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DRAFT REVISION

EFFECTS OF NUCLEAR WEAPONS
CHAPTER IX

RESIDUAL NUCLEAR RADIATION AND FALLOUT

Sources of Residual Radiation

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FISSION PRODUCTS

9.4 As stated in Chapter I, the fission products constitute a very complex mixture of some 200 different forms (isotopes) of 40 elements. Most of these isotopes are radioactive, decaying by the emission of beta particles, usually accompanied by gamma radiation. About 57 grams (0.125 pound) of fission products are formed for each kiloton (or 125 pounds per megaton) of fission energy yield. The total radioactivity of the fission products initially is extremely large, but it falls off at a fairly rapid rate as the result of decay (para. 1.23).

9.5 At 1 minute after a nuclear explosion, the radioactivity from the 0.125 pound of fission products, from a 1-kiloton explosion, is comparable (i.e., in number of disintegrations per second) to that of three hundred thousand tons of radium. It is seen, therefore, that for explosions in the megaton range of fission yield the amount of radioactivity produced is enormous. Even though there is a decrease from the 1-minute value by a factor of over 3000 by the end of the day, the radiation intensity will still be large.

9.6 It has been calculated that if all the radioactive products from an explosion with a fission yield of 1 megaton could be spread uniformly

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over a smooth plane of 10,000 square miles in area, the radiation intensity at 1 hour would be about 410 roentgens per hour at a level of 3 feet above the ground. (It would be about 400 roentgens per hour if one ignored induced activities and considered fission products only.) For a ground surface explosion, a uniform distribution would be improbable. In general, a larger proportion of the fission products would be deposited downwind from ground zero than in upwind or cross-wind directions. The distribution of this material on the ground depends on a number of parameters--wind structure, yield and height of burst, and kind of surface. It has been observed, for example that the maximum radiation intensity of fallout from megaton detonations occurs at 50 to 75 miles downwind from the explosion center. Fractionation, the result of disproportionate condensation of gaseous fission products, produces further non-uniform distributions in the fallout field (see para. 9.112). These fractionation losses have been calculated to reduce the above mentioned radiation intensity at 1 hour from a value of 410 to 162 roentgens per hour. Geographical features and non-uniform wind behaviors will further prevent uniform distribution.

9.7 Some indication of the rate at which the air ionization rate (dose rate) from the radioactivity in fallout particles from large yield surface land explosions decreases with time may be obtained from the following <u>approximation</u>: for every seven-fold increase in time after the explosion, the dose rate decreases by a factor of ten. For example, if the radiation intensity at 1 hour after the explosion is taken as a reference point, then at 7 hours after the explosion the intensity will have decreased to one-tenth; at 7X7=49 hours (or roughly 2 days) it will be one-hundredth; and at 7X7X7=343 hours (or roughly 2 weeks) the activity will be one-thousandth of that at 1 hour after burst. Another aspect of this approximation is that at the end of 1 week (7 days), the radiation intensity will be about one-tenth of the value after 1 day. This is roughly applicable (to within a factor of 2) for about 200 days, after which time the radiation intensity decreases at a more rapid rate.

9.8 Information concerning the decrease of activity of the fission products can be obtained from Fig. 9.8, in which the ratio of the approximate exposure dose rate (in r/hr, i.e., in roentgens per hour) at any time after the explosion to the dose rate at 1 hour is plotted against the time (curve I(F)). It will be noted that the dose rate at 1 hour after the burst is used here as a reference value. This is done purely for the purpose of simplifying the calculation and representation of the results. At great distances from explosions of high yield, the fission products may not arrive until several hours have elapsed. Nevertheless, the hypothetical (reference) dose rate at 1 hour after the explosion is still used in making calculations. It is, in principle, the dose rate referred back to what it would have been at 1 hour after the explosion, if the fallout had been complete at that time. There is a second curve drawn in Fig. 9.8, a straight line labelled $t^{-1.2}$. The agreement between this curve and the I(F) curve is seen to be favorable in the time interval: .2 hour (12 minutes) to 5000 hours (about 200 days). It is this favorable agreement that gives rise to the approximation method discussed in para. 9.7. The reductions in dose rate with 7-, 49-, and 343-fold increase in time are by 1/10.3, 1/106, and 1/1094 respectively for the $t^{-1.2}$ curve and 1/12.1, 1/94.4, and 1/1350 for the I(F) curve; deviations of up to 25% from the approximation method. At times less than .2 hour and greater than 5000 hours the I(F) decay curve falls off significantly from the $t^{-1.2}$ (straight line) curve. Calculations involving times in excess of several months, such as predicting when natural decay will bring radiation levels down to acceptable dose rates for re-entry into cities or resumption of agricultural operations, should not be based upon the $t^{-1.2}$ decay rule. This also applies to calculations involving decontamination of areas several months after time of burst. These should be based upon the I(F) curves.

9.9 As an example of calculating with these curves, suppose that at a given location, the fallout commences at 5 hours after the explosion, and that at 15 hours, when the fallout has ceased to descend, the observed dose rate is 3.9 roentgens per hour. From the I(F) curve in Fig. 9.8 (or the I(F) results in Table 9.11), it is readily found that the hypothetical (reference) dose rate at 1 hour after the explosion is 105 roentgens per hour (divide the observed dose rate, 3.9 r/hr by the dose rate read off at the corresponding time, .037 r/hr, yielding 105). By means of this reference value and the I(F) decay curve in Fig. 9.8, it is possible to determine the actual dose rate at the place under consideration at any time after fallout is complete. Thus, if the value is required at 24 hours after the explosion, Fig. 9.8 is entered at the point representing 24 hours on the horizontal axis. Moving upward vertically until the plotted line is reached, it is seen that the required dose rate is 0.02 times the 1-hour reference value, i.e., 0.02X105=2.1 roentgens per hour.

