CALCULATION OF ENERGY AND ANGULAR DISTRIBUTION OF WALL SINGLE SCATTERED GAMMA RADIATION FROM A SEMI-INFINITE ISOTROPIC PLANE SOURCE

by

JAMES MILTON ROYER

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Approved by

Richard E. Faw

Major Professor

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1.0 INTRODUCTION

The specific objective of this work was the calculation of the energy and angular distribution of gamma radiation scattering only once while penetrating a vertical slab bounded by a semi-infinite, horizontal, plane, monoenergetic radiation source.

All calculations were made for a point on the slab 3 ft above grade with air at 20 °C and 1 atm pressure. The test slab is a 4 inch concrete slab of mass thickness 48 psf. The results of the calculations were used in the analysis of experimental measurements of multiply scattered gamma radiation made at the Kansas State University Nuclear Engineering Shielding Facility (KSUNESF). The vertical slab was divided into many thin slabs and the continuous plane source was divided into many point sources. These approximations represent the numerical methods used to solve the integral equations describing the physical situation.

One of the problems associated with most experimental work in structure shielding is obtaining data for ground contamination extending over an infinite plane. The ideal method is to use experimental source configurations extending far enough from the structure to simulate the infinite field. This procedure is so prohibitively expensive and time consuming that an alternate method must be used.

Radiation penetrating the test slab may be divided into three components:

(a) Direct-beam, direct-barrier radiation, i.e., radiation not scattered in the air or in the barrier.

(b) Direct-beam, barrier-single scattered radiation.

(c) Multiply scattered radiation, i.e., the remainder after subtracting components (a) and (b) from the total.

Components (a) and (b) may be computed for finite as well as infinite source planes; therefore, the far-field corrections for these components are trivial. Component (c) for the experimental source areas may be determined by subtraction of computed components (a) and (b) from measured totals.

Estimation of the far-field contribution for component (c) is based on the following assumptions:

(1) At any selected angle, the energy spectrum for the far-field contribution is the same as the energy spectrum for the outermost experimental area.

(2) The ratio of the magnitude of the far-field contribution to the contribution from the outermost experimental area is the same as the ratio of the corresponding total theoretical exposure rates for wall-penetrating radiation for the two areas.

Data for the computation of theoretical total exposure rates for wall-penetrating radiation are obtained from a report by Burson*. The direct-beam, barrier-single-scattered radiation is the quantity calculated in this work.

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* Z. G. Burson, E.G.& G., LVO, Interoffice Memorandum, November 28, 1967.

2.0 THEORY

The geometry of the problem is shown in Figures 2-1, 2-2, and 2-3. Figure 2-1 is an isotropic view of a scattering event for a gamma ray originating in the source plane. Figure 2-2 is an enlargement of the center section of the slab as shown in Figure 2-1. Figure 2-3 is the same scattering event viewed in the scattering plane. The source plane is a semicircular area at grade extending from the face of the slab to a distance R (ft). The single scatter differential gamma-ray flux, Φ_d ($cm^{-2}sec^{-1}sr^{-1}$), emerging from the slab at a point 3 ft above grade at a given angle η, ξ is

$$\Phi_d(E,\eta,\xi)\ (cm^{-2}\ sec^{-1}\ sr^{-1}) = \frac{S_A}{4\pi}\int_0^R r\,dr \int_0^\pi d\nu \int_0^t dx\ m^{-2}\ \sec\eta$$

$$\times\ K(E_o,E,\psi)\ n\ \exp-\{\mu_a(E_o)[m-x\sec\eta_o] + \mu_c(E_o)\ x\sec\eta_o$$

$$+\ (t-x)\mu_c(E)\sec\eta\} \qquad (2\text{-}1)$$

where S_A = strength of plane source ($cm^{-2}sec^{-1}$)

E_o,η_o,ξ_o = incident gamma ray parameters, E_o specified (η_o,ξ_o functions of η,ξ,r,ν and x)

E,η,ξ = emergent gamma ray parameters, η,ξ specified

$E = E(E_o,\psi)$

$\psi = \psi(\eta_o,\xi_o,\eta,\xi)$

m = distance from source plane to scattering point, function of η,ξ,r,ν and x

ν = azimuthal angle in source plane

x = depth of penetration into slab (cm)

t = slab thickness (cm)

r = radius of source plane

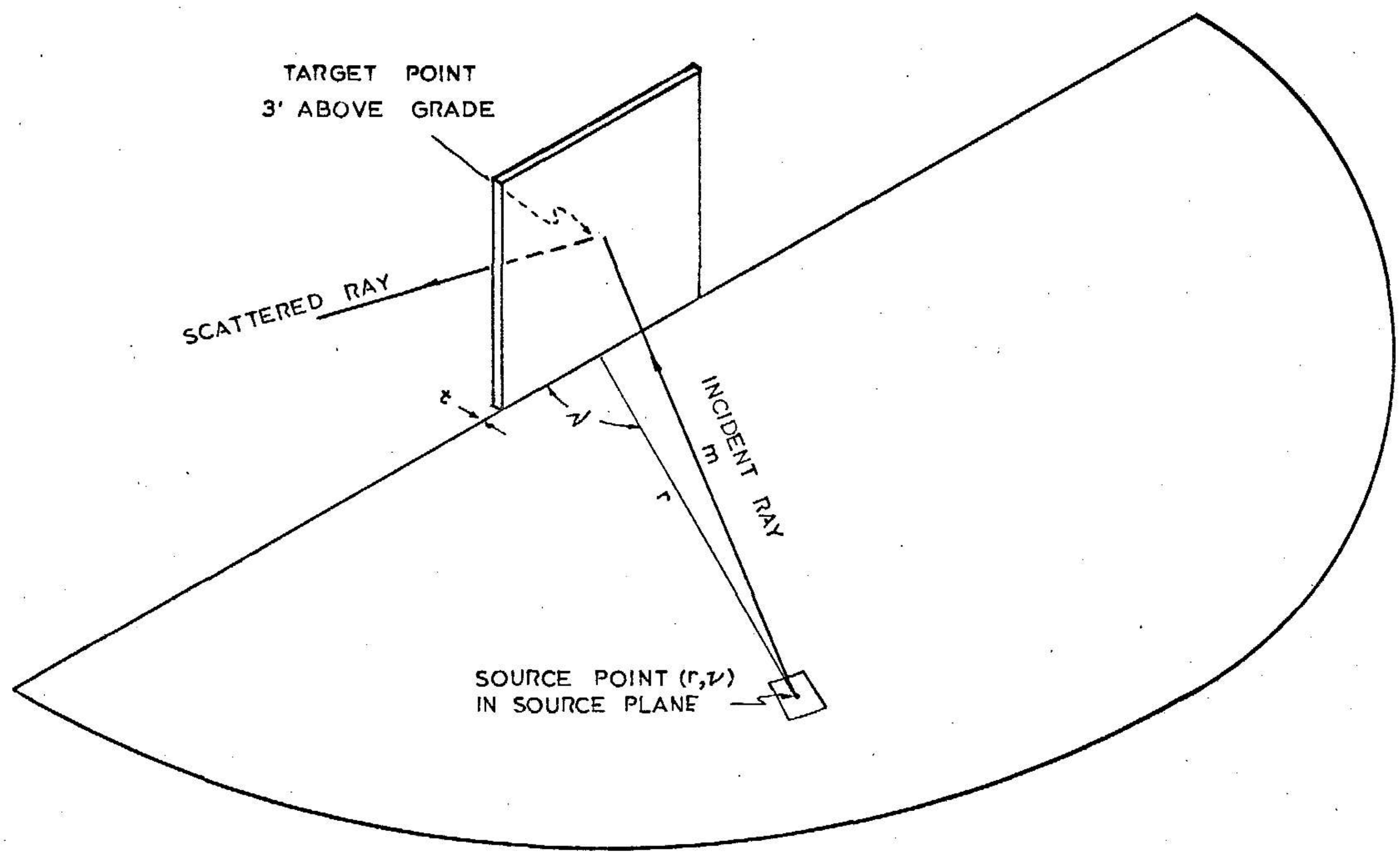

Figure 2-1 Isotropic view of a scattering event.

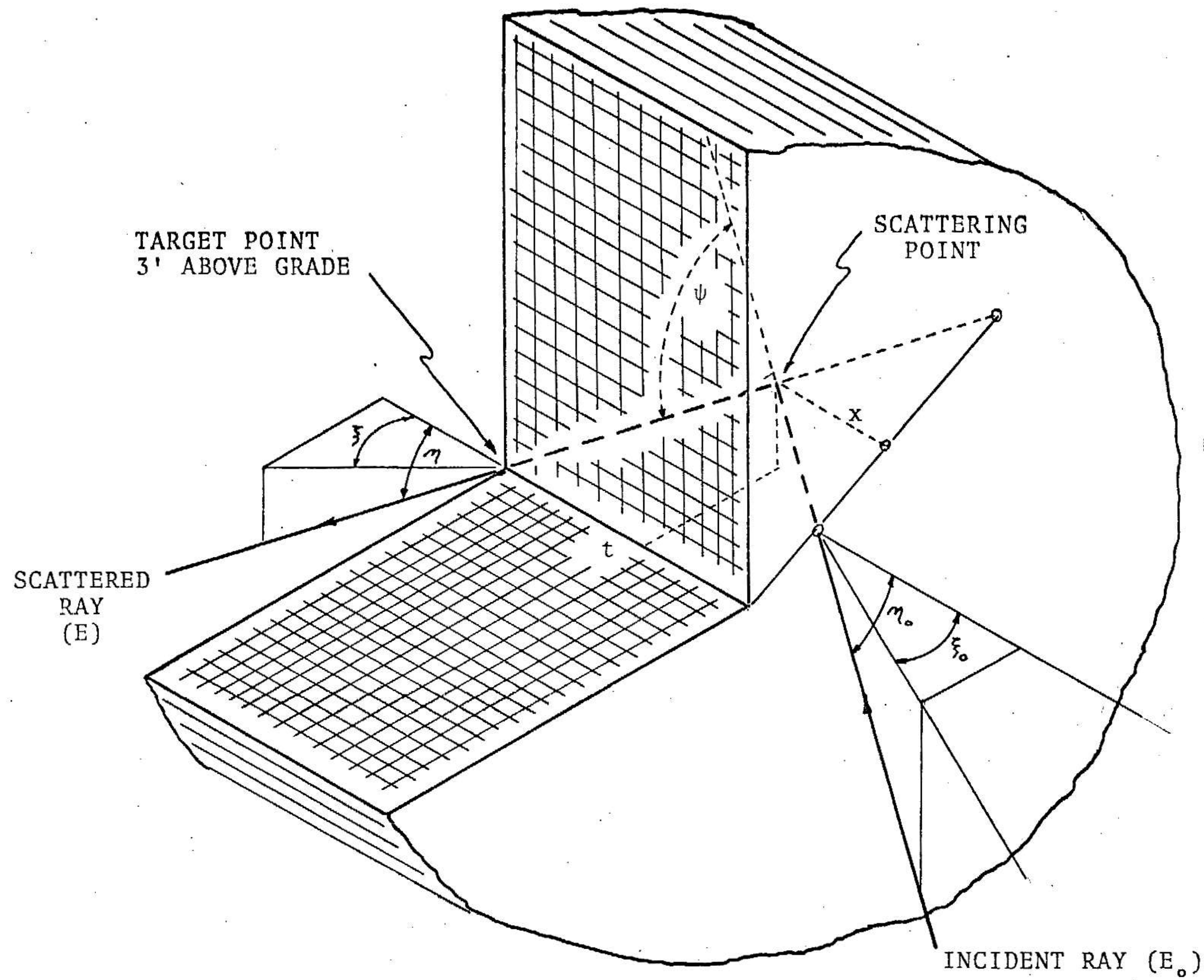

Figure 2-2 Enlargement of the center section of the wall showing a scattering event

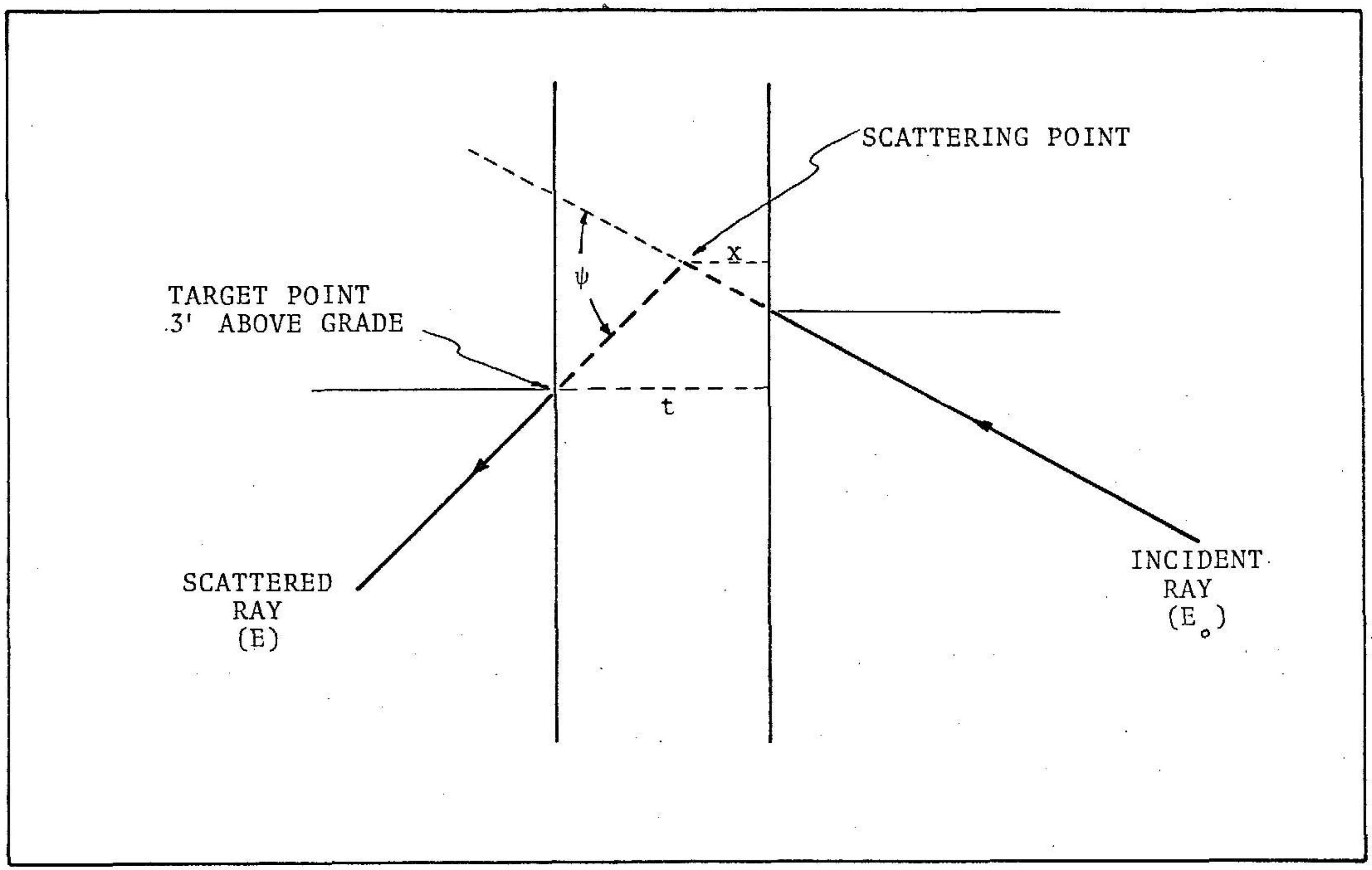

Figure 2-3 Scattering event shown in the scattering plane.

$K(E_o, E, \psi)$ = differential Compton scattering cross-section ($cm^2 sr^{-1}$)

n = electron density of slab (cm^{-3})

$\mu_a(E_o)$ = total attenuation coefficient for gamma rays of energy E_o in air (cm^{-1})

$\mu_c(E)$ = total attenuation coefficient for gamma rays of energy E in concrete. (cm^{-1})

Two assumptions were made to simplify equation 2-1.

1. The slab of thickness t was subdivided into many thin slabs each of thickness ℓ (cm), with the entire mass of each thin slab concentrated at its midpoint.

2. The plane source was divided into point sources of strength

$$S_o = S_A \, r \, \Delta r \, \Delta\nu$$

with the source located at $r + \Delta r/2$ and $\nu + \Delta\nu/2$.

Based on the first assumption, the scattering cross-section is constant for each thin slab and all scattering collisions occur at the mid-point. For the thin slab in which scattering occurs, the incident gamma ray will be attenuated by one half the thickness and the scattered gamma ray by the other half. The second assumption allows the integrals over r and ν, of the source plane, to be approximated by the summation of many point sources. The final approximate solution for the differential flux leaving the slab in the direction η and ξ is

$$\Phi_d(E,\eta,\xi) \; (cm^{-2} sec^{-1} sr^{-1}) \simeq \frac{S_A}{4\pi} \sum_{i=1}^{R/\Delta r} \sum_{j=1}^{\pi/\Delta\nu} \sum_{k=1}^{t/\ell} r_i \, \Delta r_i \, \Delta\nu_j$$

$$\times \, m_{i,j,k}^{-2} \sec\eta \; \ell \; K(E_o,E,\psi) \; n \; \exp -\{\mu_a(E_o)[m_{i,j,k} - \ell(i-1/2)$$

$$\times \sec\eta_o] + \ell(i-1/2) \, \mu_c(E_o) \sec\eta_o + [t - \ell(i-1/2)]\mu_c(E) \sec$$

(2-2)

where m, η_o and ξ_o now depend on the indices i, j and k as well as the emergent angles η and ξ.

The position of each incremental source area and the specified emergent angle will determine the scattering angle and thus the energy of the single scattered gamma-ray photons:

$$E = \frac{E_o}{1 + \alpha(1 - \cos\psi)}$$

where E = energy of scattered photon

E_o = initial energy of photon

$\alpha = E_o/mc^2$ = the ratio of the initial energy of the photon to the rest mass energy of an electron

ψ = scattering angle.

Keeping track of the magnitude of the gamma-ray differential flux associated with a given scattered photon energy, it was possible to compile an energy distribution of single scattered photons from a plane source.

