APPENDIX 16-B

A_1 and A_2 Values for Radionuclides

I. Single Radionuclides

1. For a single radionuclide of known identity, the values of A_1 and A_2 are taken from Table 1 if listed there. The values A_1 and A_2 in Table 1 are also applicable for the radionuclide contained in (α,n) or (γ,n) neutron sources.

2. For any single radionuclide whose identity is known but which is not listed in Table 1, the value of A_1 and A_2 are determined according to the following procedure.

(a) If the radionuclide emits only one type of radiation, A_1 is determined according to the following method. For radionuclides emitting different kinds of radiation, A_1 is the most restrictive value of those determined for each kind of radiation. However, in either case, A_1 is restricted to a maximum of 1000 curies (37 TBq). If a parent nuclide decays into a shorter lived daughter with a half-life not greater than 10 days, A_1 is calculated for both the parent and the daughter, and the more limiting of the two values is assigned to the parent nuclide.

(1) For gamma emitters, A_1 is determined by the expression:

$$A_1 = \frac{9 \text{ curies}}{\Gamma}$$

Where Γ is the gamma-ray constant, corresponding to the dose in roentgens per curie-hour at 1 meter, and the number 9 results from the choice of 1 rem per hour at a distance of 3 meters as the reference dose-equivalent rate.

(2) For x-ray emitters, A_1 is determined by the atomic number of the nuclide:

for $Z \leq 55$, A_1 = 1000 Ci (37 TBq); and

for $Z > 55$, A_1 = 200 Ci (7.4 TBq)

where Z is the atomic number of the nuclide.

(3) For beta emitters, A_1 is determined by the maximum beta energy (E max) according to Table 2; and

(4) For alpha emitters, A_1 is determined by the expression:

$A_1 = 1000\ A_3$

where A_3 is the value listed in Table 3;

(b) A_2 is the more restrictive of the following two values:

(1) The corresponding A_1; and

(2) the value A_3 obtained from Table 3.

3. For any single radionuclide whose identity is unknown, the value of A_1 is taken to the 2 Ci (74 MBq) and the value of A_2 is taken to be 0.002 Ci (74 MBq). However, if the atomic number of the radionuclide is known to be less than 82, the value of A_1 is taken to be 10 Ci (370 GBq) and the value of A_2 is taken to be 0.4 Ci (14.8 GBq).

II. Mixtures of Radionuclides, Including Radioactive Decay Chains.

1. For mixed fission products, the activity limit may be assumed if a detailed analysis of the mixture is not carried out,

$A_1 = 10$ Ci (370 GBq)

$A_2 = 0.4$ Ci (14.8 GBq)

2. A single radioactive decay chain is considered to be a single radionuclide when the radionuclides are present in their naturally occurring proportions and no daughter nuclide has a half-life either longer than 10 days or longer than that of the parent nuclide. The activity to be taken into account and the A_1 of A_2 value from Table 1 to be applied are those corresponding to the parent nuclide of that chain. When calculating A_1 or A_2 values, radiation emitted by daughters must be considered. However, in the case of radioactive decay chains in which any daughter nuclide has a half-life either longer than 10 days or greater than that of the parent nuclide, the parent and daughter nuclides are considered to be mixtures of different nuclides.

3. In the case of a mixture of different radionuclides, where the identity and activity of each radionuclide are known, the permissible activity of each radionuclide R_1, R_2 . . .R_n is such that $F_1 + F_2 + \ldots F_n$ is not greater than unity, where:

$$F_1 = \frac{\text{Total activity of } R_1}{A_1(R_1)}$$

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$F_2 = \frac{\text{Total activity of } R_2}{A_1(R_2)}$

$F_n = \frac{\text{Total activity of } R_n}{A_1(R_n)}$ and

$A_i (R_1, R_2 \ldots R_n)$ is the value of A_1 or A_2 as appropriate for the nuclide $R_1, R_2 \ldots R_n$.

4. When the identity of each radionuclide is known but the individual activities of some of the radionuclides are not known, the formula given in paragraph 3. is applied to establish the values of A_1 or A_2 as appropriate. All the radionuclides whose individual activities are not known (their total activity will however, be known) are classed in a single group and the most restrictive value of A_1 and A_2 applicable to any one of them is used as the value of A_1 or A_2 in the denominator of the fraction.

5. Where the identity of each radionuclide is known but the individual activity of none of the radionuclides is known, the most restrictive value of A_1 or A_2 applicable to any one of the radionucides present is adopted as the applicable value.

