AD 673078

TECHNICAL STUDY #30 IN ATOMIC DEFENSE ENGINEERING

"CEILING-SHINE CONTRIBUTION WITHIN BUILDINGS FROM FALLOUT RADIATION FIELD"

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February 1963

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ABSTRACT

Ceiling-shine is that radiation which enters through the wall of a structure, reflects from the ceiling and increases the radiation within a shielded space. In most cases the ceiling-shine contribution is small when compared to direct and wall-scattered radiation. In some cases it can be an important contribution. The present method of analyzing buildings, the Engineering Manual, OCD PM 100-1, includes the ceiling-shine effect in the air scattered contribution, but does not provide a separate method of analysis. This report discusses the theory and application of ceiling-shine and proposes a method of computing its contribution.

Ceiling-Shine Contribution

BACKGROUND

The Engineering Manual[1] includes the ceiling-shine effect in the air-scattered (skyshine) directional response function, G_a. Since ceiling-shine is assumed to be small compared to skyshine, it was added as a corrective factor to skyshine. There are certain cases, however, where ceiling-shine could be a predominant effect in an otherwise well shielded structure. A building with a high narrow band of windows protected by a large roof overhang would appear to be a very good shelter if the roof and wall thicknesses were in the 200 to 250 psf range. Present methods of analysis would indicate excellent shielding against direct, wall-scattered, and air-scattered radiation. Calculations based on the method presented here, reduce the protection factor for such a building from 300 to 150 when ceiling-shine contribution is considered. Perhaps a more likely example would be a mutual shield which blocks out skyshine. Ceiling-shine would still be present and in the present method would be neglected. In view of this, it is evident that a method of computing ceiling-shine is needed to insure that its effect will not be overlooked.

THEORY

Figure 1 illustrates a simple building with windows and the two contributions--skyshine and ceiling-shine. Since there is little theoretical or experimental data available upon which to base a calculational procedure, we must use those functions which are now available in the Engineering Manual and the Spencer Monograph.[2]

Figure 2 is a sketch indicating that ceiling-shine must be some function of the radiation which is incident on the ceiling. The direct radiation directional response function, G_d, measures the radiation which comes from an infinite plane source of radiation, through the complement of the solid angle fraction which is below the detector plane. If we place a detector on the ceiling directly above the room detector position and measure the radiation which enters this detector through the complement of the solid angle fraction, we would have some measure of the radiation incident on the ceiling. The ceiling-shine response function, G_c, must then be proportional to G_d.

Scattering does not take place at the surface of the ceiling but within the interior of the slab. First floor ceiling height would be about 10 feet and we might be tempted to use G_d for H=10'. Within the first mean free path (about 2.5 inches of concrete for 1 mev gamma photons), 50% of the incident photons would suffer some interaction with the electrons. Only a smaller fraction of these would be back-scattered out of the slab to contribute to the ceiling-shine. The deeper the penetration into the slab before an interaction, the less is the probability that the photon will emerge again. Consequently, most of the gamma radiation contributing to ceiling-shine will be back-scattered within the first mean free path (32 psf). Fifty percent of the radiation which is back-scattered comes from the first 6 psf of a reflecting slab.[3]

Charts 5 and 6 of the Engineering Manual plot G_d as a function of solid angle fraction and height of the detector. In order to use this information to correspond to radiation incident on and then reflected from the ceiling, the slab was divided into a number of small horizontal slabs each at 1 psf. The thickness of the mid-point of each differential slab was converted to equivalent height of air. To this was added a nominal first floor ceiling height of 10'. The proper value of G_d was then obtained from Chart 6. This value was multiplied by the fraction of the radiation reflected from this incremental slab.[3] A response function was then constructed which "accounts" for the radiation incident on the ceiling and then reflected back toward the floor detector. Figure 5 has two G_r curves: one for a ceiling height, H_c, of 10 feet; one for a ceiling height of 100 feet. These curves have been normalized so that the 10' curve has a value of 1.0 for $\omega = 0$.

Since radiation which emerges from the ceiling and strikes the lower detector is all scattered radiation, it must be similar to air-scattered radiation. The 'S_a' function from the Spencer Monograph[2] (Figure 28.15) is the geometry factor for air-scattered radiation incident in a limited cone of directions about a perpendicular axis through the detector. S_a is a function of the solid angle fraction, ω_o, which measures the overhead contributing ceiling. The ceiling-shine function must then be proportional to S_a.