9.10 If the dose rate at any time after cessation of fallout is known by actual measurement, that at any other time can be estimated. All that is necessary is to compare the ratios (to the 1-hour reference value) for the two given times as obtained from Fig. 9.8. For example, suppose the dose rate at 3 hours after the explosion is found to be 50 roentgens per hour; what would be the value at 18 hours? The respective ratios, as given by the I(F) curve in Fig. 9.8 are 0.22 and 0.031,

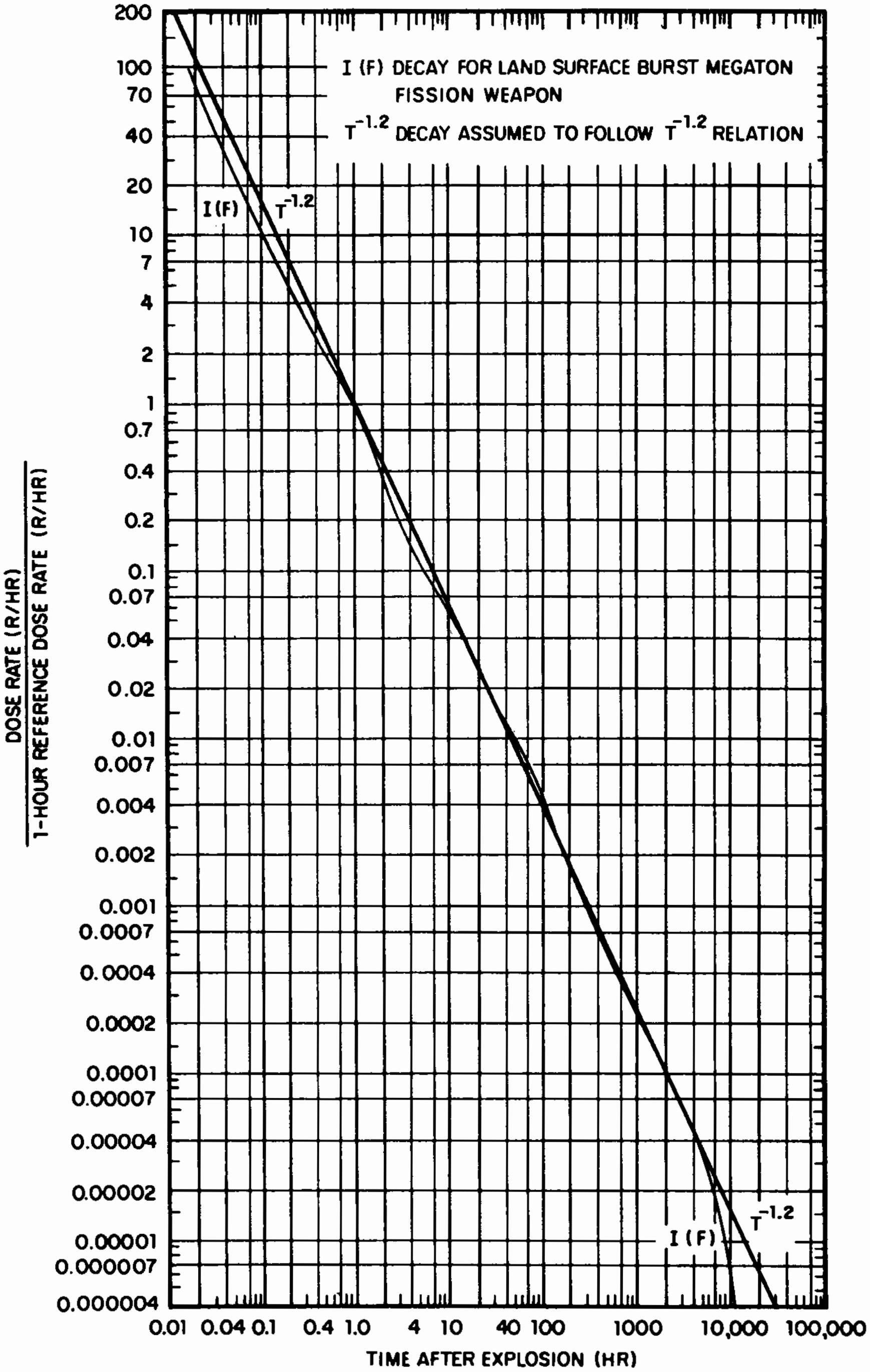

Figure 9.8 Decrease of dose rate from fission products with time

Table 9.11

RELATIVE DOSE RATES AT VARIOUS TIMES AFTER A NUCLEAR EXPLOSION

Time (hours)	Relative Dose Rate I(F)*
1	1000
1.5	580
2	380
3	220
5	120
7	84
10	57
15	37
20	26
30	17
40	13
60	8.4
100	4.5
200	1.6
400	0.60
600	0.39
800	0.29
1000	0.23

***I(F) Relative dose rate for land surface burst megaton fission weapon.**

with respect to the 1 hour reference dose rate. Hence, the dose rate at 18 hours after the explosion is 50X0.031/0.22=7.05 roentgens per hour.

