Technical Report **137**

DOSE ATTENUATION FACTORS FOR CONCRETE SLAB SHIELDS COVERED WITH FALLOUT AS A FUNCTION OF TIME AFTER FISSION

1 June 1961

U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

DOSE ATTENUATION FACTORS FOR CONCRETE SLAB SHIELDS COVERED WITH FALLOUT AS A FUNCTION OF TIME AFTER FISSION

Y-F011-05-329

Type C

by

L. K. Donovan, A. B. Chilton

OBJECT OF TASK

To improve existing knowledge of gamma and neutron-shielding properties of shelters, and where necessary, to verify experimentally the theoretical information developed in this field.

ABSTRACT

For radiation shielding, underground or buried fallout shelters have an important advantage over other types of shelters, because the attenuation of the radiation in such a shelter is primarily a function of the thickness of the material in the roof only.

This study was made to investigate the dose attenuation of fallout gamma radiation by various thicknesses of concrete roofs of buried fallout shelters as a function of time after a nuclear detonation. A spectrum of energies is used for the fallout source rather than a single average energy as has been done in previous studies. Dose attenuation factors are derived and presented as a function of the above parameters. The Office of Civil and Defense Mobilization recommends a two-week shelter-stay time in the event of a nuclear attack; therefore, also presented is an average dose attenuation factor for any fourteen-day stay time as a function of time of arrival of the fallout or of shelter-entry time, for various roof thicknesses.

INTRODUCTION

In this nuclear age, warfare and defense problems have become increasingly more scientific. A nuclear weapon explosion results in earth and bomb debris which is contaminated with radioactive fission products. This radioactive debris is known as residual radiation or fallout, and it constitutes a serious hazard to unsheltered personnel. It is necessary therefore to provide shelter from the harmful radiation.

Underground or buried shelters have a definite advantage over other types in resisting the effects of atomic weapons, especially fallout. The amount of protection received from an underground shelter is a function of the mass density of material in the shelter roof since the amount of radiation coming through the walls is negligible compared to that coming through the roof. This results in greater net protection than afforded by a surface shelter of equal cost.

If the size of the shelter is large, that is, not the small, single-family type, the roof can be approximated by an infinite concrete slab for acceptably precise mathematical determination of its shielding capabilities.

The purpose of this study is to investigate the dose attenuation factor for fallout gamma radiation as a function of time after detonation of a nuclear weapon for various thicknesses of infinite concrete slab shields. In addition, using the Office of Civil and Defense Mobilization criterion of a two-week stay time in fallout shelters, a factor has been calculated which will determine the dose received during that stay time as a function of the H + 1-hour dose rate, of the time of arrival of the fallout after detonation or of shelter entry time, and of the slab thickness of the shelter roof. An average dose attenuation factor for any fourteen-day shelter-stay time as a function of the above is also presented.

Previous work has been done by Chilton and Saunders[1] to determine the dose attenuation factor as a function of roof slab thickness by using an average energy of 1.0 mev for the fallout radiation. This study will to a great extent parallel the above work, but will use the gamma spectral data of Nelms and Cooper[2] for various times after fission to specify the energy of the fallout radiation.

PROBLEM CONSIDERATIONS

The geometrical situations investigated are shown in Figure 1. In Figure 1(a), it is assumed the fallout is evenly distributed on top of a smooth infinite plane surface. Two dose points, D_1 and D_2, are indicated. D_2 is the dose received at the standard 3-foot distance above a uniformly contaminated infinite plane. D_1 is the dose received at a vertical distance h beneath the contaminated plane with a varying thickness of material, t, in between the contaminated plane and the dose point D_1. In this study, concrete was the material considered, but earth could be used if the appropriate mass density equivalent is used.

It has been found that in the computation of the dose at D_1 the value of h does not greatly affect the result provided h is less than a mean free path in air and t is about 0.25 feet of concrete or greater. The area of interest in this study is for roof slabs with thicknesses equal to or greater than 0.25 feet; therefore, for convenience, h was arbitrarily chosen to be 3 feet. This choice was made so that when the same computation is made for $t = 0$, the dose calculated at D_1 would be numerically valid for the dose received at D_2.

A dose attenuation factor for the smooth plane case can now be defined as the ratio of the dose received in the open at a distance of 3 feet above a uniformly contaminated plane source to the dose received inside a buried shelter where the roof approximates a concrete slab shield. This smooth plane dose attenuation factor, AF_1, is equal to D_1/D_2.

In order to account for the roughness of terrain that would be encountered in practical cases, a method[3] suggested by the U. S. Naval Radiological Defense Laboratory in 1955 is used. As can be seen in Figure 1(b), the contamination is assumed to be uniformly distributed in the top one-half inch of soil under the infinite plane. The distance h is the vertical distance from the incremental segment of contamination to the dose-point D_3. The distance H is the distance from the top of the soil to dose-point D_3 and was assumed to be 3 feet in the calculation.

The dose attenuation factor for the rough-plane case, AF_2, is defined as D_1/D_3. (The concrete roof of the structure is not considered to be rough, even though the surrounding plane area of soil is so considered.)

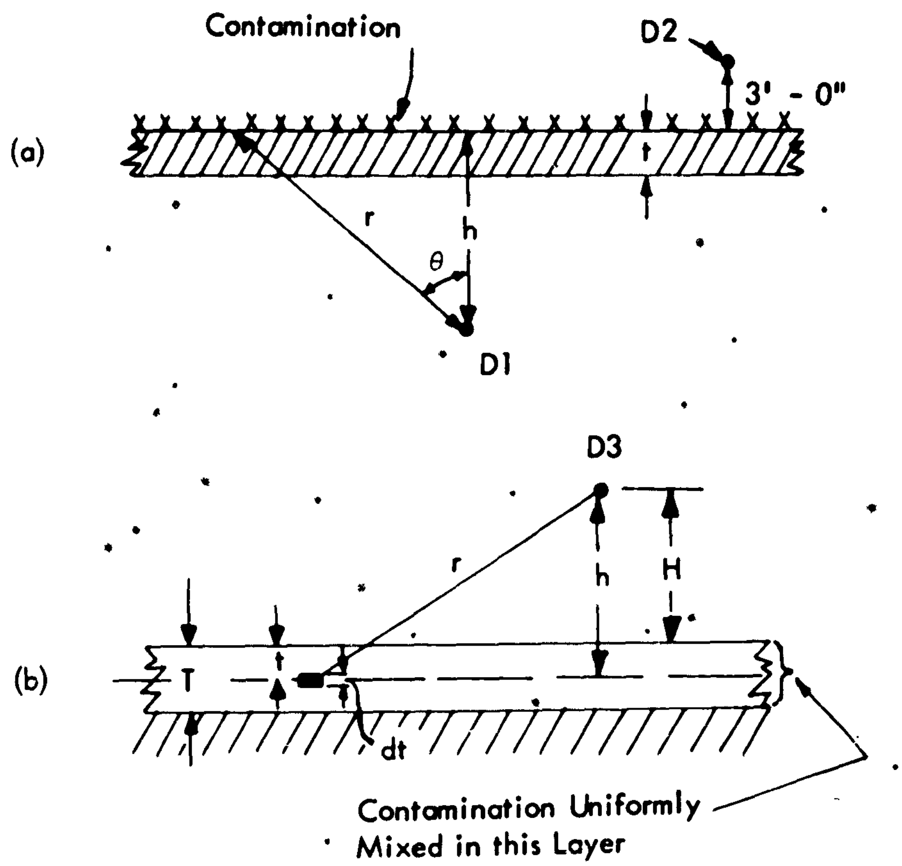


Figure 1. Geometric situations studied.

CALCULATIONS

The calculations used in this study for the doses at D_1, D_2, and D_3 are slight modifications of the calculations presented in the Chilton and Saunders study. Details of the derivations are presented in the Appendix. Only the three integrated dose equations used in the study will be presented here.

$$D_1 = \frac{K E_o \bar{\mu}_o}{2\rho} \left[-E_i(-\mu_1 h) + A_1 e^{-B_1 \mu_1 h} + A_2 e^{-B_2 \mu_1 h} \right] \quad (1)$$

$$D_2 = \frac{K E_o \bar{\mu}_o}{2\rho} \left[-E_i(-\mu_a h) + A_1 e^{-B_1 \mu_a h} + A_2 e^{-B_2 \mu_a h} \right] \quad (2)$$

$$D_3 = \frac{K E_o \bar{\mu}_o}{2\rho \mu_e T} \Bigg\{ \left[-E_i(-\mu_3 H)\, \mu_3 H \right] - \left[-E_i(-\mu_a H)\, \mu_a H - e^{-\mu_a H} + e^{-\mu_3 H} \right] + \frac{A_1}{B_1} \left[e^{-B_1 \mu_a H} - e^{-B_1 \mu_3 H} \right] + \frac{A_2}{B_2} \left[e^{-B_2 \mu_a H} - e^{-B_2 \mu_3 H} \right] \Bigg\} \quad (3)$$

where: $\mu_1 = \mu_a + \frac{t}{h}(\mu_c - \mu_a)$

$\mu_3 = \mu_a + \mu_e \frac{T}{H}$

K = Photons/sec for each energy group specified by Nelms and Cooper[2]

E_o = The mean energy of the energy group at which all other energy dependent properties are evaluated, mev

$\bar{\mu}_o$ = Linear energy absorption coefficient of air, cm^{-1}

ρ = Density of air, gm/cc

μ_a = Linear total absorption coefficient of air (12.06×10^{-4} gm/cc), cm^{-1}

μ_e = Linear total absorption coefficient of earth (1.442 gm/cc), cm^{-1}

μ_c = Linear total absorption coefficient of concrete (2.357 gm/cc), cm^{-1}

$-E_i(-\mu X)$ = Exponential integral of form $\int_{\mu X}^{\infty} \frac{e^{-t}}{t}\, dt$

A_1, B_1, A_2, B_2 = Build-up factor coefficients of Berger and Spencer.[4]

The build-up factor is defined as the ratio of some measurable property of the photon beam (i.e., intensity, number of photons, energy flux, or biological dose), when the effects of all quanta are included, to that obtained when only the uncollided flux is considered. Many analytical functions have been derived to describe the dose build-up factor for all photon energies. In this study a biological dose build-up factor of the following form (suggested by Berger and Spencer[4]) is used:

$$B_r = 1 + A_1 B_1 \mu r e^{-(B_1-1)\mu r} + A_2 B_2 \mu r e^{-(B_2-1)\mu r} \qquad (4)$$

where A_1, A_2, B_1, B_2 are dimensionless coefficients and μr is the number of mean free paths of material. The coefficients A_1, B_1, A_2, and B_2 allow the empirical dose build-up factors of Berger[4] to fit the dose build-up factor data of Goldstein and Wilkins[5] for aluminum. This is also considered reasonably valid for concrete and earth.