Finally the ceiling-shine will depend on the thickness of the reflecting slab. A thin slab will reflect some radiation, but will also transmit some. The G_r curves of Figure 5 have assumed an infinitely thick ceiling slab to produce maximum reflection. Actually a 4" concrete slab will reflect this same maximum amount. Any additional thickness does not materially increase the amount reflected out. Since 4" of concrete is a common thickness found in most floor slabs and would be a minimum thickness for shelters, maximum reflection is a good assumption.

The ceiling-shine equation must have a normalizing factor to make the function agree with some known conditions. The ceiling-shine equation would then be of the following form;

$$G_c = KG_r(\omega_c, H_c)\, S_a(\omega_o)$$

This equation has the proper characteristics. As the area of the reflecting surface increases, ceiling-shine increases. As the cleared area around the detector increases, ceiling-shine decreases. When either $\omega_o = 0$, or $\omega_c = 1$, ceiling-shine must be zero.

In order to determine our normalizing factor 'K', assume an infinite plane of contamination. Over this plane, place an infinitely thick roof slab of infinite extent at normal first floor ceiling height, 10'. Under these conditions, $\omega_o = 1$, and $\omega_c = 0$. From Figure 5, $G_r = 1.0$, and $S_a = 1.0$. Then:

$$G_c = K$$

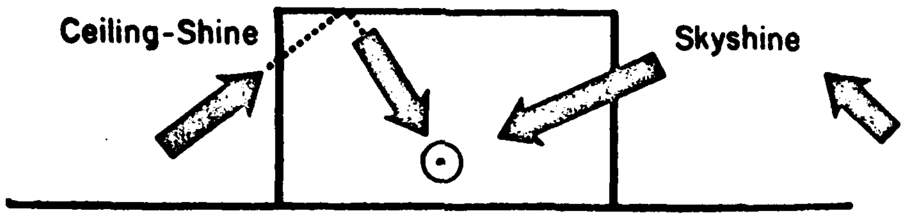


Figure I. Concept of Ceiling-shine and Skyshine

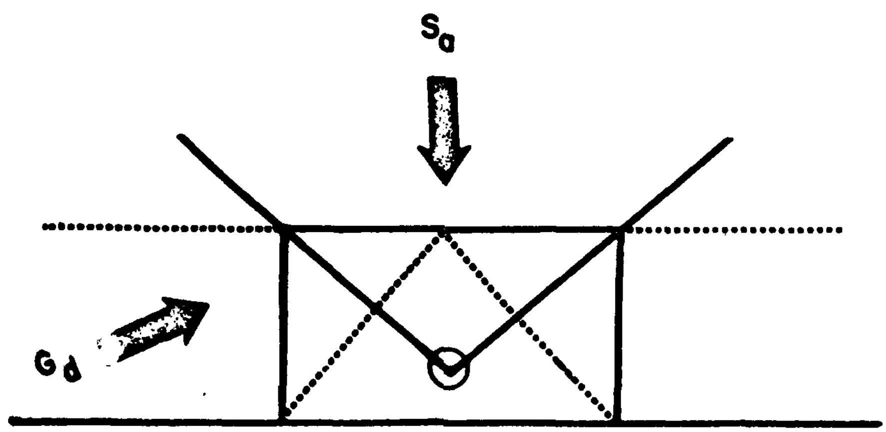


Figure 2. Dependence of Ceiling-shine on Functions G_d and S_a

Since we have assumed maximum reflection, ceiling-shine for this case must equal maximum skyshine which is 0.10. Therefore, K must equal 0.10. Figure 5 also plots S_a from the Spencer Monograph for two values of detector height, H. As detector height increases from 3', K must be modified by an additional height correction factor. Figure 5 has a chart of this correction.

GENERAL SOLUTION

Figure 3 illustrates the various parameters for a completely general case. This is a building with windows which do not extend to ceiling height. ω_c is the ceiling solid angle fraction which measures the extent of the cleared area. ω_g and ω_g' are the solid angle fractions which measure the lower and upper window sills respectively. Similar angles could be used if a limited plane of contamination existed and would apply to the value of G_r.

