BASIC CONCEPTS OF STRUCTURE SHIELDING FROM FALLOUT

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A MASTER'S REPORT

submitted in partial fulfillment of the

requirements of the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

Approved by:

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GENERAL NOMENCLATURE

B_c -- Barrier reduction factor for exterior walls.

C_g -- The total ground contribution to a detector.

C_o -- The overhead contribution to a detector.

G_a -- The geometry factor for skyshine radiation

G_d -- The geometry factor for direct radiation

G_s -- The geometry factor for scatter radiation

H -- Height of detector above the contaminated plane.

L -- Length of a rectangular structure.

L_c -- Length of an interior core area.

MT -- Megaton, explosive energy equivalent of one million tons of TNT

PF -- Protection factor

R_f -- Reduction factors sum of all contributions.

S_w -- Scatter fraction, fraction of wall emergent radiation that has been scattered in the wall.

W -- Width of a rectangular structure.

W_c -- Width of an interior core area.

X_e -- Mass thickness of an exterior wall.

X_o -- Total overhead mass thickness.

Z -- Distance from the detector to an overhead plane of contamination.

ω_L -- Lower solid angle fraction defined by a segment of wall in elevation below the detector plane.

ω_u -- Upper solid angle fraction, defined by a wall segment above the plane of the detector.

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CHAPTER I BACKGROUND

INTRODUCTION

President John F. Kennedy in addressing the United Nations General Assembly on September 25, 1961 stated, "Every man, woman, and child lives under a nuclear sword of Damocles, hanging by the slenderest of threads, capable of being cut at any moment by accident, miscalculation, or madness" (9)*. While we have learned that a nuclear war would be pure lunacy, it is still an ever present possibility. A nation can be provoked to the point of lunacy when it becomes exasperated to the point where only violence can relieve its frustrations. It is the business of governments to know where this point of uncontrollable lunacy is, and stay well back from it. Nuclear weapons are very efficient from the military point of view. Nuclear weapons are very reliable, predictable in performance, can be delivered to nearly any target anywhere in the world, and produce fire and blast effects on unimaginable scales with the added bonus of radioactive fallout. The problem of providing protection from thermal radiation and blast destruction will be expensive and difficult to solve for above ground structures. The area involved with thermal radiation and blast destruction is small in comparison to the area affected by fallout. Millions of people will need only fallout protection which can be obtained at a relatively low cost, thus it is the present practice to emphasize fallout radiation shielding.

Procedures and standards for evaluating a fallout shelter's protection have been developed (6). These procedures and standards can be used to evaluate the fallout shelter potential of existing structures or structures

*Numerals in parentheses refer to items listed in Bibliography.

in the preliminary design stage and to modify both types of structures so protection will be present. Every building provides some degree of protection against fallout radiation, but some provide more protection than others. Many existing buildings have shelter even though a fallout shelter was not considered in the design. Many buildings could have provided shelter except that they contain weak points. If these weak points could have been detected in the initial design phase, revisions of the initial design could be made thus providing protection without significantly exceeding budget limitations. It is much cheaper to provide shelter in the preliminary stage of design than to do so by modifying an existing building.

This report will deal with the general effects of nuclear weapons and fallout, the basic concepts of structure shielding used in shelter analysis, the quantitative evaluation of protection factors, and slanting techniques.

GENERAL EFFECTS OF NUCLEAR WEAPONS

To help understand the general nature of the fallout problem, some background information is needed. Conventional and nuclear explosions both deal with the sudden release of a large amount of energy in a limited space, but the energy is produced in different ways. In a nuclear explosion, energy is produced by the formation of different atomic nuclei resulting from the redistribution of the protons and neutrons within interacting nuclei (6). In conventional explosions the energy is released all at once as kinetic energy. In a nuclear explosion only 85% of the energy is released in the form of kinetic energy. Of this 85%, 50% is converted into blast and shock and the remaining 35% is thermal radiation. The other 15% will form nuclear radiation. Maximum temperatures in conventional explosions are around 9000^{o}F while in nuclear explosions the maximum temperatures reach several million degrees Fahrenheit. The maximum pressures in conventional explosions are several hundred atmospheres while in a nuclear explosion they reach a maximum of several hundred thousand atmospheres. The nuclear device may be detonated in the air at a high altitude or relatively near the surface. Some of the general characteristics of a surface burst nuclear explosion are the crater, fireball, atomic cloud, air blast, and thermal and nuclear radiation.

The size of the crater depends on the weapons yield and the material making up the soil.

The fireball may be described as a roughly spherical, hot, luminous mass of air, gaseous weapon, and vaporized debris. The fireball would, as seen by an observer 60 miles away, appear to be 30 times brighter than the sun. If the fireball touches the earth's surface, many tons of vaporized debris will be added to the fireball along with much debris sucked up by the afterwinds caused by the ascending heated air.

The atomic cloud is composed of solid particulate matter, cooling vaporized material, water, and debris sucked up by the afterwinds. The stem that gives the mushroom shape to the atomic cloud is formed from the debris sucked up by the afterwinds.

The air blast may be described as a moving wall of compressed air traveling at the speed of sound. The wall of compressed air may be thought of as a wave of pressure. This wave of pressure is produced so suddenly by the explosion that it is called a shock wave. "The increase in the air pressure caused by the air compression in the shock wave is called the air blast overpressure, or simply the overpressure. This is a descriptive name because it is the pressure of the air over that associated with the normal atmospheric pressure" (9). The overpressure acts in all directions, from all sides, from the top, and even through the soil to some extent. The pressure on the outside of a structure is increased very rapidly while the inside pressure stays the same thus upsetting the pressure equilibrium. A general inward-directed crushing effect on any structure above the ground is produced to restore the pressure equilibrium. Peak overpressures are of the magnitude of 200 to 300 psi close to the burst point and may be as low as 1 or 2 psi several miles away. To help visualize the magnitude of these pressures, a 1 psi pressure corresponds to 144 psf, 5 psi corresponds to to 720 psf, 14 psi corresponds to a little more than 2000 psf or 1 tsf, and 100 psi corresponds to 7 tsf. Very few private or public buildings are designed for loads in excess of 100 psf. Added to the problem of excessive loads is the fact that the overpressure is a dynamic load. It follows that the air blast is responsible for a large part of the total destruction created by the nuclear explosion.

The thermal radiation emitted from a nuclear explosion that is the main hazard in producing skin burns, eye damage, and fires lasts generally for several seconds and consists mostly of visible and infrared rays. Thermal radiation travels in a straight line and is attenuated by opaque material. When thermal radiation impinges upon an object, it may either be reflected, partly absorbed, or part may pass completely through. The portion that is absorbed is what causes the damage. For every kiloton of weapon yield, there is released about 330 billion calories of thermal radiation. To enhance the feeling of this, the potential for a first degree burn extends to a distance of 15 miles, the potential for a second degree burn would extend to about 11 miles, and fine grass, leaves, twigs have the potential to be ignited for a distance of 10 miles from the point of detonation of a weapon with a one megaton yield (6).

The magnitude and extent of the previously described characteristics depend upon the yield of the weapon. The weapons yield is expressed in terms of the amount of TNT required to produce the same amount of energy. A 1 kiloton explosion is equivalent, in energy released, to 1000 tons of TNT. To show the direct effects of the weapon yield with respect to the damage caused by blast and thermal energy, Figure 1 compares a 1 MT (megaton), 5 MT, and 25 MT blast. It may be stated for practical purposes that the reach of the blast and fire effects vary as the cube root of the weapon yield. As can be seen from Figure 1, the chances for survival improve markedly as one moves out from the area to total destruction. While millions of people could survive the initial effects, namely blast and thermal, they would be exposed to lethal amounts of radioactive fallout.

The last characteristic to be discussed is the nuclear radiation. The nuclear radiation from which shelters provide protection is called residual radiation. Residual radiation is defined as that radiation emitted later than one minute after the explosion. Gamma rays constitute the radioactivity that is associated with the residual radiation with which we are interested. Gamma radiation is not visible and it can penetrate all materials no matter how dense they are. The primary hazard from residual radiation stems from the formation of fallout particles which incorporate the radioactive elements. Fallout may be described as vaporized material that has condensed or debris on which minute radioactive particles either are incorporated into the material, or that cling to the surface of the material. The particles will become heavy enough to descend to earth. The fallout may drift, sometimes many miles, from the point of denotation settling on exposed surfaces. "Radioactivity is the spontaneous emission of energy from the bomb's unstable atoms which are carried by the fallout debris" (7).

Gamma radiation can damage living tissue and cells. When a sufficient number of cells are damaged a person may become ill. The body may be able to repair the damage, but excessive exposure may result in death due to an excessive amount of damage to the tissues of the body. No special clothing, chemicals, or drugs can prevent large doses of radiation from causing damage to the cells of the body. The only way to avoid illness or death from gamma radiation is by shielding the body from it.

There is no way of predicting in advance what locations in the country would be affected by fallout in the event of a nuclear war. Distribution of the fallout depends upon wind currents, weather conditions, height of the atomic cloud, and the quantity and size distribution of the fallout particles to mention a few. "Even if targets, enemy intentions and offensive capabilities could be accurately predicted, the winds as of any day on which a potential attack might occur, could not be so predicted. Therefore, we must plan on providing fallout protection everywhere" (1).

CHAPTER II BASIC CONCEPTS OF SHELTER ANALYSIS AND STRUCTURE SHIELDING

It must be kept in mind that gamma radiation constitutes the sole consideration, with respect to radiation, involved in structure shielding. A fallout shelter does not need to be a special type of building or an underground bunker-type of structure. It can be any space that will keep dangerous amounts of radiation from reaching the people inside the structure. Protection from fallout may be achieved through the application or existence of four basic form principles--barrier and geometry shielding, distance, and time. Barrier shielding generally affords protection by absorption of the radiation. Geometry shielding is somewhat more difficult to describe. Radiation reaching any given point in the building may have to pass through one or more of the following; exterior walls, roof, floors, apertures, and/or interior partitions. The positioning of these elements with respect to each other may be even more important than their ability to act individually as a barrier shield. The third of the basic form principles is distance. The intensity of the radiation follows the inverse square law as applied to a light source. Through the physical separation of the fallout particles from the shelter, protection may be afforded through distance. Figure 8 shows the dose contribution that a detector receives vs. distance. The fourth basic form principle, time, takes advantage of the decay characteristic of the gamma radiation. The rate of emission of radiation decreases rapidly following the detonation. With these basic form principles in mind, the parameters used in the evaluation of structure shielding will be discussed.

The qualitative evaluation of these parameters is stressed in the following material. Tables and charts have been provided to show, quantitatively, the effect that each parameter has. It must be understood that these numbers represent only the relative magnitude of change for the subject structure only, due to the variation of the parameters, and are not intended to be used as design criteria for the design or analysis of fallout shelters. Each shelter must be looked at individually. The charts and tables are to serve as an aid in understanding the qualitative evaluation of these parameters.

As mentioned above, radiation exposure is reduced by the effects of barrier shielding. Gamma radiation consists of streams of photons, packets of energy without mass, that travel in a straight line from their source. If a photon is incident upon a barrier, it may react in one of three ways. The photon may not interact at all with the barrier and thus pass through the barrier unaffected, in which case it is termed direct radiation. The photon may interact with the barrier and lose all of its energy, in which case it is termed absorbed radiation. Finally the photon may interact with the barrier, but not be completely absorbed. In this case a new photon with a lower energy will leave the barrier in a direction different from the one of the entering photon. The departing photon will be called scattered radiation.

The standard detector and its location is another important concept. The standard detector is used to evaluate the protection afforded by the shelter by comparing the amount of radiation received at some location within the shelter with respect to that which would have been received at that location if unprotected. "The standard reference location used in shielding analysis is a detector which measures the amount of radiation received from all directions and which is located 3 feet above a smooth plane of infinite extent (in all directions) upon which fallout particles (having the average energy of the fission product at 1.12 hours after weapon detonation) are uniformly distributed." (6) This represents a radiation detecting instrument carried at about the midbody height in monitoring operations. It is also at the height of the body where the gut and reproductive organs are located which are very sensitive to the affects of radiation.

Barrier effectiveness depends, to a large part, on the parameter known as mass thickness. For all practical purposes in structural shielding, mass thickness may be defined simply as the weight per unit of area of the barrier. For example the specific weight of concrete is around 145 pcf. Using a slab with a 1 ft. square area which is 1 in. thick, the mass thickness of this concrete is 12 psf.

Contributions of radiation emerging through the solid parts of the walls, through the apertures, through the floors, and through the roof as measured by a standard detector are summed to yield a reduction factor. The contributions received by an unprotected detector are calculable quantities which can be normalized to unity. "Lesser quantities of radiation received at protected locations may then be related to the standard and expressed as a decimal fraction called a reduction factor." (6) The reciprocal of the reduction factor is the protection factor. A reduction factor of 0.10 corresponds to a protection factor of 10. Throughout the following material the terms reduction factor and protection factor will be abbreviated using the symbols R_f and PF respectively. It must be kept in mind that a PF or R_f does not give a direct indication of the fallout radiation hazard. This is because the standard as defined does not consider the intensity of radiation associated with the uniformly contaminated field. A PF of 40 is used as a design criteria to provide adequate protection.

QUALITATIVE EVALUATION OF STRUCTURE SHIELDING PARAMETERS

The following material will discuss from a qualitative point of view how variations in certain parameters would probably affect the various contributions, reduction factor, and protection factor.

A one-story simple structure of the blockhouse type will be used to help develop an understanding of the fallout shelter shielding parameters. This typical structure is assumed to be isolated on a horizontal planar field that extends infinitely in all direction over which the radioactive fallout particles are assumed to be uniformly distributed. Unless otherwise stated, the structure is rectangular in plan, one story in height, the floor is at grade, there is assumed to be no apertures, and the walls and roof have uniform mass thickness, but not necessarily the same mass thickness. It will be assumed that the detector is located centrally in plan and at a height of 3 ft. above the floor (standard detector). Some of the physical dimensions of the building are given in Figure 2. Physically the blockhouse structure may be described by four parameters. In plan view the structure may be described by the dimensions of length and width. Length represented by the symbol L, is the greater horizontal dimension of the rectangular structure. The width is represented by W. In elevation the structure may also be described by the use of two dimensions. The symbol Z, represents the vertical distance from a contaminated overhead plane to the detector. The symbol H, represents the vertical distance from a contaminated ground plane to the detector. In this case the sum of Z plus 3 feet will yield the building height.

The detector will receive only radiation originating from the contributions of the ground and overhead planes of contamination. The ground contribution C_g, represents the contributions to the detector originating from a plane or planes of contamination below a horizontal plane running through the standard detector, or simply from the ground. The overhead contribution consists only of the contributions received by the detector from a contaminated roof plane or planes of contamination above the detector plane. From a strict point of view, the detector sees the walls and roof as radiating surfaces, thus we may speak of wall and roof contributions instead of ground and overhead contributions.

A closer examination of the wall and roof contributions is in order. All wall contributions originate from the fallout particles on the contaminated ground plane. The radiation comprising the wall contributions is of three types: direct, scatter, and skyshine radiation. As discussed earlier, direct radiation comes from the source to the detector without any interaction with the wall. Direct radiation travels in a straight line from the source through the wall to the detector, thus only that portion of the wall below a horizontal plane running through the standard detector may contribute direct radiation. Scatter radiation as discussed earlier is that radiation that undergoes an interaction with the barrier producing a photon of lower energy traveling in a different direction than that of the original photon. Scatter radiation may reach the detector from the portions of the wall both above and below the plane of the detector.

