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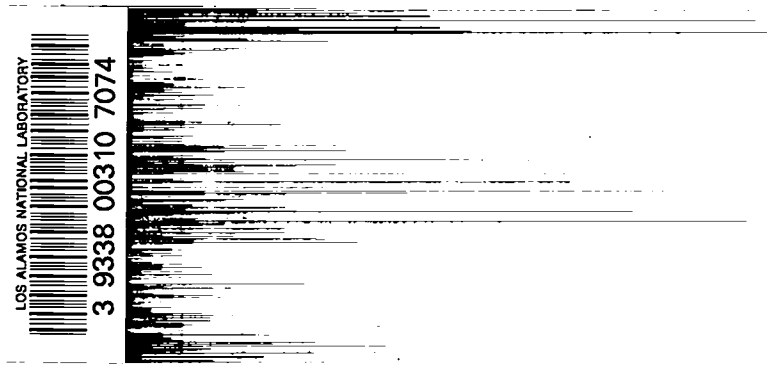
LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA o LOS ALAMOS NEW MEXICO

DOSE RATES, ACTIVITY, AND SHIELDING TRANSMISSION FACTORS FOR U^{235} FISSION PRODUCTS AFTER SHORT IRRADIATION



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LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA LOS ALAMOS NEW MEXICO

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DOSE RATES, ACTIVITY, AND SHIELDING TRANSMISSION FACTORS FOR U^{235} FISSION PRODUCTS AFTER SHORT IRRADIATION

by

Donald A. McKown

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ABSTRACT

The calculated gamma dose rates and shielding dose transmission factors with buildup for U^{235} fission products are tabulated for various times after fission. The transmission factors are listed for lead, iron, concrete, aluminum, and water. The calculations are based on the U^{235} fission product gamma-ray spectra and activities presented by Ann T. Nelms and J. W. Cooper in Health Physics, V. 1, No. 4, (March 1959) 427 - 441. Point source geometry is assumed, and the buildup factors are for infinite media.

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INTRODUCTION

In the handling and shipping of fission products produced in Rover tests there often is a need for some convenient basis upon which to make rough calculations of the activity in curies, the dose rate, and the attenuation of shielding materials. The tabulations given in this report should be useful in making such calculations for U^{235} fission products resulting from short irradiation times.

CALCULATIONS

Ann T. Nelms and J. W. Cooper in Health Physics, Vol. 1, No. 4 (1959), p. 427, have tabulated the calculated gamma-ray spectral density of U^{235} fission products for each of 22 energy groups from 0 to 5.8993 MeV for 20 values of time t after 10^4 fissions ranging from 31.2 minutes to 119 years. The spectral densities are given for total fission products and fission products with volatiles removed. Also listed in the article are the total fission product activities for the same values of t per 10^4 fissions in disintegrations per second.

The photon emission rate and, in turn, the dose rate for each energy group can be calculated from the spectral density. A summation of the dose rates over the 22 energy groups yields the total rate at time t.

The spectral density as given by Nelms and Cooper:

$$K(t_i, E_l)=\sum_j \sum_{\epsilon_l<E_r<\epsilon_{l+1}} N_j(E_r)L_j(t_i)/(\epsilon_{l+1}-\epsilon_l) \text{ photons/sec (MeV)}$$

where $L_j(T_i)$ is the activity in dis/sec for the j^{th} nuclide at time t_i after fission, and $N_j(E_r)$ is the photons/dis of energy E_r from the j^{th} nuclide. ϵ_l is the lower limit of an energy group, and ϵ_{l+1} is the upper limit. $\epsilon_{l+1}-\epsilon_l$ is the energy span of a group.

Photon emission rate:

$$P(t_i,E_l)=K(t_i,E_l)\,(\epsilon_{l+1}-\epsilon_l)$$

photons/sec at time t_i (assigned representative energy E_l includes all photons whose energies fall between ϵ_l and ϵ_{l+1}).