RESULTS

The doses from the above equations were calculated on an IBM-705 computer, using the spectral data of Nelms and Cooper,[2] the air linear energy absorption coefficients provided by Berger,[4] and the linear total absorption coefficient data of

Gladys W. Grodstein[6] for each energy group. The sum of the doses received from each of the energy groups represents the dose received through a particular thickness of slab shield. Fallout spectra for 1.12 hours, 5.15 hours, 23.8 hours, 2.13 days, 4.57 days, 9.82 days, 21.1 days, 45.3 days, 97.3 days, and 208 days after fission were investigated. Data for these spectra are tabulated by Nelms and Cooper.[2]

Figure 2 is a presentation of the dose attenuation factor AF_1 plotted as a function of concrete shield thickness for the 1.12-hour, 23.8-hour, 4.57-day, 21.1-day, and 208-day spectra. It can be noted that the attenuation of the 21.1-day spectrum is definitely less than that of the 23.8-hour spectrum. On the other hand, on the basis of data provided by Miller, based on a spectrum identical to Nelms and Cooper[2] and plotted in Figure 3, it can be seen that the average energy per photon from fission products at 23.8 hours is greater than at 21.1 days. If the mean energy per photon is a good estimation of the penetration power of the radiation, then it would be expected that the attenuation of the 23.8-hour fallout spectrum would be less than that of the later 21.1 day spectrum. It is shown in Figure 2 that the opposite is true. This anomaly is discussed in the next section.

Figure 4 shows the attenuation factor for the rough-plane case, AF_2, plotted against slab thickness for the same spectra as AF_1. It was found that the only difference between the AF_2 and AF_1 curves is that the attenuation for the rough-plane source is less by a factor of about 1.6 at all times.

Figure 5 shows the attenuation factor AF_1 plotted as a function of time after fission for various slab thicknesses. It can be seen that, as the shield thickens, the attenuation factor varies more radically with time. It can be noted that the second maximum reached at about 500 hours is never greater than the initial maximum at 1.12 hours, for any of the thicknesses specified. Thus, the 1.12 hour fallout spectrum, which has been used in many shielding calculations to represent the fallout spectra in general, is still a conservative basis for use.

It is desirable to define a factor F as a function of the time of arrival of fallout or the shelter entry time (if fallout has already arrived) for various slab thicknesses, so that the factor F when multiplied by the dose rate at H + 1 hour will give the dose received by sheltered personnel in a fourteen-day stay-time after the burst. This factor F is derived by integrating the attenuation factor multiplied by the $t^{-1.2}$ decay scheme over various fourteen-day periods. If time is measured in hours, it can be seen that the fourteen-day stay dose is given by:

$$(\text{Dose})_{14\ \text{days}} = D_o\, F(t_1, T) = D_o \int_{t_1}^{t_1 + 336} t^{-1.2}\, AF(t_1, T)\, dt \qquad (5)$$

where: D_o = H + 1 hour dose rate in the open [at reference point 2 in Figure 1(a)]

AF = Attenuation factor at time t for concrete roof thickness T [Note: $AF(t,0) = 1$]

t_1 = Time of arrival of fallout or start of 14-day stay-time if fallout has already arrived, hours

Figure 6 gives a plot of the factor F as a function of t_1. The factor does not vary in a simple mathematical way as a function of shelter entry time (t_1). This can be seen by the variation in the curves plotted for the 2- and 3-foot slab cases after about 40 hours.

An average attenuation factor can be plotted for any fourteen-day stay-time as a function of slab thickness and time of arrival of fallout or shelter-entry time. This average attenuation factor is determined by dividing the F factors for various slab thicknesses by the F factor for a 0.0-foot slab thickness at a particular time. The formula is:

$$AF_{ave} = \frac{\int_{t_1}^{t_1 + 336} t^{-1.2} \, AF(t,T) \, dt}{\int_{t_1}^{t_1 + 336} t^{-1.2} \, AF(t,0) \, dt} \qquad (6)$$

Figure 7 is a plot of AF_{ave} as a function of t_1 for various thicknesses of concrete roof shields. The dose that will be received in the open during any 14-day period after a nuclear explosion can be calculated by the following formula:

$$\text{Dose}(t_1)_{14\text{ days (open)}} = \frac{D_o}{0.2}\left[\frac{1}{t_1^{0.2}} - \frac{1}{(t_1 + 336)^{0.2}}\right] \qquad (7)$$

where D_o and t_1 are as defined before. The dose received inside the shelter for a 14-day stay-time would be:

$$\text{Dose}_{14\text{ days (inside)}} = \text{Dose}(t_1)_{14\text{ days (open)}} \, AF_{ave}(t_1, T) \qquad (8)$$

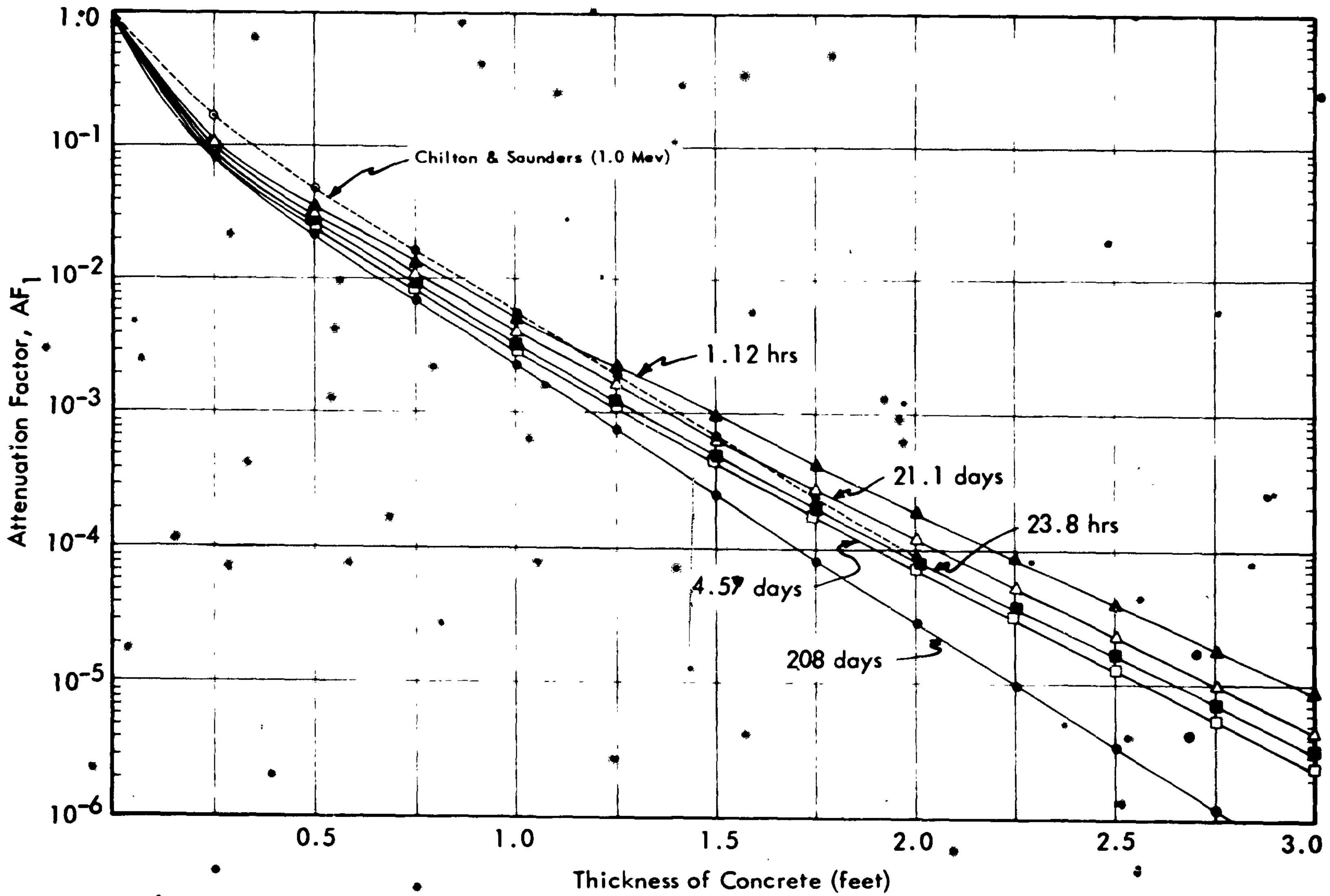


Figure 2. Attenuation factor versus concrete thickness for smooth isotropic plane source for various fission spectra.