Skyshine radiation is that radiation originating from the contaminated ground or roof plane that has undergone a scattering interaction in the air above the plane of contamination which then proceeds directly to the detector. The skyshine contribution may be received through both portions of the wall above and below the plane of the detector.

Radiation passing through the wall that would ordinarily miss the detector could scatter in the air of the structure, scatter off the ceiling, or scatter off the opposite wall, but these secondary effects are usually minor and are generally neglected in the calculations. The radiation that is absorbed in the barrier will not be detected. The radiation comprising the roof contribution is also composed of direct, scatter, and skyshine radiation. Direct and scatter radiation forming the roof contribution originates from the contaminated roof plane. The skyshine radiation may originate from the contaminated ground or roof planes.

Considering the roof as a horizontal contaminated plane, most of the radiation emerging from the underside surface of the roof reaches the detector on straight lines lying wholly within an imaginary pyramidal volume formed by projecting lines from each corner of the roof plane to the central detector. A figure showing this is provided on Chart 1A or the OCD Standard Method Charts provided in the Appendix. Shown at the apex of the pyramid on the chart is a curved arrow representing a solid angle fraction which will be identified by the character ω. The parameters W, L, and Z will define ω. Knowing the ratios of altitude to length (Z/L) and width to length (W/L) the solid angle may be found by using Chart 1A. The solid angle fraction is a measure of the effect of geometry on detector response. The effect of ω on the detector's response may be visualized through the use of an analogy. Consider the detector as an eye, the contaminated plane as a window, and the gamma radiation as a source of light. If Z were to remain constant, and the area of the window is increased by either increasing W, L. or both, it would stand to reason that the eye would receive more light, or in our case, the detector would receive more radiation. A corresponding decrease in area would decrease the detectors response. If the area were to remain constant and the window (plane of contamination) were moved further from the eye, there would be a decrease in the eyes (detectors) response. It may be concluded that an increase of Z with the area remaining constant would result in a decrease in detector response. An opposite change would result with a decrease in Z.

In summary, a change in any of the three variables W, L, or Z would result in a change of ω. As ω increases the detectors response will increase and with a decrease in ω the opposite will be true. Two-dimensional sketches may be used to represent the above interpretation. A two-dimensional sketch of this type is provided in Figure 2. It should be noted that there are two solid angles represented in this figure. The difference between these two solid angles is the altitude Z used to determine the corresponding solid angle. For ω_u, the upper solid angle, the distance from the detector to the contaminated roof plane was used. For ω_L, the lower solid angle, the distance from the detector to the floor of the building was used for Z.

From the preceding discussion and Figure 2, it can be seen that ω_u and ω_L do not consider the zones of the walls through which radiation emerges. Even though ω_u is the solid angle fraction of the pyramidal volume with respect to the roof and emergent wall radiation does not have to travel through this volume to reach the detectors, the upper solid angle fraction ω_u may be used to interpret the effect of geometry on the response to the detector through the shaded zone of the upper wall segments (that portion of the wall above the horizontal plane through the detector). The same holds true for the lower wall segment and ω_L. The zones of contribution for the upper and lower wall segments are shown in Figure 4.

The wall contribution and detector response may be visualized through the same analogy as used for the roof. An increase in ω_u would result in a decrease in the detector response with respect to the emergent wall radiation from the upper wall segment. A decrease in ω_u would result in a corresponding increase in the detector response. Keeping W and L constant, an increase of Z will decrease ω_u and thus increase the detector response with respect to the upper wall contribution.

From the preceeding discussion it has been shown that with a single function ω_u, the detectors response with respect to the overhead and upper wall segment contributions can be qualitatively interpretted. As $\bar{\omega}_u$ increases the overhead contribution increases and the upper wall segments contribution decreases. With a decrease of $\bar{\omega}_u$ the reverse is true. These remarks concerning the solid angle fraction and upper wall segments hold true also for $\bar{\omega}_L$ and the lower wall segments.

Another important parameter is mass thickness. In general, as the mass thickness of a barrier, between the source of radiation and the detectors, is increased there should be a smaller contribution reaching the detector through the barrier. This is usually true but there are some exceptions. These exceptions involve low mass thicknesses. As discussed earlier, three types of radiation are considered when radiation is incident upon walls. Consider the structure in Figure 2. The upper wall segments receive only scattered and skyshine radiation. If the upper wall mass thickness is 0 psf then the detector receives only skyshine and ceiling-shine radiation from the upper wall segment. Since there is no mass thickness in the upper wall segment, there can be no scattering of the radiation in the wall. Without the scatter contribution, the total contributions received by the detector will be lowered with a corresponding increase in the PF. As the mass thickness is increased from 0 psf to say 15 psf, the mass thickness will produce more scattered radiation in relation to the radiation it attenuates. In other words, it is doing more harm than it is good. As the mass thickness is increased beyond some break even point, the mass thickness will attenuate more radiation and the amount that is scattered is reduced. An example of this will be shown in the discussion of multistory buildings. Chart 5 in the Appendix shows the relationship of scatter. $S_w(X_e)$ represents the scatter fraction, which is the fraction of the wall emergent radiation that has been scattered in the wall. The symbol inside the parenthesis means that the scatter fraction S_w is a function of only X_e the exterior wall mass thickness. As can be seen on Chart 5, as the exterior wall mass thickness increases, the scatter fraction increases. This means that as the mass thickness increases, there is more of a chance that the radiation will react with the materal of the barrier and scatter. Referring to the relationship between the PF and R_f discussed earlier, it can be shown that if only the scatter fraction increased the R_f would increase with a corresponding decrease in protection. However, as the mass thickness increases it will generally attenuate more radiation than it will scatter.

Chart 6 shows that the exterior wall barrier factor B_e is a function of the exterior wall mass thickness X_e and the detector height H. Chart 6 also shows that as the mass thickness is increased with a constant H, the exterior wall barrier factor will decrease. Chart 6 may be interpretated as giving the percentage of the radiation that will not be attenuated by the wall mass thickness through the barrier effect. In other words as the mass thickness increases the exterior wall barrier factor will become more significant than the scatter fraction and offset it.

With a general understanding of the effect that the mass thickness and the solid angle fraction has on the detector's response, the other parameters which will be directly or indirectly related to mass thickness and/or solid angle fraction will now be discussed. Some quantitative values will be used as an aid to understanding what happens when the parameters are changed.

The first parameter to be discussed is mass thickness with respect to its effect on the overhead (roof) and ground (wall) contributions.

Table 1 of the Appendix yields values for the overhead (C_o) and ground (C_g) contributions for the blockhouse structure mentioned earlier by varying only the roof and exterior wall mass thicknesses. From this table it can be seen that as the overhead mass thickness X_o is increased, a reduction in the overhead contribution C_o is obtained. This can also be shown directly by Chart 9 of the Appendix. The overhead contribution $C_o(X_o, \omega_u)$ is a function of the upper solid angle fraction and the overhead mass thickness. This chart also shows that if the overhead mass thickness X_o were to remain constant and the solid angle decreased, the overhead contribution would be smaller thus yielding a smaller R_f and a larger PF. The results from Table 1 show that even though the ground contribution can be reduced to very low values, that protection is still not adequate due to the overhead contributions. Similar results are shown for the case where the overhead contribution is greatly reduced, but the ground contribution eliminates the protection.

The next parameter to be discussed is the variation in the story height. Keeping all the parameters as given in Figure 2 constant except Z will yield a different story height. It can be visualized that if Z is increased the solid angle ω_u will decrease with a corresponding decrease in the overhead contribution C_o and a corresponding increase in the wall contribution C_g resulting from an increased area in the upper wall segment. For a decrease in Z the reverse is true. Values of C_g and C_o are given in Table 4 for the variation of the parameter Z only. As can be seen from this table, when Z increases, the value of C_o decreases and the value of C_g increases. As shown in the table, the PF decreases with an increasing Z. This is due to the fact that the increase in C_g overshadows the decrease in C_o. Care must be taken to avoid rash assumptions that with an increase in Z the PF decreases. As a case in point, if the wall mass thickness were so high that C_g can be neglected, then as Z increases C_o would decrease with the net result that the PF would increase. Thus it can be concluded that the total effect of a change in the story height is qualitatively inconclusive. Another important point is that the wall contribution of the lower wall segment will remain constant when only Z is varied.

A closer look at the components of the ground contribution is in order. As stated earlier, the upper and lower solid angle fractions define geometrically the volume zones that the radiation must pass through upon emerging from the exterior wall to reach the detector. The three components of the ground contribution are direct, skyshine, and scatter radiation. Direct radiation may reach the detector from only the lower wall segment of the structure. Charts 3A and 3B show the direct geometry factor contribution, $G_d(H,\omega_L)$. This factor is a function of the detector height and the lower solid angle fraction. From the two figures it can be seen that if the detector height remains constant and the solid angle fraction is increased, the direct geometry factor contribution will decrease, thus reducing the C_g and increasing the PF. If the solid angle fraction remains constant, the direct geometry factor will decrease with an increase of the detectors height. This will also lower the R_f and raise the PF. Further elaboration of this will appear in the discussion of the parameters; W, L, and H.

The skyshine geometry factor $G_a(\omega_u)$ is shown in Chart 2. The skyshine radiation will be limited to the upper wall segment as shown in the figure on the chart.

The scatter geometry factor $G_s(W)$ must be accounted for in both the upper and lower wall segments as shown in Chart 2. As the solid angle fraction increases, the geometry factors of $G_s(W)$ and $G_a(\omega_u)$ will decrease resulting in a decrease in the R_f which will increase the PF. It should be noted that $G_a(\omega_u)$, $G_s(W)$, and $G_d(H,\omega_L)$ are all geometry factors and depend only on the geometry of the structure and the location of the detector. These are the wall contributions that have yet to be adjusted by the scatter fraction, barrier effect factor or the shape factor. It can now be understood why the direct contribution remained unchanged when only Z was changed. It will also be shown how the unadjusted skyshine and scatter contributions can vary with a change in ω.

The next parameters to be discussed are W and L. A change in either or both of the dimensions W or L will have a corresponding change in the plan area of the structure. Keeping all other parameters constant, an increase in either W, L, or both will result in an increase in ω_L and ω_u. As ω_u increases, the overhead contribution $C_o(X_o,\omega_u)$ will increase, but the upper and lower wall segments will contribute less. With a decrease in either W, L, or both, the reverse will be true. As can be seen from the discussion, one can interpret qualitatively the separate effect of a change in the parameters W and L on the roof and wall contributions. As before, the combined effect may be hard or impossible to interpret qualitatively. Table 5 gives values for C_g and C_o for the bunkerhouse structure by varying W and L by a factor of "X" which will range from ½ to 3. From Table 5 it can be seen that as W and L, or the plan area, is increased the value of C_o increases while the value of C_g decreases. Again, rash assumptions should be avoided due to some exceptional cases.

The effect of interior partitions will be mentioned next. Interior partitions provide further protection through two means, First, they furnish an increase in the mass thickness between the source of radiation and the detector. This is true for both the ground and a portion of the roof contribution. Table 3 shows how the contributions and the protection factors vary with a variation in the interior partitions mass thickness. The interior partitions were placed half way between the detector and the exterior walls. Table 3 shows that as the interior partition mass thickness goes up the ground and overhead contribution will both go down and the PF will go up.

The position of the interior partition is also important. Due to the position of the partitions, the C_o contribution is divided into two parts as shown by Figure 5. This shows the effect of interior partitions on the radiation that reaches the detector. The area designated by the letter A represents the core area formed by the partitions in which the radiation from this area is unaffected by the partition. The area designated A_1 represents that radiation from the roof that is as yet unaffected by the interior partition. It can be seen that for this radiation to reach the detector, it must pass through the interior partition which will further reduce it. Any radiation incident upon the exterior wall must pass through the interior partition to reach the detector. The areas designated C and E represent that radiation incident upon the exterior wall that is yet unaffected by the interior partitions. The areas designated D and F represent the radiation that is emergent from the exterior wall that has been further attenuated by the interior partition. In summary, the general overall effect of interior partitions is one of reducing both C_g and C_o with a corresponding increase in the PF.

As can be seen from Figure 5, the wall contributions are only changed by the added mass of the partition and are independent of the partitions location. The relationship between the core and peripheral areas formed by the partitions is a very important factor in cutting down the overhead contribution to the detector. In the methodology, scatter radiation occurs only in the exterior wall or roof regions. Even though there will be some scattered radiation from the interior partition, it is incompletely understood and is thus neglected by assuming that the partition will scatter as much radiation away from the detector as it will to the detector. Table 6 shows what happens when the interior partition dimensions are changed. W_c and L_c represent the width and length of the core area respectively. The area was centered about the detector. The only parameters changed were W_c and L_c. As the area of the core is increased, the value of C_o is increased as would be expected. The location of the interior partition has no effect whatsoever on the value of C_g as is shown. Chart 7 shows the attenuation factors applied to interior partitions.

Apertures as will be discussed throughout the following material will represent windows, doors, skylights, or any opening in any wall or overhead barrier. Throughout the following, the emphasis will be placed only on openings in the exterior wall. It is assumed for discussion that the mass thickness of these apertures is 0 psf. In reality they may be some value around 5 psf or below. With such a low mass thickness the aperture will have a negligible influence on the radiation incident upon them. For analysis, any mass thickness of the magnitude of 5 psf or less is considered as an aperture and thus may be neglected.

Figure 6 shows the effect of apertures on a detectors response. Only the radiation that is incident upon the exterior wall will be considered since the overhead contribution is unaffected. Radiation that is incident upon the aperture is unaffected since neither scattering nor attenuation of the radiation can occur. The radiation that is incident upon the solid portion of the exterior wall is scattered and/or absorbed by the mass thickness of the exterior wall. In the case shown in Figure 6, the radiation emergent from the exterior wall is designated by the letter B. Radiation incident upon the aperature, in this case, is divided into two portions. The first portion designated by A is composed of skyshine radiation only. The second portion designated by C is composed of direct radiation.

There is another source of radiation that the detector will receive that enters through the aperture, ceiling shine. Ceiling shine is that radiation that enters the aperture from the contaminated ground plane, strikes the ceiling and is deflected to the detector. Generally the ceiling shine contribution will be negligible, but there are some situations in which it may be very important. In general the affect of ceiling shine is washed out by the affects of scatter and direct radiation. When there is little direct or scatter radiation the ceiling shine may become significant. This is especially true in buildings that contain many large windows. The ceiling shine contribution is part of the total ground contribution and is designated by G_c. Values of G_c will be given in the tables for the aperture calculations.

Three parameters deal specifically with apertures. These are the sill height, perimeter ratio, and area of the window. The sill height of a window is obtained by measuring the distance from the floor to the sill of the aperture. If the sill falls below the horizontal plane running through the detector the aperature will allow direct radiation to enter the structure. This is the case as shown in Figure 6. As the sill height is lowered below 3 feet there may be a pronounced adverse effect on the protection of the structure due to the increase of the direct contribution. Table 8 shows the affect that a variation in the sill height has on the structure. For these calculations the area of the window was kept constant and the perimeter ratio was set equal to unity. By keeping the perimeter ratio equal to unity and the window area constant only the detector's response to the variation in the sill height will be measured. It should be noted that, as shown in Table 8, as the sill is dropped below 3 feet, the protection factor drops very significantly due to the increase in C_g. It should also be noted that as the sill height is raised from 0 to 5 feet, the ceiling shine contribution increases. In summary, sill heights below 3 feet generally have an adverse effect on the structure.