Dose rate from any group represented by E_l at time t_i without shielding:

$$d(t_i, E_l) = \frac{P(t_i, E_l)\,(3600)\,\mu_a\,E_l}{\frac{4\pi X^2}{34 \times 10^{-6}}\,4.8 \times 10^{-10}}$$

where X is taken as 1 cm from a point source.

$$d(t_i, E_l) = P(t_i, E_l)\,\mu_a\,E_l\,(4.05 \times 10^{-3})$$

R/hr at 1 cm per 10^4 fissions at time t_i for an energy group represented by E_l .

Total dose rate:

$$D(t_i) = \sum_{0.034 \rightarrow E_l \rightarrow 5.1089} d(t_i, E_l) = \sum_{0.034 \rightarrow E_l \rightarrow 5.1089} P(t_i, E_l)(\mu_a)_{E_l} E_l (4.05 \times 10^{-3})$$

R/hr at 1 cm, at time t_i per 10^4 fissions.

The shielding dose transmission factors can be obtained by first calculating the dose transmission for the desired thickness of shielding material for each energy group at time t_i, summing over all energy groups for the total dose with shielding, and taking the ratio of the total dose rate with shielding to the total dose rate without shielding.

Dose rate of each energy group with shielding:

$$d(t_i, E_l, S_{m,n}) = d(t_i, E_l) \left(e^{-\mu_m E_l n}\right) B(m, n, E_l)$$

R/hr at 1 cm per 10^4 fissions at time t_i for an energy group represented by E_l where $S_{m,n}$ is the attenuation of thickness n of material m whose absorption coefficient is μ_m at a photon energy E_l . $B(m, n, E_l)$ is the dose buildup factor as a function of thickness n of material m for a photon energy E_l .

Total dose rate with shielding:

$$D(t_i, S_{m,n}) = \sum_{0.034 \rightarrow E_l \rightarrow 5.1089} d(t_i, E_l) \left(e^{-\mu_m E_l n}\right) B(m, n, E_l)$$

R/hr at 1 cm per 10^4 fissions at time t_i.

Dose transmission factor:

$$F(t_i, S_{m,n}) = \frac{D(t_i, S_{m,n})}{D(t_i)}$$ = Fraction of "no shielding" dose transmitted by n cm of material m.

The dose rates without shielding and the shielding dose transmission factors were calculated as described by setting up the problem on the IBM 7094.

Point source geometry is assumed, and the dose buildup factors are for infinite media. The fact that the dose build-up factors are for infinite media will probably influence the transmission factors toward the conservative because of the reduction of backscatter in the finite case. Care should be taken in applying these tabulations to thin shields e.g., < 4 cm for aluminum and concrete, < 10 cm for water, < 2 cm for lead and iron. It would be well to keep in mind that the numbers tabulated are calculated and have not been well verified by experimental data.

Table 1 lists the sources of quantities and some of the values used in the calculations.

Table 2 lists curies/fission, R/hr at 1 cm per 10^4 fissions, and R/hr at 1 cm per curie for total U^{235} fission products for times ranging from 31.2 minutes to 12 years after fission. Table 3 lists the same quantities for U^{235} fission products with volatiles omitted. Tables 4 through 13 list

the shielding dose transmission factors with buildup for several thicknesses of lead, iron, ordinary concrete, aluminum, and water, with and without volatiles for the times after fission as mentioned above.

Table 1

Sources of Quantities Used in the Calculations

Quantity	Value	Source
Photon Spectral Density	----	Ann T. Nelms and J. W. Cooper, "U^{235} Fission Product Decay Spectra at Various Times After Fission," Health Physics, Vol. 1, No. 4 (1959), Tables 3 and 5, pp. 431 and 433.
$\varepsilon_{l+1} - \varepsilon_l$	----	Ibid., Table 1, p. 428.
Total Fission Product Activities	----	Ibid., Table 7, p. 435.
True Linear Absorption Coefficient for Air	----	NBS-1003, Gladys R. White, X-Ray Attenuation Coefficients from 10 KeV to 100 MeV (1952), Table II, pp. 74-75.
Attenuation Coefficients	----	Ibid.
Lead	----	Table I, pp. 70-71.
Iron	----	Table I, pp. 56-57.
Concrete	----	Table II, pp. 78-79.
Aluminum	----	Table I, pp. 48-49.
Water	----	Table II, p. 77.
Effective Z No. for Concrete	11.5	Ibid., calculated from Table II, p. 78.