9.11 The results in Fig. 9.8 (curve I(F)) may be represented in an alternative form, as in Table 9.11, that is more convenient, although somewhat less complete. The 1-hour reference dose rate is taken as 1000, in any desired units. The dose rates at a number of subsequent times, in the same units, are given in the table. If the actual dose rate at 1 hour (or any other time) after the explosion is known, the value at any specified time, up to 1000 hours, can be obtained by simple proportion.[1] It is of interest to compute the hypothetical (reference) dose rate using the curve labelled $t^{-1.2}$ in Fig. 9.8. In the example in para. 9.9, the hypothetical (reference) dose rate at 1 hour after burst is 100 roentgens per hour (instead of 105) and the calculated dose rate at 24 hours after burst is then 2 roentgens per hour (instead of 1.9), 5% higher. In the case of the example in paragraph 9.10, using the $t^{-1.2}$ curve yields a dose rate ratio at 3 hours of 0.27 instead of 0.22, hence the calculated dose rate at 18 hours is 5.7 roentgens per hour (instead of 7.05), 25% lower.

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[1] Several simple devices, similar to a slide rule are available for making rough calculations of fallout decay dose rates and related matters.

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For very early and very late times (less than 12 minutes and more than 5000 hours) the deviations become much greater. In general, the dose rate calculations (between these times) using the $t^{-1.2}$ curves will be correct to within a factor of 2. Table 9.11(a) or the nomogram Fig. 12.106 can be used in calculating dose rates based on the $t^{-1.2}$ approximation.

9.12 It should be noted that Fig. 9.8 and Table 9.11 are used for calculations of dose rates. In order to determine the actual or total radiation dose received it is necessary to multiply the average dose rate by the exposure time (para. 8.24). However, since the dose rate is steadily decreasing during the exposure, appropriate allowance must be made. This may be achieved by the mathematical process of integration. The results of graphical integration of the curves in Fig. 9.8 are represented in Fig. 9.12. It gives the total dose received between 1 minute and any other specified time after the explosion, in terms of the 1-hour reference dose rate (up to 1000 hours). The accumulated dose using the $t^{-1.2}$ decay curve is included for comparison purposes. A more convenient method of calculating accumulated dose is through the use of dose rate multipliers (para. 9.114). Figure 9.12(a) is a plot of dose rate multiplier as a function of time after 1 hour (the reference time). The accumulated dose in any time interval

Table 9.11(a)

RELATIVE DOSE RATES AT VARIOUS TIMES AFTER A NUCLEAR EXPLOSION, USING THE $t^{-1.2}$ DECAY SCHEME

Time t(min)	 t(hr)	I(1.2) r/hr (relative)
1	0.017	136,100
1.5	0.025	81,600
2	0.033	59,100
4	0.067	25,800
6	0.10	15,800
10	0.17	8,580
15	0.25	5,270
20	0.33	3,730
40	0.67	1,620
60	1.00	1,000
	2	436
	5	145
	10	63.1
	20	27.5
	50	9.14
	100	3.98
	200	1.73
	500	0.577
	1000	0.251

Table 9.11(a) (Cont.)

RELATIVE DOSE RATES AT VARIOUS TIMES AFTER A NUCLEAR EXPLOSION, USING THE $t^{-1.2}$ DECAY SCHEME

Time		I(1.2)
t(min)	t(hr)	r/hr (relative)
	2000	0.109
	5000	0.0364
	10000	0.0158
	20000	0.00690