The aperature area is also important from the standpoint that as the aperture area increases, there will be a corresponding decrease in the material of the wall with which the radiation may interact. Table 7 shows the result of varying the area of the aperture. The perimeter ratio was set equal to unity and the sill height was set equal to 3 feet. From Table 7 it can be seen that as the aperture area increases, the ceiling shine and ground contribution both increase while the protection factor decreases. In general, windows produce an adverse affect on the protection of a structure. The exceptions to this were discussed earlier when it was stated that exterior walls that have a small mass thickness will actually be more harmful than if they had a mass thickness of 0 psf.

The perimeter ratio may be defined as the fraction of the perimeter of an aperture strip that is occupied by apertures. An aperture strip is a strip running completely around the structure that has a thickness equal to the average height of the apertures. Thus a perimeter ratio equal to unity means that a continuous aperture runs completely around the building. As the perimeter ratio assumes some value less than 1, the aperture strip is now composed of apertures along with the wall material separating the apertures. Table 9 shows what effect the perimeter ratio has on the contributions and protection factor of the building. In determining the values of Table 9, the window area and sill height were kept constant, with the area equal to 200 square feet and the sill height equal to 3 feet. Table 9 shows that as the perimeter ratio decreases the C_g contribution decreases with the resulting increase in the protection factor.

It can be seen that windows generally have an adverse affect on the protection of the structure with the area of the windows, the number of windows present, and the sill height being important factors.

Partially buried or completely buried structures provide improvement in the protection afforded by the structure. The bottom drawing in Figure 3 shows the structure depressed with respect to the plane of contamination. If the detector were to remain 3 feet above the floor of the structure, the detector will also be depressed with respect to the contaminated plane. As the structure is depressed into the ground, that portion of the exterior wall buried will not yield any contribution to the detector. It can be visualized that as the structure is depressed into the ground, the direct and scatter contributions from the lower wall segment will be reduced. When the structure is depressed 3 feet into the ground the lower wall segment will not yield any contribution to the detector. As the structure is further depressed into the ground the upper wall segment yielding scatter and skyshine contributions will show a reduction in these contributions. When the structure is completely buried, there will be no ground contribution and the only radiation reaching the detector will be the overhead contribution. As the structure is further depressed to the point where it is completely buried and the roof is covered with earth, the protection will be increased due to the added mass thickness provided by the depth to help attenuate the overhead contribution.

The qualitative interpretation of the effect of burial, with all other parameters remaining constant, is to increase the protection of the structure. Table 2 compares the contributions and protection factors of the blockhouse structure as the value of H is varied. The columns with the values of H equal to -10, 0, 1.5 and 3 feet are of concern in this discussion. When H is equal to -10 feet the structure is completely buried. When H is equal to 3 feet, the structure is not depressed at all. As H decreases, the value of C_g becomes smaller until the building is completely depressed into the ground where the value of C_g becomes 0. It should be noted that as long as the overhead mass thickness remains constant the overhead contribution will remain constant independent of what the value of H is.

As the detector is moved upward from the plane of contamination, less radiation will be received from the source. The reason for this may not be evident at first. If two particles, on the infinite horizontal plane upon which we assume the building to be, are considered as the only source of radiation, then a line drawn from the source to the detector may be called the direct path or slant distance from the source to the detector. It can be shown that the further the particle of contamination is from the detector, the larger the slant distance between the source of radiation and the detector becomes. It can also be shown that for particles further away, horizontally, from the structure the magnitude of change in the slant distance is smaller for a given change in H. It may be recalled that radiation generated in the fallout particles on the contaminated plane must travel through the air in order to reach the detector. The greater the distance through the air that the photons must travel, the greater the barrier effect of the air due to the mass thickness of the air itself. Also since the intensity of radiation follows the inverse square law of light, the distance between the source and the detector becomes very important. An increase in H will create an effective increase in the mass thickness of the barrier due to the increase in the slant distance through the barrier material of the structure. This is more significant for close-in particles.

The upper sketch in Figure 3 shows the structure elevated above the plane of contamination. No contribution will reach the detector through the floor. Skyshine radiation in the upper wall segment will remain unaffected by the variation in H. Scatter radiation in both the upper and lower wall segments will change some. Elevating the detector does not eliminate any particle from the consideration of it being scattered. However, by increasing the slant distance we have increased both the distance through the air and barrier material that the radiation will travel and thus allowed for more interaction of the radiation between either the air or the barrier or both. The portion of the wall below the detector provides direct radiation which will also be affected by elevating the structure. In the top drawing of Figure 3 it can be seen that if the lines from the detector to the floor corners were extended to the contaminated ground plane, that a portion of the close-in fallout will not be seen by the detector and thus can not yield any direct radiation. This fallout can yield only scatter and skyshine radiation. In effect the plane of contamination was moved away from the building when considering the direct contribution. By increasing the slant distance that the direct radiation may be initiated from, there will be a reduction in the direct contribution for the same reasons mentioned earlier. This reduction in the direct contribution is a very important factor in that upper story locations in multistory buildings often afford excellent protection. It should be obvious that the overhead contribution is unchanged with an increase in the detector height since Z remained unchanged. Table 2 shows how the contributions and the protection factors change by increasing H above the contaminated plane. The columns containing the values of H equal to 3, 6, 10, and 100 feet are used for the elevated structure. It can be seen that as H increases the ground contribution decreases with a corresponding increase in the protection factor.

Mutual shielding may occur when either another building or some structure is adjacent to the building under consideration and will block off some radiation by acting as a barrier. Thus adjacent buildings may effectively reduce the amount of radiation reaching the detector. Depending on how close and how tall the adjacent structure is to the one being studied, some skyshine may also be eliminated. When a building is surrounded by other buildings of some size, the contribution through the walls of the building in question is essentially limited to radiation from those particles on the streets, alleys, and open spaces between the buildings. In other words the other structures have limited the field of ground contamination which will affect the structure. Radiation originating from other ground sources is effectively blocked off by the other buildings. Stone walls or retaining walls can also produce this limited field effect. Thus mutual shielding may prove to be very effective in reducing the wall contributions. "Mutual shielding is an important parameter in shielding calculations and, in part, accounts for the fact that large numbers of shelter spaces having acceptable factors are located in aboveground positions in many buildings." (6)

Multistory buildings will be discussed next. With the basic understanding of the single story blockhouse structure and the qualitative interpretations made with respect to the parameters involved, only a few simple extensions need be applied to understand a multistory building. From Figure 7 it can be visualized that for any radiation to reach the detector from the contaminated roof, it must travel through the roof and the intervening floors to reach the detector. The mass thickness of the intervening floors will aid that of the roof in attenuating the radiation. Also as explained previously the further away the roof plane of contamination is from the detector, the smaller the contribution it will yield to the detector. Thus, as one goes down through the building the overhead contribution will decrease due to a decrease in the solid angle fraction for the roof and the increase in mass thickness added by each intervening floor between the detector and the contaminated roof plane.

The reduction in the ground contribution will be for the same reasons as were applied to the single story structure when the detector height above the contaminated ground plane was increased.

There are some other reasons for the reduction in the ground contribution that are unique to the multistory structure. The skyshine contribution through the exterior walls of the detector story is no different than that for the single story structure, but the skyshine radiation that enters the structure above or below the detector story must pass through the intervening floors and possibly some interior partitions to reach the detector. Thus the skyshine radiation entering the structure much above or below the detector story will be completely eliminated.

The scatter radiation reaching the detector undergoes the same affect that the skyshine does. In the methodology used to analyze the structure, only the wall contributions from the floor above and below the detector story are considered. Since the radiation from the story above or below the detector may enter the detector story only by passing through the ceiling or the floor of the detector story, an attenuation factor is applied to the entering radiation to account of the attenuating properties of the ceiling and the floor. Chart 8A and 8B show these attenuating factors for the ceiling and the floor.

Four multistory structures were analyzed to show the effects discussed above. Table 10 shows the results of the analysis. All of the multistory structures were 10 stories high and had a basement. The story heights were 13 feet, giving the over-all building height of 130 feet. The plan dimensions were 100 feet by 100 feet. The roof mass thickness was set at 10 psf with the floor mass thickness set at 50 psf. The multistory building was then analyzed as if it were placed on an infinite horizontal plane by itself. The exterior wall mass thickness of the structures A, B, C, and D are 80, 20, 0, and 20 psf respectively. As can be seen from the results for the four structures, the overhead contribution decreased going down through the building while the ground contribution increased except for the basement area as would be expected. It should also be noted that as one goes up through the structure the PF values increase up to a point and then start to decrease again. This is explained by the fact that at or near the top of the structure the majority of the R_f is made up of the overhead contribution while at the bottom the major contribution is from the ground. As you go through the structure, the magnitudes of the overhead and ground contributions change until at some location in the midregion of the structure the summation of the overhead and ground contributions is a minimum.

It is important to note the difference between the ground contribution and the protection factor for structures B and C. Even though structure C has no exterior wall mass thickness to attenuate the ground contribution, it still has low ground contributions and high protection factors for levels 3 through 10. This shows the effect that a light mass thickness wall has on scatter.

Structure D is somewhat different from the others in that interior partitions were placed in it. The interior partitions were located half way between the exterior wall and the detector. They were given a mass thickness of 42 psf which would correspond to a lightweight hollow concrete block. The total mass thickness of the exterior wall and interior partition together is 62 psf which is lighter than the exterior wall used for structure A. Comparing structure A with structure D we see that the interior partitions made a pronounced difference. As explained in the section on interior partitions the overhead and ground contributions were both reduced.

There are many problems associated with trying to describe in simple terms the parameters involved in shelter shielding for fallout radiation. So many of the parameters are interrelated with one or another that the total overall effect on the structure that a change in one parameter would be difficult or impossible to judge qualitatively. Also as pointed out through the report there are many exceptions or special cases for each rule. It is emphasized here that each structure must be analyzed individually. The preceding material presents only the most common parameters that are considered. Understanding these basic parameters and generally what effect they have on the protection provided by the shelter should aid the designer if he wants to consider providing fallout shelter in a structure. After the designer makes his preliminary design keeping in mind the parameters involved, he should then submit the design to be analyzed quanitatively by a qualified shelter analyst to determine the location of existing shelter or what could be done to provide shelter in the structure.

SLANTING AND SLANTING TECHNIQUES

Existing buildings, or buildings in the preliminary design stage may contain weak points with respect to providing shelter from fallout. When the structure is analyzed quantitatively the weak points will show up and can thus be specifically identified. If the structure is to include shelter, the structure must be slanted. The basic function of slanting is to increase the protective characteristics of a designated or possible shelter area in the building without creating a significant increase in the cost, or without sacrificing the esthetics, function, or efficiency of the structure. If one fully understands and recognizes the various parameters that influence protection factors, then through the judicial application of three of the basic form principles namely distance, geometry shielding, and barrier shielding, the weak points may be correcte thus providing protection.

Quantitatively, slanting requires a detailed evaluation of the contri butions involved in the total reduction factor in order that the analyst may observe to what extent each contribution influences the degree of protection. As stressed earlier, each building has its own individual characteristics with respect to the radiation shielding parameters to be considered. In the Office of Civil Defense publication Shelter Design and Analysis--Fallout Radiation Shielding, several items for consideration in slanting are suggested. As stated in the publication, this list is by no means complete nor are the items listed applicable to all structures If shelter is to be provided, these items may aid the designer throughout all phases of the design of the structure. Some of these items are listed below.

(1) A building can often be located on a site so as to achieve maximum benefit of mutual shielding from adjacent buildings.

(2) Topography of such a nature that the earth slopes down away from the building can materially reduce the direct contribution through the walls. This may be a natural feature of the site or a consideration in the grading plan.

(3) In grading of the site, earth berms artificially produced and attractively designed can provide a very effective element of field limitation and increased protection.

(4) Walls as low as 3 feet high for first story (floor at grade) shelter areas, can serve effectively in limiting the contributing field of contamination. These could be screen walls, retaining walls or planter boxes.

(5) Where it is not appropriate to depress a potential shelter area completely below ground, consideration may be given to a partial depression of the first floor. This eliminates the contribution through the depressed portion of the wall while still allowing the normal amount of light and ventilation.

(6) Planters, immediately adjacent to the exterior walls, up to detector height in first story shelter locations could add enough mass thickness to reduce the contribution from below the detector plane to negligible quantities.

(7) Raising of sill heights to at least detector level aids materially in reducing direct radiation contributions.

(8) Modern lighting systems are such as to eliminate the necessity for wide expanses of glass as light sources. Consideration should be given to reducing window areas as much as possible.

(9) In aboveground shelter locations, interior corridors often offer good potential for shelter areas, but this potential is often nullified by entranceways permitting direct entry of ground radiation. In many instances, doorways can be positioned off corridor ends to eliminate direct entry, or baffels can be used to provide barriers at the corridor ends.

(10) Consideration should be given to the use of dense solid walls, both exterior and interior.

(11) Where walls or partitions are constructed of hollow masonry units, increased mass thickness can be obtained by filling the voids with sand, gravel or grout at little additional cost.

(12) Interior partitions can be judiciously placed to block direct entry of radiation into a shelter area.

(13) Openings in partitions and exterior walls should be studied from the viewpoint of staggering them so as to avoid direct penetration of radiation into a shelter area without the benefit of barrier reduction.

(14) The arrangement of building elements can be such as to obtain maximum advantage in forming a protected core area.

(15) Protection afforded by protective core areas can be materially enhanced by more massive construction in partitions, floors and roofs than that of other portions of the building.

(16) Due consideration should be given to the more massive types or structural systems for floors, walls and roofs. Cost differentials between such systems and lighter forms of construction are often negligible, but the more massive system obviously provides greater protection.

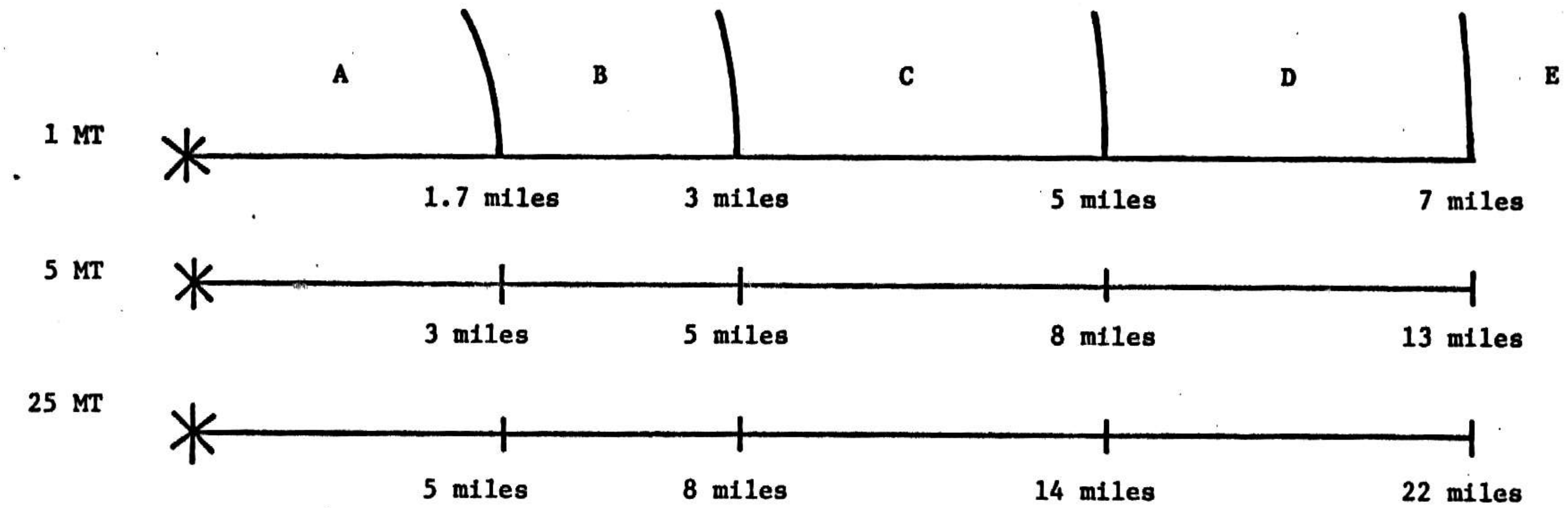
(17) In interior corridors of aboveground buildings, protection can be enhanced by using a more massive type of floor or roof construction directly overhead.