The total ceiling-shine contribution, C_c, would then be:

$$C_c = C_{cg} + C_{cw} - C_{cgw}$$

where C_{cg} is the ceiling-shine through windows

C_{cw} is the ceiling-shine through total solid wall

C_{cgw} is the ceiling-shine through window area with solid walls

$$C_{cg} = 0.1\ B_w(0,H)\ [G_r(\omega_g,H_c) - G_r(\omega_g',H_c)]\ S_a(\omega_o)P_rF_h(H)$$

$$C_{cw} = 0.1\ B_w(X_e,H)\ G_r(\omega_c,H_c)\ \ S_a(\omega_o)\ [1-S_w]\ F_h(H)$$

$$C_{cgw} = 0.1\ B_w(X_e,H)\ [G_r(\omega_g,H_c) - G_r(\omega_g',H_c)]\ S_a(\omega_o)P_r\ [1-S_w]\ F_h(H)$$

where B_w is the wall barrier factor, Chart 2 E.M.

H is the detector height

H_c is the height of ceiling

P_r is the perimeter ratio of windows

S_w is the scattering fraction, Chart 7 E.M.

F_h is height correction factor, Figure 5

APPLICATION

Normally, ceiling-shine, like skyshine,is small when compared with direct and wall-scattered radiation. Since it is small,some simplifying assumptions can be made for most building types.

Figure 4 illustrates the solid angle fractions which can be used for most buildings with little error. Three assumptions are made: (1) the lower sill height is at detector height, 3 feet; (2) windows extend to the ceiling; and (3) the ceiling-shine contribution from below the sill or through the solid wall is negligible. Using these assumptions, $\omega_o = \omega_c$ and composite curves of skyshine + ceiling-shine can be plotted as a function of a single solid angle fraction. Figure 6 is a replacement for Chart 5 of the Engineering Manual. Two air-scattered curves are shown: G_a which is still skyshine + ceiling-shine, and G_a' which is skyshine only.

Buildings which meet the conditions of these three assumptions are handled in the usual manner using G_a. Slight variations from this idealized building will not introduce serious errors. For other applications, G_a' is used in place of G_a' is used in place of G_a, and the ceiling-shine contribution, C_c, is computed and added to C_o and C_g.[1] Figure 5 is used to compute C_c and has two curves for G_r and S_a; one for first floor applications and one for a height of 100 feet.

EFFECT OF HEIGHT

As the ceiling or reflecting surface height increases, ceiling-shine will decrease. The directional distribution of radiation changes from a horizon oriented distribution at the 3' level to a more and more vertical orientation as the height increases. This change in distribution is reflected in the G_d function as used in the Engineering Manual and in the G_r function used in this paper. Figure 5 has a plot of two G_r curves, one for a ceiling height of 10 feet and one for a ceiling height of 100 feet. Linear interpolation between these two curves for other heights should be accurate enough for ceiling-shine problem. The amount of radiation available for contribution to ceiling-shine decreases also due to absorption and scattering which take place before the ceiling is reached. This effect is reflected in the S_a curves and the Height Correction chart on Figure 5. The Height Correction (F_h) is a simple multiplying factor applied to the basic equations. H is the height of the room detector.

EXAMPLE

There are certain cases where ceiling-shine could be an important contribution to the total radiation. For example, a building with a roof overhang and a high band of windows could have an important contribution from ceiling-shine. If the roof and wall mass thicknesses are in the 200 to 300 psf range and if the overhang shields out air-scattered radiation from the window areas, ceiling-shine could be the most important contribution. Another and perhaps more likely example, is the case where a mutual shield apparently blocks out all skyshine. Ceiling-shine will still be present. In fact, the major source of ceiling-shine is fallout particles which are close to the structure.

The following example illustrates this point. Two solutions are shown: one with the usual Engineering Manual solution using the new value of G_a, and the second solution using G_a' and computing the ceiling-shine separately. The ceiling-shine contribution through the solid wall is computed but it is negligible.

