7	92.7	141
Mn-57	9.87×10^{-14}	0.51	0.963	5.83	14.4	27.2	66	110
Mn-58m	2.40×10^{-12}	12.4	0.965	13	25.3	41.7	84.7	129
Mo-101	1.50×10^{-12}	7.74	0.964	11.4	24	41.2	86.1	131
Mo-102	2.07×10^{-14}	0.107	0.962	0.582	1.25	2.27	6.1	12.7
Mo-89	1.34×10^{-12}	6.92	0.965	5.65	11.2	19.4	52.5	97.9
Mo-90	1.40×10^{-12}	7.23	0.952	0.879	4.73	13.8	48.9	88.6
Mo-91m	1.48×10^{-12}	7.65	0.964	8.42	18	33.1	75.7	118
Mo-91	1.11×10^{-12}	5.72	0.965	4.88	9.49	15.4	32	65.1
Mo-93	3.99×10^{-13}	2.06	0.921	0.00673	0.0134	0.0221	0.0439	0.0622
Mo-93m	2.46×10^{-12}	12.7	0.962	11	23.9	41.2	85.2	128
Mo-99	1.78×10^{-13}	0.917	0.959	5.83	13.7	23.4	46.8	69.5
N-13	1.13×10^{-12}	5.86	0.876	4.95	9.46	15.1	28.9	42.5
N-16	2.76×10^{-12}	14.2	0.949	21.7	39	61.5	117	171
Na-22	2.29×10^{-12}	11.8	0.965	9.2	19.9	35.7	75.8	114
Na-24	3.53×10^{-12}	18.2	0.964	19.9	36.8	58.1	111	162
Nb-87	1.62×10^{-12}	8.39	0.960	2.47	6.92	12.7	26.6	40.2
Nb-88m	4.34×10^{-12}	22.4	0.965	8.65	18.5	33	72.3	114
Nb-88	4.77×10^{-12}	24.6	0.962	7.54	16.6	29.7	63.9	98.1
Nb-89	1.48×10^{-12}	7.65	0.962	7.01	15.7	32.8	84.7	137
Nb-89m	1.54×10^{-12}	7.93	0.963	4.71	9.42	15.5	32.2	55.9
Nb-90	4.25×10^{-12}	21.9	0.960	12.7	28.1	48.4	99.2	149
Nb-91	4.37×10^{-13}	2.26	0.921	0.00657	0.0131	0.0218	0.0482	9.59
Nb-91m	3.63×10^{-13}	1.87	0.923	0.00779	0.0165	0.0383	37.1	75.3
Nb-92	2.03×10^{-12}	10.5	0.955	5.91	14.4	25.6	54.6	83.4
Nb-92m	1.45×10^{-12}	7.48	0.948	6.03	16.7	29.4	60	90.6
Nb-93m	7.12×10^{-14}	0.368	0.921	0.00673	0.0134	0.0221	0.0439	0.0622
Nb-94m	2.74×10^{-13}	1.42	0.921	0.00696	0.014	0.0241	8.39	37.8
Nb-94	1.68×10^{-12}	8.69	0.965	9.36	17.6	28.1	54	79.8
Nb-95	8.31×10^{-13}	4.29	0.965	9.03	17	26.8	50.6	73.6
Nb-95m	3.32×10^{-13}	1.71	0.938	0.0101	0.0295	0.929	3.76	7.43
Nb-96	2.63×10^{-12}	13.6	0.965	9.31	18.5	30.9	63.5	97.4
Nb-97	7.31×10^{-13}	3.77	0.965	7.38	14	22.3	43.1	65.9
Nb-98m	2.92×10^{-12}	15.1	0.965	11	21.6	36.1	77.3	122
Nb-99	3.89×10^{-13}	2.01	0.952	0.0222	0.218	0.565	1.42	2.24
Nb-99m	7.15×10^{-13}	3.69	0.960	14.2	30.4	51.6	104	156
Nd-134	6.42×10^{-13}	3.32	0.951	2	6.45	13.8	38	68.3
Nd-135	1.44×10^{-12}	7.43	0.955	3.92	8.84	15.9	42.9	85.5
Nd-136	3.98×10^{-13}	2.05	0.938	1.02	6.28	14.8	40.9	73
Nd-137	1.32×10^{-12}	6.83	0.950	6.54	15	28.7	70.8	116
Nd-138	1.16×10^{-13}	0.597	0.926	0.0468	0.104	0.697	6.69	13.5
Nd-139	5.34×10^{-13}	2.76	0.947	4.73	10.6	19.8	52.2	90
Nd-139m	1.75×10^{-12}	9.06	0.951	8.79	18.5	31.4	66.7	107
Nd-140	9.77×10^{-14}	0.504	0.923	0.0374	0.0719	0.118	0.239	0.369
Nd-141	1.48×10^{-13}	0.765	0.927	0.0934	3.78	13.7	49.2	86.8
Nd-141m	7.60×10^{-13}	3.92	0.963	8.76	16.6	26.2	49.6	72.3
Nd-147	1.80×10^{-13}	0.931	0.943	1.48	5.77	11.9	27.3	43

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Table 1. *(Continued)*

Nuclide	Exposure rate constant		*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Nd-149	4.11×10^{-13}	2.12	0.956	1.7	4.93	11.6	31.4	54.6
Nd-151	8.86×10^{-13}	4.57	0.959	7.92	18.9	33.4	71.1	110
Nd-152	2.13×10^{-13}	1.1	0.957	1.04	2.52	4.98	18.6	35.5
Ne-19	1.14×10^{-12}	5.86	0.965	4.95	9.46	15.1	28.9	42.5
Ne-24	5.99×10^{-13}	3.09	0.965	4.69	9.19	15.4	35.6	61.7
Ni-56	1.81×10^{-12}	9.35	0.965	7.46	16.3	28.3	62.1	101
Ni-57	1.92×10^{-12}	9.93	0.965	12.5	26.4	44.7	89.3	133
Ni-65	5.49×10^{-13}	2.83	0.965	15.7	29.7	47.3	90	132
Np-232	1.50×10^{-12}	7.75	0.957	4.63	13.5	25.3	54.2	83.8
Np-233	1.94×10^{-13}	1	0.951	0.023	0.197	0.554	6.25	20.2
Np-234	1.24×10^{-12}	6.4	0.955	11.9	26.6	45.1	89.7	133
Np-235	1.04×10^{-13}	0.538	0.922	0.007	0.0139	0.0233	0.051	0.44
Np-236	5.72×10^{-13}	2.95	0.944	0.0119	0.0389	0.356	1.42	3.06
Np-236m	1.22×10^{-13}	0.628	0.949	0.0188	0.177	0.703	18.4	38
Np-237	2.32×10^{-13}	1.2	0.932	0.0091	0.0206	0.0552	0.983	2.31
Np-238	7.12×10^{-13}	3.67	0.954	9.96	20.9	34.3	66.4	97.5
Np-239	3.32×10^{-13}	1.72	0.952	0.0674	0.552	1.77	6.01	10.9
Np-240	1.39×10^{-12}	7.19	0.954	5.14	13.7	25.4	55.7	86.2
Np-240m	4.30×10^{-13}	2.22	0.953	4.95	12.2	23	58.6	100
Np-241	7.92×10^{-14}	0.409	0.951	0.0318	0.307	1.06	17.6	42.3
Np-242	2.78×10^{-13}	1.44	0.960	12.6	25.4	42.7	88.2	134
Np-242m	1.26×10^{-12}	6.49	0.952	5.4	14.8	26.3	54.3	81.8
O-14	3.07×10^{-12}	15.9	0.965	12.4	28.3	50.5	104	156
O-15	1.14×10^{-12}	5.86	0.876	4.95	9.46	15.1	28.9	42.5
O-19	9.22×10^{-13}	4.76	0.965	11.9	26.5	44.2	86.3	127
Os-180	1.80×10^{-13}	0.929	0.942	0.321	3.31	10.8	31.6	52.3
Os-181	1.41×10^{-12}	7.29	0.956	9.03	20.6	36	77.5	122
Os-182	4.66×10^{-13}	2.4	0.954	2.46	6.78	12.5	26.5	40.1
Os-183	6.69×10^{-13}	3.46	0.953	2.55	6.36	13.8	46.6	83
Os-183m	1.04×10^{-12}	5.35	0.955	12.4	24.1	38.7	73.7	108
Os-185	7.55×10^{-13}	3.9	0.955	6.89	13.7	22.4	44.5	67.7
Os-190m	1.74×10^{-12}	8.97	0.964	4.11	8.87	15.4	32.3	49.4
Os-191	7.82×10^{-14}	0.404	0.950	0.227	0.438	0.715	1.44	2.19
Os-191m	6.03×10^{-15}	0.0311	0.943	0.162	0.32	0.531	1.09	1.69
Os-193	7.05×10^{-14}	0.364	0.955	2	5.45	10.5	24.1	38.9
Os-194	5.24×10^{-15}	0.027	0.927	0.0582	0.112	0.184	0.382	0.706
Os-196	8.54×10^{-14}	0.441	0.956	1.91	5.17	10.4	26.1	43.2
P-30	1.14×10^{-12}	5.87	0.965	4.96	9.47	15.2	29.2	44
Pa-227	1.03×10^{-13}	0.533	0.940	0.00952	0.0237	0.174	0.836	1.45
Pa-228	1.73×10^{-12}	8.94	0.955	5.73	16	30.4	68.9	111
Pa-229	1.85×10^{-13}	0.953	0.948	0.0143	0.0662	0.321	1.03	1.34
Pa-230	9.04×10^{-13}	4.67	0.954	5	14.3	26.6	56.9	86.2
Pa-231	2.41×10^{-13}	1.24	0.931	0.00972	0.0247	0.761	6.21	11.8
Pa-232	1.15×10^{-12}	5.96	0.957	7.05	16.4	28.5	58.3	87.4
Pa-233	3.83×10^{-13}	1.98	0.953	0.304	1.86	4.31	10.6	17.6
Pa-234	1.83×10^{-12}	9.44	0.956	6.33	16	28.8	62.5	100
Pa-234m	1.58×10^{-14}	0.0816	0.958	9.33	19.9	33.3	67.1	103
Pa-236	1.01×10^{-12}	5.24	0.958	9.68	21.8	39.2	86.6	134
Pa-237	6.63×10^{-13}	3.42	0.965	8.53	16.8	27.6	54.9	82.3
Pb-194	1.10×10^{-12}	5.66	0.958	8.39	20.2	36.8	80.3	124
Pb-195m	1.77×10^{-12}	9.16	0.961	5.39	12.2	23	53.9	88.9
Pb-196	5.19×10^{-13}	2.68	0.957	2.37	6.61	13.8	36.4	63.7
Pb-197	1.53×10^{-12}	7.91	0.960	9.92	22.7	40.1	85.6	132
Pb-197m	1.25×10^{-12}	6.43	0.960	4.87	11.7	23.3	57.5	96.2
Pb-198	4.58×10^{-13}	2.36	0.957	1.87	4.95	11.5	35.9	61.8
Pb-199	1.05×10^{-12}	5.4	0.959	8.66	21.4	38.8	83.3	128
Pb-200	2.01×10^{-13}	1.04	0.954	0.49	1.21	3.33	14.7	28.8
Pb-201	7.98×10^{-13}	4.12	0.959	4.26	11.2	23.9	57.1	91.5
Pb-201m	4.00×10^{-13}	2.07	0.960	6.35	12.5	20.1	38.7	56.8
Pb-202m	2.14×10^{-12}	11.1	0.964	7.85	16.3	27.8	56.9	85.8
Pb-203	3.24×10^{-13}	1.68	0.957	1.08	2.45	4.4	11.6	28.2
Pb-204m	2.20×10^{-12}	11.4	0.965	8.89	18.3	30.3	59.1	86.9
Pb-210	1.79×10^{-14}	0.0923	0.926	0.00875	0.0211	0.073	0.288	0.504
Pb-211	6.97×10^{-14}	0.36	0.964	6.25	13.5	23.8	50.4	76.9
Pb-212	1.53×10^{-13}	0.792	0.958	0.756	1.64	2.88	6.37	11.1
Pb-214	2.78×10^{-13}	1.43	0.961	1.88	4.09	7.48	23.1	47.6
Pd-100	5.94×10^{-13}	3.07	0.935	0.0106	0.0251	0.164	1.08	2.04
Pd-101	8.49×10^{-13}	4.38	0.935	0.0336	3.71	12.6	44.1	81.8