6. When the identity of none of the nuclides is known, the value of A_1 is taken to be 2 Ci (74 GBq) and the value of A_2 is taken to be 0.002 Ci (74 MBq). However, if alpha emitters are known to be absent, the value of A_2 is taken to be 0.4 Ci (14.8 GBq).

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Table 1

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Ac-227	Actinium (89)	1000	0.003	7.2 E+01
Ac-228		10	4	2.2 E+06
Ag-105	Silver (47)	40	40	3.0 E+07
Ag-110m		7	7	4.7 E+03
Ag-111		100	20	1.5 E+05
Am-241	Americium (95)	8	0.008	3.2
Am-243		8	0.008	1.9 E-01
Ar-37 (compressed or uncompressed)*	Argon (18)	1000	1000	1.0 E+05
Ar-41 (uncompressed)*		20	20	4.3 E+07
Ar-41 (compressed)*		1	1	4.3 E+07
As-73	Arsenic (33)	1000	400	2.4 E+04
As-74		20	20	1.0 E+05
As-76		10	10	1.6 E+06
As-77		300	20	1.1 E+06
At-211	Astatine (85)	200	7	2.1 E+06
Au-193	Gold (79)	200	200	9.3 E+05
Au-196		30	30	1.2 E+05
Au-198		40	20	2.5 E+05
Au-199		200	25	2.1 E+05
Ba-131	Barium (56)	40	40	8.7 E+04
Ba-133		40	40	4.0 E+03
Ba-140		20	20	7.3 E+04
Be-7	Beryllium (4)	300	300	3.5 E+05

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Table 1 (Continued-2)

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Bi-206	Bismuth (83)	5	5	9.9 E+04
Bi-207		10	10	2.2 E+02
Bi-210 (RaE)		100	4	1.2 E+05
Bi-212		6	6	1.5 E+07
Bk-249	Berkelium (97)	1000	1	1.8 E+03
Br-77	Bromine (35)	70	25	7.1 E+03
Br-82		6	6	1.1 E+06
C-11	Carbon (6)	20	20	8.4 E+08
C-14		1000	60	4.6
Ca-45	Calcium (20)	1000	25	1.9 E+04
Ca-47		20	20	5.9 E+05
Cd-109	Cadmium (48)	1000	70	2.6 E+03
Cd-115m		30	30	2.6 E+04
Cd-115		80	20	5.1 E+05
Ce-139	Cerium (58)	100	100	6.5 E+03
Ce-141		300	25	2.8 E+04
Ce-143		60	20	6.6 E+05
Ce-144		10	7	3.2 E+03
Cf-249	Californium (98)	2	0.002	3.1
Cf-250		7	0.007	1.3 E+02
Cf-252		2	0.009	6.5 E+02
Cl-36	Chlorine (17)	300	10	3.2 E-02
Cl-38		10	10	1.3 E+08
Cm-242	Curium (96)	200	0.2	3.3 E+03

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Table 1 (Continued-3)

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Cm-243		9	0.009	4.2 E+01
Cm-244		10	0.01	8.2 E+01
Cm-245		6	0.006	1.0 E-01
Cm-246		6	0.006	3.6 E-01
Co-56	Cobalt (27)	5	5	3.0 E+04
Co-57		90	90	8.5 E+03
Co-58m		1000	1000	5.9 E+06
Co-58		20	20	3.1 E+05
Co-60		7	7	1.1 E+03
Cr-51	Chromium (24)	600	600	9.2 E+04
Cs-129	Cesium (55)	40	40	7.6 E+05
Cs-131		1000	1000	1.1 E+05
Cs-134m		1000	10	7.4 E+06
Cs-134		10	10	1.2 E+03
Cs-135		1000	25	8.8 E-04
Cs-136		7	7	7.4 E+04
Cs-137		30	10	9.8 E+01
Cu-64	Copper (29)	80	25	3.8 E+06
Cu-67		200	25	7.9 E+05
Dy-165	Dysprosium (66)	100	20	8.2 E+06
Dy-166		1000	200	2.3 E+05
Er-169	Erbium (68)	1000	25	8.2 E+04
Er-171		50	20	2.4 E+06
Eu-152m	Europium (63)	30	30	2.2 E+06

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Table 1 (Continued-4)