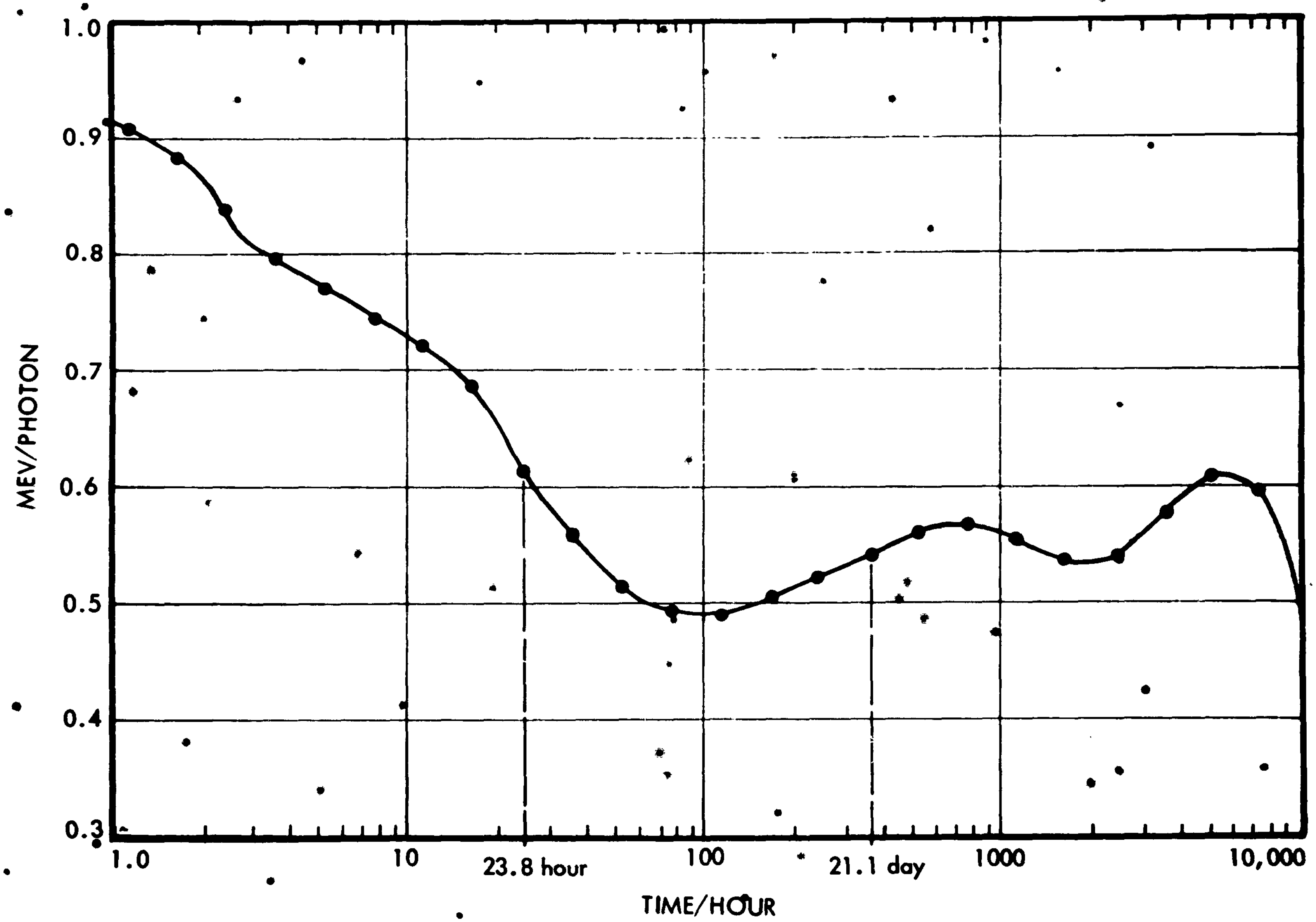


Figure 3. Mean energy per photon versus time after fission.

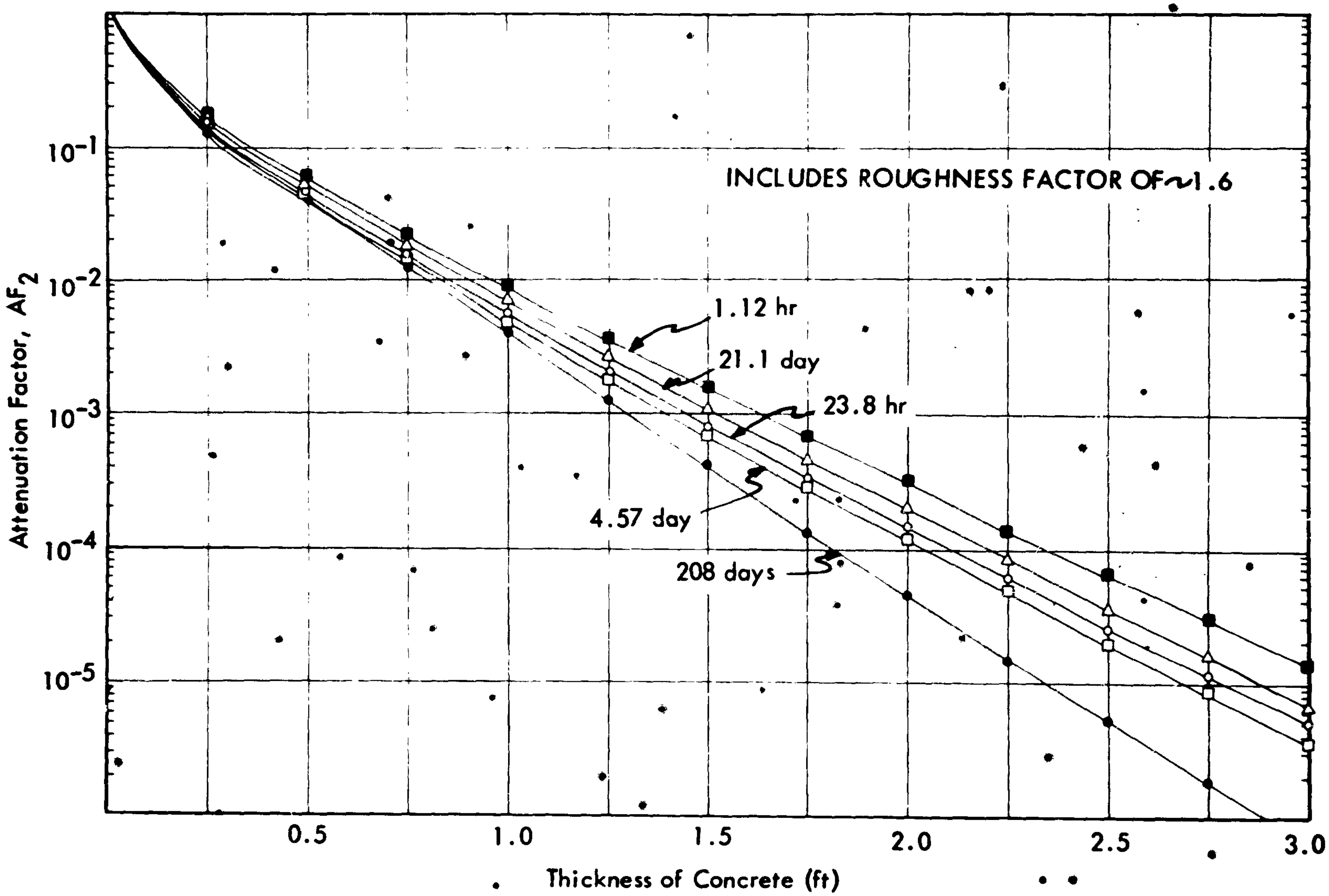


Figure 4. Attenuation factor versus concrete thickness for isotropic plane source of various fission spectra.