(18) Stairwells can be positioned to provide additional barrier shielding at corridor ends.

CHAPTER III SUMMARY AND CONCLUSION

As has been stated in the introduction, to utilize structural designs that would afford mass protection against initial radiation, thermal radiation, and blast effects would be an economic impracticability. Thus it is the present practice to design the shelters to protect the occupants only from the gamma radiation produced from fallout. The location and accessibility of these shelters is a very important point to consider. Shelters in the central business district of large cities are of little use to those people in the suburbs since they may not be easily accessible. Thus, there is a need to put the shelters where the people are. Dual-purpose shelter space in such buildings as new schools which tend to be centered in the neighborhood population areas which would be more readily accessible to the population. In the publication Shelter Design and Analysis--Fallout Radiation Shielding mentioned earlier, it was pointed out that engineers and architects should recognize that, for increasing numbers of clients, the fallout shelter has become still another functional design requirement and that the designer must understand and be aware of the principles involved in shelter shielding. Techniques in building design that provide protection against radiation may yield other benefits. Substantial materials although having, generally, a higher capital cost than lighter materials may pay dividends in the long run in the form of being easier to maintain, need not be replaced as often if ever, may provide for lower insurance cost, and may also counteract noise pollution. For protection to be most effective and economical, it must be considered in the early design stage by designers and analysts that are knowledgable in shelter shielding.

APPENDIX



Area Classifications for Blast and Thermal Damage

Area A: Total destruction, Pressures in excess of 12 psi, 98% of the people dead, 2% of the people hurt, many fires initiated.

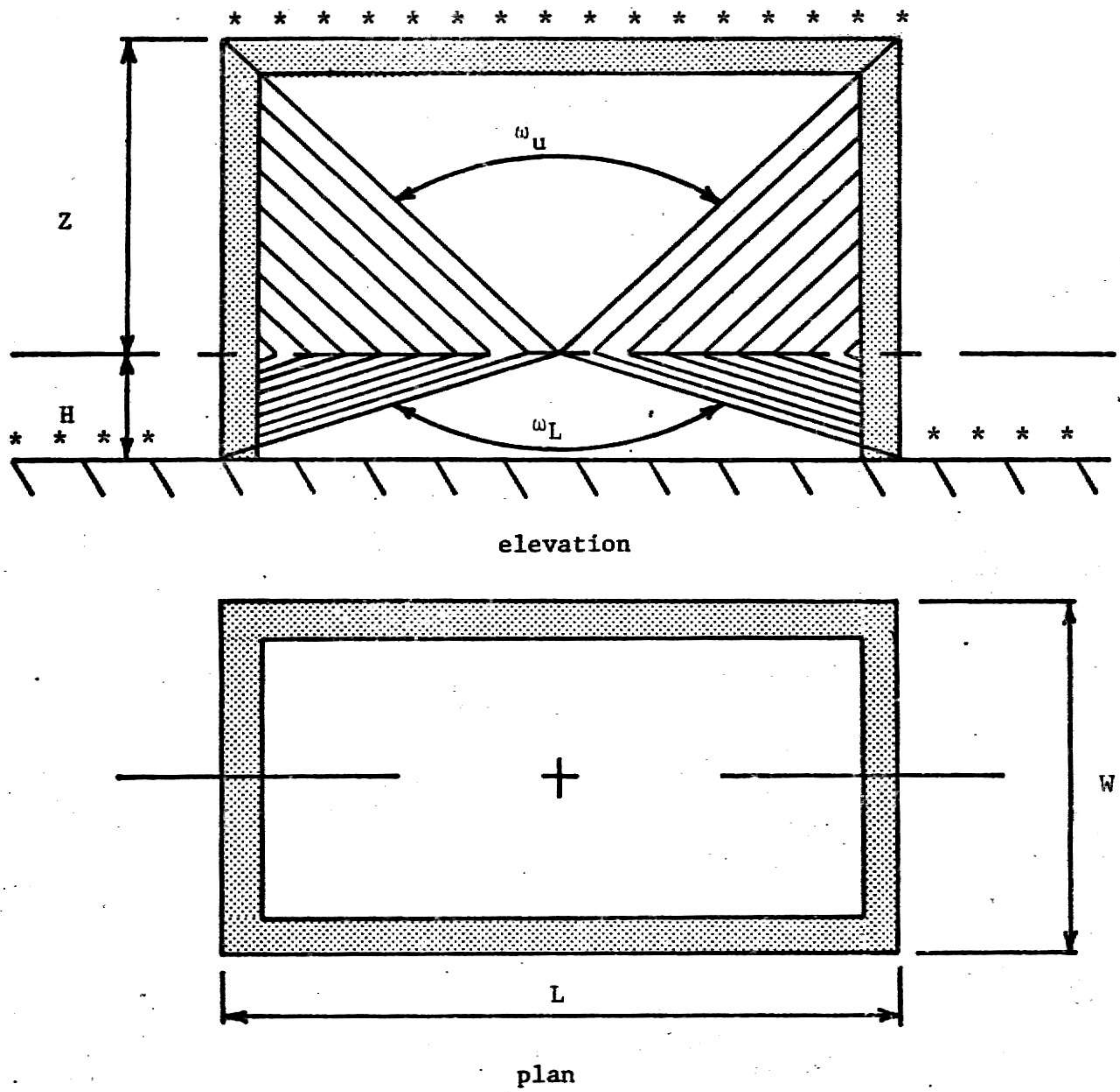
Area B: Heavy damage, Pressures from 5-12 psi, 50% of the people dead, 40% of the people hurt, 10% of the people are safe, many fires initiated.

Area C: Moderate damage, Pressures from 2-5 psi, 5% of the people dead, 45% of the people hurt, 50% of the people are safe, many fires initiated.

Area D: Light damage, Pressures from 1-2 psi, 25% of the people hurt, 75% of the people are safe, potential fire spread.

Area E: Little if any damage, Pressures from 0-1.5 psi, 100% of the people are safe, potential fire spread.

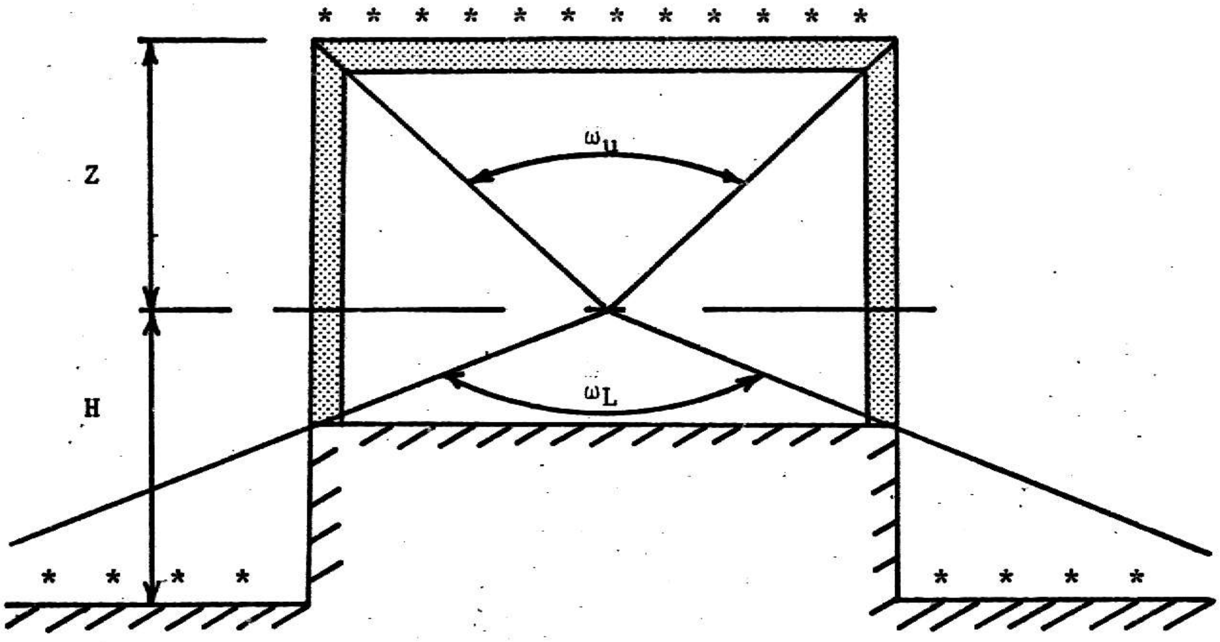
Fig. 1 DIRECT EFFECTS OF BLAST AND THERMAL DAMAGE
(Surface Burst)



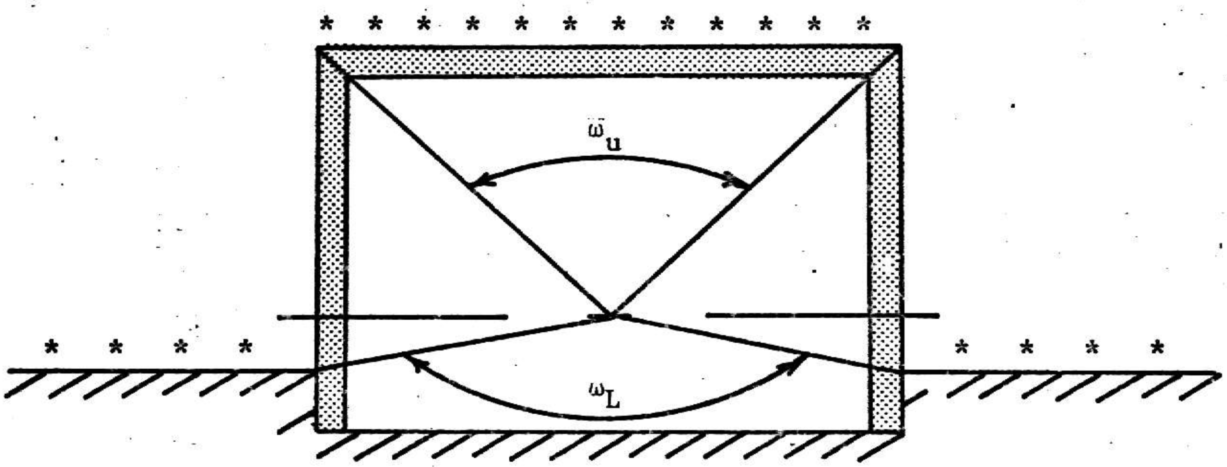
W = 40 ft.
L = 60 ft.
H = 3 ft.
Z = 10 ft.
X_o=150 psf
X_e=100 psf

These values will remain constant unless otherwise noted.

