NBS

Approximate Procedures for Calculating Protection From Initial Nuclear Radiation From Weapons

C. M. Eisenhauer and L. V. Spencer

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Radiation Research
Gaithersburg, MD 20899

February 1987

i for:
l Emergency Management Agency
ıgton, DC 20472

NBSIR 87-3507

APPROXIMATE PROCEDURES FOR CALCULATING PROTECTION FROM INITIAL NUCLEAR RADIATION FROM WEAPONS

C. M. Eisenhauer and L. V. Spencer

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Radiation Research
Gaithersburg, MD 20899

February 1987

Prepared for:
Federal Emergency Management Agency
Washington, DC 20472

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

CONTENTS

Abstract

In this report we discuss procedures for routine evaluation of the protection of complex structures against the initial radiations from nuclear detonations. We describe procedures for evaluating and combining dose reduction factors for four radiation components: early fission product gamma rays, air secondary gamma rays generated by neutron interactions in the air, neutrons, and wall capture gamma rays generated by neutrons through interactions with nuclei in structural materials. We describe computer codes developed to evaluate reduction factors for each of these components. The radiation field in the vicinity of the structure was generated for a 30° elevation angle for the detonation, as well as a "ring source" averaging over the points of the compass. Comparisons are made with Monte Carlo calculations for a series of five benchmark structures.

I. INTRODUCTION

The purpose of developing approximate shielding procedures is to allow calculation of shielding in many structures with a simple method that can be programmed for fast operation on a personal or mainframe computer. In this paper, we report on approximate procedures developed at NBS to calculate protection afforded by structures against initial gamma and neutron radiation.[1] These procedures are modeled on earlier procedures [1,2][2] for estimating protection from fallout radiation, which have proven very useful in evaluating the fallout shelter potential in the United States.

Calculation of shielding for initial radiation is more complicated than for fallout radiation because four components, namely, fission product gamma rays (FP), secondary gamma rays generated in air (AS), prompt neutrons (N), and gamma rays from neutrons captured in the structure (NG) must be considered. Under special circumstances other radiation such as prompt gammas or delayed neutrons may also be of interest. Much of the data base for procedures discussed here is given in an earlier paper by Spencer [3]; and the procedures have followed the pattern developed in that paper.

The role of neutrons is more complicated than that of gamma rays for at least three reasons: 1) neutron reflection from wall surfaces is a dominant, rather than perturbation effect; 2) neutrons give rise to capture gamma rays (NG) in the structure, and these are more penetrating than the neutrons themselves; and 3) the neutron source intensity relative to that of the initial gamma rays is a function of weapon design. Due to the importance of neutron reflections, additional procedures have been developed which are based

---

[1]Initial radiation is that which is emitted during the first minute after a detonation.

[2]Figures in brackets indicate literature references at the end of this paper.

on the accumulated data and experience for enclosures and ducts. To take the secondary gamma rays produced in the structure into account, additional data for this component have been generated, on the general pattern of reference [3]. For relative source intensities we have utilized available data, beginning with that available in an important report by Auxier et al. [4]. Published and unpublished sources of shielding data used in INR computer codes are given in Appendix A.

II. SOURCE DISTRIBUTION

In order to compare various techniques for calculating shielding in structures, it is helpful to establish standard angular-energy distributions in the vicinity of the structure, for the different types of radiation. We have chosen AS and N distributions from a study [4] requested by the Radiation Shielding Subcommittee of the Advisory Committee on Civil Defense, National Academy of Science. These are presented together with the FP angle-energy distributions [4,5] in Tables I-III. The polar angle in these tables is defined relative to the direction vector from source to detector.

We have also followed the recommendations of the same study to assume a ring source of bursts at a fixed angle of elevation. The rationale for choosing a ring source is that the direction of burst cannot be predicted beforehand — particularly if the building is likely to be exposed to more than one weapon. Therefore, a protection factor for a building is averaged over horizontal directions. The use of a ring source allows the averaging to be done before the protection factor is calculated. For buildings whose construction is similar on all sides, the protection is not likely to vary significantly from this average. An angle of elevation of 30° was chosen as typical of low air bursts. In order to calculate the protection factor in a building, we start with the radiation dose in air. There is still some question as to whether the presence of the ground is important enough to be included in calculating this dose. Although the effect of the ground may be important in estimating the absolute dose, its impact on the protection factor, which is a ratio of doses, is small enough to ignore. The calculations reported here assume that the detector with reference to which the protection factor is estimated is located in a free air medium with no ground-air interface present.

In the calculations of reference [3], the asymmetry of the fission product source about the detonation point, due to cloud rise, was ignored. This aspect of those calculations has been criticized [6]; and there is general agreement that for barrier factors, at least, more precise calculations are required. These have been performed, and are routinely included below.

III. APPROACH TO SHIELDING CALCULATIONS

A. General Approach

The protection in a building against initial radiation is estimated in terms of a reduction factor IRF, which is defined as the ratio of the dose D from initial radiation at a point in the structure to the dose D_0 from initial radiation at the reference point in free air. If the fraction of the free-air dose contributed by FP and AS gamma rays and by neutrons is denoted by f_{FP}, f_{AS}, and f_N, respectively, then the reduction factor is calculated from

$$\mathrm{IRF} = \frac{D}{D_0} = R_{FP}\, f_{FP} + R_{AS}\, f_{AS} + (R_N + R_{NG})\, f_N \qquad (1)$$

where R_{FP} and R_{AS} are reduction factors for the FP and AS components of the gamma radiation, and R_N and R_{NG} are reduction factors for the neutrons and the secondary gammas generated in the structure.

We now consider approximate procedures for estimating the component reduction factors R_{FP}, R_{AS}, R_N and R_{NG}. Since the approach is the same for all components, we drop the subscript in the following discussion.

The general approach which we have taken in developing shielding procedures can be described as follows. We start with the free field dose for each of the radiation components. We then consider the dose at a position on the exterior surface of the roof or one of the walls of a building. The ratio of this dose to the free field dose we call the mutual shielding factor, M. Next, we consider the dose at a point on the <u>interior</u> surface of the roof or wall, immediately opposite the point on the exterior surface. We call the ratio of these two doses a barrier factor, B(X). Next we consider the dose at some arbitrary point inside the building, with no internal structure. The ratio of the dose at this point to that on the interior surface of the wall or roof is called the geometry factor, G, for that wall or roof. Finally, we consider the dose with any internal partitions or floors in place and call the ratio of this dose to that in the empty structure the attenuation factor, A. The reduction factor for each component, i.e., the ratio of the dose at an arbitrary point in the structure to the free field dose, is then calculated from the product

$$R = M \cdot B(X_e) \cdot G(X_e,\omega) \cdot A(X_i) \qquad (2)$$

where X_e is the thickness of an exterior wall or roof and X_i is the thickness of an internal barrier. $A(X_i)$ may be the attenuation due to the combined effect of several floors and walls for any radiation component. The reduction factor at a point in the structure for any radiation component is obtained by summing the expression of eq (2) over the roof and exterior wall surfaces. In programming calculations in the INR codes some modifications of this simple product of four factors were necessary. These modifications will be explained in section IV.B.

B. Mutual Shielding Factor, M

This factor evaluates the effect of moving the detector from a free-air situation to an exterior surface of the building. It may include reductions in exposure due to the presence of nearby buildings. In the simple case of an isolated building, it is approximated for gamma rays by the integral of the free-air distribution over the hemisphere from which radiation is incident divided by the integral over all directions. For a roof, the partial integral is taken over the upper hemisphere; for a ring source incident on a wall, the integral is exactly one-half. The roof factor 0.85 has been used for both FP and AS gamma ray components [3].

The case of neutrons is treated somewhat differently, although it appears formally the same. Because the contribution from neutrons is not as highly concentrated along the line of sight between source and detector as is that from high energy gamma rays, our approach is that of reducing the overall source strength entering roof or side in accordance with the solid angle subtended by nearby shielding. This means the introduction of a cosine factor into the relevant integrals. Calculated in this way, the dose current entering one side of a building turns out to be 0.47 that of the dose current entering the roof.

In more complicated cases where neighboring buildings restrict the angles from which radiation can reach the detector point, the concept of cut-off angle is introduced. The source angular distribution for air-secondary gamma radiation is peaked in the downward direction at an angle of 30° from the horizontal. For fission product gamma radiation the distribution is still peaked but somewhat more diffuse due to averaging over the cloud-rise time. Furthermore, the INR gamma-ray source energies are higher than for fallout, so that INR gamma radiation tends to preserve its original direction. The effect of this phenomenon is that the photon detector responds as if the walls of the building were being x rayed with the source radiation. Therefore, we assume that cut-off angles for the mutual shielding factor can be determined by a line between the detector point and an important change in a neighboring building (e.g., the roof line of the neighboring building). For neutrons the above arguments are not valid. Instead, neutron transport is less sensitive to the original direction of motion of the neutron. The effect of a neighboring building is evaluated in terms of the cut-off angle measured from that building to a point on the exterior surface of the building in which the detector is located rather than to the detector location, itself. Whenever there is a cut-off angle introduced by the presence of nearby building, the factor M in eq (2) is replaced by a difference of mutual shielding geometry factors which are functions of exterior cut-off angles. The use of figure 17 to determine these factors will be described under the Geometry Factor section.

C. Barrier Factor, $B(X_e)$

This factor is the ratio of dose at the inner surface of an exterior wall or roof to that at the outer surface of the same barrier. In order to generate the angular distribution of radiation from a ring source incident on a barrier, the distributions in tables I-III which are a function of the polar angle β (see fig. 1) were averaged over directions of the compass ϕ, rotated to a system in which the new polar angle θ or χ is relative to a line perpendicular to the barrier surface, and then weighted by the cosine of the new polar angle to obtain the current incident on the barrier surface.

Approximate barrier factors for initial gamma radiation were obtained by one-dimensional transport calculations for the rotated roof and wall sources in an infinite medium of concrete. In these calculations concrete is substituted for the air that is exterior to the barrier. This introduces an error of order 10% in the dose, but less in the reduction factor, which is a ratio. The error introduced by the substitution of a concrete backing for the interior of the structure, that is, behind the detector, is expected to be still smaller because gamma rays are reflected from other structural materials.

The barrier factors calculated for initial gamma radiation are shown in figure 2. As expected, the AS gamma rays are generally more penetrating than the FP gamma rays because they include higher energy photons. Furthermore, the two AS curves are rather similar. The two curves for FP gammas would also be similar due largely to the choice of a 30° angle of elevation for the gamma ray sources. But cloud rise has the consequence of depressing the wall curve and raising significantly the roof curve, thus making the latter much less steep. The data from which these curves were derived were obtained using a gamma ray adjoint moments program written by G. L. Simmons [7], and a distribution construction program written by L. V. Spencer [8].

Barrier factors for neutrons and for the capture gamma rays which they produce in the structure are shown in figure 3. These data correspond to Snyder-Neufeld [9] dose weighting factors for the neutrons, and Henderson [9] weighting factors for the gamma rays. These were generated by ANISN calculations for the roof, and DOT calculations for the walls [9]. They are based on calculations for slabs and therefore do not include any neutrons reflected from behind the detector. The contribution from reflected neutrons is evaluated by a reflection factor added to the geometry factors (see section D.2).

D. Geometry Factor, $G(X_e,\omega)$

1. Unreflected component. The geometry factor is the ratio of the exposure at an arbitrary distance from the inner surface of an exterior wall or roof to the exposure at the surface. A cumulative integral over the angular distribution of radiation emerging from the surface is required to estimate this factor. Calculations used to approximate this integral for gamma rays, however, give the cumulative angular distribution over the incident radiation. The two integrals are equal only for the radiation not scattered in the barrier. But, in view of the fact that unscattered and small-angle-scattered components dominate the dose for the source energies and barrier thicknesses of interest, we believe that the calculated integrals represent an adequate approximation for this application. For neutrons, integrals were taken over angular distributions of emerging neutrons.

A polar reference axis for specifying the cumulative angular distribution of the incident radiation must be selected. For a ring source incident on a horizontal roof, the vertical direction is the obvious choice. Cumulative angular distributions are expressed in terms of the solid angle fraction ω subtended by the roof. Figure 4 shows these geometry factors for the air secondary gammas. In this figure and in some of the following figures, as well as elsewhere in the text, thickness of barriers are given in units of pounds per square foot (psf) of concrete. The sharp rise in the curves for thin barriers shows the effect of the concentration of photons at 30° angle of elevation. The higher values of the curves for thick barriers and small solid angle fractions indicate the increased importance of radiation traveling more nearly perpendicular to the roof slab. Similar curves for FP gamma radiation are shown in figure 5, and for neutrons and neutron-capture gamma rays (in the structure) in figures 6 and 7, respectively. The single curve for neutrons is a good approximation for all thicknesses.

For radiation incident on a vertical wall, the choice of a reference direction is not so obvious. Figure 1 shows two possible directions: the vertical direction, normal to the roof, and the horizontal direction, normal to the wall slab. Since cumulative integrals over polar angles are correct only for circular source areas and cylindrical symmetry, one tries to choose the direction which most closely approximates this. We feel that most large buildings with story-heights small compared to wall-lengths can be better approximated by a cylindrical wall with a vertical reference axis rather than a series of four circular walls, each with a horizontal reference axis. The symmetry of the ring source about the vertical direction provides an additional reason for choosing a vertical axis as the reference direction.

Geometry factors for walls are approximated by the product of two functions. The first function $G_1(Xe,\omega)$, given in figures 8-11 is an integral over the region of polar angles subtended by the walls of the structure. The second function, $G_2(Xe,\phi_0)$, varies with the limits on the azimuthal angle ϕ_0 (see figs. 13-16) for each wall. The sum of values of this function for each of the walls of a structure is therefore dependent on the shape of the building.

Geometry factors $G_1(Xe,\omega)$ are plotted as a function of the solid angle fraction ω subtended by the ceiling (or floor) rather than that subtended by the walls. Therefore, for increasing values of ω the geometry factors in figures 8-11 decrease. Note that the horizontal scales in figures 8-11 are semi-log scales in the quantity $(1 - \omega)$. The curves for AS gammas show a steep slope near $\omega = 0.5$, due to the concentration of photons at the 30°

angle of elevation. The corresponding curves for FP gammas are shown in figure 9, and for neutrons and capture gammas (in the structure) in figures 10 and 11, respectively. Note again that figure 10 does not include reflected neutrons.

When the detector is on the same story as the radiating walls, a geometry factor for radiation from portions of the walls above the detector plane must be added to a geometry factor for portions of the wall below the detector plane (see fig. 12a). When the detector is on the story below, geometry factors must be estimated for the solid angle fractions subtended by the ceiling of the higher story, and the floor of the higher story, and the two subtracted (see fig. 12b). A similar subtraction is required when the detector is on the story above the radiating walls.

Geometry factors $G_2(Xe,\omega)$ for AS gamma rays and for a single wall are plotted as a function of $\sin\phi_0$ in figure 13. The curve for zero thickness in figure 13 is proportional to the angle ϕ_0. The line for 36 pounds per square foot (psf) of concrete is nearly proportional to $\sin\phi_0$ and is therefore equivalent to the prediction for thick walls in the fallout methodology.[3] The higher geometry factors for thickness greater than 36 psf show the effect of increased peaking in the angular distribution, relative to the direction perpendicular to the wall surface. The curves for FP gammas (fig. 14) are almost a duplicate of this set. Corresponding curves for unreflected neutrons and wall capture gammas are presented in figures 15 and 16. The single curve that approximates the function G_2 for neutrons for all wall thicknesses is proportional to the azimuthal angle subtended by the wall.

---

[3]In the methodology for calculating fallout protection this information is not available and it is arbitrarily assumed that for thin walls the geometry factor is proportional to ϕ_0 and for thick walls it is proportional to $\sin\phi_0$, where ϕ_0 is the azimuthal angle between a line perpendicular to the wall and a line drawn to one end of the wall. This implies that at the center of a rectangular building with thick walls, the relative contributions of the long and short walls is equal to the ratio of their lengths.

The expression of the geometric effect as a product of a polar and an azimuthal factor was made possible by a remarkably good approximation of separability evidenced by the data. The assumption of separability was made in the fallout methodology only because of the lack of data on the azimuthal dependence. It was later supported by Monte Carlo calculations [10]. Current evidence, still somewhat limited, also points to this approximation as justifiable in the cases of unreflected neutrons and wall-capture gammas.

When the incident gamma radiation field is limited by the geometry of both the building in which the detector is located and an exterior structure, the product $M \cdot G(X_e,\omega)$ in eq (2) is replaced by a difference of geometry factors. For example, figure 12 shows a detector position for which the incident field of radiation through the first story wall is limited by the solid angle fraction ω_u' defined by the first floor of the ceiling of the first story and the solid angle fraction ω_u'' defined by the presence of an exterior structure. The combined interior and exterior geometry effects in this case are approximated by the expression

$$[G(X_e,\omega_u') - G(X_e,\omega_u'')] \tag{3}$$

This procedure is not applicable to neutrons and wall-capture gammas, however. For these radiations one simply applies a factor M obtained from figure 17, which records the part of the upper hemisphere not blocked off, in terms of an upper hemisphere free-field geometry factor for neutrons. This factor is applied equally to upper and lower hemisphere reduction factors.

2. Reflected component. The contribution from gamma rays reflected from structural material behind the detector is of the order of 10% and is neglected in these calculations. However, the contribution from reflected neutrons is of the same order as that from unreflected neutrons and must be taken into account.

For many enclosures an adequate rule for this is simply to calculate the unreflected neutron reduction factor, including all contributing walls and roof, and multiply by a (total/unreflected) factor $(1 + \rho_0)$ which we take here to be 3. This assigns to the reflected neutrons twice the dose contributed by the unreflected components, a value obtained by several rather different calculations using Snyder-Neufeld dose weights. Problems arise when an important wall surface subtends a rather small solid angle fraction, as shown by ω in the sketch in figure 18. The sidewalls and endwall then act as in a closed duct, to contribute a dose attenuated by geometry and by one or more albedo factors. We then multiply the unreflected component G_u directly from the given wall surface by a factor $(1 + \rho + \rho_e)$. Here ρ and ρ_e, the contributions from sidewalls and endwalls, respectively, are evaluated for ω and ω_e, as presented on figure 18. We should note that this approach ignores variations in the length-to-width ratio of a source wall; but calculations have indicated that these reflection factors vary only weakly with this ratio.

In a building with many windows the reflected neutrons will not make such a large contribution. To account for this effect we have made the reflected contribution dependent on the relative window area on the story in which the detector is located. One then multiplies the reflected neutron components ρ and ρ_e by $(1 - w)$ and $(1 - w_e)$, respectively, where w_e is the fraction of endwall solid angle subtended by windows, and w is the fraction of sidewall solid angle subtended by windows, so that the detector does not receive reflected neutrons from a window. The INR codes assume a central detector location. Furthermore, for wall sources, w is assumed to be zero, since the floor and ceiling are two of the "side walls," and w_e is approximated by FW, the fraction of wall perimeter occupied by windows. For roof sources or contributions from upper (or lower) stories, where the floor (or ceiling) is the "end wall," w_e is assumed to be zero and w is approximated by FW. However, in basements below grade, the full reflected contribution is assumed, regardless of the window configuration on higher stories.

E. Attenuation Factor, $A(X_i)$

This factor is a ratio of the exposure with interior structure in place to the exposure in an empty building. In the INR calculations it often does not appear as an explicit factor. For all types of roof radiation the thicknesses of all horizontal barriers above the detector, including the roof, are added to obtain a total thickness X_0. The product of the barrier factor $B(X_e)$ and the attenuation factor $A(X_i)$ in eq (2) is replaced in the calculations by a table-lookup of the roof barrier factor $B(X_0)$. The variables of the geometry factor are X_0 and ω, the solid angle fraction subtended by the roof. Similarly, for all types of wall radiation, the thickness of all vertical interior partitions is added to the exterior thickness to obtain a total thickness X_T. A single table-lookup is then used to obtain a wall barrier factor.

For gamma rays, the attenuation of radiation from walls of the next higher story through a ceiling to a detector, say, in the basement, is evaluated by an attenuation factor $A(X_0')$. Figures 19 and 20 give the attenuation of AS gamma and FP gammas, respectively, from a ring source for different incident polar angles θ_0. Each curve contains information for the energy spectrum at that angle. In order to apply these curves to a basement detector, we could estimate the average angle to the upper story walls and interpolate for the corresponding value of $\cos\theta_0$ and the thickness of the ceiling. However, these curves were approximated in the INR codes by the two roof curves from figure 2. The adequacy of this approximation is discussed in section V.C.

For neutrons and secondary gammas the attenuation is accounted for by adding the thickness of the ceiling (or floor) barrier to the thickness of the interior and exterior walls of the upper (or lower) story to obtain the argument for the wall barrier factor.

F. Overall Protection Factors

A much-used concept in fallout shielding studies is that of the Protection Factor (PF). To apply this to initial radiations, one must choose one or more standard mixtures of the different source components. The difficulty of this is quickly seen in the variety exibited in figures 10-13 of Auxier et al. [4]. Nevertheless some patterns do emerge which may provide useful reference for this purpose.

Very high megaton (MT) detonations are apt to be based on energies provided largely by the fission process; and shielding at greater distances from the detonation becomes important. These aspects, together with the 1 MT data of reference [4], figure 12, suggest using a high MT reference reduction factor such as the following:

$$IRF_G = 0.5\ R_{FP} + 0.2\ R_{AS} + 0.3\ (R_N + R_{NG}) \tag{4}$$

Where it is understood that R_N always includes the wall capture gamma-ray component.

Similarly, low kiloton (kT) detonations can feature neutrons generated by fusion reactions, with only a limited fission component. The neutrons generate a substantial air secondary component, however. This is illustrated in figure 10 of reference 41, and suggests a representative combination such as the following, for low kT cases:

$$IRF_N = 0.6\ (R_N + R_{NG}) + 0.2\ R_{AS} + 0.2\ R_{FP} \quad . \tag{5}$$

The more general problem of mixed cases should not be ignored, and hence we tentatively suggest even-balancing for an intermediate, or "other" reduction factor representation:

$$IRF_0 = \frac{R_{AS}}{3} + \frac{(R_N + R_{NG})}{3} + \frac{R_{FP}}{3} \quad . \tag{6}$$

This is consistent, more or less, with figures 11 and 13 of reference [4].

These three combinations, translated into reciprocals, can perhaps serve to cover any possible requirements for "IPF's." Note that by choosing three such representations, a full set of values can be used in combination, without loss of information about the three radiation components.

IV. DISCUSSION OF INR COMPUTER CODES

A. Limitations of Codes

The present version of the INR codes (INRG6 for gamma rays and INRN6 for neutrons) has several limitations, some of which may have to be modified in the future.

1. Codes calculate contribution from roof and from walls of the same story, story above, and story below the detector location. Contributions from walls of stories more than once-removed from the detector are assumed to be negligible.
2. Codes calculate protection at a central location of each story. The concepts used for the central detector can be extended to off-center detectors, as is done in the PFCOMP code. The extension requires significant increase in coding because four solid angles are required for every solid angle calculated for the central detector. Unless more experimental data or Monte Carlo calculations become available for comparison, this refinement does not seem justified.
3. A limited number of configurations of interior partitions are included. Interior partition configurations are limited to a rectangular central core or a central corridor, extending the length of the building.
4. Each story of a building must be approximated by a square or rectangle.
5. Windows are assumed to have the same configuration on opposite sides of a building.
6. Linear interpolation between tabulated points on linear or log scales is used. The number of tabulated points for barrier and geometry factors should be increased so that interpolation is more accurate.
7. The ceiling attenuation factor for AS and FP gamma rays is approximated by the roof barrier factor. The ceiling attenuation factor for AS and FP gamma rays should be made dependent on the average angle of incidence of radiation rather than approximating it by the roof barrier factor.
8. The contribution from windows of the story above is overestimated. A better calculation may require more input parameters.

B. Description of Subroutines

INTRPB Calculates barrier factors for four walls and overhead barriers by interpolating on tabulated values

Input:

XTAB(11)	tabulated values of barrier thickness
X(5)	array of barrier thicknesses for four walls and overhead, in units of pounds per square foot (psf) of concrete
BTAB(11,4)	tabulated barrier factors for roof and walls for two types of radiation

Output

B(5,2)	barrier factors for air secondaries and fission product gammas (INRG) or neutrons and capture gammas (INRN) for four walls and overhead

Remark:

The number of tabulated values of barrier thickness is currently assumed to be 6 in the neutron code and 11 in the gamma-ray code.

INTRPG Calculates geometry factors G_1 and G_2 for four walls, and geometry factor G for overhead, by interpolating on tabulated values.

For roof geometry factors linear interpolation on log G _vs_. log ω is used. However, for side-wall G_1 geometry factors, linear interpolation on log G _vs_. log $(1-\omega)$ is used. For side-wall G_2 geometry factors, linear interpolation on log G _vs_. log $\sin\phi$ is used.

Common:

ZTAB(6)	tabulated value of barrier thickness
YTAB(11,2)	tabulated array of values of ω and $\sin\phi$
GTAB(6,11,6)	tabulated array of geometry factors for walls and overhead.

Input:

X(9)	array of barrier thicknesses with X(n + 5) = X(n), psf
Y(18,2)	array of values of ω and $\sin\phi$ defining each surface

Output:

G(9,2)	geometry factors for air-secondary and fission product gammas (INRG) or neutrons and capture gammas (INRN) with four values of G_1, one value of G, and four values of G_2.

Remark:

The number of tabulated values of barrier thickness is currently assumed to be 6 in both neutron and gamma codes.

GEOM Calculates values of ω and $\sin\phi$ for four walls from input linear dimensions for story.

Input:

HI	height of portion of wall above detector plane, ft
XL	length of story, ft
W	width of story, ft

Output:

OM(4)	solid angle fraction subtended by equivalent circular ceiling associated with each wall
SPHI(4)	value of $\sin\phi$ for each wall

SECTOR Calculates values of the array Y (see INTRPG) for the upper and lower portions of a partial story (sector)

Input:

IL	parameter indicating whether to neglect (IL = 0) or calculate (IL = 1) values of Y for the lower portion of the wall.
HU	height of portion of wall above detector plane, ft
HUR	height of roof above detector plane, ft
HL	height of portion of wall below detector plane, ft
XL	length of story, ft
W	width of story, ft

Output:

Y(18,2)	array containing values of ω in the first column and $\sin\phi$ in the second column. The first 9 entries are for surfaces above the detector plane; the remainder are for surfaces below the detector plane.

Subroutines called:

GEOM

INPUTT Input routine data storage for tabulated barrier and geometry factors

Input/Output:

IPR	print index: (IPR > 0), print all tabulated barrier and geometry factors
OMTAB	tabulated values of solid angle fractions
SPTAB	tabulated values of $\sin\phi$

Common:

XTAB	tabulated values of barrier thickness
BTAB	tabulated values of barrier factors
ZTAB	barrier thicknesses for which geometry factors are tabulated
GTAB	tabulated values of geometry factors
OMRTAB(17)	tabulated values of solid angle fraction for duct data (INRN,only)
RTAB(17,2)	tabulated values of duct attenuation (INRN,only)
OMSTAB(17)	tabulated values of solid angle fraction for mutual shielding (INRN,only)
XMSTAB(17,2)	tabulated values of mutual shielding (INRN,only)

TEST   Calls in input data for building parameters*

Input:

TITLE (20A4) Descriptive title for building

IW, ID, IPR, IMS, IP, HI, HS(>0), HT, HD, HR, FW, HIU, HIL, XL, W (5I5, 5F10.2/5F10.2)

Indices

IW   Window index

- IW = 0 No windows
- IW = 1 Windows on all four sides
- IW = 2 Windows on two long sides

ID   Detector index

- ID = 0 Sub basement
- ID = 1 Basement below grade
- ID = 2 Basement - partly above grade**
- ID = 3 First story of multistory building
- ID = 4 Second or higher story
- ID = 5 Second or higher story, but immediately below roof.
- ID = 6 First story, immediately below roof.

IPR   Print index

- IPR = 0 Suppress printout of input tabulations and some geometry factors
- IPR > 0 Print this information

---

*TEST is replaced by CETE1 (for neutrons and secondary gammas) and CETE2 (for AS and FP gamma rays) in program written by R. Lyday for FEMA. His subroutines CHARLI and CECARD are used to relate input data in the SANDINR system to input parameters required by the INR codes.

**Code will overestimate contribution in this case if detector is below grade. For calculating geometry factor, code assumes grade level is at detector level. If detector is above grade, code does not calculate contribution from below detector plane and contribution will be slightly underestimated.

IMS Mutual shielding index

- IMS = 0 Set mutual shielding equal to 0.5 for walls, 0.85 for roof gamma rays, and 0.58 for roof neutrons.
- IMS > 0 Determine mutual shielding from heights of neighboring buildings.

IP Index for configuration of interior partitions

- IP = 0 No interior partitions
- IP = 1 Four-sided core configuration of interior partitions
- IP = 2 Central corridor extending the length of the building

Linear dimensions (Relative to floor of this story, in units of ft)

HI	Ceiling height
HS(>0)	Sill height
HT	Height of top of window
HD	Detector height (Not actually used in INRG code, where test is made on HL. Used for mutual shielding test in INRN code
HR	Roof height
FW	Fraction of perimeter occupied by windows
HIU	Height of story above
HIL	Height of story below
XL	Length of building
W	Width of building

XLM(4F10.3)	Length of first plane along each wall of building (not used in INRG code)
WM(4F10.3)	Width of first plane in direction perpendicular to each wall of building
HM(4F10.3)	Height of SECOND plane on each side of building

After reading in these data, codes call subroutine INPUTT to read in tabulated shielding data. Codes then read in:

Wall Thicknesses (psf)

XE(5E10.3)	Thickness of each exterior wall (L = 1,4) and of roof plus intervening ceilings (L = 5)
XI(5E10.3)	Thickness of each interior wall (L = 1,4)
XUE(5E10.3)	Thickness of each exterior wall of story above (L = 1,4)
XUI(5E10.3)	Thickness of each interior wall of story above (L = 1,4) and of ceiling (L = 5)
XXLE(510.3)	Thickness of each exterior wall of story below (L = 1,4)
XXLI(510.3)	Thickness of each interior wall of story below (L = 1,4) and of floor (L = 5)

RFSTOR Calculates the reduction factor for the four walls and overhead of a story

Input: (Barrier thicknesses in psf, linear dimensions in ft)

IW	index to indicate configuration of windows
HI	story height
HIU	height of story above
HIL	height of story below
HS	average height of window sills above floor
HT	average height of top of windows above floor (HT>HS)
XL	length of story
W	width of story
X(9)	array containing values of four wall thicknesses and overhead thickness, with X(n + 5) = X(n). Thickness includes that of intervening interior partitions.
XU(9)	array for thicknesses of four walls of story above and total overhead thickness (XU(5)), with X(n + 5) = X(n)
XXL(9)	array for thicknesses of four walls of story below, with X(n + 5) = X(n)
FW	fraction of the length of the wall that is occupied by windows

XMS(5,2)	mutual shielding factor (INRN only)
ID	detector index, indicating basement, first story, etc.
IPR	print index
IMS	mutual shielding index (INRG only)
IP	index for configuration of interior partitions
WM(4)	width of area at grade level perpendicular to each wall (INRG only)
HM(4)	height of building nearest to each wall (INRG only)
HD	detector height (absolute or relative to floor of this story; but definition must be consistent with that of HR and HM)
HR	roof height (absolute or relative to floor of this story; but definition must be consistent with that of HD and HM)
XI(5)	thicknesses of interior partitions
XUI(5)	thicknesses of interior partitions of story above and of ceiling (XUI(5))
XXLI(5)	thicknesses of interior partitions of story below and of floor (XXLI(5))

Output:

RF(5,2)	reduction factor array for four walls and overhead, for air-secondary and fission product gammas (INRG) or neutrons and capture gammas (INRN)

Subroutines called:

INTRPB
SECTOR
INTRPG
GMSHLD (INRG only)
INTRPR (INRN only)

INTRPR Interpolates on tabulated reflection factors for neutrons to obtain a reflection factor for the "side" and "end" walls of the room. Here "end" refers to the surface opposite the one through which the radiation enters and "side" refers to the remaining four surfaces.