Table 1. *(Continued)*

Nuclide	Exposure rate constant		f-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Pd-103	2.73×10^{-13}	1.41	0.921	0.00811	0.0161	0.0267	0.054	0.0865
Pd-109m	2.03×10^{-13}	1.05	0.950	0.143	0.683	1.39	3.11	4.81
Pd-109	1.26×10^{-13}	0.649	0.924	0.0112	0.0222	0.0378	0.362	9.3
Pd-111	5.09×10^{-14}	0.263	0.959	8.13	18.2	33.1	74.5	116
Pd-112	1.39×10^{-13}	0.718	0.876	0.00716	0.0142	0.0235	0.0466	0.0697
Pd-114	2.95×10^{-14}	0.152	0.960	0.689	1.73	3.56	10	17.1
Pd-96	1.74×10^{-12}	8.98	0.957	5.98	13.8	25.1	57.8	94.3
Pd-97	2.49×10^{-12}	12.9	0.962	8.16	19.3	37.2	85.8	135
Pd-98	7.55×10^{-13}	3.9	0.945	0.517	6.35	16.3	42.9	72.7
Pd-99	1.49×10^{-12}	7.69	0.958	5.42	13.6	27.9	73.5	121
Pm-136	2.98×10^{-12}	15.4	0.964	5.86	12.2	21.3	47.1	74.8
Pm-137m	1.98×10^{-12}	10.2	0.958	4.57	10.5	19.9	52.3	89.7
Pm-139	1.05×10^{-12}	5.4	0.960	5.11	10.3	18	50.9	97.3
Pm-140m	3.28×10^{-12}	16.9	0.963	7.7	16.1	28	60.1	94.1
Pm-140	1.16×10^{-12}	6.01	0.964	5.33	10.4	17.5	42.2	80.9
Pm-141	8.18×10^{-13}	4.22	0.955	5.87	12.4	23.3	64.4	109
Pm-142	9.55×10^{-13}	4.93	0.961	5.15	10.1	17	44.4	90.6
Pm-143	4.03×10^{-13}	2.08	0.938	5.69	13.5	23	45.9	68
Pm-144	1.78×10^{-12}	9.2	0.955	6.34	12.6	20.6	40.5	60.2
Pm-145	9.23×10^{-14}	0.476	0.925	0.0418	0.0813	0.136	0.321	0.85
Pm-146	8.64×10^{-13}	4.46	0.953	5.52	11.7	20.2	42.5	64.6
Pm-148	5.83×10^{-13}	3.01	0.965	12.1	24.5	41.4	84.2	126
Pm-148m	2.18×10^{-12}	11.3	0.964	6.68	13.3	22.3	47.3	75
Pm-149	1.28×10^{-14}	0.0659	0.962	1.96	4.31	10.3	36.4	62.5
Pm-150	1.49×10^{-12}	7.68	0.965	10.5	23.4	40.1	82.9	127
Pm-151	3.68×10^{-13}	1.9	0.955	2.3	6.18	13.7	36.4	60
Pm-152m	1.56×10^{-12}	8.07	0.960	8.38	21	37	77.6	119
Pm-152	2.96×10^{-13}	1.53	0.957	10.3	21.6	36.7	78.1	123
Pm-153	1.02×10^{-13}	0.527	0.946	0.176	0.589	1.93	18	39.3
Pm-154	1.71×10^{-12}	8.82	0.958	15.7	30.3	49.4	98	147
Pm-154m	1.81×10^{-12}	9.34	0.958	11.3	24.9	42.7	87.1	131
Po-203	1.69×10^{-12}	8.73	0.960	10.6	21.9	36.7	75.9	118
Po-204	1.26×10^{-12}	6.49	0.957	6.35	15.9	28.1	58.6	89
Po-205	1.64×10^{-12}	8.49	0.960	10.9	21.9	36.2	74.7	117
Po-206	1.30×10^{-12}	6.69	0.959	6.42	15.4	27.7	59.3	91
Po-207	1.36×10^{-12}	7.01	0.960	9.86	20.1	33.3	66.9	102
Po-209	6.44×10^{-15}	0.0332	0.960	5.83	15.8	27.8	56.4	83.9
Po-211	8.81×10^{-15}	0.0455	0.965	8.61	16.7	27.5	55	82.5
Po-212m	6.75×10^{-14}	0.349	0.964	17.4	35.1	57.8	113	166
Po-214	8.95×10^{-17}	0.000462	0.876	9.67	18.2	28.6	53.9	78.4
Po-215	1.95×10^{-16}	0.00101	0.876	3.7	7.1	11.4	22	32.4
Pr-134	3.40×10^{-12}	17.5	0.963	6.12	13.3	24.8	61.7	106
Pr-134m	2.41×10^{-12}	12.4	0.963	7.09	15.7	32.1	80.9	130
Pr-135	1.02×10^{-12}	5.26	0.952	4.13	9.45	17.6	51.8	98.5
Pr-136	2.27×10^{-12}	11.7	0.961	7.31	15.4	29.7	76.7	126
Pr-137	4.57×10^{-13}	2.36	0.945	4.3	9.85	18.2	51.4	95.3
Pr-138	9.22×10^{-13}	4.76	0.961	4.93	9.65	15.8	33.6	65.9
Pr-138m	2.70×10^{-12}	14	0.958	8.24	17.8	30.4	62.5	95.6
Pr-139	2.10×10^{-13}	1.08	0.931	1.28	6.37	14.2	47.5	91.8
Pr-140	6.43×10^{-13}	3.32	0.954	4.47	9.07	15	31	58
Pr-142	5.48×10^{-14}	0.283	0.965	18.6	33.8	53.2	98.9	143
Pr-144	2.72×10^{-14}	0.14	0.965	14.2	28.5	48.5	99.7	150
Pr-144m	4.00×10^{-14}	0.206	0.924	0.0405	0.0809	0.151	23.2	67.1
Pr-145	1.93×10^{-14}	0.0994	0.953	9.14	18.3	30.3	61.2	92.6
Pr-146	1.00×10^{-12}	5.18	0.965	11	24.4	42.9	90	137
Pr-147	5.86×10^{-13}	3.02	0.943	4.51	12.8	26.3	65.6	107
Pr-148	9.94×10^{-13}	5.13	0.964	9.44	22.4	39.8	85.3	132
Pr-148m	1.01×10^{-12}	5.21	0.964	4.29	10.1	20.4	54.1	94.8
Pt-184	7.61×10^{-13}	3.93	0.954	2.01	6.74	14.2	33.7	54.2
Pt-186	7.40×10^{-13}	3.82	0.955	5.82	12.6	21	41.6	61.6
Pt-187	6.49×10^{-13}	3.35	0.953	4.19	11.7	23.2	55.1	89.3
Pt-188	2.09×10^{-13}	1.08	0.951	0.617	1.78	4.94	14.8	25.1
Pt-189	5.11×10^{-13}	2.64	0.952	4.06	11.1	21.5	53.5	92.8
Pt-191	3.12×10^{-13}	1.61	0.950	1.56	5.2	10.6	25.2	40.3
Pt-193m	1.04×10^{-14}	0.0535	0.945	0.188	0.373	0.62	1.27	1.99
Pt-195m	7.24×10^{-14}	0.374	0.947	0.186	0.375	0.63	1.35	2.18