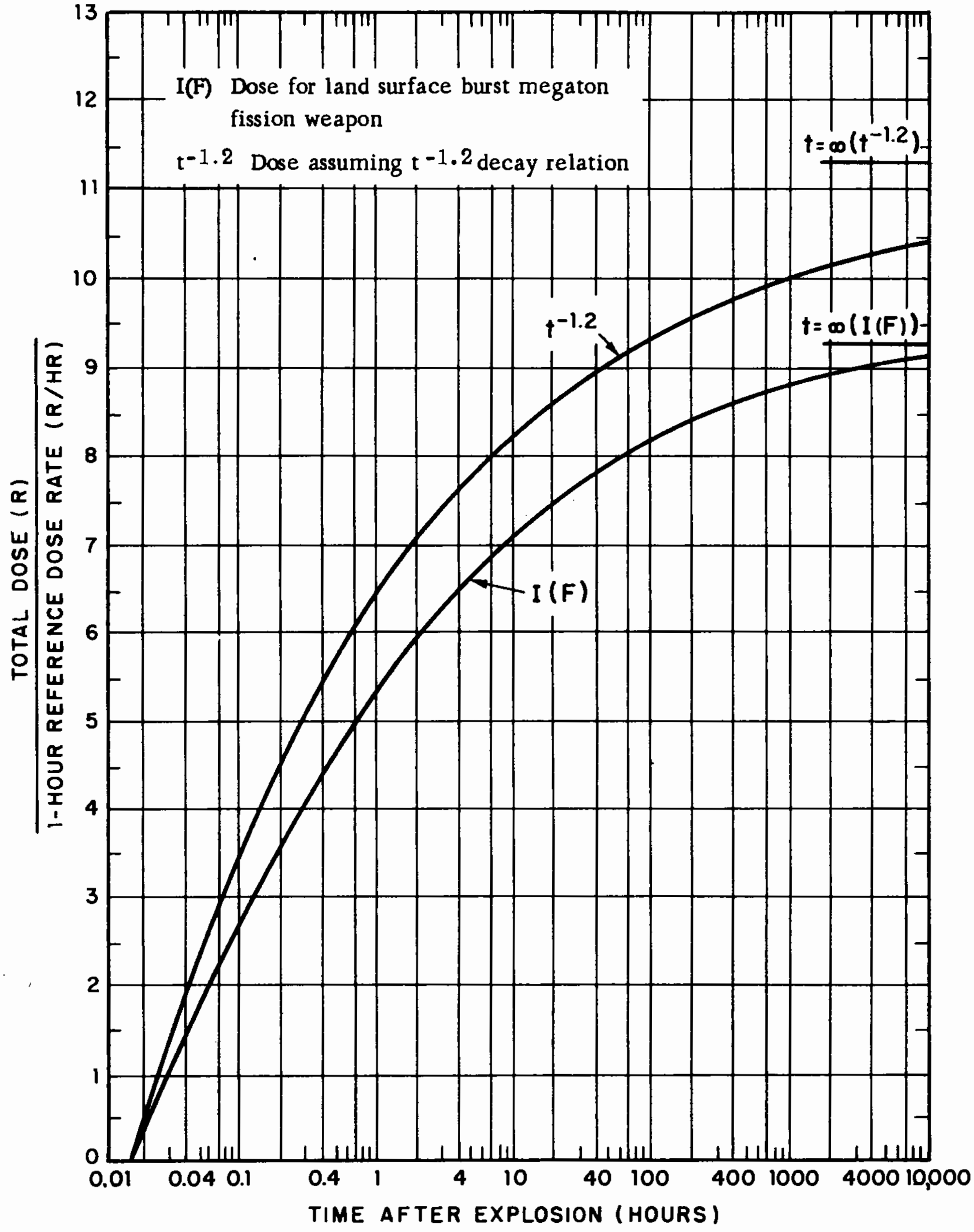

Figure 9.12 Accumulated total dose of residual radiation from fission products from 1 minute after explosion