Input:

OMRTAB(17)	list of solid angle fractions at which reflection factors are tabulated
RTAB(17,2)	reflection factors for 17 solid angle fractions for "side" walls (K=1) and "end" walls (K=2)
TAUR(5)	solid angle fraction subtended by the four walls (I=1,4) and ceiling (I=5). Values of TAUR are calculated in RFSTOR, assuming detector is centrally located, vertically as well as horizontally. Thus the solid angle fraction subtended by the "end" wall is always equal to that subtended by the source wall, and the same value is used for each of the two reflection factors.

Output:

RHO(5,2)	reflection factor for four walls (I=1,4) and ceiling (I=5), for "side"walls (K=1) and "end" wall (K=2).

NMSHLD (INRN only) Calculates the mutual shielding factor for neutrons incident on the roof and walls of a building. The solid angle fraction of open sky is calculated at the center of the roof and at exterior points at detector height at the center of each of the four walls. (For a detector below grade the exterior points are also below grade, although, physically, they should be at grade level or higher.) Mutual shielding factors are then interpolated from curves for either the roof or walls. A factor of 0.5 for the walls and 0.58 for the roof is included in the mutual shielding factor for neutrons. Reduction factors are multiplied by mutual shielding factors in the RFSTOR subroutine.

Input: (in units of ft)

XLM(4)	length of area at grade level parallel to each wall
WM(4)	width of area at grade level perpendicular to each wall (INRG only)
XL	length of building
HM(4)	height of building nearest to each wall (INRG only)
W	width of building
HD	detector height (absolute or relative to floor of this story; but definition must be consistent with that of HR and HM)
HR	roof height (absolute or relative to floor of this story; but definition must be consistent with that of HD and HM)

Internal Variables:

TAUM(5)	Solid angle fraction of open sky for each wall. Areas for calculating solid angle fractions are projected on to the horizontal plane at the height of the building nearest to each wall.
TAUMRF(5)	Solid angle fraction of open sky for each quadrant of roof. Areas for calculating solid angle fractions are projected on to the horizontal plane at the height (HMAX) of the highest nearby building.

Output:

XMS(5,2)	Mutual shielding factor for walls (J = 1,4) and roof (J = 5), for neutrons (I = 1) and neutron capture gammas (I = 2). Mutual shielding factors for neutron capture gammas are assumed to be equal to those for neutrons in the current version of NMSHLD.

Subroutines called:

INTRPR

Remark: See Appendix B for more detailed description of mutual shielding for neutrons.

GMSHLD (INRG only) Calculates mutual shielding factors for gamma rays through roof and walls of building. As viewed from the detector, the nearest building limits the amount of open sky. For each side of the building the intersection on the wall of the plane formed by the nearer edge of the roof of a nearby building and the detector is determined (i.e., the edge of the "shadow"). Mutual shielding factors for sections of the walls below this intersection are set equal to zero. For example, if this intersection (shadow edge) is at a height halfway between the window sill and top, a ratio is formed of the contributions from above that intersection and from the whole window. This ratio -- the mutual shielding factor -- is applied as a correction to the window contribution. If the shadow intersects the roof, rather than the wall, then the intersection (instead of the real roof edge), determines the size of the effective roof on that side. A factor of 0.5 for the walls and 0.85 for the roof is included in the mutual shielding factor for both types of gamma rays. Corrections for mutual shielding are applied in the RFSTOR subroutine.

Input: (Linear dimensions in units of ft, barrier thicknesses in psf)

WM(4)	width of area at grade level perpendicular to each wall
HM(4)	height of nearest building to each wall
XL	length of building
W	width of building
HD	detector height. (Absolute or relative to floor of this story; but definition must be consistent with that of HR and HM.)
HI	height of the story
HL	height of portion of wall below detector plane
HIU	height of story above this one
HT	height of top of window
HUR	distance from detector to roof. HUR is set equal to HR-HD in the RFSTOR subroutine.

XW(9)	thickness of walls
Y(18,2)	solid angle fraction and sinϕ arrays
GP(7,18,2)	geometry factor for up to 7 different contributing sections of wall, different sides -- upper and lower --, and 2 types of gamma radiation.
IW	window index: IW = 0 no windows; IW = 1 windows on four sides; IW = 2 windows on two long sides.

Output:

XMSW(4,5,2)	mutual shielding factor for four walls and roof for air secondary gammas (M = 1) or fission product gammas (M = 2). Corrections for walls of same story (J = 1), windows of same story (J = 2), walls of story above (J = 3), and windows of story above (J = 4).

Subroutines called:

SECTOR

INTRPG

C. Listing of Computer Codes.

FORTRAN listing of subroutines of the INRG6 and INRN6 computer codes are shown in Appendix C. Data input for sample neutron and gamma programs are shown in Appendix D. Finally, output for the same sample programs are shown in Appendix E.

V. COMPARISON WITH MONTE CARLO CALCULATIONS

A. Monte Carlo Calculations on Benchmark Structures

Since several approximations have been made in the derivation of eq (2) and in the determination of the component functions, it is necessary to check the results either with experiments or with more rigorous calculations. Experimental checks of approximate procedures for predicting fallout shielding were extensive. However, there have been no systematic experiments developed to either predict or check theoretical procedures for estimating protection from initial nuclear radiation. Therefore comparisons must be made with independent calculations.

The approximate procedures of eq (2) will be applied mainly to three dimensional structures with rectangular roofs and walls. Monte Carlo calculations probably offer the most promising approach for obtaining accurate and independent results for a small number of configurations.

Unfortunately we have available only one set of Monte Carlo calculations with which we can compare our calculated reduction factors. The Monte Carlo calculations considered here were performed by Beer and Cohen of MAGI [11,12] under subcontract to NBS and FEMA. Although the Monte Carlo method is a rigorous one, its application to any particular problem may contain errors due to poor sampling techniques or inadequate modeling of the geometry of the problem. Therefore, discrepancies between NBS approximate procedures and MAGI Monte Carlo calculations do not necessarily imply that the procedures are inadequate.

A series of structures of increasing complexity were selected as benchmark structures to test the adequacy of the approximate procedures. They were designed to approach in complexity a typical multi-story dormitory building. Cross section and elevation sketches of these structures are shown in figures 21 and 22. Figure 21 indicates a structure that contains a basement ceiling (elevation view), and windows on two sides (plan view). These structural details are given in table IV.

B. Combined Components

First we present a comparison of the overall protection factors calculated by NBS and MAGI for the high and low yield combination of components discussed in Section III.E. This comparison can be made only for structures 4 and 5 since MAGI did not calculate reduction factors for neutrons in structures 1 through 3.

Table VI shows reduction factors for the four radiation components and for overall reduction factors according to the weighting factors shown in eqs. (4) and (5) of Section III.F. Comparisons are made for structures 4 and 5 at central positions in the first story and basement. The first fact to note is that the first story provides protection factors of 2 to 4, while basements provide protection factors of 6 to 20. Secondly, the NBS estimates of reduction factors are up to 40% higher than those of MAGI and are therefore conservative, in that they estimate less protection. The computer codes generated by NBS therefore seem to predict reasonable estimates of reduction factors. Reasons for discrepancies with the MAGI Monte Carlo calculations and possible improvements in the NBS computer codes are discussed in the following sections.

C. AS and FP Gamma Rays

Monte Carlo calculations were made by Beer and Cohen [11] to determine reduction factors for AS and FP gamma rays incident on the five benchmark structures. In a preliminary exercise the roof barrier for air-secondary and fission-product gammas was determined. Comparison of these results with those estimated from figure 2 is shown in table V. The agreement between the two methods for this simple configuration is within 10%.

Now we turn to comparisons for the benchmark structures. Tables VII through XII give comparisons of reduction factors for AS and FP gamma radiations calculated by MAGI and NBS for centrally-located detectors ($x = y = 0$) in the five benchmark structures. We consider first, structure #1. The comparisons shown in table VII indicate reasonably good agreement for the AS gamma radiation, but the NBS calculations for the FP gamma radiation are as much as 46% higher than the MAGI calculations. The discrepancy is probably due to the calculation of geometry factors, since the calculated barrier factors for the roof show only a few percent discrepancy. The NBS geometry factors may be high because of the approximation, discussed earlier, of integrating over the incident angular distribution rather than the emergent angular distribution.

Structure #2 includes windows. Since the contribution from windows involves merely an integral over portions of the source angular distribution, the two methods ought to agree well. The observed discrepancies for the basement are due to insufficient characterization by the computer codes of the geometry of the windows on upper stories. The code assumes erroneously that the windows of the upper story extend from the tops of the windows of the detector story to the top of the upper story, thus accounting for a larger window area than intended from the input data. Comparison of the contributions from the walls shows the same discrepancies as observed in Structure #1.

The approximate procedures do not predict any differences in roof dose between structures #1 and #2, because of the presence of windows in structure #2. The Monte Carlo calculations, on the other hand, seem to show about a 5% decrease in reduction factor because of leakage of gamma rays through the windows.

In structure #3, the main effect of the basement ceiling is to reduce the dose in the basement. Table IX shows that NBS calculation for the roof is still high, but that the wall results also differ by about 35%. To examine the effect of the ceiling barrier we take ratios of the contributions calculated by MAGI for structures #3 and #1. We then compare these values with the NBS attenuation factors interpolated from figures 19 and 20. Table X shows the results. The agreement for the component from the roof is reasonably good. The agreement for radiation from the wall, however, is not as good.

The main reason for this is that the barrier factor of the ceiling was originally made dependent on the average angle of incidence of the photons on the upper surface of the barrier. When the computer code was written, the roof barrier was substituted as a simplification. Table IX shows that the approximation results in a reduction factor from the walls that is lower by a factor of 1.9 for air secondaries and by a factor of 3.2 for fission product gammas. The approximation made in the INR code is conservative and tends to overestimate reduction factors or underestimate protection.

Structure #4 is similar to structure #3 except that it contains windows. Comparisons of the contributions to a basement detector from the walls and windows of the first story calculated by the two methods are shown in table XI. Both calculations predict a lower wall contribution in structure #4 than in #3 because of reduced wall area. The window contribution calculated by NBS for the air secondaries and the fission product gammas is much larger than that calculated by Monte Carlo. This is the largest discrepancy in the comparisons we have considered. The attenuation in the basement ceiling as calculated from ratios of entries in tables VIII and XI is in reasonable agreement for the wall sources. Furthermore, the attenuation for window sources calculated for air secondaries by MAGI is (.0098/.0693) = .141, not too different from the value of .165 calculated by MAGI for wall sources. However, the attenuation predicted for fission product gammas is (.0010/.0409) = .024, considerably lower than the value of .065 calculated by MAGI for wall sources. Therefore, the MAGI results for windows are believed to be about a factor of 2.5 too low, reducing the discrepancy from a factor of 13 to 5.2.

Figure 21 shows multistory structure #5. Because of the many stories, the roof source is not expected to contribute to the dose on the first story or in the basement. However, since the ambient source radiation is directed downward, walls above the first story may be expected to contribute to the dose at these points. Table XII shows a comparison of the contributions from the first, second, and third story walls to detectors on the first story and in the basement. Both calculations indicate that for ceiling thicknesses of 57 psf, the first story is the major contributor. Contributions from higher stories increase the dose by about 1/3 for AS gamma rays and are almost negligible for FP gamma rays. These increments would vary with the geometry of the building and the thickness of the ceilings. Agreement between the two types of calculations is good for the first story and, for the basement, a factor of 2 to 3 better than for structure #4. This reinforces the argument that the MAGI calculations of the window contribution to the basement of structure #4 may be low by a factor of 2.5.

D. Neutrons and Secondary Gamma Rays

Under a later subcontract with NBS (March 1981) MAGI also made Monte Carlo calculations of reduction factors for neutrons incident on benchmark structure #4. They tabulated reduction factors for both neutrons and for gamma rays produced by neutron interaction in the structure. These calculations were reported in MAGI-7072 [12]. Table XII shows comparisons for source neutrons entering through the roof and windows.

MAGI also distinguished between reflected and unreflected components. Although there is some question of the MAGI's operational definition of the two terms, unreflected is intended to mean the contribution from neutrons (or gammas) which enter the room through the floor, ceiling or exterior walls and reach the detector before being reflected from a room surface. All others are reflected, including gammas which were generated in a surface by neutrons entering the room.

For the roof source in Table XIII we find reasonable agreement for the sum of reflected and unreflected and for individual components. The agreement is also reasonable for basement detectors.

For the window source and first-story detector however, the NBS results are generally higher by a factor of 2. In this case, we believe that the unreflected neutron component may have been underestimated by MAGI. For example, they calculated .034 and .048 for the air-secondary and fission product source in structure #2 (See Table VIII). Since the neutrons are even more isotropic than the FP gamma rays we would expect a greater contribution from neutrons. Therefore the unreflected contribution of .0566 calculated by NBS seems more reasonable than the contribution of .0266 calculated by MAGI. Furthermore, the reflected contribution calculated by MAGI is almost three times that of the unreflected — too high a ratio, in our opinion. We therefore believe that the MAGI calculation of the unreflected contribution is low by at least a factor of 2.

For the window source and basement detectors the same problem exists. In this case, however, the problems is complicated by the attenuation in the ceiling barrier. But the attenuation factor for neutrons is less sensitive to the incident angle than for gamma rays. Therefore, even though the ceiling barrier factor for neutrons and secondary gammas is treated by "folding" the ceiling up against the outer wall and calculating the barrier factor for a roof source, the approximation is expected to be a good one.

For the wall source and first-story detector the same comments apply as for the window source. For the wall source and basement detector the NBS unreflected neutron contribution is even more than a factor of 2 greater than that calculated by MAGI, but the reflected contribution is lower. The result is fortuitously close agreement for the sum of the two contributions both for neutrons and secondary gammas.

The combined contributions of all three sources are also shown in Table XIII. Since the contribution from the roof source dominates, the ratio of NBS results for all sources are similar to those for the roof source alone.

Table XIII shows a similar comparison for Benchmark structure #5. For the first story source and the first-story detector, we believe that the NBS reflected neutron contribution may be somewhat high because the code does not take into account the decreased reflection when the two walls adjacent to the source wall are replaced by windows. It does, however, account for the decreased reflection from windows in the wall opposite to the source wall. On the other hand, just as for the other structures, we believe that the MAGI calculation of the unreflected neutron component is too small. This can be demonstrated for the detector on the first story, in which case the estimate is particularly simple. The INR code gives a reasonably rigorous estimate for the unreflected neutrons, namely:

$$R_f = 0.58\ G(\omega_w)$$

where $G(\omega_w)$ is the geometry factor for the solid angle opening ω_w of the windows. This yields $R_f = 0.196$, almost a factor of 2 greater than the MAGI value of .106.

For the basement, the MAGI values for the unreflected component are probably again too low, but the MAGI values for the reflected component are high, so that the sum of the contributions is consistent with those of NBS.

The contributions from stories 2-9 are also shown in Table XIV. For the first story detector the NBS values are consistently lower, probably because contributions from the third and higher stories are neglected in the INR code. The MAGI values for the basement detector give an idea of the underestimate of the NBS calculation.

Finally, the contribution from all sources are shown in Table XIV. The "bottom line" is that the NBS values for the reduction factors for neutrons and secondary gammas in a detector above grade are higher than the MAGI values by a factor of about 1.5 but probably more correct. For detectors in the basement the NBS value for the sum of the components is 0.8 times that of MAGI, that is, in rough agreement because of compensating estimates of reflected and unreflected contributions.

VI. CONCLUSIONS

In summary, the approximate procedures developed for calculating protection from initial gamma radiation appear to be promising. Estimates of protection with a single ceiling slab in place have been compared with those from Monte Carlo calculations. Procedures for more complicated interior structure such as interior walls are available, but have not yet been compared with more accurate calculations.

The two areas in which the INR codes could be improved are the ceiling attenuation for AS and FP gamma rays, and the calculation of the contribution from windows in the story above the detector.

References

[1] L. V. Spencer, Structure Shielding Against Fallout Radiation from Nuclear Weapons, NBS Monograph 42, U.S. Government Printing Office (June 1962).

[2] C. Eisenhauer, An Engineering Method for Calculating Protection Afforded by Structures Against Fallout Radiation, NBS Monograph 76, U.S. Government Printing Office (July 1964).

[3] L. V. Spencer, Structure Shielding Against Initial Radiation from Nuclear Explosions, I. Attenuation of Air Secondary and Fission Product Gamma Rays, Nucl. Sci. Eng. 57, 129-154 (June 1975).

[4] J. A. Auxier, Z. G. Burson, R. L. French, F. F. Haywood, L. G. Mooney, and E. A. Straker, Nuclear Weapons Free-Field Environment Recommended for Initial Radiation Shielding Calculations, ORNL TM 3396, Oak Ridge National Laboratory (Feb. 1972).

[5] L. G. Mooney and R. L. Swanson, Initial Nuclear Radiation Support Studies, RRA T7411, Radiation Research Associates, Inc., Ft. Worth, Texas (1974).

[6] M. Beer and M. O. Cohen, Effects of Ambient Field Specification on Initial Radiation Dose in Concrete Structures, Trans. Am. Nuc. Soc. 21, 545 (1975).

[7] G. L. Simmons, An Adjoint Gamma-Ray Moments Computer Code, ADJM/M I, NBS Technical Note 748, National Bureau of Standards (Feb. 1973).

[8] L. V. Spencer, "Plural-Series" Approximations of Functions, NBS J. Res., 76B, 91 (1972).

[9] G. L. Simmons and W. K. Hagan, Initial Nuclear Radiation Penetration Study, SAI01381 052LJ, Science Applications, La Jolla, California (1981).

[10] C. Eisenhauer and A. B. Chilton, Angular Distribution of Scattered Gamma Rays from a Fan Source, Trans. Am. Nuc. Soc. 14, 1 (June 1971).

[11] M. Beer and M. O. Cohen, Adjoint Monte Carlo Calculations of Initial Gamma Radiation Doses in Structures, Trans. Am. Nuc. Soc. 18, 377 (1974). (See also: M. Beer and M. O. Cohen, Initial Gamma Radiation Dose in Five Concrete Structures, Report Mr 7037, Mathematical Applications Group, Inc., Elmsford, N.Y., Nov. 1973).

[12] M. Beer, Monte Carlo Studies of the Shielding of Blockhouse Structures Against Initial Neutron Radiation, Mathematical Applications Group, Inc. Report No. MAGI-7072, Elmsford, New York (March 1981).

Table I. Relative Energy and Angle Distribution of $4\pi R^2$ Secondary Gamma Fluence 1200 m from a Point TN Source in Infinite Air. (Reference [4])

(gammas/group/angle bin/incident dose)

Energy Group (MeV)	Angle 2 MU=-0.9894	Angle 3 MU=-0.9446	Angle 4 MU=-0.8656	Angle 5 MU=-0.7550	Angle 6 MU=-0.6179	Angle 7 MU=-0.4580	Angle 8 MU=-0.2816	Angle 9 MU=-0.0950
8.00E 00---1.00E 01	3.072E 03	1.606E 04	4.193E 04	6.944E 04	8.374E 04	8.509E 04	9.393E 04	1.303E 05
6.50E 00---8.00E 00	-5.686E 03	1.923E 04	1.054E 05	1.814E 05	2.018E 05	1.705E 05	1.591E 05	2.491E 05
5.00E 00---6.50E 00	5.848E 04	3.085E 05	7.997E 05	1.297E 06	1.538E 06	1.535E 06	1.674E 06	2.340E 06
4.00E 00---5.00E 00	-9.176E 04	3.754E 03	2.433E 05	6.297E 05	5.854E 05	1.433E 05	1.495E 05	4.529E 05
3.00E 00---4.00E 00	-6.227E 04	2.427E 04	4.042E 05	6.747E 05	6.698E 05	3.277E 05	4.121E 05	8.246E 05
2.50E 00---3.00E 00	-8.974E 03	3.155E 04	1.602E 05	2.522E 05	2.520E 05	1.950E 05	2.315E 05	4.534E 05
2.00E 00---2.50E 00	4.485E 04	9.735E 04	1.342E 05	1.605E 05	2.046E 05	3.064E 05	4.746E 05	6.550E 05
1.66E 00---2.00E 00	7.169E 04	9.128E 04	3.316E 04	5.669E 03	7.897E 04	2.760E 05	4.753E 05	5.181E 05
1.33E 00---1.66E 00	1.060E 05	1.140E 05	1.407E 04	-2.798E 04	9.495E 04	4.073E 05	6.494E 05	6.069E 05
1.00E 00---1.33E 00	8.112E 04	7.651E 04	-6.597E 03	-1.182E 04	1.253E 05	4.100E 05	5.541E 05	5.092E 05
8.00E-01---1.00E 00	-8.096E 03	6.265E 03	7.111E 04	1.509E 05	2.104E 05	2.058E 05	2.177E 05	5.010E 05
6.00E-01---8.00E-01	-4.887E 04	2.868E 03	1.968E 05	3.559E 05	3.348E 05	3.042E 05	6.144E 05	1.834E 06
4.00E-01---6.00E-01	3.856E 05	8.701E 05	1.340E 06	1.936E 06	2.941E 06	4.694E 06	7.356E 06	1.068E 07
3.00E-01---4.00E-01	2.457E 05	6.607E 05	1.356E 06	2.543E 06	4.295E 06	6.364E 06	8.246E 06	9.463E 06
2.00E-01---3.00E-01	2.191E 06	5.055E 06	7.760E 06	1.011E 07	1.193E 07	1.319E 07	1.402E 07	1.463E 07
1.00E-01---2.00E-01	5.606E 06	1.298E 07	2.019E 07	2.710E 07	3.357E 07	3.943E 07	4.451E 07	4.858E 07
5.00E-02---1.00E-01	8.815E 06	2.036E 07	3.156E 07	4.215E 07	5.191E 07	6.055E 07	6.778E 07	7.326E 07
2.00E-02---5.00E-02	1.641E 06	3.775E 06	5.806E 06	7.669E 06	9.309E 06	1.067E 07	1.170E 07	1.235E 07

Table I. Continued

(gammas/group/angle bin/incident dose)

Energy Group (MeV)	Angle 10 MU= 0.0950	Angle 11 MU= 0.2816	Angle 12 MU= 0.4580	Angle 13 MU= 0.6179	Angle 14 MU= 0.7550	Angle 15 MU= 0.8656	Angle 16 MU= 0.9446	Angle 17 MU= 0.9894
8.00E 00---1.00E 01	1.969E 05	2.779E 05	3.632E 05	4.951E 05	8.214E 05	1.666E 06	3.591E 06	7.047E 06
6.50E 00---8.00E 00	4.466E 05	6.623E 05	8.183E 05	1.023E 06	1.714E 06	3.743E 06	8.503E 06	1.828E 07
5.00E 00---6.50E 00	3.530E 06	4.836E 06	5.955E 06	7.507E 06	1.163E 07	2.200E 07	4.204E 07	6.277E 07
4.00E 00---5.00E 00	1.241E 06	1.899E 06	1.967E 06	1.996R 06	3.860E 06	9.795E 06	1.984E 07	2.687E 07
3.00E 00---4.00E 00	1.647E 06	2.291E 06	2.420E 06	2.973E 06	6.066E 06	1.354E 07	2.372E 07	2.574E 07
2.50E 00---3.00E 00	7.640E 05	9.794E 05	1.165E 06	1.930E 06	4.244E 06	8.555E 06	1.334E 07	1.378E 07
2.00E 00---2.50E 00	7.792E 05	9.168E 05	1.442E 06	3.025E 06	6.244E 06	1.079E 07	1.446E 07	1.229E 07
1.66E 00---2.00E 00	4.513E 05	5.352E 05	1.337E 06	3.226E 06	6.095E 06	9.083E 06	1.047E 07	7.727E 06
1.33E 00---1.66E 00	4.554E 05	8.026E 05	2.311E 06	5.112E 06	8.447E 06	1.086E 07	1.076E 07	6.888E 06
1.00E 00---1.33E 00	7.006E 05	1.902E 06	4.612E 06	8.372E 06	1.167E 07	1.272E 07	1.057E 07	5.518E 06
8.00E-01---1.00E 00	1.391E 06	3.090E 06	5.410E 06	7.666E 06	8.904E 06	8.410E 06	6.174E 06	2.846E 06
6.00E-01---8.00E-01	4.112E 06	6.832E 06	9.207E 06	1.041E 07	1.018E 07	8.683E 06	6.214E 06	2.928E 06
4.00E-01---6.00E-01	1.397E 07	1.634E 07	1.719E 07	1.652E 07	1.481E 07	1.242E 07	9.140E 06	4.434E 06
3.00E-01---4.00E-01	9.887E 06	9.787E 06	9.547E 06	9.272E 06	8.661E 06	7.294E 06	5.057E 06	2.252E 06
2.00E-01---3.00E-01	1.511E 07	1.536E 07	1.516E 07	1.431E 07	1.271E 07	1.033E 07	7.147E 06	3.244E 06
1.00E-01---2.00E-01	5.138E 07	5.261E 07	5.188E 07	4.884E 07	4.317E 07	3.474E 07	2.368E 07	1.059E 07
5.00E-02---1.00E-01	7.660E 07	7.738E 07	7.521E 07	6.970E 07	6.065E 07	4.807E 07	3.235E 07	1.435E 07
2.00E-02---5.00E-02	1.259E 07	1.237E 07	1.169E 07	1.053E 07	8.927E 06	6.914E 06	4.571E 06	2.006E 06

Table II. Fission-Product Gamma-Ray Fluence as a Function of Energy and Polar Angle with Respect to the Source-Detector Axis 30° above the Horizon (300 kT, 30 PSI) (Reference [5]).