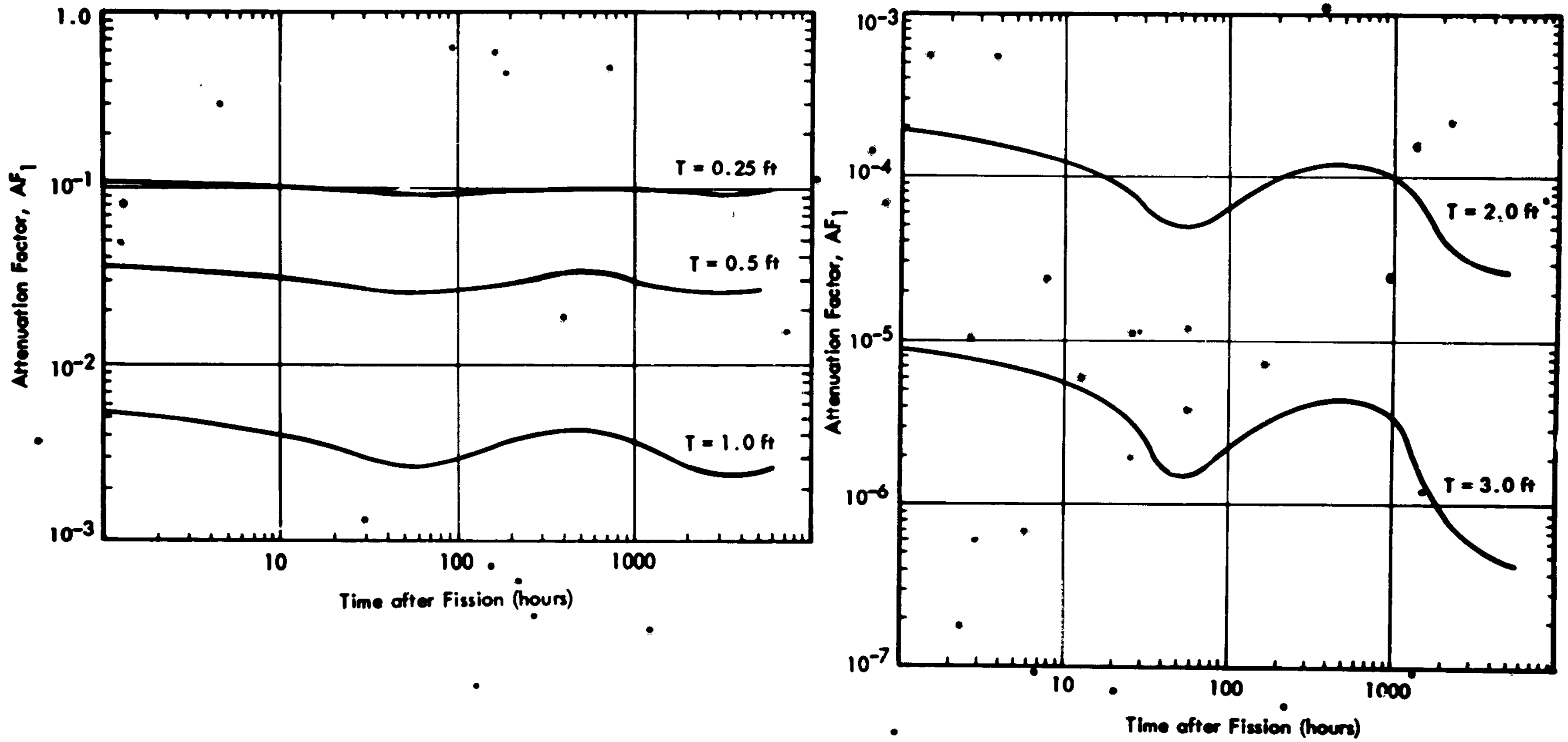
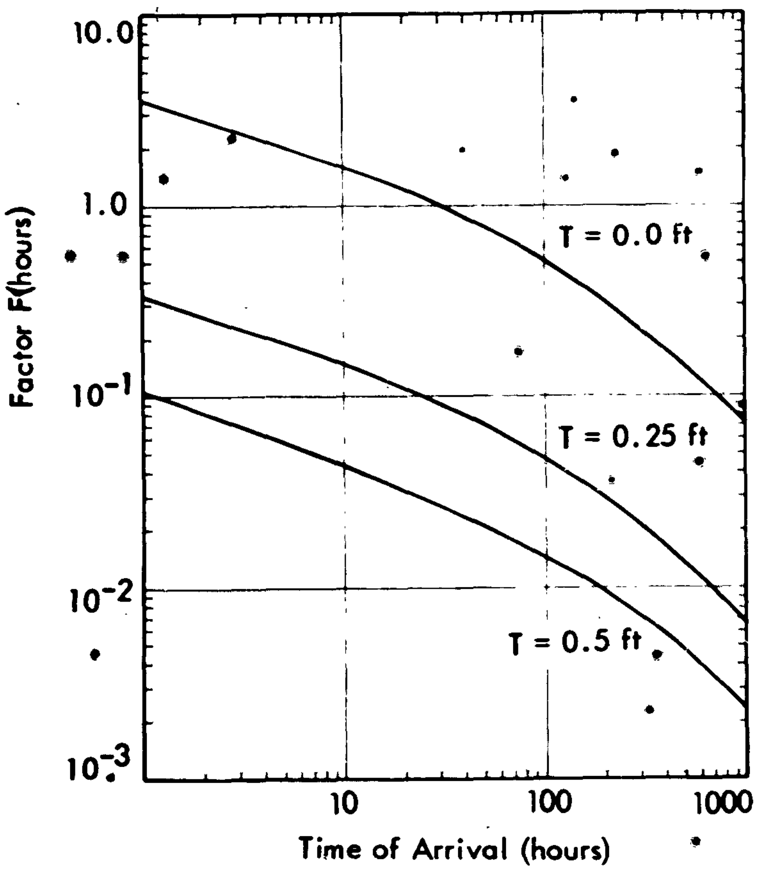


Figure 5. Attenuation factor versus time after fission for various thicknesses of concrete.



F x Dose Rate at H + 1 = Dose for 14 day stay time

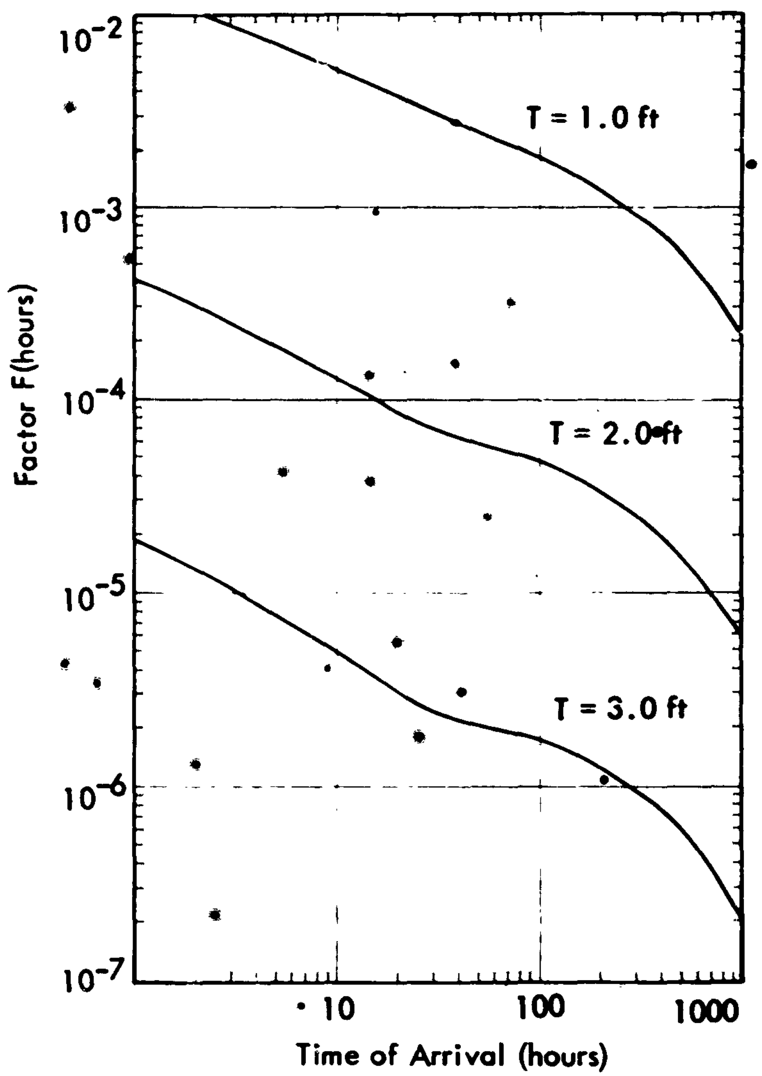


Figure 6. Factor F versus time of arrival of fallout for various thicknesses.

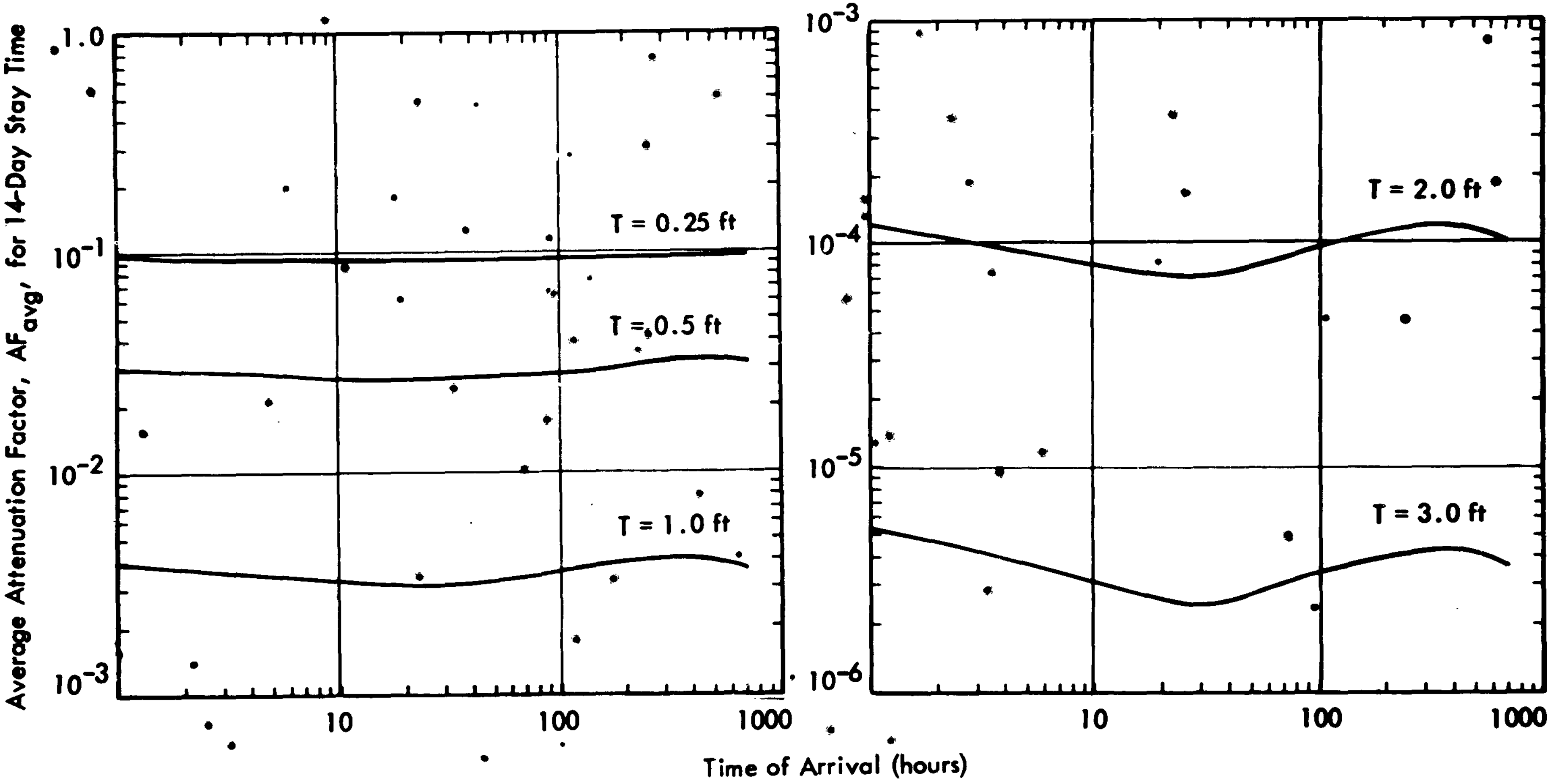


Figure 7. Average attenuation factor versus time of arrival of fallout for various concrete thicknesses.