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Table 1. *(Continued)*

Nuclide	Exposure rate constant		*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Pt-197	2.23×10^{-14}	0.115	0.952	0.355	0.732	1.32	3.28	5.95
Pt-197m	8.36×10^{-14}	0.432	0.949	0.754	2.55	5.19	11.8	18.3
Pt-199	2.17×10^{-13}	1.12	0.963	4.43	9.65	16.9	38.1	63.5
Pt-200	5.85×10^{-14}	0.302	0.951	0.413	1.04	2.53	9.26	18.8
Pu-232	1.38×10^{-13}	0.712	0.951	0.0213	0.151	0.415	1.12	1.63
Pu-234	1.63×10^{-13}	0.84	0.950	0.0185	0.126	0.391	1.09	1.63
Pu-235	2.36×10^{-13}	1.22	0.948	0.0178	0.136	0.506	18.6	46
Pu-236	4.04×10^{-14}	0.209	0.921	0.00694	0.0138	0.0229	0.0465	0.0788
Pu-237	1.73×10^{-13}	0.891	0.945	0.0126	0.0419	0.278	0.95	1.61
Pu-238	3.71×10^{-14}	0.192	0.921	0.00693	0.0138	0.0228	0.0459	0.0683
Pu-239	1.53×10^{-14}	0.079	0.921	0.00694	0.0138	0.0229	0.0466	0.082
Pu-240	3.50×10^{-14}	0.181	0.921	0.00693	0.0138	0.0228	0.046	0.0683
Pu-242	3.00×10^{-14}	0.155	0.921	0.00693	0.0138	0.0228	0.046	0.0683
Pu-243	5.66×10^{-14}	0.292	0.946	0.0181	0.23	0.804	6.26	14.4
Pu-244	4.27×10^{-14}	0.22	0.935	0.0526	8.67	26.7	75.4	125
Pu-245	4.68×10^{-13}	2.42	0.960	4.05	10.7	21.4	49.9	78.9
Pu-246	2.64×10^{-13}	1.36	0.947	0.0637	0.42	1.17	3.51	5.99
Ra-219	1.84×10^{-13}	0.95	0.962	1.76	3.77	6.75	20.8	43.5
Ra-220	5.18×10^{-15}	0.0267	0.965	4.12	7.89	12.7	24.4	35.8
Ra-221	4.76×10^{-14}	0.246	0.956	0.211	0.584	1.14	6.38	17.8
Ra-222	9.86×10^{-15}	0.0509	0.965	1.94	3.8	6.18	12.1	17.9
Ra-223	1.49×10^{-13}	0.77	0.958	0.69	1.92	4.22	12.2	23.8
Ra-224	1.08×10^{-14}	0.0557	0.963	0.952	1.83	2.98	5.84	8.69
Ra-225	8.04×10^{-14}	0.415	0.924	0.0119	0.0347	0.0904	0.237	0.384
Ra-226	7.63×10^{-15}	0.0394	0.962	0.555	1.06	1.72	3.36	5
Ra-227	3.43×10^{-13}	1.77	0.944	0.0394	1.81	5.82	21.4	41.1
Ra-228	9.43×10^{-14}	0.487	0.921	0.00651	0.0129	0.0213	0.0425	0.0593
Ra-230	1.24×10^{-13}	0.638	0.952	0.362	2.19	6.73	18.9	31
Rb-77	1.67×10^{-12}	8.63	0.962	5.48	11.3	20.3	53.7	97.4
Rb-78m	3.28×10^{-12}	16.9	0.965	8.44	18.5	35.4	83.6	132
Rb-78	3.66×10^{-12}	18.9	0.965	11.2	26.2	48.4	104	158
Rb-79	1.57×10^{-12}	8.09	0.965	4.87	10	17.1	40.3	79
Rb-80	1.32×10^{-12}	6.82	0.965	5.21	9.99	16.1	31.8	50.3
Rb-81	5.55×10^{-13}	2.86	0.965	4.96	9.69	16.2	37.9	71.6
Rb-81m	2.86×10^{-14}	0.148	0.954	3.46	9.85	20.2	56.9	99.2
Rb-82	1.23×10^{-12}	6.33	0.965	5.3	10.2	16.8	35.5	61.5
Rb-82m	3.09×10^{-12}	16	0.965	9.24	18.4	31.3	67.6	107
Rb-83	5.38×10^{-13}	2.78	0.965	5.28	10.1	16.1	31.2	46.7
Rb-84	9.73×10^{-13}	5.02	0.965	8.47	16.8	27.9	56.7	87.1
Rb-84m	4.08×10^{-13}	2.11	0.965	1.76	4.12	8.58	20.3	31.8
Rb-86m	6.06×10^{-13}	3.13	0.876	5.68	10.8	17.2	32.8	48
Rb-86	9.60×10^{-14}	0.495	0.876	13.5	25	39.3	73.5	106
Rb-88	5.85×10^{-13}	3.02	0.965	17.5	33.1	53.2	103	152
Rb-89	2.15×10^{-12}	11.1	0.965	15.6	29.4	47.5	94.4	143
Rb-90	1.61×10^{-12}	8.3	0.962	17.9	34.2	56.1	112	167
Rb-90m	2.89×10^{-12}	14.9	0.964	16	30.8	50.9	104	157
Re-178	1.62×10^{-12}	8.38	0.958	9.56	22.7	42.3	94.5	147
Re-179	1.12×10^{-12}	5.78	0.957	5.64	15	32.3	78.4	124
Re-180	1.27×10^{-12}	6.56	0.956	9.47	19.1	31.4	62.8	97.1
Re-181	8.63×10^{-13}	4.46	0.954	4.26	10.7	22.6	56.2	92.2
Re-182	1.83×10^{-12}	9.43	0.955	7.5	20.9	37.1	75.7	113
Re-182m	1.23×10^{-12}	6.36	0.952	12.2	25	41.1	80.6	120
Re-183	1.64×10^{-13}	0.847	0.945	0.248	0.592	1.34	5.27	10.8
Re-184	9.51×10^{-13}	4.91	0.954	9.13	18.3	29.7	57.3	84.5
Re-184m	4.00×10^{-13}	2.06	0.953	3.7	12.1	24.3	54.4	84.3
Re-186	1.99×10^{-14}	0.103	0.952	0.268	0.53	0.918	9.97	32.9
Re-186m	1.93×10^{-14}	0.0997	0.937	0.103	0.219	0.386	0.844	1.43
Re-188	6.11×10^{-14}	0.316	0.960	2.54	9.98	21.7	56.6	96.9
Re-188m	6.95×10^{-14}	0.359	0.945	0.171	0.332	0.552	1.19	1.75
Re-189	5.70×10^{-14}	0.294	0.960	1	2.27	5.5	20.2	35.6
Re-190	1.44×10^{-12}	7.45	0.964	4.98	11.3	20.7	49.2	84.3
Re-190m	1.00×10^{-12}	5.17	0.961	4.51	10.2	18.6	45.3	79.6
Rh-100m	3.95×10^{-13}	2.04	0.925	0.0106	0.0244	1.14	34.2	80.6
Rh-100	2.92×10^{-12}	15.1	0.956	10.9	25.1	44.8	94.6	144
Rh-101	6.22×10^{-13}	3.21	0.949	0.0331	0.502	1.42	5.54	11.5
Rh-101m	6.06×10^{-13}	3.13	0.945	0.125	1.86	4.39	12.6	26.3
Rh-102	7.43×10^{-13}	3.83	0.951	3.11	8.05	15.1	40	75.2
Rh-102m	2.63×10^{-12}	13.6	0.957	6.27	13.9	24.8	55	87