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Eu-152		20	10	1.9 E+02
Eu-154		10	5	1.5 E+02
Eu-155		400	60	1.4 E+03
F-18	Fluorine (9)	20	20	9.3 E+07
Fe-52	Iron (26)	5	5	7.3 E+06
Fe-55		1000	1000	2.2 E+03
Fe-59		10	10	4.9 E+04
Ga-67	Gallium (31)	100	100	6.0 E+03
Ga-68		20	20	4.0 E+07
Ga-72		7	7	3.1 E+06
Gd-153	Gadolinium (64)	200	100	3.6 E+03
Gd-159		300	20	1.1 E+06
Ge-68	Germanium (32)	20	10	7.0 E+03
Ge-71		1000	1000	1.6 E+05
H-3	Hydrogen (1)	see Tritium		
Hf-181	Hafnium (72)	30	25	1.6 E+04
Hg-197m	Mercury (80)	200	200	6.6 E+05
Hg-197		200	200	2.5 E+05
Hg-203		80	25	1.4 E+04
Ho-166	Holmium(67)	30	30	6.9 E+05
I-123	Iodine (53)	50	50	6.9 E+04
I-125		1000	70	1.7 E+04
I-126		40	10	7.8 E+04
I-129		1000	2	1.6 E-04

Table 1 (Continued-5)

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A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
I-131		40	1	1.2 E+05
I-132		7	7	1.1 E+07
I-133		30	10	1.1 E+06
I-134		8	8	2.7 E+07
I-135		10	10	3.5 E+06
In-111	Indium (49)	30	25	4.2 E+05
In-113m		60	60	1.6 E+07
In-114m		30	20	2.3 E+04
In-115m		100	20	6.1 E+06
Ir-190	Iridium (77)	10	10	6.2 E+04
Ir-192		20	10	9.1 E+03
Ir-194		10	10	8.5 E+05
K-42	Potassium (19)	10	10	6.0 E+06
K-43		20	10	3.3 E+06
Kr-85m (uncompressed)*	Krypton (36)	100	100	8.4 E+06
Kr-85m (compressed)*		3	3	8.4 E+06
Kr-85 (uncompressed)*		1000	1000	4.0 E+02
Kr-85 (compressed)*		5	5	4.0 E+02
Kr-87 (uncompressed)*		20	20	2.8 E+07
Kr-87 (compressed)*		0.6	0.6	2.8 E+07
La-140	Lanthanum (57)	30	30	5.6 E+05
Lu-177	Lutetium (71)	300	25	1.1 E+05
MFP	Mixed Fission Products	10	0.4	---
Mg-28	Magnesium (12)	6	6	5.2 E+06

Table 1 (Continued-6)

APPENDIX 16-B

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Mn-54		20	20	8.3 E+03
Mn-56		5	5	2.2 E+07
Mo-99	Molybdenum (42)	100	20	4.7 E+05
N-13	Nitrogen (7)	20	10	1.5 E+09
Na-22	Sodium (11)	8	8	6.3 E+03
Na-24		5	5	8.7 E+06
Nb-93m	Niobium (41)	1000	200	4.1 E+02
Nb-95		20	20	3.9 E+04
Nb-97		20	20	2.6 E+07
Nd-147	Neodymium (60)	100	20	8.0 E+04
Nd-149		30	20	1.1 E+07
Ni-59	Nickel (28)	1000	900	8.1 E-02
Ni-63		1000	100	4.6 E+01
Ni-65		10	10	1.9 E+07
Np-237	Neptunium (93)	5	0.005	6.9 E-04
Np-239		200	25	2.3 E+05
Os-185	Osmium (76)	20	20	7.3 E+03
Os-191		600	200	4.6 E+04
Os-191m		200	200	1.2 E+06
Os-193		100	20	5.3 E+05
P-32	Phosphorus (15)	30	30	2.9 E+05
Pa-230	Protactinium (91	20	0.8	3.2 E+04
Pa-231		2	0.002	4.5 E-02
Pa-233		100	100	2.1 E+04

Table 1 (Continued-7)

A_1 and A_2 Values for Radionuclides

APPENDIX 16-B

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Pb-201	Lead (82)	20	20	1.7 E+06
Pb-210		100	0.2	8.8 E+01
Pb-212		6	5	1.4 E+06
Pd-103	Palladium (46)	1000	700	7.5 E+04
Pd-109		100	20	2.1 E+06
Pm-147	Promethium (61)	1000	25	9.4 E+02
Pm-149		100	20	4.2 E+05
Po-210	Polonium (84)	200	0.2	4.5 E+03
Pr-142	Praseodymium (59	10	10	1.2 E+06
Pr-143		300	20	6.6 E+04
Pt-191	Platinum (78)	100	100	2.3 E+05
Pt-193m		200	200	2.0 E+05
Pt-197m		300	20	1.2 E+07
Pt-197		300	20	8.8 E+05
Pu-238	Plutonium (94)	3	0.003	1.7 E+01
Pu-239		2	0.002	6.2 E-02
Pu-240		2	0.002	2.3 E-01
Pu-241		1000	0.1	1.1 E+02
Pu-242		3	0.003	3.9 E-03
Ra-223	Radium (88)	50	0.2	5.0 E+04
Ra-224		6	0.5	1.6 E+05
Ra-226		10	0.05	1.0
Ra-228		10	0.05	2.3 E+02
Rb-81	Rubidium (37)	30	24	8.2 E+04