Gamma-Ray Fluence/Steradian

Energy(MeV)	Angle(deg) 0.0-13.4	Angle(deg) 13.4-24.4	Angle(deg) 24.4-35.4	Angle(deg) 35.4-46.3	Angle(deg) 46.3-57.2	Angle(deg) 57.2-68.1	Angle(deg) 68.1-79.1	Angle(deg) 79.1-90.0
6.5 - 5.0	2.502E-03	8.158E-04	3.407E-04	1.955E-04	1.066E-04	4.887E-05	2.374E-05	1.437E-05
5.0 - 4.0	6.381E-03	2.528E-03	1.198E-03	6.989E-04	3.815E-04	1.768E-04	8.724E-05	5.280E-05
4.0 - 3.0	1.273E-02	6.559E-03	3.503E-03	2.063E-03	1.126E-03	5.270E-04	2.591E-04	1.521E-04
3.0 - 2.5	8.273E-03	5.149E-03	2.954E-03	1.756E-03	9.638E-04	4.595E-04	2.281E-04	1.307E-04
2.5 - 2.0	1.133E-02	7.510E-03	4.478E-03	2.697E-03	1.505E-03	7.382E-04	3.782E-04	2.187E-04
2.0 - 1.6	9.930E-03	7.415E-03	4.699E-03	2.903E-03	1.660E-03	8.443E-04	4.473E-04	2.609E-04
1.6 - 1.3	1.183E-02	9.784E-03	6.546E-03	4.171E-03	2.462E-03	1.308E-03	7.183E-04	4.240E-04
1.3 - 1.0	1.317E-02	1.309E-02	9.999E-03	6.923E-03	4.393E-03	2.536E-03	1.476E-03	8.834E-04
1.0 - 0.8	7.594E-03	8.878E-03	7.600E-03	5.702E-03	3.935E-03	2.491E-03	1.546E-03	9.566E-04
0.8 - 0.6	6.717E-03	9.454E-03	9.226E-03	7.643E-03	5.830E-03	4.086E-03	2.720E-03	1.751E-03
0.6 - 0.4	7.202E-03	1.057E-02	1.128E-02	1.045E-02	9.033E-03	7.220E-03	5.390E-03	3.840E-03
0.4 - 0.3	3.324E-03	5.451E-03	6.225E-03	6.043E-03	5.454E-03	4.677E-03	4.026E-03	3.525E-03
0.3 - 0.2	3.822E-03	6.489E-03	7.799E-03	8.036E-03	7.745E-03	7.147E-03	6.621E-03	6.204E-03
0.2 - 0.1	7.387E-03	1.257E-02	1.586E-02	1.715E-02	1.733E-02	1.680E-02	1.628E-02	1.586E-02
0.1 - 0.05	1.008E-02	1.749E-02	2.286E-02	2.543E-02	2.640E-02	2.629E-02	2.601E-02	2.576E-02
0.05- 0.02	3.879E-03	6.848E-03	9.158E-03	1.036E-02	1.094E-02	1.108E-02	1.111E-02	1.111E-02

Table II. Continued

Energy(MeV)	Angle(deg) 90 - 100	Angle(deg) 100 - 112	Angle(deg) 112 - 123	Angle(deg) 123 - 134	Angle(deg) 134 - 145	Angle(deg) 145 - 156	Angle(deg) 156 - 167	Angle(deg) 167 - 180
6.5 - 5.0	1.039E-05	8.522E-06	7.401E-06	6.646E-06	6.180E-06	5.993E-06	6.120E-06	6.463E-06
5.0 - 4.0	3.770E-05	3.055E-05	2.633E-05	2.349E-05	2.173E-05	2.098E-05	2.139E-05	2.260E-05
4.0 - 3.0	1.046E-04	8.199E-05	6.893E-05	6.021E-05	5.463E-05	5.195E-05	5.245E-05	5.516E-05
3.0 - 2.5	8.582E-05	6.384E-05	5.105E-05	4.256E-05	3.700E-05	3.393E-05	3.335E-05	3.455E-05
2.5 - 2.0	1.408E-04	1.005E-04	7.668E-05	6.112E-05	5.107E-05	4.537E-05	4.369E-05	4.482E-05
2.0 - 1.6	1.650E-04	1.131E-04	8.215E-05	6.230E-05	4.972E-05	4.251E-05	3.984E-05	4.030E-05
1.6 - 1.3	2.653E-04	1.764E-04	1.232E-04	8.979E-05	6.915E-05	5.744E-05	5.278E-05	5.285E-05
1.3 - 1.0	5.403E-04	3.401E-04	2.204E-04	1.478E-04	1.046E-04	8.032E-05	6.928E-05	6.674E-05
1.0 - 0.8	5.896E-04	3.648E-04	2.283E-04	1.468E-04	9.943E-05	7.322E-05	6.093E-05	5.733E-05
0.8 - 0.6	1.101E-03	6.829E-04	4.239E-04	2.694E-04	1.803E-04	1.313E-04	1.081E-04	1.008E-04
0.6 - 0.4	2.658E-03	1.816E-03	1.245E-03	8.773E-04	6.513E-04	5.217E-04	4.630E-04	4.514E-04
0.4 - 0.3	3.144E-03	2.866E-03	2.670E-03	2.554E-03	2.529E-03	2.600E-03	2.791E-03	3.049E-03
0.3 - 0.2	5.864E-03	5.595E-03	5.395E-03	5.294E-03	5.339E-03	5.562E-03	6.043E-03	6.660E-03
0.2 - 0.1	1.548E-02	1.517E-02	1.494E-02	1.492E-02	1.526E-02	1.609E-02	1.766E-02	1.962E-02
0.1 - 0.05	2.551E-02	2.533E-02	2.562E-02	2.551E-02	2.635E-02	2.801E-02	3.100E-02	3.463E-02
0.05- 0.02	1.110E-02	1.112E-02	1.117E-02	1.136E-02	1.181E-02	1.262E-02	1.405E-02	1.575E-02

Table III. Relative Energy and Angle Distribution of $4\pi R^2$ Neutron Fluence 1200 m from a Point TN Source in Infinite Air (Reference [4])

(neutrons/group/angle bin/incident dose)

Energy Group (MeV)	Angle 2 MU=-0.9894	Angle 3 MU=-0.9446	Angle 4 MU=-0.8656	Angle 5 MU=-0.7550	Angle 6 MU=-0.6179	Angle 7 MU=-0.4580	Angle 8 MU=-0.2816	Angle 9 MU=-0.0950
1.22E 01---1.50E 01	-3.970E 02	2.416E 01	1.743E 03	3.299E 03	3.383E 03	4.825E 03	9.865E 03	2.244E 04
1.00E 01---1.22E 01	3.526E 03	8.502E 03	1.366E 04	1.834E 04	2.285E 04	2.918E 04	4.000E 04	5.599E 04
8.19E 00---1.00E 01	5.173E 03	1.250E 04	2.039E 04	2.836E 04	3.728E 04	4.995E 04	6.981E 04	9.764E 04
6.36E 00---8.19E 00	1.587E 04	3.674E 04	5.809E 04	8.234E 04	1.125E 05	1.555E 05	2.095E 05	2.730E 05
4.97E 00---6.36E 00	3.577E 04	8.293E 04	1.312E 05	1.842E 05	2.468E 05	3.209E 05	4.047E 05	4.944E 05
4.07E 00---4.97E 00	5.036E 04	1.177E 05	1.863E 05	2.561E 05	3.271E 05	3.995E 05	4.745E 05	5.545E 05
3.01E 00---4.07E 00	7.471E 04	1.717E 05	2.641E 05	3.508E 05	4.322E 05	5.099E 05	5.871E 05	6.672E 05
2.46E 00---3.01E 00	6.245E 04	1.443E 05	2.242E 05	3.021E 05	3.799E 05	4.614E 05	5.526E 05	6.601E 05
2.35E 00---2.46E 00	1.792E 04	4.209E 04	6.739E 04	9.442E 04	1.242E 05	1.577E 05	1.962E 05	2.412E 05
1.83E 00---2.35E 00	1.283E 05	2.996E 05	4.740E 05	6.533E 05	8.410E 05	1.040E 06	1.255E 06	1.489E 06
1.11E 00---1.83E 00	3.402E 05	7.912E 05	1.243E 06	1.693E 06	2.146E 06	2.599E 06	3.049E 06	3.488E 06
5.50E-01---1.11E 00	8.103E 05	1.885E 06	2.963E 06	4.038E 06	5.112E 06	6.178E 06	7.225E 06	8.231E 06
1.11E-01---5.50E-01	2.135E 06	4.950E 06	7.724E 06	1.042E 07	1.299E 07	1.538E 07	1.752E 07	1.932E 07
3.35E-03---1.11E-01	4.158E 06	9.606E 06	1.488E 07	1.986E 07	2.443E 07	2.845E 07	3.175E 07	3.418E 07
5.83E-04---3.35E-03	1.802E 06	4.157E 06	6.423E 06	8.541E 06	1.045E 07	1.210E 07	1.341E 07	1.432E 07
1.01E-04---5.83E-04	1.803E 06	4.158E 06	6.422E 06	8.534E 06	1.044E 07	1.206E 07	1.335E 07	1.423E 07
2.90E-05---1.01E-04	1.264E 06	2.913E 06	4.498E 06	5.973E 06	7.299E 06	8.430E 06	9.322E 06	9.928E 06
1.07E-05---2.90E-05	9.983E 05	2.302E 06	3.553E 06	4.718E 06	5.765E 06	6.657E 06	7.361E 06	7.838E 06
3.06E-06---1.07E-05	1.194E 06	2.752E 06	4.247E 06	5.639E 06	6.888E 06	7.952E 06	8.788E 06	9.354E 06
1.12E-06---3.06E-06	8.586E 05	1.979E 06	3.054E 06	4.054E 06	4.951E 06	5.713E 06	6.312E 06	6.715E 06
4.14E-07---1.12E-06	7.263E 05	1.674E 06	2.583E 06	3.428E 06	4.185E 06	4.828E 06	5.332E 06	5.670E 06
0.0 ---4.14E-07	6.510E 05	1.500E 06	2.312E 06	3.064E 06	3.735E 06	4.302E 06	4.741E 06	5.032E 06

Table III. Continued

Energy Group (MeV)	Angle 10 MU= 0.0950	Angle 11 MU= 0.2815	Angle 12 MU= 0.4580	Angle 13 MU= 0.6179	Angle 14 MU= 0.7550	Angle 15 MU= 0.8656	Angle 16 MU= 0.9446	Angle 17 MU= 0.9894
1.22E 01---1.50E 01	3.993E 04	5.747E 04	7.770E 04	1.121E 05	1.837E 05	3.070E 05	4.570E 05	6.175E 05
1.00E 01---1.22E 01	7.455E 04	9.256E 04	1.126E 05	1.478E 05	2.181E 05	3.339E 05	4.656E 05	5.671E 05
8.19E 00---1.00E 01	1.303E 05	1.649E 05	2.067E 05	2.749E 05	3.962E 05	5.813E 05	7.811E 05	9.204E 05
6.36E 00---8.19E 00	3.427E 05	4.219E 05	5.269E 05	6.862E 05	9.224E 05	1.214E 06	1.437E 06	1.389E 06
4.97E 00---6.36E 00	5.898E 05	6.972E 05	8.341E 05	1.016E 06	1.238E 06	1.451E 06	1.519E 06	1.252E 06
4.07E 00---4.97E 00	6.441E 05	7.496E 05	8.773E 05	1.027E 06	1.181E 06	1.286E 06	1.232E 06	8.681E 05
3.01E 00---4.07E 00	7.544E 05	8.505E 05	9.524E 05	1.047E 06	1.106E 06	1.082E 06	9.074E 05	5.152E 05
2.46E 00---3.01E 00	7.908E 05	9.504E 05	1.142E 06	1.360E 06	1.583E 06	1.753E 06	1.744E 06	1.401E 06
2.35E 00---2.46E 00	2.947E 05	3.594E 05	4.389E 05	5.359E 05	6.475E 05	7.561E 05	8.112E 05	7.556E 05
1.83E 00---2.35E 00	1.740E 06	2.003E 06	2.259E 06	2.475E 06	2.591E 06	2.519E 06	2.126E 06	1.271E 06
1.11E 00---1.83E 00	3.900E 06	4.256E 06	4.515E 06	4.613E 06	4.459E 06	3.943E 06	2.955E 06	1.446E 06
5.50E-01---1.11E 00	9.156E 06	9.934E 06	1.047E 07	1.060E 07	1.015E 07	8.888E 06	6.588E 06	3.178E 06
1.11E-01---5.50E-01	2.065E 07	2.137E 07	2.131E 07	2.028E 07	1.812E 07	1.472E 07	1.011E 07	4.545E 06
3.35E-03---1.11E-01	3.555E 07	3.569E 07	3.442E 07	3.164E 07	2.730E 07	2.147E 07	1.435E 07	6.341E 06
5.83E-04---3.35E-03	1.476E 07	1.467E 07	1.401E 07	1.275E 07	1.090E 07	8.502E 06	5.650E 06	2.487E 06
1.01E-04---5.83E-04	1.465E 07	1.454E 07	1.386E 07	1.259E 07	1.075E 07	8.371E 06	5.557E 06	2.444E 06
2.90E-05---1.01E-04	1.021E 07	1.012E 07	9.633E 06	8.742E 06	7.452E 06	5.799E 06	3.847E 06	1.691E 06
1.07E-05---2.90E-05	8.055E 06	7.984E 06	7.600E 06	6.896E 06	5.877E 06	4.572E 06	3.033E 06	1.333E 06
3.06E-06---1.07E-05	9.610E 06	9.519E 06	9.058E 06	8.215E 06	6.998E 06	5.443E 06	3.609E 06	1.587E 06
1.12E-06---3.06E-06	6.895E 06	6.827E 06	6.493E 06	5.886E 06	5.012E 06	3.896E 06	2.583E 06	1.135E 06
4.14E-07---1.12E-06	5.820E 06	5.760E 06	5.475E 06	4.961E 06	4.223E 06	3.282E 06	2.175E 06	9.560E 05
0.0 ---4.14E-07	5.154E 06	5.089E 06	4.828E 06	4.366E 06	3.710E 06	2.880E 06	1.907E 06	8.375E 05

Table IV. Structural Details

Structure Number	Thickness of Basement Ceiling	Windows ?
1	0 psf	No
2	0 psf	Yes
3	57 psf	No
4	57 psf	Yes

Table V

Comparison of Roof Barrier Factors

Z(psf)	Air Secondaries			FP Gammas		
	MAGI	NBS	RATIO	MAGI	NBS	RATIO
0	1.00	1.00	1.00	1.00	1.00	1.00
10	.72	.80	.90	.58	.63	.92
28	.47	.53	.89	.31	.33	.94
57	.27	.28	.96	.153	.145	1.05
85	.156	.155	1.01	.076	.071	1.07

Table VI. Comparison of Reduction factors for combined Components

Structure #4

First Story

	AS	FP	N	NG	High Yield IRF (eq. 4)	Low Yield IRF (eq. 5)
NBS	.305	.208	.485	.096	.258	.451
MAGI	.298	.173	.339	.060	.266	.334
Ratio					1.0	1.4

Basement

	AS	FP	N	NG	High Yield IRF (eq. 4)	Low Yield IRF (eq. 5)
NBS	.234	.128	.1127	.0343	.155	.161
MAGI	.178	.085	.0814	.0351	.113	.122
Ratio					1.4	1.3

Structure #5

First Story

	AS	FP	N	NG	High Yield IRF (eq. 4)	Low Yield IRF (eq. 5)
NBS	.242	.260	.490	.082	.350	.444
MAGI	.225	.190	.331	.047	.253	.310
Ratio					1.4	1.4

Basement

	AS	FP	N	NG	High Yield IRF (eq. 4)	Low Yield IRF (eq. 5)
NBS	.073	.0290	.063	.0122	.052	.066
MAGI	.059	.0102	.069	.026	.045	.056
Ratio					1.2	1.2

Table VII. Comparison of AS and FP Gamma-Ray Reduction Factors

Structure #1

(On first story at a height of 3 feet above the floor)

	Air Secondaries			FP Gammas		
	Roof	Walls	Total	Roof	Walls	Total
NBS	.232	.053	.285	.123	.043	.166
MAGI	.228	.052	.280	.101	.034	.135
Ratio	1.02	1.02	1.02	1.22	1.26	1.23
	(In basement at a depth of 9 feet below the basement ceiling)					
NBS	.184	.109	.293	.112	.038	.150
MAGI	.156	.091	.247	.083	.026	.109
Ratio	1.18	1.20	1.19	1.35	1.46	1.38

Table VIII. Comparison as AS and FP Gamma-Ray Reduction Factors

Structure #2

(On first story at a height of 3 feet above the floor)

	Air Secondaries			FP Gammas		
	Walls	Windows	Walls and Windows	Walls	Windows	Walls and Windows
NBS	.042	.031	.073	.032	.053	.085
MAGI	.0360	.0340	.070	.0244	.0480	.072
Ratio	1.17	0.91	1.04	1.31	1.10	1.18

(In basement at a depth of 9 feet below the basement ceiling)

	Walls	Windows	Walls and Windows	Walls	Windows	Walls and Windows
NBS	.068	.119	.187	.025	.088	.113
MAGI	.0664	.0693	.136	.0209	.0409	.062
Ratio	1.02	1.72	1.38	1.20	2.15	1.82

Table IX. Comparison of AS and FP Gamma-Ray Reduction Factors

Structure #3

(In basement at a depth of 9 feet below the basement ceiling)

	Air Secondaries			FP Gammas		
	Roof	Walls	Total	Roof	Walls	Total
NBS	.066	.029	.095	.0312	.0055	.037
MAGI	.053	.015	.068	.025	.0017	.026
Ratio	1.25	1.93	1.40	1.25	3.2	1.42

Table X. Calculated Gamma-Ray Attenuation Factors for Basement Ceiling

Structure #3

	Air Secondaries		FP Gammas	
	Roof	Walls	Roof	Walls
NBS	.36	.266	.28	.211
MAGI	.34	.165	.29	.065

Table XI. Comparison of AS and FP Gamma-Ray Reduction Factors

Structure #4

(In basement at a depth of 9 feet below the basement ceiling)

	Air Secondaries			FP Gammas		
	Walls	Windows	Walls and Windows	Walls	Windows	Walls and Windows
NBS	.018	.032	.050	.0036	.0128	.0164
MAGI	.012	.0098	.022	.0014	.0010	.0024
Ratio	1.50	3.3	2.3	2.6	13.	6.8

Table XII. Comparison of AS and FP Gamma-Ray Reduction Factors.

Structure #5

(On first story at a height of 3 feet above the floor)

	Air Secondaries				FP Gammas			
Walls:	Story 1	Story 2	Stories 3-9	All Walls	Story 1	Story 2	Stories 3-9	All Walls
NBS	.165	.077	.0	.242	.233	.027	.0	.260
MAGI	.165	.041	.019	.225	.179	.009	.002	.190
Ratio	1.00	1.88	0.0	1.08	1.30	3.0	0.0	1.37

(In basement at a depth of 9 feet below the basement ceiling)

NBS	.073	.0	.0	.073	.0290	.0	.0	.0290
MAGI	.039	.013	.007	.059	.0080	.0014	.0008	.0102
Ratio	1.87	.0	.0	1.24	3.62	.0	.0	2.84

Table XIII. Comparison of Neutron and Secondary-Gamma Reduction Factors Calculated by MAGI and NBS for Benchmark Structure #4.

Roof Source

First Story Detector

	Neutrons		Secondary Gammas		Sum		
	MAGI	NBS	MAGI	NBS	MAGI	NBS	Ratio
Reflected	.0990	.126	.0302	.0378	.1292	.164	
Unreflected	.1117	.124	.00820	.0108	.1199	.135	
Sum	.2107	.250	.0384	.0486	.2491	.299	1.2

Basement Detector

	Neutrons MAGI	Neutrons NBS	Secondary Gammas MAGI	Secondary Gammas NBS	Sum MAGI	Sum NBS	Ratio
Reflected	.0377	.0322	.0122	.0097	.0499	.419	
Unreflected	.0172	.0318	.0076	.0114	.0248	.0432	
Sum	.0549	.0640	.0198	.0211	.0747	.0851	1.1

Window Source

First Story Detector

	Neutrons MAGI	Neutrons NBS	Secondary Gammas MAGI	Secondary Gammas NBS	Sum MAGI	Sum NBS	Ratio
Reflected	.0657	.0852	.00795	.0255	.0737	.1203	
Unreflected	.0226	.0566	.0	.0	.0226	.0566	
Sum	.0883	.1418	.00795	.0255	.0963	.1975	2.0

Basement Detector

	Neutrons MAGI	Neutrons NBS	Secondary Gammas MAGI	Secondary Gammas NBS	Sum MAGI	Sum NBS	Ratio
Reflected	.0119	.0175	.00273	.0060	.0146	.0235	
Unreflected	.00432	.0173	.00477	.00121	.00909	.0185	
Sum	.0162	.0348	.00750	.0072	.0237	.0420	1.8

Table XIII. (Continued)

Wall Source

First Story Detector

	Neutrons		Secondary Gammas		Sum		
	MAGI	NBS	MAGI	NBS	MAGI	NBS	Ratio
Reflected	.0246	.0524	.0113	.01574	.0359	.0681	
Unreflected	.0152	.0403	.00222	.00620	.0174	.0465	
Sum	.0398	.0927	.0135	.0219	.0533	.115	2.2

Basement Detector

Reflected	.00915	.00697	.00554	.00209	.0147	.00906	
Unreflected	.00112	.00688	.00225	.00392	.00337	.01080	
Sum	.01026	.01385	.00779	.00601	.0181	.0199	1.1

All Sources

First Story Detector

Reflected	.189	.264	.0494	.0790	.238	.343	
Unreflected	.150	.221	.0104	.0170	.160	.238	
Sum	.339	.485	.0598	.0960	.399	.581	1.5

Basement Detector

Reflected	.0588	.0567	.0205	.0178	.0793	.0745	
Unreflected	.0226	.0560	.0146	.0165	.0372	.0725	
Sum	.0814	.1127	.0351	.0343	.1165	.147	1.3

Table XIV. Comparison of Neutron and Secondary-Gamma Reduction Factors Calculated by MAGI and NBS for Benchmark Structure #5.

	Neutrons		Secondary Gammas		Total		Ratio
	MAGI	NBS	MAGI	NBS	MAGI	NBS	
First Story Source							
First Story							
Reflected	.157	.248	.026	.074	.183	.334	
Unreflected	.106	.196	.0	.0	.106	.184	
Sum	.263	.444	.026	.074	.289	.518	1.8
Basement Detector							
Reflected	.041	.032	.011	.0095	.052	.041	
Unreflected	.012	.031	.006	.0027	.018	.034	
Sum	.053	.063	.017	.0122	.070	.075	1.1
2-9 Story Source							
First Story Detector							
Reflected	.047	.017	.011	.006	.058	.023	
Unreflected	.021	.029	.010	.002	.031	.031	
Sum	.068	.046	.021	.008	.089	.054	0.6
Basement Detector							
Reflected	.0106	0	.0038	0	.0144	0	
Unreflected	.0054	0	.0053	0	.0107	0	
Sum	.0160	0	.0091	0	.0251	0	0.0
All Sources							
First Story Detector							
Reflected	.204	.265	.037	.080	.241	.345	1.4
Unreflected	.127	.225	.010	.002	.137	.227	1.7
Sum	.331	.490	.047	.082	.378	.572	1.5
Basement Detector							
Reflected	.0516	.032	.015	.0095	.067	.041	0.6
Unreflected	.0174	.031	.011	.0027	.028	.034	1.2
Sum	.0690	.063	.026	.0122	.095	.075	0.8

LIST OF FIGURES

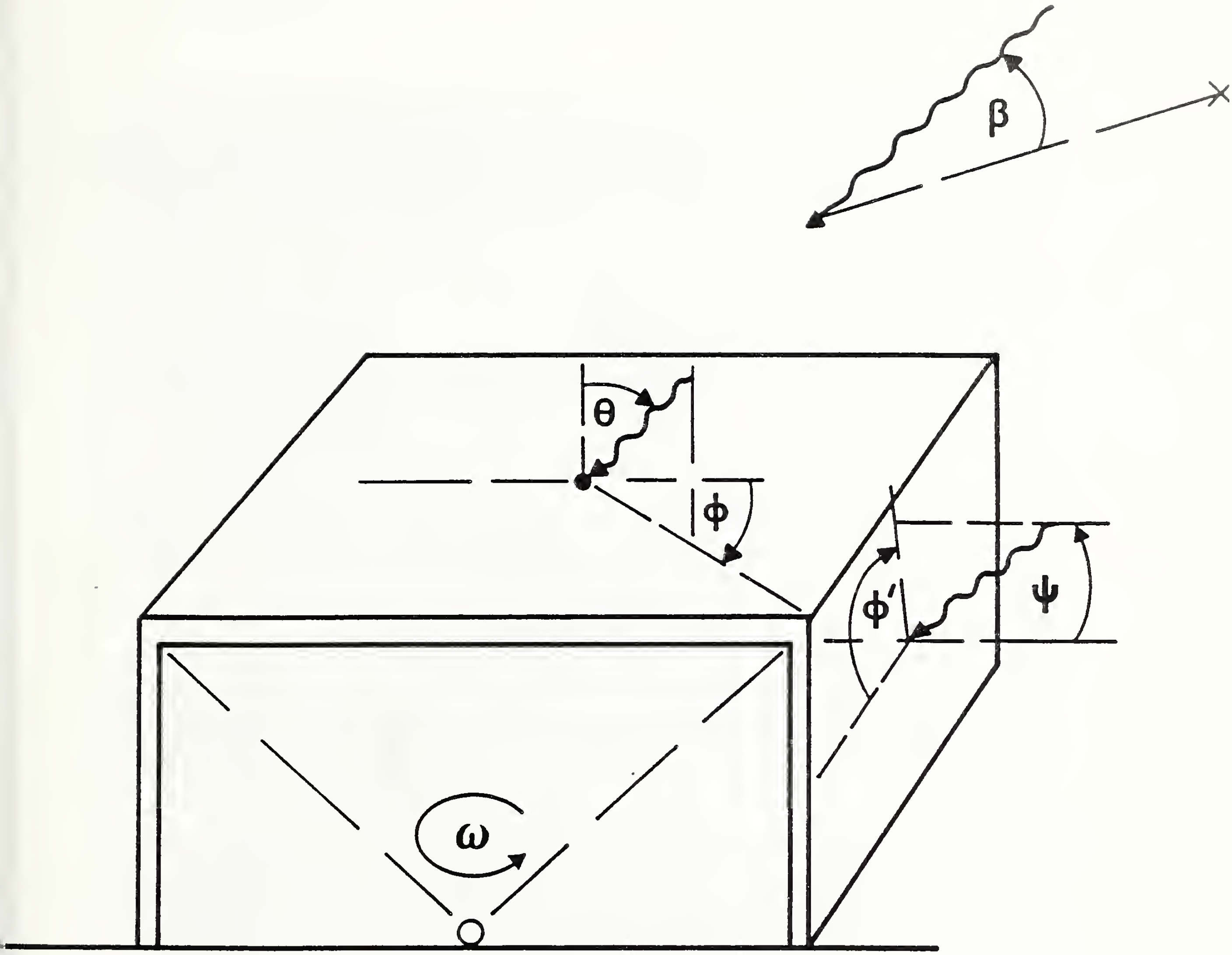


Fig. 1. Angular coordinate systems: The angle β is the polar angle with respect to the original source-detector line. The angular distribution from a point source is averaged over all azimuthal directions ϕ to form a ring source. Angular distributions are rotated to (θ,ϕ) polar and azimuthal angles for radiation incident on the roof, and to (ψ,ϕ) polar and azimuthal angles for radiation incident on the walls.

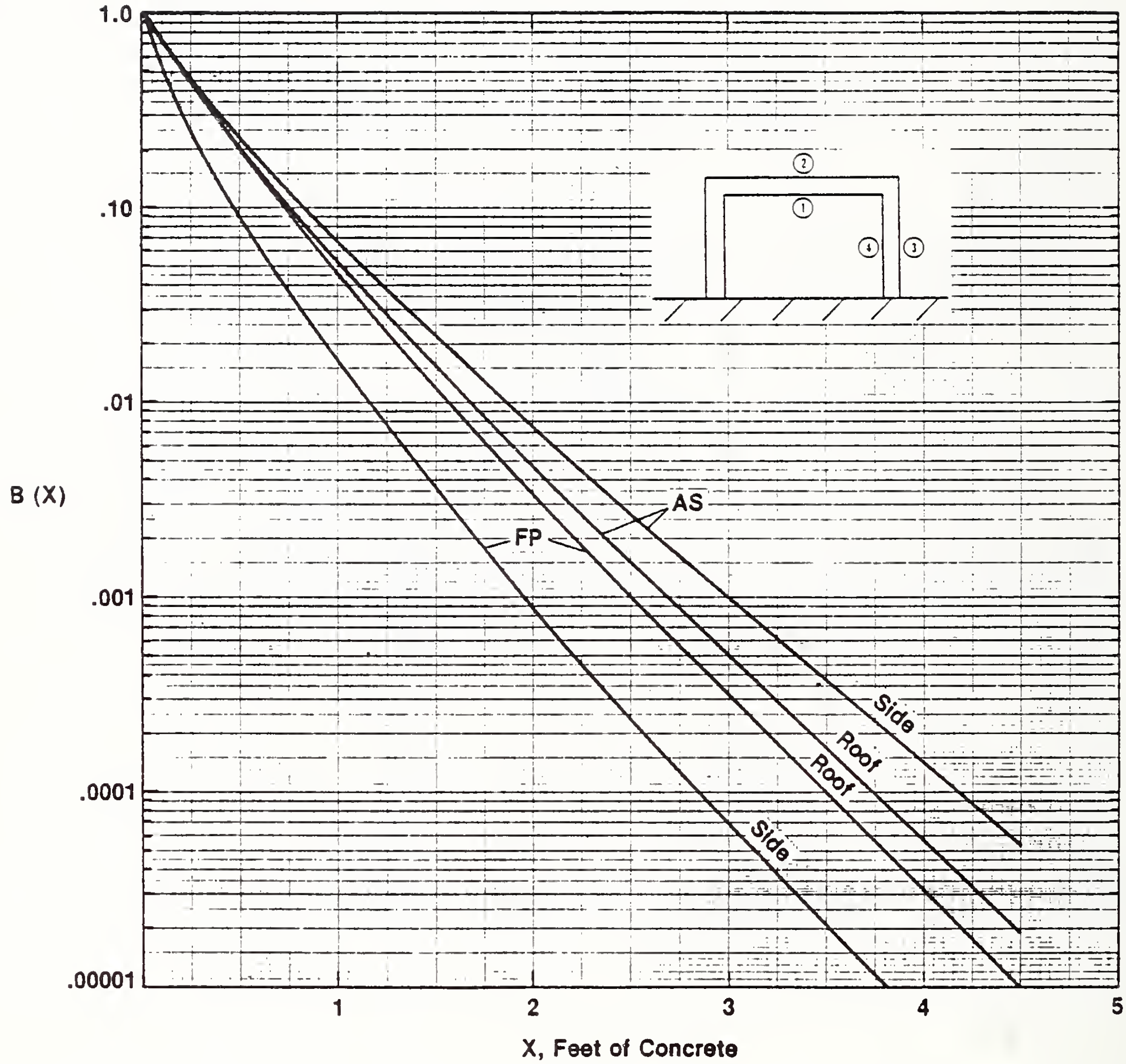


Fig. 2. Initial gamma ray barrier factors.

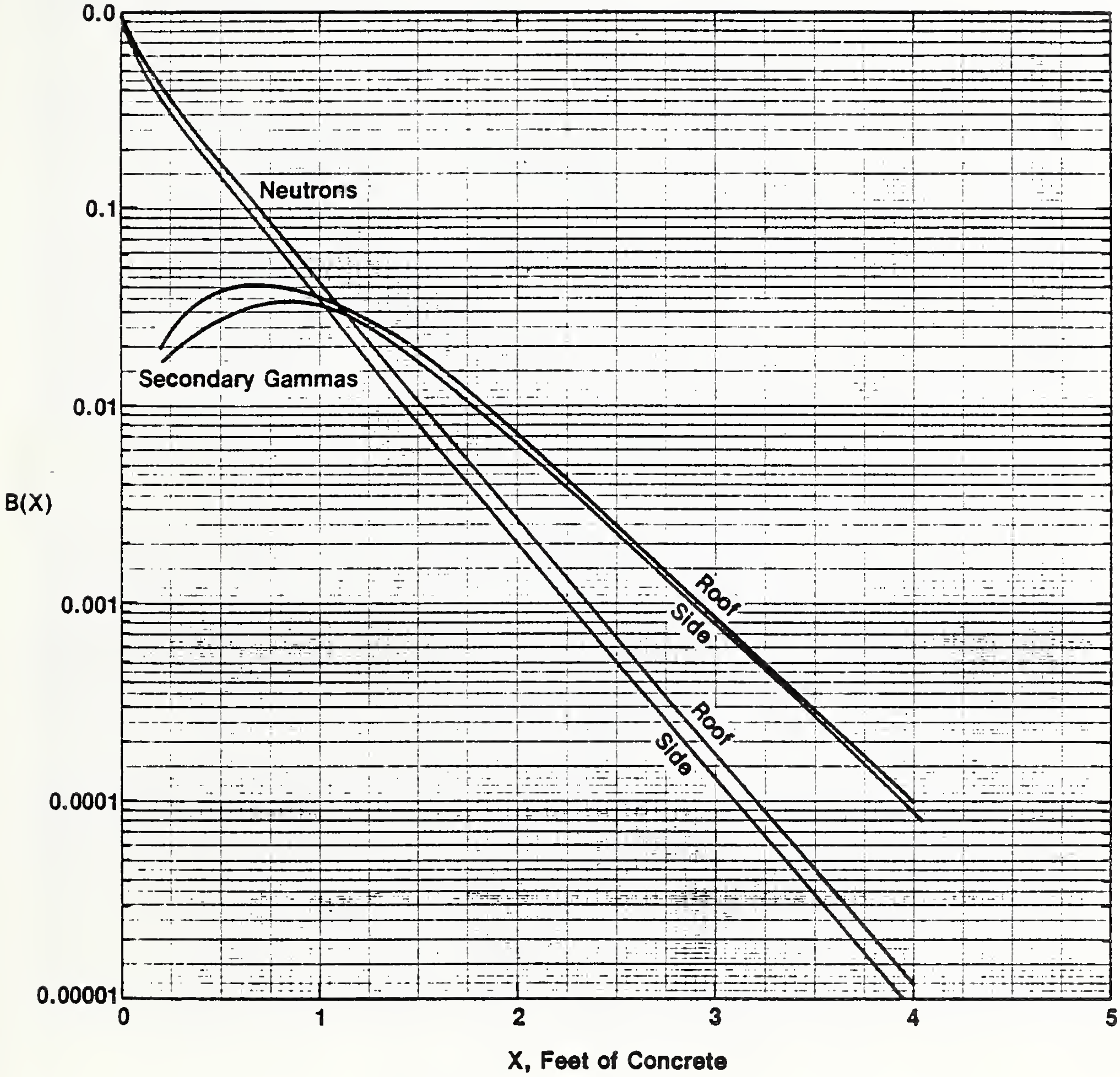


Fig. 3. Initial neutron and wall secondary gamma barrier factors.