3.0 CALCULATIONS

To illustrate the calculations, the test slab is treated as a single thin slab of infinitesimal linear thickness but of mass thickness equal to that of the actual test slab. The geometry is shown in Figure 3-1. Extension of the calculations to the representation of the test slab as a lamination of a number of thin slabs is discussed in Appendix C.

A point isotropic source is at grade level some distance from the "hot" side of a 6' x 6' test slab. In the experiment a detector was located on the "cold" side of the slab above, at, or below grade. The detector was collimated so that it views point 0 at the center of the "cold" side of the test slab, i.e., at H = 3 ft above the source plane. Although the presence of a detector is irrelevant in these calculations, a detector location is shown to facilitate identification of angles η and ξ. At point 0, radiation is incident on the slab at a polar angle, η_o, measured from the outward normal from the "hot" surface.

$$\cos\eta_o = x_s/[x_s^2 + y_s^2 + z_s^2]^{1/2} = [1 + H^2/r^2]^{-1/2}\sin\nu \qquad (3\text{-}1)$$

$$\xi_o = (\pi/2) - \nu \qquad (3\text{-}2)$$

The collimated detector views the slab at an angle, η, measured from the outward normal from the "cold" surface.

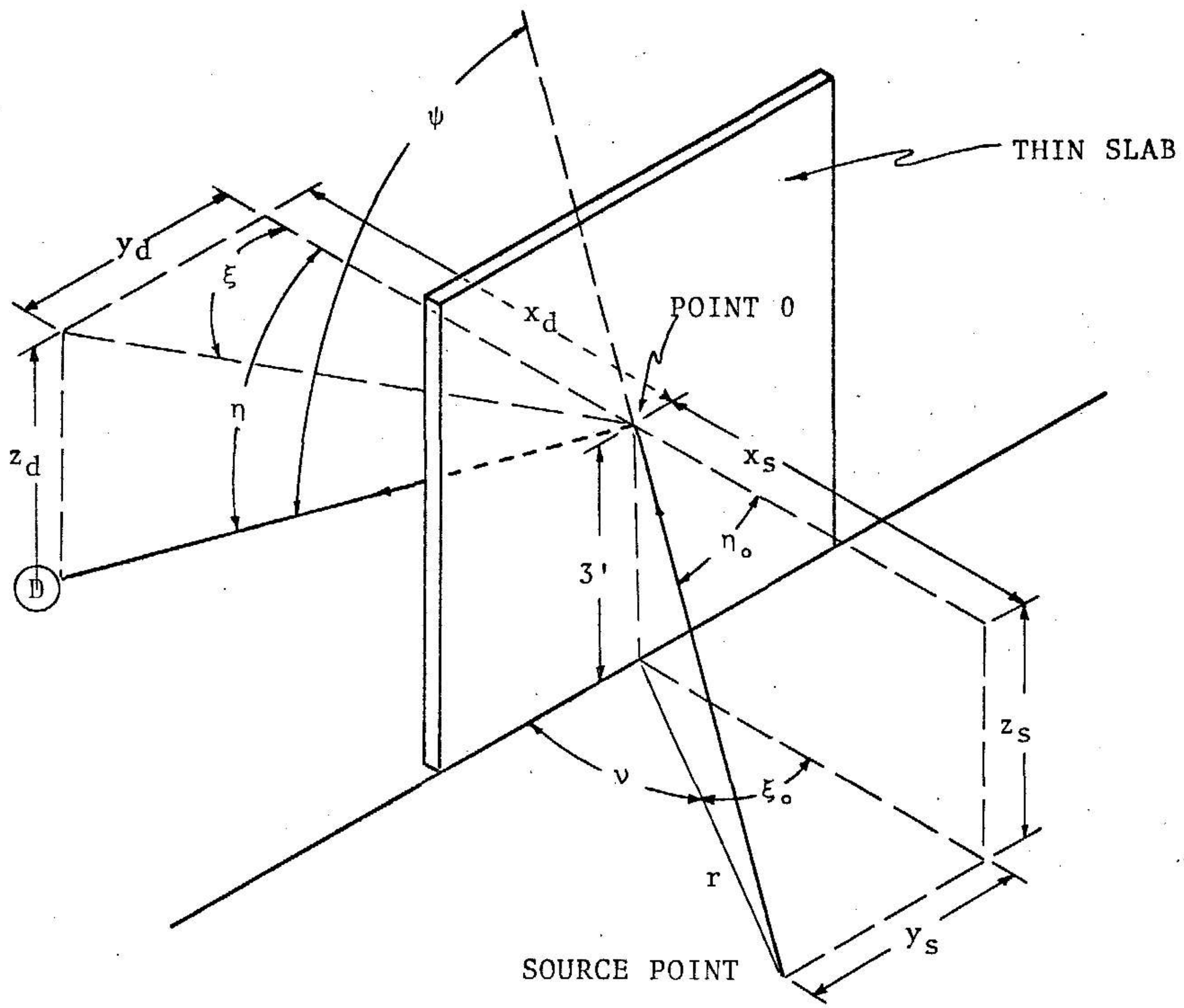

Figure 3-1 Geometry for thin slab calculations.

$$\cos\eta = x_d/[x_d^2 + y_d^2 + z_d^2]^{1/2} \quad (3\text{-}3)$$

$$\xi = \tan^{-1} y_d/x_d . \quad (3\text{-}4)$$

Knowing these geometrical properties, the scattering angle ψ can be calculated and thus the Klein-Nishina cross-section determined.

$$K(E_o,E,\psi) = \frac{r_o}{2}\left[\frac{1}{1 + \alpha(1 - \cos\psi)}\right]^2 \left[\frac{1 + \cos^2\psi}{2}\right] \times \left\{1 + \frac{\alpha^2(1 - \cos\psi)^2}{(1 + \cos^2\psi)[1 + \alpha(1 - \cos\psi)]}\right\} \quad (3\text{-}5)$$

where r_o = classical electron radius = 2.82×10^{-13} cm

$\alpha = E_o/(m_o c^2)$ = ratio of initial energy to rest mass energy of an electron

ψ = scattering angle

$$\cos\psi = \cos\eta \cos\eta_o\{1+\tan\xi_o \tan\xi\}\pm\{[1-(\cos\eta_o/\cos\xi_o)^2] \times [1-(\cos\eta/\cos\xi)^2]\}^{1/2}$$

The electron density of the slab is

$$n = N_a \sum_i (Z/A)_i \rho_i \quad (cm^{-3})$$

in which N_a is Avogadro's number, ρ_i is the partial density for component i and $(Z/A)_i$ is the ratio of atomic number to atomic weight for component i. The composition by weight fraction of the test slab used is:

Cement	0.150
Sand	0.535
Water	0.038
Rock	0.277

Using (Z/A) = 0.55 for water and 0.50 for other components, $n = 6.81\times10^{23}$ (cm^{-3}).

A computer program was used to calculate the flux as defined by equation 2-2. The number of summations over the source parameters, Δr_i and $\Delta \nu_j$, and the number of thin slabs used, t/ℓ_i, could be varied. The energy spectrum calculated was binned into 27 bins from 20 keV to 1425 keV such that it could be directly compared to the data from experiments at the KSUNESF. Exposure rates in (mR)(hr sr)$^{-1}$ were calculated by using the mid-point energy of each bin:

$$D = 0.0658 \sum_i \Phi_{di}\, E_i\, (\mu_{en}/\rho)_{air,i} \quad (mR)(hr\ sr)^{-1} \qquad (3\text{-}6)$$

where $(\mu_{en}/\rho)_{air}$ = mass energy absorption coefficient for air (cm^2/g)

E_i = mid-point energy of bin i (MeV)

Φ_{di} = magnitude of flux in bin i ($cm^{-2}sec^{-1}sr^{-1}$)

Table 3-1 is a list of the conversion factors used for each bin of the energy spectra.

$$C_i = 0.0685\, E_i\, (\mu_{en}/\rho)_{air,i} \quad (mR/hr)(cm^2\ sec) \qquad (3\text{-}7)$$

Point source calculations were made for a varying number of thin slabs. The results of the calculations are shown in Figure 3-2. All values of the differential flux increased by less than 0.5% when the number of thin slabs was increased from 5 to 20. Using five incremental slabs, point source calculations were made for the detector opposite the test point on the slab, i.e., the

TABLE 3-1

Bin No. (i)	Energy Limits (keV)	Exposure Rate Conversion Factor (C_i) (mR/hr) (cm^2 sec) × 10^7
1	20.00-30.85	8.371
2	30.85-42.59	4.683
3	42.59-55.44	3.446
4	55.44-69.53	3.132
5	69.53-85.04	3.274
6	85.04-102.20	3.844
7	102.20-121.27	4.818
8	121.27-142.85	5.719
9	142.85-167.10	7.046
10	167.10-194.63	8.541
11	194.63-225.87	10.304
12	225.87-260.16	12.280
13	260.16-299.10	14.503
14	299.10-343.37	16.981
15	343.37-391.79	19.653
16	391.79-446.58	22.602
17	446.58-507.84	25.943
18	507.84-575.74	29.403
19	575.74-646.91	32.884
20	646.91-723.74	36.540
21	723.74-806.91	40.342
22	806.91-897.16	44.324
23	897.16-994.93	48.483
24	994.93-1099.85	52.771
25	1099.85-1209.89	57.096
26	1209.89-1320.50	61.311
27	1320.50-1425 00	65.217

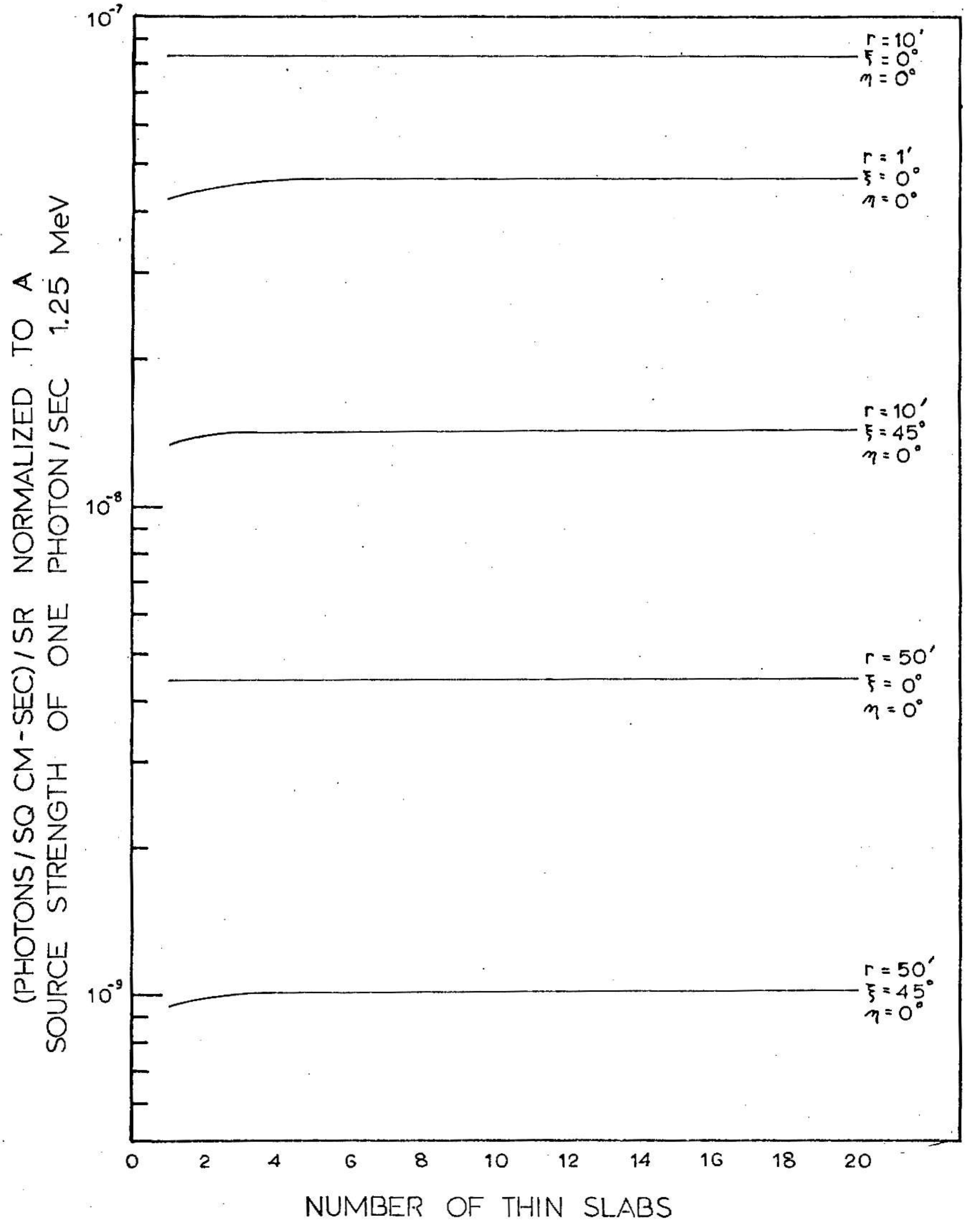

Figure 3-2 Variation of differential flux with number of thin slabs.

differential flux evaluated at $\eta = 0°$. The results were normalized to a unit point source of 1.25 MeV gamma rays, one photon per second. Source location was at grade. Two cases were considered: (1) the source on a line normal to the slab surface, and (2) the source on a line 45° from the vertical centerline of the slab. The results of these cases are reported in Figure 3-3. As the distance from the slab increases, the flux increases because the scattering angle decreases; on the other hand, geometric attenuation forces a decrease in the flux. Competition between these two effects accounts for the maxima in the curves. The scattering angle effect is also exhibited by the results for case (2) being substantially lower than the results for case (1).

For plane source calculations, the number of summations over r and ν of the source plane will affect the magnitude and energy distribution of the differential flux. The size of Δr, for small r (close to the slab), should be small to account for large changes in the scattering angle resulting from small changes in r. For large r, Δr can be large because geometric and air attenuation become predominant and vary only slightly for large changes in r. The size of $\Delta\nu$ was chosen to be independent of ν.

Calculations were made to observe the above effects for two different detector locations. The detector location is given by the parameters ϕ_d and θ_d shown in Figure 3-4. Tables 3-2, 3-3, and 3-4 give the energy distributions and associated exposure rates for a small circular annuli at r equal to 10, 50, and 1500 feet for a number of different $\Delta\nu$'s. Values of Δr were respectively 1, 1, and 100 ft. Five thin slabs were used in the calculations. Tables 3-5, 3-6, and 3-7 give the energy distributions and exposure rates for different Δr's at; 1) $r = 0$ ft $\rightarrow$ 10 ft, 2) $r = 50$ ft $\rightarrow$ 60 ft, and 3) $r = 1500$ ft $\rightarrow$ 1600 ft. A $\Delta\nu$ of 2° was used with five thin slabs for the calculations. For the calculations used to compare with experimental values a $\Delta\nu$ equal to 2° and the number of thin slabs equal to five were used. The values of Δr used are given below;

r (ft)	Δr (ft)
1→10	1
10→30	2
30→60	3
60→80	4
80→105	5
105→115	10
115→130	15
130→150	20
150→180	30
180→220	40
220→270	50
270→330	60
330→400	70
400→500	100
500→700	200
700→1000	300
1000→1400	400
1400→2000	600

To calculate the exposure rate for a semi-infinite plane source, it was necessary to determine a distance, R_N, from the wall beyond which the source made a negligible contribution to the total. The value of R_N was chosen as 2000 feet. It is shown in Appendix B that this value includes an estimated 99.98 percent of the exposure rate from a semi-infinite plane source.