Table 1 (Continued-8)

A_1 and A_2 Values for Radionuclides

APPENDIX 16-B

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Rb-87		Unlimited	Unlimited	6.6 E-08
Rb (natural)		Unlimited	Unlimited	1.8 E-08
Re-186	Rhenium (75)	100	20	1.9 E+05
Re-187		Unlimited	Unlimited	3.8 E-08
Re (natural)		Unlimited	Unlimited	2.4 E-08
Rh-103m	Rhodium (45)	1000	1000	3.2 E+07
Rh-105		200	25	8.2 E+05
Rn-222	Radon (86)		2	1.5 E+05
Ru-97	Ruthenium (44)	80	80	5.5 E+05
Ru-103		30	25	3.2 E+04
Ru-105		20	20	6.6 E+06
Ru-106		10	7	3.4 E+03
S-35	Sulphur (16)	1000	60	4.3 E+04
Sb-122	Antimony (51)	30	30	3.9 E+05
Sb-124		5	5	1.8 E+04
Sb-125		40	25	1.4 E+03
Sc-46	Scandium (21)	8	8	3.4 E+04
Sc-47		200	20	8.2 E+05
Sc-48		5	5	1.5 E+06
Se-75	Selenium (34)	40	40	1.4 E+04
Si-31	Silicon (14)	100	20	3.9 E+07
Sm-147	Samarium (62)	Unlimited	Unlimited	2.0 E-08
Sm-151		1000	90	2.6 E+01
Sm-153		300	20	4.4 E+05

Table 1 (Continued-9)

A_1 and A_2 Values for Radionuclides

APPENDIX 16-B

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Sn-119m		100	100	4.4 E+03
Sn-125		10	10	1.1 E+05
Sr-85m	Strontium (38)	80	80	3.2 E+07
Sr-85		30	30	2.4 E+04
Sr-89		100	10	2.9 E+04
Sr-90		10	0.4	1.5 E+02
Sr-91		10	10	3.6 E+06
Sr-92		10	10	1.3 E+07
T (uncompressed)*	Tritium (1)	1000	1000	9.7 E+03
T (compressed)*		1000	1000	9.7 E+03
T (activated luminous paint)		1000	1000	9.7 E+03
T (adsorbed on solid carrier)		1000	1000	9.7 E+03
T (tritiated water)		1000	1000	9.7 E+03
T (other forms)		20	20	9.7 E+03
Ta-182	Tantalum (73)	20	20	6.2 E+03
Tb-182	Terbium (65)	20	10	1.1 E+05
Tc-96m	Technetium (43)	1000	1000	3.8 E+07
Tc-96		6	6	3.2 E+05
Tc-97m		1000	200	1.5 E+04
Tc-97		1000	400	1.4 E+04
Tc-99m		100	100	5.2 E+06
Tc-99		1000	25	1.7 E-02
Te-125m	Tellurium (52)	1000	100	1.8 E+04
Te-127m		300	20	4.0 E+04

Table 1 (Continued-10)

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

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Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity (Ci/g)
Te-127		300	20	2.6 E+06
Te-129m		30	10	2.5 E+04
Te-129		100	20	2.0 E+07
Te-131m		10	10	8.0 E+05
Te-132		7	7	3.1 E+05
Th-227	Thorium (90)	200	0.2	3.2 E+04
Th-228		6	0.008	8.3 E+02
Th-230		3	0.003	1.9 E-02
Th-231		1000	25	5.3 E+05
Th-232		Unlimited	Unlimited	1.1 E-07
Th-234		10	10	2.3 E+04
Th (natural)		Unlimited	Unlimited	2.2 E-07
Th (irradiated)**		---	---	---
Tl-200	Thallium (81)	20	20	5.8 E+05
Tl-201		200	200	2.2 E+05
Tl-202		40	40	5.4 E+04
Tl-204		300	10	4.3 E+02
Tm-170	Thulium (69)	300	10	6.0 E+03
Tm-171		1000	100	1.1 E+03
U-230	Uranium (92)	100	0.1	2.7 E+04
U-232		30	0.03	2.1 E+01
U-233		100	0.1	9.5 E-03
U-234		100	0.1	6.2 E-03
U-235		100	0.2	2.1 E-06

Table 1 (Continued-11)