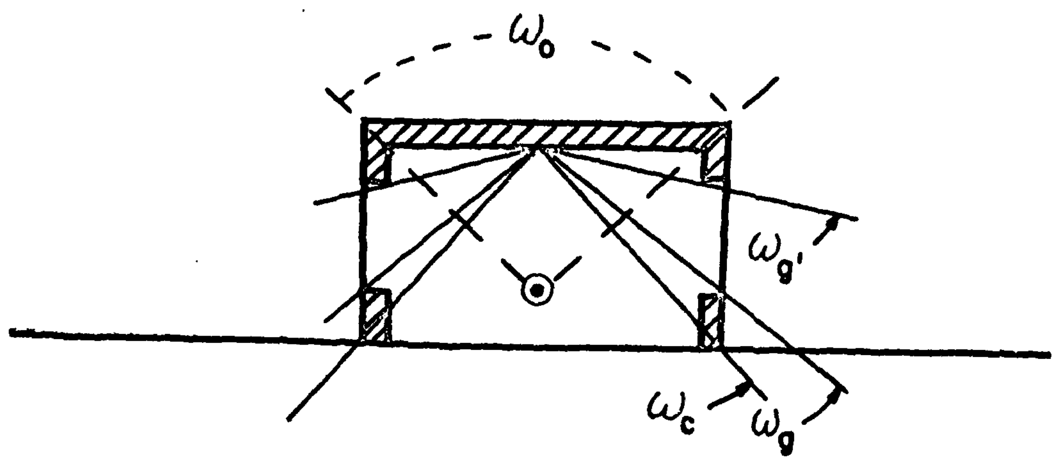


Figure 3. Solid Angle Fractions for general case.

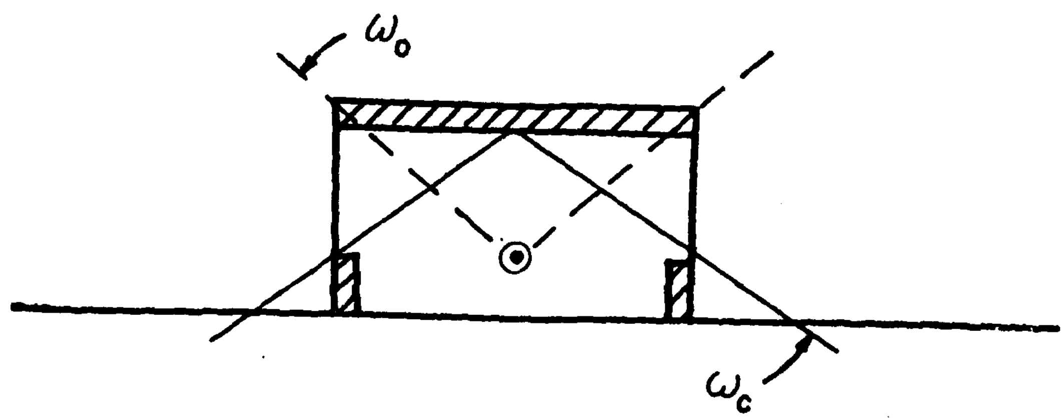


Figure 4. Solid Angle Fractions for simplified case.