Fig. 2 SINGLE-STORY BLOCKHOUSE

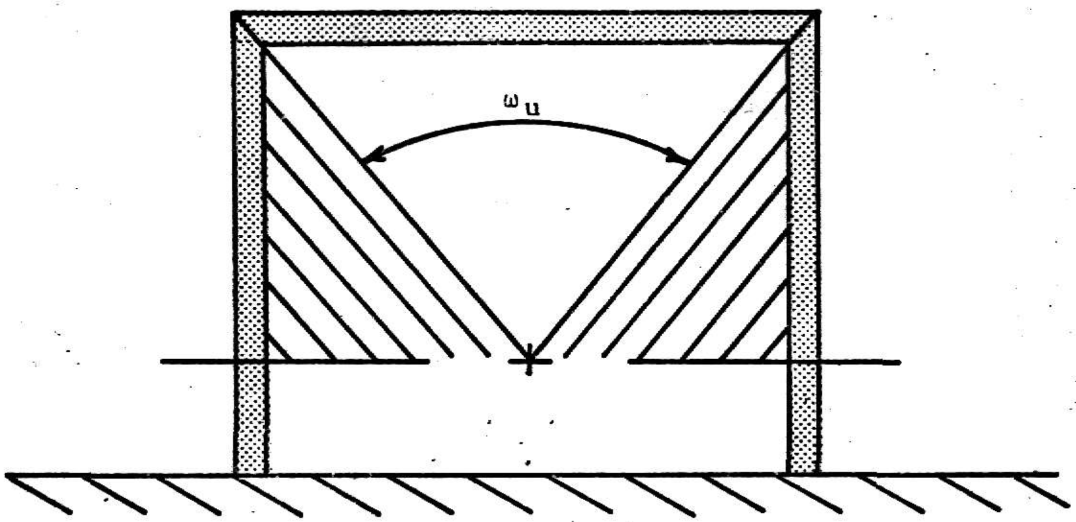


Elevated Detector With Respect To The Plane Of Contamination

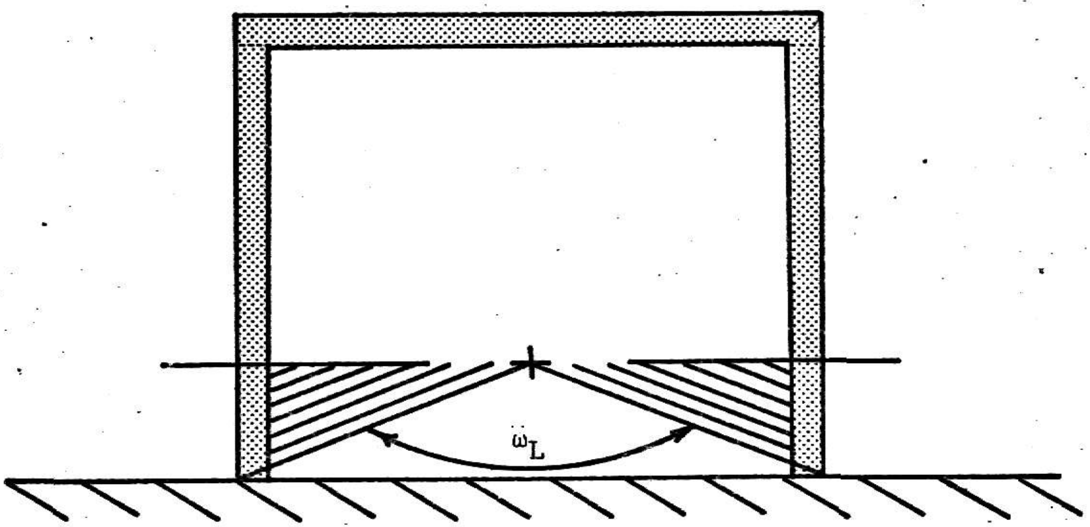


Depressed Detector With Respect To The Plane Of Contamination

Fig. 3 VARIATION OF DETECTOR HEIGHT (H) WITH RESPECT TO THE PLANE OF CONTAMINATION



Upper Wall Segment



Lower Wall Segment

Fig. 4 ZONE OF CONTRIBUTION FOR THE UPPER AND LOWER WALL SEGMENTS

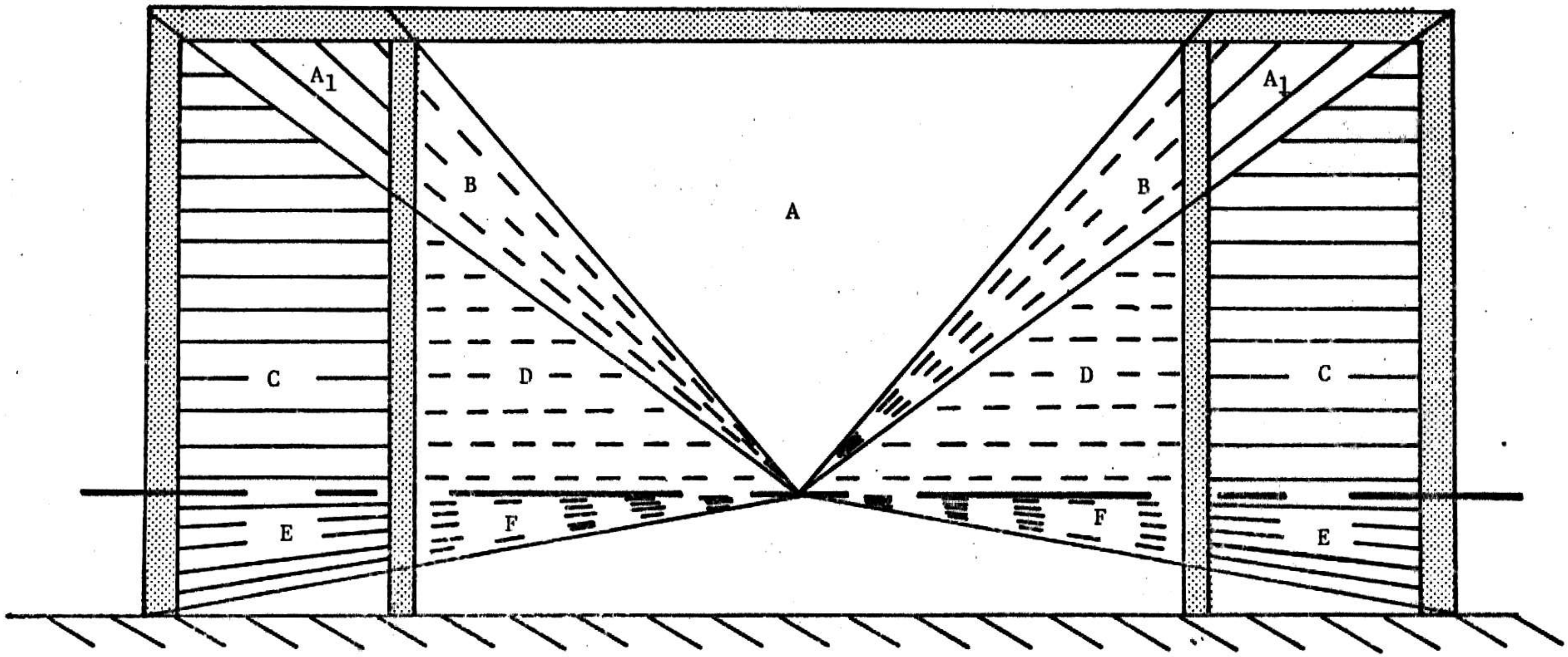


Fig. 5 EFFECT OF INTERIOR PARTITIONS ON DETECTOR RESPONSE

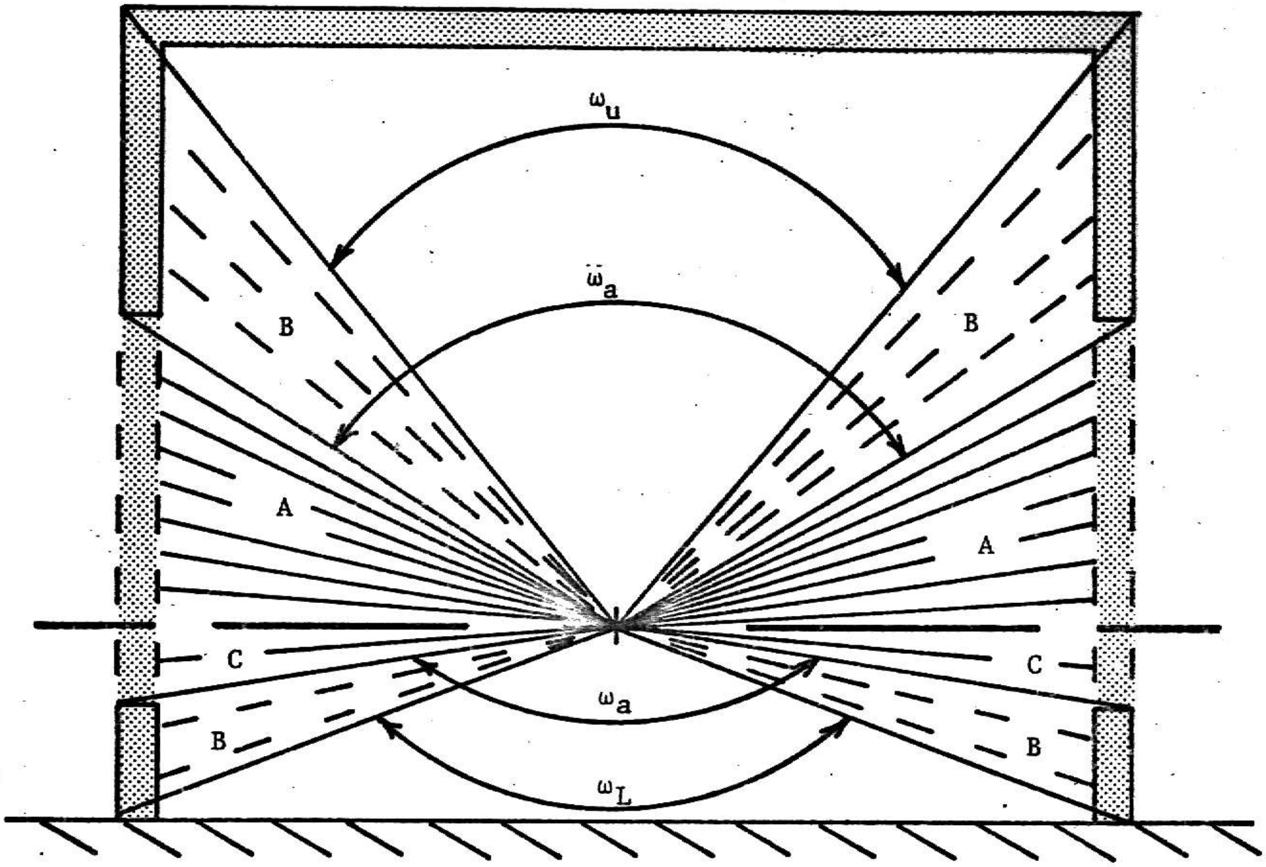


Fig. 6 EFFECT OF APERTURES ON DETECTOR RESPONSE

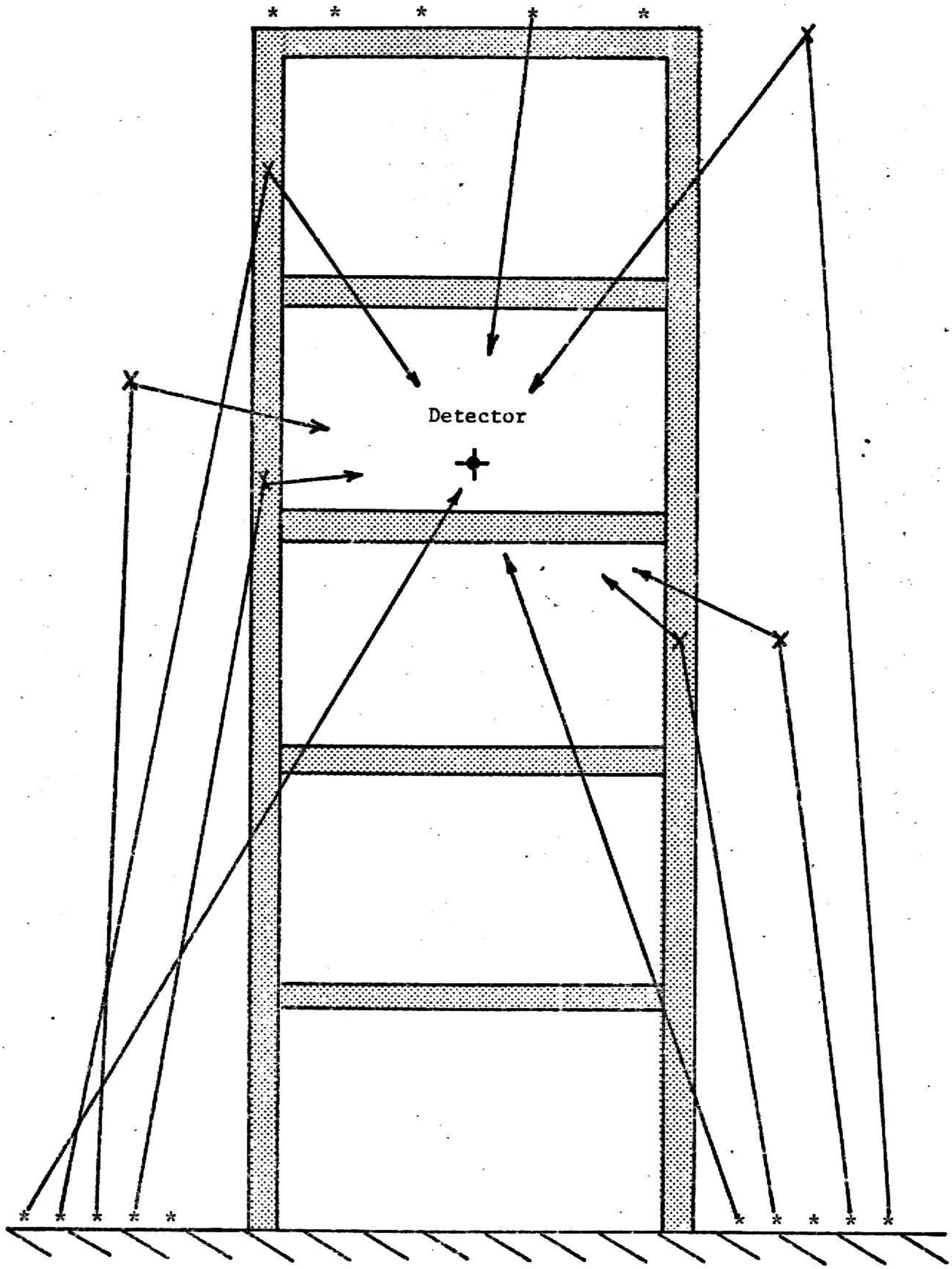


Fig. 7 MULTISTORY BUILDING

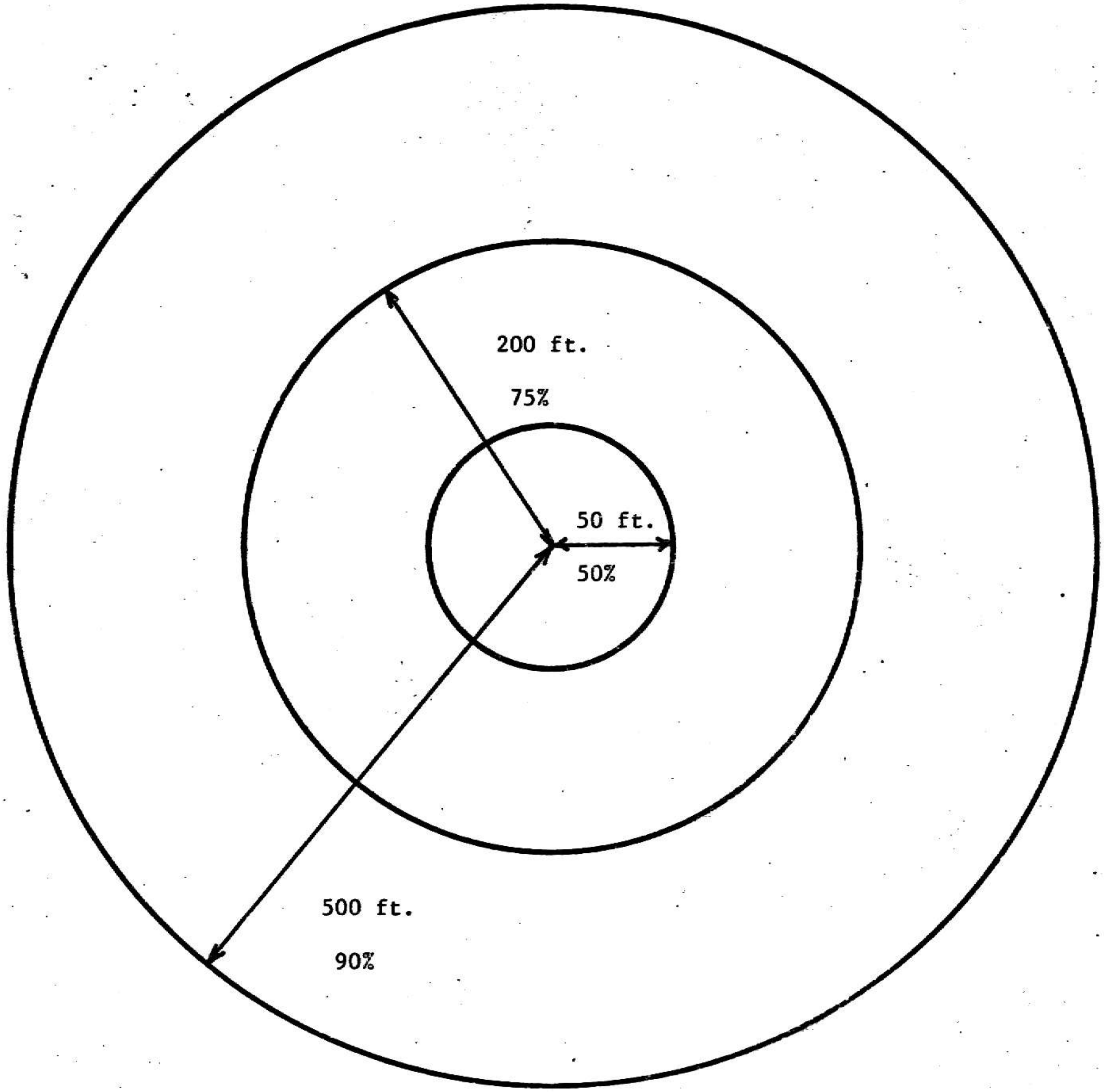


Fig. 8 DOSE CONTRIBUTION vs. DISTANCE

TABLE 1

Protection Factors and Contributions, Varying X_o and X_e

Overhead Mass Thickness (X_o)

Exterior Wall Mass Thickness (X_e) \ X_o	10 psf		50 psf		70 psf		100 psf		150 psf	
20 psf	C_g: .364 C_o: .171*	PF 1.9	C_g: .364 C_o: .054	PF 2.4	C_g: .364 C_o: .0285	PF 2.5	C_g: .364 C_o: .0147	PF 2.6	C_g: .365 C_o: .0043	PF 2.7
60 psf	C_g: .146 C_o: .171	PF 3.2	C_g: .146 C_o: .054	PF 5	C_g: .146 C_o: .0285	PF 5.7	C_g: .146 C_o: .0147	PF 6.2	C_g: .146 C_o: .0043	PF 6.7
100 psf	C_g: .057 C_o: .171	PF 4.4	C_g: .057 C_o: .054	PF 9	C_g: .057 C_o: .0285	PF 11.7	C_g: .057 C_o: .0147	PF 13.9	C_g: .057 C_o: .0043	PF 16.3
150 psf	C_g: .025 C_o: .171	PF 5.1	C_g: .025 C_o: .054	PF 12.7	C_g: .025 C_o: .0285	PF 18.7	C_g: .025 C_o: .0147	PF 25.2	C_g: .025 C_o: .0043	PF 34.1
200 psf	C_g: .007 C_o: .171	PF 5.6	C_g: .007 C_o: .054	PF 16.4	C_g: .007 C_o: .0285	PF 28.2	C_g: .007 C_o: .0147	PF 46.1	C_g: .007 C_o: .0043	PF 88.5

* Value of C_o, for X_o = 10 psf, was determined by computer instead of charts.