Table 1 (Continued)

Quantity	Value	Source
Densities (g/cm^3)		
Lead	11.3	Charles D. Hodgman, Robert C. Weast, and Samuel M. Selby, Eds., "Handbook of Chemistry and Physics", Forty-First Edition, Chemical Rubber Publishing Co. Cleveland, Ohio (1959-1960), p. 2118. Assumed value based on density tabulations.
Iron	7.85	Ibid.
Aluminum	2.7	Ibid., p. 2117.
Ordinary Concrete	2.3	Edwin J. Callan, Introduction to "Concrete for Radiation Shielding," Second Edition, American Concrete Institute, Detroit, Michigan (1962), Footnote for Table 4, p. 13.
Buildup Factors for Infinite Media	----	NYO-3075, Herbert Goldstein and J. Ernest Wilkins, Jr., Calculations of the Penetration of Gamma Rays (1954).
Lead	----	Ibid, Table 7.126, p. 140.
Iron	----	Ibid, Table 7.118, p. 137.
Concrete	----	Ibid, Figures 8.66 through 8.73, pp. 188-192.
Aluminum	----	Ibid, Table 7.115, p. 136.
Water	----	Ibid, Table 7.112, p. 135.
Energy to Create Ion Pair in Water (eV)	34	Gerald J. Hine and Gordon L. Brownell "Radiation Dosimetry," Academic Press Inc., New York (1956), p. 904.

Table 2

U^{235} Total Fission Product Dose Rates and Activity

at Various Times after Fission

Time after Fission	Curies/Fission	R/hr at 1 cm per 10^4 Fissions	R/hr at 1 cm per Curie
31.2 min.	6.0×10^{-15}	3.2×10^{-7}	5.3×10^{3}
1.12 hr.	2.8×10^{-15}	1.5×10^{-7}	5.2×10^{3}
2.40 hr.	1.1×10^{-15}	5.2×10^{-8}	4.6×10^{3}
5.16 hr.	4.9×10^{-16}	1.9×10^{-8}	3.8×10^{3}
11.1 hr.	2.2×10^{-16}	8.0×10^{-9}	3.6×10^{3}
23.8 hr.	8.9×10^{-17}	2.9×10^{-9}	3.2×10^{3}
2.13 days	3.2×10^{-17}	9.4×10^{-10}	2.9×10^{3}
4.57 days	1.2×10^{-17}	3.6×10^{-10}	3.0×10^{3}
9.82 days	5.3×10^{-18}	1.7×10^{-10}	3.1×10^{3}
21.1 days	2.3×10^{-18}	7.2×10^{-11}	3.1×10^{3}
45.3 days	1.0×10^{-18}	2.6×10^{-11}	2.6×10^{3}
97.3 days	4.3×10^{-19}	9.3×10^{-12}	2.2×10^{3}
208 days	1.5×10^{-19}	3.1×10^{-12}	2.1×10^{3}
1.2 yr.	3.7×10^{-20}	3.8×10^{-13}	1.0×10^{3}
2.6 yr.	1.1×10^{-20}	5.9×10^{-14}	5.5×10^{2}
5.58 yr.	2.9×10^{-21}	2.8×10^{-14}	9.7×10^{2}
12 yr.	1.8×10^{-21}	2.3×10^{-14}	1.2×10^{3}