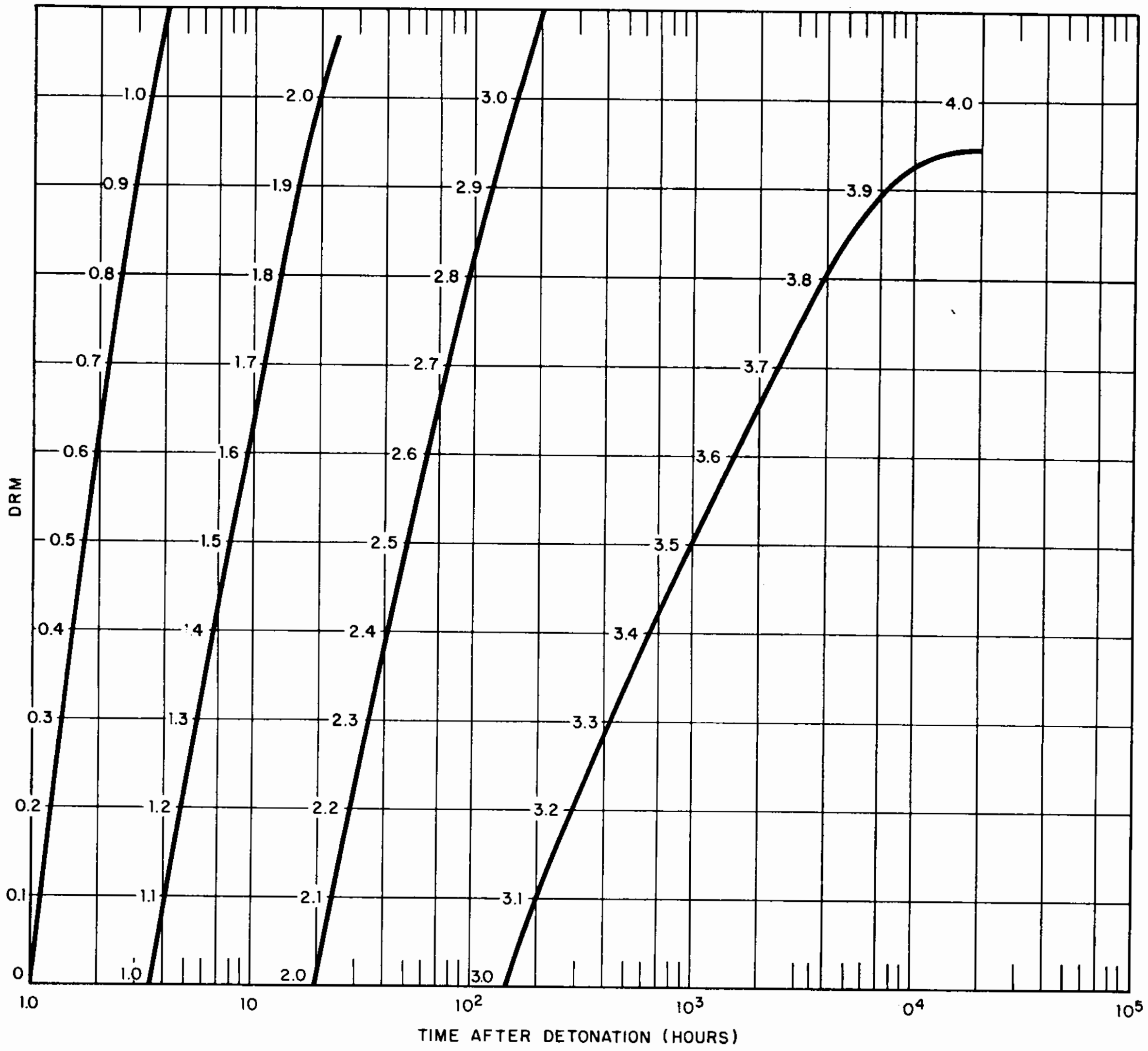

Figure 9.12(a) Dose rate multipliers for I(F) decay curve

after 1 hour is simply the difference between the dose rate multiplier at those times, multiplied by the 1-hour (theoretical) dose rate, as calculated in para. 9.8 and 9.9.

9.13 To illustrate the application of Fig. 9.12(a), suppose that an individual becomes exposed to gamma radiation from fallout 2 hours after a nuclear explosion, and the dose rate, measured at that time, is found to be 1.5 roentgens per hour. What will be the total dose received during the subsequent 12 hours, i.e., by 14 hours after the explosion? The first step is to determine the (hypothetical) 1-hour reference dose rate. From Fig. 9.8 it is seen that

$$\frac{\text{Dose rate at 2 hours after explosion}}{\text{1-hour reference dose rate}} = 0.38$$

and, since the dose rate at 2 hours is known to be 1.5 roentgens per hour, the reference value at 1 hour is 1.5/0.38= 4.0 roentgens per hour. Next, from Fig. 9.12(a), it is found that for 2 hours and 14 hours, respectively, after the explosion,

Dose rate multiplier at 2 hours after explosion= .616

and

Dose rate multiplier at 14 hours after explosion= 1.825.

Hence, by subtraction,

Dose rate multiplier for dose received between 2 and 14 hours after explosion = 1.209.

The reference dose rate at 1 hour is 4.0 roentgens per hour, and so the total dose received in the 12 hours, between 2 and 14 hours after the explosion, is 4.0X1.209=4.8 roentgens.

9.14 The percentage of the "infinity (residual radiation) dose" that would be received from a given quantity of radioactive products, up to various times after a land surface burst, is given in Table 9.14. The infinity dose is essentially that which would be received as a result of continued exposure to a certain quantity of these radioactive products for many years. These data can be used to determine the proportion of the infinity dose received during any specified period following the complete deposition of the radioactive products from a nuclear explosion.

9.15 For example, if an individual is exposed to a certain amount of gamma radiation, e.g., from fallout, during the interval from 2 hours to 14 hours after the explosion, the percentage of the infinity dose received may be obtained by subtracting the respective values in Table 9.14, i.e., 77 (for 14 hours) minus 64 (for 2 hours), giving 13 percent of the infinity dose. The actual value of the infinity dose computed from 1 minute after detonation is 9.25 times the 1-hour reference dose rate (in roentgens per hour), as shown in Fig. 9.12, labelled: t=∞ (I(F)). Hence, if this reference dose rate is known

Table 9.14

PERCENTAGES OF INFINITY RESIDUAL RADIATION DOSE RECEIVED UP TO VARIOUS TIMES AFTER EXPLOSION

Time (hours)	Percent of Infinity Dose
1	57
2	64
4	68
6	73
12	77
24	80
36	83
48	84
72	87
100	88
200	91
500	93
1000	95
2000	97
5000	99

(or can be evaluated), the dose received during any period of time can be calculated from Table 9.14, instead of by using the dose rate multipliers of Fig. 9.12(a).

9.16 With the aid of Figs. 9.8 and 9.12(a) (or the equivalent Tables 9.11 and 9.14) many different types of calculations relating to radiation dose rates and total doses received from radioactive products from land surface detonations can be made. If only rough approximations are necessary, the procedures can be simplified by means of special charts based on the $t^{-1.2}$ decay portions of Figs. 9.8 and 9.12, shown later as Figs. 12.106, 12.107 and 12.108).

9.17 It is essential to understand that the tables and figures given above, and the calculations of radiation dose rates and doses in which they are used, are based on the assumption that an individual is exposed to a certain quantity of gamma radiation and remains exposed continuously (without protection) to this same quantity for a period of time. In an actual fallout situation, however, these conditions would probably not exist. For one thing, any shelter which attenuates the radiation will reduce the exposure dose rate (and dose) as given by the calculations. Further, the action of wind and weather will generally tend to disperse the fallout particles. As a result there may be a decrease (or increase) in the amount of activity at a given location and thus a decrease (or increase) in the radiation dose rate and dose.

TECHNICAL ASPECTS OF RESIDUAL NUCLEAR RADIATION

9.110 Because of the large number of radioactive fission products present in the mixture, a mathematical expression of their gross decay in terms of individual half-lives is impractical. However, knowledge of the individual decay rates and estimates of the independent fission yields have been utilized to compute the gross decay of the mixture in disintegrations per unit time for a given number of fissions. The results of such a calculation for thermal neutron fission of U^{235} are given in Table 9.110. The disintegration rates include the liberation of a beta particle for each beta emitting radionuclide plus those radionuclides that are delayed gamma emitters (isomeric transitions). The latter are relatively few in number. The gamma ray photons emitted from the mixture average about 1 photon per disintegration from 1 hour after fission to about 3 weeks after fission. As time increases, the number decreases until it reaches about 0.2 photons per disintegration at 2 years (see Table 9.111).