TABLE 2

Protection Factors and Contributions, Varying H

Detector Height (ft.)		-10	0	1.5	3	6	10	100
Contributions & Protection Factors	C_o	.0043	.0043	.0043	.0043	.0043	.0043	.0043
	C_g	0.0	.034	.047	.057	.049	.042	.015
	PF	232.6	26.3	19.5	16.3	18.8	21.6	21.8

TABLE 3

Protection Factors and Contributions, Varying X_i

Interior Partition Mass Thickness (psf)		0	10	30	90	150
Contributions & Protection Factors	C_o	.0043	.0040	.0038	.0036	.0035
	C_g	.057	.045	.027	.007	.002
	PF	16.3	20.6	32.5	95.2	188.7

TABLE 4

Protection Factors and Contributions, Varying Z

Distance From The Detector To An Overhead Plane Of Contamination (ft.)		8	10	15	20
Contributions & Protection Factors	C_o	.0045	.0043	.0038	.0036
	C_g	.053	.057	.062	.065
	PF	17.4	16.3	15.2	14.5

TABLE 5

Protection Factor and Contributions, Varying W & L

Factor For Distances W & L X(W) & X(L) where X is:		½	1	2	3
Contributions & Protection Factors	C_o	.0035	.0043	.0047	.0048
	C_g	.079	.057	.035	.025
	PF	12.1	16.3	25.2	33.6

TABLE 6

Protection Factors and Contributions, Varying W_c & L_c

Factor For Distances W_c & L_c X(W) & X(L) where X is:		1/4	1/2	3/4
Contributions & Protection Factors	C_o	.0027	.0038	.0041
	C_g	.0274	.0274	.0274
	PF	33.2	32.5	31.7

TABLE 7

Protection Factors and Contributions, Varying Aperture Area

Aperture Area (ft.^{2})		200	600	1200	2000
Contributions & Protection Factors	C_o	.0043	.0043	.0043	.0043
	C_g	.0627	.0731	.0850	.0990
	G_c	.0009	.0021	.0050	.0110
	PF	14.9	12.9	11.2	9.7

TABLE 8

Protection Factors and Contributions, Varying the Sill Height

Sill Height (ft.)		0	2	3	5
Contributions & Protection Factors	C_o	.0043	.0043	.0043	.0043
	C_g	.5102	.3118	.0850	.0953
	G_c	.0032	.0047	.0050	.0099
	PF	1.9	3.2	11.2	10.5

TABLE 9

Protection Factors and Contributions, Vary the Perimeter Ratio

Perimeter Ratio P_a		1	.67	.33	.2
Contributions & Protection Factors	C_o	.0043	.0043	.0043	.0043
	C_g	.0824	.0679	.0664	.0655
	G_c	.0014	.0014	.0016	.0022
	PF	11.5	13.9	14.1	14.3

TABLE 10

Multistory Structure Calculations

Structure: *		A	B	C	D
Contributions & Protection Factors					
<u>Level</u>					
10	C_o	.2382	.2382	.2382	.1928
	C_g	.0111	.0328	.0237	.0088
	PF	4	4	4	5
9	C_o	.0414	.0414	.0414	.0312
	C_g	.0119	.0353	.0256	.0094
	PF	19	13	15	25
8	C_o	.0091	.0091	.0091	.0091
	C_g	.0150	.0438	.0329	.0117
	PF	41	19	24	55
7	C_o	.0025	.0025	.0025	.0016
	C_g	.0163	.0472	.0361	.0126
	PF	53	20	26	70
6	C_o	.0006	.0006	.0006	.0004
	C_g	.0179	.0520	.0410	.0139
	PF	54	19	24	70
5	C_o	.0002	.0002	.0002	.0001
	C_g	.0200	.0580	.0475	.0156
	PF	50	17	21	64
4	C_o	.0000	.0000	.0000	.0000
	C_g	.0226	.0662	.0571	.0177
	PF	44	15	18	56
3	C_o	.0000	.0000	.0000	.0000
	C_g	.0265	.0803	.0763	.0215
	PF	38	12	13	47
2	C_o	.0000	.0000	.0000	.0000
	C_g	.0334	.1070	.1200	.0287
	PF	30	9	8	35
1	C_o	.0000	.0000	.0000	.0000
	C_g	.0534	.2040	.3037	.0546
	PF	19	5	3	18
Bsmt	C_o	.0000	.0000	.0000	.0000
	C_g	.0016	.0039	.0020	.0011
	PF	627	256	505	951

* Description of structure in material on multistory buildings.

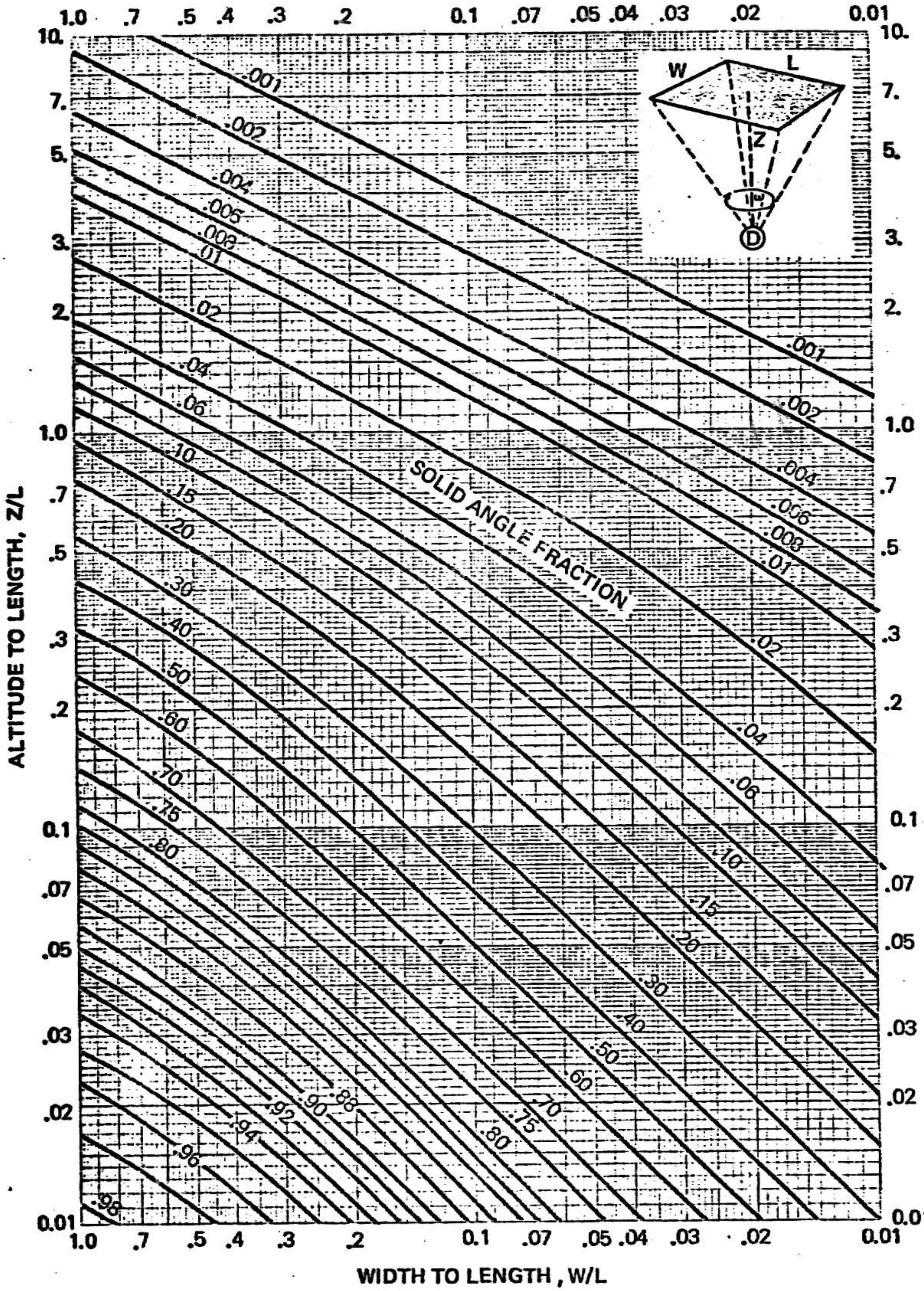


CHART 1 A

SOLID ANGLE FRACTION, ω(W/L,Z/L)