Table 1. *(Continued)*

	Exposure rate constant			Lead attenuation thicknesses (mm Pb)				
Nuclide	C m^2 / kg MBq s	R cm^2 / mCi h	*f*-factor (cGy/R)	HVL	QVL	TVL	CVL	MVL
Rh-103m	2.91×10^{-14}	0.15	0.921	0.00813	0.0162	0.0269	0.0549	0.0929
Rh-104	1.46×10^{-14}	0.0755	0.960	5.21	10.7	18.1	40.5	74.2
Rh-104m	3.01×10^{-13}	1.56	0.927	0.00995	0.0221	0.0581	0.436	7.83
Rh-105	8.51×10^{-14}	0.44	0.964	1.83	3.61	5.9	11.6	17.3
Rh-106	2.24×10^{-13}	1.15	0.965	6.29	12.3	21	49.8	87.7
Rh-106m	3.00×10^{-12}	15.5	0.965	8.97	18.7	32.8	71.6	112
Rh-107	3.45×10^{-13}	1.78	0.964	2.03	4.14	7.34	20.9	41.8
Rh-108	3.52×10^{-13}	1.82	0.965	4.55	9	15.2	33.3	55.2
Rh-109	3.57×10^{-13}	1.84	0.960	1.54	3.53	6.43	16.6	41.4
Rh-94	3.82×10^{-12}	19.7	0.965	10.3	22.2	39.3	83.9	129
Rh-95	2.68×10^{-12}	13.8	0.963	9.54	20.6	36.9	81.7	129
Rh-95m	9.06×10^{-13}	4.68	0.962	7.45	15.7	31.5	86.9	143
Rh-96	4.25×10^{-12}	21.9	0.964	8.39	17	29.6	68.4	113
Rh-96m	1.43×10^{-12}	7.37	0.958	8.54	19	34.9	80.4	128
Rh-97	1.67×10^{-12}	8.6	0.960	5.42	11.9	23.4	64.8	112
Rh-97m	2.30×10^{-12}	11.9	0.956	10.8	26.1	46.6	97.8	148
Rh-98	1.99×10^{-12}	10.3	0.964	6.39	12.7	22.1	58.3	106
Rh-99	1.03×10^{-12}	5.31	0.945	1.01	5.13	12.3	39.3	78.6
Rh-99m	9.83×10^{-13}	5.08	0.950	2.43	7.65	18.9	55.2	93.1
Rn-207	1.07×10^{-12}	5.52	0.962	5.23	11.8	21.8	51.1	86.8
Rn-209	1.24×10^{-12}	6.42	0.961	6.98	16.2	31	74.8	123
Rn-210	6.60×10^{-14}	0.341	0.960	5.83	13.4	24.1	53.3	84.3
Rn-211	1.96×10^{-12}	10.1	0.962	9.92	20.5	35	73.3	112
Rn-212	3.70×10^{-16}	0.00191	0.876	7.72	14.5	23	43.6	63.7
Rn-218	8.36×10^{-16}	0.00432	0.876	6.62	12.5	19.9	37.8	55.3
Rn-219	6.33×10^{-14}	0.327	0.964	1.85	3.94	7.18	16.4	26.1
Rn-220	6.96×10^{-16}	0.00359	0.876	5.57	10.6	16.9	32.2	47.2
Rn-222	4.31×10^{-16}	0.00223	0.876	4.94	9.43	15.1	28.9	42.4
Rn-223	3.79×10^{-13}	1.96	0.960	5.83	13.2	23.9	56.2	93.2
Ru-103	5.56×10^{-13}	2.87	0.965	4.79	9.23	14.8	28.8	42.9
Ru-105	8.59×10^{-13}	4.44	0.961	5.85	12.7	21.9	45.6	71.1
Ru-107	3.64×10^{-13}	1.88	0.964	8.02	18.4	32.9	72	114
Ru-108	8.58×10^{-14}	0.443	0.956	0.257	0.656	1.15	2.34	3.54
Ru-92	2.80×10^{-12}	14.4	0.954	2.7	9.85	24	68.5	115
Ru-94	9.00×10^{-13}	4.65	0.947	1.59	5.99	15.5	44.1	71.8
Ru-95	1.59×10^{-12}	8.2	0.955	5.14	14.4	29.2	69.3	111
Ru-97	5.95×10^{-13}	3.07	0.946	0.0233	0.689	1.93	7.6	22.8
S-37	2.24×10^{-12}	11.6	0.962	22.4	41	64.7	121	176
S-38	1.50×10^{-12}	7.76	0.965	20.7	37.5	58.9	110	158
Sb-111	1.67×10^{-12}	8.64	0.962	4.89	10.4	18.3	45.5	80
Sb-113	1.47×10^{-12}	7.59	0.961	4.73	9.66	16.6	42.2	82.8
Sb-114	2.80×10^{-12}	14.4	0.963	10.1	21.8	38.3	80.5	122
Sb-115	1.11×10^{-12}	5.74	0.955	4.1	8.73	14.8	33.8	70.8
Sb-116	2.38×10^{-12}	12.3	0.959	11	23.8	41.2	85.5	131
Sb-116m	3.46×10^{-12}	17.8	0.956	9.53	21	36.2	74.1	112
Sb-117	3.98×10^{-13}	2.05	0.943	0.0556	0.475	1.41	19.9	50.8
Sb-118	9.40×10^{-13}	4.85	0.960	4.78	9.6	16	36.6	71.7
Sb-118m	3.02×10^{-12}	15.6	0.950	9.82	22.4	37.8	74.8	111
Sb-119	2.64×10^{-13}	1.36	0.921	0.0165	0.0308	0.049	0.0955	0.144
Sb-120	6.14×10^{-13}	3.17	0.950	3.59	8.37	14.6	32.8	62.1
Sb-120m	2.77×10^{-12}	14.3	0.954	10.2	22.3	37.1	72.5	107
Sb-122m	2.50×10^{-13}	1.29	0.932	0.025	0.0552	0.178	0.746	1.42
Sb-122	4.97×10^{-13}	2.57	0.964	6.02	11.6	18.8	39.1	66.9
Sb-124	1.85×10^{-12}	9.57	0.965	11.7	24.1	42.2	89.5	136
Sb-124m	4.87×10^{-13}	2.51	0.965	6.21	11.9	19.2	37.9	58
Sb-125	5.87×10^{-13}	3.03	0.948	3.22	8.04	14.6	31.9	49.5
Sb-126	3.02×10^{-12}	15.6	0.965	7.09	14	23	46.3	71.7
Sb-126m	1.70×10^{-12}	8.79	0.965	6.35	12.6	21	42.4	65.3
Sb-127	7.68×10^{-13}	3.96	0.963	6.21	12.7	21.4	44.1	68.6
Sb-128	3.36×10^{-12}	17.4	0.965	7.51	15.1	25.1	51.8	82.8
Sb-128m	2.07×10^{-12}	10.7	0.965	7.27	15.1	25.1	50	76.6
Sb-129	1.51×10^{-12}	7.81	0.965	10.9	21.6	36.1	76.1	119
Sb-130m	2.87×10^{-12}	14.8	0.964	10.1	19.8	32.2	64.7	101
Sb-130	3.48×10^{-12}	18	0.964	8.41	17.8	30.3	64.4	104
Sb-131	2.08×10^{-12}	10.8	0.965	12.5	24.7	41	85.1	131
Sb-133	2.63×10^{-12}	13.6	0.965	15.1	29.1	47.4	94.3	142