9.111 In considering the radiation dose (or dose rate) due to radioactive decay of fission products, e.g., in fallout, the gamma rays, because of their long range and penetrating power, are of greater

Table 9.110

ACTIVITIES* IN d/sec OF TOTAL FISSION PRODUCT MIXTURE AFTER SLOW NEUTRON FISSION OF 10,000 ATOMS OF U^{235}

Time	d/sec	Time	d/sec	Time	d/sec
0s	2439	1.12h	1.071	1.20y	(4)1674
1s	1982	1.64h	0.6843	1.78y	(5)984
2s	1641	2.40h	0.4352	2.60y	(5)605
3s	1376	3.52h	0.2819	3.80y	(5)372
4s	1171	5.16h	0.1846	5.58y	(5)248
6s	878.9	7.56h	0.1231	8.18y	(5)1913
9s	614.0	11.1h	0.08162	12.0y	(5)1508
13s	417.4	16.2h	0.05258	17.6y	(5)1189
19s	266.0	23.8h	0.03269	25.7y	(6)9080
28s	162.3			37.7y	(6)6454
41s	99.21	1.45d	0.02011	55.3y	(6)4087
60s	62.26	2.13d	0.01217	81.0y	(6)2193
		3.12d	(2)7315	119y	(7)954
1.47m	40.89	4.57d	(2)4781	174y	(7)308
2.15m	27.75	6.70d	(2)3230	255y	(8)717
3.15m	19.10	9.82d	(2)2217	374y	(8)111
4.62m	13.07	14.4d	(2)1520	548y	(9)188
6.77m	9.022	21.1d	(2)1027	803y	(10)91
9.92m	6.282	30.9d	(3)6818	1177y	(10)81
14.5m	4.495	45.3d	(3)4457	Plateau	(10)81
21.3m	3.255	66.4d	(3)2859		
31.2m	2.336	97.3d	(3)1836		
45.8m	1.618	143d	(3)1117		
		20	(4)6139		
		30.	(4)3193		

* After Glendenin, Coryell, and Edwards, NNES, IV Vol 9 Paper 52, McGraw-Hill, New York (1951)

significance than the beta particles, provided the radioactive material is not actually on the skin or within the body. Consequently, the beta radiation can be neglected in estimating the variation with time of the dose rate from the residual nuclear radiation. If the fraction of fission product disintegrations accompanied by gamma ray emission and the energy of the gamma ray photons remained essentially constant with time, the dose rate, e.g., in roentgens per hour, would be directly related to the rate of emission of gamma rays. As mentioned in para. 9.34, this is not the case. For the fission products only, the weighted mean energy of the gamma rays is about 0.92 Mev/photon at 1 hour after fission. The mean value decreases with time during the first and second day after fission and remains between 0.5 and 0.6 Mev/photon up to about 3 weeks after fission; it then gradually decreases to about 0.1 Mev/photon at 2 years (see Table 9.111). If the mixture contained neutron-induced activities, such as U^{239} - Np^{239} in large amount, the mean energy at early times would be much lower.

9.112 The gamma radiation dose rate, or more strictly, the air ionization rate in roentgens/hr from fallout depends upon the type of weapon and its yield, the environmental materials at the point of detonation, the wind speeds and directions from the ground to the top

Table 9.111

SUMMARY OF ACTIVITIES AS A FUNCTION OF TIME AFTER SLOW FISSION OF U^{235} (Per 10,000 Fissions)*

Time			dis/sec	Photons/dis	Mev/Photon	γ Mev/dis
Hours	Days	Years				
0.763	0.0318		1.618	1.19	0.915	1.09
1.12	0.0416		1.071	1.19	0.909	1.08
1.64	0.0683		0.684	1.17	0.884	1.03
2.40	0.100		0.435	1.13	0.839	0.948
3.52	0.1467		0.282	1.06	0.796	0.844
5.16	0.215		0.185	0.995	0.772	0.768
7.56	0.315		0.123	0.967	0.747	0.722
11.1	0.421		(1)816	0.971	0.723	0.702
16.2	0.675		(1)526	0.968	0.688	0.656
23.8	0.992		(1)327	1.01	0.614	0.620
34.9	1.455		(1)201	1.02	0.561	0.572
51.1	2.13		(1)122	1.04	0.515	0.535
74.9	3.12		(2)732	1.08	0.496	0.536
109.7	4.57		(2)478	1.09	0.492	0.536
160.9	6.70		(2)323	1.07	0.507	0.543
235.7	9.82		(2)222	1.03	0.524	0.540
345.7	14.4		(2)152	0.974	0.541	0.527
506	21.1		(2)103	0.904	0.561	0.507
742	30.9		(3)682	0.837	0.567	0.464
1087	45.3		(3)446	0.756	0.555	0.419
1570	66.4		(3)286	0.682	0.538	0.367
2336	97.3		(3)184	0.630	0.540	0.340
3432	143		(3)112	0.597	0.577	0.344
4990	208		(4)614	0.550	0.606	0.333
7225	301		(4)319	0.455	0.594	0.272

*From C.F. Miller, USNRDL-TR-187, p.4.