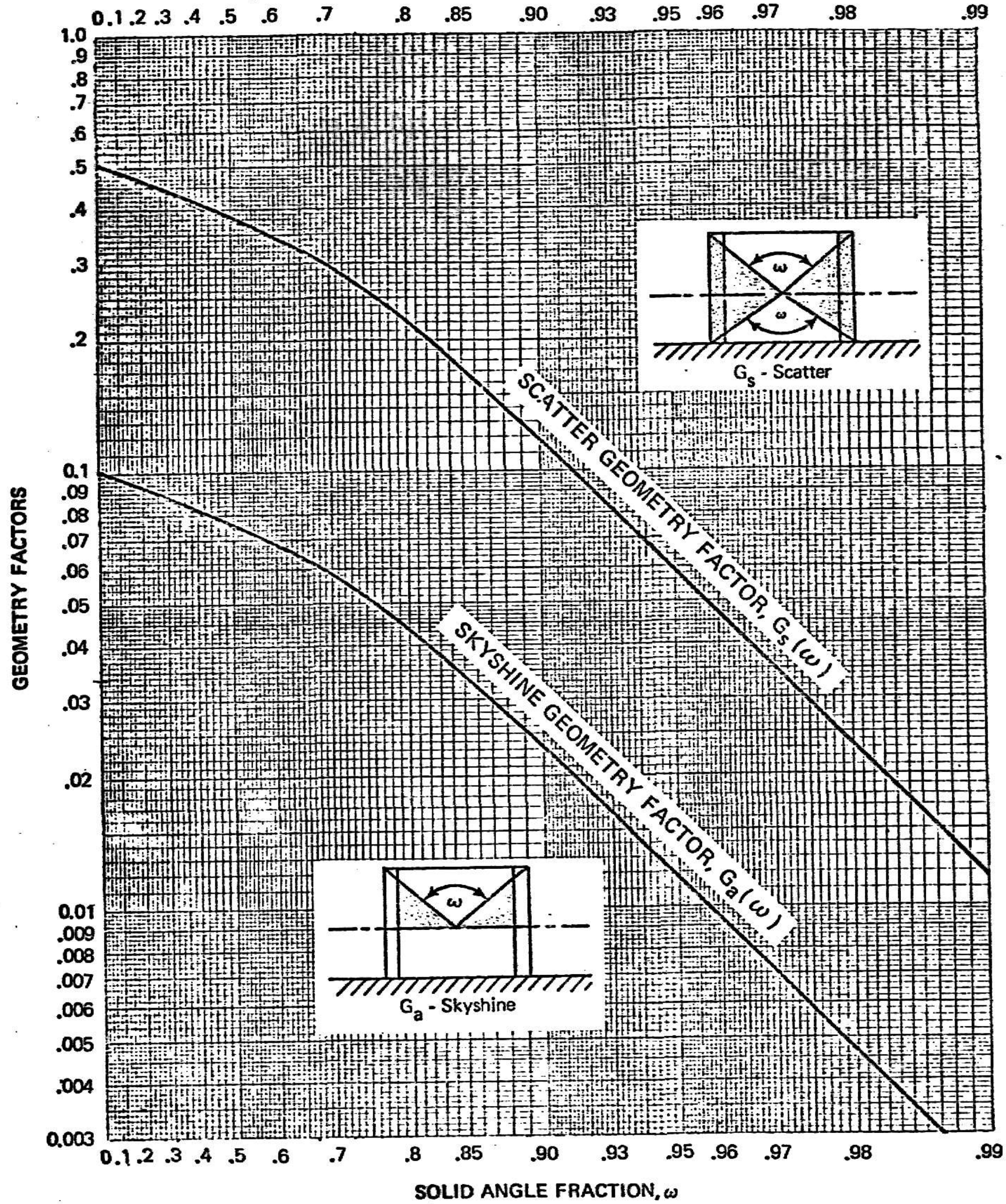


CHART 2

GEOMETRY FACTORS - SCATTER, $G_s(\omega)$ AND SKYSHINE, $G_a(\omega)$

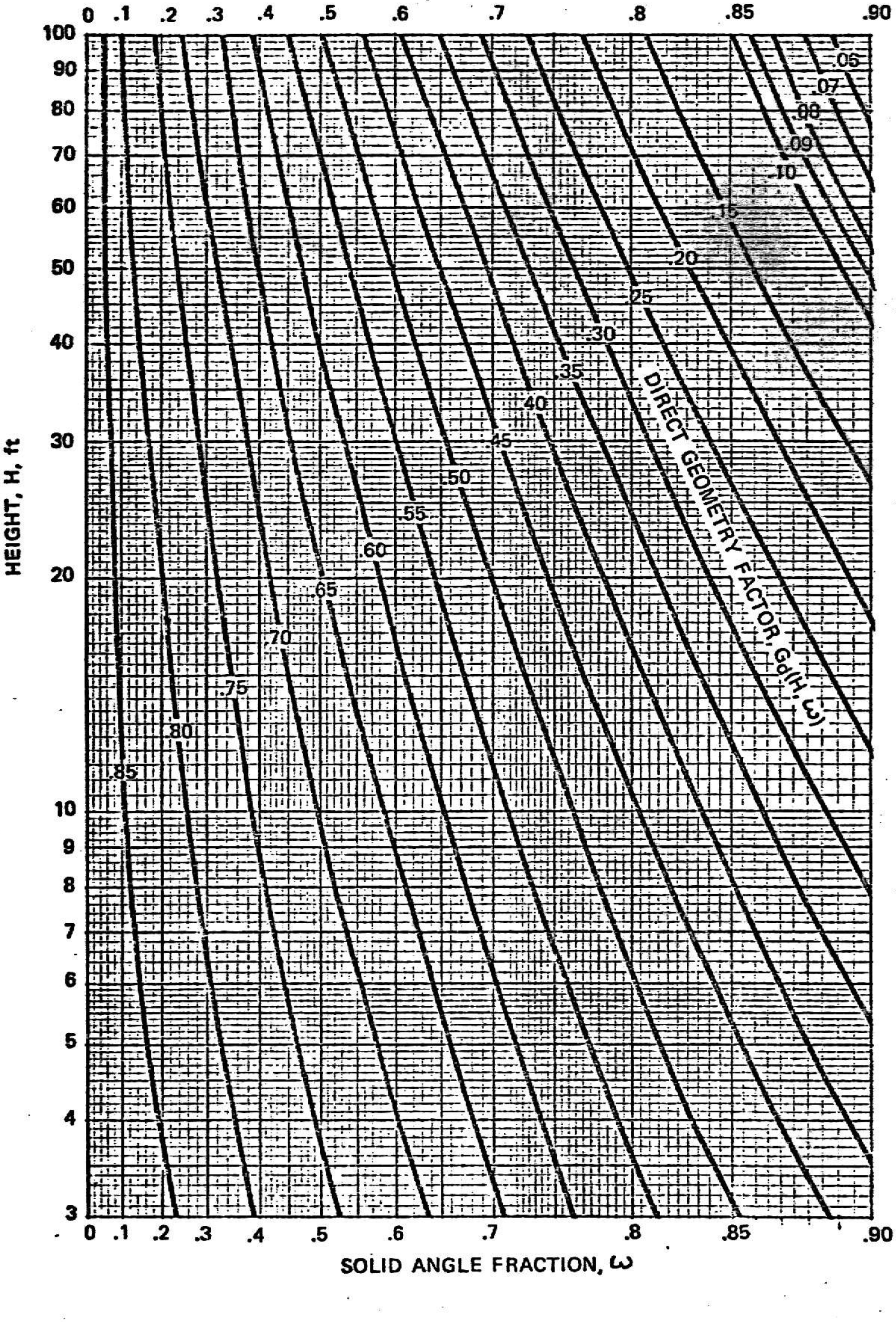


CHART 3A
GEOMETRY FACTOR - DIRECT, $G_d(H,\omega)$

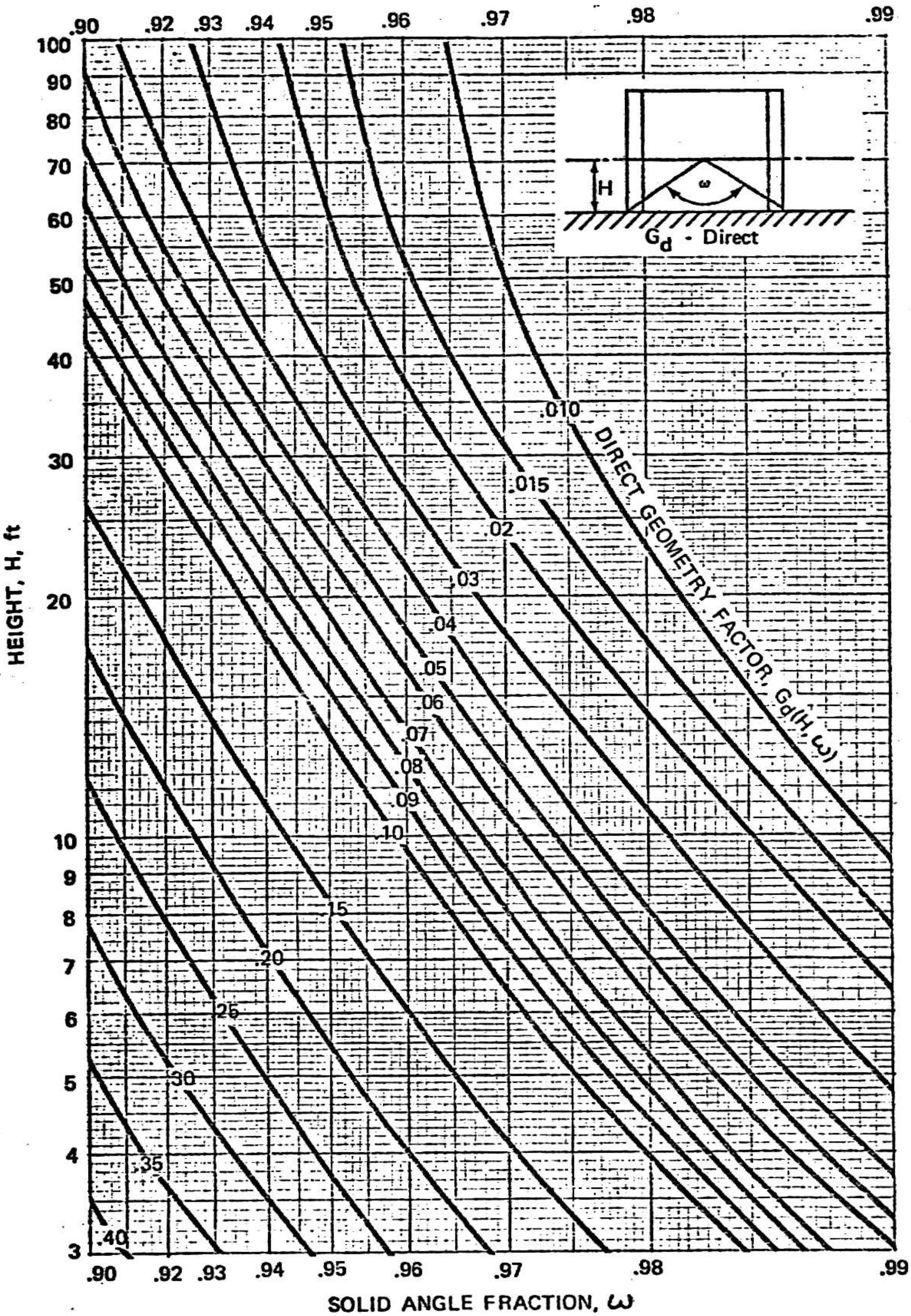


CHART 3B
GEOMETRY FACTOR - DIRECT, $G_d(H,\omega)$

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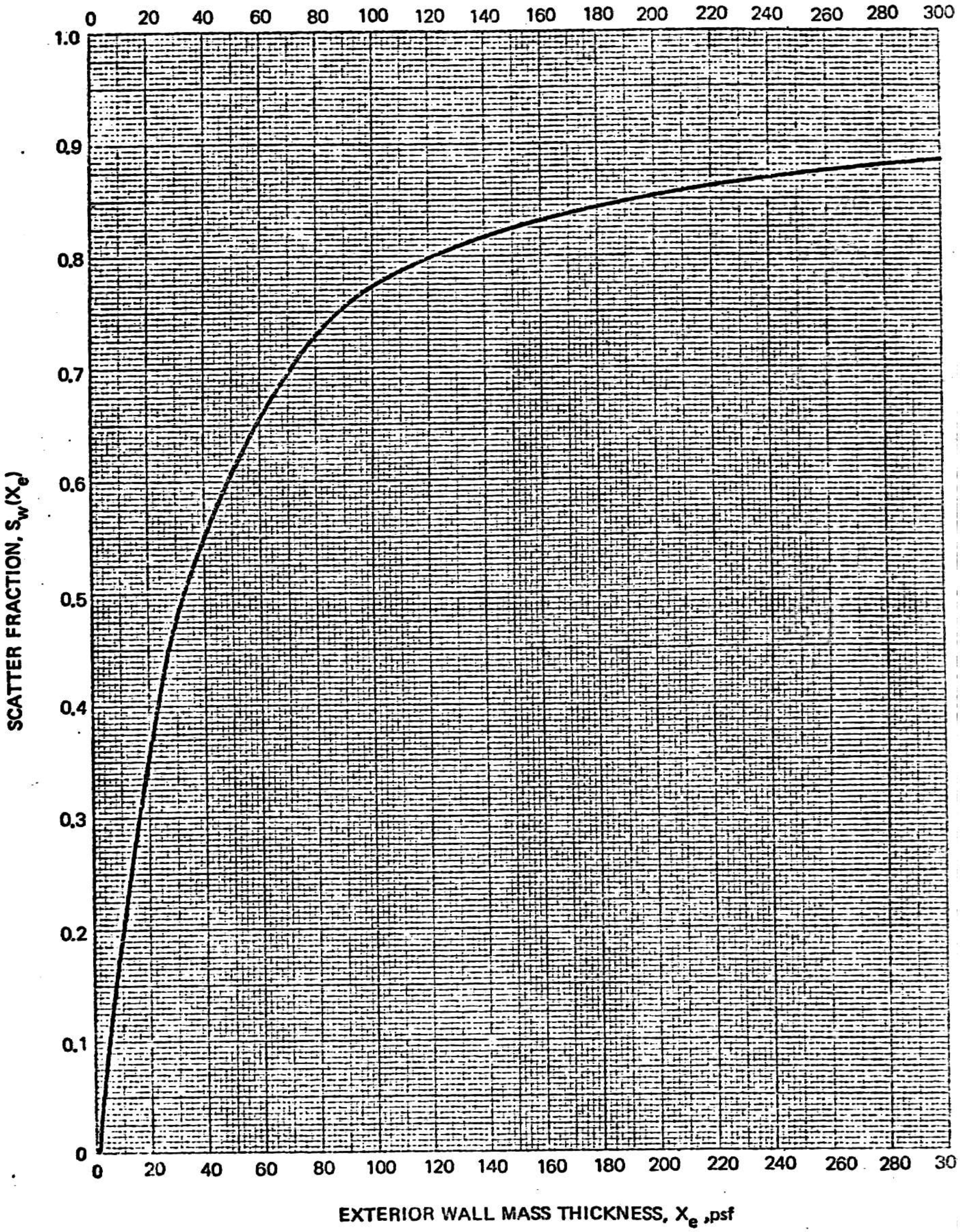