Table 3

U^{235} Fission Product Dose Rates and Activity

with Volatiles Removed

Time after Fission	Curies/Fission	R/hr at 1 cm per 10^4 Fissions	R/hr at 1 cm per Curie
31.2 min.	5.2×10^{-15}	2.7×10^{-7}	5.1×10^{3}
1.12 hr.	2.3×10^{-15}	1.1×10^{-7}	4.9×10^{3}
2.4 hr.	8.5×10^{-16}	3.4×10^{-8}	4.0×10^{3}
5.16 hr.	3.6×10^{-16}	1.2×10^{-8}	3.2×10^{3}
11.1 hr.	1.6×10^{-16}	5.4×10^{-9}	3.3×10^{3}
23.8 hr.	6.2×10^{-17}	1.9×10^{-9}	3.0×10^{3}
2.13 days	2.3×10^{-17}	5.7×10^{-10}	2.5×10^{3}
4.57 days	8.1×10^{-18}	2.0×10^{-10}	2.5×10^{3}
9.82 days	3.5×10^{-18}	1.1×10^{-10}	3.2×10^{3}
21.1 days	1.8×10^{-18}	6.1×10^{-11}	3.4×10^{3}
45.3 days	8.9×10^{-19}	2.4×10^{-11}	2.7×10^{3}
97.3 days	4.0×10^{-19}	8.4×10^{-12}	2.1×10^{3}
208 days	1.4×10^{-19}	2.9×10^{-12}	2.1×10^{3}
1.2 yr.	3.7×10^{-20}	3.8×10^{-13}	1.0×10^{3}
2.6 yr.	1.1×10^{-20}	5.9×10^{-14}	5.6×10^{2}
5.58 yr.	2.7×10^{-21}	2.8×10^{-14}	1.0×10^{3}
12 yr.	1.7×10^{-21}	2.2×10^{-14}	1.3×10^{3}

Table 4

Shielding Dose Transmission Factors for Lead with Buildup for U^{235} Total Fission Products

Time after Fission	Thickness of Lead in Centimeters						
	1	2	4	8	12	16	20
31.2 min.	.54	.35	.13	.019	.0029	4.5×10^{-4}	7.2×10^{-5}
1.12 hr.	.54	.34	.13	.020	.0031	5.0×10^{-4}	8.0×10^{-5}
2.4 hr.	.53	.32	.12	.017	.0027	4.4×10^{-4}	7.1×10^{-5}
5.16 hr.	.50	.29	.10	.015	.0024	3.8×10^{-4}	6.2×10^{-5}
11.1 hr.	.49	.28	.092	.013	.0020	3.3×10^{-4}	5.3×10^{-5}
23.8 hr.	.45	.23	.069	.0086	.0013	2.0×10^{-4}	3.2×10^{-5}
2.13 days	.41	.20	.052	.0053	6.9×10^{-4}	9.6×10^{-5}	1.4×10^{-5}
4.57 days	.42	.22	.069	.0083	.0011	1.5×10^{-4}	2.1×10^{-5}
9.82 days	.46	.26	.089	.012	.0017	2.4×10^{-4}	3.3×10^{-5}
21.1 days	.47	.28	.098	.014	.0020	2.8×10^{-4}	3.8×10^{-5}
45.3 days	.47	.25	.082	.011	.0015	2.0×10^{-4}	2.8×10^{-5}
97.3 days	.46	.22	.048	.0032	3.3×10^{-4}	4.3×10^{-5}	6.0×10^{-6}
208 days	.48	.22	.047	.0022	1.7×10^{-4}	2.1×10^{-5}	3.1×10^{-6}
1.2 yr.	.47	.22	.055	.0049	6.6×10^{-4}	9.9×10^{-5}	1.5×10^{-5}
2.6 yr.	.38	.17	.050	.0077	.0013	2.0×10^{-4}	3.2×10^{-5}
5.58 yr.	.36	.13	.022	.0025	4.4×10^{-4}	7.9×10^{-5}	1.4×10^{-5}
12 yr.	.37	.13	.021	.0019	3.2×10^{-4}	5.5×10^{-5}	9.8×10^{-6}

Table 5

Shielding Dose Transmission Factors for Lead with Buildup for U^{235} Fission Products with Volatiles Removed