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Table 1. *(Continued)*

Nuclide	Exposure rate constant		*f*-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Sc-42m	4.30×10^{-12}	22.2	0.965	10.1	22.5	40	83.1	125
Sc-43	1.09×10^{-12}	5.65	0.965	4.7	9.08	14.7	28.5	42.2
Sc-44	2.26×10^{-12}	11.7	0.965	8.49	18	32.1	68.8	105
Sc-44m	2.89×10^{-13}	1.49	0.965	1.63	3.44	8.43	45.4	80.3
Sc-46	2.09×10^{-12}	10.8	0.965	12.5	23.4	37	70.4	103
Sc-47	1.03×10^{-13}	0.534	0.876	0.492	0.86	1.33	2.47	3.61
Sc-48	3.43×10^{-12}	17.7	0.965	13.9	25.9	41	77.9	115
Sc-49	9.57×10^{-16}	0.00494	0.965	19.6	35.5	55.8	104	150
Sc-50	3.19×10^{-12}	16.5	0.965	13.7	27.2	44.8	88	131
Se-70	7.95×10^{-13}	4.11	0.958	3.86	8.07	13.7	29.8	58.7
Se-71	1.72×10^{-12}	8.88	0.965	6.26	13	23.8	59.7	101
Se-72	5.13×10^{-14}	0.265	0.876	0.068	0.131	0.214	0.423	0.633
Se-73	1.20×10^{-12}	6.2	0.960	3.71	7.65	13.1	28.3	49.1
Se-73m	2.88×10^{-13}	1.49	0.964	4.81	9.57	15.9	34.6	61.8
Se-75	3.93×10^{-13}	2.03	0.963	0.985	2.29	4.32	11.3	20.3
Se-77m	8.23×10^{-14}	0.425	0.876	0.502	0.881	1.36	2.54	3.71
Se-79m	7.96×10^{-15}	0.0411	0.876	0.23	0.406	0.672	1.4	1.4
Se-81	8.60×10^{-15}	0.0444	0.965	3.54	9.13	18.4	42.9	67.8
Se-81m	1.20×10^{-14}	0.0621	0.959	0.251	0.45	0.745	1.67	5.29
Se-83m	9.87×10^{-13}	5.1	0.965	12.4	24.9	41.6	85.9	132
Se-83	2.65×10^{-12}	13.7	0.965	9.64	21.8	39	85.2	132
Se-84	4.65×10^{-13}	2.4	0.965	3.3	6.36	10.3	20	29.7
Si-31	8.84×10^{-16}	0.00456	0.876	15.9	29.2	45.9	85.5	124
Sm-139	1.59×10^{-12}	8.18	0.961	5.07	11.1	20.7	57.5	104
Sm-140	6.43×10^{-13}	3.32	0.948	5.59	14	28.2	68.9	110
Sm-141	1.52×10^{-12}	7.82	0.959	6.16	13.5	27.7	72.5	118
Sm-141m	2.08×10^{-12}	10.7	0.958	7.36	16.8	31.2	72.2	116
Sm-142	1.69×10^{-13}	0.875	0.932	1.08	5.66	12.2	31.9	65.7
Sm-143	6.10×10^{-13}	3.15	0.953	4.79	9.8	16.7	41.8	81
Sm-143m	7.48×10^{-13}	3.86	0.962	8.71	16.5	26.1	49.4	72
Sm-145	1.62×10^{-13}	0.837	0.926	0.0475	0.0933	0.158	0.385	0.78
Sm-151	1.19×10^{-16}	0.000614	0.876	0.0093	0.0183	0.0298	0.0584	0.0868
Sm-153	9.32×10^{-14}	0.481	0.938	0.0876	0.204	0.432	1.67	17.6
Sm-155	1.05×10^{-13}	0.541	0.953	0.232	0.5	1.13	16.4	53.5
Sm-156	1.30×10^{-13}	0.673	0.953	0.477	1.11	2.07	5.23	9.21
Sm-157	4.37×10^{-13}	2.26	0.958	2.77	10.7	26	66.1	106
Sn-106	1.51×10^{-12}	7.81	0.953	4.29	11.4	23.1	57	92.6
Sn-108	9.78×10^{-13}	5.05	0.951	1.65	5.28	12	35.6	66.3
Sn-109	2.34×10^{-12}	12.1	0.953	12.4	26.5	44.8	91.2	138
Sn-110	5.24×10^{-13}	2.7	0.946	0.337	1.64	3.4	7.69	11.9
Sn-111	6.66×10^{-13}	3.44	0.947	4.43	11.2	23.5	68	115
Sn-113	2.34×10^{-13}	1.21	0.922	0.0153	0.0294	0.0494	1.4	4.68
Sn-113m	1.47×10^{-13}	0.759	0.921	0.017	0.0317	0.0506	0.102	0.336
Sn-117m	3.27×10^{-13}	1.69	0.945	0.0567	0.374	0.864	2.01	3.14
Sn-119m	1.74×10^{-13}	0.898	0.921	0.0159	0.0298	0.0475	0.0924	0.14
Sn-121m	4.25×10^{-14}	0.219	0.921	0.0197	0.0367	0.0592	0.124	0.213
Sn-123	7.06×10^{-15}	0.0364	0.965	13.6	25.2	39.6	74.1	107
Sn-123m	1.59×10^{-13}	0.823	0.959	0.385	0.767	1.25	2.47	4.9
Sn-125m	3.78×10^{-13}	1.95	0.964	2.21	4.43	7.72	36	79.6
Sn-125	3.41×10^{-13}	1.76	0.965	12.7	24.4	39.5	78.9	122
Sn-126	1.46×10^{-13}	0.753	0.940	0.0271	0.0937	0.494	1.62	2.77
Sn-127m	6.15×10^{-13}	3.18	0.965	5.8	11.7	22.2	63.6	107
Sn-127	1.93×10^{-12}	9.99	0.964	11.9	24	40	82.4	128
Sn-128	9.98×10^{-13}	5.15	0.940	1.6	6.12	12.4	28.8	46.6
Sn-129	1.07×10^{-12}	5.51	0.965	9.07	18	30.8	69.6	112
Sn-130	1.13×10^{-12}	5.81	0.954	4.15	11.8	21.7	46.2	70.3
Sn-130m	1.00×10^{-12}	5.16	0.953	8.74	19.7	34.4	74.6	117
Sr-79	1.32×10^{-12}	6.8	0.961	4.33	8.78	14.5	28.5	42.4
Sr-80	4.79×10^{-13}	2.47	0.965	4.98	10.1	16.7	33	49.2
Sr-81	1.51×10^{-12}	7.78	0.965	4.73	9.84	17	41	76
Sr-82	5.77×10^{-15}	0.0298	0.921	0.00633	0.0125	0.0207	0.0412	0.0617
Sr-83	8.79×10^{-13}	4.54	0.964	6.82	14.3	25.6	60.8	102
Sr-85	5.53×10^{-13}	2.86	0.965	4.93	9.47	15.2	29.1	42.8
Sr-85m	2.23×10^{-13}	1.15	0.964	0.875	1.67	2.73	5.41	8.43
Sr-87m	3.62×10^{-13}	1.87	0.964	2.81	5.53	8.99	17.5	25.9
Sr-91	7.48×10^{-13}	3.86	0.965	10.7	20.4	33.1	65.6	98.9
Sr-92	1.31×10^{-12}	6.77	0.965	16.3	30.4	48	90	130
Sr-93	2.30×10^{-12}	11.9	0.965	10.7	22	38.2	83.3	131

Table 1. *(Continued)*

	Exposure rate constant			Lead attenuation thicknesses (mm Pb)				
Nuclide	C m^2 / kg MBq s	R cm^2 / mCi h	*f*-factor (cGy/R)	HVL	QVL	TVL	CVL	MVL
Sr-94	1.39×10^{-12}	7.16	0.965	16.8	31.1	49.2	92.5	134
Ta-170	1.16×10^{-12}	5.98	0.960	5.33	11.1	19.5	46.6	78.7
Ta-172	1.75×10^{-12}	9.04	0.958	8.76	20	35.7	76.5	118
Ta-173	6.06×10^{-13}	3.13	0.948	6.56	17	32.9	76.3	121
Ta-174	9.98×10^{-13}	5.15	0.956	6.54	16.7	33.4	79.3	127
Ta-175	1.12×10^{-12}	5.78	0.951	9.53	23.4	41.3	85.8	130
Ta-176	2.13×10^{-12}	11	0.955	15.3	30	48.9	95.9	143
Ta-177	7.72×10^{-14}	0.398	0.940	0.165	0.374	1.98	30.9	62.3
Ta-178	1.31×10^{-13}	0.678	0.941	2.03	12.5	29.6	71.6	112
Ta-178m	1.25×10^{-12}	6.44	0.956	1.7	4.06	7.53	16.9	26.6
Ta-179	2.98×10^{-14}	0.154	0.937	0.118	0.232	0.384	0.783	1.22
Ta-180	5.60×10^{-14}	0.289	0.939	0.125	0.245	0.408	0.871	1.32
Ta-182	1.31×10^{-12}	6.75	0.957	12.8	25.4	41.1	78.5	115
Ta-182m	2.67×10^{-13}	1.38	0.952	0.405	0.879	1.65	5.86	11.7
Ta-183	3.09×10^{-13}	1.6	0.952	0.663	1.78	3.68	9.67	16.5
Ta-184	1.68×10^{-12}	8.67	0.962	5.06	12.6	24.2	54.4	84.9
Ta-185	1.55×10^{-13}	0.801	0.954	0.56	1.35	4.45	28.4	58.2
Ta-186	1.52×10^{-12}	7.86	0.963	4.85	11.6	21	47.5	79.2
Tb-146	3.56×10^{-12}	18.4	0.963	12.5	26.4	45.1	91.7	138
Tb-147m	1.89×10^{-12}	9.75	0.956	13.5	27.9	46.6	92.3	137
Tb-147	2.26×10^{-12}	11.7	0.957	10.5	22	37.8	78.9	122
Tb-148m	3.42×10^{-12}	17.7	0.961	7.31	15	25.6	54.1	87.1
Tb-148	2.42×10^{-12}	12.5	0.961	9.21	19.4	35.2	82.4	132
Tb-149m	1.52×10^{-12}	7.84	0.956	7.71	15.4	25.6	52.5	83.5
Tb-149	1.41×10^{-12}	7.27	0.955	8.09	19.1	35.3	80.9	129
Tb-150m	2.80×10^{-12}	14.5	0.960	5.84	11.8	19.8	40.8	63
Tb-150	2.35×10^{-12}	12.2	0.957	11.2	24.3	43.8	95.8	147
Tb-151	1.11×10^{-12}	5.71	0.951	3.82	9.99	20.3	54.4	95
Tb-151m	1.03×10^{-13}	0.534	0.940	2.47	7.66	16.6	42.1	67.7
Tb-152m	8.60×10^{-13}	4.44	0.952	2.58	6.64	14.9	45.1	79.3
Tb-152	1.52×10^{-12}	7.84	0.955	7.95	19.8	38.3	87.3	137
Tb-153	3.91×10^{-13}	2.02	0.944	1.38	6.27	17.3	46.9	77.1
Tb-154	2.15×10^{-12}	11.1	0.952	15.3	30.7	50.8	101	152
Tb-155	2.26×10^{-13}	1.17	0.942	0.178	0.623	1.73	8.31	19
Tb-156	2.04×10^{-12}	10.5	0.954	8.96	20.7	36.8	77.5	118
Tb-156m	5.75×10^{-14}	0.297	0.876	0.0839	0.163	0.266	0.525	0.784
Tb-156n	5.98×10^{-15}	0.0309	0.933	0.0743	0.15	0.268	0.849	1.16
Tb-157	9.67×10^{-15}	0.0499	0.927	0.0598	0.116	0.191	0.388	0.6
Tb-158	8.83×10^{-13}	4.56	0.947	9.65	19.9	32.5	63.1	93
Tb-160	1.18×10^{-12}	6.09	0.960	10.5	21.6	35.5	69.8	104
Tb-161	1.11×10^{-13}	0.571	0.930	0.0283	0.0707	0.187	0.857	8.15
Tb-162	1.18×10^{-12}	6.1	0.962	6.88	16.2	27.6	55.3	83
Tb-163	8.72×10^{-13}	4.5	0.963	3.48	7.21	12.6	28	46
Tb-164	2.52×10^{-12}	13	0.962	9.26	19.8	34.9	77.6	123
Tb-165	8.32×10^{-13}	4.3	0.963	14.1	27.7	45.1	87.4	129
Tc-101	3.70×10^{-13}	1.91	0.964	2.02	4.19	7.71	23.2	43.8
Tc-102m	2.44×10^{-12}	12.6	0.965	11.4	24.6	43.4	91.7	140
Tc-102	8.48×10^{-14}	0.438	0.965	7.35	15.8	30.2	73.8	121
Tc-104	2.14×10^{-12}	11.1	0.965	11.3	26.2	46.2	96.8	147
Tc-105	8.86×10^{-13}	4.57	0.959	5.49	15.5	32	77.9	125
Tc-91	2.45×10^{-12}	12.6	0.964	9.7	22.2	42.1	93.7	144
Tc-91m	1.58×10^{-12}	8.13	0.965	5.45	10.7	18.4	49.7	92.2
Tc-92	4.03×10^{-12}	20.8	0.963	8.1	18.9	35.5	80.5	125
Tc-93	1.86×10^{-12}	9.63	0.951	11.6	26.2	44.4	87.8	130
Tc-93m	9.97×10^{-13}	5.15	0.955	8.47	24.5	47.2	102	155
Tc-94	3.20×10^{-12}	16.5	0.959	8.03	16.6	27.6	55	83.9
Tc-94m	2.15×10^{-12}	11.1	0.962	7.96	16.9	30.5	71.9	120
Tc-95	1.23×10^{-12}	6.35	0.948	4.62	13.2	23.5	48.8	74.3
Tc-95m	1.11×10^{-12}	5.71	0.951	2.23	9.3	19.6	45.6	71.9
Tc-96	3.06×10^{-12}	15.8	0.957	8.26	17.2	28.3	55.6	83.3
Tc-96m	2.19×10^{-13}	1.13	0.926	0.0114	0.0389	10.7	45.2	81.7
Tc-97	3.64×10^{-13}	1.88	0.921	0.00695	0.0138	0.0228	0.0453	0.0678
Tc-97m	2.51×10^{-13}	1.3	0.921	0.00725	0.0144	0.0239	0.0483	0.0797
Tc-98	1.55×10^{-12}	7.99	0.965	7.96	15	23.9	45.6	67
Tc-99m	1.54×10^{-13}	0.795	0.959	0.234	0.535	0.905	1.8	2.7
Te-113	2.30×10^{-12}	11.9	0.964	8.59	18.5	34.7	80.6	128