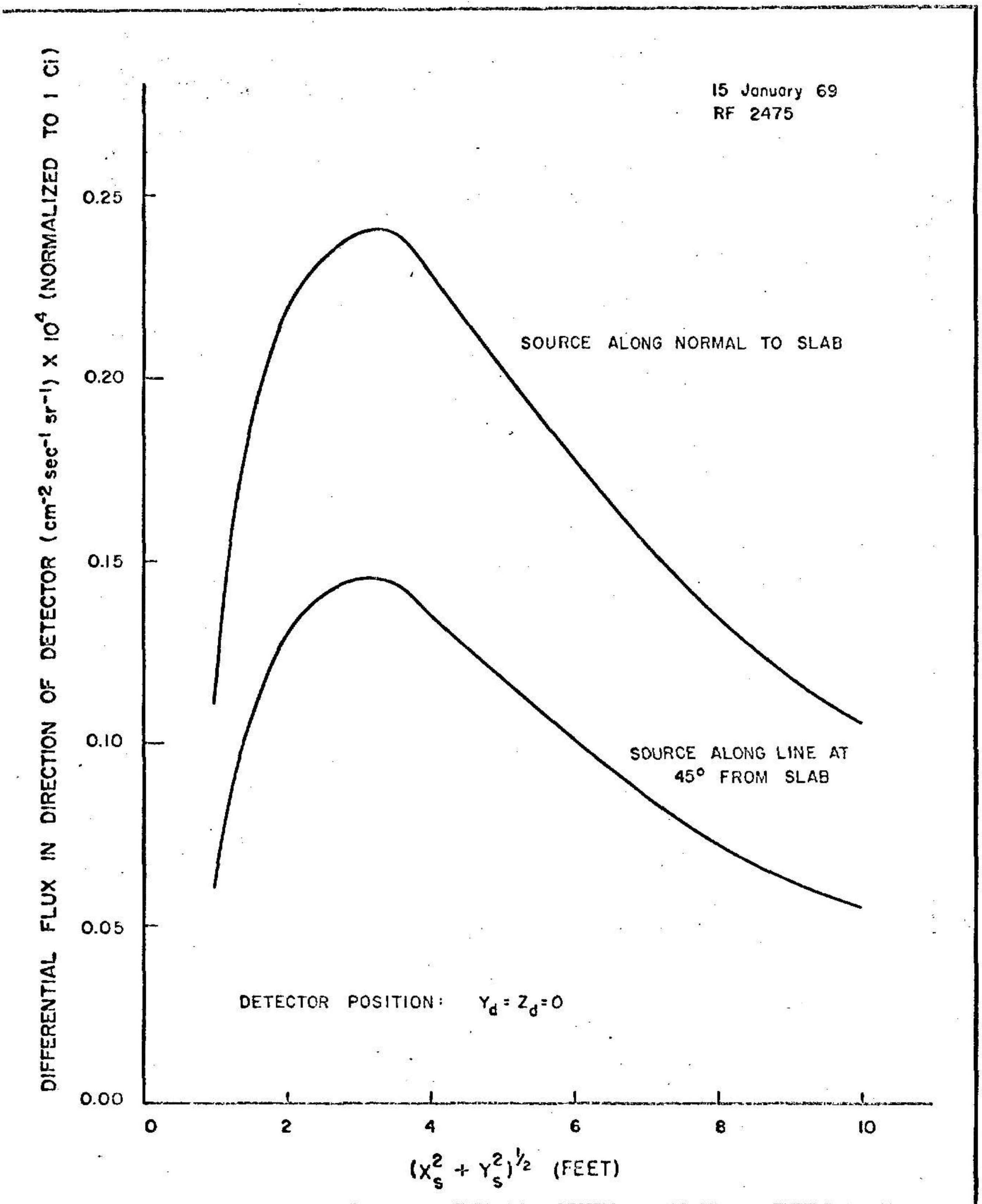

Figure 3-3 Differential flux as a function of distance of unit

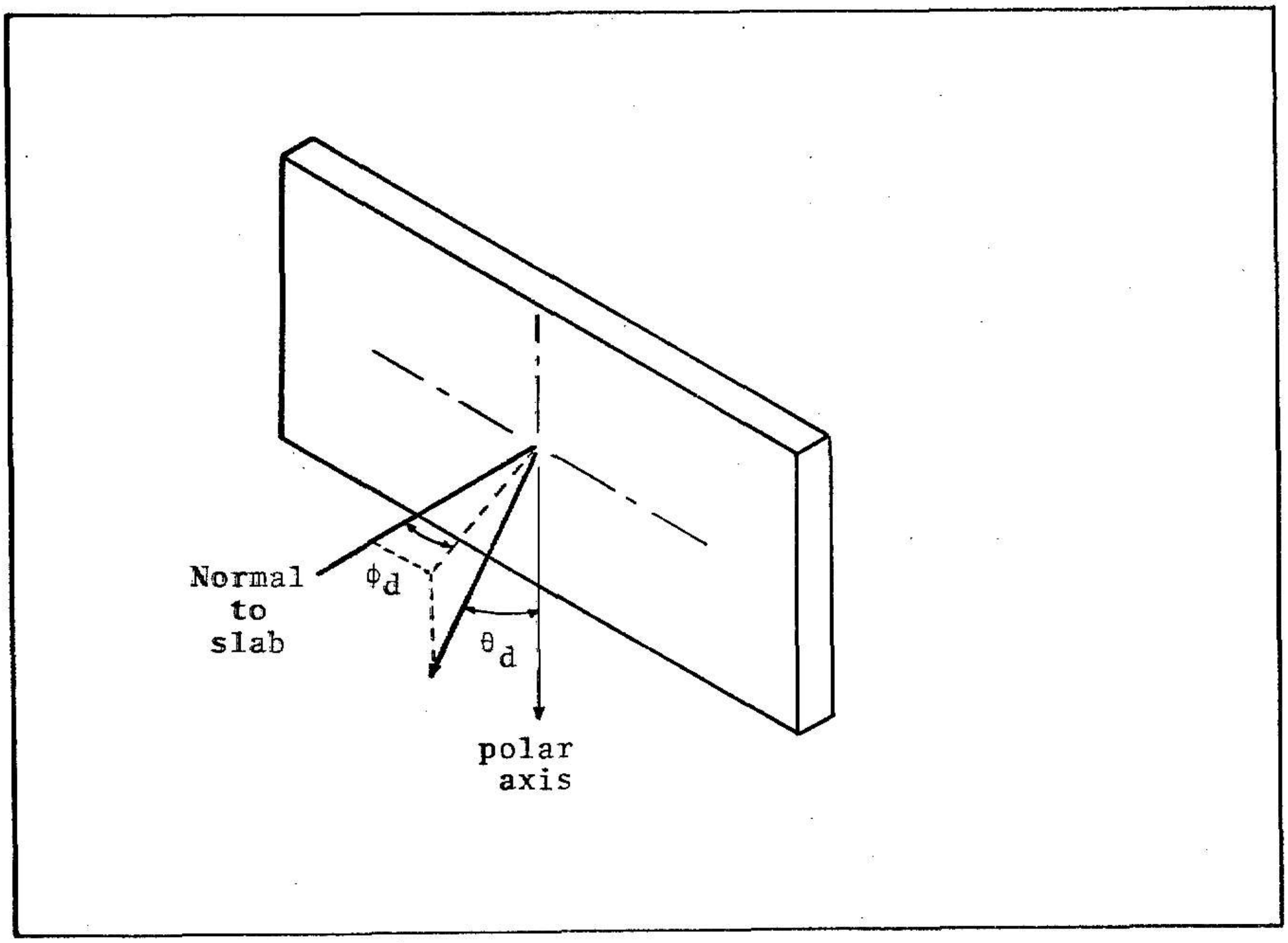

Figure 3-4 Detector position parameters.

Table 3-2 Variation of energy spectrum and total exposure rate with change in $\Delta\nu$'s of the source plane for a 1 ft wide annulus at the given r.

Binned Flux (Photons/sq cm -sec)/(keV-sr) Per Photon/(sq ft -sec)×10⁹ — Exposure Rate (mR/hr)/sr

$\Delta\nu$ \ #	15	16	17	18	19	20	21	22	23	24	25	26	Exposure Rate (mR/hr)/sr
30°	0.0	.3597	.0540	0.0	0.0	2.540	0.0	0.0	0.0	6.626	0.0	0.0	118.15
10°	.0233	.1199	.0180	.2875	.5293	.8468	0.0	1.188	1.689	2.209	2.546	0.0	120.87
5°	.0024	.0718	.2137	.2311	.4774	.3711	1.018	.6657	1.693	2.204	2.531	0.0	120.57
2°	.0063	.0810	.1741	.2868	.4290	.4805	.7215	.8670	1.301	2.181	2.896	0.0	121.57
1°	.0063	.0800	.1811	.2864	.4093	.5328	.6826	.9014	1.312	2.191	2.851	0.0	121.41
0.5°	.0064	.0784	.1810	.2905	.4062	.5331	.6715	.9269	1.279	2.208	2.852	0.0	121.43

$\cos\theta_d = 0.0$ $\phi_d = 0°$ $r = 10$ ft

$\Delta\nu$ \ #	13	14	15	16	17	18	19		
30°	0.0	0.0	.2483	0.0	1.257	2.046	0.0		16.84
10°	0.0	.0114	.2507	.3654	1.039	1.944	0.0		16.61
5°	0.0	.0132	.1953	.5194	1.015	1.879	0.0		16.53
2°	0.0	.0187	.2004	.5330	.9876	1.886	0.0		16.52
1°	0.0	.0172	.2017	.5185	1.013	1.875	0.0		16.52

$\cos\theta_d = 0.707$ $\phi_d = 0°$ $r = 10$ ft

Table 3-3 Variation of energy spectrum and total exposure rate with change in Δν's of the source plane for a 1 ft wide annulus at the given r.

Δν \ #	Binned Flux (Photons/sq cm -sec)/(keV-sr) Per Photon/(sq ft -sec)×10[10]: 15	16	17	18	19	20	21	22	23	24	25	26	Exposure Rate (mR/hr)/sr
30°	0.0	.8660	0.0	0.0	0.0	0.0	5.360	0.0	0.0	0.0	16.64	0.0	32.93
10°	0.048	0.289	0.0	0.612	1.166	0.0	1.787	2.831	0.0	3.956	5.546	6.689	32.99
5°	0.005	0.147	0.449	0.369	1.178	0.838	1.028	1.244	3.376	2.206	5.481	6.647	32.74
2°	0.013	0.174	0.358	0.618	0.703	0.927	1.204	2.164	2.119	3.207	6.167	5.376	32.49
1°	0.012	0.144	0.386	0.545	0.772	1.116	1.274	1.619	2.416	3.092	5.628	6.010	32.57

$\cos \theta_d = 0.0$ $\phi_d = 0°$ $r = 50$ ft

Δν \ #	15	16	17	18	19	20	21		
30°	0.0	0.562	0.0	3.359	0.0	6.172	0.0		6.59
10°	0.027	0.689	0.816	1.120	3.364	4.302	0.0		6.49
5°	0.031	0.398	1.084	1.839	2.678	4.292	0.0		6.46
2°	0.056	0.432	0.988	1.649	2.903	4.291	0.0		6.47
1°	0.056	0.432	0.953	1.635	2.972	4.267	0.0		6.47

$\cos \theta_d = 0.707$ $\phi_d = 0°$ $r = 50$ ft

Table 3-4 Variation of energy spectrum and total exposure rate with change in Δν's of the source plane for a 10 ft wide annulus at the given r.

Binned Flux (Photons/sq cm -sec)/(keV-sr) Per Photon/(sq ft -sec)×10^{12}

Δν \ #	15	16	17	18	19	20	21	22	23	24	25	26	Exposure Rate (mR/hr)/sr
30°	0.0	1.258	0.0	0.0	0.0	0.0	7.927	0.0	0.0	0.0	24.51	0.0	0.4852
10°	0.069	0.419	0.0	0.897	1.717	0.0	2.642	4.208	0.0	5.908	8.169	10.05	0.4909
5°	0.007	0.213	0.655	0.542	1.735	1.239	1.523	1.845	5.029	3.296	8.216	9.995	0.4899
2°	0.018	0.253	0.522	0.906	1.035	1.368	1.784	3.213	3.158	3.875	8.194	9.971	0.4891
1°	0.019	0.209	0.563	0.763	1.172	1.649	1.887	2.404	3.600	4.621	8.441	9.031	0.4873

$\cos\theta_d = 0.0$ $\phi_d = 0°$ r = 1500 ft

Δν \ #	15	16	17	18	19	20	21	22		
30°	0.0	0.866	0.0	5.457	0.0	1.049	0.0	0.0		0.1104
10°	0.041	0.289	0.703	2.995	2.444	1.026	0.0	0.0		0.1120
5°	0.048	0.297	1.280	2.486	2.445	8.301	1.793	0.0		0.1131
2°	0.026	0.433	1.054	2.180	3.426	8.151	1.435	0.0		0.1127
1°	0.038	0.424	1.181	2.066	3.133	8.217	1.625	0.0		0.1130

$\cos\theta_d = 0.707$ $\phi_d = 0°$ r = 1500ft

Table 3-5 Variation of energy spectrum and total exposure rate with change in Δr's of the source plane for a 10 ft wide annulus at the given r.

Binned Flux (Photons/sq cm -sec)/(keV-sr) Per Photon/(sq ft -sec)×10[8]; Exposure Rate (mR/hr)/sr

Δr \ #	14	15	16	17	18	19	20	21	22	23	24	25	Exposure Rate (mR/hr)/sr
10'	0.0	0.009	0.147	0.364	0.579	0.821	1.061	1.666	2.679	3.612	0.0	0.0	1072.45
5'	0.0	0.012	0.166	0.410	0.703	1.240	1.779	0.499	0.678	1.078	2.147	0.0	840.82
2'	0.0	0.013	0.178	0.458	0.436	0.657	1.034	1.170	1.066	1.505	1.412	0.364	844.71
1'	0.0	0.013	0.165	0.352	0.617	0.682	0.984	1.130	1.251	1.411	1.432	0.284	840.98

$\cos\theta_d = 0.0$ $\phi_d = 0°$ $r = 1$ ft → 10 ft $\Delta\nu = 2°$

Δr \ #	12	13	14	15	16	17	18		
10'	0.0	0.009	0.321	1.099	3.090	0.0	0.0		136.38
5'	0.0	0.146	1.133	0.542	0.492	1.374	0.0		113.02
2'	0.008	0.155	0.339	0.836	0.986	0.805	0.278		111.83
1'	0.009	0.150	0.443	0.750	0.893	0.901	0.268		112.12

$\cos\theta_d = 0.707$ $\phi_d = 0°$ $r = 1$ ft → 10 ft $\Delta\nu = 2°$

Table 3-6 Variation of energy spectrum and total exposure rate with change in Δr's of the source plane for a 10 ft wide annulus at the given r.

	Binned Flux (Photons/sq cm -sec)/(keV-sr) Per Photon/(sq ft -sec)×10^9												Exposure Rate (mR/hr)/sr
Δr \ #	15	16	17	18	19	20	21	22	23	24	25	26	
10'	0.012	0.158	0.326	0.562	0.639	0.844	1.097	1.971	1.931	2.551	5.960	4.904	296.40
5'	0.012	0.159	0.326	0.563	0.641	0.846	1.099	1.975	1.935	2.655	5.777	5.023	297.18
2'	0.012	0.159	0.326	0.564	0.641	0.846	1.099	1.976	1.936	2.644	5.796	5.024	297.37
1'	0.012	0.159	0.326	0.564	0.641	0.846	1.100	1.976	1.937	2.662	5.759	5.046	297.40

$\cos\theta_d = 0.0$ $\phi_d = 0°$ $r = 50$ ft → 60 ft $\Delta\nu = 2°$

Δr \ #	15	16	17	18	19	20	21		
10'	0.051	0.395	0.829	1.426	2.619	4.136	0.0		59.79
5'	0.051	0.395	0.822	1.467	2.663	4.078	0.0		59.83
2'	0.051	0.396	0.838	1.452	2.635	4.110	0.0		59.87
1'	0.051	0.396	0.824	1.463	2.638	4.108	0.0		59.88

$\cos\theta_d = 0.707$ $\phi_d = 0°$ $r = 50$ ft → 60 ft $\Delta\nu = 2°$

Table 3-7 Variation of energy spectrum and total exposure rate with caange in Δr's of the source plane for a 100 ft wide annulus at the given r.

Δr \ #	15	16	17	18	19	20	21	22	23	24	25	26	Exposure Rate (mR/hr)/sr
	Binned Flux (Photons/sq cm -sec)/(keV-sr) Per Photon/(sq ft -sec)×10[11]												
100'	0.016	0.223	0.461	0.799	0.912	1.206	1.572	2.833	2.783	3.417	7.224	8.790	4.312
50'	0.016	0.224	0.462	0.801	0.914	1.209	1.576	2.840	2.790	3.426	7.242	8.813	4.323
20'	0.016	0.224	0.462	0.801	0.915	1.210	1.577	2.842	2.793	3.427	7.246	8.817	4.325
10'	0.016	0.224	0.462	0.801	0.915	1.210	1.577	2.842	2.793	3.428	7.247	8.819	4.326

$\cos\theta_d = 0.0$ $\phi_d = 0°$ $r = 1500$ ft → 1600 ft $\Delta\nu = 2°$

Δr \ #	15	16	17	18	19	20	21		
100'	0.023	0.382	0.929	1.922	3.021	7.186	1.265		.9936
50'	0.023	0.383	0.931	1.927	3.028	7.204	1.268		.9962
20'	0.023	0.383	0.932	1.928	3.031	7.209	1.269		.9969
10'	0.023	0.383	0.932	1.928	3.031	7.209	1.269		.9969

$\cos\theta_d = 0.0$ $\phi_d = 0°$ $r = 1500$ ft → 1600 ft $\Delta\nu = 2°$

4.0 RESULTS

Point source calculations were made using the sum of a 1.17 MeV and 1.33 MeV gamma ray to simulate a ^{60}Co source. The same calculations were also made using an average value gamma ray of 1.25 MeV. The results of these calculations along with the experimental point source measurements are presented in Figure 4-1, 4-2, and 4-3. Also shown are the results of point source experimental measurements. The spectra are expressed as the double-differential flux, in units of ($cm^{-2}sec^{-1}sr^{-1}keV^{-1}$) normalized to a ^{60}Co source strength of one Curie. The measurements and calculations were made at a distance H = 3 ft above grade for a detector angular position of $\cos\theta_d = 0.742$ and $\phi_d = 0°$. The source was located at grade on a line perpendicular to the wall at distances of 3, 5, and 10 feet. The wall mass thickness was 48 psf. The calculated single scattered exposure rates are given in the following table.

Table 4-1 Calculated single scattered exposure rates for point sources.