Time after Fission	Thickness of Lead in Centimeters						
	1	2	4	8	12	16	20
31.2 min.	.53	.34	.12	.018	.0028	4.4×10^{-4}	7.0×10^{-5}
1.12 hr.	.53	.34	.13	.020	.0031	5.0×10^{-4}	7.9×10^{-5}
2.4 hr.	.51	.31	.11	.016	.0025	3.9×10^{-4}	6.1×10^{-5}
5.16 hr.	.48	.26	.078	.0093	.0013	1.9×10^{-4}	2.7×10^{-5}
11.1 hr.	.48	.25	.070	.0072	9.1×10^{-4}	1.2×10^{-4}	1.7×10^{-5}
23.8 hr.	.46	.22	.055	.0045	4.9×10^{-4}	6.1×10^{-5}	7.9×10^{-6}
2.13 days	.42	.21	.053	.0047	5.4×10^{-4}	6.9×10^{-5}	9.0×10^{-6}
4.57 days	.43	.24	.082	.011	.0014	1.9×10^{-4}	2.6×10^{-5}
9.82 days	.49	.30	.11	.016	.0022	3.1×10^{-4}	4.3×10^{-5}
21.1 days	.51	.30	.11	.016	.0023	3.2×10^{-4}	4.4×10^{-5}
45.3 days	.49	.28	.091	.012	.0016	2.3×10^{-4}	3.1×10^{-5}
97.3 days	.48	.23	.053	.0035	3.7×10^{-4}	4.8×10^{-5}	6.7×10^{-6}
208 days	.49	.23	.049	.0023	1.8×10^{-4}	2.2×10^{-5}	3.2×10^{-6}
1.2 yr.	.47	.23	.055	.0049	6.6×10^{-4}	1.0×10^{-4}	1.5×10^{-5}
2.6 yr.	.38	.17	.050	.0077	.0013	2.0×10^{-4}	3.2×10^{-5}
5.58 yr.	.36	.13	.022	.0025	4.4×10^{-4}	7.9×10^{-5}	1.4×10^{-5}
12 yr.	.36	.12	.015	.0011	2.0×10^{-4}	4.1×10^{-5}	8.0×10^{-6}

Table 6

Shielding Dose Transmission Factors for Iron with Buildup for U^{235} Total Fission Products

Time after Fission	Thickness of Iron in Centimeters						
	1	2	4	8	12	16	20
31.2 min.	.85	.64	.42	.14	.048	.015	.0048
1.12 hr.	.84	.63	.42	.14	.048	.016	.0050
2.4 hr.	.84	.64	.41	.14	.043	.014	.0043
5.16 hr.	.84	.63	.39	.12	.038	.012	.0037
11.1 hr.	.84	.63	.38	.12	.035	.011	.0032
23.8 hr.	.83	.62	.36	.10	.027	.0075	.0022
2.13 days	.80	.60	.33	.087	.022	.0054	.0014
4.57 days	.79	.59	.34	.097	.027	.0075	.0021
9.82 days	.79	.60	.36	.11	.034	.010	.0031
21.1 days	.80	.62	.37	.12	.037	.012	.0035
45.3 days	.82	.63	.37	.11	.032	.0092	.0027
97.3 days	.85	.65	.36	.092	.021	.0045	.0010
208 days	.87	.67	.37	.094	.020	.0040	8.0×10^{-4}
1.2 yr.	.84	.64	.36	.096	.023	.0054	.0013
2.6 yr.	.75	.57	.32	.083	.021	.0061	.0019
5.58 yr.	.82	.62	.32	.071	.014	.0031	8.4×10^{-4}
12 yr.	.84	.64	.33	.072	.014	.0029	7.2×10^{-4}

Table 7

Shielding Dose Transmission Factors for Iron with Buildup for U^{235} Fission Products with Volatiles Removed