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Table 1. *(Continued)*

	Exposure rate constant			Lead attenuation thicknesses (mm Pb)				
Nuclide	C m^2 / kg MBq s	R cm^2 / mCi h	*f*-factor (cGy/R)	HVL	QVL	TVL	CVL	MVL
Te-114	1.51×10^{-12}	7.8	0.948	7.63	19.5	37.1	83.2	129
Te-115	2.39×10^{-12}	12.3	0.962	8.72	19.1	34.7	76.5	119
Te-115m	2.73×10^{-12}	14.1	0.961	9.99	21.5	38.1	83	129
Te-116	3.83×10^{-13}	1.98	0.931	0.0288	0.0761	3.15	26	53.3
Te-117	1.69×10^{-12}	8.73	0.954	9.09	20	36.5	84	133
Te-118	1.88×10^{-13}	0.971	0.921	0.019	0.0352	0.0559	0.109	0.165
Te-119	9.96×10^{-13}	5.14	0.947	5.72	13	23	55.4	99.1
Te-119m	1.69×10^{-12}	8.73	0.953	9.85	22.9	39	78.6	119
Te-121	8.14×10^{-13}	4.2	0.946	3.61	8.95	15.6	31.7	47.5
Te-121m	3.32×10^{-13}	1.71	0.948	0.415	1.39	3.6	38.5	73.3
Te-123	3.09×10^{-16}	0.00159	0.921	0.0188	0.0346	0.0548	0.106	0.159
Te-123m	2.40×10^{-13}	1.24	0.948	0.14	0.521	1	2.15	3.28
Te-125m	2.79×10^{-13}	1.44	0.921	0.0212	0.0392	0.0628	0.127	0.216
Te-127	5.55×10^{-15}	0.0287	0.961	2.94	5.99	9.9	19.6	29.2
Te-127m	8.67×10^{-14}	0.448	0.921	0.021	0.039	0.0623	0.131	1.39
Te-129	1.01×10^{-13}	0.523	0.939	1.67	5.98	12.7	38.5	71.8
Te-129m	9.62×10^{-14}	0.497	0.927	0.048	3.7	13.3	35.5	57.3
Te-131	4.57×10^{-13}	2.36	0.960	4.26	11.8	24	58.1	92.7
Te-131m	1.57×10^{-12}	8.1	0.960	9.21	19.2	32.5	68.3	108
Te-132	3.73×10^{-13}	1.93	0.944	0.262	1.04	2.08	4.66	7.21
Te-133	1.22×10^{-12}	6.29	0.964	8.46	20.8	38.1	83.9	131
Te-133m	1.97×10^{-12}	10.2	0.961	9.82	20.4	34.6	73.8	117
Te-134	9.94×10^{-13}	5.13	0.958	4.32	10.9	19.8	43.1	66.5
Th-223	1.57×10^{-13}	0.81	0.951	0.0218	0.219	0.636	3.11	8.92
Th-224	3.37×10^{-14}	0.174	0.958	0.338	0.998	2.27	10.6	20.1
Th-226	3.51×10^{-14}	0.181	0.944	0.0103	0.0308	0.409	2.62	5.43
Th-227	3.07×10^{-13}	1.58	0.947	0.0224	0.735	2.31	7.04	12.5
Th-228	3.71×10^{-14}	0.192	0.930	0.00706	0.0146	0.0276	1.08	3.03
Th-229	3.16×10^{-13}	1.63	0.945	0.0115	0.0463	0.429	1.92	3.97
Th-230	3.05×10^{-14}	0.157	0.923	0.00658	0.0132	0.0222	0.0691	0.968
Th-231	2.69×10^{-13}	1.39	0.927	0.00822	0.0173	0.0326	0.523	1.53
Th-232	2.78×10^{-14}	0.143	0.922	0.00654	0.013	0.0218	0.0513	0.51
Th-233	7.01×10^{-14}	0.362	0.945	0.247	3.89	11.4	32.5	55.8
Th-234	3.98×10^{-14}	0.206	0.941	0.0106	0.029	0.208	0.82	1.3
Th-235	6.01×10^{-14}	0.31	0.963	5.91	12.5	21.6	45.1	69.2
Th-236	5.63×10^{-14}	0.29	0.953	0.518	3.85	10.9	29.7	48.9
Ti-44	1.35×10^{-13}	0.698	0.948	0.222	0.443	0.742	1.53	2.35
Ti-45	9.68×10^{-13}	5	0.965	4.97	9.49	15.2	29.3	44.5
Ti-51	3.99×10^{-13}	2.06	0.965	2.53	5.28	11.4	40.8	69.8
Ti-52	2.25×10^{-13}	1.16	0.955	0.0579	0.297	0.595	1.33	2.11
Tl-190	1.41×10^{-12}	7.29	0.963	5.06	10.2	17.9	46.3	83.2
Tl-190m	2.67×10^{-12}	13.8	0.963	6.01	12.4	21.8	50.2	84.6
Tl-194	1.00×10^{-12}	5.17	0.961	4.71	9.58	16.5	38.9	68.5
Tl-194m	2.73×10^{-12}	14.1	0.962	5.95	12.4	21.4	48.6	86.3
Tl-195	1.19×10^{-12}	6.16	0.957	12.1	25.7	44	91.3	139
Tl-196	1.86×10^{-12}	9.59	0.961	9.55	22.8	42	90.5	138
Tl-197	4.69×10^{-13}	2.42	0.954	5.93	15.3	30.2	71.1	112
Tl-198	1.96×10^{-12}	10.1	0.960	11.2	25.5	44.7	92.7	140
Tl-198m	1.32×10^{-12}	6.84	0.961	4.52	9.8	17	36.3	58.7
Tl-199	2.59×10^{-13}	1.33	0.954	1.46	4.88	11.9	38.2	69.1
Tl-200	1.36×10^{-12}	7	0.960	7.56	18.9	34.7	74.6	114
Tl-201	8.72×10^{-14}	0.45	0.949	0.258	0.52	0.887	1.94	3.1
Tl-202	5.06×10^{-13}	2.61	0.957	3.14	6.59	11	21.8	32.9
Tl-204	1.14×10^{-15}	0.0059	0.948	0.215	0.428	0.714	1.47	2.3
Tl-206m	2.59×10^{-12}	13.4	0.964	5.62	13.3	24.5	55.3	86.7
Tl-206	4.47×10^{-17}	0.000231	0.949	0.233	0.459	0.755	1.5	2.26
Tl-207	2.48×10^{-15}	0.0128	0.876	11	20.6	32.4	60.8	88.3
Tl-208	2.94×10^{-12}	15.2	0.964	15.5	32.4	54.9	110	163
Tl-209	2.09×10^{-12}	10.8	0.963	11.9	26.8	46	92	136
Tl-210	2.74×10^{-12}	14.2	0.965	11.9	24.6	41.8	88	136
Tm-161	1.33×10^{-12}	6.88	0.946	8.35	22.5	41.9	89.6	136
Tm-162	1.87×10^{-12}	9.65	0.956	11.3	24.8	43.7	93.1	143
Tm-163	1.36×10^{-12}	7	0.948	10.5	24.1	41.6	84.5	127
Tm-164	8.24×10^{-13}	4.25	0.954	6.79	14.8	29.3	75.2	122
Tm-165	6.29×10^{-13}	3.24	0.948	2.81	8.65	19.8	52.4	87.9
Tm-166	1.96×10^{-12}	10.1	0.954	12.5	25.9	44	91.2	139
Tm-167	1.75×10^{-13}	0.903	0.942	0.32	1.04	2.23	12.1	26.8
Tm-168	1.35×10^{-12}	6.98	0.955	6.38	14.5	24.9	51.2	78.5