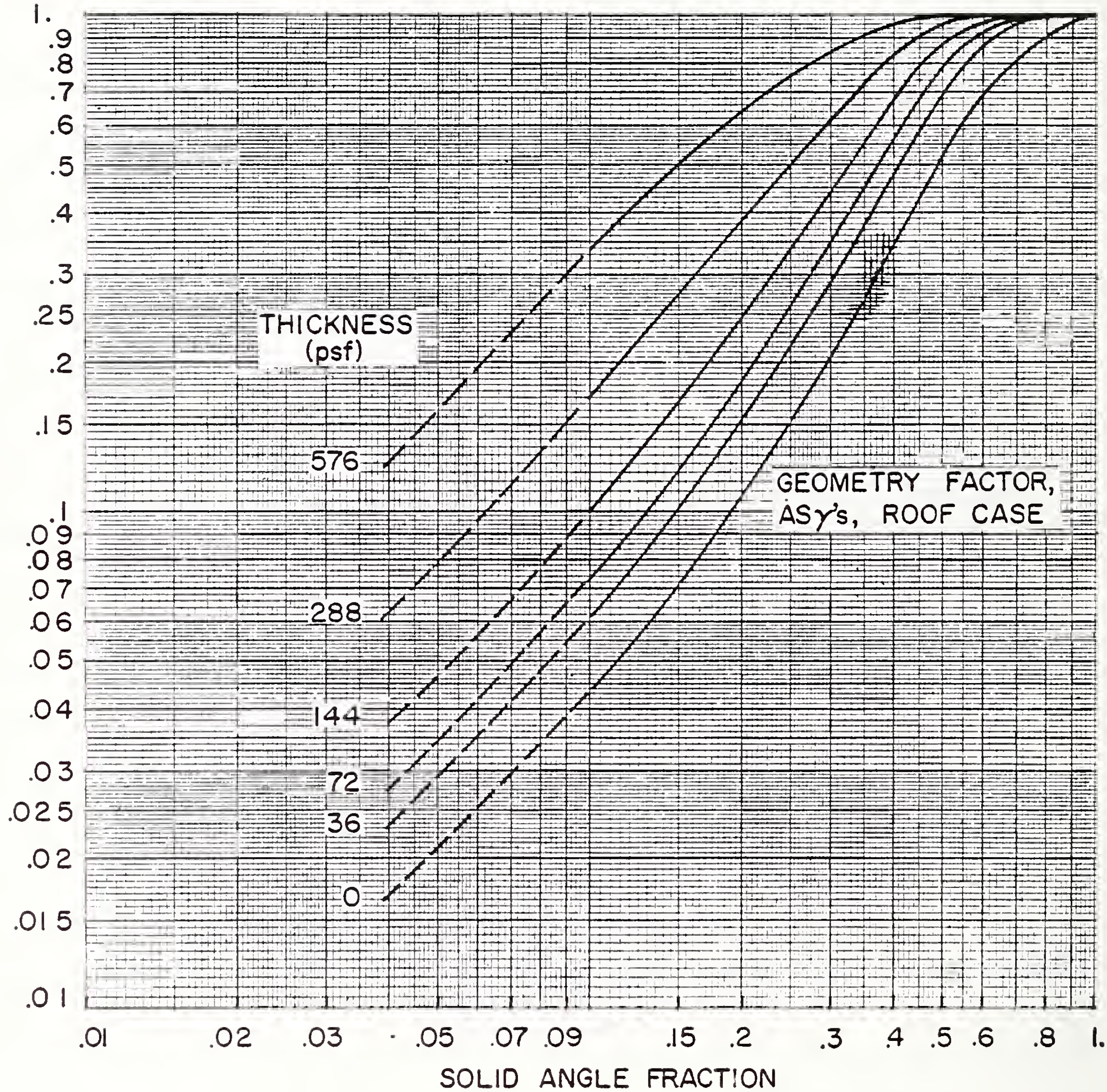


Fig. 4. Overhead geometry factor, air secondary gamma rays.

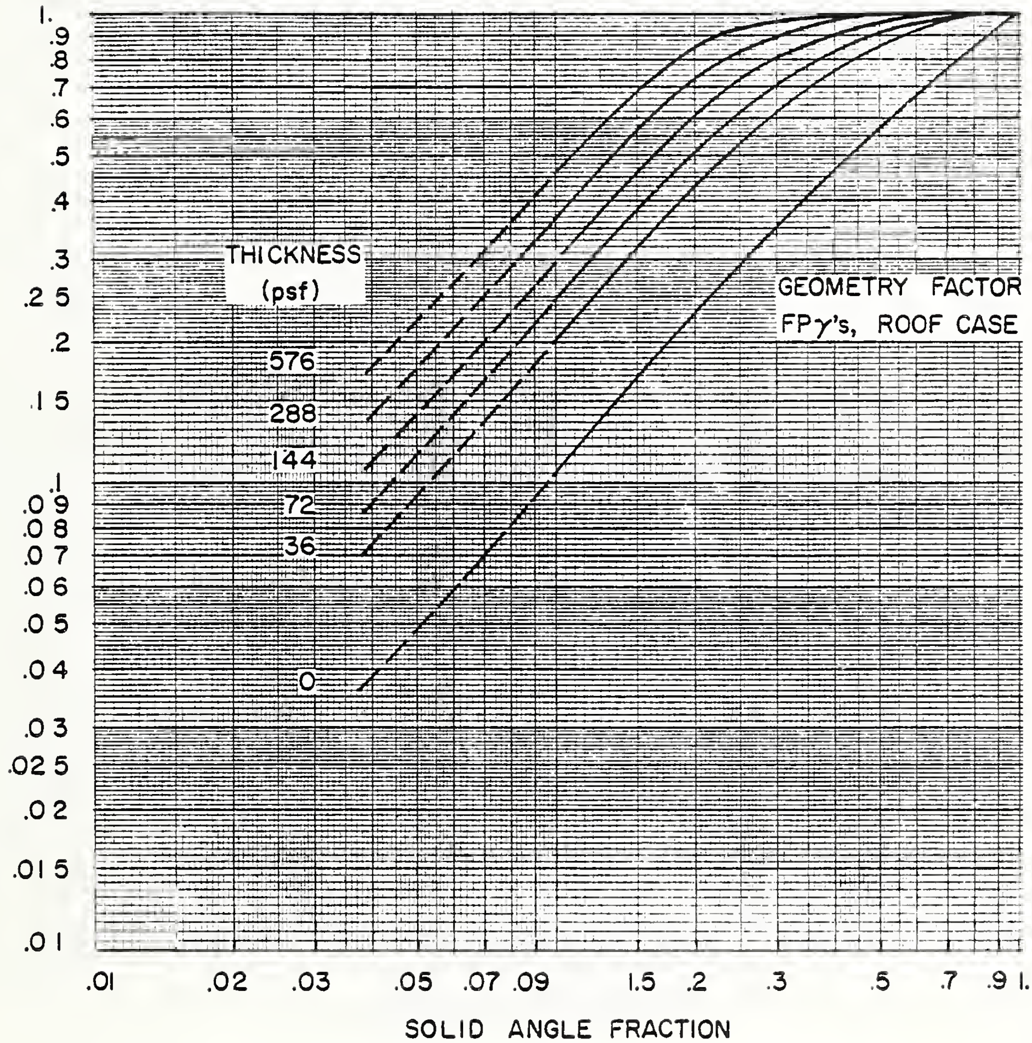


Fig. 5. Overhead geometry factor, fission product gamma rays.

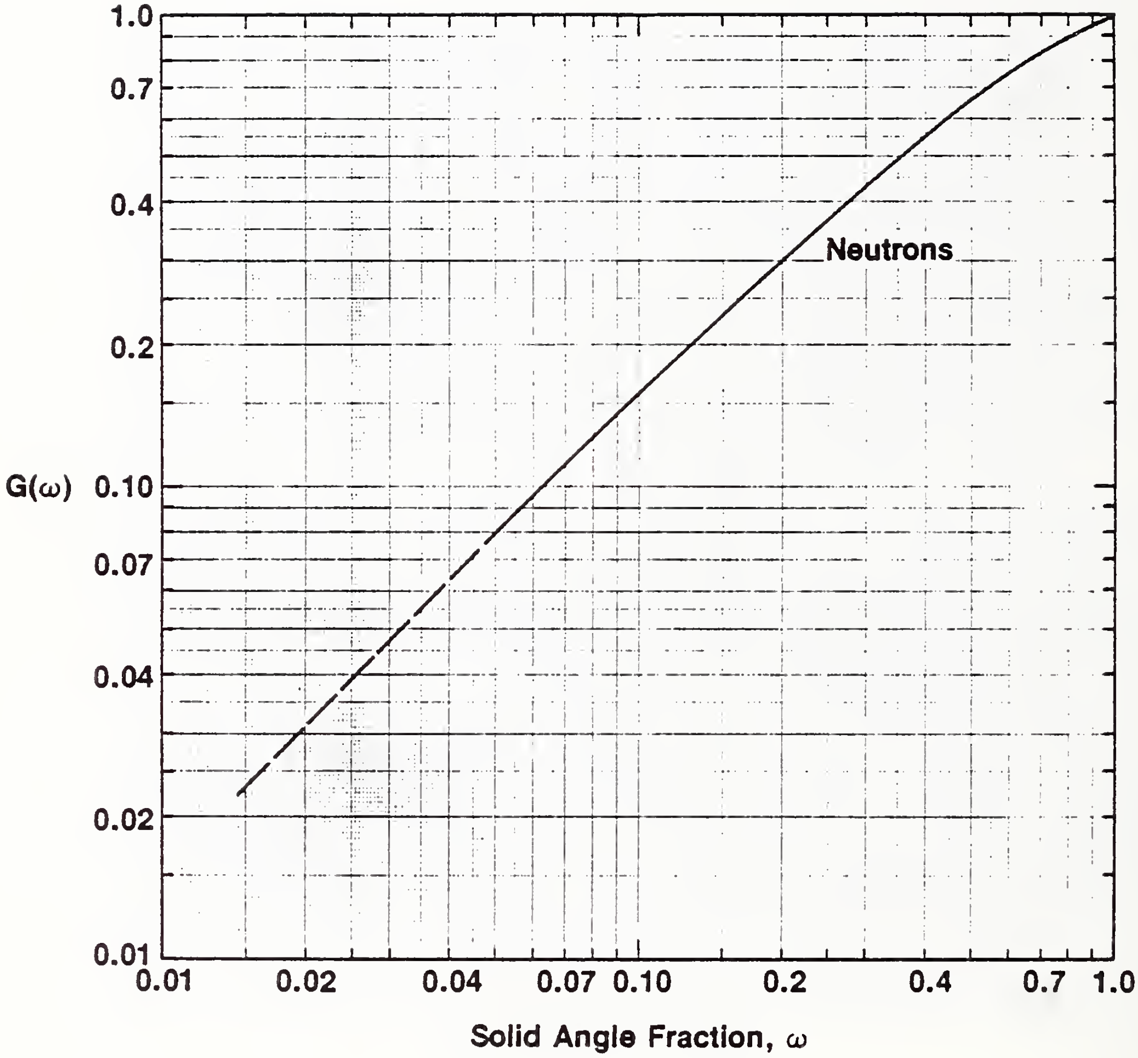


Fig. 6. Overhead geometry factors, neutrons.

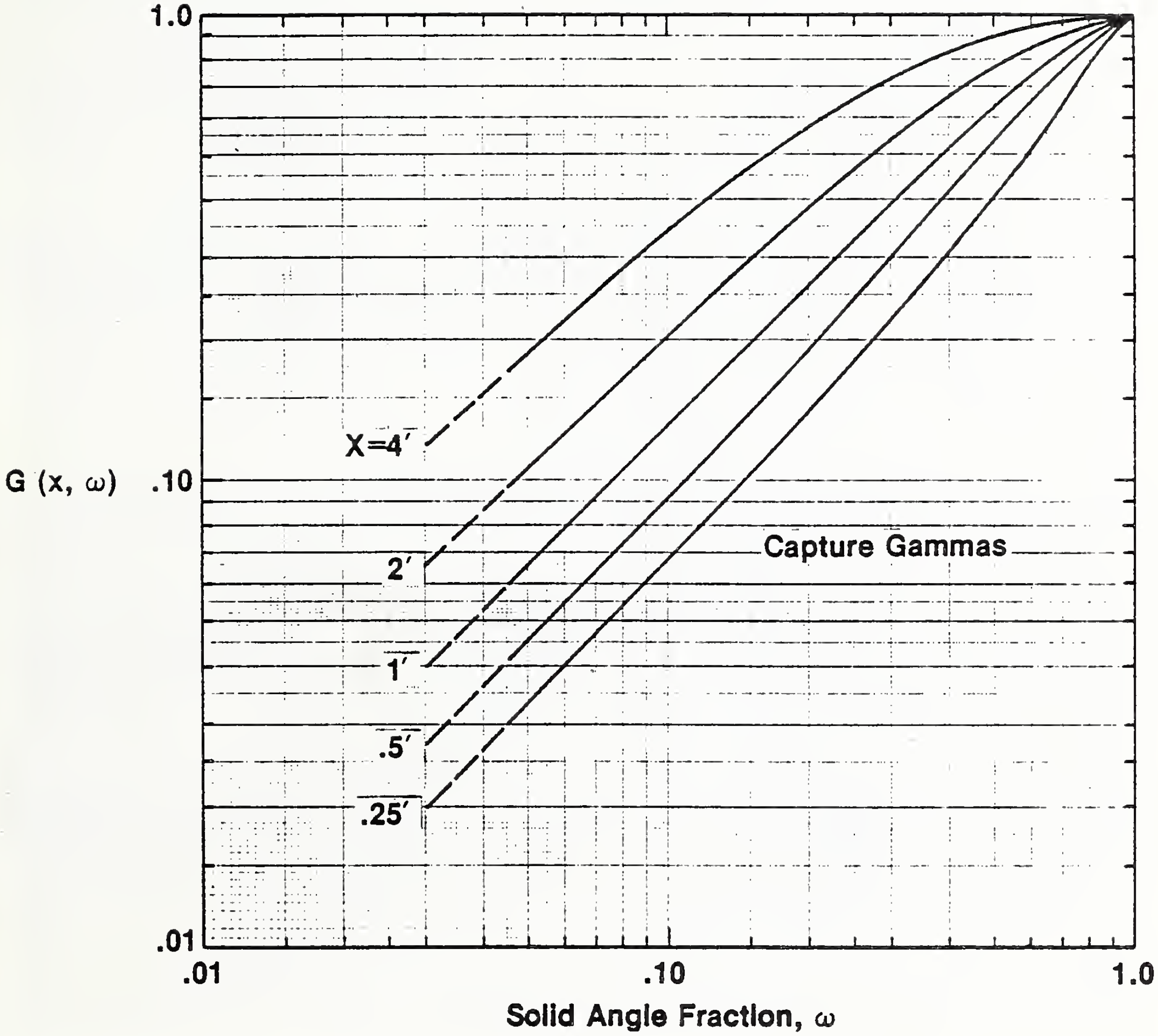


Fig. 7. Overhead geometry factors, wall capture gamma rays.

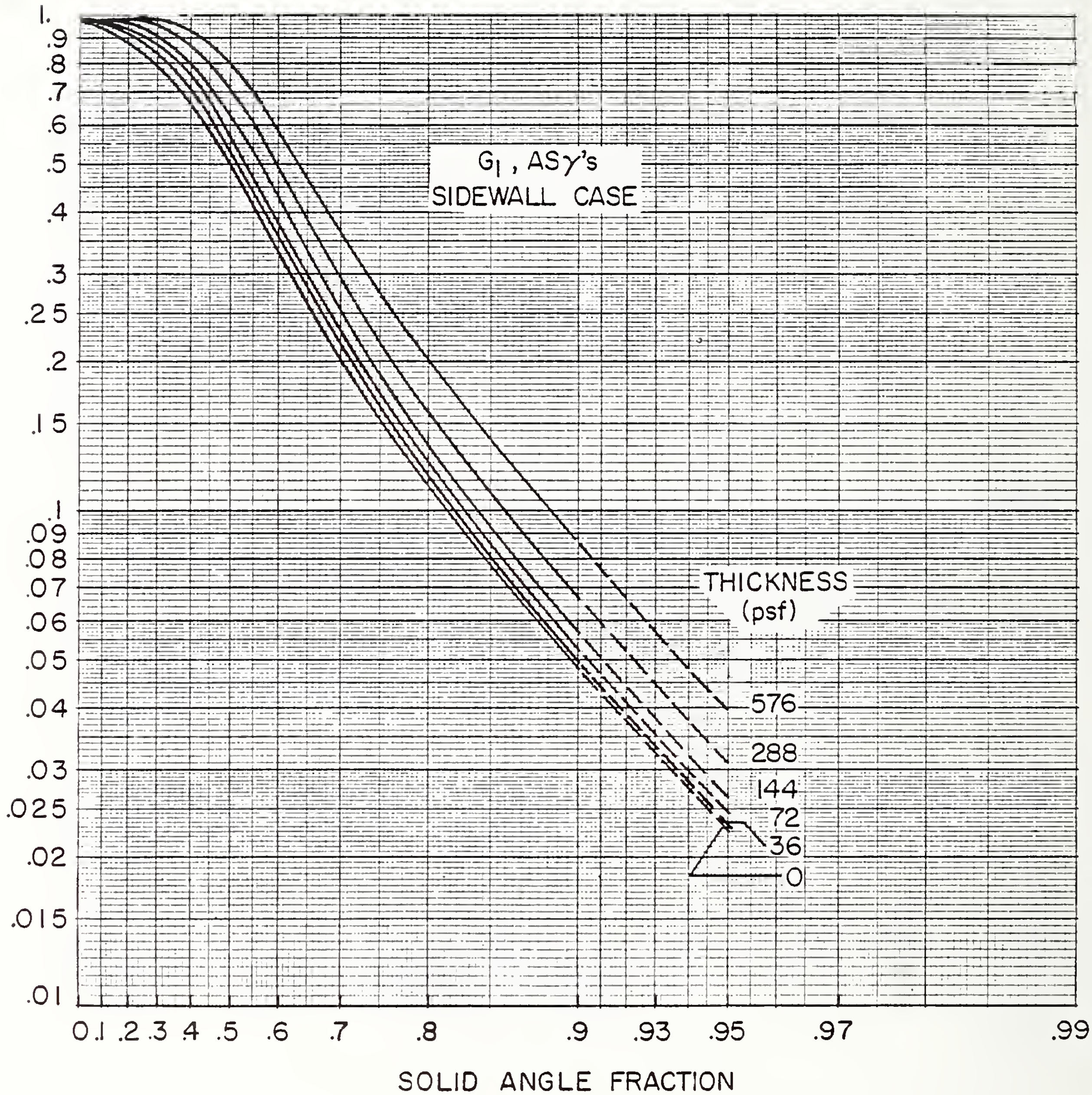


Fig. 8. Wall geometry factor G_1, air secondary gamma rays.

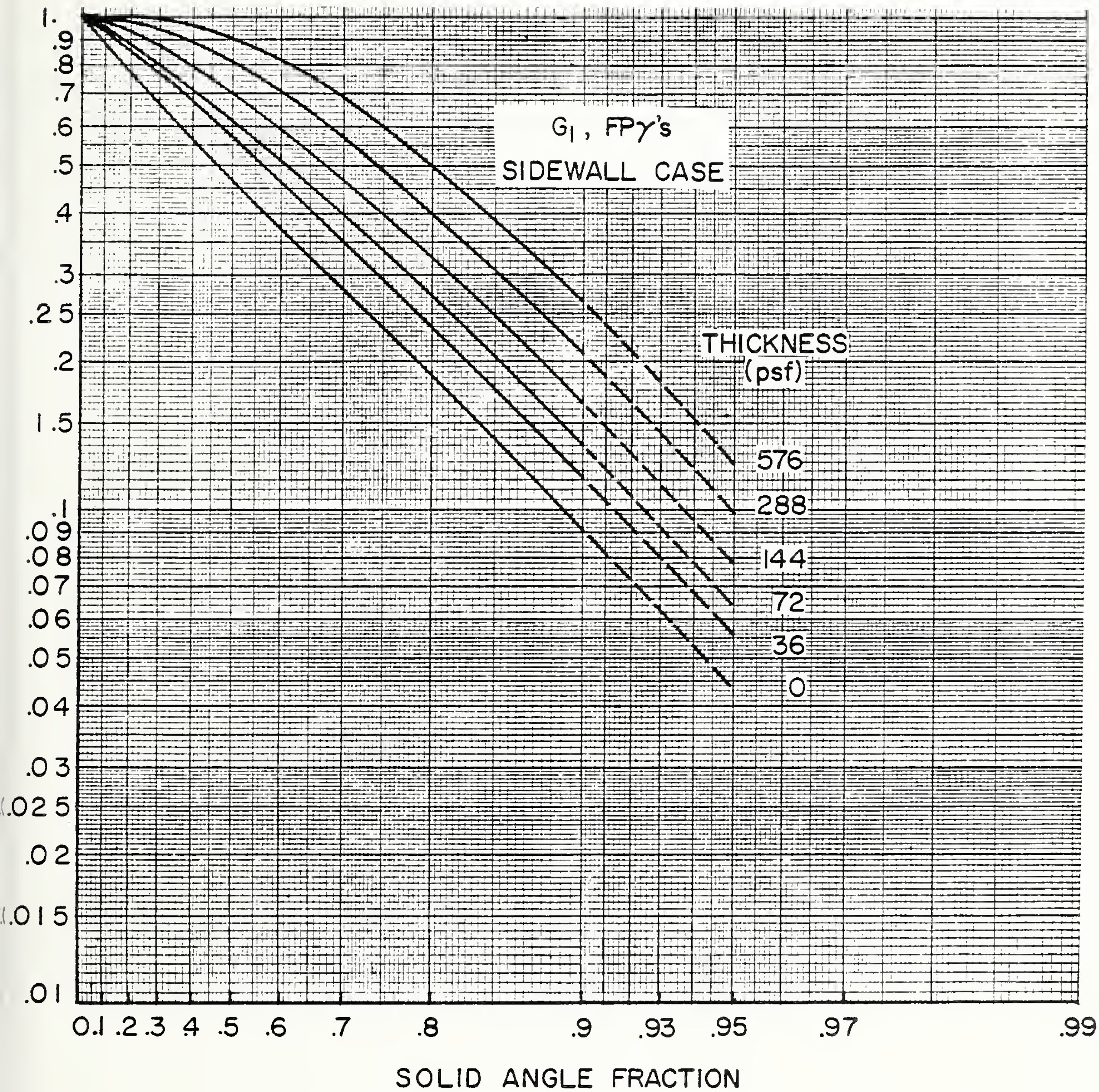


Fig. 9. Wall geometry factors G_1, fission product gamma rays.

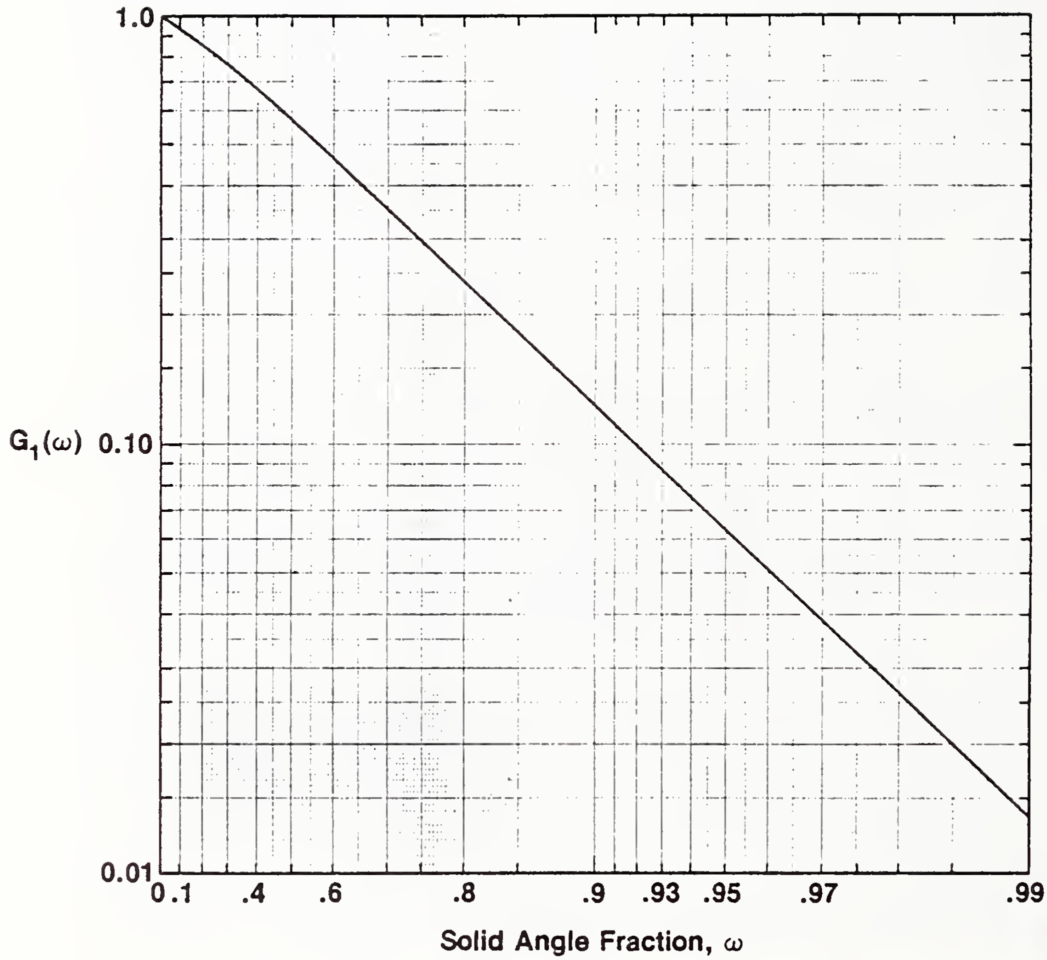


Fig. 10. Wall geometry factor G_1, neutrons.

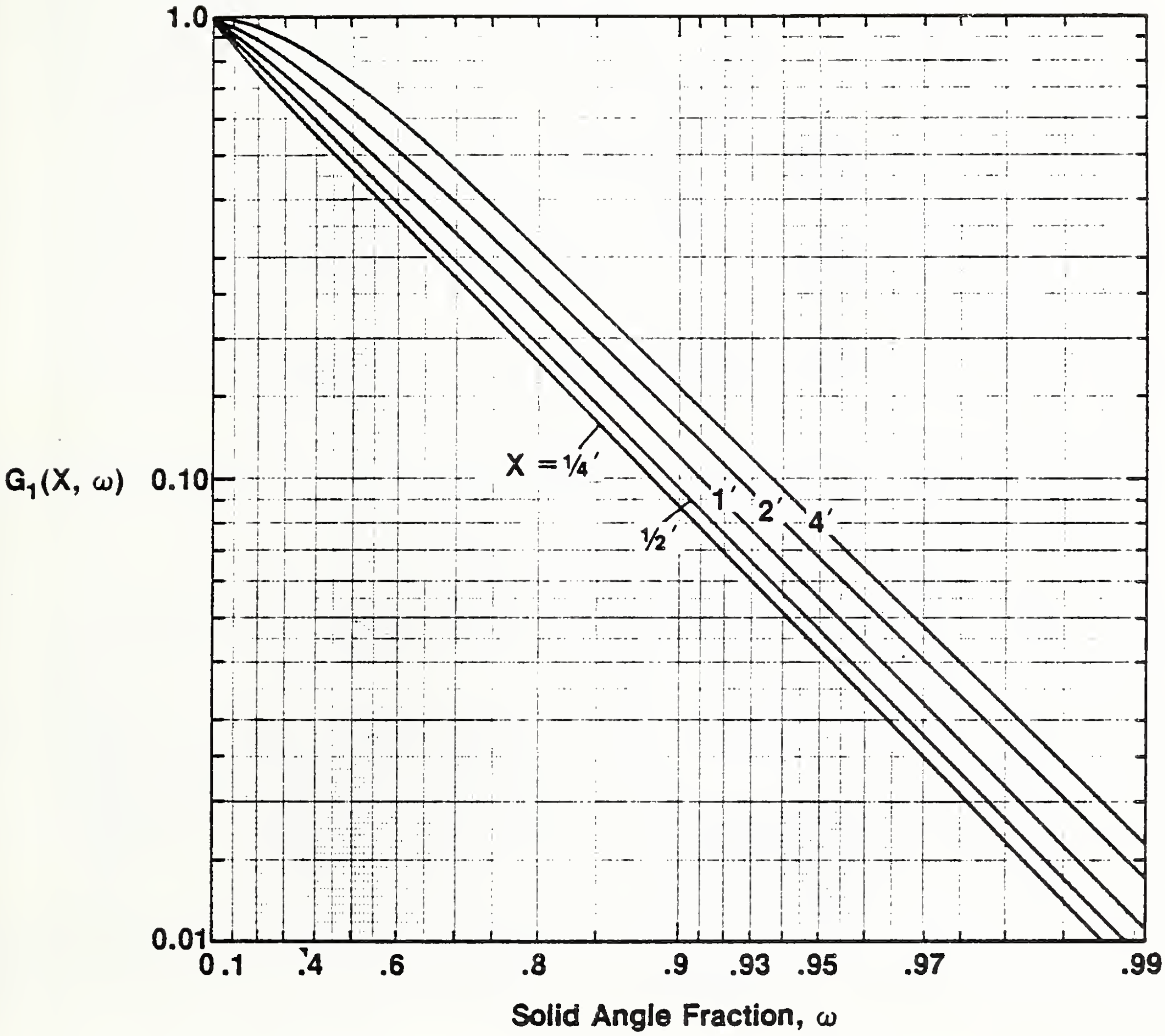


Fig. 11. Wall geometry factor G_1, wall capture gamma rays.

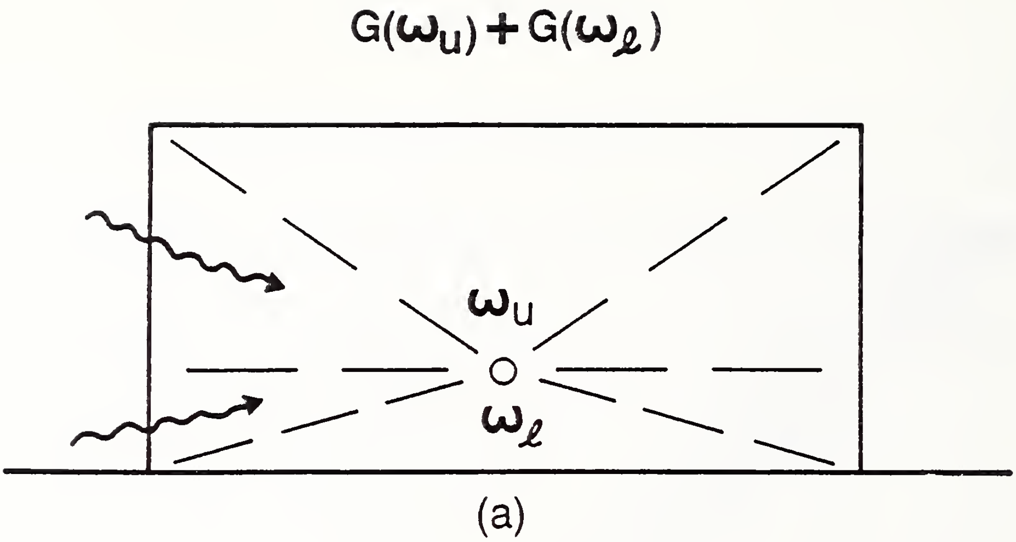


Fig. 12(a). Detector on same story as radiating walls: geometry factors for upper and lower solid angles are added.