Time after Fission	Thickness of Iron in Centimeters						
	1	2	4	8	12	16	20
31.2 min.	.84	.63	.41	.14	.046	.015	.0047
1.12 hr.	.84	.63	.41	.14	.048	.016	.0051
2.4 hr.	.84	.63	.40	.13	.042	.013	.0041
5.16 hr.	.84	.64	.37	.11	.030	.0083	.0023
11.1 hr.	.85	.65	.37	.11	.027	.0070	.0019
23.8 hr.	.85	.64	.36	.095	.023	.0053	.0013
2.13 days	.80	.59	.33	.088	.022	.0052	.0013
4.57 days	.77	.57	.33	.10	.031	.0091	.0027
9.82 days	.80	.61	.38	.13	.041	.013	.0039
21.1 days	.82	.64	.39	.13	.042	.013	.0040
45.3 days	.83	.64	.38	.12	.035	.010	.0030
97.3 days	.85	.65	.37	.097	.022	.0049	.0011
208 days	.88	.67	.37	.096	.021	.0041	8.3×10^{-4}
1.2 yr.	.84	.64	.36	.096	.023	.0054	.0014
2.6 yr.	.75	.57	.32	.084	.021	.0061	.0019
5.58 yr.	.82	.62	.32	.071	.014	.0031	8.4×10^{-4}
12 yr.	.84	.63	.32	.068	.012	.0023	5.3×10^{-4}

Table 8

Shielding Dose Transmission Factors for Ordinary Concrete with Buildup for U^{235} Total Fission Products

Time after Fission	Thickness of Concrete in Centimeters							
	4	8	16	32	48	64	80	96
31.2 min.	.74	.66	.39	.11	.025	.0061	.0015	3.8×10^{-4}
1.12 hr.	.74	.66	.39	.11	.026	.0065	.0016	4.1×10^{-4}
2.4 hr.	.75	.67	.39	.10	.024	.0058	.0014	3.6×10^{-4}
5.16 hr.	.76	.68	.39	.096	.022	.0051	.0012	3.1×10^{-4}
11.1 hr.	.77	.68	.38	.091	.020	.0046	.0011	2.7×10^{-4}
23.8 hr.	.77	.68	.36	.079	.016	.0032	7.1×10^{-4}	1.7×10^{-4}
2.13 days	.76	.66	.34	.068	.012	.0022	4.1×10^{-4}	8.6×10^{-5}
4.57 days	.73	.63	.34	.074	.015	.0029	5.9×10^{-4}	1.3×10^{-4}
9.82 days	.73	.63	.35	.083	.018	.0039	8.6×10^{-4}	2.0×10^{-4}
21.1 days	.74	.64	.36	.087	.020	.0044	9.8×10^{-4}	2.3×10^{-4}
45.3 days	.77	.67	.37	.084	.017	.0036	7.6×10^{-4}	1.7×10^{-4}
97.3 days	.80	.71	.38	.076	.013	.0019	3.0×10^{-4}	5.2×10^{-5}
208 days	.81	.73	.40	.079	.013	.0018	2.5×10^{-4}	3.7×10^{-5}
1.2 yr.	.78	.70	.38	.078	.014	.0024	4.3×10^{-4}	8.9×10^{-5}
2.6 yr.	.74	.64	.33	.065	.012	.0026	6.1×10^{-4}	1.5×10^{-4}
5.58 yr.	.83	.71	.35	.058	.0082	.0014	3.0×10^{-4}	8.0×10^{-5}
12 yr.	.84	.73	.36	.058	.0078	.0012	2.3×10^{-4}	6.0×10^{-5}

Table 9

Shielding Dose Transmission Factors for Ordinary Concrete with Buildup for U^{235} Fission Products with Volatiles Removed