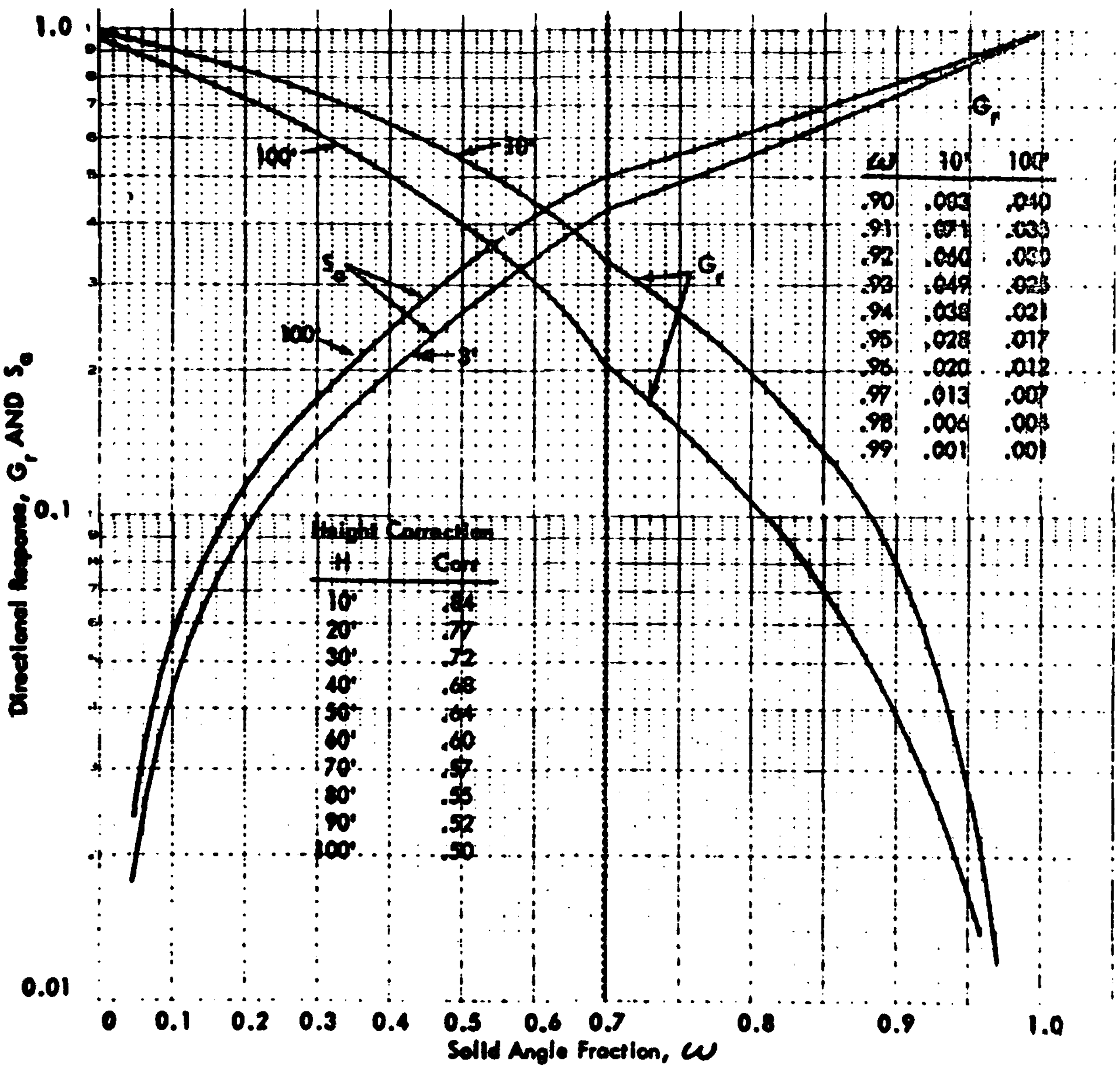
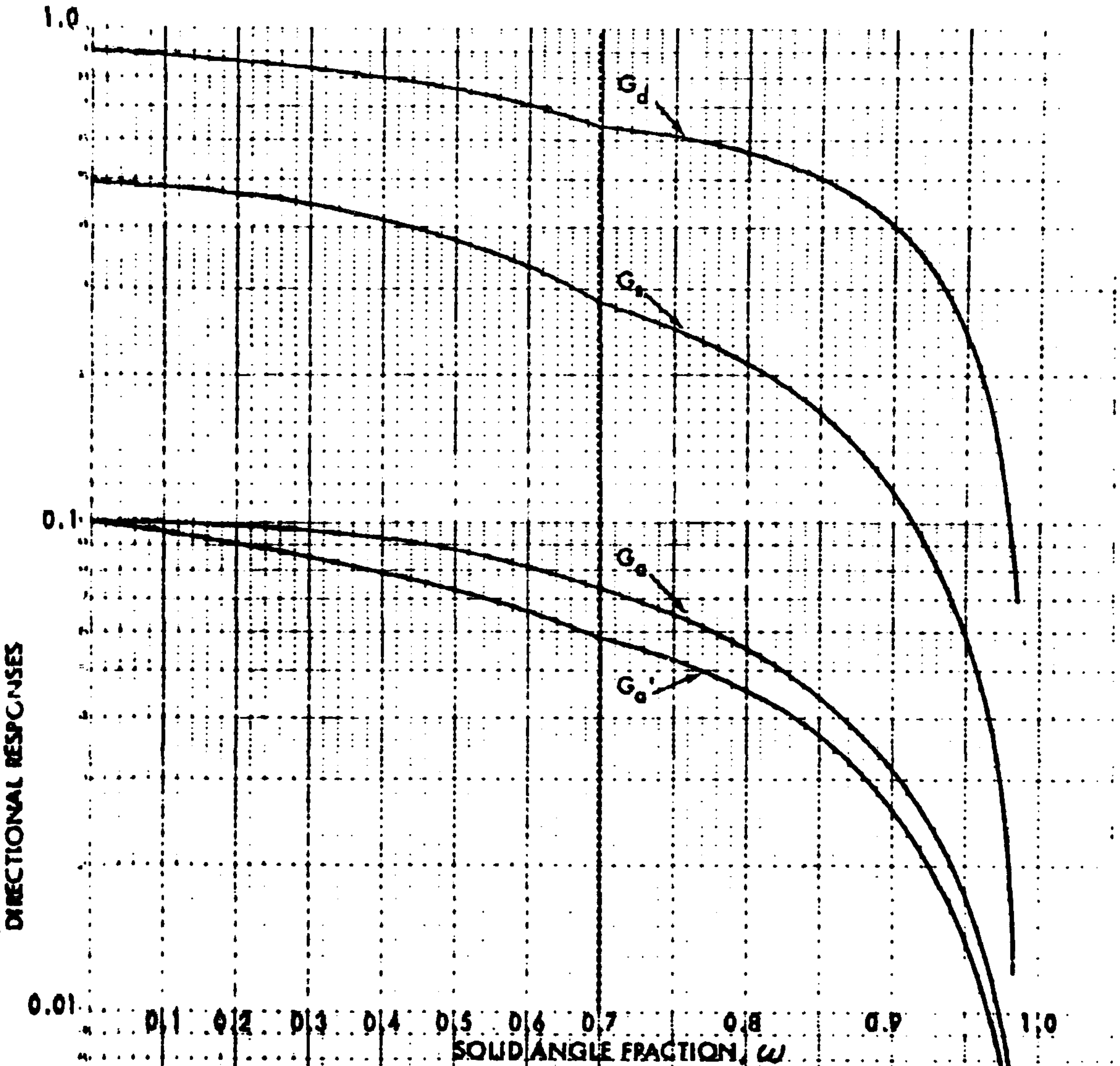