DISCUSSION AND CONCLUSIONS

In Figure 2, the Chilton-Saunders results for 1-mev photons are plotted as a dotted line for comparison with the present results. It can be noted that the slope of the Chilton-Saunders curve closely follows that of the 208-day spectrum. This indicates that the 208-day fallout spectrum, after a few inches of concrete has filtered out the softer gamma rays, has penetration properties similar to monoenergetic gamma radiation with an energy of 1 mev. The 1.12-hour spectrum is obviously more penetrating than a 1-mev photon beam, after about the first foot of penetration.

As previously noted, the attenuation at 23.8 hours is greater than that at 21.1 days even though the mean energy per photon is greater at 23.8 hours. This is explained as follows: In the spectral dose calculations (Table I), it can be seen that the contribution of the spectrum to D_1 changes quite radically from 23.8 hours to 21.1 days. About 94.2 percent of the total contribution to D_1 for the 21.1-day spectrum came from radiation in the 1.47 - 2.95-mev initial energy range, while for the 23.8-hour spectrum, only 79.3 percent of the total dose comes from that same initial energy range and a greater contribution comes from photons of lower initial energies. Thus, even though the average energy of the photons may be greater for the 23.8-hour spectrum, the contribution to the dose shows a peak at a higher energy in the 21.1-day spectrum, which explains the lesser attenuation of the 21.1-day spectrum. After 21.1 days, the attenuation factor follows the expected path (Figure 5) but does not peak again around 208 days as would be expected from the Miller[7] data (Figure 3). This data indicates that the mean energy per photon is about the same at 208 days as it is for 23.8 hours. The explanation is similar to that given above.

In conclusion, it can be seen that at no initial entry time after 1.12 hours will a person in a shelter for fourteen days receive a greater dose than if fallout arrives at or before 1.12 hours after fission, and entry time is at 1.12 hours. This is obvious since there are no maxima greater than at 1.12 hours in the curves of Figure 7 for any of the thicknesses indicated.

If however an average attenuation factor for a particular fourteen-day stay-time is needed for accurately calculating the dose to be received, some care must be taken since the average attenuation factor may vary as much as a factor of two for stays commencing at some later time than 1.12 hours after fission.

Table I. Dose Contribution of Various Initial Energy Groups Through 2 Feet of Concrete for 23.8 Hours and 21.1 Days After Fission

	Percent Contribution to Total Dose			
Energy	23.8 Hour Spectrum Ref. 2		21.1 Day Spectrum Ref. 2	
0.0340	Negligible		Negligible	
0.0425	Negligible		Negligible	
0.0567	Negligible		Negligible	
0.0729	Negligible		Negligible	
0.1021	Negligible		Negligible	
0.1277	Negligible		Negligible	
0.1703	Negligible		Negligible	
0.2128	Negligible		Negligible	
0.2554	0.01		Negligible	
0.3193	0.01		0.02	
0.4257	Negligible		0.02	
0.5108	0.54		0.43	
0.6386	1.65		0.46	
0.8514	8.69		4.52	
0.0217	6.49		0.20	
1.2772	3.26		0.18	
1.7029	17.52		75.06	
2.0435	25.09	79.34	1.45	94.17
2.5545	36.73		17.66	

REFERENCES

1. Bureau of Yards and Docks, Technical Study No. 15, The Shielding Characteristics of Concrete Slab Roofs on Underground Shelters, by Arthur B. Chilton and L. N. Saunders. Washington, D. C., 11 September 1956.

2. National Bureau of Standards. Report No. 5853, U^{235} Fission Products Spectra of Various Times After Fission, by A. T. Nelms and J. W. Cooper. Washington, D. C., 11 April 1958.

3. U. S. Naval Radiological Defense Laboratory. TM-27, Gamma Radiations from Contaminated Planes and Slabs, by C. F. Ksanda, et al. San Francisco, 19 January 1955.

4. National Bureau of Standards. Technical Note No. 11, Penetration of Gamma Rays from Isotope Sources Through Aluminum and Concrete, by M. J. Berger and L. V. Spencer. Washington, D. C., 11 May 1959.

5. Atomic Energy Commission. NYO-3075, Calculations of the Penetrations of Gamma Rays, by H. Goldstein and J. E. Wilkins, Jr. New York, 1954.

6. National Bureau of Standards, Circ. 583, X-Ray Attenuation Coefficients from 10 Kev to 100 Mev, by G. W. Grodstein. Washington, D. C., 1957.

7. U. S. Naval Radiological Defense Laboratory. TR-187, Gamma Decay of Fission Products from the Slow Neutron Fission of U^{235}, by C. F. Miller. San Francisco, 11 July 1957.

Appendix

DERIVATION OF INTEGRATED DOSE EQUATIONS FOR A CONCRETE ROOF SLAB SHIELD COVERED WITH FALLOUT

CALCULATION OF THE DOSE RECEIVED AT D_1 [see Figure 1(a)]

The dose received at D_1 from an infinite contaminated smooth plane is:

$$D_1 = \frac{K\, E_o\, \bar{\mu}_o}{4\pi\rho} \int_{area} \frac{e^{-\mu_1 r}}{r^2} B_r\, dA \qquad (9)$$

where: K, E_o, $\bar{\mu}_o$ and ρ are as defined for Equation 1

B_r = Dose build-up factor

dA = An incremental area on the surface of the plane, cm^2

μ_1 = Effective linear absorption coefficient, cm^{-1}

It can be shown by similar triangles that $dA = 2\pi r dr$. Thus, Equation 7 becomes:

$$D_1 = \frac{K\, E_o\, \bar{\mu}_o}{2\rho} \int_{r=h}^{\infty} e^{-\mu_1 r} B_r \frac{dr}{r} \qquad (10)$$

The effective linear absorption coefficient, μ_1, takes into consideration the absorption of the air and the concrete slab. Therefore, $\mu_1 r$ can be expressed as:

$$\mu_1 r = \mu_a (h - t) \sec\theta + \mu_e t \sec\theta \qquad (11)$$

where μ_a and μ_e are as defined for Equation 1, and h, t, and θ as shown in Figure 1(a).

Since: $r = h \sec\theta$

then: $$\mu_1 = \mu_a + (\mu_e - \mu_a)\frac{t}{h} \qquad (12)$$

A dose build-up factor will be used as recommended by Berger and Spencer:[4]

$$B_r = 1 + A_1 B_1 \mu_1 r\, e^{-(B_1-1)\mu_1 r} + A_2 B_2 \mu_1 r\, e^{-(B_2-1)\mu_1 r} \qquad (13)$$

where: A_1, A_2, B_1, B_2 are dimensionless coefficients.

Substituting Equation 13 into Equation 10, we have:

$$\dot{D}_1 = \frac{K E_o \bar{\mu}_o}{2\rho} \left[\int_{r=h}^{\infty} e^{-\mu_1 r} \frac{dr}{r} + \int_{r=h}^{\infty} A_1 B_1 \mu_1 r\, e^{-B_1 \mu_1 r} \frac{dr}{r} + \int_{r=h}^{\infty} A_2 B_2 \mu_1 r\, e^{-B_2 \mu_1 r} \frac{dr}{r} \right] \qquad (14)$$

Looking at the first integral of Equation 14, it can be seen that it is in the form of the exponential integral.

$$\int_{r=h}^{\infty} e^{-\mu_1 r} \frac{d(\mu_1 r)}{\mu_1 r} = -E_i(-\mu_1 h) \qquad (15)$$

In computing the second integral

since: $$\frac{d}{dr}\left(A_1 e^{-B_1 \mu_1 r}\right) = A_1 e^{-B_1 \mu_1 r}(-B_1 \mu_1)$$

$$= -A_1 B_1 \mu_1 e^{-B_1 \mu_1 r}.$$

then: $$\int_{r=h}^{\infty} A_1 B_1 \mu_1 r e^{-B_1 \mu_1 r} \frac{dr}{r} = -A_1 e^{-B_1 \mu_1 r} \Big|_h^{\infty} = A_1 e^{-B_1 \mu_1 h} \quad (16)$$

Similarly for the third integral:

$$\int_{r=h}^{\infty} A_2 B_2 \mu_1 r e^{-B_2 \mu_1 r} \frac{dr}{r} = A_2 e^{-B_2 \mu_1 h} \quad (17)$$

Combining Equations 15, 16, and 17, we have:

$$D_1 = \frac{K E_o \bar{\mu}_o}{2\rho} \left[-E_i(-\mu_1 h) + A_1 e^{-B_1 \mu_1 h} + A_2 e^{-B_2 \mu_1 h} \right] \quad (1)$$

CALCULATION OF THE DOSE RECEIVED AT D_2

The equation for the dose received at D_2 is derived in the same way as dose D_1 except that only the absorption by the air need be considered. Thus $\mu_1 = \mu_a$. The standard 3-foot height above the contaminated plane was selected (see Figure 1), but is represented in the equation by h.

$$D_2 = \frac{K E_o \bar{\mu}_o}{2\rho} \left[-E_i(-\mu_a h) + A_1 e^{-B_1 \mu_a h} + A_2 e^{-B_2 \mu_a h} \right] \quad (2)$$