Table 9.111 (Cont.)

Time			dis/sec	Photons/dis	Mev/photon	γ Mev/dis
Hours	Days	Years				
	438	1.20	(4)167	0.323	0.497	0.160
	650	1.78	(5)984	0.229	0.380	0.0870
	949	2.60	(5)605	0.195	0.375	0.0731
	1387	3.80	(5)372	0.170	0.443	0.0753
	2037	5.58	(5)248	0.155	0.530	0.0822
	2987	8.18	(5)191	0.161	0.568	0.0915
	4380	12.0	(5)151	0.184	0.579	0.107
	6425	17.6	(5)119	0.208	0.581	0.121
	9380	25.7	(6)908	0.236	0.575	0.136
	13760	37.7	(6)645	0.267	0.568	0.152
	20180	55.3	(6)409	0.308	0.557	0.171
	29570	81.0	(6)219	0.362	0.549	0.199
	43430	119	(7)954	0.443	0.532	0.236
	63500	174	(7)308	0.529	0.492	0.260
	93100	255	(8)717	0.642	0.422	0.271
		374	(8)111	0.847	0.313	0.265
		548	(9)188	0.718	0.218	0.157
		808	(10)91	0.122	0.183	0.0243
		1177	(10)81	0.00391	0.183	0.000715

of the cloud, and the location relative to shot point. The kind and amount of induced activities, which enhance the dose rate of the fission products, depend upon the type of weapon detonated and the elements in the soil or target materials at the point of detonation. In the explosion, all the fission products are vaporized along with some of the target materials. In the condensation process that occurs as the fireball cools, the vapors are selectively condensed on soil or other particles that enter the fireball from below as it rises in the air. For land surface detonations where the particles consist of soil minerals, some of the fission products condense onto melted soil particles, some condense on the surface of soil particles, some condense on the surface of other solid particles, and some vapor-condense with other vaporized material. In this process of fallout particle formation, the original fission product mixture is altered. The altered mixture of activities is then said to be fractionated, that is, its composition is not the same as that of the original mixture of fission-product nuclides produced in the fission process. The larger particles that fall out of the fireball at early times and land nearest ground zero have radioactive compositions different from the smaller particles that leave the fireball or cloud at later times and land farther downwind.

9.113 For large yield detonations at sea where the particles consist of seawater salts and water, the fractionation is usually very small. In this case, the fireball must cool to 100°C or less before the evaporated water condenses. The low temperature and long time in cooling along with the presence of the small water drops permits a high degree of scavenging of the fission product elements including the daughter products of the rare gases. In this case, little or no variation in the radioactive fallout composition with distance occurs.

9.114. The decay data given in curve I(F) of Fig. 9.8 and Table 9.114 are representative of that expected some distance downwind from a land surface detonation in the MT yield range. The decay data, I(U), also given in Table 9.114 is representative of that from a seawater surface detonation in the MT yield range. Data for $t^{-1.2}$ decay is included for comparison. Although at times less than 12 minutes there is very little fallout on the ground (for bursts in the MT yield range) there is activity in the air and thus for certain applications (such as operation of aircraft) the I(F) and I(U) dose rate curves at early times are useful. If we compare the data with the $t^{-1.2}$ rule we note that: (1) The land surface burst, I(F) is nearer to the $t^{-1.2}$ approximation than is the water surface burst, I(U).

Table 9.114

DECAY SCHEMES FOR LAND SURFACE MT BURST AND WATER SURFACE MT BURST COMPARED WITH $t^{-1.2}$ DECAY SCHEME

Time		r/hr (relative)		
t(min)	t(hr)	I(1.2)	I(F)	I(U)
1	0.017	136,100	97,700	91,300
1.5	0.025	81,600	61,600	57,700
2	0.033	59,100	43,900	41,100
4	0.067	25,800	18,900	17,700
6	0.10	15,800	11,800	11,100
10	0.17	8,580	7,000	6,630
15	0.25	5,270	4,520	4,310
20	0.33	3,730	3,320	3,180
40	0.67	1,620	1,590	1,560
60	1.00	1,000	1,000	1,000
	2	436	381	404
	5	145	121	114
	10	63.1	57.4	52.5
	20	27.5	26.5	23.5
	50	9.14	10.2	7.58
	100	3.98	4.48	3.42
	200	1.73	1.63	1.42
	500	0.577	0.468	0.404
	1000	0.251	0.226	0.162
	2000	0.109	0.112	0.0604
	5000	0.0364	0.0337	0.0127
	10000	0.0158	0.00516	0.00248
	20000	0.00690	0.000371	0.000409

I(1.2) ~ -1.2 rule
I(F) ~ land surface burst, fractionated, MT yield range
I(U) ~ water surface burst, unfractionated, MT yield range