Time after Fission	Thickness of Concrete in Centimeters							
	4	8	16	32	48	64	80	96
31.2 min.	.74	.66	.38	.11	.025	.0059	.0015	3.7×10^{-4}
1.12 hr.	.73	.65	.39	.11	.026	.0064	.0016	4.1×10^{-4}
2.4 hr.	.75	.66	.38	.098	.023	.0054	.0013	3.2×10^{-4}
5.16 hr.	.77	.68	.37	.084	.017	.0034	7.0×10^{-4}	1.6×10^{-4}
11.1 hr.	.79	.70	.38	.082	.016	.0029	5.5×10^{-4}	1.1×10^{-4}
23.8 hr.	.79	.69	.37	.075	.013	.0021	3.6×10^{-4}	6.5×10^{-5}
2.13 days	.75	.64	.34	.069	.012	.0021	3.6×10^{-4}	6.9×10^{-5}
4.57 days	.70	.59	.33	.077	.017	.0034	7.4×10^{-4}	1.6×10^{-4}
9.82 days	.73	.62	.36	.091	.021	.0048	.0011	2.5×10^{-4}
21.1 days	.75	.65	.38	.094	.022	.0049	.0011	2.6×10^{-4}
45.3 days	.76	.66	.38	.089	.019	.0039	8.5×10^{-4}	1.9×10^{-4}
97.3 days	.79	.71	.39	.080	.014	.0021	3.3×10^{-4}	5.8×10^{-5}
208 days	.81	.73	.40	.080	.013	.0019	2.6×10^{-4}	3.9×10^{-5}
1.2 yr.	.78	.70	.38	.078	.014	.0024	4.4×10^{-4}	8.9×10^{-5}
2.6 yr.	.74	.64	.33	.065	.012	.0026	6.1×10^{-4}	1.5×10^{-4}
5.58 yr.	.82	.71	.35	.058	.0082	.0014	3.0×10^{-4}	8.0×10^{-5}
12 yr.	.84	.73	.35	.055	.0070	9.6×10^{-4}	1.8×10^{-4}	4.9×10^{-5}

Table 10

Shielding Dose Transmission Factors for Aluminum with Buildup for U^{235} Total Fission Products

Time after Fission	Thickness of Aluminum in Centimeters					
	2	4	8	12	16	20
31.2 min.	.79	.78	.60	.43	.31	.21
1.12 hr.	.79	.77	.60	.43	.31	.21
2.4 hr.	.81	.77	.61	.43	.30	.20
5.16 hr.	.81	.77	.60	.43	.29	.20
11.1 hr.	.82	.78	.60	.42	.29	.19
23.8 hr.	.81	.77	.59	.40	.27	.17
2.13 days	.80	.75	.57	.38	.24	.15
4.57 days	.77	.73	.55	.37	.25	.16
9.82 days	.76	.72	.56	.38	.26	.17
21.1 days	.77	.73	.57	.39	.27	.18
45.3 days	.79	.75	.59	.40	.27	.17
97.3 days	.83	.78	.61	.41	.26	.16
208 days	.85	.79	.63	.42	.27	.17
1.2 yr.	.82	.77	.61	.41	.27	.17
2.6 yr.	.77	.74	.56	.38	.25	.16
5.58 yr.	.83	.81	.61	.40	.25	.15
12 yr.	.84	.82	.62	.40	.26	.16

Table 11

Shielding Dose Transmission Factors for Aluminum with Buildup for U^{235} Fission Products with Volatiles Removed

Time after Fission	Thickness of Aluminum in Centimeters					
	2	4	8	12	16	20
31.2 min.	.78	.78	.60	.43	.30	.21
1.12 hr.	.79	.77	.60	.43	.30	.21
2.4 hr.	.80	.77	.60	.42	.29	.20
5.16 hr.	.82	.77	.60	.41	.27	.18
11.1 hr.	.83	.78	.61	.41	.27	.17
23.8 hr.	.83	.77	.60	.40	.26	.16
2.13 days	.79	.73	.55	.37	.24	.15
4.57 days	.75	.69	.52	.36	.24	.16
9.82 days	.76	.73	.56	.39	.27	.18
21.1 days	.77	.74	.58	.40	.28	.19
45.3 days	.79	.75	.59	.40	.27	.18
97.3 days	.83	.77	.61	.41	.27	.16
208 days	.85	.79	.63	.42	.27	.17
1.2 yr.	.82	.77	.61	.41	.27	.17
2.6 yr.	.77	.74	.56	.38	.25	.16
5.58 yr.	.83	.81	.61	.40	.25	.15
12 yr.	.85	.82	.62	.40	.25	.15