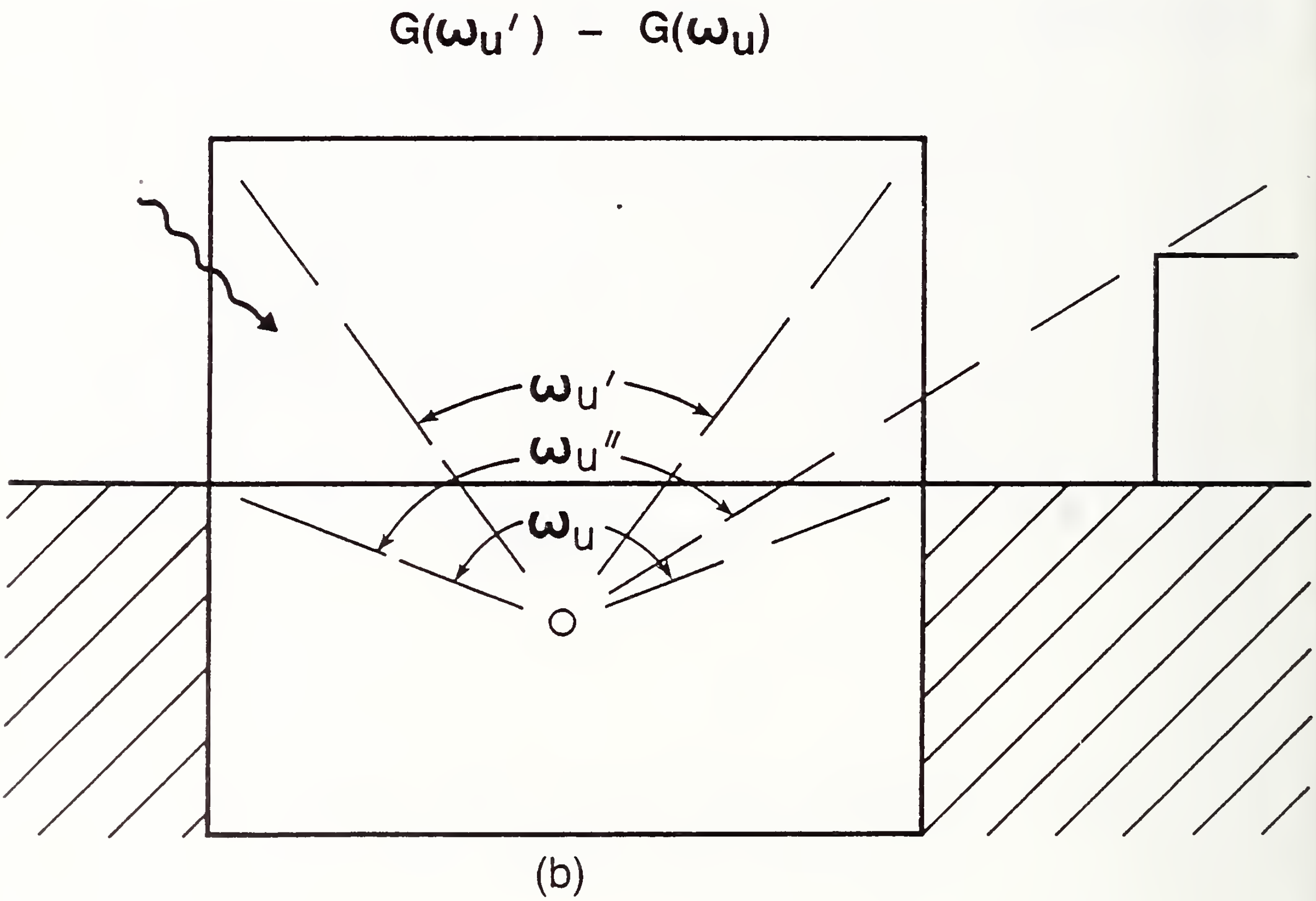


Fig. 12(b). Detector on story below radiation walls: geometry factors for upper solid angles are subtracted. Solid angle fractions such as ω_u'' may be determined by exterior building.

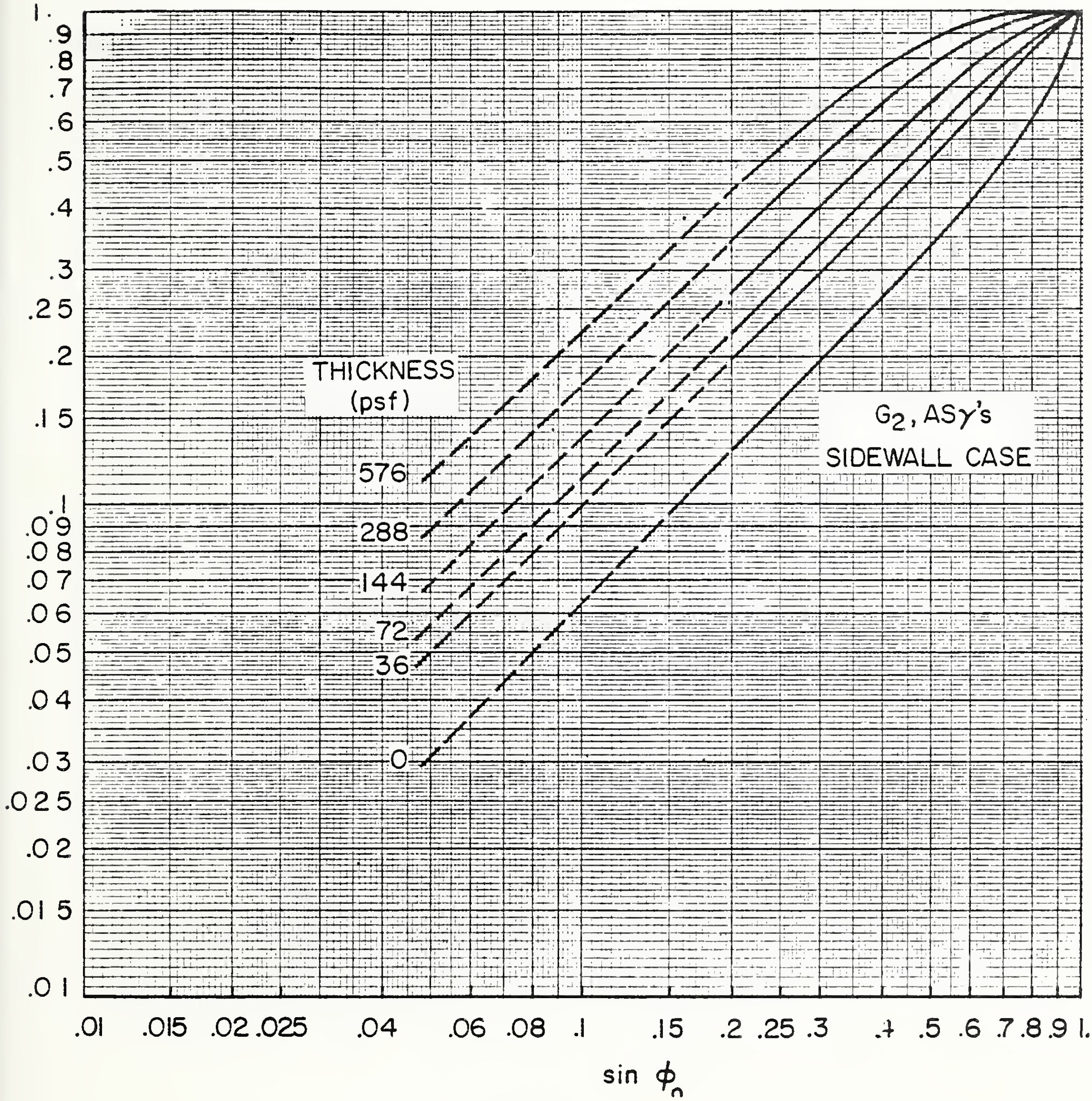


Fig. 13. Wall geometry factors G_2, air secondary gamma rays.

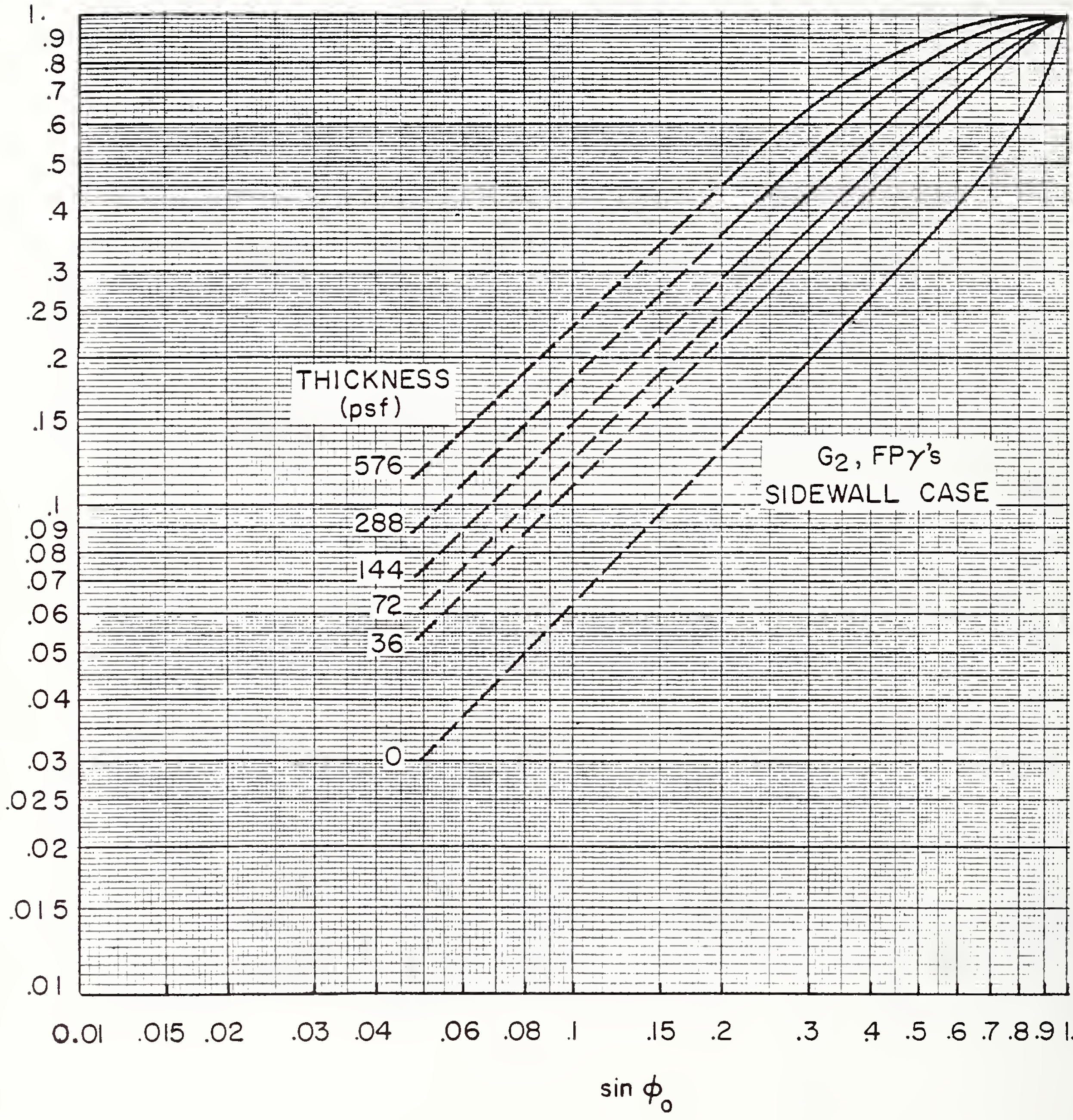


Fig. 14. Wall geometry factors G_2, fission product gamma rays.

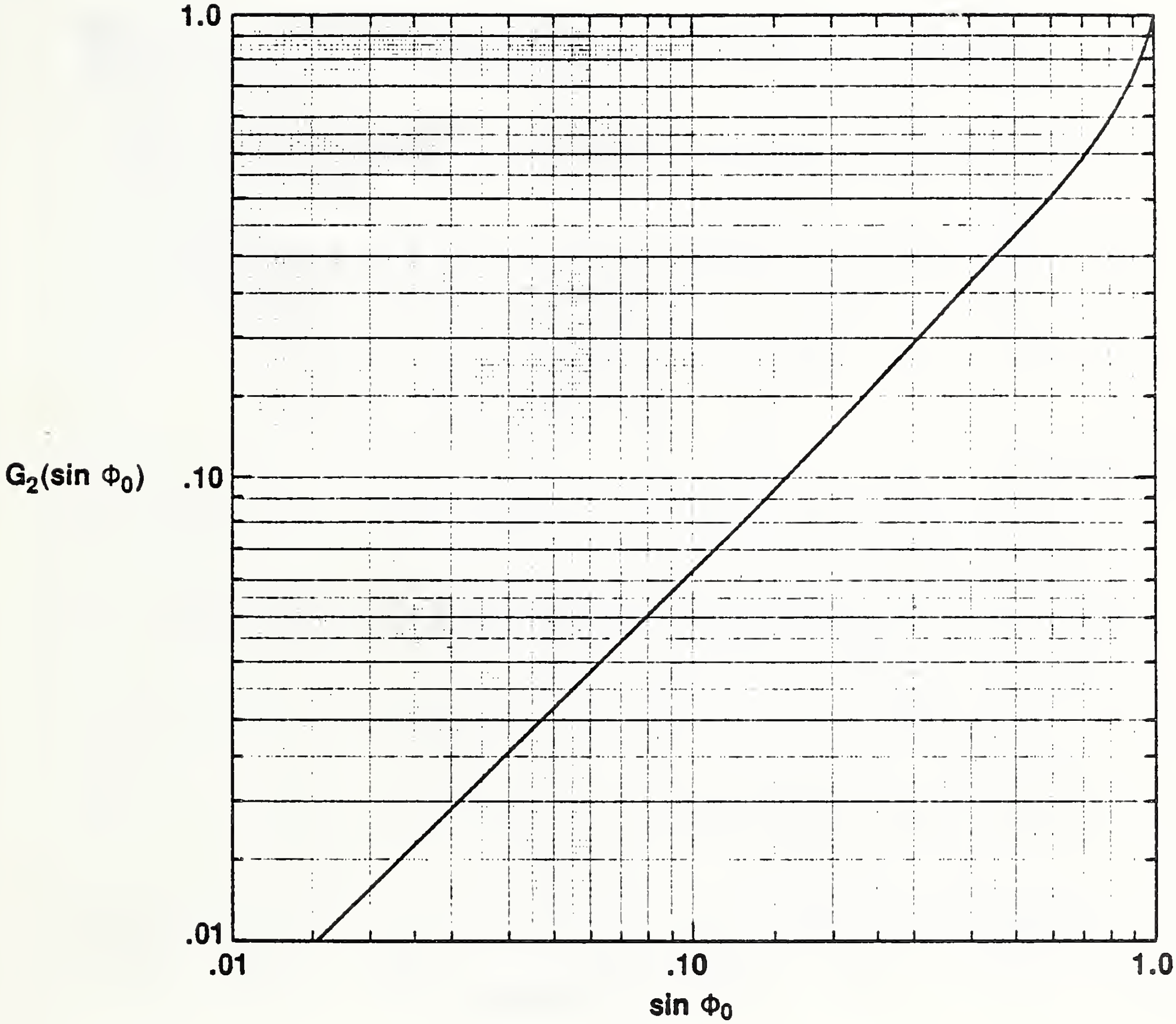


Fig. 15. Wall geometry factor G_2, Neutrons.

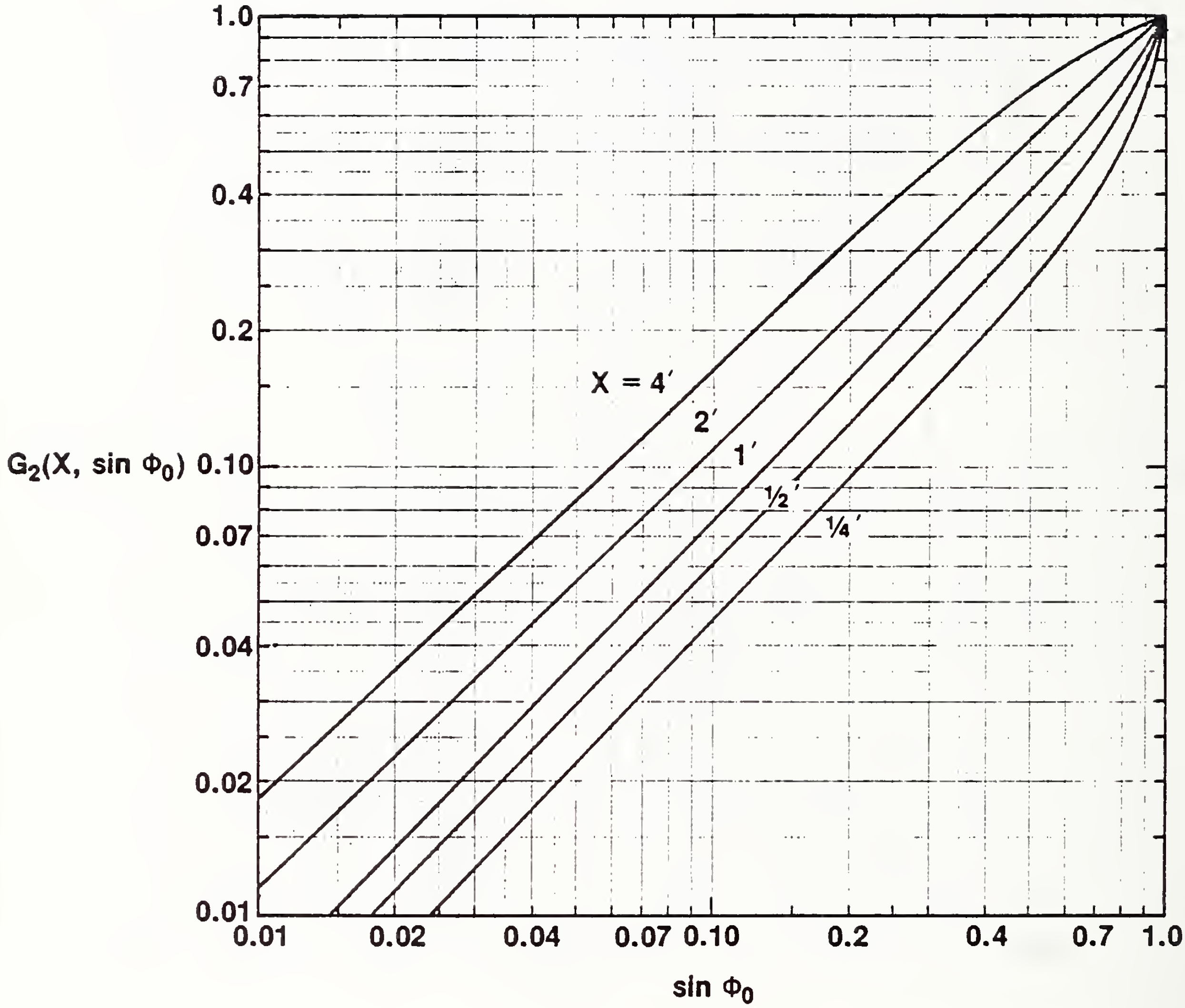


Fig. 16. Wall geometry factor G_2, wall capture gamma raus.

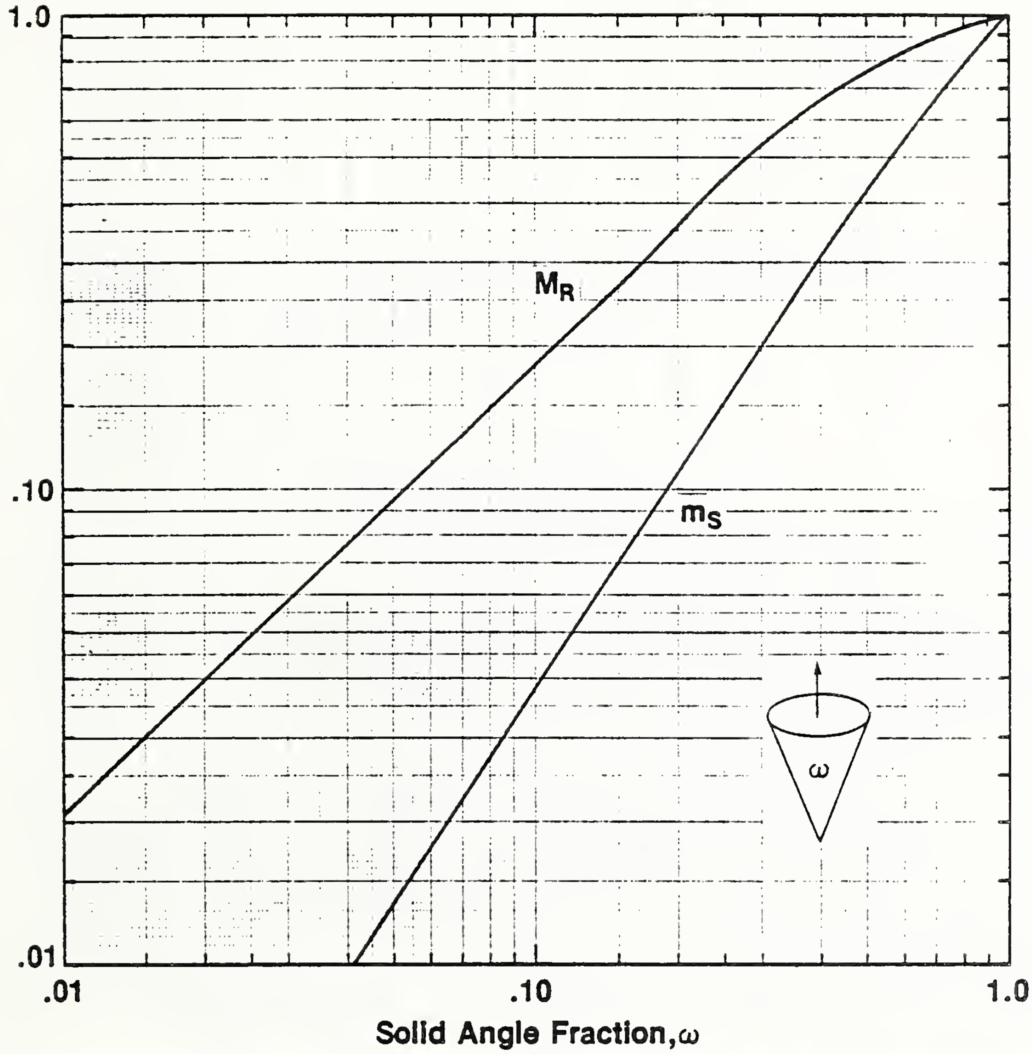


Fig. 17. Mutual shielding geometry factors M_R for roof and $M_S = \overline{m}_s \frac{\sin\phi_0}{2}$ for walls. Data for mutual shielding estimates.

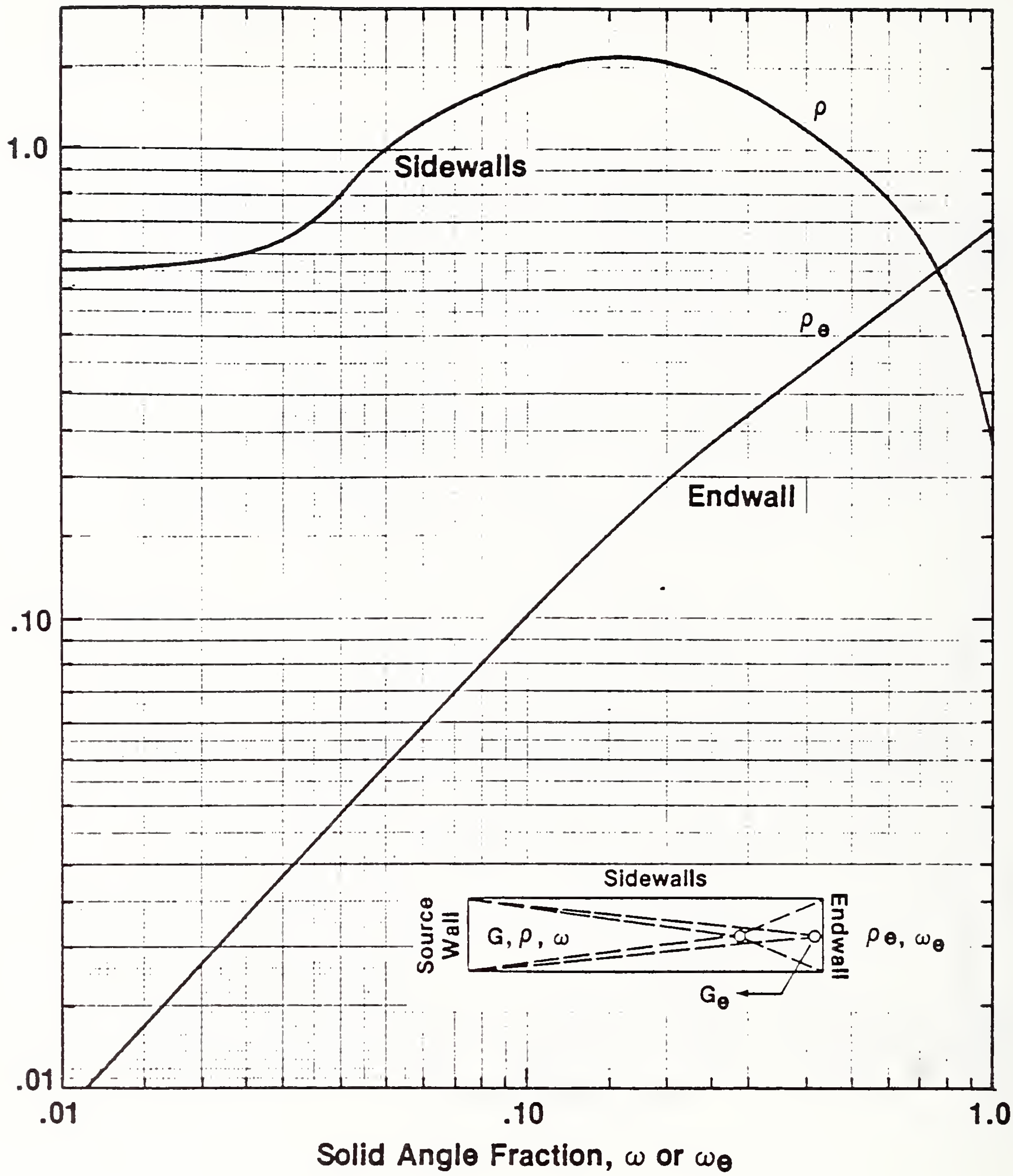


Fig. 18. Neutron reflection factors ρ for sidewalls and ρ_e for end walls.

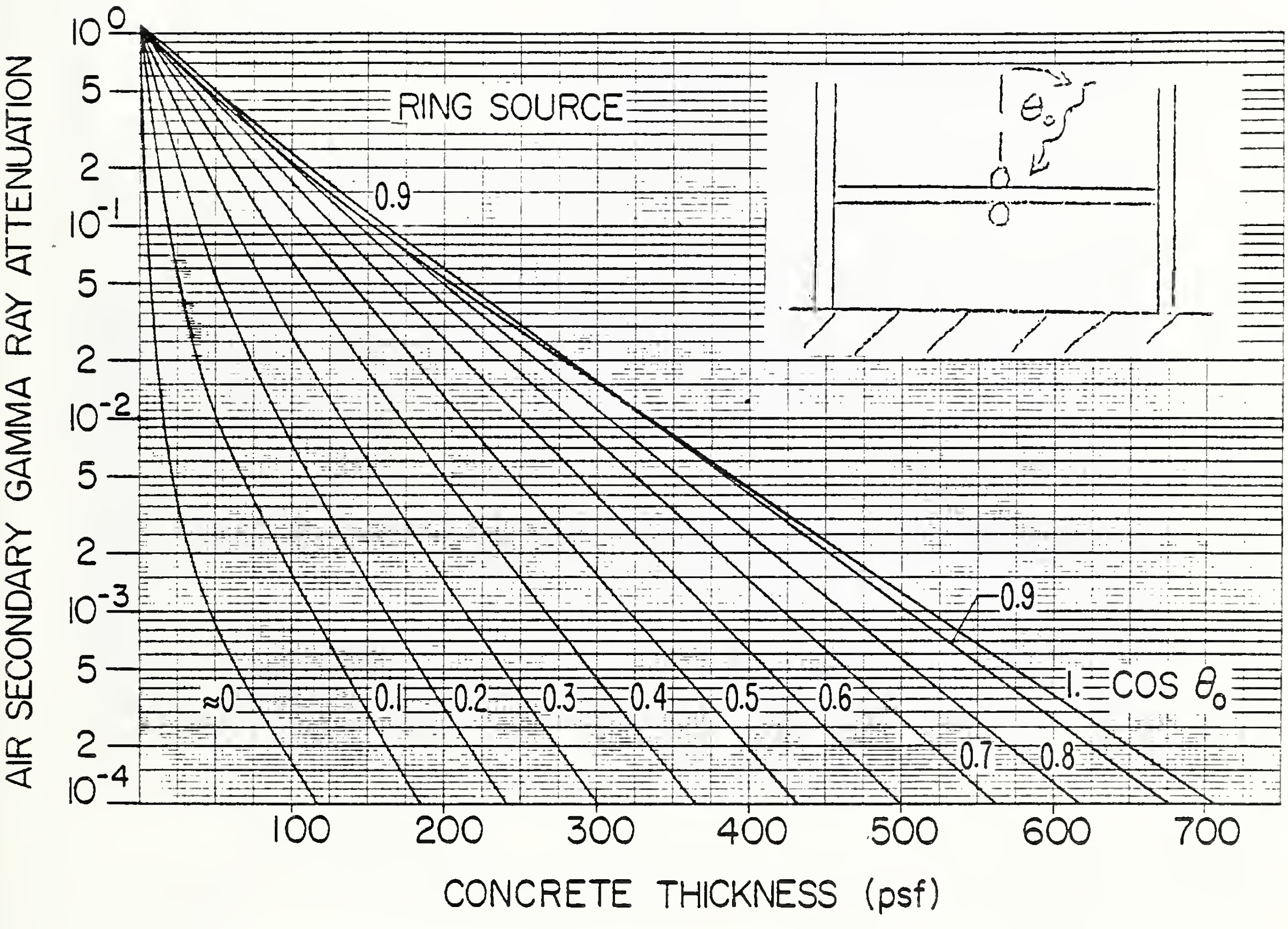


Fig. 19. Data for estimating attenuation factors in ceiling, air secondary gamma rays.