CALCULATION OF THE DOSE RECEIVED AT D_3

The dose at D_3 is due to the contamination mixed uniformly in a thin layer at the surface of the plane as shown in Figure 1(b). This method is used to approximate surface roughness. The general equation for the dose at D_3 is:

$$D_3 = \frac{K E_o \bar{\mu}_o}{4\pi\rho} \int_{t=0}^{T} \int_{area} B_r e^{-\mu_1 r} dA \frac{dt}{T} \quad (18)$$

where: K, E_o, $\bar{\mu}_o$, ρ, B_r, and dA are as defined previously

t, dt, and T are as shown in Figure 1(b)

μ_1 = An effective total linear absorption coefficient

From Figure 1(b), it can be seen that

$$H = h - t$$

$$r = h \sec\theta$$

If:

$$\mu_1 r = \mu_e t \sec\theta - \mu_a (h - t) \sec\theta,$$

then:

$$\mu_1 \doteq \mu_a + (\mu_e - \mu_a) \frac{t}{h} \tag{19}$$

where: μ_e and μ_a are as defined for Equation 3

θ = Angle between r and h

Since: dA = $2\pi r\, dr$, Equation 18 becomes

$$D_3 = \frac{K E_o \bar{\mu}_o}{2 \rho T} \int_{t=0}^{T} \int_{r=h}^{\infty} B_r e^{-\mu_1 r} \frac{dr}{r} dt \tag{20}$$

Using the build-up factor, Equation 13, and substituting into Equation 20, gives:

$$D_3 = \frac{K E_o \bar{\mu}_o}{2 \rho T} \left[\int_{t=0}^{T} \int_{r=h}^{\infty} e^{-\mu_1 r} \frac{dr}{r} dt + \int_{t=0}^{T} \int_{r=h}^{\infty} A_1 B_1 \mu_1 r\, e^{-B_1 \mu_1 r} \frac{dr}{r} dt + \int_{t=0}^{T} \int_{r=h}^{\infty} A_2 B_2 \mu_1 r\, e^{-B_2 \mu_1 r} \frac{dr}{r} dt \right] \tag{21}$$

Computation of the first integral:

$$\int_{t=0}^{T} \int_{r=h}^{\infty} e^{-\mu_1 r} \frac{dr}{r} dt = \int_{t=0}^{T} -E_i(-\mu_1 h)\, dt \qquad (22)$$

Using integration by parts of the form: $\int u\, dv = uv - \int v\, du$

$$\int_{t=0}^{T} -E_i(-\mu_1 h)\, dt = \left[-E_i(-\mu_1 h)\ t \right]_0^T + \int_{t=0}^{T} t \frac{d}{dt}\left[E_i(-\mu_1 h)\right] dt \quad (23)$$

But:

$$\mu_1 h = \mu_a H + \mu_e t$$

$$\frac{d}{dt}(\mu_1 h) = \mu_e$$

$$d(\mu_1 h) = \mu_e\, dt$$

$$dt = \frac{d(\mu_1 h)}{\mu_e}$$

Also when:

$$t = 0, \quad \mu_1 h = \mu_a H$$

$$t = T, \quad \mu_1 h = \mu_a H + \mu_e T$$

Since:

$$E_i(-\mu_1 h) = \int \frac{e^{-\mu_1 h}}{(-\mu_1 h)} d(-\mu_1 h)$$

$$\frac{d}{dt}\left[E_i(-\mu_1 h)\right] = \frac{d\,[E_i(\mu_1 h)]}{d(-\mu_1 h)} \frac{d}{dt}(-\mu_1 h)$$

$$\frac{d}{dt}\left[E_i(-\mu_1 h)\right] = \frac{-e^{-\mu_1 h}}{\mu_1 h}(-\mu_e) = \frac{\mu_e}{\mu_1 h} e^{-\mu_1 h} \tag{24}$$

therefore: $$\int_{t=0}^{T} -E_i(-\mu_1 h)\,dt = -E_i(-\mu_a H - \mu_e T)\,T + \int_0^T \frac{\mu_e t}{\mu_1 h} e^{-\mu_1 h}\,dt$$

$$\int_{t=0}^{T} -E_i(-\mu_1 h)\,dt = -E_i(-\mu_a H - \mu_e T)\,T + \int_0^T e^{-\mu_1 h}\,dt - \int_0^T \frac{\mu_a H}{\mu_1 h} e^{-\mu_1 h}\,dt$$

$$= -E_i(-\mu_a H - \mu_e T)\,T + \frac{1}{\mu_e}\int_{\mu_a H}^{\mu_a H + \mu_e T} e^{-\mu_1 h}\,d(\mu_1 h)$$

$$- \frac{\mu_a H}{\mu_e}\int_{\mu_a H}^{\mu_a H + \mu_e T} \frac{e^{-\mu_1 h}}{\mu_1 h}\,d(\mu_1 h)$$

$$= \left[-E_i(-\mu_a H - \mu_e T)\,T\right] - \frac{1}{\mu_e}\left[e^{-\mu_1 h}\right]_{\mu_a H}^{\mu_a H + \mu_e T}$$

$$- \frac{\mu_a H}{\mu_e}\left[E_i(-\mu_1 h)\right]_{\mu_a H}^{\mu_a H + \mu_e T}$$

$$= \left[-E_i(-\mu_a H - \mu_e T)\,T\right] - \frac{1}{\mu_e} e^{-\mu_a H - \mu_e T} + \frac{1}{\mu_e} e^{-\mu_a H}$$

$$- \frac{\mu_a H}{\mu_e}\left[E_i(-\mu_a H - \mu_e T)\right] + \frac{\mu_a H}{\mu_e}\left[E_i(-\mu_a H)\right]. \tag{25}$$

To simplify, let $\mu_3 H = \mu_a H + \mu_e T$; and since $T = (\mu_3 H - \mu_a H)/\mu_e$, Equation 25 becomes:

$$\int_{t=0}^{T} -E_i(-\mu_1 h)\, dt = \frac{1}{\mu_e} \left\{ -E_i(-\mu_3 H)\, \mu_3 H \right.$$

$$\left. - \left[-E_i(-\mu_a H)\, \mu_a H - e^{-\mu_a H} + e^{-\mu_3 H} \right] \right\} \quad (26)$$

Computation of the second integral:

$$\int_{t=0}^{T} \int_{r=h}^{\infty} A_1 B_1 \mu_1 r\, e^{-B_1 \mu_1 r} \frac{dr}{r}\, dt = \int_{t=0}^{T} A_1 e^{-B_1 \mu_1 h}\, dt \quad (27)$$

But: $\mu_1 h = \mu_a H + \mu_e T$

$$\int_{t=0}^{T} A_1 e^{-B_1 \mu_1 h}\, dt = \int_{t=0}^{T} A_1 e^{-B_1(\mu_a H + \mu_e t)}\, dt$$

$$= A_1 e^{-B_1 \mu_a h} \int_{t=0}^{T} e^{-B_1 \mu_e t}\, dt$$

$$= A_1 e^{-B_1 \mu_a H} \left[- \frac{e^{-B_1 \mu_e t}}{B_1 \mu_e} \right|_0^T$$

$$= \frac{A_1}{B_1 \mu_e} e^{-B_1 \mu_a H} \left[1 - e^{-B_1 \mu_e T} \right] \quad (28)$$

Since $T = \mu_3 H - \mu_a H/\mu_e$, then Equation 28 becomes:

$$\int_{t=0}^{T} A_1 e^{-B_1 \mu_1 h} dt = \frac{A_1}{\mu_e B_1} \left(e^{-B_1 \mu_a H} - e^{-B_1 \mu_3 H} \right) \qquad (29)$$

Computation of the third integral:

$$\int_{t=0}^{T} \int_{r=h}^{\infty} A_2 B_2 \mu_1 r\, e^{-B_2 \mu_1 r} \frac{dr}{r} dt = \frac{A_2}{\mu_e B_2} \left(e^{-B_2 \mu_a H} - e^{-B_2 \mu_3 H} \right) \qquad (30)$$

Combining Equations 26, 29, and 30, we have as the solution to Equation 18:

$$D_3 = \frac{K E_o \bar{\mu}_o}{2 \rho \mu_e T} \Bigg(-E_i(-\mu_3 H)\, \mu_3 H$$

$$- \left[-E_i(-\mu_a H)\, \mu_a H - e^{-\mu_a H} + e^{-\mu_3 H} \right]$$

$$+ \frac{A_1}{B_1} \left[e^{-B_1 \mu_a H} - e^{-B_1 \mu_3 H} \right]$$

$$+ \frac{A_2}{B_2} \left[e^{-B_2 \mu_a H} - e^{-B_2 \mu_3 H} \right] \Bigg) \qquad (3)$$

DISTRIBUTION LIST

No. of Copies	SNDL Code	
10		Chief, Bureau of Yards and Docks
		<u>BuDocks Standard Distribution</u>
1	23A	Naval Forces Commanders (Taiwan Only)
2	39B	Construction Battalions
9	39D	Mobile Construction Battalions
3	39E	Amphibious Construction Battalions
2	39F	Construction Battalion Base Units
1	A2A	Chief of Naval Research - Only
2	A3	Chief of Naval Operations (Op-07, Op-04)
5	A5	Bureaus
3	B3	Colleges
2	F4	Laboratory ONR (Washington, D. C. Only)
1	E16	Training Device Center
8	F9	Station - CNO (Boston; Key West; New Orleans; San Juan; Long Beach; San Diego; Treasure Island; and Rodman, C. Z. Only)
5	F17	Communication Station (San Juan; San Francisco; Pearl Harbor; Adak, Alaska; and Guam only)
1	F21	Administration Command and Unit CNO (Saipan only)
2	F40	Communication Facility (Pt. Lyautey and Japan only)
1	F41	Security Station
2	F42	Radio Station (Oso and Cheltanham only)
2	F48	Security Group Activities (Winter Harbor only)
8	H3	Hospital (Chelsea; St. Albans; Portsmouth, Va; Beaufort; Great Lakes; San Diego; Oakland; and Camp Pendleton only)
1	H6	Medical Center
2	J1	Administration Command and Unit-BuPers (Great Lakes and San Diego only)
1	J3	U. S. Fleet Anti-Air Warfare Training Center (Virginia Beach only)
2	J4	Amphibious Bases
1	J19	Receiving Station (Brooklyn only)
1	J34	Station - BuPers (Washington, D. C. only)
1	J37	Training Center (Bainbridge only)
1	J46	Personnel Center
1	J48	Construction Training Unit
1	J60	School Academy