Table 12

Shielding Dose Transmission Factors for Water with Buildup for U^{235} Total Fission Products

Time after Fission	Thickness of Water in Centimeters						
	10	20	40	80	120	160	200
31.2 min.	.85	.67	.32	.060	.011	.0019	3.6×10^{-4}
1.12 hr.	.86	.68	.33	.061	.011	.0020	3.9×10^{-4}
2.4 hr.	.85	.68	.32	.057	.0098	.0018	3.4×10^{-4}
5.16 hr.	.85	.67	.31	.052	.0086	.0016	2.9×10^{-4}
11.1 hr.	.86	.67	.31	.049	.0077	.0013	2.4×10^{-4}
23.8 hr.	.86	.68	.30	.041	.0056	8.8×10^{-4}	1.5×10^{-4}
2.13 days	.85	.66	.28	.035	.0039	5.0×10^{-4}	7.1×10^{-5}
4.57 days	.82	.64	.28	.039	.0051	7.1×10^{-4}	1.0×10^{-4}
9.82 days	.83	.64	.29	.045	.0067	.0010	1.6×10^{-4}
21.1 days	.84	.65	.30	.048	.0074	.0012	1.9×10^{-4}
45.3 days	.84	.65	.29	.044	.0061	9.1×10^{-4}	1.4×10^{-4}
97.3 days	.82	.65	.28	.035	.0034	3.5×10^{-4}	4.0×10^{-5}
208 days	.83	.66	.29	.035	.0032	2.8×10^{-4}	2.6×10^{-5}
1.2 yr.	.81	.64	.28	.037	.0041	5.1×10^{-4}	7.1×10^{-5}
2.6 yr.	.78	.60	.26	.036	.0048	7.8×10^{-4}	1.4×10^{-4}
5.58 yr.	.85	.67	.28	.031	.0031	4.5×10^{-4}	9.3×10^{-5}
12 yr.	.87	.68	.28	.030	.0028	3.6×10^{-4}	7.1×10^{-5}

Table 13

Shielding Dose Transmission Factors for Water with Buildup for U^{235} Fission Products with Volatiles Removed

Time after Fission	Thickness of Water in Centimeters						
	10	20	40	80	120	160	200
31.2 min.	.85	.67	.32	.059	.010	.0019	3.5×10^{-4}
1.12 hr.	.86	.68	.33	.061	.011	.0020	3.9×10^{-4}
2.4 hr.	.86	.68	.32	.055	.0091	.0016	2.9×10^{-4}
5.16 hr.	.85	.67	.30	.043	.0058	8.4×10^{-4}	1.3×10^{-4}
11.1 hr.	.85	.67	.30	.040	.0050	6.4×10^{-4}	8.9×10^{-5}
23.8 hr.	.84	.66	.29	.036	.0038	4.2×10^{-4}	4.9×10^{-5}
2.13 days	.83	.64	.28	.034	.0037	4.3×10^{-4}	5.4×10^{-5}
4.57 days	.81	.62	.28	.041	.0059	8.8×10^{-4}	1.3×10^{-4}
9.82 days	.83	.64	.30	.051	.0081	.0013	2.1×10^{-4}
21.1 days	.84	.65	.31	.052	.0083	.0013	2.1×10^{-4}
45.3 days	.83	.65	.30	.046	.0067	.0010	1.6×10^{-4}
97.3 days	.82	.65	.28	.036	.0037	3.8×10^{-4}	4.4×10^{-5}
208 days	.83	.66	.29	.035	.0033	2.9×10^{-4}	2.7×10^{-5}
1.2 yr.	.81	.64	.28	.037	.0041	5.1×10^{-4}	7.2×10^{-5}
2.6 yr.	.78	.60	.26	.036	.0048	7.8×10^{-4}	1.4×10^{-4}
5.58 yr.	.85	.67	.28	.031	.0031	4.5×10^{-4}	9.3×10^{-5}
12 yr.	.87	.68	.28	.029	.0025	3.1×10^{-4}	6.4×10^{-5}