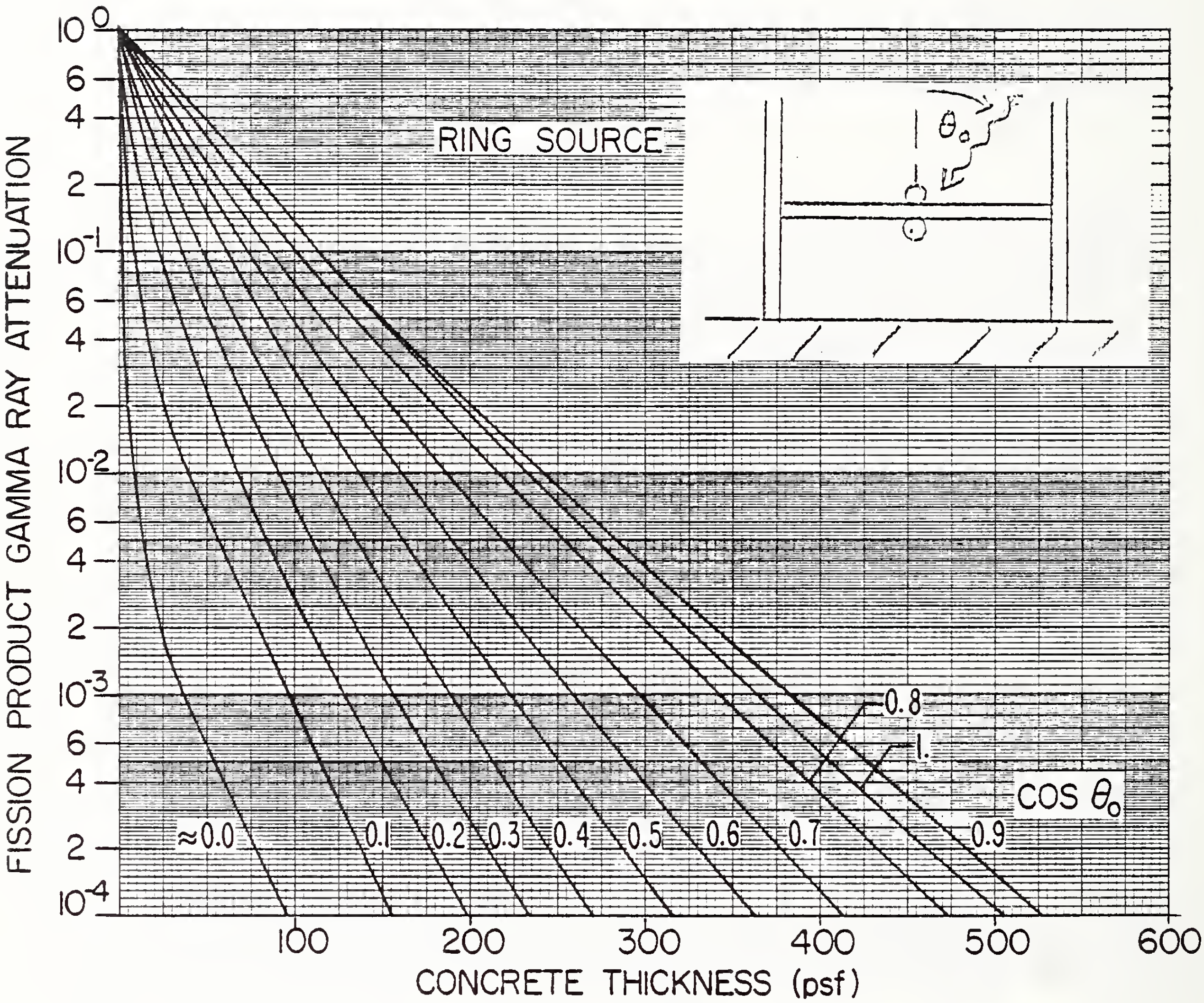


Fig. 20. Data for estimating attenuation factors in ceiling, fission product gamma rays.

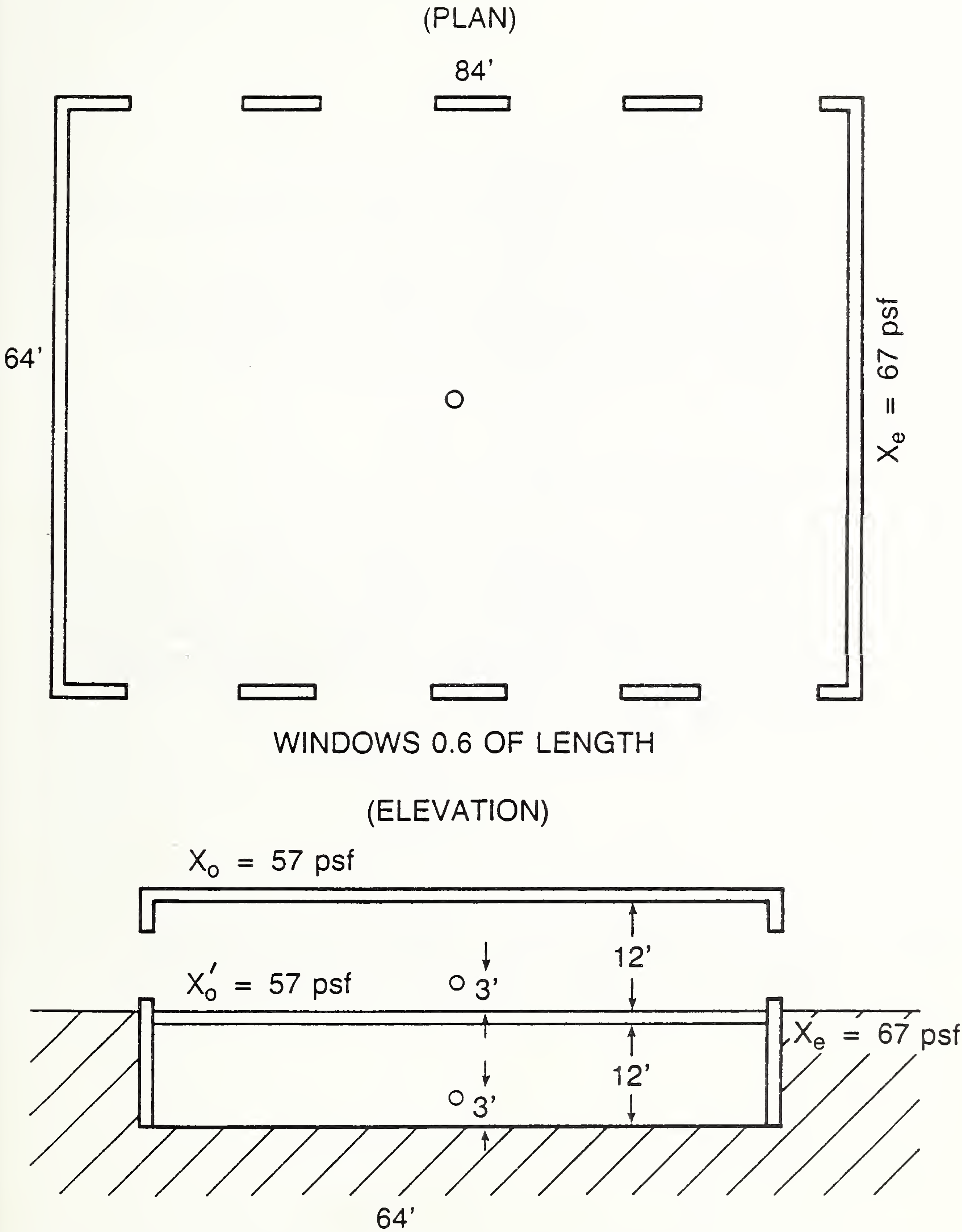


Fig. 21. Plan and elevation views of benchmark structure with basement ceiling and windows on two sides.

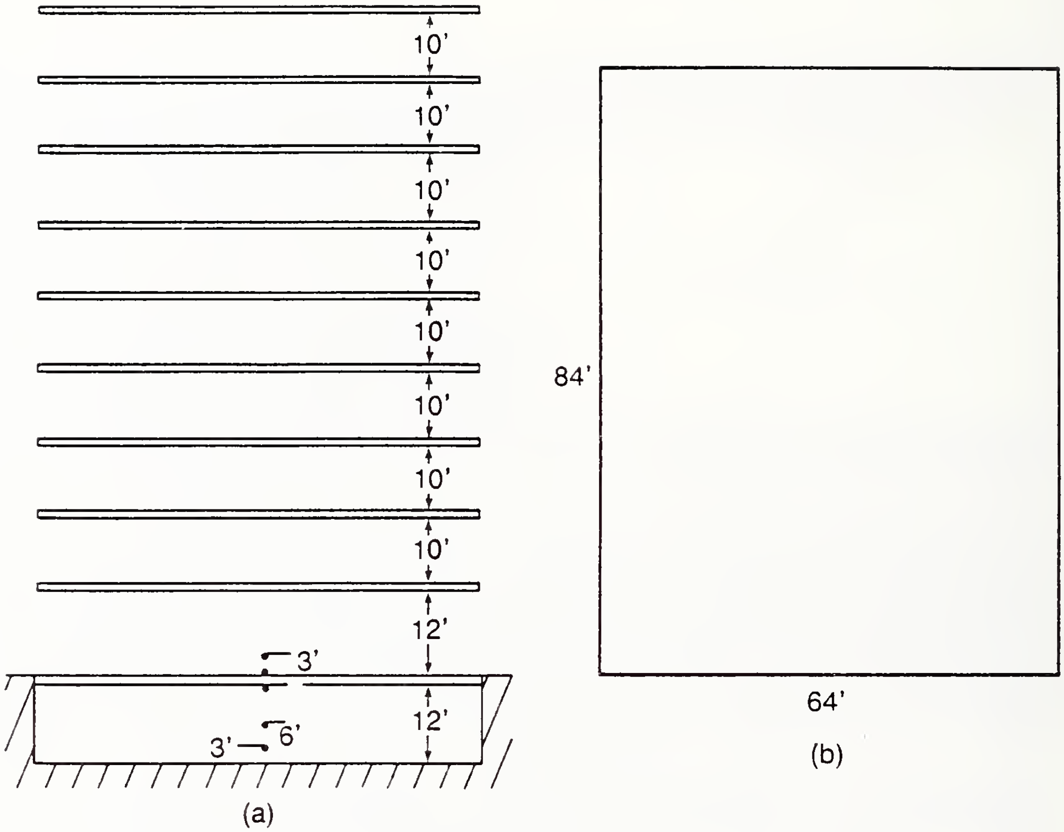


Fig. 22. Views of benchmark structure 5. Figures a) and b) represent elevation and plan views, respectively. Dots represent detector points.

APPENDIX A

Sources of Data for INR Computer Codes

INRG5

Barrier Factors L.V. Spencer NSE 57, 129-154 (1975) Table X

Geometry Factors L.V. Spencer *op cit*, Tables XIV, XV, XVI, XVII, XVIII, and XX

INRN5

Barrier Factors L.V. Spencer (unpublished) 1 ft concrete = 146.6 pst

Geometry Factors L.V. Spencer (unpublished) Tables

Duct Reflection Factors L.V. Spencer (unpublished) Graphs

Mutual Shielding Factor L.V. Spencer (unpublished) Graphs M_R, m_s

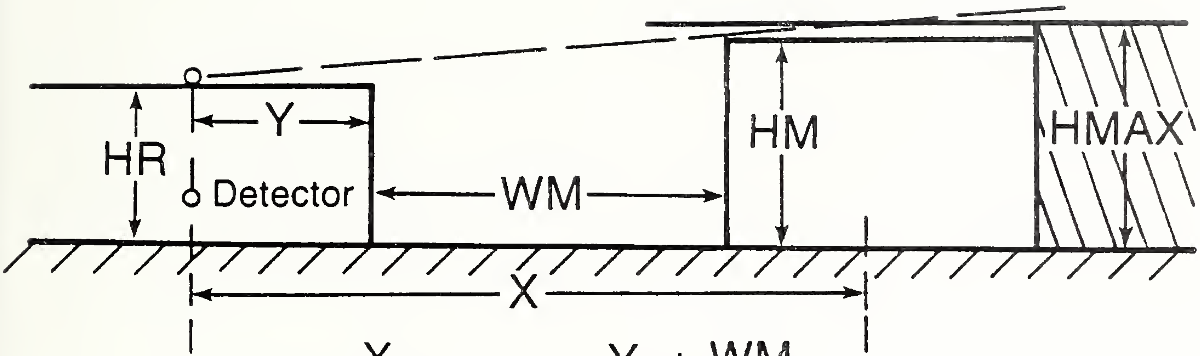
APPENDIX B

TREATMENT OF MUTUAL SHIELDING FOR NEUTRONS

The present version of the code assumes that the mutual shielding factor for a wall or roof is determined by the m_s and M_r curves generated by Spencer (fig. 17). The solid angle subtended by open space in the upper hemisphere is determined for the exterior walls and the roof. A table-lookup for each solid angle is used to find some response for the walls (m_s) or the response for the roof (M_r).

The following steps are included in the subroutine NMSHLD:

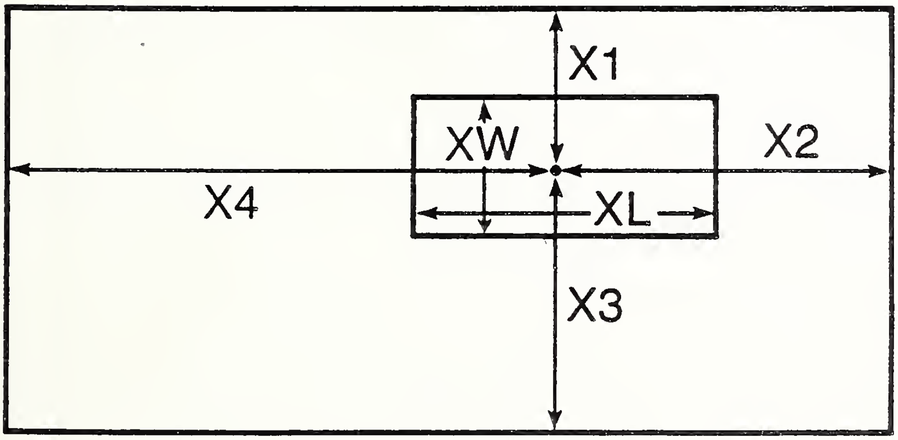
1. If the mutual shielding input index IMS $\leq$ 0 the mutual shielding factor for the walls is set equal to 0.5 and that for the roof is 0.58.
2. If IMS > 0, solid angle fractions are determined for each of the four walls at a point at detector height on the <u>outside</u> wall. The solid angle fraction is calculated on the center line of a hypothetical horizontal area <u>twice</u> the size of the actual open horizontal area next to the side of the building. The field length is assumed to be symmetrical about the vertical plane perpendicular to the wall and including the detector point. The mutual shielding factor is set equal to 1/2 of the solid angle fraction.
3. To determine the mutual shielding factor for radiation incident on the roof, the maximum height HMAX of nearby buildings is first determined. If the height on any side is less than the roof height, the distance to the nearest building is arbitrarily set at 1000 ft. Otherwise, the unobstructed solid angle is projected onto a horizontal plane at level of HMAX. In this plane the width X of the clear field of view is determined by similar triangles, as shown in figure B.1.



$$\frac{X}{(HMAX - HR)} = \frac{Y + WM}{HM - HR}$$

Fig. B.1

4. Solid angle fractions are then calculated for the four quadrants around the detector point on the roof, as shown in figure B.2.



$$\epsilon_i = X_i/X_{i+1}$$

$$\eta_i = \frac{(HMAX - HR)}{X_{i+1}}$$

Fig. B.2

5. Response functions m_s are then looked up (INTRPR) for solid angles subtended by detectors on each of the four sides of the building. These are multiplied by 0.5. Response functions M_r are looked up for each of the four quadrants surrounding the roof detectors. These four responses are averaged and multiplied by 0.58 to obtain the mutual shielding factor for the roof.