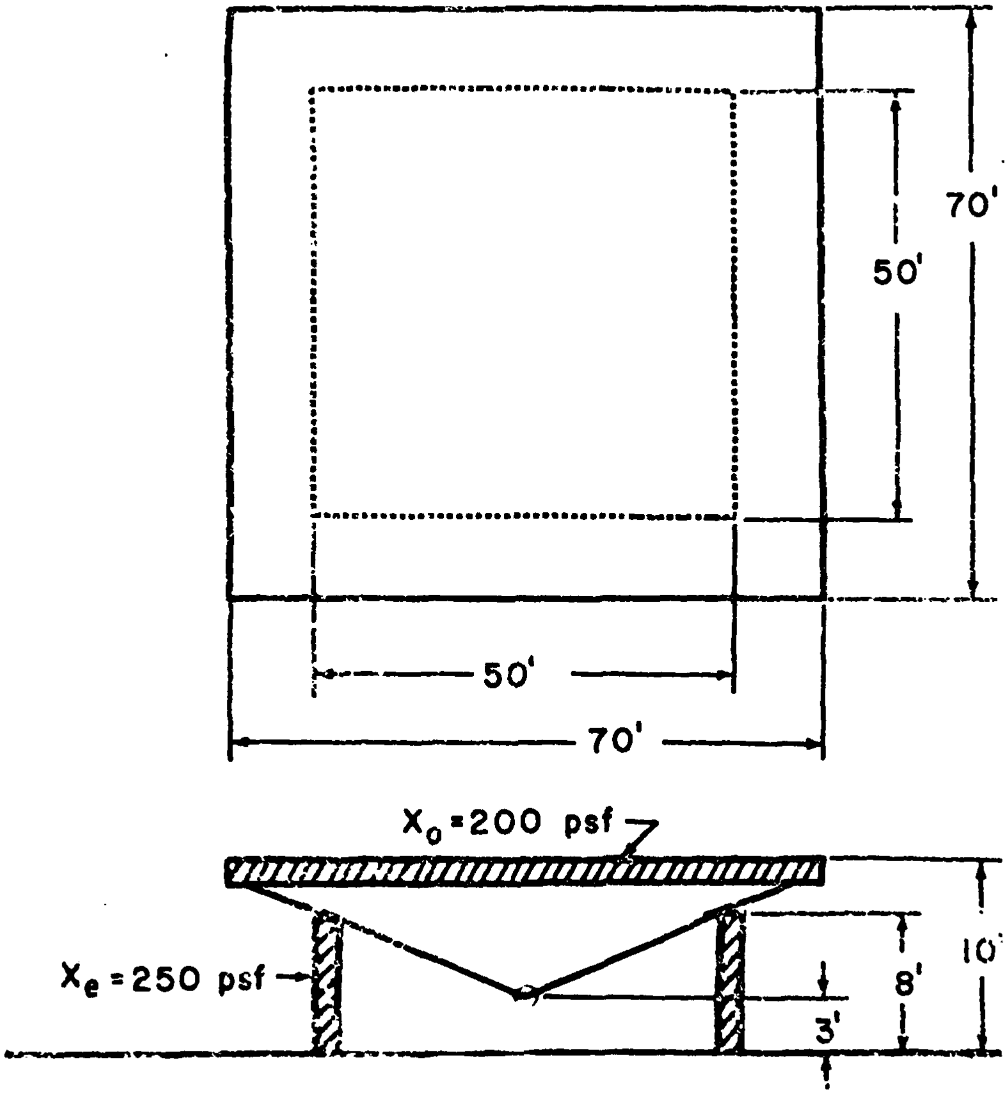
Figure 5. PLOT OF G_r AND S_a VS SOLID ANGLE FRACTION AND HEIGHT