Distance From Wall (ft)	Exposure Rate for Sum of 1.17 MeV and 1.33 MeV (mR/hr)/sr	Exposure Rate for 1.25 MeV (mR/hr)/sr
3	1.846	1.821
5	1.992	2.018
10	1.298	1.239

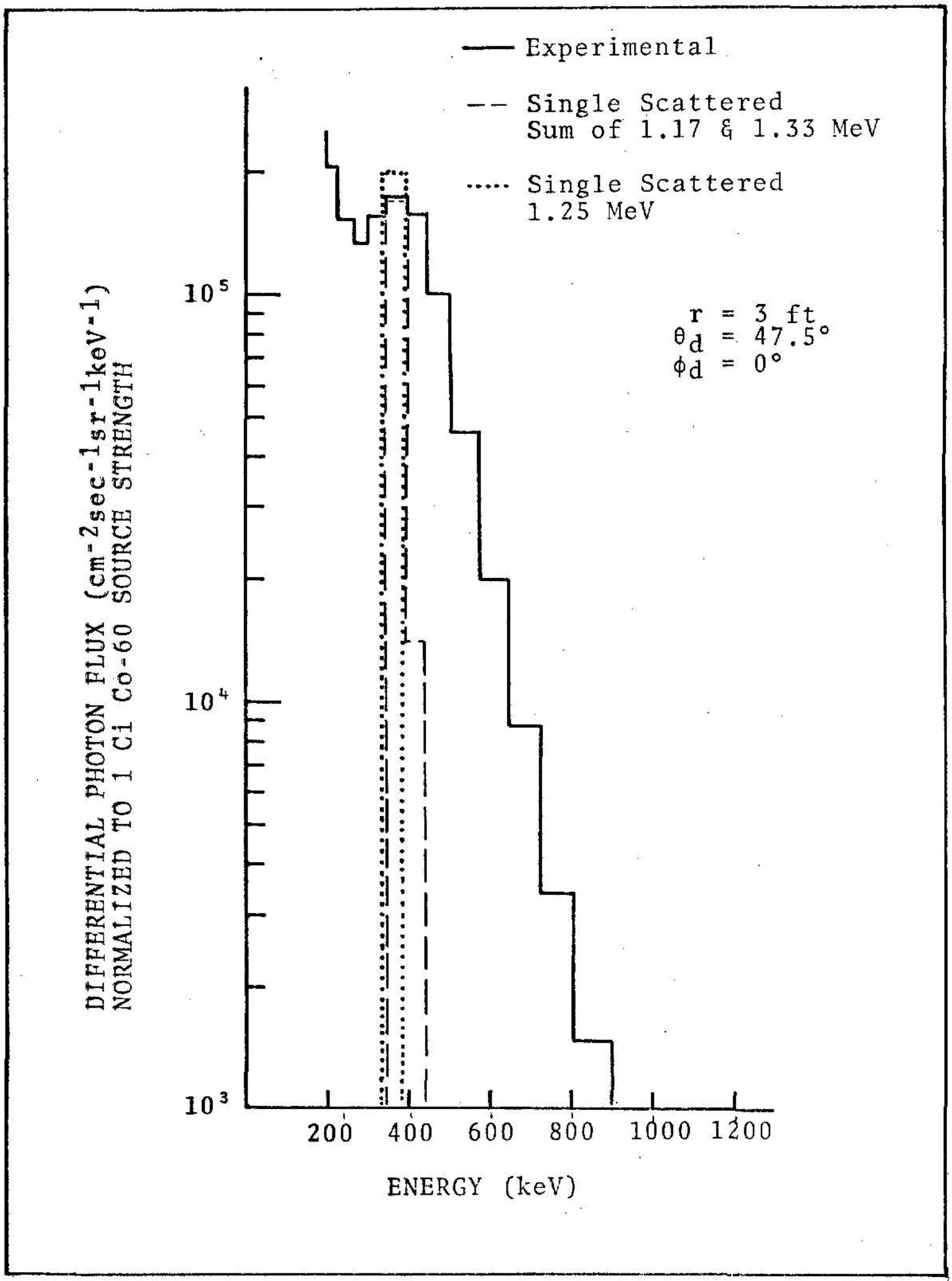

Figure 4-1 Comparison of calculated single scattered flux with measured flux for a point source.

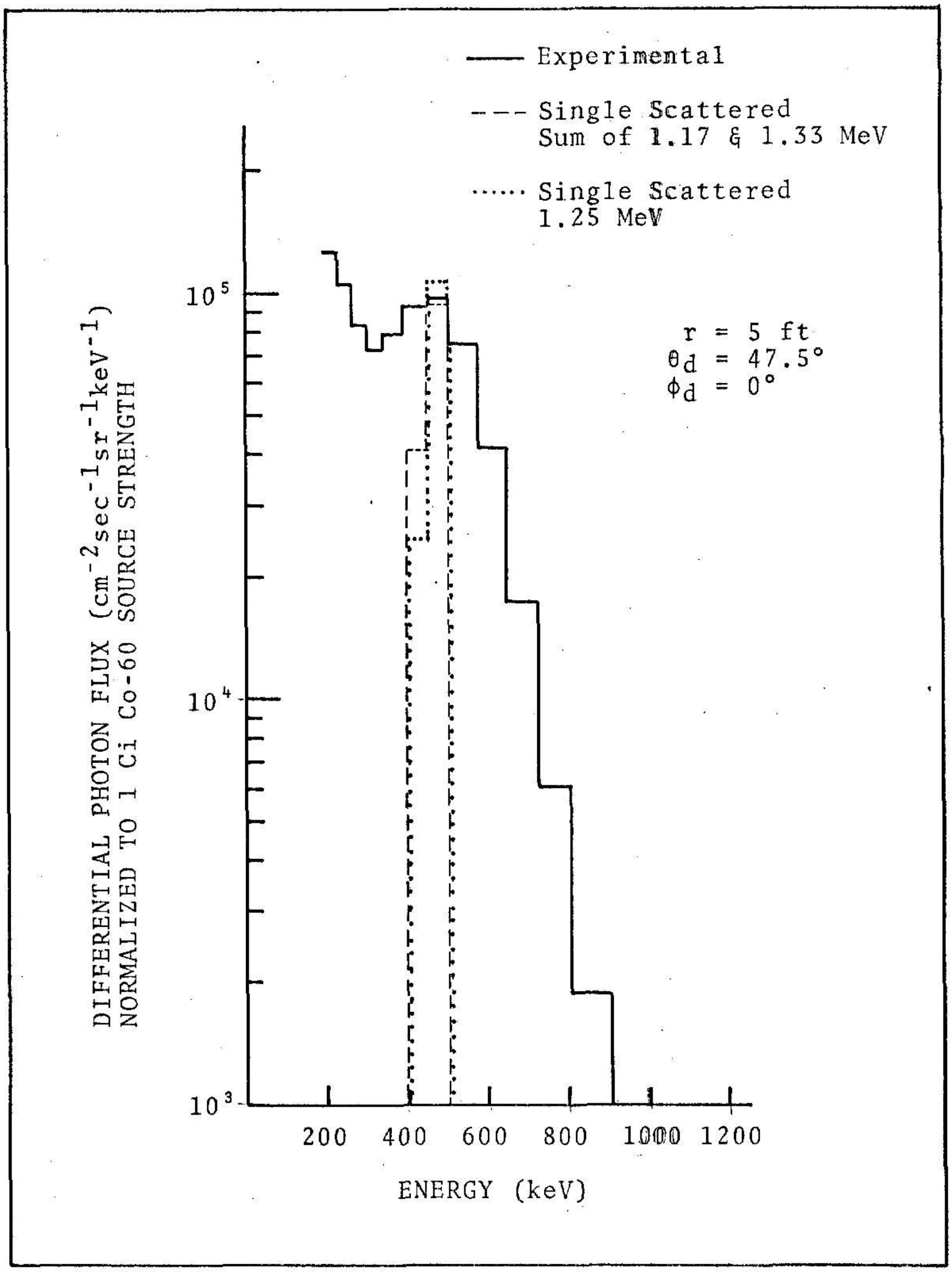

Figure 4-2 Comparison of calculated single scattered flux with measured flux for a point source.

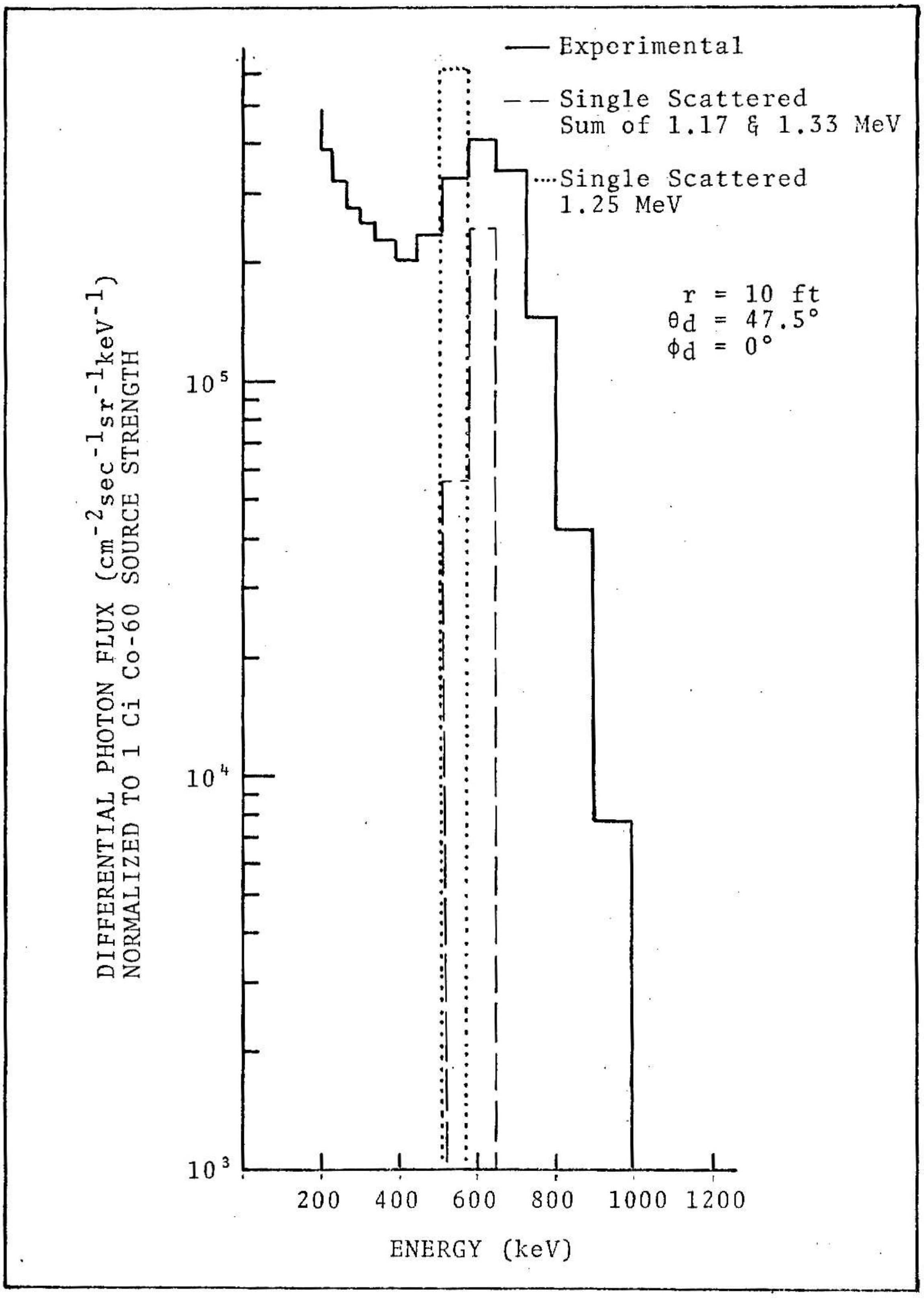

Figure 4-3 Comparison of calculated single scattered flux with measured flux for a point source.

Calculated energy spectra and exposure rates of wall single scattered gamma rays from a semi-infinite plane source are presented in Tables 4-2 through 4-42. A 1.25 MeV gamma ray was used. The detector positions were for $\cos\theta_d$ = ±.1, ±.2, ±.4, +.7, and -.48 at each azimuthal angle of ϕ_d = 0°, 10°, 20°, 35°, and 45°. The first two columns give the number of the energy bin and its size in keV. The next three columns give the energy spectra for source areas 1 and 2 and the far field (see Figure 4-4). The total spectrum is given in the last column. All spectra have the same units as for the point source spectra except they are normalized to a ^{60}Co source strength of 1 Ci/ft^2. The exposure rates in (mR/hr)/sr are listed in the last row. Figure 4-5 shows the single scattered exposure rates as a function of $\cos\theta_d$ for ϕ_d = 0°, 20°, 35°, and 45°.

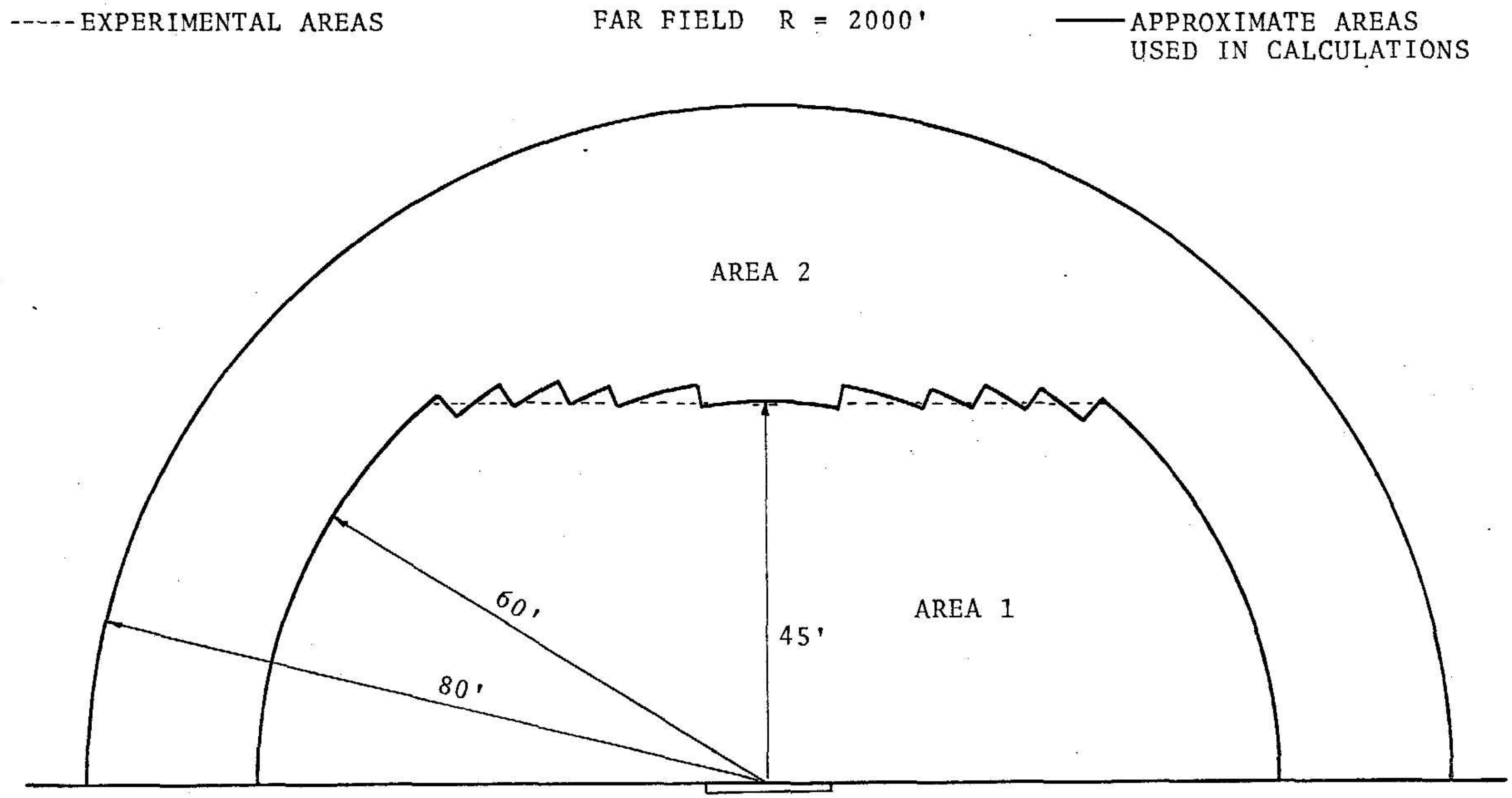

Figure 4-4 Approximate source areas used in calculations.

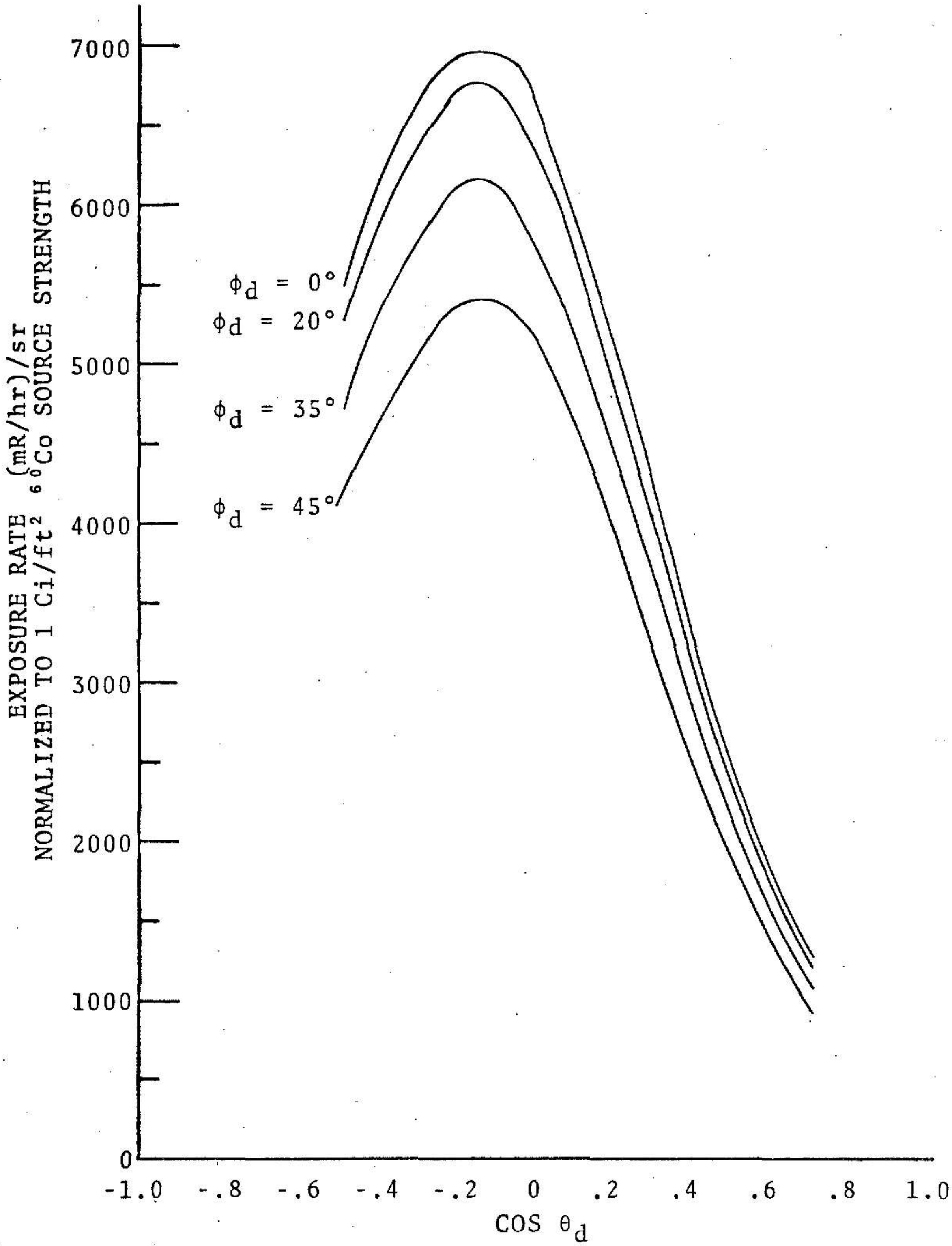

Figure 4-5 Wall single scattered Exposure Rate angular distributior

TABLE 4-2

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.70 PHI = 0 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	6.640	0.000	0.000	6.640
13	260.16- 299.10	103.852	0.000	0.000	103.852
14	299.10- 343.37	324.978	0.000	0.000	324.978
15	343.37- 391.79	654.408	6.616	15.361	676.385
16	391.79- 446.58	1089.496	39.797	169.088	1298.381
17	446.58- 507.84	1529.474	93.411	430.237	2053.122
18	507.84- 575.74	1859.973	170.646	754.376	2784.994
19	575.74- 646.91	2074.103	454.361	1231.083	3759.547
20	646.91- 723.74	756.393	900.972	2916.710	4574.074
21	723.74- 806.91	0.000	47.302	738.635	785.938
22	806.91- 897.16	0.000	0.000	0.000	0.000
23	897.16- 994.93	0.000	0.000	0.000	0.000
24	994.93-1099.85	0.000	0.000	0.000	0.000
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		554.583	152.738	569.827	1277.147