Table 1. *(Continued)*

Nuclide	Exposure rate constant		f-factor (cGy/R)	Lead attenuation thicknesses (mm Pb)				
	C m^2 / kg MBq s	R cm^2 / mCi h		HVL	QVL	TVL	CVL	MVL
Tm-170	4.34×10^{-15}	0.0224	0.943	0.157	0.354	0.7	1.72	2.77
Tm-171	7.81×10^{-16}	0.00403	0.936	0.107	0.212	0.357	0.765	1.24
Tm-172	4.64×10^{-13}	2.4	0.958	15.6	29.8	47.7	90.9	133
Tm-173	4.31×10^{-13}	2.23	0.962	3.13	6.1	9.9	19.4	28.8
Tm-174	1.88×10^{-12}	9.71	0.962	5.14	14.3	27.9	61	93.4
Tm-175	1.17×10^{-12}	6.02	0.962	7.47	15.8	27.9	61.6	97.6
Tm-176	1.92×10^{-12}	9.9	0.961	10.9	24.7	42.7	90	139
U-227	2.24×10^{-13}	1.16	0.953	0.0789	0.697	1.95	5.67	10.1
U-228	4.31×10^{-14}	0.222	0.933	0.00797	0.017	0.0413	1.57	4.32
U-230	4.85×10^{-14}	0.25	0.924	0.00693	0.014	0.0242	0.462	2.39
U-231	4.33×10^{-13}	2.23	0.939	0.0101	0.0241	0.126	0.869	1.82
U-232	4.53×10^{-14}	0.234	0.921	0.00672	0.0134	0.0223	0.0487	0.398
U-233	2.09×10^{-14}	0.108	0.921	0.00673	0.0134	0.0224	0.0488	0.235
U-234	4.11×10^{-14}	0.212	0.921	0.0067	0.0133	0.0221	0.0465	0.238
U-235	2.64×10^{-13}	1.36	0.957	0.208	0.692	1.35	3.13	5.36
U-236	3.72×10^{-14}	0.192	0.921	0.00669	0.0133	0.022	0.0453	0.119
U-237	3.21×10^{-13}	1.66	0.946	0.0234	0.246	0.816	3.51	8.27
U-238	2.99×10^{-14}	0.154	0.921	0.00669	0.0133	0.022	0.0451	0.101
U-239	9.12×10^{-14}	0.471	0.944	0.0439	0.36	1.82	28.2	54.7
U-240	8.71×10^{-14}	0.449	0.928	0.00787	0.0163	0.0306	0.577	1.99
U-242	5.27×10^{-14}	0.272	0.949	1.61	6.13	13	29.7	46
V-47	1.10×10^{-12}	5.7	0.965	4.99	9.53	15.3	30.1	50.3
V-48	3.00×10^{-12}	15.5	0.965	11.7	23.5	39	77.6	116
V-50	1.37×10^{-12}	7.05	0.965	17.1	32	50.8	96.2	140
V-52	1.40×10^{-12}	7.21	0.965	17.5	32	50.2	93.5	135
V-53	1.08×10^{-12}	5.57	0.965	12.9	24.1	38.1	71.9	105
W-177	9.68×10^{-13}	5	0.953	4.86	13.3	26.3	60.2	94.1
W-178	1.72×10^{-14}	0.0888	0.939	0.128	0.252	0.417	0.85	1.32
W-179	8.56×10^{-14}	0.442	0.936	0.0668	0.175	0.338	0.769	1.24
W-179m	5.92×10^{-14}	0.305	0.944	0.251	0.631	1.53	4.08	6.78
W-181	4.58×10^{-14}	0.236	0.939	0.128	0.252	0.417	0.853	1.33
W-185m	2.47×10^{-14}	0.127	0.950	0.27	0.565	1.02	2.35	3.79
W-185	4.47×10^{-17}	0.000231	0.948	0.206	0.398	0.655	1.35	2.11
W-187	4.89×10^{-13}	2.52	0.958	5.79	11.9	19.8	40.3	61.1
W-188	1.95×10^{-15}	0.0101	0.958	1.13	2.4	4.13	8.67	13.3
W-190	1.50×10^{-13}	0.776	0.949	0.276	0.572	0.999	2.12	3.25
Xe-120	6.94×10^{-13}	3.59	0.937	1.03	6.67	16.4	42.4	69.7
Xe-121	1.54×10^{-12}	7.96	0.955	7.68	18.6	37.7	89.7	141
Xe-122	2.09×10^{-13}	1.08	0.928	0.0352	0.116	2.39	10.1	18.3
Xe-123	7.88×10^{-13}	4.07	0.949	3.88	11.6	25.7	69.3	115
Xe-125	4.65×10^{-13}	2.4	0.941	0.23	1.3	4.41	32.6	65.7
Xe-127	4.42×10^{-13}	2.28	0.946	0.3	1.14	2.72	10	17.9
Xe-127m	2.38×10^{-13}	1.23	0.948	0.15	0.465	0.907	2.15	3.46
Xe-129m	2.42×10^{-13}	1.25	0.923	0.0283	0.0536	0.0938	1.27	3.22
Xe-131m	1.01×10^{-13}	0.521	0.923	0.0276	0.0516	0.0875	0.745	1.98
Xe-133	1.10×10^{-13}	0.568	0.935	0.0379	0.0982	0.4	1.35	2.29
Xe-133m	1.24×10^{-13}	0.639	0.928	0.0369	0.0924	0.92	3.63	6.31
Xe-135	2.67×10^{-13}	1.38	0.963	1.16	2.32	4.19	18.3	36.9
Xe-135m	4.92×10^{-13}	2.54	0.959	4.85	9.56	15.5	29.9	44
Xe-137	2.01×10^{-13}	1.04	0.965	5.1	10.4	20.5	65	113
Xe-138	1.06×10^{-12}	5.46	0.963	13.1	29.7	50.6	101	150
Y-81	1.31×10^{-12}	6.77	0.963	4.16	8.61	14.2	28	41.5
Y-83	1.51×10^{-12}	7.82	0.961	5.57	11.4	20.5	55.8	101
Y-83m	9.39×10^{-13}	4.85	0.965	3.7	7.93	13.5	27.1	40.6
Y-84m	4.22×10^{-12}	21.8	0.965	9.26	18.7	31.8	67.3	106
Y-85	1.21×10^{-12}	6.26	0.965	5.1	9.97	16.4	35.6	62
Y-85m	1.38×10^{-12}	7.13	0.964	7.59	16.8	33.1	81.5	130
Y-86	3.66×10^{-12}	18.9	0.965	11.1	22.9	39.3	83.2	129
Y-86m	2.26×10^{-13}	1.17	0.964	0.943	1.9	4.23	35.6	70.6
Y-87	5.47×10^{-13}	2.82	0.962	3.8	7.92	13.1	25.8	38.1
Y-87m	3.48×10^{-13}	1.8	0.964	2.69	5.32	8.7	17.3	26.3
Y-88	2.62×10^{-12}	13.5	0.963	15.8	30.3	49.3	97.5	145
Y-89m	9.57×10^{-13}	4.94	0.965	11.1	20.8	32.9	61.7	89.5
Y-90m	6.91×10^{-13}	3.57	0.965	2.54	6.42	11.6	24.1	36.5
Y-91	3.16×10^{-15}	0.0163	0.876	15.1	27.8	43.8	81.7	118
Y-91m	5.89×10^{-13}	3.04	0.965	5.63	10.7	17.1	32.7	47.9

(Continued on next page)