(2) In I(U) a rapid negative departure from the $t^{-1.2}$ rule occurs at about 500 hours (3 weeks). (3) In I(F) a rapid negative departure occurs after 5000 hours (30 weeks or 7 months). For calculations involving re-entry into cities, resumption of agricultural operations, decontamination of areas several months after time of burst, and so forth, these I(F) curves should be used. (4) Both I(U) and I(F) predict negligible hazards at around 10,000 hr. The calculations in Table 9.114 are based on the following criteria: (1) For the I(F) data, using 8 Mev neutrons (the mid point of the neutron energy distribution) fissioning U^{238}, there is a calculated dose rate at one hour of 1,480 r/hr per KT per square mile. Because of fractionation losses this value is much lower than the dose rate assuming the original composition of fission products falling on the ground (3600 r/hr). There is some induced activity due to Np^{239}, giving a dose rate of about 144 r/hr per KT per square mile at 1 hour. The total calculated dose rate at 1 hour is then, 1620 r/hr per KT per square mile.
(2) For the I(U) data, thermal U^{235} fission was used,* yielding a dose rate of 3,950 r/hr per KT per square mile at 1 hour (instead of 3600 r/hr for unfractionated U^{238} fission products). In this case, also, 140 r/hr per KT per square mile at 1 hour was added for the induced Np^{239} activity, yielding a total of 4090 r/hr per KT per square mile at 1 hour.

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*Miller and Loeb, USNRDL-TR-247.

9.115 The total dose for the 1000 r/hr at 1 hr (reference standard) dose rate can be obtained by integrating the decay curves of Fig. 9.8 graphically. The dose from 1 hour to any later time, divided by the reference standard dose rate is defined as the dose rate multiplier (DRM) and is given by:

$$\mathrm{DRM} = \frac{1}{I_o} \int_{t=1\,\mathrm{hr}}^{t_b} I dt$$

The dose between a time t_a and another time t_b for the reference dose rate, I_o, is then given by

$$\text{Total Dose} = \left[\mathrm{DRM}(t_b) - \mathrm{DRM}(t_a)\right] I_o = \int_{t_a}^{t_b} I dt \quad .$$

The dose rate multipliers for the decay curves I(F) and I(U) are given in Fig. 9.12(a) and Table 9.115.

9.116 Another application of Dose Rate Multipliers is to determine the length of time an individual can stay in a location contaminated by fission products without receiving more than a specified dose of radiation. In this case, the total dose is specified; t_a is the known time of entry into the contaminated area and t_b is the required time at (or before) which the exposed individual must leave. In order to solve this problem it is necessary to know the reference dose rate, I_1. This can be obtained if the dose rate, I_t, is measured

Table 9.115

DOSE RATE MULTIPLIERS FOR LAND SURFACE MT BURST AND WATER SURFACE MT BURST COMPARED WITH THOSE FOR $t^{-1.2}$ RELATION

Time, t (hours)	Dose Rate Multiplier		
	($t^{-1.2}$)	(F)	(U)
1	0	0	0
2	0.645	0.614	0.635
5	1.380	1.219	1.252
10	1.845	1.626	1.630
20	2.250	2.009	1.978
50	2.715	2.484	2.362
100	3.010	2.821	2.610
200	3.265	3.094	2.827
500	3.560	3.339	3.046
1000	3.745	3.499	3.174
2000	3.905	3.653	3.270
5000	4.090	3.848	3.368
10000	4.210	3.929	3.404
20000	4.310	3.945	3.413

$t^{-1.2}$ ~ -1.2 relation
F ~ land surface burst, fractionated, MT yield range
U ~ water surface burst, unfractionated, MT yield range

at any time, t, after the explosion, e.g., at the time of entry. The results can be expressed graphically as in Figs. 12.107 and 12.108 (based on $t^{-1.2}$ decay).

9.117 In principle, one could use this method to estimate the total dose received from fallout in a contaminated area, provided the whole of the fallout arrives in a very short time. Actually, the contaminated particles may descend for several hours, and without knowing the rate at which the fission products reach the ground, it is not possible to make a useful calculation. When the fallout has ceased, however, Figs. 12.106, 12.107 and 12.108 may be employed to make various rough estimates of radiation doses, provided one measurement of the dose rate is available.

POSSIBLE ADDITIONAL ERRATA

Sections 12.105, 12.106, 12.107, 12.108, 12.109, 12.110 and Figs. 12.106, 12.107, and 12.108 should be checked for revisions to bring them into line with Chapter 9 or at least make the statement on Figs. 12.106, 12.107, and 12.108 that since the calculations are based on the $t^{-1.2}$ decay rule, that they are approximate but roughly correct if used for times less than 5,000 hours.

Paragraph 9.19

The seventh line and following should be changed to read:

> "...not be in agreement with Figs. 9.8 and 9.12(a), the deviations from the basic dose rate decay curve, I(F), are not likely to be significant, except possibly soon after an explosion."

Paragraph 9.34

Delete footnote (bottom of p. 402)

Paragraph 9.119, Line 7

> "Using equation (9.110.1)" should be deleted and "Using values in Tables 9.110 and 9.111 for fission product and adding 140 r/hr for neptunium" should be substituted.

POSSIBLE ADDITIONAL ERRATA (Cont.)

Paragraph 9.119

Table 9.119 should be corrected to read:

	Megacuries
1 hr	470,000
1 day	13,000
1 week	1,200
1 month	280
1 year	9.0

Paragraph 9.120

Is the curve for 0.7 Mev applicable? Shouldn't another curve be drawn in Fig. 9.120, say at 0.92 Mev?

Paragraph 9.124

Again is the curve for 0.7 Mev in Fig. 9.124a applicable? Shouldn't there be a curve for .92 Mev?

Paragraph 1.50, Line 7

> "...can be roughly calculated by means of a fairly simple relation."