TABLE 4-3

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.40 PHI = 0 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	1.743	0.000	0.000	1.743
14	299.10- 343.37	60.040	0.000	0.000	60.040
15	343.37- 391.79	305.596	3.223	8.546	317.364
16	391.79- 446.58	584.088	21.998	96.524	702.609
17	446.58- 507.84	923.733	40.154	246.156	1210.042
18	507.84- 575.74	1226.158	85.999	375.341	1687.499
19	575.74- 646.91	1553.593	109.170	546.027	2208.789
20	646.91- 723.74	1817.631	154.804	739.203	2711.638
21	723.74- 806.91	2141.575	252.589	1011.575	3405.739
22	806.91- 897.16	2363.701	434.284	1403.964	4201.949
23	897.16- 994.93	1812.910	1246.158	2536.427	5595.492
24	994.93-1099.85	0.000	388.989	2723.140	3112.129
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		1402.375	413.971	1453.805	3270.152

TABLE 4-4

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.20 PHI = 0 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	4.468	0.000	0.000	4.468
15	343.37- 391.79	103.397	1.718	9.265	114.380
16	391.79- 446.58	418.187	17.848	96.267	532.301
17	446.58- 507.84	679.877	35.818	193.874	909.569
18	507.84- 575.74	1029.149	61.291	333.065	1423.506
19	575.74- 646.91	1290.720	98.039	535.343	1924.101
20	646.91- 723.74	1529.551	100.560	551.069	2181.180
21	723.74- 806.91	1892.852	198.510	725.041	2816.403
22	806.91- 897.16	2204.814	231.206	1220.173	3656.193
23	897.16- 994.93	2737.281	453.666	1234.903	4425.852
24	994.93-1099.85	3109.385	778.144	2302.664	6190.191
25	1099.85-1209.89	1251.937	1458.015	4629.047	7339.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2314.885	645.320	2120.812	5081.016

TABLE 4-5

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.10 PHI = 0 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.000	0.000	0.000	0.000
15	343.37- 391.79	57.516	1.760	9.459	68.736
16	391.79- 446.58	287.150	18.236	97.980	403.366
17	446.58- 507.84	640.657	36.619	197.282	874.559
18	507.84- 575.74	886.368	62.903	339.958	1289.229
19	575.74- 646.91	1191.165	71.299	386.455	1648.919
20	646.91- 723.74	1482.177	133.074	717.450	2332.701
21	723.74- 806.91	1774.656	144.517	742.385	2661.559
22	806.91- 897.16	2203.138	213.714	932.733	3349.584
23	897.16- 994.93	2605.904	327.278	1157.092	4090.274
24	994.93-1099.85	3202.474	613.916	1963.482	5779.871
25	1099.85-1209.89	3711.355	1643.666	3659.500	9014.520
26	1209.89-1320.50	0.000	447.286	2397.100	2844.385
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2819.556	734.404	2371.591	5925.551

TABLE 4-6

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = -0.10   PHI = 0   DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.000	0.000	0.000	0.000
15	343.37- 391.79	12.129	1.782	9.505	23.415
16	391.79- 446.58	170.593	18.386	98.476	287.455
17	446.58- 507.84	450.306	37.271	198.483	686.060
18	507.84- 575.74	724.519	64.080	342.428	1131.025
19	575.74- 646.91	1102.323	72.947	389.933	1565.203
20	646.91- 723.74	1246.023	96.234	514.584	1856.841
21	723.74- 806.91	1662.702	125.125	876.254	2664.081
22	806.91- 897.16	2092.798	263.852	1010.337	3366.988
23	897.16- 994.93	2784.833	333.250	1176.349	4294.430
24	994.93-1099.85	2978.424	484.718	2001.470	5464.613
25	1099.85-1209.89	4768.691	1115.327	3207.713	9091.727
26	1209.89-1320.50	3174.913	1280.142	2979.577	7434.629
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3729.867	794.889	2429.881	6954.633

TABLE 4-7

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.20 PHI = 0 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.000	0.000	0.000	0.000
15	343.37- 391.79	5.371	1.760	9.354	16.485
16	391.79- 446.58	120.727	18.054	97.242	236.023
17	446.58- 507.84	395.132	37.179	196.253	628.563
18	507.84- 575.74	636.240	63.567	337.844	1037.651
19	575.74- 646.91	1004.495	72.097	453.186	1529.778
20	646.91- 723.74	1311.220	130.731	647.748	2089.699
21	723.74- 806.91	1715.292	148.868	722.721	2586.881
22	806.91- 897.16	2114.782	215.308	907.652	3237.742
23	897.16- 994.93	2502.752	319.508	1560.972	4383.230
24	994.93-1099.85	3484.549	621.752	2025.390	6131.691
25	1099.85-1209.89	5359.801	1637.732	5213.613	12211.140
26	1209.89-1320.50	3517.611	469.177	0.000	3986.787
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3995.659	739.296	2211.521	6946.473

TABLE 4-8

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.40 PHI = 0 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.000	0.000	0.000	0.000
15	343.37- 391.79	2.722	1.637	8.630	12.989
16	391.79- 446.58	87.363	17.311	91.193	195.868
17	446.58- 507.84	289.855	38.010	254.915	582.781
18	507.84- 575.74	587.860	78.264	362.200	1028.324
19	575.74- 646.91	897.256	96.393	558.433	1552.082
20	646.91- 723.74	1303.265	115.584	743.197	2162.046
21	723.74- 806.91	1713.186	211.061	958.812	2883.059
22	806.91- 897.16	2276.157	347.162	1356.117	3979.436
23	897.16- 994.93	2899.635	606.771	2186.095	5692.500
24	994.93-1099.85	4856.910	1600.038	3579.255	10036.190
25	1099.85-1209.89	5856.617	0.000	0.000	5856.617
26	1209.89-1320.50	1651.692	0.000	0.000	1651.692
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3995.804	526.421	1565.034	6087.254

TABLE 4-9

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.48 PHI = 0 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.000	0.000	0.000	0.000
15	343.37- 391.79	2.215	1.548	8.138	11.901
16	391.79- 446.58	80.407	16.582	109.069	206.058
17	446.58- 507.84	280.367	46.769	251.589	578.725
18	507.84- 575.74	575.857	69.039	437.469	1082.365
19	575.74- 646.91	943.906	116.221	584.997	1645.123
20	646.91- 723.74	1315.288	150.534	820.239	2286.061
21	723.74- 806.91	1760.852	263.130	1175.129	3199.112
22	806.91- 897.16	2488.555	440.364	1740.747	4669.664
23	897.16- 994.93	3497.285	1225.735	4067.730	8790.750
24	994.93-1099.85	5394.652	468.205	0.000	5862.855
25	1099.85-1209.89	4234.363	0.000	0.000	4234.363
26	1209.89-1320.50	1317.245	0.000	0.000	1317.245
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3796.157	431.135	1270.250	5497.539

TABLE 4-10

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.70 PHI = 10 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	7.391	0.000	0.000	7.391
13	260.16- 299.10	113.119	0.000	0.000	113.119
14	299.10- 343.37	353.922	0.451	0.916	355.289
15	343.37- 391.79	700.212	10.968	50.644	761.824
16	391.79- 446.58	1070.851	41.856	196.292	1308.999
17	446.58- 507.84	1477.400	81.850	417.636	1976.886
18	507.84- 575.74	1815.403	170.319	730.612	2716.333
19	575.74- 646.91	2031.452	361.206	1205.574	3598.233
20	646.91- 723.74	771.417	1014.190	2874.947	4660.555
21	723.74- 806.91	0.000	0.000	728.644	728.644
22	806.91- 897.16	0.000	0.000	0.000	0.000
23	897.16- 994.93	0.000	0.000	0.000	0.000
24	994.93-1099.85	0.000	0.000	0.000	0.000
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		548.042	150.823	562.325	1261.189

TABLE 4-11

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR
A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = 0.40   PHI = 10   DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	4.198	0.000	0.000	4.198
14	299.10- 343.37	91.700	0.690	2.166	94.556
15	343.37- 391.79	362.482	9.826	42.289	414.597
16	391.79- 446.58	598.514	26.456	121.719	746.689
17	446.58- 507.84	904.960	40.014	246.674	1191.647
18	507.84- 575.74	1204.075	82.733	363.222	1650.031
19	575.74- 646.91	1515.356	112.279	529.383	2157.017
20	646.91- 723.74	1738.833	171.921	721.671	2632.425
21	723.74- 806.91	2091.561	259.095	994.484	3345.140
22	806.91- 897.16	2393.996	414.140	1387.021	4195.156
23	897.16- 994.93	1824.237	1197.948	2510.724	5532.906
24	994.93-1099.85	0.000	383.784	2704.831	3088.615
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		1392.275	404.865	1439.708	3236.849

TABLE 4-12

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.20 PHI = 10 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	23.560	0.750	4.041	28.351
15	343.37- 391.79	179.429	7.972	42.974	230.375
16	391.79- 446.58	429.314	22.269	120.411	571.994
17	446.58- 507.84	679.888	36.238	195.220	911.346
18	507.84- 575.74	1024.153	58.966	321.894	1405.013
19	575.74- 646.91	1213.729	94.886	518.323	1826.937
20	646.91- 723.74	1495.577	108.492	537.214	2141.283
21	723.74- 806.91	1876.779	219.632	712.417	2808.828
22	806.91- 897.16	2175.168	235.411	1200.725	3611.304
23	897.16- 994.93	2663.162	448.695	1222.783	4334.641
24	994.93-1099.85	3167.472	753.718	2277.352	6198.543
25	1099.85-1209.89	1261.458	1395.167	4608.125	7264.750
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2303.093	629.361	2103.410	5035.863

TABLE 4-13

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = 0.10   PHI = 10 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	8.639	0.766	4.119	13.525
15	343.37- 391.79	141.012	8.117	43.616	192.745
16	391.79- 446.58	328.697	22.631	121.928	473.256
17	446.58- 507.84	635.324	36.746	198.385	870.455
18	507.84- 575.74	817.042	60.742	328.551	1206.334
19	575.74- 646.91	1207.955	68.945	373.852	1650.752
20	646.91- 723.74	1488.525	140.593	700.908	2330.025
21	723.74- 806.91	1694.951	160.861	726.299	2582.112
22	806.91- 897.16	2080.115	221.401	918.825	3220.341
23	897.16- 994.93	2578.381	338.937	1143.811	4061.129
24	994.93-1099.85	3228.549	574.913	1946.803	5750.266
25	1099.85-1209.89	3768.263	1578.492	3637.144	8983.895
26	1209.89-1320.50	0.000	441.617	2384.752	2826.369
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2807.293	716.414	2352.848	5876.555

TABLE 4-14

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.10 PHI = 10 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	2.560	0.773	4.134	7.467
15	343.37- 391.79	67.867	8.203	43.795	119.864
16	391.79- 446.58	214.351	22.819	122.500	359.669
17	446.58- 507.84	438.489	37.387	199.566	675.442
18	507.84- 575.74	764.487	61.878	330.934	1157.298
19	575.74- 646.91	992.570	70.543	377.220	1440.333
20	646.91- 723.74	1187.163	100.797	500.797	1788.757
21	723.74- 806.91	1657.054	144.800	862.652	2664.506
22	806.91- 897.16	2148.395	277.144	991.327	3416.866
23	897.16- 994.93	2583.828	333.290	1162.898	4080.017
24	994.93-1099.85	3131.044	463.479	1982.591	5577.113
25	1099.85-1209.89	4645.922	1114.665	3189.679	8950.262
26	1209.89-1320.50	3252.160	1192.610	2964.115	7408.883
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3715.114	773.979	2410.724	6899.816

TABLE 4-15

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.20 PHI = 10 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.528	0.318	4.061	4.907
15	343.37- 391.79	56.178	8.549	43.339	108.066
16	391.79- 446.58	177.213	22.442	121.539	321.193
17	446.58- 507.84	399.120	37.432	197.561	634.113
18	507.84- 575.74	651.957	61.384	326.515	1039.855
19	575.74- 646.91	967.809	69.706	439.582	1477.096
20	646.91- 723.74	1245.025	137.476	630.223	2012.724
21	723.74- 806.91	1557.266	166.383	708.572	2432.220
22	806.91- 897.16	2014.714	223.275	893.899	3131.888
23	897.16- 994.93	2729.746	328.369	1541.172	4599.285
24	994.93-1099.85	3312.777	580.915	2011.108	5904.801
25	1099.85-1209.89	5277.305	1611.424	5183.121	12071.830
26	1209.89-1320.50	3658.469	426.689	0.000	4085.158
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3978.240	720.380	2193.395	6892.016

TABLE 4-16

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.40 PHI = 10 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.193	0.237	1.741	2.170
15	343.37- 391.79	37.441	8.191	42.853	88.486
16	391.79- 446.58	143.699	22.031	116.561	282.291
17	446.58- 507.84	314.486	38.540	255.560	608.586
18	507.84- 575.74	580.677	75.298	349.310	1005.284
19	575.74- 646.91	906.198	93.734	541.106	1541.038
20	646.91- 723.74	1207.760	130.873	726.313	2064.946
21	723.74- 806.91	1701.239	230.891	943.570	2875.700
22	806.91- 897.16	2160.810	345.204	1336.572	3842.586
23	897.16- 994.93	2974.186	576.613	2166.809	5717.605
24	994.93-1099.85	4853.582	1543.652	3552.791	9950.023
25	1099.85-1209.89	5629.465	0.000	0.000	5629.465
26	1209.89-1320.50	1784.974	0.000	0.000	1784.974
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3966.669	513.719	1550.107	6030.492

TABLE 4-17

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = -0.48   PHI = 10 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	0.136	0.224	1.181	1.540
15	343.37- 391.79	32.025	7.882	41.538	81.445
16	391.79- 446.58	133.896	21.434	136.591	291.922
17	446.58- 507.84	324.459	46.888	250.685	622.032
18	507.84- 575.74	567.465	67.170	422.169	1056.804
19	575.74- 646.91	894.397	115.647	567.320	1577.363
20	646.91- 723.74	1278.990	169.847	802.338	2251.175
21	723.74- 806.91	1711.544	268.316	1154.442	3134.303
22	806.91- 897.16	2482.875	439.682	1723.116	4645.672
23	897.16- 994.93	3398.163	1203.924	4032.139	8634.223
24	994.93-1099.85	5531.750	419.503	0.000	5951.250
25	1099.85-1209.89	4142.008	0.000	0.000	4142.008
26	1209.89-1320.50	1251.583	0.000	0.000	1251.583
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3760.364	420.449	1257.089	5437.902

TABLE 4-18

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET　　　　BARRIER THICKNESS = 48 PSF

COS THETA = 0.70　　PHI = 20　DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	11.500	0.000	0.000	11.500
13	260.16- 299.10	151.442	0.000	0.000	151.442
14	299.10- 343.37	437.865	5.180	19.749	462.794
15	343.37- 391.79	781.802	25.995	129.809	937.606
16	391.79- 446.58	1045.166	52.846	263.101	1361.114
17	446.58- 507.84	1348.126	89.274	401.741	1839.140
18	507.84- 575.74	1658.400	194.909	666.232	2519.541
19	575.74- 646.91	1893.626	371.645	1121.978	3387.249
20	646.91- 723.74	826.931	884.851	2746.343	4458.125
21	723.74- 806.91	0.000	0.000	699.148	699.148
22	806.91- 897.16	0.000	0.000	0.000	0.000
23	897.16- 994.93	0.000	0.000	0.000	0.000
24	994.93-1099.85	0.000	0.000	0.000	0.000
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		528.105	142.029	539.560	1209.694

TABLE 4-19

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = 0.40   PHI = 20 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	21.469	0.014	0.017	21.500
14	299.10- 343.37	198.860	7.148	30.940	236.948
15	343.37- 391.79	481.040	22.562	108.387	611.988
16	391.79- 446.58	637.881	37.915	185.549	861.345
17	446.58- 507.84	851.822	41.493	260.517	1153.831
18	507.84- 575.74	1122.434	83.795	338.421	1544.651
19	575.74- 646.91	1381.446	127.538	484.480	1993.464
20	646.91- 723.74	1626.996	196.027	670.160	2493.183
21	723.74- 806.91	1977.020	269.456	940.616	3187.093
22	806.91- 897.16	2304.507	410.375	1330.222	4045.104
23	897.16- 994.93	1917.999	1019.464	2433.638	5371.102
24	994.93-1099.85	0.000	373.375	2640.743	3014.118
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		1359.122	378.282	1395.378	3132.782

TABLE 4-20

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.20 PHI = 20 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	2.301	0.015	0.081	2.397
14	299.10- 343.37	114.848	7.588	40.880	163.316
15	343.37- 391.79	305.956	19.271	104.138	429.365
16	391.79- 446.58	514.984	33.691	182.730	731.405
17	446.58- 507.84	657.017	39.478	209.661	906.156
18	507.84- 575.74	950.080	58.249	302.887	1311.215
19	575.74- 646.91	1123.914	104.996	474.045	1702.955
20	646.91- 723.74	1394.458	124.818	496.535	2015.811
21	723.74- 806.91	1718.531	243.711	673.411	2635.652
22	806.91- 897.16	2093.357	244.234	1140.325	3477.917
23	897.16- 994.93	2603.442	446.953	1181.688	4232.082
24	994.93-1099.85	3080.272	686.306	2217.746	5984.324
25	1099.85-1209.89	1404.381	1220.763	4513.891	7139.031
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2263.198	584.071	2047.277	4894.547