APPENDIX C

INRG

```
      SUBROUTINE SECTOR (IL,HU,HUR,HL,XL,W,Y)
      DIMENSION Y(18,2),OM(4),SPHI(4)

C          EXPRESSION FOR SOLID ANGLE SUBTENDED BY A RECTANGLE

      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159
      H=HU
      CALL GEOM (H,XL,W,OM,SPHI)

C          SET UP Y ARRAY FROM VALUES OF OMEGA AND SIN PHI

      DO 20 J=1,4
      JP=J+5
      Y(J,1)=OM(J)
   20 Y(JP,2)=SPHI(J)

C          EQUATE FIFTH Y VALUE TO SOLID ANGLE FRACTION SUBTENDED BY ROOF

      EPS=W/XL
      TZP=2.*HUR
      ETA=TZP/XL
      Y(5,1)=TAU(EPS,ETA)

C          TEST TO SEE WHETHER TO CALCULATE Y ARRAY FOR PORTION OF WALL
C          L/TESTDETECTOR PLANE (IL=1) OR EXIT (IL=0)

      IF (IL.EQ.0) GO TO 200
      H=HL
      CALL GEOM (H,XL,W,OM,SPHI)
      DO 40 J=1,4
      J1=J+9
      J2=J+14
      Y(J1,1)=OM(J)
   40 Y(J2,2)=SPHI(J)

C          CALCULATE SOLID ANGLE FRACTION SUBTENDED BY FLOOR (NOT USED)

      TZP=2.*HL
      ETA=TZP/XL
      Y(14,1)=TAU(EPS,ETA)
  200 RETURN
      END
```

```
*GEOM
      SUBROUTINE GEOM (HI,XL,W,OM,SPHI)
      DIMENSION         OM(4),SPHI(4)

C        EXPRESSION FOR SOLID ANGLE SUBTENDED BY A RECTANGLE

      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159

C        CALCULATE PARAMETERS ETA AND EPS(ILON) FOR SOLID ANGLE FRACTION SUB
C        SUBTENDED BY EACH WALL

      DO 40 J=1,4
      TZP=W
      IF (J.EQ.2.OR.J.EQ.4) TZP=XL
      XLP=XL
      IF (J.EQ.2.OR.J.EQ.4) XLP=W
      ETA=TZP/XLP

C        CALCULATE AZIMUTHAL HALF-ANGLE PHI SUBTENDED BY EACH WALL

      PHI=ATAN(XL/W)
      IF (J.EQ.2.OR.J.EQ.4) PHI=ATAN(W/XL)
      WP=2.*HI
      EPS=WP/XLP

C        REPLACE EACH WALL BY SECTION OF CYLIDER WITH VERTICAL AXIS THRU
C        DETECTOR POINT AND CALCULATE SOLID ANGLE FRACTION OMEGA SUBTEND
C        -ED BY EQUIVALENT CIRCULAR CEILING

      OM(J) =1.-1.5708*TAU(EPS,ETA)/PHI
   40 SPHI(J)=SIN(PHI)
  200 RETURN
      END
```

```
*INPUTT
      SUBROUTINE INPUTT (IPR,OMTAB,SPTAB)
      DIMENSION XTAB(11),BTAB(11,4),ZTAB(6),OMTAB(11),SPTAB(11),GTAB(6,
     1 11,6),YTAB(11,2)
      DIMENSION XLABEL(18)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB
      DATA XLABEL /4HG(X,,4HOM)R,4HAS    ,4HG(X,,4HOM)R,4HFP    ,4HG(X,,
     14HOM)W,4HAS    ,4HG(X,,4HOM)W,4HFP    ,4HG2(X,4H,SIN,4H)WAS,4HG2(X,4H,
     2SIN,4H)WFP/
C         READ IN TABULATED BARRIER THICKNESSES
      READ   1, XTAB
      DO 30 I=1,11
   30 XTAB(I)=68.1*XTAB(I)
C         READ IN TABULATED BARRIER FACTORS
      READ   1, ((BTAB(I,J),J=1,4),I=1,11)
    1 FORMAT (8E10.3)
    2 FORMAT (1H0)
    3 FORMAT (1H )
    5 FORMAT (3X,'XTAB',6X,'B(X)RAS',5X,'B(X)RFP',5X,'B(X)WAS',5X,'B(X)W
     1FP')
    7 FORMAT (F10.3,1P4E12.3)
      IF (IPR.EQ.0) GO TO 60
      PRINT 2
      PRINT 5
      PRINT 2
      DO 50 I=1,11
      PRINT  7, XTAB(I),(BTAB(I,J),J=1,4)
   50 CONTINUE
C         READ IN TABULATED BARRIER THICKNESSES, SOLID ANGLE FRACTIONS, AN
C         AND VALUES OF SIN PHI FOR GEOMETRY FACTORS
   60 READ  110, ZTAB
      READ  110, OMTAB
      READ  110, SPTAB
      OMTAB(1)=1.0E-10
      SPTAB(1)=1.0E-10
  110 FORMAT (12F6.4)
C         READ IN TABULATED GEOMETRY FACTORS
      DO 150 K=1,4
      IF (K-2) 130,120,130
  120 READ  110, ((GTAB(I,J,K),I=1,6),J=2,11)
      GO TO 140
  130 READ  110, ((GTAB(I,J,K),I=1,6),J=1,11)
  140 DO 145 I=1,6
      IF (K.LE.2) GTAB(I,1,K)=1.0E-10
      IF (K.GT.2) GTAB(I,11,K)=1.0E-10
      IF (K.GT.2.AND.K.LE.4) GTAB(I,11,K)=1.0E-10
  145 CONTINUE
  150 CONTINUE
      DO 154 K=5,6
      READ  110, ((GTAB(I,J,K),I=1,6),J=1,6)
      DO 154 I=1,6
      DO 153 J=7,11
  153 GTAB(I,J,K)=1.0E-10
  154 GTAB(I,1,K)=1.0E-10
      IF (IPR.EQ.0) GO TO 400
      PRINT 2
```

```
      PRINT 165
  160 FORMAT (23X,'X(PSF)=',6F10.0)
  162 FORMAT (50X,3A4)
  165 FORMAT(10X,'OMEGA',10X,'SIN PHI',15X,'G T A B  ( X , O M E G A ) ')
     1)
      DO 250 K=1,6
      PRINT 2
      K1=3*K-2
      K2=K1+2
      PRINT 162, (XLABEL(I),I=K1,K2)
      PRINT 3
      PRINT 160, ZTAB
      PRINT 3
      DO 250 J=1,11
      PRINT 170, OMTAB(J),SPTAB(J),(GTAB(I,J,K),I=1,6)
  170 FORMAT  (2F15.4,6F10.4)
  250 CONTINUE
  400 RETURN
      END
```

```
*INNER
      SUBROUTINE INNER (IP,XE,XI,XUE,XUI,XXLE,XXLI,XW,XU,XXL)
      DIMENSION XE(5),XI(5),XUE(5),XUI(5),XXLE(5),XXLI(5),XW(9),XU(9),
     1 XXL(9)

C         SET ROOF BARRIER THICKNESS EQUAL TO XE(5), CEILING THICKNESS
C         EQUAL TO XUI(5), AND FLOOR THICKNESS EQUAL TO XXLI(5)

      XW(5)=XE(5)
      XU(5)=XUI(5)
      XXL(5)=XXLI(5)
      IF (IP.GT.0) GO TO 50
      DO 20 L=1,4
      XW(L)=XE(L)
      XU(L)=XUE(L)
   20 XXL(L)=XXLE(L)
      GO TO 200
   50 IF (IP.GT.1) GO TO 100
      DO 60 L=1,4
      XW(L)=XE(L)+XI(L)
      XU(L)=XUE(L)+XUI(L)
   60 XXL(L)=XXLE(L)+XXLI(L)
      GO TO 200
  100 XW(1)=XE(1)+XI(1)
      XW(3)=XW(1)
      XW(2)=XE(2)
      XW(4)=XW(2)
      XU(1)=XUE(1)+XUI(1)
      XU(3)=XU(1)
      XU(2)=XUE(2)
      XU(4)=XU(2)
      XXL(1)=XXLE(1)+XXLI(1)
      XXL(3)=XXL(1)
      XXL(2)=XXLE(2)
      XXL(4)=XXL(2)
  200 RETURN
      END
```

```
*INTRPB
      SUBROUTINE INTRPB (XTAB,X,BTAB,B)
      DIMENSION XTAB(11),BTAB(11,4),B(5,2),X(5)
C         RELAXATION LENGTHS FOR EXTRAPOLATION
C         RELATE K (TYPE OF RADIATION) AND L (INDEX OF WALL OR OVERHEAD
C         TO PARAMETER J WHICH INDEXES BARRIER FACTOR TABLES
  100 DO 250 K=1,2
      DO 250 L=1,5
      IF (K.EQ.1.AND.L.EQ.5) J=1
      IF (K.EQ.1.AND.L.NE.5) J=3
      IF (K.EQ.2.AND.L.EQ.5) J=2
      IF (K.EQ.2.AND.L.NE.5) J=4
  200 I=1
  210 I=I+1
      IF (I.EQ.11) GO TO 220
      IF (X(L).LT.XTAB(I)) GO TO 220
      GO TO 210
C         LINEAR INTERPOLATION ON X AND LOG OF BARRIER FACTOR
  220 B(L,K)=EXP(ALOG(BTAB(I-1,J))+ALOG(BTAB(I,J)/BTAB(I-1,J))*
     1 (X(L)-XTAB(I-1))/(XTAB(I)-XTAB(I-1)))
  250 CONTINUE
  300 RETURN
      END
```

```
*INTRPG
      SUBROUTINE INTRPG (X ,Y,G)
      DIMENSION ZTAB( 6),YTAB(11,2),GTAB(6,11,6),Y(18,2),G1(11,6),X(9),
     1 G(9,2),XTAB(11),BTAB(11,4)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB

C        RELATE M (TYPE OF RADIATION) AND L (INDEX OF WALL OR OVERHEAD)
C        TO PARAMETER K WHICH INDEXES GEOMETRY FACTOR TABLES

      DO 450 M=1,2
      DO 450 L=1,9
      IF (M.EQ.1.AND.L.EQ.5) K=1
      IF (M.EQ.2.AND.L.EQ.5) K=2
      IF (M.EQ.1.AND.L.LT.5) K=3
      IF (M.EQ.2.AND.L.LT.5) K=4
      IF (M.EQ.1.AND.L.GT.5) K=5
      IF (M.EQ.2.AND.L.GT.5) K=6

C        INDEX I FOR TWO NEAREST BARRIER THICKNESSES

      I=1
  110 I=I+1
      IF (I.EQ. 6) GO TO 200
      IF (X(L).LT.ZTAB(I)) GO TO 200
      GO TO 110
  200 IX=I
      IN=I-1

C        DETERMINE IF VARIABLE IS OMEGA (K.LE.4) OR SIN PHI (K.GT.4)

      IF (K-4) 320,320,330
  320 KI=1
      GO TO 350
  330 KI=2

C        INDEX J FOR TWO NEAREST OMEGA OR SIN PHI VALUES

  350 J=1
  360 J=J+1
      IF (Y(L,KI).LT.YTAB(J,KI)) GO TO 300
      GO TO 360
  300 J2=J
      J1=J-1

C        TWO-WAY INTERPOLATION ON GEOMETRY FACTORS

  390 DO 400 J=J1,J2

C        LINEAR INTERPOLATION ON BARRIER THICKNESS X AND LOG OF
C        GEOMETRY FACTORS

      G1(J,K)=EXP(ALOG(GTAB(IN,J,K))+ALOG(GTAB(IX,J,K)/GTAB(IN,J,K))
     1*(X(L)-ZTAB(IN))/(ZTAB(IX)-ZTAB(IN)))
  400 CONTINUE

C        LINEAR INTERPOLATION ON LOG Y AND LOG OF GEOMETRY FACTORS

      IF (K.EQ.3.OR.K.EQ.4) GO TO 425
      G(L,M)=EXP(ALOG(G1(J1,K))+ALOG(G1(J2,K)/G1(J1,K))*ALOG(Y(L,KI)/
     1YTAB(J1,KI))/ALOG(YTAB(J2,KI)/YTAB(J1,KI)))
      GO TO 450

C        FOR K=3 AND K=4, INTERPOLATE ON LOG(1-OMEGA)
```

```
425 YI=1.-Y(L,KI)
    IF (YI.LT.1.0E-10) YI=1.0E-10
    Y1=1.-YTAB(J1,KI)
    IF (Y1.LT.1.0E-10) Y1=1.0E-10
    Y2=1.-YTAB(J2,KI)
    IF (Y2.LT.1.0E-10) Y2=1.0E-10
    G(L,M)=EXP(ALOG(G1(J1,K))+ALOG(G1(J2,K)/G1(J1,K))*ALOG(YI/Y1)/ALOG
   1(Y2/Y1))
450 CONTINUE
    RETURN
    END
```

```
      PROGRAM TEST (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION XTAB(11),BTAB(11,4),        YTAB(11,2),        X(9)
      DIMENSION ZTAB(6),OMTAB(11),SPTAB(11),GTAB(6,11,6)
      DIMENSION RF(5,2),XU(9),XXL(9)
      DIMENSION XLM(4),WM(4),HM(4),XE(5),XI(5),XUE(5),XUI(5),XXLE(5),
     1 XXLI(5),TITLE(20)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB
    1 FORMAT (8E10.3)
    2 FORMAT (1H0)
    3 FORMAT (1H )
    4 FORMAT (5X,'X',7X,'B(X)AS',8X,'B(X)FP')
    5 FORMAT (3X,'XTAB',6X,'B(X)RAS',5X,'B(X)RFP',5X,'B(X)WAS',5X,'B(X)W
     1FP')
    6 FORMAT (1H1)
    8 FORMAT (F10.3,1P2E12.4)
    9 FORMAT (20A4)
      READ  (5,9) TITLE
      WRITE (6,6)
      WRITE (6,2)
      WRITE (6,9) TITLE
      READ  (5,10) IW,ID,IPR,IMS,IP,HI,HS,HT,HD,HR,FW,HIU,HIL,XL,W
      WRITE (6,10) IW,ID,IPR,IMS,IP,HI,HS,HT,HD,HR,FW,HIU,HIL,XL,W
   10 FORMAT (5I5,5F10.2/5F10.2)
   40 READ  45, XLM
      PRINT 45, XLM
      READ  45, WM
      PRINT 45, WM
      READ  45, HM
      PRINT 45, HM
   45 FORMAT (4F10.3)
      CALL        INPUTT (IPR,OMTAB,SPTAB)
      DO 50 J=1,11
      YTAB(J,1)=OMTAB(J)
   50 YTAB(J,2)=SPTAB(J)
      READ  (5,1) (XE(L),L=1,5)
      WRITE (6,1) (XE(L),L=1,5)
      READ  (5,1) (XI(L),L=1,5)
      WRITE (6,1) (XI(L),L=1,5)
      XMAX=681.
      READ  (5,1) (XUE(L),L=1,5)
      WRITE (6,1) (XUE(L),L=1,5)
      READ  (5,1) (XUI(L),L=1,5)
      WRITE (6,1) (XUI(L),L=1,5)
      READ  (5,1) (XXLE(L),L=1,5)
      WRITE (6,1) (XXLE(L),L=1,5)
      READ  (5,1) (XXLI(L),L=1,5)
      WRITE (6,1) (XXLI(L),L=1,5)
      CALL        INNER (IP,XE,XI,XUE,XUI,XXLE,XXLI,X ,XU,XXL)
      CALL RFSTOR (IW,HI,HIU,HIL,HS,HT,XL,W,X,XU,XXL,FW,
     1ID,IPR,IMS,IP,WM,HM,HD,HR,XI,XUI,XXLI,RF)
 1000 STOP
      END
```

```
*RFSTOR
      SUBROUTINE RFSTOR (IW,HI,HIU,HIL,HS,HT,XL,W,X,XU,XXL,FW,
     1ID,IPR,IMS,IP,WM,HM,HD,HR,XI,XUI,XXLI,RF)
      DIMENSION XTAB(11),BTAB(11,4),Y(18,2),YTAB(11,2),G(9,2),X(9)
      DIMENSION ZTAB(6),                        GTAB(5,11,6),B(5,2)
      DIMENSION GP(7,18,2),XW(9)
      DIMENSION XMSG(4,5,2),RF(5,2),F(4),XU(9),XXL(9),BU(5,2),BL(5,2)
      DIMENSION XI(5),XUI(5),XXLI(5),XX(9),BI(5,2),BUI(5,2),BLI(5,2)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB
      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159
    1 FORMAT (1H1)
    2 FORMAT (1H0)
    3 FORMAT (1H )
    4 FORMAT (5X,'X',7X,'B(X)AS',8X,'B(X)FP')
    8 FORMAT (F10.3,1P2E12.4)
    9 FORMAT (F10.0,3F10.4)
      DO 50 M=1,2
      DO 50 J=1,18
      DO 50 K=1,7
   50 GP(K,J,M)=0.0

C         CALCULATE BARRIER FACTORS FOR FOUR WALLS AND OVERHEAD

      CALL INTRPB (XTAB,X,BTAB,B)
      CALL INTRPB (XTAB,XU,BTAB,BU)
      CALL INTRPB (XTAB,XXL,BTAB,BL)
      IF (IP.EQ.0) GO TO 60
      CALL INTRPB (XTAB,XI,BTAB,BI)
      CALL INTRPB (XTAB,XUI,BTAB,BUI)
      CALL INTRPB (XTAB,XXLI,BTAB,BLI)
      GO TO 75
   60 DO 70 K=1,2
      DO 70 L=1,5
      BI(L,K)=1.0
      BUI(L,K)=1.0
   70 BLI(L,K)=1.0
   75 CONTINUE
      PRINT 2
      PRINT 2
      PRINT 4
      PRINT 2
      DO 80 L=1,5
   80 PRINT  8, X(L),(B(L,K),K=1,2)
      PRINT 2
      DO 81 L=1,5
   81 PRINT 8, XU(L),(BU(L,K),K=1,2)
      PRINT 2
      DO 82 L=1,5
   82 PRINT 8, XXL(L),(BL(L,K),K=1,2)
      PRINT 2
      DO 83 L=1,5
   83 PRINT 8, XI(L),(BI(L,K),K=1,2)
      PRINT 2
      DO 84 L=1,5
   84 PRINT 8, XUI(L),(BUI(L,K),K=1,2)
      PRINT 2
      DO 85 L=1,5
   85 PRINT 8, XXLI(L),(BLI(L,K),K=1,2)

C         SET PARAMETERS F(L) FOR FRACTION OF PERIMETER OCCUPIED BY
C         WINDOWS


C         IW=0 NO WINDOWS, IW=1 WINDOWS ON ALL FOUR SIDES, IW=2 WINDOWS
```

```
C          ON TWO LONG SIDES

      DO 300 L=1,4
      IF (IW.EQ.0) F(L)=0.0
      IF (IW.GT.0) F(L)=FW
      IF (IW.GT.1.AND.L.EQ.2) F(L)=0.0
      IF (IW.GT.1.AND.L.EQ.4) F(L)=0.0
  300 CONTINUE
      XW(5)=X(5)

C          LOOP ON K,
C                K=1  ROOF,WALLS OF SAME STORY
C                K=2  WINDOW WALLS OF SAME STORY
C                K=3  WINDOWS OF SAME STORY
C                K=4  WALLS OF UPPER STORY
C                K=5  WINDOWS OF UPPER STORY
C                K=6  WALLS OF LOWER STORY
C                K=7  WINDOWS OF LOWER STORY

      DO 450 K=1,7

C          FOR NO WINDOWS, CALCULATE ONLY FOR K=1,4, AND6

      IF (IW) 320,310,320
  310 HU=HI-3.
      HL=3.
      IF (K.NE.1.AND.K.NE.4.AND.K.NE.6) GO TO 450
      GO TO 330

C          SET DETECTOR HEIGHT TO SILL HEIGHT UNLESS THERE ARE NO WINDOWS
C          (IW=0) , IN WHICH CASE SET IT EQUAL TO 3 FT

  320 HU=HT-HS
      HL=HS
      IF (K.EQ.1) HU=HI-HS
  330 IF (K.EQ.4.OR.K.EQ.5) HU=HI+HIU-HS
      IF (K.EQ.6.OR.K.EQ.7) HL=HS+HIL
      IF (K.EQ.1) HUR=HR-HD
      IL=0

C          CALCULATE GEOMETRY FACTOR FOR WALLS BELOW DETECTOR PLANE ON FIRS
C          FIRST PASS (K=1) THRU 'DO 450' LOOP

      IF (K.EQ.1.OR.K.EQ.6.OR.K.EQ.7) IL=1
      DO 340 L=1,4
      LP=L+5
      XW(L)=X(L)
      XX(L)=XI(L)
      XX(LP)=XI(L)
      X(LP)=X(L)
  340 XW(LP)=X(L)
      IF (K-4) 345,341,343
  341 DO 342 L=1,4
      LP=L+5
      XW(L)=XU(L)
      XX(L )=XUI(L)
      XX(LP)=XUI(L)
  342 XW(LP)=XU(L)
      GO TO 345
  343 IF (K.NE.6) GO TO 345
      DO 344 L=1,4
      LP=L+5
      XW(L)=XXL(L)
      XX(L )=XXLI(L)
```

```
      XX(LP)=XXLI(L)
  344 XW(LP)=XXL(L)
  383 FORMAT (I5,7F10.3)
  345 IF (IW.EQ.0) GO TO 380
      IF (K-3) 380,346,346
  346 IF (K.NE.3.AND.K.NE.5.AND.K.NE.7) GO TO 380
C         RESET VALUE OF XW TO ZERO FOR WALLS WITH WINDOWS
      IF (IW.GT.1) GO TO 350
      DO 348 L=1,4
      LP=L+5
      XW(LP)=XX(L)
  348 XW(L)=XX(L)
      GO TO 380
  350 XW(1)=XX(1)
      XW(2)=X(2)
      XW(3)=XX(3)
      XW(4)=X(4)
      DO 370 L=1,4
      LP=L+5
  370 XW(LP)=XW(L)
C         CALCULATE Y ARRAY
  380 CALL        SECTOR (IL,HU,HUR,HL,XL,W,Y)
  381 FORMAT (2F10.3)
C         CALCULATE GEOMETRY FACTORS ABOVE DETECTOR PLANE
      CALL        INTRPG (XW,Y,G)
      IF (K.GT.1.AND.K.LT.6) GO TO 385
C         CALCULATE GEOMETRY FACTORS BELOW DETECTOR PLANE
      DO 382 L=1,4
      LP=L+9
      DO 382 M=1,2
  382 GP(K,LP,M)=1.-Y(LP,1)**3
  385 DO 390 L=1,9
      DO 390 M=1,2
  390 GP(K,L,M)=G(L,M)
      IF (IPR.EQ.0) GO TO 450
      PRINT 3
      DO 515 L=1,9
      IF (L.EQ.1) PRINT 520
      IF (L.EQ.6) PRINT 521
      IF (L.LE.5) J=1
      IF (L.GT.5) J=2
  515 PRINT 9, XW(L),Y(L,J),(G(L,M),M=1,2)
      PRINT 410, GP
  410 FORMAT (7F10.4)
  450 CONTINUE
  520 FORMAT ('     X          OMEGA        G(X,OM) AS    G(X,OM) FP')
  521 FORMAT ('     X          SIN PHI    G2(X,SIN) AS    G2(X,SIN)FP')
       IF (IMS) 5150,5150,518
 5150 DO 517 M=1,2
      DO 517 J=1,4
      DO 516 L=1,4
  516 XMSG(J,L,M)=0.5
  517 XMSG(J,5,M)=0.85
      GO TO 500
  518 CALL GMSHLD (WM,HM,XL,W,HD,HI,HIU,HS,HT,HUR,X,Y,GP,IW,
     1XMSG)
```

```
  500 DO 551 M=1,2
C         CALCULATE REDUCTION FACTOR FOR ROOF
  530 RF(5,M)=B(5,M)*GP(1,5,M)
      RF(5,M)=RF(5,M)*XMSG(1,5,M)
      IF (ID.EQ.0) GO TO 551
C         CALCULATE REDUCTION FACTOR FOR WALLS
  540 DO 550 L=1,4
      LP=L+5
      LPP=L+9
      CSU1=B(L,M)*(0.85*GP(1,L,M)*GP(1,LP,M))
     1*XMSG(1,L,M)
      CSU2=
     1 +.85*F(L)*(BI(L,M)*GP(3,L,M)*GP(3,LP,M)-B(L,M)*GP(2,L,M)*GP(2,LP,
     2M))*XMSG(2,L,M)
      CSU=CSU1+CSU2
      IF (ID.LT.2) CSU=0.0
      CSL=B(L,M)*(0.15*GP(1,LPP,M)*GP(1,LP,M))
      CSL=0.5*CSL
      IF (ID.LT.3) CSL=0.0
      CS=CSU+CSL
      CU1=
     2 +.85*BU(L,M)*(GP(4,L,M)*GP(4,LP,M)-GP(1,L,M)*GP(1,LP,M))
     1*XMSG(3,L,M)
      CU2=0.85*F(L)*
     3 (BUI(L,M)*(GP(5,L,M)*GP(5,LP,M)-GP(3,L,M)   *GP(3,LP,M))
     4 -BU(L,M)*(GP(4,L,M)*GP(4,LP,M)-GP(1,L,M)*GP(1,LP,M)))
     5*XMSG(4,L,M)
      CU=CU1+CU2
      IF (ID.GE.5) CU=0.0
      CL=
     5 +.15*BL(L,M)*(GP(6,LPP,M)*GP(6,LP,M)-GP(1,LPP,M)*GP(1,LP,M))
     6 +.15*F(L)*(BLI(L,M)*(GP(7,LPP,M)*GP(7,LP,M)-GP(1,LPP,M)*GP(1,LP,M
     7 ))-BL(L,M)*(GP(6,LPP,M)*GP(6,LP,M)-GP(1,LPP,M)*GP(1,LP,M)))
      CL=0.5*CL
      IF (ID.LT.4.OR.ID.GT.5) CL=0.0
C     PRINT 1050, CSU1,CSU2,CSL,CU1,CU2,CL,BU(5,M),BL(5,M),XMSG(2,L,M)
 1050 FORMAT (1P9E10.2)
      RF(L,M)=CS+BU(5,M)*CU+BL(5,M)*CL
  550 CONTINUE
  551 CONTINUE
      GO TO 900
  600 DO 650 M=1,2
      DO 650 L=1,5
  650 RF(L,M)=0.0
  900 PRINT 1
      PRINT 2
      PRINT 920
      DO 915 L=1,5
      PRINT 910, X(L),(RF(L,M),M=1,2)
  910 FORMAT (F10.0,10X,1P2E10.2)
  915 CONTINUE
  920 FORMAT ('      X                    RF-AS      RF-FP')
      RETURN
      END
```

```
*GMSHLD
      SUBROUTINE GMSHLD (WM,HM,XL,W,HD,HI,HIU,HL,HT,HUR,XW,Y,GP,IW,
     1XMSW)
      DIMENSION XW(9),GP(7,18,2),XMSW(4,5,2),HM(4),Y(18,2),GM(9,2),YM(4)
     1 ,X(4),TAUMRF(4),G(9,2),WM(4)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB

      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159

C         XMSW(1,L,M) IS THE MUTUAL SHIELDING FOR THE SOLID WALL
C              CONTRIBUTION TO CSU (IN RFSTOR)
C         XMSW(2,L,M) IS THE MUTUAL SHIELDING FOR THE WINDOW CONTRIBUTION
C              TO CSU
C         XMSW(3,L,M) IS THE MUTUAL SHIELDING FOR THE SOLID WALL
C              CONTRIBUTION TO CU
C         XMSW(4,L,M) IS THE MUTUAL SHIELDING FOR THE WINDOW CONTRIBUTION
C              TO CU
C         XMSW (1,5,M) IS THE MUTUAL SHIELDING FOR THE ROOF

      IL=0
      YM(1)=0.5*W
      YM(2)=0.5*XL
      YM(3)=YM(1)
      YM(4)=YM(2)
      DO 100 L=1,4
      IF(HM(L)-HD)  10,10,30
   10 DO 15 M=1,2
      DO 15 J=1,4
   15 XMSW(J,L,M)=0.5
      GO TO 100
   30 HTEST=(HM(L)-HD)*YM(L)/(WM(L)+YM(L))
      HU=HT-HL
      IF (HTEST-HU) 35,35,60
   35 CALL SECTOR (IL,HTEST,HUR,HL,XL,W,Y)
      CALL INTRPG (XW,Y,GM)
      DO 50 M=1,2
      XMSW(1,L,M)=(GP(1,L,M)-GM(L,M))/GP(1,L,M)/2.
      IF (IW.GT.0)
     1XMSW(2,L,M)=(GP(3,L,M)-GM(L,M))/GP(3,L,M)/2.
      XMSW(3,L,M)=0.5
   50 XMSW(4,L,M)=0.5
      GO TO 100
   60 HU=HI-HL
      IF (HTEST-HU) 65,65,80
   65 CALL SECTOR (IL,HTEST,HUR,HL,XL,W,Y)
      CALL INTRPG (XW,Y,GM)
C         REDUNDANT WITH PREVIOUS LOOP, BUT INCLUDED FOR POSSIBLE
C              FUTURE CHANGES
      DO 70 M=1,2
      XMSW(1,L,M)=(GP(1,L,M)-GM(L,M))/GP(1,L,M)/2.
      IF (IW.GT.0)
     1XMSW(2,L,M)=(GP(3,L,M)-GM(L,M))/GP(3,L,M)/2.
      PRINT 1050, GP(3,L,M),GM(L,M),XMSW(2,L,M)
 1050 FORMAT (1P4E10.2)
      XMSW(3,L,M)=0.5
   70 XMSW(4,L,M)=0.5
      GO TO 100
   80 HU=HI+HIU-HL
      IF (HTEST-HU) 85,85,95
   85 CALL SECTOR (IL,HTEST,HUR,HL,XL,W,Y)
      CALL INTRPG (XW,Y,GM)
      DO 90 M=1,2
      XMSW(1,L,M)=0.0
      XMSW(2,L,M)=0.0
```

```
      XMSW(3,L,M)=(GP(4,L,M)-GM(L,M))/(GP(4,L,M)-GP(1,L,M))/2.
      IF (IW.GT.0)
     1XMSW(4,L,M)=(GP(5,L,M)-GM(L,M))/(GP(5,L,M)-GP(3,L,M))/2.
   90 CONTINUE
      GO TO 100
   95 DO 98 M=1,2
      XMSW(1,L,M)=0.0
      XMSW(2,L,M)=0.0
      XMSW(3,L,M)=0.0
   98 XMSW(4,L,M)=0.0
  100 CONTINUE
      DELH=HUR
      DO 300 L=1,4
      HTEST=(HM(L)-HD)*YM(L)/(WM(L)+YM(L))
      IF (HTEST-DELH) 220,220,240
  220 X(L)=YM(L)
      GO TO 300
  240 X(L)=DELH*(WM(L)+YM(L))/(HM(L)-HD)
  300 CONTINUE
      EPS=X(1)/X(2)
      ETA=DELH/X(2)
      TAUMRF(1)=TAU(EPS,ETA)
      EPS=X(2)/X(3)
      ETA=DELH/X(3)
      TAUMRF(2)=TAU(EPS,ETA)
      EPS=X(3)/X(4)
      ETA=DELH/X(4)
      TAUMRF(3)=TAU(EPS,ETA)
      EPS=X(4)/X(1)
      ETA=DELH/X(1)
      TAUMRF(4)=TAU(EPS,ETA)
      DO 400 L=1,4
      Y(5,1)=TAUMRF(L)
      CALL INTRPG (XW,Y,G)
      DO 400 M=1,2
  400 GM(L,M)=G(5,M)
      DO 500 M=1,2
  500 XMSW(1,5,M)=0.25*0.85*(GM(1,M)+GM(2,M)+GM(3,M)+GM(4,M))/GP(1,5,M)
      RETURN
      END
```