Distribution List (Cont'd)

No. of copies	SNDL Code	
1	J65	School CEC Officers
1	J84	School Postgraduate
1	J90	School Supply Corps
1	J95	School War College
1	J99	Communication Training Center
11	L1	Shipyards
4	L7	Laboratory - BuShips (New London; Panama City; Carderock; and Annapolis only)
5	L26	Naval Facilities - BuShips (Antigua; Turks Island; Barbados; San Salvador; and Eleuthera only)
1	L30	Submarine Base (Groton, Conn. only)
2	L32	Naval Support Activities (London & Naples only)
2	L42	Fleet Activities - BuShips
4	M27	Supply Center
7	M28	Supply Depot (Except Guantanamo Bay; Subic Bay; and Yokosuka)
2	M61	Aviation Supply Office
3	N1	BuDocks Director, Overseas Division
42	N2	Public Works Offices
7	N5	Construction Battalion Center
5	N6	Construction Officer-in-Charge
1	N7	Construction Resident-Officer-in-Charge
12	N9	Public Works Center
1	N14	Housing Activity
2	R9	Recruit Depots
2	R10	Supply Installations (Albany and Barstow only)
1	R20	Marine Corps Schools, Quantico
3	R64	Marine Corps Base
1	R66	Marine Corps Camp Detachment (Tengan only)
7	W1A1	Air Station
35	W1A2	Air Station
9	W1B	Air Station Auxiliary
4	W1C	Air Facility (Phoenix; Monterey; Oppama; Naha; and Naples only)
3	W1E	Marine Corps Air Station (Except Quantico)
1	W1F	Marine Corps Auxiliary Air Station
8	W1H	Station - BuWeps (Except Rota).

Distribution List (Cont'd)

No. of copies	
1	Chief of Staff, U. S. Army, Chief of Research and Development, Department of the Army, Washington 25, D. C.
1	Office of the Chief of Engineers, Asst. Chief of Engineering for Civil Works, Department of the Army, Washington 25, D. C.
1	Chief of Engineers, Department of the Army, Attn: Engineering R & D Division, Washington 25, D. C.
1	Commanding Officer, Engineering R & D Laboratories, Attn: Technical Intelligence Branch, Fort Belvoir, Virginia
1	Commanding General, Wright Air Development Center, Air Research and Development Command, Wright-Patterson Air Force Base, Ohio
1	Deputy Chief of Staff, Development, Director of Research and Development, Department of the Air Force, Washington
1	President, Marine Corps Equipment Board, Marine Corps Schools, Quantico, Virginia
1	Director, National Bureau of Standards, Department of Commerce, Connecticut Avenue, Washington, D. C.
10	Armed Services Technical Information Agency, Arlington Hall Station, Arlington 12, Virginia
1	Deputy Chief of Staff, Research and Development Headquarters, U. S. Marine Corps
3	Headquarters, USAF, Directorate of Civil Engineering, Attn: AFOCE-ES, Washington 25, D. C.
2	Commander, Headquarters, Air Research and Development Command, Andrews Air Force Base, Washington 25, D. C.
2	Office of the Director, U. S. Coast and Geodetic Survey, Washington 25, D. C.
2	Library of Congress, Washington 25, D. C.
10	Director, Office of Technical Services, Department of Commerce, Washington 25, D. C.
	NCEL Standard Distribution
2	Director of Defense Research and Engineering, Department of Defense, Washington 25, D. C.
2	Director, Division of Plans and Policies, Headquarters, U. S. Marine Corps, Washington 25, D. C.
2	Director, Bureau of Reclamation, Washington 25, D. C.
2	Commanding Officer, U. S. Naval Construction Battalion Center, Attn: Technical Division, Code 141, Port Hueneme, California
2	Commanding Officer, U. S. Naval Construction Battalion Center, Attn: Materiel Department, Code 142, Port Hueneme, California
1	Commanding Officer (Patent Dept.), Office of Naval Research Branch Office, 1030 E. Green Street, Pasadena, California
1	**Commanding Officer, Yards and Docks Supply Office, U. S. Naval Construction Battalion Center, Port Hueneme, Calif.**

Distribution List (Cont'd)

No. of copies	
	NCEL Supplemental Distribution
1	Commandant, Industrial College of the Armed Forces, Washington, D. C.
1	Commandant, U. S. Armed Forces Staff College, U. S. Naval Base, Norfolk, Va.
1	Chief, Bureau of Ships, Attn: Chief of Research and Development Division, Navy Department, Washington, D. C.
1	Officer in Charge, U. S. Naval Biological Laboratory, Naval Supply Center, Oakland, Calif.
1	Officer in Charge, U. S. Navy Unit, Rennsselaer Polytechnic Institute, Troy, N. Y.
1	Chief, Bureau of Medicine and Surgery, Attn: Research Division, Navy Department, Washington, D. C.
1	Chief, Bureau of Naval Weapons, Attn: Research Division, Navy Department, Washington, D. C.
1	Commander, Pacific Missile Range, Attn: Technical Director, Point Mugu, Calif.
1	Commander, Norfolk Naval Shipyard, Attn: Chemical Laboratory, Portsmouth, Va.
1	Commander, U. S. Naval Shipyard, Attn: Materials and Chemical Lab., Boston, Mass.
1	Commander, U. S. Naval Shipyard, Attn: Material Laboratory, Brooklyn, N. Y.
1	Office of Naval Research, Branch Office, Navy No. 100, Box 39, FPO, New York
1	Commanding Officer, Naval Electronics Laboratory, Attn. Technical Director, San Diego
1	Commanding Officer, U. S. Naval Unit, U. S. Army Chemical Corps School, Fort McClellan, Ala.
1	U. S. Naval Research Laboratory, Chemistry Division, Washington, D. C.
1	Deputy Chief of Staff, Research & Development Headquarters, U. S. Marine Corps, Washington, D. C.
1	Deputy CCMLO for Scientific Activities, Washington, D. C.
1	U. S. Army, Attn: Director of Research and Development Group, Washington, D. C.
1	Commanding Officer, Signal Corps Engineering Labs, Fort Monmouth, N. J.
1	President, Chemical Warfare Board, Army Chemical Center, Md.
1	U. S. Army Corps of Engineers, Office of the District Engineer, St. Paul District, 1217 U.S.P.O. and Customs House, St. Paul, Minn.
1	Chief, Concrete Division, Waterways Experiment Station, P. O. Drawer 2131, Jackson, Miss.
1	Taft Sanitary Engineering Center USPHS, 4676 Columbia Parkway, Cincinnati, Ohio
1	Air Force Cambridge Research Center, Hanscom Field, Bedford, Mass.
1	Commander, Air Research & Development Command, Attn: Library, Andrews Air Force Base, Washington, D. C.
1	Directorate of Research, Air Force Special Weapons Center, Kirtland Air Force Base, N. M.
1	Sandia Corporation, Attn: Classified Document Division, Box 5800, Albuquerque, N. M.
1	Chief, Physical Research Branch, Research Division, U. S. Department of Commerce, Bureau of Public Roads, Washington, D. C.
1	Operation Civil, University of California, Richmond Field Station, Berkeley, Calif.
1	Texas Instruments, Inc., 6000 Lemmon Avenue, Dallas, Tex.
1	Library, Engineering Department, Stanford University, Stanford, Calif.
1	Library, Harvard University, Graduate School of Engineering, Cambridge, Mass.

Distribution List (Cont'd)