TABLE 4-21

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = 0.10   PHI = 20   DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.168	0.016	0.082	0.266
14	299.10- 343.37	81.711	7.717	41.475	130.903
15	343.37- 391.79	277.399	19.509	105.122	402.031
16	391.79- 446.58	416.818	34.122	184.437	635.377
17	446.58- 507.84	651.957	39.197	212.402	903.554
18	507.84- 575.74	770.505	59.571	308.874	1138.949
19	575.74- 646.91	1096.816	77.524	341.792	1516.131
20	646.91- 723.74	1336.860	158.788	647.757	2143.404
21	723.74- 806.91	1580.259	183.393	681.729	2445.381
22	806.91- 897.16	1994.003	237.283	874.741	3106.026
23	897.16- 994.93	2477.890	360.270	1100.799	3938.959
24	994.93-1099.85	3149.694	542.762	1891.794	5584.250
25	1099.85-1209.89	3897.866	1338.230	3556.598	8792.691
26	1209.89-1320.50	0.000	427.077	2347.449	2774.526
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2760.978	664.445	2292.691	5718.113

TABLE 4-22

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.10 PHI = 20 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.054	0.016	0.083	0.152
14	299.10- 343.37	51.613	7.765	41.604	100.983
15	343.37- 391.79	186.753	19.708	105.513	311.975
16	391.79- 446.58	369.408	34.511	185.254	589.174
17	446.58- 507.84	442.246	39.772	213.609	695.628
18	507.84- 575.74	725.885	60.685	311.094	1097.663
19	575.74- 646.91	873.472	77.313	344.885	1295.669
20	646.91- 723.74	1165.755	114.106	461.183	1741.043
21	723.74- 806.91	1589.052	167.589	821.478	2578.120
22	806.91- 897.16	1950.363	302.198	931.103	3183.663
23	897.16- 994.93	2330.303	334.818	1119.297	3784.418
24	994.93-1099.85	3112.630	474.308	1921.769	5508.707
25	1099.85-1209.89	4850.766	993.388	3127.840	8971.992
26	1209.89-1320.50	3145.258	1017.716	2911.363	7074.336
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3649.242	715.702	2349.209	6714.148

TABLE 4-23

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.20 PHI = 20 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.001	0.016	0.081	0.098
14	299.10- 343.37	38.895	5.669	40.630	85.194
15	343.37- 391.79	162.285	21.508	105.378	289.171
16	391.79- 446.58	316.009	33.891	184.345	534.245
17	446.58- 507.84	451.784	40.164	212.060	704.008
18	507.84- 575.74	633.748	60.248	307.175	1001.170
19	575.74- 646.91	863.358	76.413	405.956	1345.727
20	646.91- 723.74	1129.622	155.794	578.216	1863.632
21	723.74- 806.91	1475.126	191.533	664.984	2331.644
22	806.91- 897.16	1942.324	239.625	850.287	3032.236
23	897.16- 994.93	2514.534	337.473	1483.291	4335.297
24	994.93-1099.85	3291.250	555.756	1957.706	5804.711
25	1099.85-1209.89	5355.859	1422.564	5080.254	11858.670
26	1209.89-1320.50	3543.866	359.951	0.000	3903.817
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3898.770	666.873	2135.313	6700.953

TABLE 4-24

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.40 PHI = 20 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.002	0.002
14	299.10- 343.37	20.509	5.104	29.003	54.617
15	343.37- 391.79	131.842	21.186	110.709	263.737
16	391.79- 446.58	274.548	33.735	179.267	487.550
17	446.58- 507.84	407.799	41.974	270.879	720.651
18	507.84- 575.74	577.946	75.025	324.403	977.373
19	575.74- 646.91	818.015	104.507	494.350	1416.872
20	646.91- 723.74	1090.615	147.163	676.253	1914.031
21	723.74- 806.91	1574.569	257.638	892.267	2724.473
22	806.91- 897.16	2015.321	348.455	1279.531	3643.307
23	897.16- 994.93	2821.872	559.165	2102.768	5483.805
24	994.93-1099.85	4922.242	1337.009	3463.628	9722.875
25	1099.85-1209.89	5598.254	0.000	0.000	5598.254
26	1209.89-1320.50	1606.125	0.000	0.000	1606.125
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3862.879	477.064	1502.939	5842.879

TABLE 4-25

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR
A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.48 PHI = 20 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	0.000	0.000	0.000	0.000
14	299.10- 343.37	16.623	4.888	25.869	47.380
15	343.37- 391.79	117.892	20.723	109.725	248.339
16	391.79- 446.58	266.549	33.135	204.248	503.932
17	446.58- 507.84	410.192	49.823	262.832	722.846
18	507.84- 575.74	580.806	68.890	389.609	1039.304
19	575.74- 646.91	825.070	126.531	518.166	1469.766
20	646.91- 723.74	1128.210	191.466	746.550	2066.226
21	723.74- 806.91	1586.872	288.818	1097.916	2973.606
22	806.91- 897.16	2321.875	435.699	1654.522	4412.094
23	897.16- 994.93	3393.035	1087.188	3920.175	8400.395
24	994.93-1099.85	5306.391	339.051	0.000	5645.438
25	1099.85-1209.89	4068.455	0.000	0.000	4068.455
26	1209.89-1320.50	1252.731	0.000	0.000	1252.731
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3654.058	390.878	1215.841	5260.773

TABLE 4-26

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.70 PHI = 35 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	29.874	0.000	0.000	29.874
13	260.16- 299.10	269.680	1.612	6.050	277.342
14	299.10- 343.37	626.027	23.492	114.965	764.483
15	343.37- 391.79	860.719	52.751	262.342	1175.810
16	391.79- 446.58	977.299	78.412	344.172	1399.883
17	446.58- 507.84	1120.997	136.299	439.738	1697.033
18	507.84- 575.74	1309.388	209.442	556.346	2075.176
19	575.74- 646.91	1552.406	340.463	902.838	2795.706
20	646.91- 723.74	830.193	627.506	2329.789	3787.489
21	723.74- 806.91	0.000	0.000	616.635	616.635
22	806.91- 897.16	0.000	0.000	0.000	0.000
23	897.16- 994.93	0.000	0.000	0.000	0.000
24	994.93-1099.85	0.000	0.000	0.000	0.000
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		469.012	119.900	474.679	1063.590

TABLE 4-27

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.40 PHI = 35 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	2.476	0.000	0.000	2.476
13	260.16- 299.10	149.836	5.552	30.083	185.471
14	299.10- 343.37	424.828	25.025	135.798	585.651
15	343.37- 391.79	627.322	41.890	228.593	897.804
16	391.79- 446.58	715.860	50.182	264.027	1030.068
17	446.58- 507.84	797.815	79.758	299.070	1176.642
18	507.84- 575.74	928.759	105.014	365.981	1399.754
19	575.74- 646.91	1124.241	142.605	434.519	1701.366
20	646.91- 723.74	1344.376	200.150	531.868	2076.393
21	723.74- 806.91	1663.614	269.969	752.757	2686.339
22	806.91- 897.16	2034.657	386.604	1178.546	3599.808
23	897.16- 994.93	1975.628	695.532	2113.463	4784.621
24	994.93-1099.85	0.000	301.158	2452.518	2753.676
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		1242.221	313.020	1256.965	2812.207

TABLE 4-28

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.20 PHI = 35 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.105	0.011	0.017	0.133
13	260.16- 299.10	96.773	8.298	44.777	149.848
14	299.10- 343.37	338.021	24.984	127.914	490.919
15	343.37- 391.79	489.031	41.592	232.258	762.880
16	391.79- 446.58	630.717	51.710	227.757	910.184
17	446.58- 507.84	668.994	63.679	308.510	1041.182
18	507.84- 575.74	835.417	92.237	329.739	1257.392
19	575.74- 646.91	922.269	127.628	312.860	1362.756
20	646.91- 723.74	1143.227	155.195	525.248	1823.669
21	723.74- 806.91	1423.515	190.820	594.562	2208.896
22	806.91- 897.16	1785.276	311.852	741.355	2838.483
23	897.16- 994.93	2319.841	341.988	1320.265	3982.094
24	994.93-1099.85	2894.724	579.090	1841.474	5315.289
25	1099.85-1209.89	1557.591	859.109	4203.434	6620.133
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2101.916	477.355	1865.268	4444.539

TABLE 4-29

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = 0.10   PHI = 35   DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.072	0.011	0.059	0.142
13	260.16- 299.10	80.317	8.441	45.405	134.163
14	299.10- 343.37	281.152	23.895	128.890	433.936
15	343.37- 391.79	480.312	43.192	233.766	757.270
16	391.79- 446.58	550.030	38.606	209.380	798.016
17	446.58- 507.84	691.329	77.129	307.754	1076.211
18	507.84- 575.74	725.302	83.111	264.472	1072.884
19	575.74- 646.91	876.690	116.381	409.846	1402.917
20	646.91- 723.74	1081.045	128.859	405.211	1615.114
21	723.74- 806.91	1313.254	198.449	0.001	1511.704
22	806.91- 897.16	1669.340	293.729	722.981	2686.050
23	897.16- 994.93	2213.442	321.822	1262.449	3797.713
24	994.93-1099.85	2873.449	480.572	1485.663	4839.684
25	1099.85-1209.89	3872.377	908.018	3297.133	8077.527
26	1209.89-1320.50	84.217	335.781	2206.257	2626.255
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2571.087	541.575	2098.335	5210.996

TABLE 4-30

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.10 PHI = 35 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.057	0.057
13	260.16- 299.10	53.634	8.516	45.544	107.694
14	299.10- 343.37	234.943	24.057	129.232	388.231
15	343.37- 391.79	374.904	34.930	216.758	626.591
16	391.79- 446.58	535.979	46.676	226.035	808.690
17	446.58- 507.84	551.086	58.630	255.454	865.170
18	507.84- 575.74	698.979	86.436	313.219	1098.633
19	575.74- 646.91	730.468	134.801	415.280	1280.548
20	646.91- 723.74	1034.394	132.788	409.521	1576.702
21	723.74- 806.91	1245.417	188.048	537.653	1971.117
22	806.91- 897.16	1600.965	237.492	710.033	2548.490
23	897.16- 994.93	2005.407	297.390	1094.342	3397.139
24	994.93-1099.85	2847.666	477.135	1497.125	4821.926
25	1099.85-1209.89	4583.141	735.247	3042.477	8360.863
26	1209.89-1320.50	3166.180	716.858	2777.884	6660.922
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3392.627	582.536	2154.441	6129.605

TABLE 4-31

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.20 PHI = 35 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	37.233	6.036	42.017	85.285
14	299.10- 343.37	211.120	26.103	131.279	368.502
15	343.37- 391.79	349.573	34.561	213.035	597.169
16	391.79- 446.58	492.130	46.967	227.881	766.978
17	446.58- 507.84	548.110	58.656	315.054	921.821
18	507.84- 575.74	669.252	85.847	303.022	1058.120
19	575.74- 646.91	742.481	133.438	361.505	1237.423
20	646.91- 723.74	936.283	130.642	398.893	1465.818
21	723.74- 806.91	1228.503	183.765	667.831	2080.100
22	806.91- 897.16	1569.645	290.681	825.010	2685.337
23	897.16- 994.93	2098.188	345.309	974.835	3418.333
24	994.93-1099.85	3024.238	481.781	1892.075	5398.094
25	1099.85-1209.89	5119.168	1043.444	4745.445	10908.050
26	1209.89-1320.50	3436.088	194.766	0.000	3630.854
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3609.219	540.660	1949.105	6098.984

TABLE 4-32

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.40 PHI = 35 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	18.405	4.341	30.112	52.857
14	299.10- 343.37	148.909	24.307	136.112	309.328
15	343.37- 391.79	320.404	36.292	218.723	575.419
16	391.79- 446.58	451.621	46.585	271.004	769.210
17	446.58- 507.84	553.170	75.542	275.622	904.334
18	507.84- 575.74	633.065	91.420	380.194	1104.679
19	575.74- 646.91	744.375	138.796	410.149	1293.320
20	646.91- 723.74	889.685	187.682	493.464	1570.830
21	723.74- 806.91	1282.825	223.018	765.862	2271.704
22	806.91- 897.16	1636.240	329.754	1102.012	3068.007
23	897.16- 994.93	2521.597	475.304	1930.558	4927.457
24	994.93-1099.85	4609.746	949.238	3130.863	8689.848
25	1099.85-1209.89	5094.641	0.000	0.000	5094.641
26	1209.89-1320.50	1490.867	0.000	0.000	1490.867
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3521.448	390.372	1356.380	5268.199

TABLE 4-33

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.48 PHI = 35 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.000	0.000	0.000	0.000
13	260.16- 299.10	11.869	3.692	21.095	36.657
14	299.10- 343.37	132.811	21.233	135.753	289.797
15	343.37- 391.79	300.086	38.584	223.834	562.504
16	391.79- 446.58	445.495	57.000	266.896	769.391
17	446.58- 507.84	544.191	69.241	332.077	945.509
18	507.84- 575.74	645.180	114.206	367.349	1126.734
19	575.74- 646.91	771.416	142.551	468.190	1382.156
20	646.91- 723.74	924.608	200.361	614.938	1739.906
21	723.74- 806.91	1260.903	267.269	867.988	2396.159
22	806.91- 897.16	1967.594	409.211	1496.186	3872.992
23	897.16- 994.93	3030.747	854.868	3502.567	7388.180
24	994.93-1099.85	4902.828	168.916	0.000	5071.742
25	1099.85-1209.89	3657.133	0.000	0.000	3657.133
26	1209.89-1320.50	1131.140	0.000	0.000	1131.140
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3303.495	319.719	1088.934	4712.145

TABLE 4-34

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.70 PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.001	0.000	0.000	0.001
12	225.87- 260.16	58.601	0.000	0.000	58.601
13	260.16- 299.10	398.849	8.011	33.937	440.796
14	299.10- 343.37	725.945	39.717	203.339	969.000
15	343.37- 391.79	857.022	68.964	323.006	1248.991
16	391.79- 446.58	906.821	110.281	377.464	1394.566
17	446.58- 507.84	961.942	160.415	456.064	1578.420
18	507.84- 575.74	1051.051	211.451	529.612	1792.114
19	575.74- 646.91	1257.041	274.721	748.543	2280.305
20	646.91- 723.74	726.838	449.390	1890.671	3066.898
21	723.74- 806.91	0.000	0.000	505.544	505.544
22	806.91- 897.16	0.000	0.000	0.000	0.000
23	897.16- 994.93	0.000	0.000	0.000	0.000
24	994.93-1099.85	0.000	0.000	0.000	0.000
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		408.474	100.590	409.958	919.022

TABLE 4-35

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.40 PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	28.152	0.586	3.162	31.901
13	260.16- 299.10	301.164	16.889	91.552	409.605
14	299.10- 343.37	535.604	38.117	207.405	781.125
15	343.37- 391.79	681.051	52.775	278.649	1012.474
16	391.79- 446.58	713.680	70.789	294.923	1079.391
17	446.58- 507.84	773.510	108.181	320.471	1202.161
18	507.84- 575.74	835.065	125.500	380.145	1340.710
19	575.74- 646.91	945.270	161.050	428.579	1534.898
20	646.91- 723.74	1104.562	187.286	475.521	1767.369
21	723.74- 806.91	1394.497	224.306	633.297	2252.099
22	806.91- 897.16	1737.512	310.238	980.237	3027.987
23	897.16- 994.93	1813.438	524.432	1807.357	4145.227
24	994.93-1099.85	0.000	224.943	2138.753	2363.696
25	1099.85-1209.89	0.000	0.000	0.000	0.000
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		1099.999	257.851	1102.910	2460.761

TABLE 4-36

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.20 PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	18.893	2.045	7.803	28.741
13	260.16- 299.10	238.128	20.868	115.544	374.540
14	299.10- 343.37	467.314	37.110	189.470	693.893
15	343.37- 391.79	565.690	51.821	282.410	899.921
16	391.79- 446.58	681.018	72.296	258.313	1011.627
17	446.58- 507.84	658.044	87.105	330.169	1075.318
18	507.84- 575.74	749.961	113.143	345.993	1209.097
19	575.74- 646.91	885.465	150.135	321.119	1356.718
20	646.91- 723.74	939.543	155.117	495.499	1590.159
21	723.74- 806.91	1154.293	180.150	509.670	1844.113
22	806.91- 897.16	1524.777	261.589	626.149	2412.515
23	897.16- 994.93	1980.801	278.263	1110.453	3369.518
24	994.93-1099.85	2607.120	451.634	1601.416	4660.168
25	1099.85-1209.89	1494.347	649.113	3726.609	5870.070
26	1209.89-1320.50	0.000	0.000	0.000	0.000
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		1883.451	391.667	1653.293	3928.412

TABLE 4-37

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = 0.10 PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	16.551	2.106	11.342	27.952
13	260.16- 299.10	201.890	21.100	113.741	361.036
14	299.10- 343.37	451.807	35.267	190.298	770.995
15	343.37- 391.79	518.043	54.236	284.389	1036.198
16	391.79- 446.58	606.143	57.054	235.704	1051.226
17	446.58- 507.84	668.512	103.282	337.972	1314.238
18	507.84- 575.74	730.410	109.402	276.994	1271.876
19	575.74- 646.91	778.399	124.460	418.885	1607.129
20	646.91- 723.74	956.280	142.611	384.660	1746.150
21	723.74- 806.91	1120.281	197.777	465.782	2116.866
22	806.91- 897.16	1417.168	244.761	624.369	2764.518
23	897.16- 994.93	1824.257	256.305	1052.506	4139.211
24	994.93-1099.85	2598.161	400.072	1298.251	5382.074
25	1099.85-1209.89	3525.419	676.594	2902.579	9725.129
26	1209.89-1320.50	113.826	260.583	1972.690	4292.773
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2308.233	2098.335	1864.243	6270.809