CHART 5

SCATTER FRACTION, $S_W(X_e)$

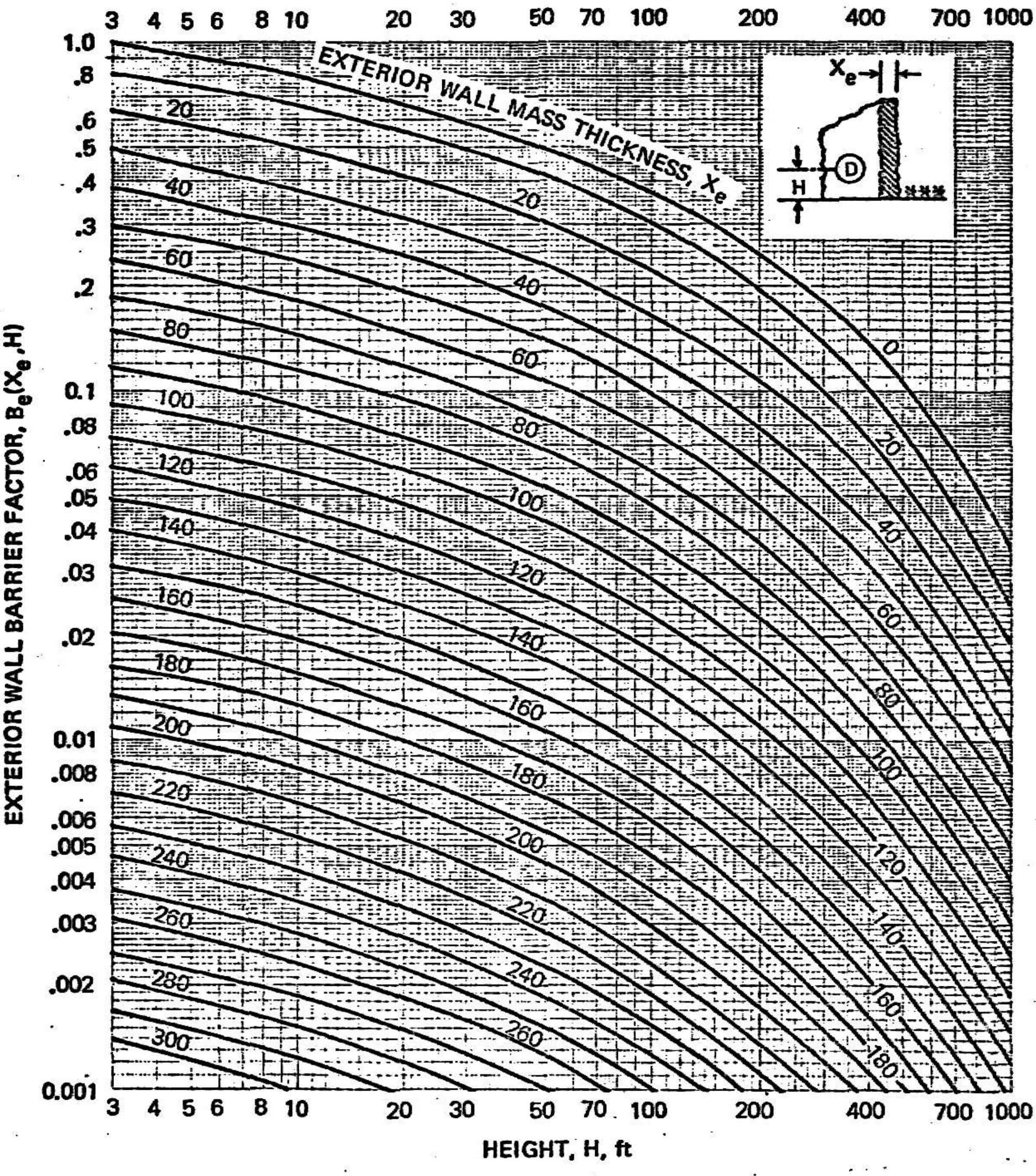

CHART 6

EXTERIOR WALL BARRIER FACTOR, $B_e(X_e, H)$

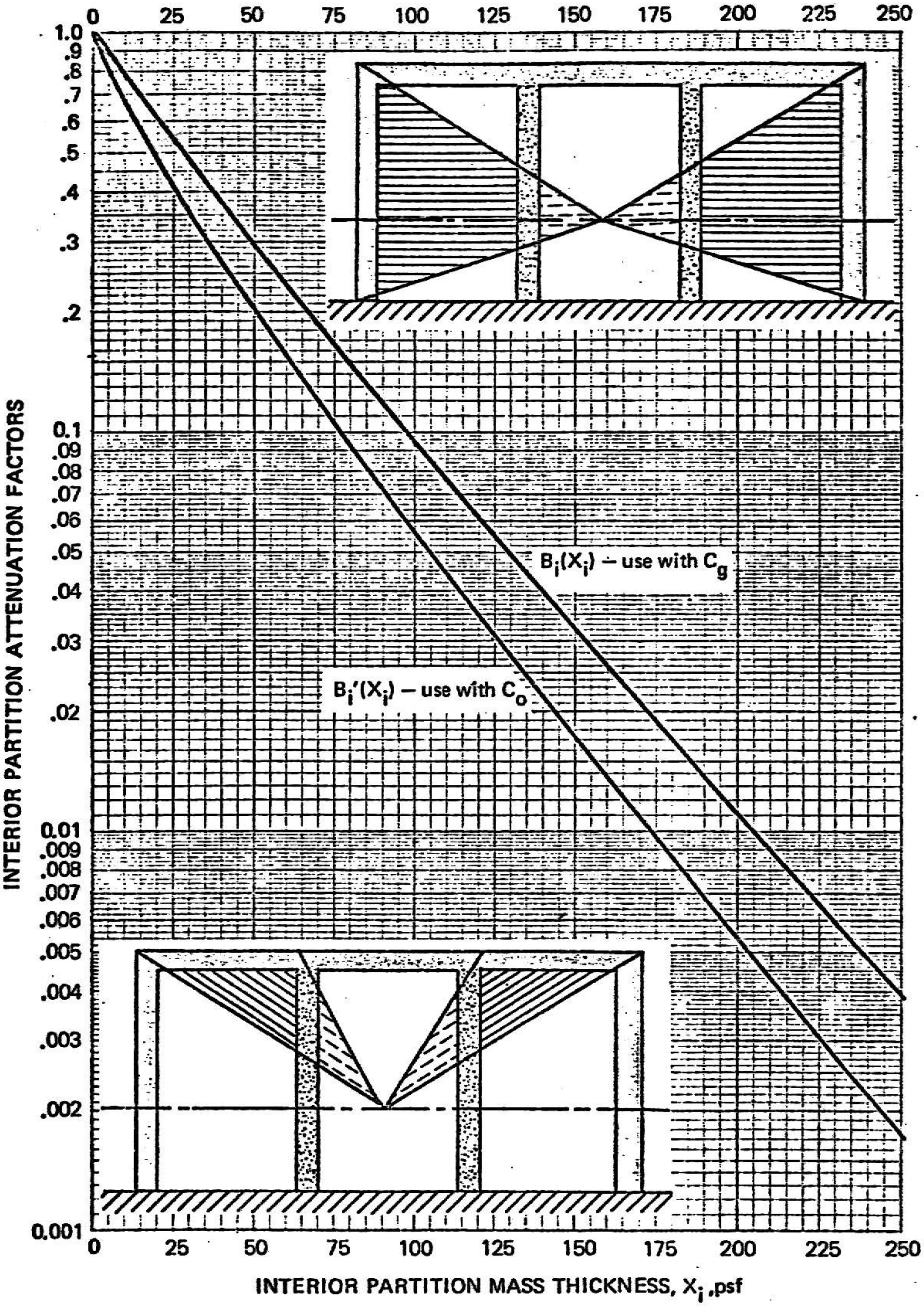

CHART 7
INTERIOR PARTITION ATTENUATION FACTORS, $B_i(X_i)$ and $B_i'(X_i)$

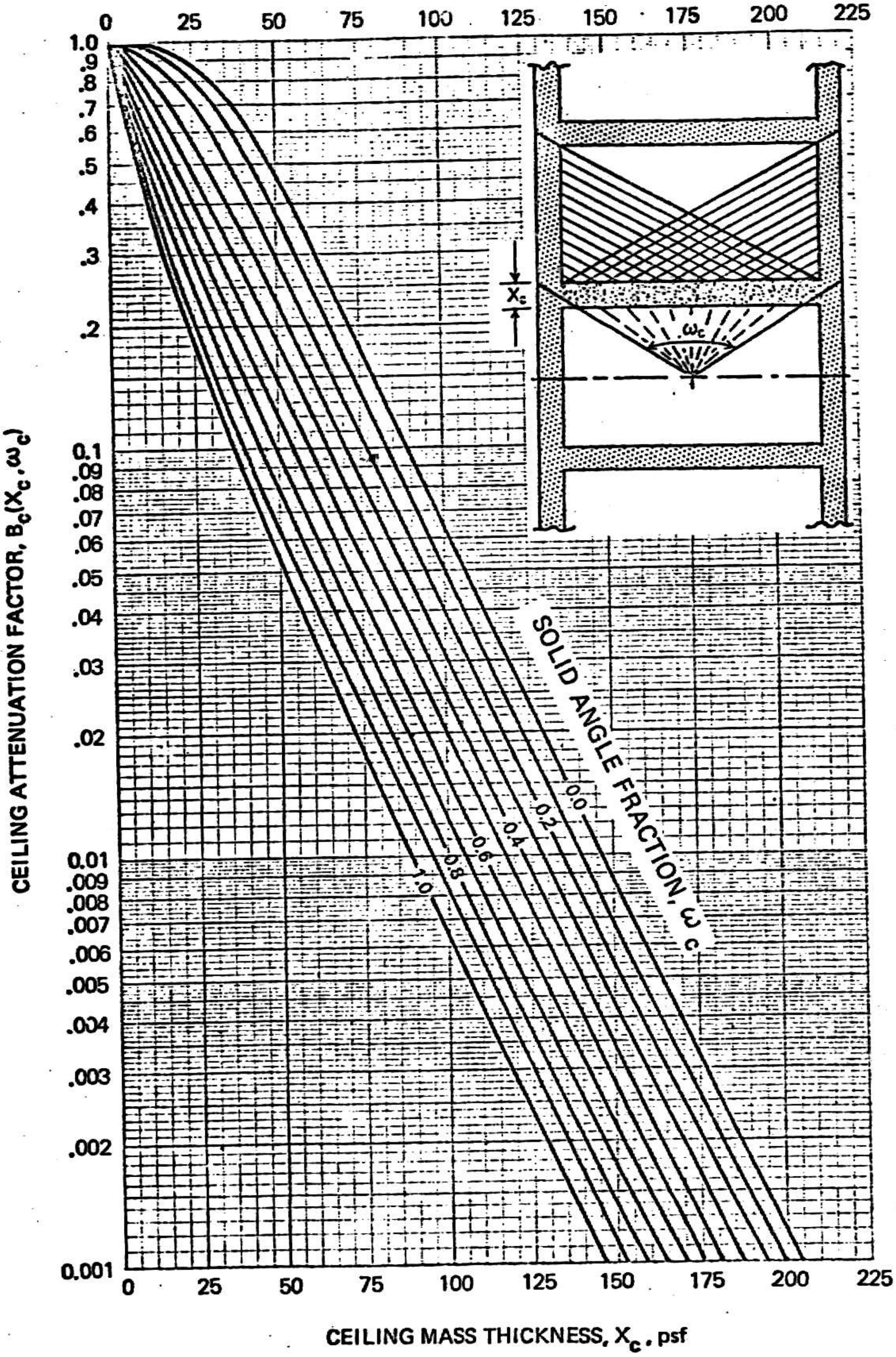

CHART 8A

CEILING ATTENUATION FACTOR, $B_c(X_c, \omega_c)$

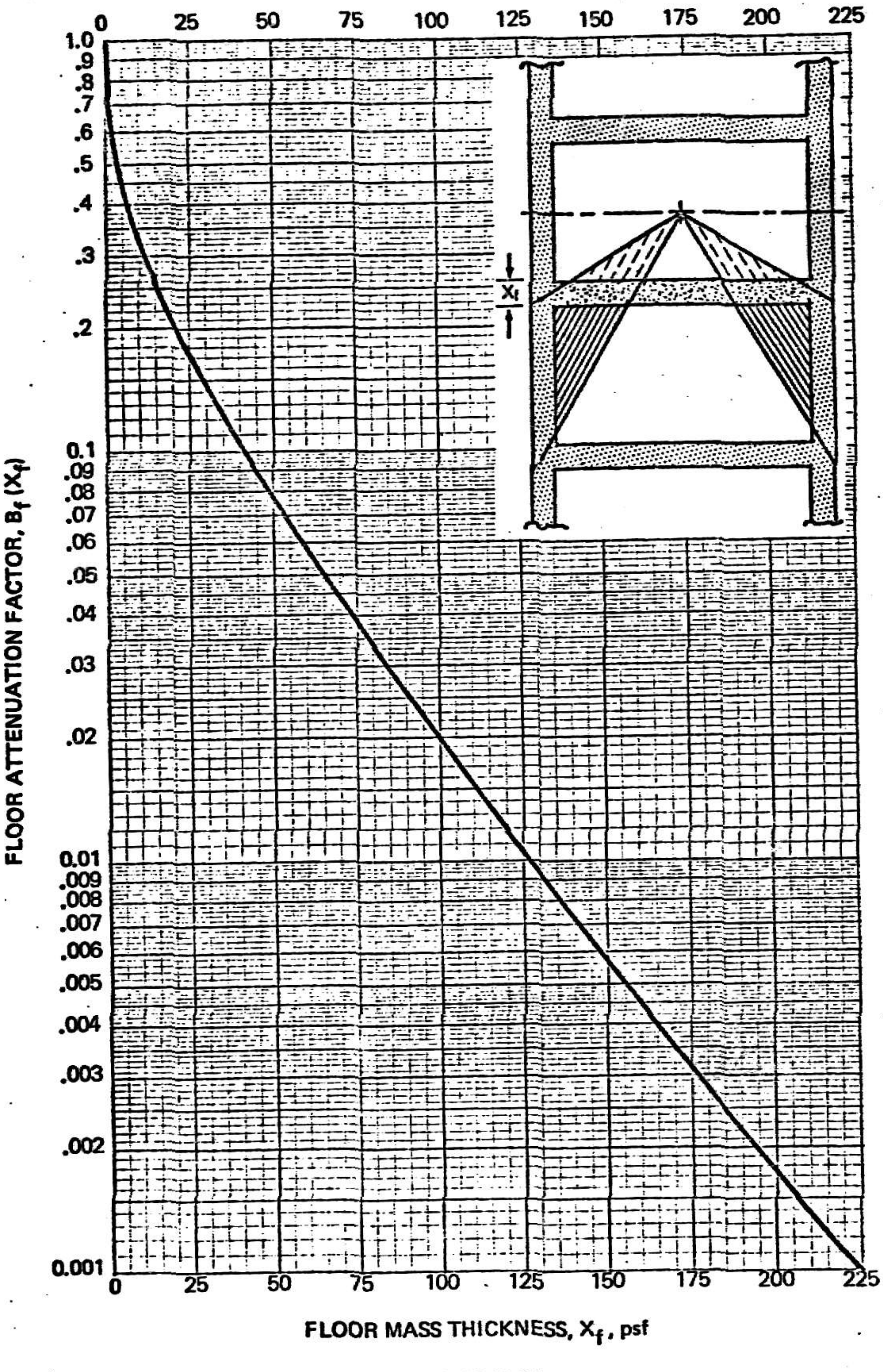

CHART 8B
FLOOR ATTENUATION FACTOR, $B_f(X_f)$

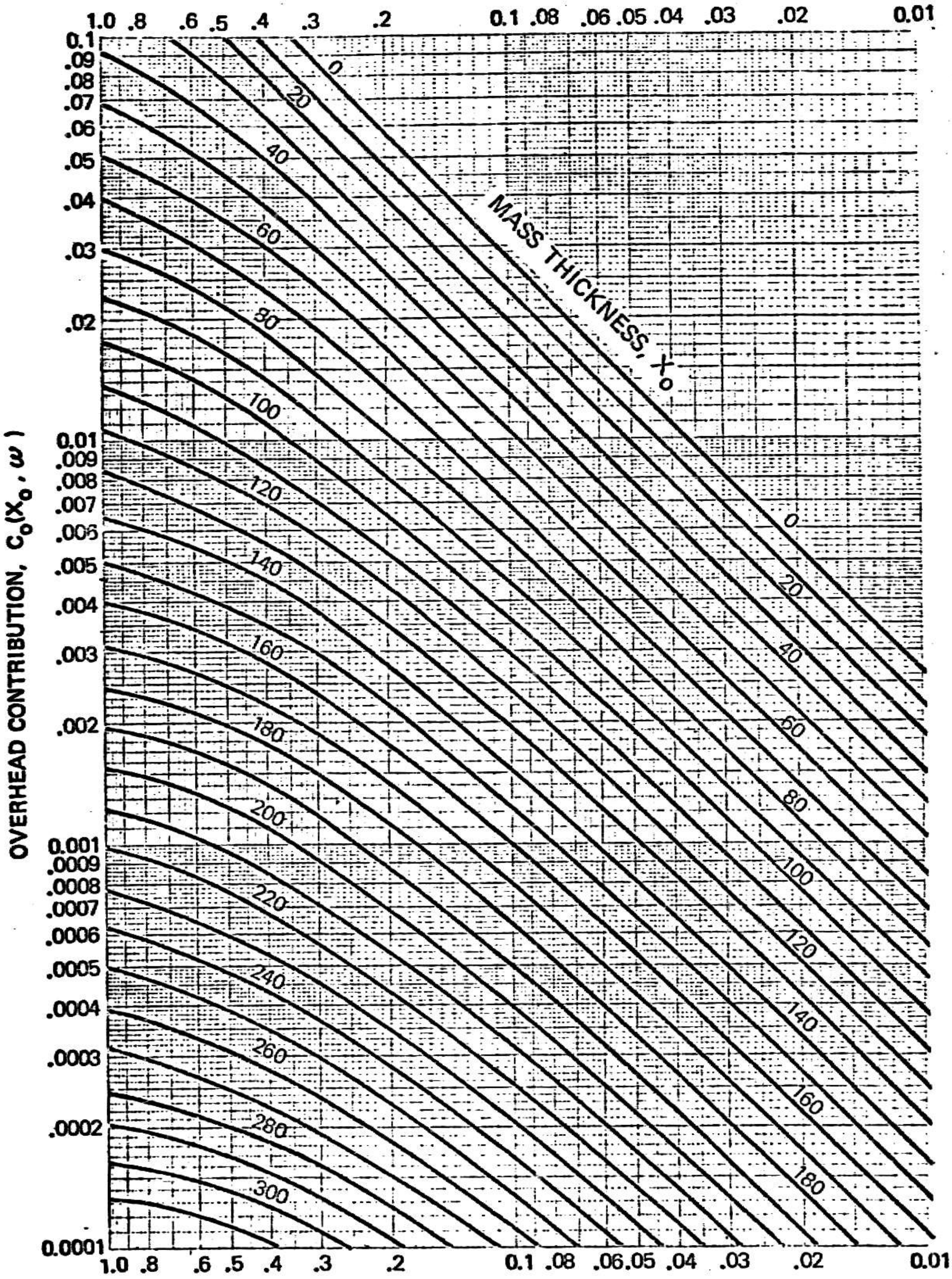

CHART 9

OVERHEAD CONTRIBUTION, $C_o(X_o, \omega)$

ACKNOWLEDGEMENTS

The author expresses his sincere appreciation to Dr. Stuart E. Swartz, Associate Professor, Department of Civil Engineering, Kansas State University, for his advice, helpful suggestions, and corrections during the preparation of this report.

Sincere thanks are also extended to Dr. Fort A. Verser, Assistant Professor, Department of Nuclear Engineering, Kansas State University, for his helpful suggestions and advice during the preparation of this report, and for making available computer time used in developing the results for some of the tables.

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BASIC CONCEPTS OF STRUCTURE SHIELDING FROM FALLOUT

by

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B.S. Civil Engineering, 1973

Kansas State University, Manhattan, Kansas

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements of the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1974

ABSTRACT

The object of this report is to describe the basic concepts of structure shielding from fallout radiation. The concepts discussed in the report may be broadly grouped into four basic form principles--barrier and geometry shielding, distance, time, and the parameters involved with each. Objective and knowledgeable designs, with regard to providing fallout shelter space, may be developed which will not impose prohibitive additional construction costs, alter the efficiency or function of the structure, and will not detract from the esthetics of the site or structure. This report includes a discussion of the meaning and importance of the basic parameters and illustrates how they may be employed in the shielding analysis for a given structure.