No. of copies	
1	Library, Engineering Department, University of California, 405 Hilgard Avenue, Los Angeles
1	Library, California Institute of Technology, Pasadena, Calif.
1	Mr. Fred Sauer, Physics Department, Stanford Research Institute, Menlo Park, Calif.
1	Dr. Harold Brode, RAND Corporation, 1700 Main Street, Santa Monica, Calif.
1	Dr. Robert V. Whitman, Massachusetts Institute of Tech., Cambridge, Mass.
1	Dr. T. H. Schiffman, Armour Research Foundation of Illinois Institute of Technology, Technology Center, Chicago, Ill.
1	Chief of Engineers, Department of the Army, Washington, D. C.
1	Commander, Air Force Ballistic Missile Division, Air Research and Development Command, Attn: Dr. George Young, Post Office Box 262, Inglewood, Calif.
1	Mr. J. O'Sullivan, The Mitre Corporation, P. O. Box 208, Lexington, Mass.
1	Dr. Lewis V. Spencer, National Bureau of Standards, Washington, D. C.
1	Mr. John Auxier, Oak Ridge National Laboratory, Oak Ridge, Tenn.
1	Dr. James O. Buchanan, Office of Civil and Defense Mobilization, Battle Creek, Mich.
1	Mr. Charles M. Eisenhauer, Radiation Physics Laboratory, National Bureau of Standards, Washington, D. C.
1	Mr. Jack C. Greene, Office of Civil and Defense Mobilization, Battle Creek, Mich.
1	Mrs. Shea L. Kruegel, CRTZS, Cambridge Research Center, Bedford, Mass.
1	Maj. F. W. Verser, Jr., U. S. A., Defense Atomic Support Agency, Washington, D. C.
1	Colonel G. D. Rich, Department Assistant and Director, Chemistry, Biology, Radiation Defense, Battle Creek, Mich.
1	Dr. Ronald Shephard, University of California, Engineering Field Station, 1301 South 46th Street, Richmond, Calif.
1	Mr. L. Neal FitzSimons, Office of Civil and Defense Mobilization, Winder Building, Washington, D. C.
1	Dr. William Kreger, U. S. Naval Radiological Defense Laboratory, San Francisco
1	Mr. Richard Park, National Academy of Sciences, 2101 Constitution Avenue, Washington, D. C.
1	Mr. E. E. Shalowitz, Protective Construction, GSA Building, 19th and F Street, N. W., Washington, D. C.
1	Lt. Col. Russell J. Hutchinson, 052921, Office of Area Engineer, Saudi Arabia, U. S. A. Engineer District, Trans-East, APO 616, New York
1	Capt A. B. Chilton, CEC, USN, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.
1	Cdr. C. A. Grubb, CEC, USN, Public Works Center, Navy No. 128, FPO, San Francisco
1	Capt W. M. McLellon , CEC, USN, Public Works Office, U. S. Naval Base, Charleston, S. C.
1	Capt L. N. Saunders, Jr., CEC, USN, Bureau of Yards and Docks, Code D-400, Washington, D. C.
1	Lcdr. C. Curione, CEC, USN, District Public Works Office, 14th Naval District, Navy No. 128, FPO, San Francisco
1	Cdr. J. F. Clarke, CEC, USN, Area Public Works Office, Chesapeake, U. S. Naval Weapons Plant, Washington, D. C.

Distribution List (Cont'd)

No. of copies	
1	Mr. G. H. Albright, The Pennsylvania State University, College of Engineering and Architecture, University Park, Pennsylvania
1	Capt J. H. Barker, Jr., CEC, USN, U. S. Naval Missile Center, Point Mugu, Calif.
1	Cdr. W. J. Christensen, CEC, USN, Bureau of Yards and Docks, Code D-400, Washington, D. C.
1	Capt J. H. Lofland, Jr., CEC, USN, Pearl Harbor Naval Shipyard, Navy No. 128, FPO, San Francisco
1	Capt W. A. McManus, CEC, USN, U. S. Naval Air Station, Norfolk, Va.
1	Lcdr. J. D. Andrews, CEC, USN, Defense Atomic Support Agency, Washington, D. C.
1	Cdr. D. P. Cunning, CEC, USN, District Public Works Office, 4th Naval District, Naval Base, Philadelphia, Penn.
1	Lcdr. W. J. Francy, CEC, USN, Bureau of Yards and Docks, Code D-500, Washington, D. C.
1	Mr. G. L. Arbuthnot, Waterways Experiment Station, Post Office Box 631, Vicksburg, Miss.
1	Lcdr. H. A. Locke, CEC, USN, Camp Smedley D. Butler, U. S. Marine Corps, Navy No. 161, FPO, San Francisco
1	Cdr. H. L. Murphy, CEC, USNR, Field Command, Defense Atomic Support Agency, Sandia Base, Albuquerque, N. M.
1	Lcdr. W. H. Sturman, CEC, USN, San Francisco Naval Shipyard, San Francisco
1	Lcdr. W. A. Wells, CEC, USN, U. S. Naval Reserve Officers, Training Corps Unit, University of Illinois, Urbana, Ill.
1	Lcdr. E. M. Saunders, CEC, USN, Bureau of Yards and Docks, Code D-440, Washington, D. C.
1	Lt. C. F. Krickenberger, CEC, USN, U. S. Naval Amphibious Construction Battalion Two, FPO, New York
1	Lcdr. B. S. Merrill, CEC, USN, U. S. Naval Station, Navy No. 138, FPO, New York
1	Lcdr. H. W. Stephens, CEC, USN, District Public Works Office, 12th Naval District, San Bruno, Calif.
1	Lcdr. R. C. Vance, CEC, USN, U. S. Naval School, CEC Officers, Port Hueneme, Calif.
1	Lcdr. W. D. Wilson, CEC, USN, Public Works Center, Navy No. 926, FPO, San Francisco
1	Lcdr. N. W. Clements, CEC, USN, Navy Nuclear Power Unit, Ft. Belvoir, Va.
1	Lcdr. J. C. LeDoux, CEC, USN, U. S. Naval School, CEC Officers, Port Hueneme, Calif.
1	LtJG. L. K. Donovan, CEC, USN, Navy Nuclear Power Unit, Ft. Belvoir, Va.
1	Office of the Chief of Engineers, Department of the Army, Washington, D. C., Attn: ENGMC-ED
1	Commanding Officer, U. S. Army Chemical Corps, Research & Development Command, Washington, D. C.
1	Officer in Charge, CECOS (Attn: ADCE Course), Port Hueneme, Calif.
1	Hdq. U. S. Air Force, Director of Research and Development, DCS/D, Washington, D. C. (Attn: Combat Components Division)
1	Commander, Air Force Special Weapons Center, Kirtland Air Force Base, Albuquerque, N. M.
1	Commander, Field Command, Defense Atomic Support Agency, Box 5100, Albuquerque, N. M.
1	Director, Civil Effects Test Group, Atomic Energy Commission, (Attn: Mr. R. L. Corsbie), Washington, D. C.
2	Chief, Defense Atomic Support Agency, Washington, D. C.

Distribution List (Cont'd)

No. of copies	
1	Office of Civil and Defense Mobilization, Attn: Mr. Ben Taylor, Battle Creek, Mich.
1	U. S. Atomic Energy Commission, Technical Information Service, P. O. Box 62, Oak Ridge, Tenn.
1	Commanding Officer, Chemical Warfare Laboratories, Army Chemical Center, Md.
1	Lcdr. C. R. Whipple, CEC, USN, NROTC Unit, University of Illinois, Urbana, Ill.
1	Headquarters, Field Command, Defense Atomic Support Agency, Sandia Base, Albuquerque, N. M.
1	Office of the Chief of Engineers, Department of the Army, T-7, Gravelly Point, Washington, D. C., Attn: ENGNB
1	Commanding Officer, Engineer Research & Development Laboratories, Fort Belvoir, Va.
1	Commanding Officer & Director, U. S. Naval Radiological Defense Laboratory, San Francisco
1	U. S. Army Chemical Center, Nuclear Defense Laboratory, Edgewood, Md.
1	Mr. W. R. Perret, 5112, Sandia Corporation, Sandia Base, Albuquerque, N. M.
1	Dr. N. M. Newmark, Civil Engineering Hall, University of Illinois, Urbana, Ill.
1	Mr. Kenneth Kaplan, Broadview Research Corporation, 1811 Trousdale Dr., Burlingame, Calif.
1	Prof. J. Neils Thompson, Civil Engineering Department, University of Texas, Austin, Tex.
1	Mr. William J. Taylor, Terminal Ballistics Laboratory, Aberdeen Proving Ground, Aberdeen Proving Ground, Md.

U. S. Naval Civil Engineering Laboratory.
Technical Report R-137.
DOSE ATTENUATION FACTORS FOR CONCRETE SLAB SHIELDS COVERED WITH FALLOUT AS A FUNCTION OF TIME AFTER FISSION, by L. K. Donovan and A. B. Chilton.
31 p. illus. 1 June 1961 UNCLASSIFIED

A study was made to determine the dose attenuation of fallout gamma radiation by various thicknesses of concrete roofs of buried personnel shelters. Dose attenuation factors are derived as a function of time after a nuclear detonation.

1. Shelters, fallout -- Dose attenuation
I. Donovan, L. K.
II. Chilton, A. B.
III. Y-F011-05-329

U. S. Naval Civil Engineering Laboratory.
Technical Report R-137.
DOSE ATTENUATION FACTORS FOR CONCRETE SLAB SHIELDS COVERED WITH FALLOUT AS A FUNCTION OF TIME AFTER FISSION, by L. K. Donovan and A. B. Chilton.
31 p. illus. 1 June 1961 UNCLASSIFIED

A study was made to determine the dose attenuation of fallout gamma radiation by various thicknesses of concrete roofs of buried personnel shelters. Dose attenuation factors are derived as a function of time after a nuclear detonation.

1. Shelters, fallout -- Dose attenuation
I. Donovan, L. K.
II. Chilton, A. B.
III. Y-F011-05-329

U. S. Naval Civil Engineering Laboratory.
Technical Report R-137.
DOSE ATTENUATION FACTORS FOR CONCRETE SLAB SHIELDS COVERED WITH FALLOUT AS A FUNCTION OF TIME AFTER FISSION, by L. K. Donovan and A. B. Chilton.
31 p. illus. 1 June 1961 UNCLASSIFIED

A study was made to determine the dose attenuation of fallout gamma radiation by various thicknesses of concrete roofs of buried personnel shelters. Dose attenuation factors are derived as a function of time after a nuclear detonation.

1. Shelters, fallout -- Dose attenuation
I. Donovan, L. K.
II. Chilton, A. B.
III. Y-F011-05-329

U. S. Naval Civil Engineering Laboratory.
Technical Report R-137.
DOSE ATTENUATION FACTORS FOR CONCRETE SLAB SHIELDS COVERED WITH FALLOUT AS A FUNCTION OF TIME AFTER FISSION, by L. K. Donovan and A. B. Chilton.
31 p. illus. 1 June 1961 UNCLASSIFIED

A study was made to determine the dose attenuation of fallout gamma radiation by various thicknesses of concrete roofs of buried personnel shelters. Dose attenuation factors are derived as a function of time after a nuclear detonation.

1. Shelters, fallout -- Dose attenuation
I. Donovan, L. K.
II. Chilton, A. B.
III. Y-F011-05-329