ω	G_d	G_s	G_a	G_a'
0.90	0.410	0.114	0.033	0.027
0.91	0.385	0.104	0.030	0.024
0.92	0.360	0.093	0.027	0.022
0.93	0.335	0.082	0.024	0.020
0.94	0.300	0.072	0.021	0.018
0.95	0.255	0.060	0.017	0.015
0.96	0.220	0.049	0.015	0.013
0.97	0.175	0.037	0.011	0.010
0.98	0.125	0.025	0.008	0.007
0.99	0.070	0.012	0.005	0.005

Figure 6. Directional Responses, Ground Contribution. (Chart 5 Engineering Manual)

Example: Building with roof overhang.



	z	e	n	ω	G_d	G_r	G_s	G_a	G_a'	S_a	
ω_o	7'	1.0	0.2	0.82	XX	XX	0.20	.051	.042	.58	$B_w(0,H)=1.0$
ω_ℓ	3'	1.0	0.12	0.89	.43	XX	0.13	XX	XX	XX	$B_x(X_e,H)=.0032$
ω_c	10'	1.0	0.4	0.66	XX	.39	XX	XX	XX	XX	$P_r=1.0$
ω_g	2'	1.0	0.08	0.92	XX	.06	XX	XX	XX	XX	E=1.41
											$S_w=0.88$

STANDARD SOLUTION USING G_a

$$C_g = B_w \left\{ [G_s(\omega_\ell) + G_s(\omega_o)]\ E\ S_w + [G_d(\omega_\ell) + G_a(\omega_o)]\ (1-S_w) \right\}$$

$$= .0032\ (.33 \times 1.41 \times .88) + (.481 \times .12)$$

$C_o = .0018$

$R_f = .0033$ $\quad$ $P_f = 303$ ANS

SOLUTION USING G_a' AND ADDING C_c

G_a' is .042 and is only slightly different than G_a which is .051
The ground contribution without ceiling-shine remains the same, to two significant figures.

$$C_c = 0.1\ Bw(0,H)\ G_r(\omega_c H_c)\ S_a(\omega_o,H)\ P_r F_h(H)$$

$$= 0.1 \times 1.0 \times .06 \times .58 \times 1.0 \times 1.0$$

$C_c = .0035$

$C_g = .0015$

$C_o = .0018$

$R_f = .0068$ $\quad$ $P_f = 147$ ANS

Ceiling-shine through solid wall is only 0.000007

SUMMARY

A recent report[4] derived a ceiling-shine solution in a similar but independent effort. Circular ring sources and reflecting areas using albedo theory were used to develop functions describing the source plane and reflecting surface. These two functions are basically the same as the G_r and S_a curves used in this paper. The correction for height is handled in a slightly different manner. This report[4] has some experimental results which verify the method. Both methods predict within a few percent the same total ceiling-shine. The method proposed in this paper is developed within the framework of the Engineering Manual and those familiar with the Engineering Manual should be able to apply it with no difficulty.

REFERENCES

1. The Engineering Manual, OCD PM 100-1. Office of Civil Defense, Washington, D. C., Draft October 1961.

2. Spencer, L. V., Structure Shielding Against Fallout Radiation from Nuclear Weapons. NBS Monograph 42. National Bureau of Standards, Washington, D.C., June 1962.

3. Private Communication from J. Batter, Technical Operations, Inc., Burlington, Massachusetts.

4. Batter, John F. and Joseph D. Velletri, The Effect of Radiation Reflected from the Ceiling of the Dose Rate Within Structures. TO-B-63-25. Technical Operations, Inc., Burlington, Massachusetts. April 1963.