TABLE 4-38

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.10 PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	7.308	1.358	11.052	19.718
13	260.16- 299.10	161.637	21.918	114.323	297.878
14	299.10- 343.37	352.119	35.404	190.781	578.303
15	343.37- 391.79	506.038	44.223	267.273	817.535
16	391.79- 446.58	560.239	65.732	252.719	878.690
17	446.58- 507.84	627.868	78.761	276.891	983.521
18	507.84- 575.74	655.537	110.393	330.813	1096.742
19	575.74- 646.91	793.597	152.758	427.427	1373.781
20	646.91- 723.74	850.140	146.792	388.735	1385.666
21	723.74- 806.91	981.981	176.325	471.777	1630.083
22	806.91- 897.16	1341.709	208.255	600.727	2150.691
23	897.16- 994.93	1705.518	240.671	954.013	2900.202
24	994.93-1099.85	2645.025	397.231	1256.574	4298.828
25	1099.85-1209.89	4015.491	568.934	2703.825	7288.246
26	1209.89-1320.50	2927.438	532.854	2467.396	5927.688
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3044.245	476.337	1913.980	5434.563

TABLE 4-39

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR
A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.20 PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	4.699	1.244	6.661	12.604
13	260.16- 299.10	132.763	17.362	111.403	261.528
14	299.10- 343.37	338.534	39.342	195.285	573.161
15	343.37- 391.79	469.163	42.433	263.905	775.501
16	391.79- 446.58	546.688	67.268	253.983	867.940
17	446.58- 507.84	615.960	80.548	343.930	1040.438
18	507.84- 575.74	610.017	107.982	321.993	1039.992
19	575.74- 646.91	830.241	151.101	364.463	1345.805
20	646.91- 723.74	833.786	144.425	378.606	1356.816
21	723.74- 806.91	1018.490	172.215	597.508	1788.213
22	806.91- 897.16	1219.276	265.934	679.501	2164.712
23	897.16- 994.93	1791.645	264.700	822.663	2879.009
24	994.93-1099.85	2697.709	399.852	1638.976	4736.535
25	1099.85-1209.89	4570.555	799.233	4202.504	9572.289
26	1209.89-1320.50	3142.216	128.766	0.000	3270.982
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3228.816	441.775	1727.760	5398.352

TABLE 4-40

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET   BARRIER THICKNESS = 48 PSF

COS THETA = -0.40   PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.598	0.277	2.996	3.870
13	260.16- 299.10	80.041	14.534	91.504	186.080
14	299.10- 343.37	277.392	38.306	207.990	523.687
15	343.37- 391.79	427.806	44.788	267.898	740.492
16	391.79- 446.58	520.783	67.280	303.792	891.854
17	446.58- 507.84	589.146	101.578	295.196	985.920
18	507.84- 575.74	676.889	111.992	397.854	1186.735
19	575.74- 646.91	718.173	155.094	407.612	1280.878
20	646.91- 723.74	883.571	190.608	443.886	1518.064
21	723.74- 806.91	1084.830	208.146	645.446	1938.422
22	806.91- 897.16	1397.007	264.082	917.059	2578.147
23	897.16- 994.93	2157.392	383.167	1642.061	4182.617
24	994.93-1099.85	4099.469	694.969	2737.439	7531.875
25	1099.85-1209.89	4371.738	0.000	0.000	4371.738
26	1209.89-1320.50	1321.091	0.000	0.000	1321.091
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		3108.163	319.157	1191.066	4618.387

TABLE 4-41

ENERGY ANGULAR DISTRIBUTION OF SINGLE SCATTERED PHOTONS FOR
A WALL BARRIER EXPOSED TO A PLANE ISOTROPIC CO-60 SOURCE

(PHOTONS/SQ.CM-SEC)/(KEV-SR)
NORMALIZED TO A SOURCE STRENGTH OF 1 CURIE/SQ.FT.

H = 3 FEET BARRIER THICKNESS = 48 PSF

COS THETA = -0.48 PHI = 45 DEGREES

BIN NO.	ENERGY LIMITS ON BIN (KEV)	AREA 1 SPECTRUM	AREA 2 SPECTRUM	FAR FIELD SPECTRUM	TOTAL SPECTRUM
1	20.00- 30.85	0.000	0.000	0.000	0.000
2	30.85- 42.59	0.000	0.000	0.000	0.000
3	42.59- 55.44	0.000	0.000	0.000	0.000
4	55.44- 69.53	0.000	0.000	0.000	0.000
5	69.53- 85.04	0.000	0.000	0.000	0.000
6	85.04- 102.20	0.000	0.000	0.000	0.000
7	102.20- 121.27	0.000	0.000	0.000	0.000
8	121.27- 142.85	0.000	0.000	0.000	0.000
9	142.85- 167.10	0.000	0.000	0.000	0.000
10	167.10- 194.63	0.000	0.000	0.000	0.000
11	194.63- 225.87	0.000	0.000	0.000	0.000
12	225.87- 260.16	0.061	0.081	1.141	1.284
13	260.16- 299.10	59.886	13.392	73.631	146.910
14	299.10- 343.37	249.923	34.454	214.367	498.744
15	343.37- 391.79	414.301	48.167	274.705	737.173
16	391.79- 446.58	515.029	78.899	297.305	891.233
17	446.58- 507.84	580.200	95.380	353.876	1029.456
18	507.84- 575.74	677.087	132.670	381.255	1191.011
19	575.74- 646.91	775.838	161.026	457.398	1394.262
20	646.91- 723.74	888.755	192.985	536.899	1618.639
21	723.74- 806.91	1108.340	227.640	717.359	2053.339
22	806.91- 897.16	1650.675	332.566	1247.035	3230.277
23	897.16- 994.93	2615.833	661.395	3012.365	6289.594
24	994.93-1099.85	4330.902	94.730	0.000	4425.629
25	1099.85-1209.89	3072.944	0.000	0.000	3072.944
26	1209.89-1320.50	964.223	0.000	0.000	964.223
27	1320.50-1425.00	0.000	0.000	0.000	0.000
EXPOSURE RATE (MR/HR)		2894.008	261.587	950.961	4106.555

5.0 DISCUSSION OF RESULTS

The measured double-differential flux and the calculated, single scattered double-differential flux are compared for a point source in Figures 4-1, 4-2, and 4-3, and for a plane source in Figures 5-1 and 5-2 (only two spectra are used for illustration as they are representative of all the spectra). It is apparent from these figures that the high-energy portion of the measured flux is due to gamma rays single scattered in the wall. It is to be noted that the single scattered portions of the measured energy spectra are spread over larger ranges of energies than are the calculated single scattered fluxes. This may be attributed to the "finite resolution" of the collimated detector system. The theoretical distribution assumes perfect energy and angular resolution. However, photons reaching the detector in the experimental measurements are scattered through a range of angles defined by the solid angle of the collimator. Thus, the measured flux contains a larger range of energies than does the theoretical flux. In addition, the system response yields a distribution of energies about the energy being measured.

The calculated spectra were redistributed by taking the higher energy bins, starting with the first bin below the peak bin, and smearing them out over the same energy bins and in the same proportion as the measured spectra. This is reasonable because the measured flux for those energies is primarly single-

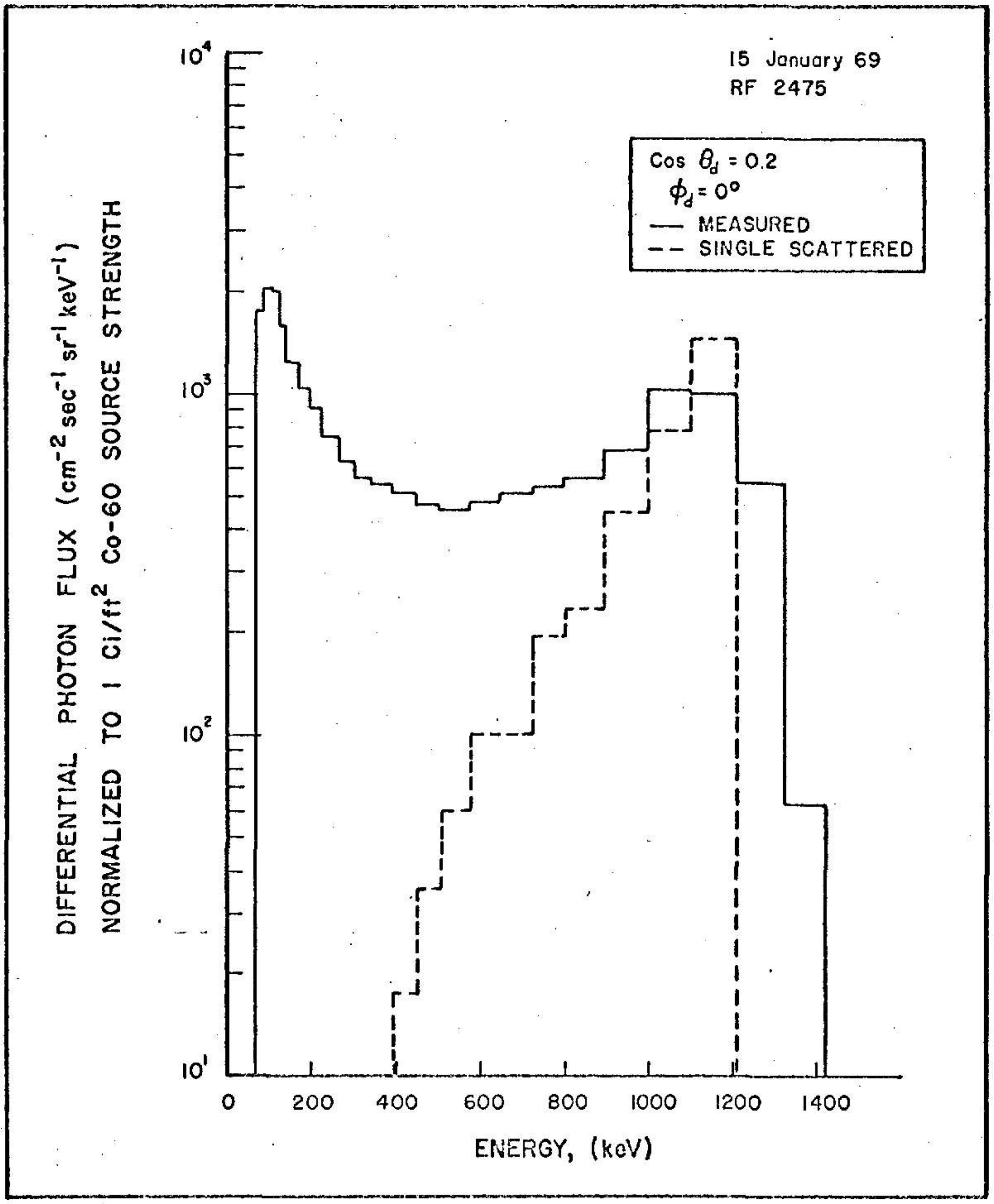

Figure 5-1 Comparison of calculated single scattered flux with measured flux. Area 2, cos θ_d = 0.2, ϕ_d = 0°.

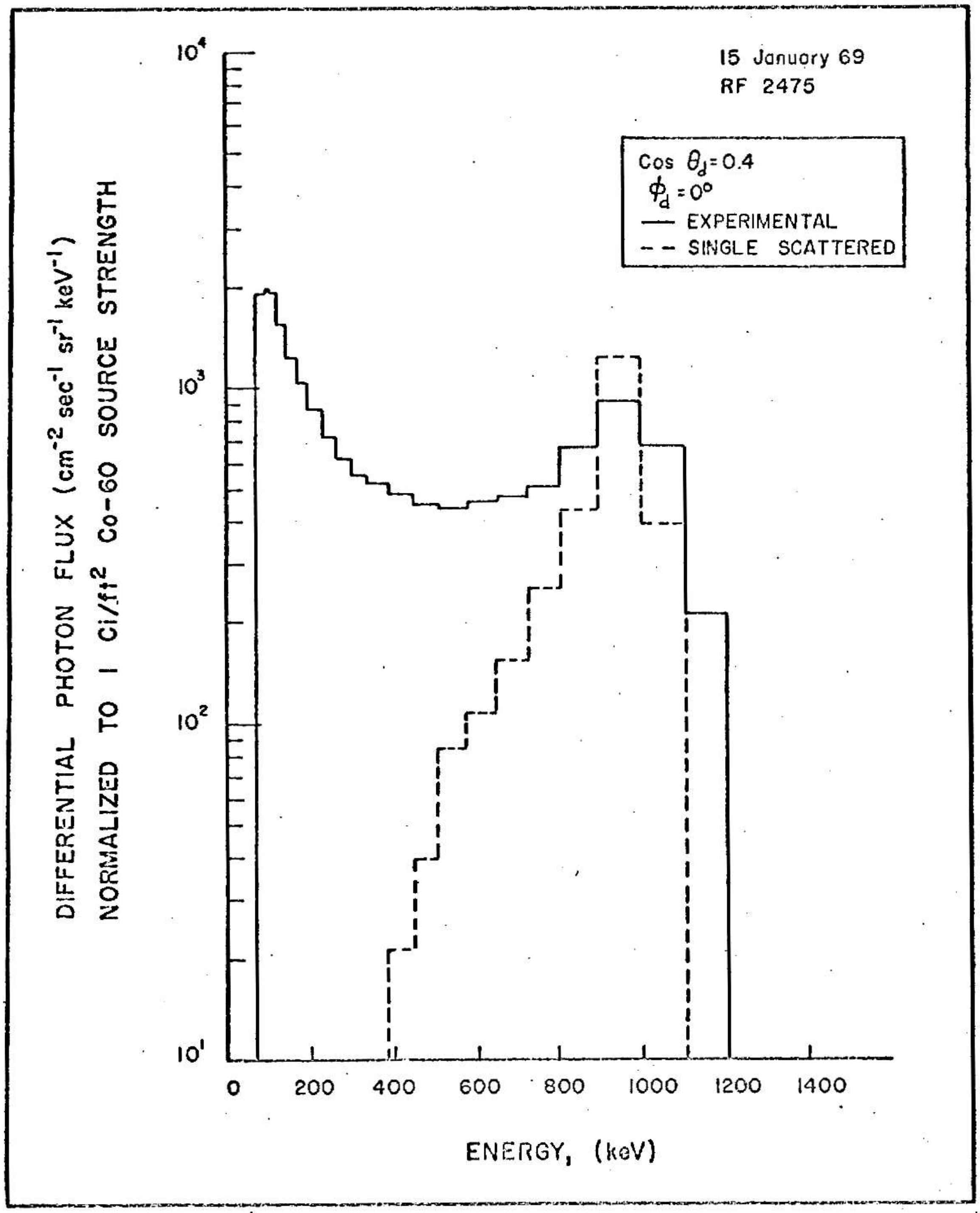

Figure 5-2 Comparison of calculated single scattered flux with measured flux, Area 2, cos θ_d = 0.4, ϕ_d = 0°

scattered radiation. Multiple-scattered radiation, emerging from the wall at that particular direction would, of necessity, be of lower energy. It should be noted that, in this "smearing" process, the total flux is conserved and the exposure-angular distribution is only slightly affected. A comparison of the redistributed single-scattered flux and the measured flux is shown in Figure 5-3 and 5-4.

An estimate of the error due to using summations instead of integrals was made. In Tables 3-2 to 3-7 different values of $\Delta\nu$ and Δr were used to calculate exposure rates from annuli in the source plane. When small values of $\Delta\nu$ and Δr were used, the exposure rates obtained were less than one percent different from the exposure rates obtained using the $\Delta\nu$ and Δr's from the actual calculations. The number of thin slabs used did not affect the scattered flux by an amount greater than one percent as seen in Figure 3-2. Thus the error due to the approximate solution of the integral equation was on the order of 3 percent or less. A more realistic error would be close to 10 percent due to errors in the attenuation coefficients, electron density, and other factors that were used to simulate the real situation in the calculations.

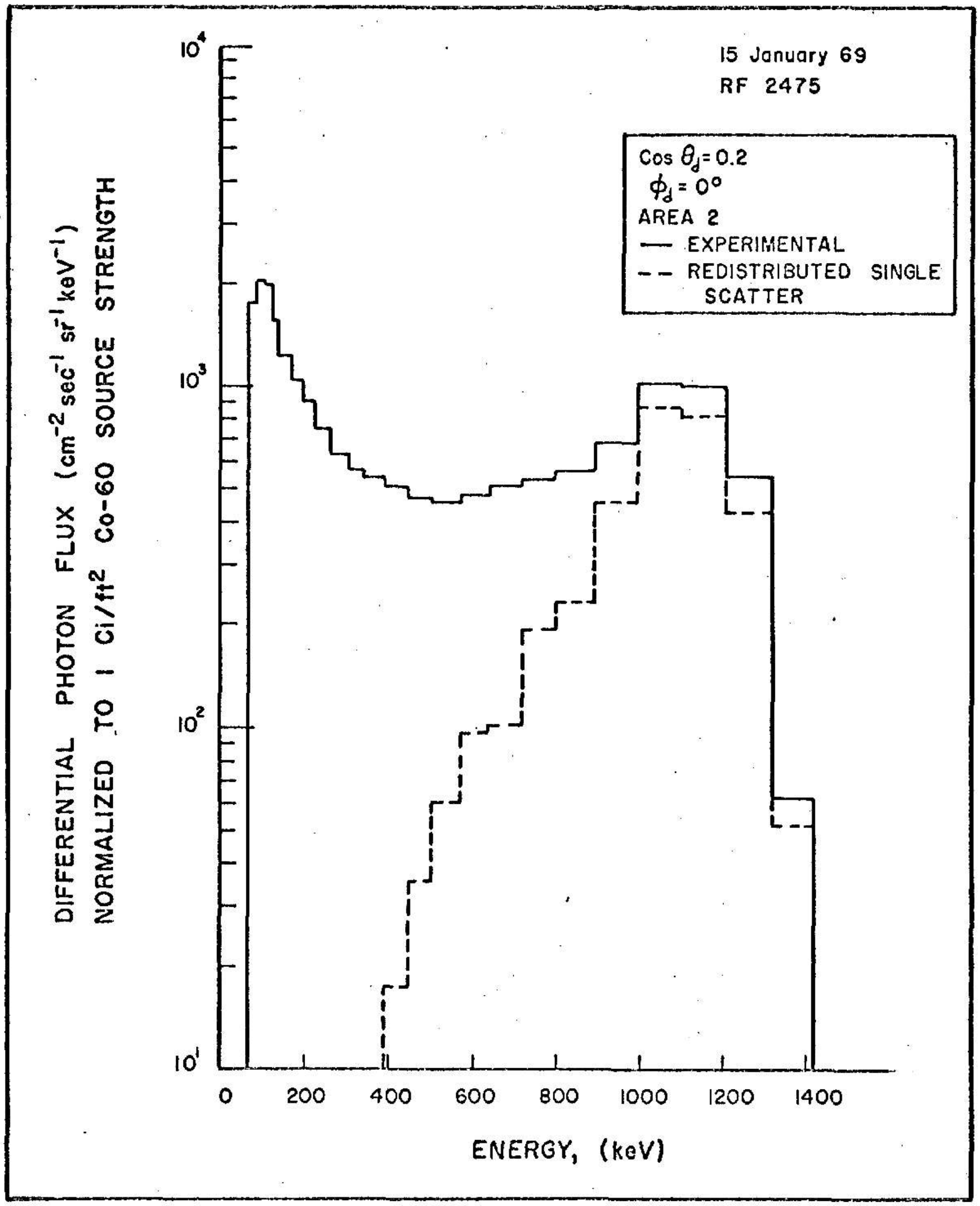

Figure 5-3 Comparison between redistributed single scattered flux and measured flux, Area 2, cos θ_d = 0.2, ϕ_d = 0°.