INRN

```
*SECTOR
      SUBROUTINE SECTOR (IL,HU,HUR,HL,XL,W,Y)
      DIMENSION Y(18,2),OM(4),SPHI(4)

C         EXPRESSION FOR SOLID ANGLE SUBTENDED BY A RECTANGLE

      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159
      H=HU
      CALL GEOM (H,XL,W,OM,SPHI)

C         SET UP Y ARRAY FROM VALUES OF OMEGA AND SIN PHI

      DO 20 J=1,4
      JP=J+5
      Y(J,1)=OM(J)
   20 Y(JP,2)=SPHI(J)

C         EQUATE FIFTH Y VALUE TO SOLID ANGLE FRACTION SUBTENDED BY ROOF

      EPS=W/XL
      TZP=2.*HUR
      ETA=TZP/XL
      Y(5,1)=TAU(EPS,ETA)

C         TEST TO SEE WHETHER TO CALCULATE Y ARRAY FOR PORTION OF WALL
C         BELOW DETECTOR PLANE (IL=1) OR EXIT (IL=0)

      IF (IL.EQ.0) GO TO 200
      H=HL
      CALL GEOM (H,XL,W,OM,SPHI)
      DO 40 J=1,4
      J1=J+9
      J2=J+14
      Y(J1,1)=OM(J)
   40 Y(J2,2)=SPHI(J)

C         CALCULATE SOLID ANGLE FRACTION SUBTENDED BY FLOOR (NOT USED)

      TZP=2.*HL
      ETA=TZP/XL
      Y(14,1)=TAU(EPS,ETA)
  200 RETURN
      END
```

```
*GEOM
      SUBROUTINE GEOM (HI,XL,W,OM,SPHI)
      DIMENSION          OM(4),SPHI(4)

C         EXPRESSION FOR SOLID ANGLE SUBTENDED BY A RECTANGLE

      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159

C         CALCULATE PARAMETERS ETA AND EPS(ILON) FOR SOLID ANGLE FRACTION SUB
C         SUBTENDED BY EACH WALL

      DO 40 J=1,4
      TZP=W
      IF (J.EQ.2.OR.J.EQ.4) TZP=XL
      XLP=XL
      IF (J.EQ.2.OR.J.EQ.4) XLP=W
      ETA=TZP/XLP

C         CALCULATE AZIMUTHAL HALF-ANGLE PHI SUBTENDED BY EACH WALL

      PHI=ATAN(XL/W)
      IF (J.EQ.2.OR.J.EQ.4) PHI=ATAN(W/XL)
      WP=2.*HI
      EPS=WP/XLP

C         REPLACE EACH WALL BY SECTION OF CYLIDER WITH VERTICAL AXIS THRU
C         DETECTOR POINT AND CALCULATE SOLID ANGLE FRACTION OMEGA SUBTEND
C         -ED BY EQUIVALENT CIRCULAR CEILING

      OM(J) =1.-1.5708*TAU(EPS,ETA)/PHI
   40 SPHI(J)=SIN(PHI)
  200 RETURN
      END
```

```
*INPUTT
      SUBROUTINE INPUTT (IPR,OMTAB,SPTAB)
      DIMENSION XTAB(11),BTAB(11,4),ZTAB(6),OMTAB(11),SPTAB(11),GTAB(6,
     1 11,6),YTAB(11,2)
      DIMENSION XLABEL(18)
     1 ,OMRTAB(17),RTAB(17,2)
      DIMENSION OMSTAB(17),XMSTAB(17,2)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB
      COMMON OMRTAB,RTAB,OMSTAB,XMSTAB
      DATA XLABEL/4HG(X,,4HOM)R,4HN    ,4HG(X,,4HOM)R,4HG    ,4HG(X,,
     14HOM)W,4HN    ,4HG(X,,4HOM)W,4HG    ,4HG2(X,4H,SIN,4H)WN ,4HG2(X,4H
     2SIN,4H)WG /

C        READ IN TABULATED BARRIER THICKNESSES

      READ  1, (XTAB(I),I=1,6)
      DO 30 I=1,6
   30 XTAB(I)=146.6*XTAB(I)

C        READ IN TABULATED BARRIER FACTORS

      READ  4,((BTAB(I,J),I=1,6),J=1,4)
    4 FORMAT (6E10.3)
      BTAB(1,2)=1.0E-10
      BTAB(1,4)=1.0E-10
    1 FORMAT (8E10.3)
    2 FORMAT (1H0)
    3 FORMAT (1H )
    5 FORMAT (3X,'XTAB',6X,'B(X)RN',6X,'B(X)RG',6X,'B(X)WN',6X,'B(X)WG')
    7 FORMAT (F10.3,1P4E12.3)
      IF (IPR.EQ.0) GO TO 60
      PRINT 2
      PRINT 5
      PRINT 2
      DO 50 I=1,6
      PRINT  7, XTAB(I),(BTAB(I,J),J=1,4)
   50 CONTINUE

C        READ IN TABULATED BARRIER THICKNESSES, SOLID ANGLE FRACTIONS, AN
C        AND VALUES OF SIN PHI FOR GEOMETRY FACTORS

   60 READ  110, ZTAB
      READ  110, (OMTAB(I),I=1,11)
      READ  110, SPTAB
      OMTAB(1)=1.0E-10
      SPTAB(1)=1.0E-10
  110 FORMAT (12F6.4)

C        READ IN TABULATED GEOMETRY FACTORS

      DO 150 K=1,4
  130 READ  110, ((GTAB(I,J,K),I=1,6),J=1,11)
  140 DO 145 I=1,6
      IF (K.LE.2) GTAB(I,1,K)=1.0E-10
      IF (K.GT.2) GTAB(I,11,K)=1.0E-10
      IF (K.GT.2.AND.K.LE.4) GTAB(I,11,K)=1.0E-10
  145 CONTINUE
  150 CONTINUE
      DO 154 K=5,6
      READ  110, ((GTAB(I,J,K),I=1,6),J=1,6)
      DO 154 I=1,6
      DO 153 J=7,11
  153 GTAB(I,J,K)=1.0E-10
  154 GTAB(I,1,K)=1.0E-10
```

```
      IF (IPR.EQ.0) GO TO 260
      PRINT 2
      PRINT 165
  160 FORMAT (23X,'X(PSF)=',6F10.0)
  162 FORMAT (50X,3A4)
  165 FORMAT(10X,'OMEGA',10X,'SIN PHI',15X,'G T A B ( X , O M E G A ) ')
     1)
      DO 250 K=1,6
      PRINT 2
      K1=3*K-2
      K2=K1+2
      PRINT 162, (XLABEL(I),I=K1,K2)
      PRINT 3
      PRINT 160, ZTAB
      PRINT 3
      DO 250 J=1,11
      PRINT 170, OMTAB(J),SPTAB(J),(GTAB(I,J,K),I=1,6)
  170 FORMAT  (2F15.4,6F10.4)
  250 CONTINUE

C          READ IN DUCT REFLECTION FACTORS

  260 READ  110, (OMRTAB(J),J=1,17)
      OMRTAB(1)=1.0E-10
      READ  110, ((RTAB(J,I),J=1,17),I=1,2)
      RTAB(1,2)=1.0E-10
      IF (IPR.EQ.0) GO TO 400
      PRINT 265
  265 FORMAT (5X,'OMEGA',6X,'RHO',4X,'RHO-SUB-E')
      DO 350 J=1,17
      PRINT 270, OMRTAB(J),(RTAB(J,I),I=1,2)
  270 FORMAT (F15.4,2F10.4)
  350 CONTINUE

C          READ IN MUTUAL SHIELDING FACTORS

  400 READ  110, (OMSTAB(J),J=1,17)
      OMSTAB(1)=1.0E-10
      DO 420 I=1,2
  420 READ  110, (XMSTAB(J,I),J=1,17)
      XMSTAB(1,1)=1.0E-10
      XMSTAB(1,2)=1.0E-10
      IF (IPR.EQ.0) GO TO 500
      PRINT 430
  430 FORMAT (5X,'OMEGA',9X,'MS',8X,'MR')
      DO 450 J=1,17
      PRINT 270, OMSTAB(J),(XMSTAB(J,I),I=1,2)
  450 CONTINUE
  500 CONTINUE
      RETURN
      END
```

```
*INTRPR
      SUBROUTINE INTRPR (OMRTAB,RTAB,TAUR,RHO)
      DIMENSION OMRTAB(17),RTAB(17,2),TAUR(5),RHO(5,2)
      DO 400 I=1,5
      J=1
  260 J=J+1
      IF (TAUR(I).LT.OMRTAB(J)) GO TO 300
      IF (J.LT.17) GO TO 260
  300 J2=J
      J1=J-1
      DO 350 K=1,2
  350 RHO(I,K)=EXP(ALOG(RTAB(J1,K))+ALOG(TAUR(I)/OMRTAB(J1))*ALOG(RTAB(J2
     12,K)/RTAB(J1,K))/ALOG(OMRTAB(J2)/OMRTAB(J1)))
  400 CONTINUE
      RETURN
      END
```

```
*INTRPB
      SUBROUTINE INTRPB (XTAB,X,BTAB,B)
      DIMENSION XTAB(11),BTAB(11,4),B(5,2),X(5)

C         RELAXATION LENGTHS FOR EXTRAPOLATION


C         RELATE K (TYPE OF RADIATION) AND L (INDEX OF WALL OR OVERHEAD
C         TO PARAMETER J WHICH INDEXES BARRIER FACTOR TABLES

  100 DO 250 K=1,2
      DO 250 L=1,5
      IF (K.EQ.1.AND.L.EQ.5) J=1
      IF (K.EQ.1.AND.L.NE.5) J=3
      IF (K.EQ.2.AND.L.EQ.5) J=2
      IF (K.EQ.2.AND.L.NE.5) J=4
  200 I=1
  210 I=I+1
      IF (I.EQ.6) GO TO 220
      IF (X(L).LT.XTAB(I)) GO TO 220
      GO TO 210

C         LINEAR INTERPOLATION ON X AND LOG OF BARRIER FACTOR

  220 B(L,K)=EXP(ALOG(BTAB(I-1,J))+ALOG(BTAB(I,J)/BTAB(I-1,J))*
     1 (X(L)-XTAB(I-1))/(XTAB(I)-XTAB(I-1)))
  250 CONTINUE
  300 RETURN
      END
```

```
*INTRPG
      SUBROUTINE INTRPG (X ,Y,G)
      DIMENSION ZTAB( 6),YTAB(11,2),GTAB(6,11,6),Y(18,2),G1(11,6),X(9),
     1 G(9,2),XTAB(11),BTAB(11,4)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB

C         RELATE M (TYPE OF RADIATION) AND L (INDEX OF WALL OR OVERHEAD)
C         TO PARAMETER K WHICH INDEXES GEOMETRY FACTOR TABLES

      DO 450 M=1,2
      DO 450 L=1,9
      IF (M.EQ.1.AND.L.EQ.5) K=1
      IF (M.EQ.2.AND.L.EQ.5) K=2
      IF (M.EQ.1.AND.L.LT.5) K=3
      IF (M.EQ.2.AND.L.LT.5) K=4
      IF (M.EQ.1.AND.L.GT.5) K=5
      IF (M.EQ.2.AND.L.GT.5) K=6

C         INDEX I FOR TWO NEAREST BARRIER THICKNESSES

      I=1
  110 I=I+1
      IF (I.EQ.6) GO TO 200
      IF (X(L).LT.ZTAB(I)) GO TO 200
      GO TO 110
  200 IX=I
      IN=I-1

C         DETERMINE IF VARIABLE IS OMEGA (K.LE.4) OR SIN PHI (K.GT.4)

      IF (K-4) 320,320,330
  320 KI=1
      GO TO 350
  330 KI=2

C         INDEX J FOR TWO NEAREST OMEGA OR SIN PHI VALUES

  350 J=1
  360 J=J+1
      IF (Y(L,KI).LT.YTAB(J,KI)) GO TO 300
      GO TO 360
  300 J2=J
      J1=J-1

C         TWO-WAY INTERPOLATION ON GEOMETRY FACTORS

  390 DO 400 J=J1,J2

C         LINEAR INTERPOLATION ON BARRIER THICKNESS X AND LOG OF
C         GEOMETRY FACTORS

      G1(J,K)=EXP(ALOG(GTAB(IN,J,K))+ALOG(GTAB(IX,J,K)/GTAB(IN,J,K))
     1*(X(L)-ZTAB(IN))/(ZTAB(IX)-ZTAB(IN)))
  400 CONTINUE

C         LINEAR INTERPOLATION ON LOG Y AND LOG OF GEOMETRY FACTORS

      IF (K.EQ.3.OR.K.EQ.4) GO TO 425
      G(L,M)=EXP(ALOG(G1(J1,K))+ALOG(G1(J2,K)/G1(J1,K))*ALOG(Y(L,KI)/
     1YTAB(J1,KI))/ALOG(YTAB(J2,KI)/YTAB(J1,KI)))
      GO TO 450

C         FOR K=3 AND K=4, INTERPOLATE ON LOG(1-OMEGA)
```

```
425 YI=1.-Y(L,KI)
    IF (YI.LT.1.0E-10) YI=1.0E-10
    Y1=1.-YTAB(J1,KI)
    IF (Y1.LT.1.0E-10) Y1=1.0E-10
    Y2=1.-YTAB(J2,KI)
    IF (Y2.LT.1.0E-10) Y2=1.0E-10
    G(L,M)=EXP(ALOG(G1(J1,K))+ALOG(G1(J2,K)/G1(J1,K))*ALOG(YI/Y1)/ALOG
   1(Y2/Y1))
450 CONTINUE
    RETURN
    END
```

```
*INNER
      SUBROUTINE INNER (IP,XE,XI,XUE,XUI,XXLE,XXLI,XW,XU,XXL)
      DIMENSION XE(5),XI(5),XUE(5),XUI(5),XXLE(5),XXLI(5),XW(9),XU(9),
     1 XXL(9)

C        SET ROOF BARRIER THICKNESS EQUAL TO XE(5), CEILING THICKNESS
C        EQUAL TO XUI(5), AND FLOOR THICKNESS EQUAL TO XXLI(5)

      XW(5)=XE(5)
      XU(5)=XUI(5)
      XXL(5)=XXLI(5)

C        FOLD CEILING INTO UPPER STORY WALLS AND
C        FLOOR INTO LOWER STORY WALLS FOR NEUTRONS AND N-GAMMAS

      IF (IP.GT.0) GO TO 50
      DO 20 L=1,4
      XW(L)=XE(L)
      XU(L)=XUE(L)+XUI(5)
      XXL(L)=XXLE(L)+XXLI(5)
      XUI(L)=XUI(L)+XUI(5)
   20 XXLI(L)=XXLI(L)+XXLI(5)
      GO TO 200
   50 IF (IP.GT.1) GO TO 100
      DO 60 L=1,4
      XW(L)=XE(L)+XI(L)
      XU(L)=XUE(L)+XUI(L)+XUI(5)
      XXL(L)=XXLE(L)+XXLI(L)+XXLI(5)
      XUI(L)=XUI(L)+XUI(5)
   60 XXLI(L)=XXLI(L)+XXLI(5)
      GO TO 200
  100 XW(1)=XE(1)+XI(1)
      XW(3)=XW(1)
      XW(2)=XE(2)
      XW(4)=XW(2)
      XU(1)=XUE(1)+XUI(1)+XUI(5)
      XU(3)=XU(1)
      XU(2)=XUE(2)+XUI(5)
      XU(4)=XU(2)
      XUI(1)=XUI(1)+XUI(5)
      XUI(3)=XUI(1)
      XUI(2)=XUI(2)+XUI(5)
      XUI(4)=XUI(2)
      XXL(1)=XXLE(1)+XXLI(1)+XXLI(5)
      XXL(3)=XXL(1)
      XXL(2)=XXLE(2)+XXLI(5)
      XXL(4)=XXL(2)
      XXLI(1)=XXLI(1)+XXLI(5)
      XXLI(3)=XXLI(1)
      XXLI(2)=XXLI(2)+XXLI(5)
      XXLI(4)=XXLI(2)
  200 RETURN
      END
```

```
*RFSTOR
      SUBROUTINE RFSTOR (IW,HI,HIU,HIL,HS,HT,HUR,XL,W,X,XU,XXL,FW,XMS,
     1 ID,IPR,IP,HR,HD,XI,XUI,XXLI,RF)
      DIMENSION XTAB(11),BTAB(11,4),Y(18,2),YTAB(11,2),G(9,2),X(9)
      DIMENSION ZTAB(6),                     GTAB(6,11,6),B(5,2)
      DIMENSION GP(7,18,2),XW(9),CSR(4),CUR(4),CLR(4)
      DIMENSION RF(5,2),XMS(5,2),F(4),XU(9),XXL(9),BU(5,2),BL(5,2)
     1 ,OMRTAB(17),RTAB(17,2),TAUR(5),RHO(5,2)
      DIMENSION XI(5),XUI(5),XXLI(5),XX(9),BI(5,2),BUI(5,2),BLI(5,2)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB
      COMMON OMRTAB,RTAB,OMSTAB,XMSTAB
      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159
    1 FORMAT (1H1)
    2 FORMAT (1H0)
    3 FORMAT (1H )
    4 FORMAT (5X,'X',7X,'B(X) N',8X,'B(X) G')
    8 FORMAT (F10.3,1P2E12.4)
    9 FORMAT (F10.0,3F10.4)
      DO 50 M=1,2
      DO 50 J=1,18
      DO 50 K=1,7
   50 GP(K,J,M)=0.0

C        CALCULATE BARRIER FACTORS FOR FOUR WALLS AND OVERHEAD

      CALL INTRPB (XTAB,X,BTAB,B)
      CALL INTRPB (XTAB,XU,BTAB,BU)
      CALL INTRPB (XTAB,XXL,BTAB,BL)
      CALL INTRPB (XTAB,XI,BTAB,BI)
      CALL INTRPB (XTAB,XUI,BTAB,BUI)
C     PRINT 999,XUI,BUI
C 999 FORMAT (10F10.5)
      CALL INTRPB (XTAB,XXLI,BTAB,BLI)
      GO TO 75
   60 DO 70 K=1,2
      DO 70 L=1,5
      BI(L,K)=1.0
      BUI(L,K)=1.0
   70 BLI(L,K)=1.0
   75 CONTINUE
      PRINT 2
      PRINT 2
      PRINT 4
      PRINT 2
      DO 80 L=1,5
   80 PRINT 8, X(L),(B(L,K),K=1,2)
      PRINT 2
      DO 81 L=1,5
   81 PRINT 8, XU(L),(BU(L,K),K=1,2)
      PRINT 2
      DO 82 L=1,5
   82 PRINT 8, XXL(L),(BL(L,K),K=1,2)

      PRINT 2
      DO 83 L=1,5
   83 PRINT 8, XI(L),(BI(L,K),K=1,2)
      PRINT 2
      DO 84 L=1,5
   84 PRINT 8, XUI(L),(BUI(L,K),K=1,2)
      PRINT 2
      DO 85 L=1,5
   85 PRINT 8, XXLI(L),(BLI(L,K),K=1,2)
C        SET PARAMETERS F(L) FOR FRACTION OF PERIMETER OCCUPIED BY
C        WINDOWS
```

```
C         IW=0 NO WINDOWS, IW=1 WINDOWS ON ALL FOUR SIDES, IW=2 WINDOWS
C         ON TWO LONG SIDES

      DO 300 L=1,4
      IF (IW.EQ.0) F(L)=0.0
      IF (IW.GT.0) F(L)=FW
      IF (IW.GT.1.AND.L.EQ.2) F(L)=0.0
      IF (IW.GT.1.AND.L.EQ.4) F(L)=0.0
  300 CONTINUE
      XW(5)=X(5)

C         LOOP ON K,
C                K=1  ROOF,WALLS OF SAME STORY
C                K=2  WINDOW WALLS OF SAME STORY
C                K=3  WINDOWS OF SAME STORY
C                K=4  WALLS OF UPPER STORY
C                K=5  WINDOWS OF UPPER STORY
C                K=6  WALLS OF LOWER STORY
C                K=7  WINDOWS OF LOWER STORY

      DO 450 K=1,7

C         FOR NO WINDOWS, CALCULATE ONLY FOR K=1,4, AND6

      IF (IW) 320,310,320
  310 HU=HI-3.
      HL=3.
      IF (K.NE.1.AND.K.NE.4.AND.K.NE.6) GO TO 450
      GO TO 330

C         SET DETECTOR HEIGHT TO SILL HEIGHT UNLESS THERE ARE NO WINDOWS
C         (IW=0) , IN WHICH CASE SET IT EQUAL TO 3 FT

  320 HU=HT-HS
      HL=HS
      IF (K.EQ.1) HU=HI-HS
  330 IF (K.EQ.4.OR.K.EQ.5) HU=HI+HIU-HS
      IF (K.EQ.6.OR.K.EQ.7) HL=HL+HIL
      IF (K.EQ.1) HUR=HP-HD
      IL=0

C         CALCULATE GEOMETRY FACTOR FOR WALLS BELOW DETECTOR PLANE ON FIRS
C         FIRST PASS (K=1) THRU 'DO 450' LOOP

      IF (K.EQ.1.OR.K.EQ.6.OR.K.EQ.7) IL=1
      DO 340 L=1,4
      LP=L+5
      XW(L)=X(L)
      XX(L)=XI(L)
      XX(LP)=XI(L)
      X(LP)=X(L)
  340 XW(LP)=X(L)
      IF (K-4) 345,341,343
  341 DO 342 L=1,4
      LP=L+5
      XW(L)=XU(L)
      XX(L )=XUI(L)
      XX(LP)=XUI(L)
  342 XW(LP)=XU(L)
      GO TO 345
  343 IF (K.NE.6) GO TO 345
      DO 344 L=1,4
```

```
C       IF (L.EQ.1.AND.M.EQ.1)
C      1PRINT 988,M,L,CU
        IF (ID.GE.5) CU=0.0
        CL=
      5 +.42*BL(L,M)*(GP(6,LPP,M)*GP(6,LP,M)-GP(1,LPP,M)*GP(1,LP,M))
      6 +.42*F(L)*(BLI(L,M)*(GP(7,LPP,M)*GP(7,LP,M)-GP(1,LPP,M)*GP(1,LP,M
      7 ))-BL(L,M)*(GP(6,LPP,M)*GP(6,LP,M)-GP(1,LPP,M)*GP(1,LP,M)))
        IF (ID.LT.4.OR.ID.GT.5) CL=0.0
C         TEMPORARY CHANGE 7-9-86
        IF (M.EQ.1.AND.ID.LT.2) CSR(L)=CS*(RHO(L,1)+RHO(L,2))
        IF (M.EQ.1.AND.ID.GE.2) CSR(L)=CS*(RHO(L,1)+RHO(L,2)*(1.-FW))
C       IF (L.EQ.1.AND.M.EQ.1) PRINT 988,L,M,RHO(L,1),RHO(L,2),CS,CSR(L)
        IF (M.EQ.1) CS=CS+CSR(L)
C       PRINT 9998, CSU,CSL,CSR(L),RHO(L,1),RHO(L,2)
C9998   FORMAT (' CSU,CSL,CSR,RHO1,RHO2,=',1P5E12.4)
        IF (M.EQ.2) CS=CS+0.3*CSR(L)
C    ADD REFLECTION TO CONTRB FROM OTHER STORIES
C         TEMPORARY CHANGE 7-9-86
        IF (M.EQ.1.AND.ID.LT.2) CUR(L)=CU*(RHO(5,1)+RHO(5,2))
        IF (M.EQ.1.AND.ID.GE.2) CUR(L)=CU*(RHO(5,1)*(1.-FW)+RHO(5,2))
C         TEMPORARY CHANGE 7-9-86
C       IF (M.EQ.1) CLR(L)=CL*(RHO(5,1)+RHO(5,2))
        IF (M.EQ.1) CLR(L)=CL*(RHO(5,1)*(1.-FW)+RHO(5,2))
        IF (M.EQ.1) CU=CU+CUR(L)
        IF (M.EQ.1) CL=CL+CLR(L)
        IF (M.EQ.2) CU=CU+0.3*CUR(L)
        IF (M.EQ.2) CL=CL+0.3*CLR(L)
C        ATTENUATION IN CEILING IS NOW INCLUDED IN WALL BARRIER
        RF(L,M)=CS+CU+CL
        RF(L,M)=RF(L,M)*XMS(L,M)
C       PRINT 9999, CS,CU,CL,XMS(L,M)
C9999   FORMAT (' CS,CU,CL,XMS=',1P4E12.4)
  550   CONTINUE
  551   CONTINUE
  900   PRINT 1
        PRINT 2
        PRINT 920
        DO 915 L=1,5
        PRINT 910, X(L),(RF(L,M),M=1,2)
  910   FORMAT (F10.0,10X,1P2E10.2)
  915   CONTINUE
  920   FORMAT ('      X                        RF- N        RF- G')
 1000   RETURN
        END
```

```
*TEST
      PROGRAM TEST (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION XTAB(11),BTAB(11,4),          YTAB(11,2),        X(9)
      DIMENSION ZTAB(6),OMTAB(11),SPTAB(11),GTAB(6,11,6)
      DIMENSION RF(5,2),XMS(5,2),XU(9),XXL(9)
      DIMENSION OMSTAB(17),XMSTAB(17,2)
      DIMENSION XLM(4),WM(4),HM(4),XE(5),XI(5),XUE(5),XUI(5),XXLE(5),
     1 XXLI(5),TITLE(20)
     1 ,OMRTAB(17),RTAB(17,2)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB
      COMMON OMRTAB,RTAB,OMSTAB,XMSTAB
    1 FORMAT (8E10.3)
    2 FORMAT (1H0)
    3 FORMAT (1H )
    4 FORMAT (5X,'X',7X,'B(X)AS',8X,'B(X)FP')
    5 FORMAT (3X,'XTAB',6X,'B(X)RAS',5X,'B(X)RFP',5X,'B(X)WAS',5X,'B(X)W
     1FP')
    6 FORMAT (1H1)
    8 FORMAT (F10.3,1P2E12.4)
    9 FORMAT (F10.0,3F10.3)
   11 FORMAT (20A4)
      READ  (5,11) TITLE
      WRITE (6,6)
      WRITE (6,2)
      WRITE (6,11) TITLE
      READ  (5,10) IW,ID,IPR,IMS,IP,HI,HS,HT,HD,HR,FW,HIU,HIL,XL,W
      WRITE (6,10) IW,ID,IPR,IMS,IP,HI,HS,HT,HD,HR,FW,HIU,HIL,XL,W
   10 FORMAT (5I5,5F10.2/5F10.2)
      HUR=HR
   40 READ  45, XLM
      PRINT 45, XLM
      READ  45, WM
      PRINT 45, WM
      READ  45, HM
      PRINT 45, HM
   45 FORMAT (4F10.3)
      CALL         INPUTT (IPR,OMTAB,SPTAB)
      DO 310 J=1,11
      YTAB(J,1)=OMTAB(J)
  310 YTAB(J,2)=SPTAB(J)
      READ  (5,1) (XE(L),L=1,5)
      WRITE (6,1) (XE(L),L=1,5)
      READ  (5,1) (XI(L),L=1,5)
      WRITE (6,1) (XI(L),L=1,5)
      READ  (5,1) (XUE(L),L=1,5)
      WRITE (6,1) (XUE(L),L=1,5)
      READ  (5,1) (XUI(L),L=1,5)
      WRITE (6,1) (XUI(L),L=1,5)
      READ  (5,1) (XXLE(L),L=1,5)
      WRITE (6,1) (XXLE(L),L=1,5)
      READ  (5,1) (XXLI(L),L=1,5)
      WRITE (6,1) (XXLI(L),L=1,5)
      CALL         INNER (IP,XE,XI,XUE,XUI,XXLE,XXLI,X ,XU,XXL)
      XMAX=681.
      IF (IMS) 60,60,80
   60 DO 70 I=1,2
      DO 65 J=1,4
   65 XMS(J,I)=0.5
   70 XMS(5,I)=0.58
      GO TO 600
   80 CALL         NMSHLD (XLM,WM,HM,XL,W,HC,HR,XMS)
  600 CONTINUE
      CALL         RFSTOR (IW,HI,HIU,HIL,HS,HT,HUR,XL,W,X,XU,XXL,FW,XMS,
     1 ID,IPR,IP,HR,HD,XI,XUI,XXLI,RF)
```

```
1000 STOP
     END
```

```
*NMSHLD
      SUBROUTINE NMSHLD (XLM,WM,HM,XL,W,HD,HR,XMS)
      DIMENSION XTAB(11),BTAB(11,4),ZTAB(6),GTAB(6,11,6),YTAB(11,2)
      DIMENSION XLM(4),WM(4),HM(4),TAUM(5),X(4),Y(4)
      DIMENSION TAUMRF(5),XMS(5,2),XMSP(5,2),OMSTAB(17),XMSTAB(17,2)
      DIMENSION OMRTAB(17),RTAB(17,2)
      COMMON XMAX,XTAB,BTAB,ZTAB,YTAB,GTAB
      COMMON OMRTAB,RTAB,OMSTAB,XMSTAB
      TAU(A,B)=2.*ATAN(A/B/SQRT(A**2+B**2+1.0))/3.14159
C     PRINT 41, XLM
C  41 FORMAT (10E10.4)
   40 DO 50 J=1,4
      DELH=HM(J)-HD
      IF (DELH) 42,42,44
   42 TAUM(J)=1.0
      GO TO 50
   44 EPS=2.*WM(J)/XLM(J)
      ETA=2.*(HM(J)-HD)/XLM(J)
      TAUM(J)=TAU(EPS,ETA)
   50 CONTINUE
      HMAX=HM(1)
      IF (HM(2).GT.HMAX) HMAX=HM(2)
      IF (HM(3).GT.HMAX) HMAX=HM(3)
      IF (HM(4).GT.HMAX) HMAX=HM(4)
      Y(1)=0.5*W
      Y(2)=0.5*XL
      Y(3)=Y(1)
      Y(4)=Y(2)
      DELH=HMAX-HR
      DO 70 J=1,4
      IF (HM(J)-HR) 52,52,54
   52 X(J)=1000.
      GO TO 70
   54 X(J)=DELH*(WM(J)+Y(J))/(HM(J)-HR)
   70 CONTINUE
      IF (DELH) 400,400,100
  100 EPS=X(1)/X(2)
      ETA=DELH/X(2)
      TAUMRF(1)=TAU(EPS,ETA)
      EPS=X(2)/X(3)
      ETA=DELH/X(3)
      TAUMRF(2)=TAU(EPS,ETA)
      EPS=X(3)/X(4)
      ETA=DELH/X(4)
      TAUMRF(3)=TAU(EPS,ETA)
      EPS=X(4)/X(1)
      ETA=DELH/X(1)
      TAUMRF(4)=TAU(EPS,ETA)
  400 TAUM(5)=1.0
      TAUMRF(5)=1.0
      CALL INTRPR (OMSTAB,XMSTAB,TAUM,XMSP)
C     PRINT 41, TAUM,XMSP
      DO 500 I=1,2
      DO 480 J=1,4
  480 XMS(J,I)=0.5*XMSP(J,2)
  500 CONTINUE
      IF (DELH) 520,520,530
  520 DO 525 I=1,2
  525 XMS(5,I)=0.58
      GO TO 200
  530 CALL INTRPR (OMSTAB,XMSTAB,TAUMRF,XMSP)
      DO 550 I=1,2
  550 XMS(5,I)=0.25*(XMSP(1,1)+XMSP(2,1)+XMSP(3,1)+XMSP(4,1))*0.58
```

```
200 RETURN
    END
```

APPENDIX D

```
BENCHMARK STRUCTURE NC 5 ( BASEMENT  ) 8-12-86
   1     1     0     0     0  12.      3.0            12.        -9.0         92.
 1.0          12.          12.          84.          64.
1000.        1000.        1000.        1000.
50.          1000.        1000.        1000.
0.           0.           0.           0.
0.0          0.1          0.2          0.4          1.0          2.0          3.0          4.0
6.0          8.0          10.0
1.03         1.01         1.03         1.01         .675         .732         .644         .703
.741         .549         .704         .511         .534         .334         .308         .301
.216         .1075        .225         .0948        .0595        .0237        .0732        .0198
.181  -01    .601-02      .258-01      .499-02 .577   -02     .167-02      .936-02      .141-02
  .676-03     .162-03      .133-02      .142-03      .919-04      .177-04      .203-03      .165-04
  .132-04     .200-05      .320-04      .200-05
0.0    36.    72.    144.   288.   576.
0.0    0.1    0.2    0.3    0.4    0.5    0.6    0.7    0.8    0.9    1.0
0.0    0.2    0.4    0.6    0.8    1.0
0.0    0.0    0.0    0.0    0.0    0.0    .0435  .0615  .0732  .0997  .1690  .335
.1061  .1514  .1819  .245   .382   .632   .1976  .282   .336   .434   .607   .833
.334   .469   .546   .663   .818   .950   .504   .678   .759   .855   .944   .991
.670   .849   .907   .958   .989   .999   .801   .950   .976   .992   .998   1.
.891   .991   .996   .999   1.     1.     .952   .999   1.     1.     1.     1.
1.     1.     1.     1.     1.     1.
.1022  .200   .243   .294   .363   .456   .228   .424   .502   .602   .723   .852
.346   .606   .693   .793   .894   .967   .453   .743   .820   .898   .962   .993
 .552  .843   .902   .954   .987   .998   .648   .916   .952   .981   .996   1.
.745   .962   .981   .993   .999   1.     .837   .989   .994   .998   1.     1.
.918   .999   .999   1.     1.     1.     1.     1.     1.     1.     1.     1.
1.     1.     1.     1.     1.     1.     0.959  0.998  0.999  0.999  1.     1.
0.897 0.928 0.953 0.976 0.993 0.999 0.805 0.854 0.890 0.930 0.967 0.990
0.668 0.721 0.763 0.816 0.879 0.942 0.499 0.542 0.578 0.631 0.708 0.810
0.334 0.362 0.388 0.429 0.494 0.596 0.203 0.217 0.232 0.256 0.297 0.370
.11250.11740.12380.13560.15760.201   .0488  .0500  .0526  .0568  .0663  .0862
0.0    0.0    0.0    0.0    0.0    0.0
1.     1.     1.     1.     1.     1.     0.902 0.994 0.996 0.998 0.999 1.0
0.781 0.854 0.894 0.939 0.981 0.998 0.666 0.763 0.815 0.879 0.947 0.988
0.563 0.666 0.724 0.801 0.892 0.962 0.468 0.567 0.626 0.707 0.811 0.911
0.375 0.464 0.518 0.597 0.705 0.823 .2817 0.354 0.401 0.470 0.571 0.692
.1862 0.238 0.272 0.326 0.405 0.508 .0919 .1175 .1354 .1641 0.209 0.268
0.0    0.0    0.0    0.0    0.0    0.0
0.0    0.0    0.0    0.0    0.0    0.0    .1294  .1976 0.224 0.270 0.342 0.435
0.265 0.399 0.449 0.529 0.646 0.769 0.415 0.609 0.668 0.761 0.870 0.947
0.600 0.835 0.871 0.925 0.980 1.0    1.0    1.0    1.0    1.0    1.0    1.0
0.0    0.0    0.0    0.0    0.0    0.0    .1305 0.219 0.248 0.291 0.358 0.452
0.267 0.437 0.488 0.561 0.666 0.788 0.417 0.654 0.711 0.787 0.881 0.958
0.602 0.862 0.895 0.937 0.982 1.0    1.0    1.0    1.0    1.0    1.0    1.0
67.          67.          67.          67.          570.
0.           0.           0.           0.           0.
67.          67.          67.          67.          0.0
0.           0.           0.           0.           57.
67.          67.          67.          67.          0.0
0.           0.           0.           0.           57.
EOR
```

```
BENCHMARK STRUCTURE NO 5 ( BASEMENT   ) 8-28-66
   1     1     0     0     0  12.      3.0           12.          -9.0       92.
 1.0         12.         12.         84.         64.
1000.        1000.       1000.       1000.
50.          1000.       1000.       1000.
0.           0.          0.          0.
0.0          .25         .5          1.0         2.0         4.0
1.0          .368        .1724       .0422       .00265      .0000119
0.0          .0192       .0273       .0350       .00696      .0000893
1.0          .304        .141        .0340       .00202      .0000082
0.0          .0245       .0400       .0347       .00629      .000092
0.0    36.    72.    144.   288.   576.
0.0    0.1    0.2    0.3    0.4    0.5    0.6    0.7    0.8    0.9    1.0
0.0    0.2    0.4    0.6    0.8    1.0
0.0    0.0    0.0    0.0    0.0    0.0    .157   .157   .157   .157   .157   .157
.304   .304   .304   .304   .304   .304   .470   .470   .470   .470   .470   .470
.552   .552   .552   .552   .552   .552   .660   .660   .660   .660   .660   .660
.752   .752   .752   .752   .752   .752   .833   .833   .833   .833   .833   .833
.900   .900   .900   .900   .900   .900   .955   .955   .955   .955   .955   .955
1.0    1.0    1.0    1.0    1.0    1.0
0.0    0.0    0.0    0.0    0.0    0.0    .04    .068   .092   .131   .205   .340
.09    .142   .192   .260   .380   .569   .14    .223   .300   .391   .532   .720
.21    .311   .412   .520   .663   .818   .29    .408   .527   .641   .763   .863
.40    .517   .644   .743   .843   .935   .52    .640   .753   .830   .907   .963
.71    .780   .853   .901   .955   .983   .86    .900   .940   .962   .983   .994
1.0    1.0    1.0    1.0    1.0    1.0    1.0
1.0    1.0    1.0    1.0    1.0    1.0    .936   .936   .936   .936   .936   .936
.858   .858   .858   .858   .858   .858   .773   .773   .773   .773   .773   .773
.678   .678   .678   .678   .678   .678   .573   .573   .573   .573   .573   .573
.464   .464   .464   .464   .464   .464   .353   .353   .353   .353   .353   .353
.238   .238   .238   .238   .238   .238   .122   .122   .122   .122   .122   .122
0.0    0.0    0.0    0.0    0.0    0.0
1.0    1.0    1.0    1.0    1.0    1.0    .850   .874   .898   .935   .962   .983
.730   .762   .799   .848   .902   .956   .620   .658   .699   .750   .823   .908
.520   .559   .597   .650   .730   .829   .430   .462   .494   .547   .628   .721
.340   .366   .395   .440   .516   .594   .250   .272   .297   .334   .393   .455
.160   .179   .198   .224   .266   .309   .080   .068   .098   .112   .133   .156
0.0    0.0    0.0    0.0    0.0    0.0
0.0    0.0    0.0    0.0    0.0    0.0    .128   .128   .128   .128   .128   .128
.262   .262   .262   .262   .262   .262   .410   .410   .410   .410   .410   .410
.590   .590   .590   .590   .590   .590   1.0    1.0    1.0    1.0    1.0    1.0
0.0    0.0    0.0    0.0    0.0    0.0    .070   .093   .122   .152   .215   .320
.160   .198   .252   .320   .427   .595   .270   .322   .401   .502   .631   .790
.400   .492   .594   .717   .826   .910   1.0    1.0    1.0    1.0    1.0    1.0
.00    .01    .02    .03    .04    .07    .10    .15    .20    .30    .40    .50
.60    .70    .80    .90    1.00
.55    .55    .58    .65    .80    1.25   1.45   1.60   1.55   1.30   1.10   0.92
.77    .64    .49    .35    .22    .00    .009   .0183  .028   .038   .069   .101   .150
.150   .195   .270   .340   .405   .465   .520   .575   .630   .670
.00    .01    .02    .03    .04    .07    .10    .15    .20    .30    .40    .50
.60    .70    .80    .90    1.00
0.0    .0205  .0395  .058   .076   .130   .183   .270   .360   .530   .660   .760
.840   .900   .950   .980   1.00
0.0    .0012  .0033  .0061  .0094  .022   .0375  .071   .109   .200   .305   .415   .530
.530   .650   .780   .900   1.00
67.          67.         67.         67.         570.
0.           0.          0.          0.          0.
67.          67.         67.         67.         0.
0.           0.          0.          0.          57.
67.          67.         67.         67.         0.
0.           0.          0.          0.          57.
/EOR
```

APPENDIX E

```
MARK STRUCTURE NO 5 ( BASEMENT ) 6-12-86
  1      0     0     0     12.00     3.00     12.00     -9.00     92.00
1.00     12.00     12.00     64.00     64.00
.000  1000.000  1000.000  1000.000
.000  1000.000  1000.000  1000.000
.000      .000      .000      .000
E+02  .670E+02  .670E+02  .670E+02  .670E+02
E+00  .000E+00  .000E+00  .000E+00  .000E+00
E+02  .670E+02  .670E+02  .670E+02  .000E+00
E+00  .000E+00  .000E+00  .000E+00  .670E+02
E+02  .670E+02  .670E+02  .670E+02  .000E+00
E+00  .000E+00  .000E+00  .000E+00  .670E+02


         E(X)CC         S(X)FP

.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  6.4179E-05  1.1248E-05

.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.7621E-01  1.4627E-01

.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.2999E-01  9.7795E-02
.000  2.7621E-01  1.4627E-01

.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00

.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00

.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
.000  1.0000E+00  1.0000E+00
```

67.	[illegible]	[illegible]
[illegible]7.	1.[illegible]7[illegible]-02	[illegible]E-03
67.	[illegible]E-0[illegible]	[illegible]E-0[illegible]
[illegible]7.	[illegible].27E-0[illegible]	[illegible]E-[illegible]
70.	1.31E-05	3.3[illegible]E-[illegible]6

```
CHMARK STRUCTURE NO 5 ( BASEMENT  ) 8-28-85
1    1    0    0    0    12.00    3.00    12.00    -9.00    92.00
  1.00     12.00     12.00     84.00     54.00
00.000  1000.000  1000.000  1000.000
50.000  1000.000  1000.000  1000.000
  .000      .000      .000      .000
70E+02   .570E+02  .570E+02  .570E+02  .570E+02
00E+00   .000E+00  .000E+00  .000E+00  .000E+00
70E+02   .570E+02  .570E+02  .570E+02  .000E+00
00E+00   .000E+00  .000E+00  .000E+00  .570E+02
70E+02   .570E+02  .570E+02  .570E+02  .000E+00
00E+00   .000E+00  .000E+00  .000E+00  .570E+02


 X          B(X) N          B(X) G

67.000   1.6091E-01   3.6768E-02
67.000   1.6091E-01   3.6768E-02
67.000   1.6091E-01   3.6768E-02
67.000   1.6091E-01   3.6768E-02
70.000   1.6101E-05   1.1394E-04

24.000   5.2716E-02   3.6255E-02
24.000   5.2716E-02   3.6255E-02
24.000   5.2716E-02   3.6255E-02
24.000   5.2716E-02   3.6255E-02
57.000   2.4154E-01   2.3344E-02

24.000   5.2716E-02   3.6255E-02
24.000   5.2716E-02   3.6255E-02
24.000   5.2716E-02   3.6255E-02
24.000   5.2716E-02   3.6255E-02
57.000   2.4154E-01   2.3344E-02

  .000   1.0000E+00   1.0000E-10
  .000   1.0000E+00   1.0000E-10
  .000   1.0000E+00   1.0000E-10
  .000   1.0000E+00   1.0000E-10
  .000   1.0000E+00   1.0000E-10

57.000   1.9843E-01   3.2164E-02
57.000   1.9843E-01   3.2164E-02
57.000   1.9843E-01   3.2164E-02
57.000   1.9843E-01   3.2164E-02
57.000   2.4154E-01   2.3344E-02

57.000   1.9843E-01   3.2164E-02
57.000   1.9843E-01   3.2164E-02
57.000   1.9843E-01   3.2164E-02
57.000   1.9843E-01   3.2164E-02
57.000   2.4154E-01   2.3344E-02
```

	RF- N	RF- G
567.	1.93E-02	3.76E-03
567.	1.23E-02	2.37E-03
567.	1.93E-02	3.76E-03
567.	1.23E-02	2.37E-03
5670.	2.17E-06	1.65E-05

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 87-3507	2. Performing Organ. Report No.	3. Publication Date FEBRUARY 1987

4. TITLE AND SUBTITLE

APPROXIMATE PROCEDURES FOR CALCULATING PROTECTION FROM INITIAL NUCLEAR RADIATION FROM WEAPONS

5. AUTHOR(S)

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

In this report we discuss procedures for routine evaluation of the protection of complex structures against the initial radiations from nuclear detonations. We describe procedures for evaluating and combining dose reduction factors for four radiation components: early fission product gamma rays, air secondary gamma rays generated by neutron interactions in the air, neutrons, and wall capture gamma rays generated by neutrons through interactions with nuclei in structural materials. We describe computer codes developed to evaluate reduction factors for each of these components. The radiation field in the vicinity of the structure was generated for a 30° elevation angle for the detonation, as well as a "ring source" averaging over the points of the compass. Comparisons are made with Monte Carlo calculations for a series of five benchmark structures.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

initial nuclear radiation; neutron transport; photon transport; protection factor; reduction factor; shielding

13. AVAILABILITY

☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

130

15. Price

$18.95

USCOMM-DC 6043-P80