Table 1. *(Continued)*

Nuclide	Exposure rate constant: C m^2 / kg MBq s	Exposure rate constant: R cm^2 / mCi h	*f*-factor (cGy/R)	HVL	QVL	TVL	CVL	MVL
				Lead attenuation thicknesses (mm Pb)				
Y-92	2.60×10^{-13}	1.34	0.965	11.7	22.8	37.4	75.2	115
Y-93	9.45×10^{-14}	0.488	0.965	10.2	24.7	43.4	91.3	139
Y-94	7.93×10^{-13}	4.09	0.965	12	22.9	37.2	75.8	119
Y-95	9.61×10^{-13}	4.96	0.964	18.4	34.7	55.7	109	161
Yb-162	2.74×10^{-13}	1.41	0.948	0.65	3.54	11.4	31.2	51.6
Yb-163	7.72×10^{-13}	3.99	0.951	7.34	16.6	31.3	73.9	118
Yb-164	7.25×10^{-14}	0.374	0.934	0.13	0.328	3.85	23.6	47.3
Yb-165	3.75×10^{-13}	1.93	0.942	3.65	12.2	26.1	64.2	103
Yb-166	1.15×10^{-13}	0.593	0.935	0.102	0.206	0.362	1.01	1.97
Yb-167	2.95×10^{-13}	1.53	0.944	0.194	0.468	1.32	30.5	68.4
Yb-169	3.75×10^{-13}	1.94	0.943	0.242	0.678	1.64	5.71	11
Yb-175	4.27×10^{-14}	0.22	0.957	2.03	4.57	8.04	16.9	25.8
Yb-177	1.99×10^{-13}	1.03	0.956	9.16	21.5	36.5	72.7	108
Yb-178	4.22×10^{-14}	0.218	0.962	2.61	5.14	8.42	16.7	25
Yb-179	1.08×10^{-12}	5.55	0.963	5.73	11.4	18.8	38.1	59.7
Zn-60	1.69×10^{-12}	8.73	0.963	5.26	10.4	17.1	34.6	53.4
Zn-61	1.62×10^{-12}	8.34	0.965	6.55	13.4	26.1	73.9	123
Zn-62	5.01×10^{-13}	2.59	0.956	4.9	9.97	16.4	32.7	49.7
Zn-63	1.21×10^{-12}	6.24	0.965	5.38	10.4	17.3	39.5	74.6
Zn-65	5.94×10^{-13}	3.07	0.965	13.5	25.4	40.2	75.5	110
Zn-69m	4.62×10^{-13}	2.38	0.965	3.7	7.1	11.4	22	32.4
Zn-71	3.40×10^{-13}	1.76	0.965	6.55	13.5	24.2	56.6	93.3
Zn-71m	1.71×10^{-12}	8.83	0.965	5.16	10.5	18.5	44.8	80.5
Zn-72	1.88×10^{-13}	0.97	0.959	0.243	0.589	1.04	2.26	3.78
Zr-85	1.61×10^{-12}	8.31	0.965	5.29	10.5	18.6	53	97.5
Zr-86	4.35×10^{-13}	2.25	0.953	0.55	1.71	3.7	19.5	37.6
Zr-87	1.03×10^{-12}	5.31	0.965	5.31	10.4	17.4	44	85.7
Zr-88	4.82×10^{-13}	2.49	0.961	2.47	5.28	8.86	17.6	26.3
Zr-89	1.28×10^{-12}	6.59	0.963	9.02	18.1	29.9	59.5	89.5
Zr-89m	7.10×10^{-13}	3.66	0.964	6.71	13.3	22.8	57.2	101
Zr-95	7.98×10^{-13}	4.12	0.965	8.62	16.2	25.7	48.5	70.7

† Data based on emissions of progeny Ba-137m.

simply do not exist for most nuclides, and decay product emissions have been omitted from what is reported here. Thus the shielding values should be used, as with the exposure rate constants, by combining the appropriate entries with regard to their proportion in a particular equilibrium situation. The notable discrepancies are easily explained by the improved treatment of bremsstrahlung in Shimizu et al. 2004. Photon buildup factors are extremely dependent on bremsstrahlung at shallow depths and high energies (e.g., Shimizu et al. 2004, Fig. 5). For example, if the current value of the HVL of ^{60}Co is compared, 15.6 mm Pb is found, while the commonly used value is 12.5 mm Pb. The majority of its emissions are at 1.17 and 1.33 MeV, which would be highly sensitive to a change in the treatment of bremsstrahlung. Low-energy emitters

Table 2. Comparison of selected exposure rate constants from this work and those from the 1970 Radiological Health Handbook.

	Exposure rate constant (R cm^2 / mCi h): This work	Radiological Health Handbook	Ratio
Ba-133	3.0	2.4	1.27
C-11	5.86	5.9	0.993
Cs-137	3.43	3.3	1.04
Co-60	12.9	13.2	0.977
Ga-67	0.80	1.1	0.730
Ga-72	13.4	11.6	1.16
I-125	1.75	0.7	2.5
I-131	2.2	2.2	1.00
Ir-192	4.6	4.8	0.958
Zn-65	3.07	2.7	1.14

Table 3. Comparison of selected exposure rate constants from this work and dose constants from Unger and Trubey (1982).

	Exposure rate constant (mSv m^2 / MBq h): This work	Unger and Trubey	Ratio
Al-26	3.52×10^{-4}	4.00×10^{-4}	0.880
Al-28	2.19×10^{-4}	2.36×10^{-4}	0.929
Ar-41	1.72×10^{-4}	1.88×10^{-4}	0.916
Au-195m	2.74×10^{-5}	4.13×10^{-5}	0.663
Ba-133	7.72×10^{-5}	1.23×10^{-4}	0.628
C-11	1.54×10^{-4}	1.91×10^{-4}	0.804
Cs-137	8.90×10^{-5}	1.02×10^{-4}	0.872
Co-60	3.38×10^{-4}	5.15×10^{-4}	0.657
F-18	1.49×10^{-4}	1.85×10^{-4}	0.805
Ga-67	2.08×10^{-5}	3.00×10^{-5}	0.694
Ga-72	3.51×10^{-4}	3.90×10^{-4}	0.901
Ho-166	4.08×10^{-6}	6.26×10^{-6}	0.651
I-123	4.54×10^{-5}	7.48×10^{-5}	0.607
I-125	4.54×10^{-5}	7.43×10^{-5}	0.584
I-131	5.65×10^{-5}	7.64×10^{-5}	0.739
In-111	8.88×10^{-5}	1.36×10^{-4}	0.653
Ir-192	1.19×10^{-4}	1.60×10^{-4}	0.746
N-13	1.53×10^{-4}	1.91×10^{-4}	0.801
O-15	1.54×10^{-4}	1.91×10^{-4}	0.805
Tc-99m	2.06×10^{-5}	3.32×10^{-5}	0.621
Tl-201	1.16×10^{-5}	2.37×10^{-5}	0.488
Zn-65	1.08×10^{-4}	8.92×10^{-5}	1.21

Table 4. Comparison of selected exposure rate constants from this work and dose constants from Tschurlovits et al. (1992).

	Exposure rate constant (mSv m^2 / MBq h)		
	This work	Tschurlovits et al.	Ratio
Al-26	3.52×10^{-4}	3.82×10^{-4}	0.921
Al-28	2.19×10^{-4}	2.00×10^{-4}	1.10
Ar-41	1.72×10^{-4}	1.57×10^{-4}	1.10
Ba-133	7.72×10^{-5}	2.74×10^{-4}	0.282
C-11	1.53×10^{-4}	1.39×10^{-4}	1.10
Cs-137	8.90×10^{-5}	8.87×10^{-5}	1.00
Co-60	3.38×10^{-4}	3.08×10^{-4}	1.10
F-18	1.49×10^{-4}	1.37×10^{-4}	1.09
Ga-67	2.08×10^{-5}	3.10×10^{-4}	0.067
Ho-166	4.07×10^{-6}	4.15×10^{-5}	0.098
I-123	4.54×10^{-5}	1.69×10^{-4}	0.269
I-125	4.34×10^{-5}	2.52×10^{-4}	0.172
I-131	5.65×10^{-5}	5.93×10^{-5}	0.953
In-111	8.88×10^{-5}	2.22×10^{-4}	0.400
Ir-192	1.19×10^{-4}	1.23×10^{-4}	0.971
N-13	1.53×10^{-4}	1.39×10^{-4}	1.10
O-15	1.54×10^{-4}	1.39×10^{-4}	1.10
Tc-99m	2.06×10^{-5}	3.60×10^{-5}	0.573
Tl-201	1.16×10^{-5}	1.05×10^{-4}	0.110
Zn-65	1.0×10^{-4}	1.98×10^{-4}	0.545

with no significant decay products are extremely close to commonly accepted values (0.021 mm Pb for ^{125}I and 0.026 mm Pb for ^{131}Cs).

CONCLUSION

The authors have calculated exposure rate constants, nuclide-specific *f*-factors, and lead shielding thicknesses for most of the more than 1,100 radionuclides described in ICRP Publication 107. This compilation adds to the literature on this important practical area of radiation protection, using up-to-date radionuclide decay and radiation attenuation data. Agreement with previous works in this area is generally good, with a few exceptions.

REFERENCES

Hubbell JH, Seltzer SM. Tables of x-ray mass attenuation coefficients and mass energy-absorption coefficients from 1 keV to 20 MeV for elements *Z* = 1 to 92 and 48 additional substances of dosimetric interest. Gaithersburg, MD: National Institute of Standards and Technology; 1996.

International Commission on Radiological Protection. ICRP Publication 107: Nuclear decay data for dosimetric calculations. New York: Elsevier; 2009.

Jaeger RG, Blizard EP, Chilton AB. Engineering compendium on radiation shielding: volume 1: shielding fundamentals and methods. New York: Springer; 1968.

Kharrati H, Agrebi A, Karaoui M-K. Monte Carlo simulation of x-ray buildup factors of lead and its applications in shielding of diagnostic x-ray facilities. Med Phys 34:1398–1404; 2007.

Shimizu A, Onda T, Sakamoto Y. Calculation of gamma-ray buildup factors up to depths of 100 mfp by the method of invariant embedding, (III) Generation of an improved data set. J Nucl Sci Technol 41:413–424; 2004.

Stabin MG. Radiation protection and dosimetry: an introduction to health physics. New York: Springer; 2007.

Tschurlovits M, Leitner A, Daverda G. Dose rate constants for new dose quantities. Radiat Protect Dosim 42:77–82; 1992.

Unger LM, Trubey DK. Specific gamma-ray dose constants for nuclides important to dosimetry and radiological assessment. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/RSIC-45/R1; 1982.

United States Department of Health, Education and Welfare. Radiological health handbook. Rockville, MD: Bureau of Radiological Health, United States Department of Health, Education and Welfare; 1970.

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