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Symbol of	Element and	A_1 (Ci)	A_2 (Ci)	Specific

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Radionuclide	Atomic number			Activity (Ci/g)
U-238		Unlimited	Unlimited	3.3 E-07
U (natural)		Unlimited	Unlimited	(see Table 4)
U (enriched) < 20%		Unlimited	Unlimited	(see Table 4)
U (enriched) 20% or greater		Unlimited	Unlimited	(see Table 4)
U (depleted)		Unlimited		(see Table IV)
U (irradiated)***		---	---	---
V-48	Vanadium (23)	6	6	1.7 E+05
W-181	Tungsten (74)	200	100	5.0 E+03
W-185		1000	25	9.7 E+03
W-187		40	20	7.0 E+05
Xe-127 (uncompressed)*	Xenon (54)	70	70	2.8 E+04
Xe-127 (compressed)*		5	5	2.8 E+04
Xe-131m (compressed)*		10	10	1.0 E+05
Xe-131m (uncompressed)*		100	100	1.0 E+05
Xe-133 (uncompressed)*		1000	1000	1.9 E+05
Xe-133 (compressed)*		5	5	1.9 E+05
Xe-135 (uncompressed)*		70	70	2.5 E+06
Xe-135 (compressed)*		2	2	2.5 E+06
Y-87	Yttrium (39)	20	20	4.5 E+05
Y-90		10	10	5.4 E+05
Y-91m		30	30	4.1 E+07
Y-91		30	30	2.5 E+04
Y-92		10	10	9.5 E+06

Table 1 (Continued-12)

A_1 and A_2 Values for Radionuclides

(See footnotes at end of Table)

Symbol of Radionuclide	Element and Atomic number	A_1 (Ci)	A_2 (Ci)	Specific Activity

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				(Ci/g)
Y-93		10	10	3.2 E+06
Yb-169	Ytterbium (70)	80	80	2.3 E+05
Yb-175		400	25	1.8 E+05
Zn-65	Zinc (30)	30	30	8.0 E+03
Zn-69m		40	20	3.3 E+06
Zn-69		300	20	5.3 E+07
Zr-93	Zirconium (40)	1000	200	3.5 E-03
Zr-95		20	20	2.1 E+04
Zr-97		20	20	2.0 E+06

* For the purpose of Table 1, compressed gas means a gas at a pressure which exceeds the ambient atmospheric pressure at the location where the containment system was closed.

** The values of A_1 and A_2 must be calculated in accordance with the procedure specified in Appendix 16-B, paragraph II 3., taking into account the activity of the fission products and of the uranium-233 in addition to that of the thorium.

*** The values of A_1 and A_2 must be calculated in accordance with the procedure specified in Appendix 16-B, paragraph II 3., taking into account the activity of the fission products and plutonium isotopes in addition to that of the uranium.

APPENDIX 16-B

Table 2

Relationship Between A_1 and E max for Beta Emitters

E max (MeV)	A_1(Ci)
< 0.5	1000
0.5 - < 1.0	300
1.0 - < 1.5	100
1.5 - < 2.0	30
≥ 2.0	10

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Table 3
Relationship Between A_3 and the Atomic Number of the Radionuclide

Atomic Number	A_3 Half-life less than 1000 days	A_3 Half-life 1000 days to 10^4 years	A_3 Half-life greater than 10^4 years
1 to 81	3 Ci	0.05 Ci	3 Ci
82 and above	0.002 Ci	0.002 Ci	3 Ci

Table 4
Activity-Mass Relationships for Uranium/Thorium

Uranium Enrichment* wt % U-235 present	Specific Activity Ci/g	Specific Activity g/Ci
0.45	5.0×10^{-7}	2.0×10^{6}
0.72(natural)	7.06×10^{-7}	1.42×10^{6}
1.0	7.6×10^{-7}	1.3×10^{6}
1.5	1.0×10^{-6}	1.0×10^{6}
5.0	2.7×10^{-6}	3.7×10^{5}
10.0	4.8×10^{-6}	2.1×10^{5}
20.0	1.0×10^{-5}	1.0×10^{5}
35.0	2.0×10^{-5}	5.0×10^{4}
50.0	2.5×10^{-5}	4.0×10^{4}
90.0	5.8×10^{-6}	1.7×10^{4}
93.0	7.0×10^{-6}	1.4×10^{4}
95.0	9.1×10^{-6}	1.1×10^{4}
Natural Thorium	2.2×10^{-7}	4.6×10^{6}

*The figures for uranium include representative values for the activity of the uranium-234 which is concentrated during the enrichment process. The activity for thorium includes the equilibrium

concentration of thorium-228.