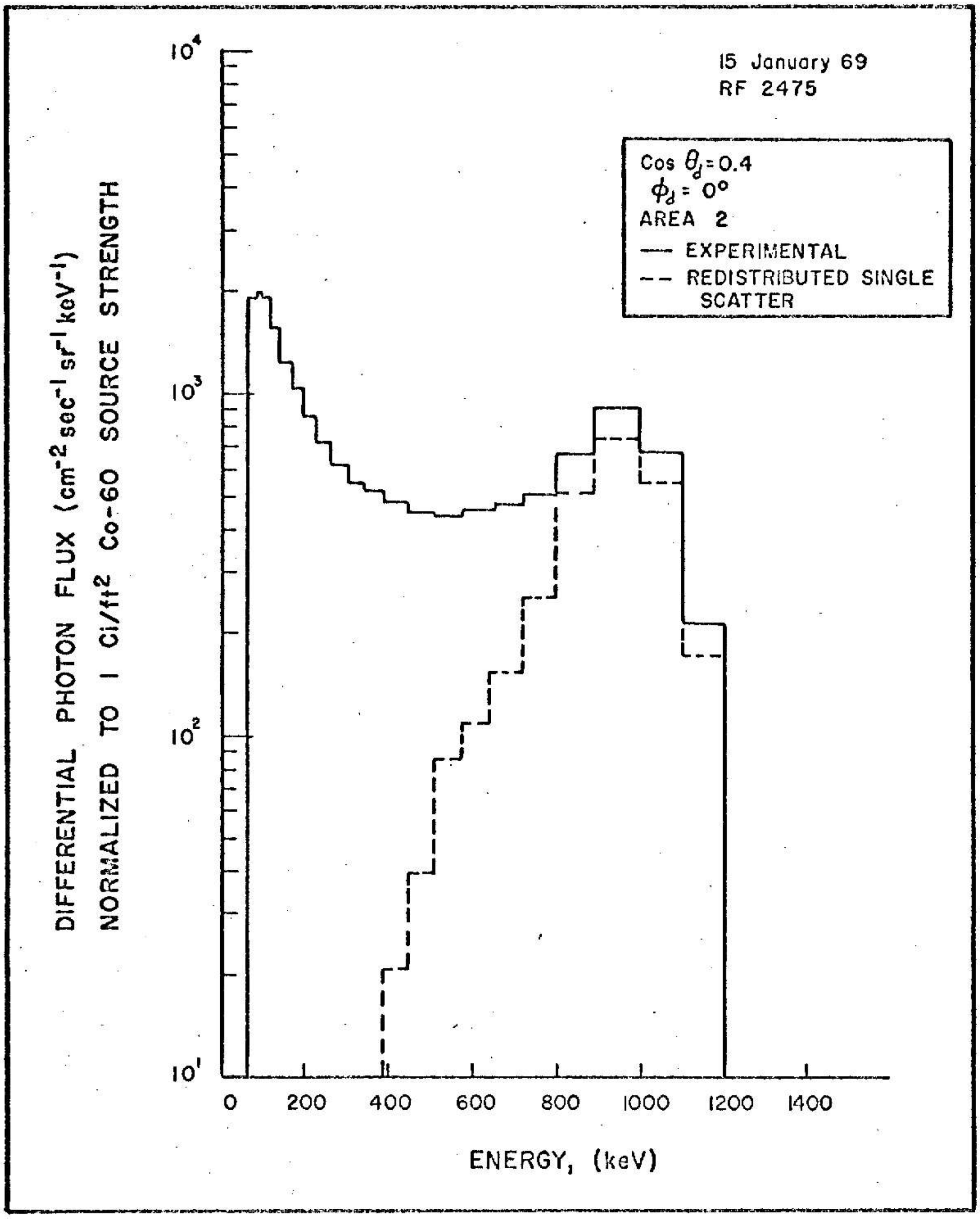

Figure 5-4 Comparison between redistributed single scattered flux and measured flux, Area 2, cos θ_d = 0.4, ϕ_d = 0°.

6.0 ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Dr. R. E. Faw under whose guidance this work was accomplished. Thanks are extended to Mr. R. M. Rubin under whose supervision the experimental work was carried out and with whom many helpful discussions were held and to the Department of Nuclear Engineering at Kansas State University for whom the author worked as a Graduate Research Assitant during this project.

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8.0 APPENDICES

APPENDIX A

DESCRIPTION OF EXPERIMENTAL WORK

1.0 Introduction

The objective was the experimental measurement of the angular and energy spectra of gamma radiation penetrating a vertical slab bounding a semi-infinite plane radiation source.

The vertical test slab was a 6-ft x 6-ft concrete test panel of 48±1 psf mass thickness mounted in a 10-ft x 15-ft reinforced concrete wall of approximately the same mass thickness (see Figures A-1, A-2, and A-3). The plane source was approximated by a ^{60}Co pumped source circulation system. Sources were pumped through polyethylene tubing arranged in annular semi-circular areas centered on and extending 100 ft from the test slab (see Figures A-4, A-5, and A-6). All measurements were made at a point on the test slab 3 ft above grade. A 3-in x 3-in NaI(Tl) scintillator in either a 0.011 or a 0.00068 steradian lead collimator was used to measure the gamma-ray energy spectra at each of 40 directions. Angular resolution was governed by the aperture size. Energy resolution was governed by the number of intervals used in the mathematical procedure for spectrum analysis.

The broad objective of the work was to provide experimental data for the refinement of methods of design and analysis of structures for protection against the effects of gamma radiation from nuclear weapon fallout.

Current standard methods of shielding analysis[1] are based largely on the work of Spencer[2] and Eisenhauer[3]. The work of Spencer has provided basic data describing the exposure angular distribution above infinite plane fallout sources. Spencer has also developed basic data for describing the penetration of gamma radiation through barriers such as the walls of structures. Eisenhauer has elaborated upon the concepts of barrier and geometry reduction factors which have found wide use in the "Engineering Manual" method for structure shielding analysis.

A long-recognized shortcoming of current analysis methods is the lack of either theoretical or experimental data describing the angular and energy spectra of radiation penetrating the walls of structures. This deficiency is being remedied by experimental data such as that obtained at the KSUNESF and by data produced by Monte Carlo calculation such as that of French et al.[4]

2.0 Experimental Study

2.1 Introduction

The specific purpose of the experimental study was the measurement of the photon flux, differential with respect to energy and direction, emerging from a vertical concrete slab of mass thickness 48 psf, bounded by a simulated semi-infinite plane source of fallout radiation. In this section details of the experimental facilities and methods are discussed.

2.2 Description of Facilities

2.2.1 The Test Structure

The wall-transmission experiments were conducted at the KSUNESF. The Facility is a 180-acre plot of land located 5 miles west of Kansas State University. It is accessible, yet isolated as required for radiation shielding studies.

The test structure shown in Figure A-1 was constructed on a plateau at the KSUNESF. Construction details are shown in Figure A-2. Except for the test panel which is described in the next section, the test structure was constructed of reinforced concrete. Walls are 8 in thick above grade and 12 in. thick below grade. Excavation to the required depth of 10 ft necessitated blasting through a massive layer of limestone. Fallout simulation areas (Figure A-7) were graded to a slope of 1.5 percent.

2.2.2 The Test Panel

The test panel, a concrete slab shown in position in Figure A-2, was constructed by the Applied Mechanics Department at Kansas State University under carefully controlled conditions. Figure A-3 is a working drawing of the forms used. Reinforcing rods were positioned 6 in. from the edges of the slab. This left a 5-ft by 5-ft area entirely free of reinforcement. Since the mean free path of ^{60}Co gamma rays is only a few inches in concrete, measurement of the gamma-ray flux at a point 3 ft above grade at the horizontal center of the slab would not be influenced by the reinforcing rods.

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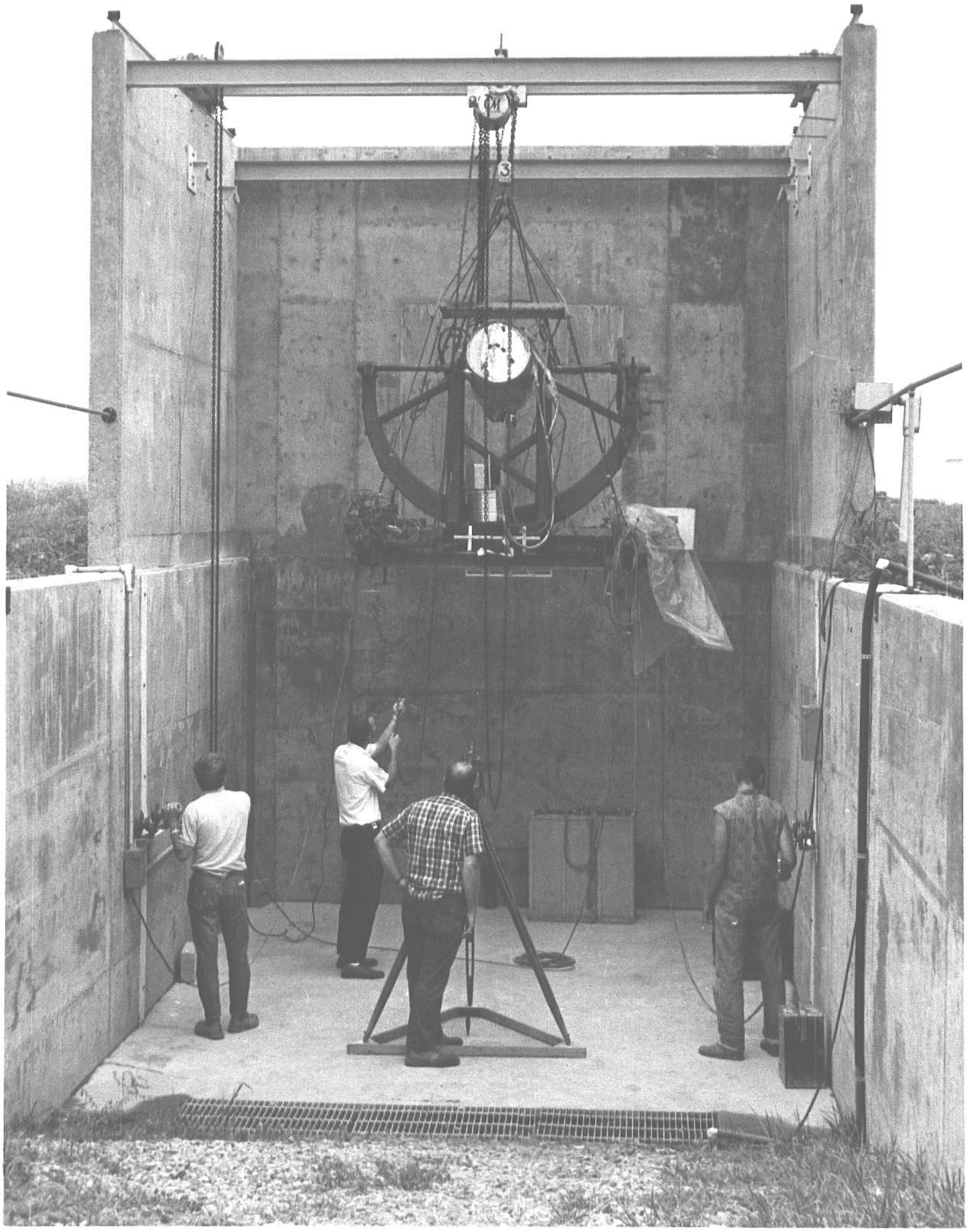

Figure A-1 View of test facility.

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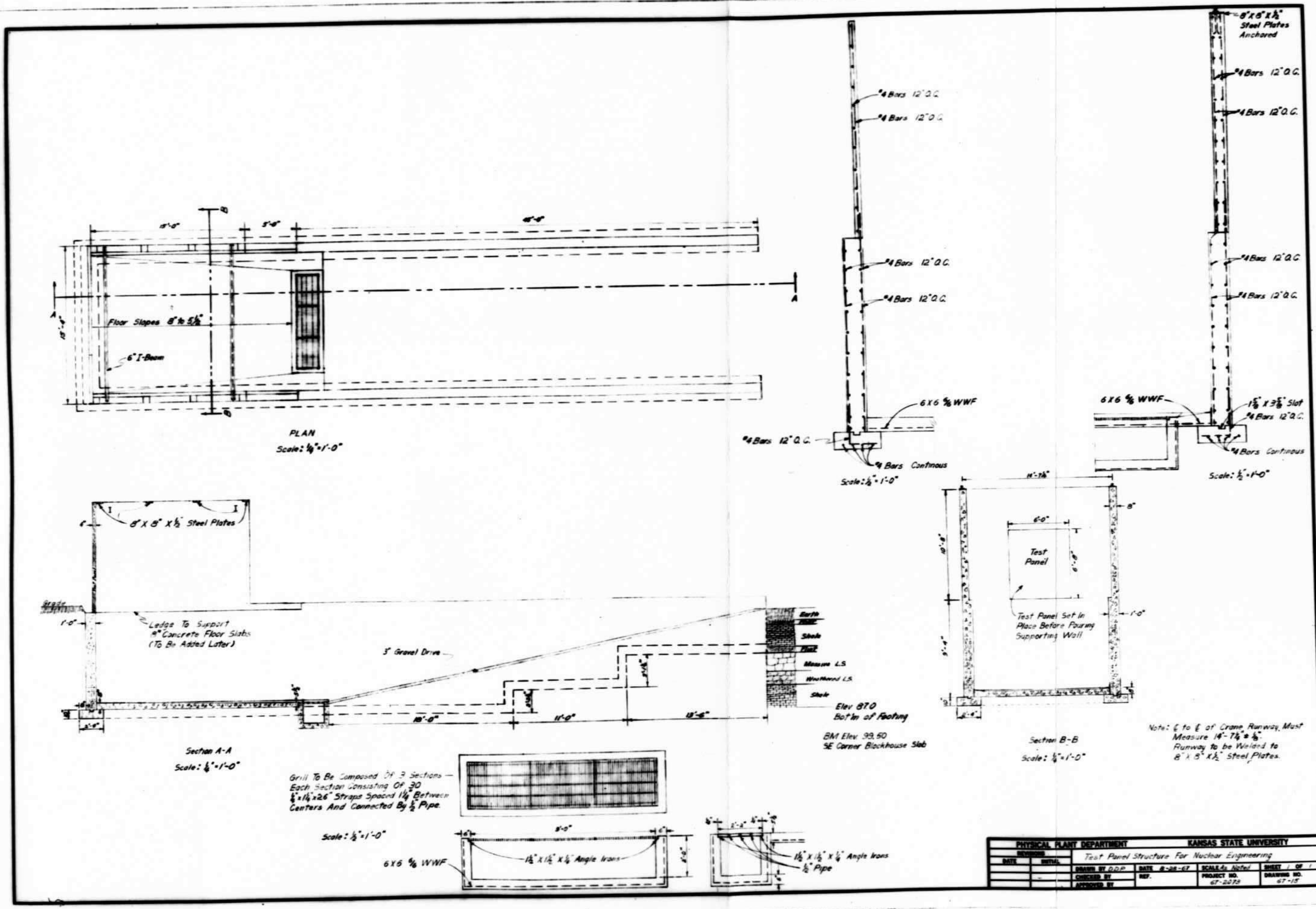
PLAN
Scale: 1/8"=1'-0"
Floor Slopes 8" to 5 1/2"
6" I-Beam
8" X 8" X 1/2" Steel Plates
Ledge To Support
9" Concrete Floor Slabs
(To Be Added Later)
3" Gravel Drive
Elev 87.0
Bot'm of Footing
BM Elev 99.50
SE Corner Blockhouse Slab
Section A-A
Scale: 1/8"=1'-0"
Grill To Be Composed Of 3 Sections —
Each Section Consisting Of 30
1/8"x1 1/4"x26" Straps Spaced 1 1/4" Between
Centers And Connected By 1/2" Pipe.
Scale: 1/2"=1'-0"
6X6 6/6 WWF
1 1/2" X 1 1/2" X 1/4" Angle Irons
1/2" Pipe
#4 Bars 12" O.C.
#4 Bars Continous
Scale: 1/2"=1'-0"
8" X 8" X 1/2" Steel Plates Anchored
1 5/8" X 3 5/8" Slot
Test Panel
Test Panel Set In Place Before Pouring Supporting Wall
Section B-B
Scale: 1/8"=1'-0"
Note: ℄ to ℄ of Crane Runway Must Measure 14'-7 1/4" ± 1/8".
Runway to be Welded to 8" X 8" X 1/2" Steel Plates.
PHYSICAL PLANT DEPARTMENT
KANSAS STATE UNIVERSITY
Test Panel Structure For Nuclear Engineering
DRAWN BY D.D.P.
DATE 8-28-67
SCALE: As Noted
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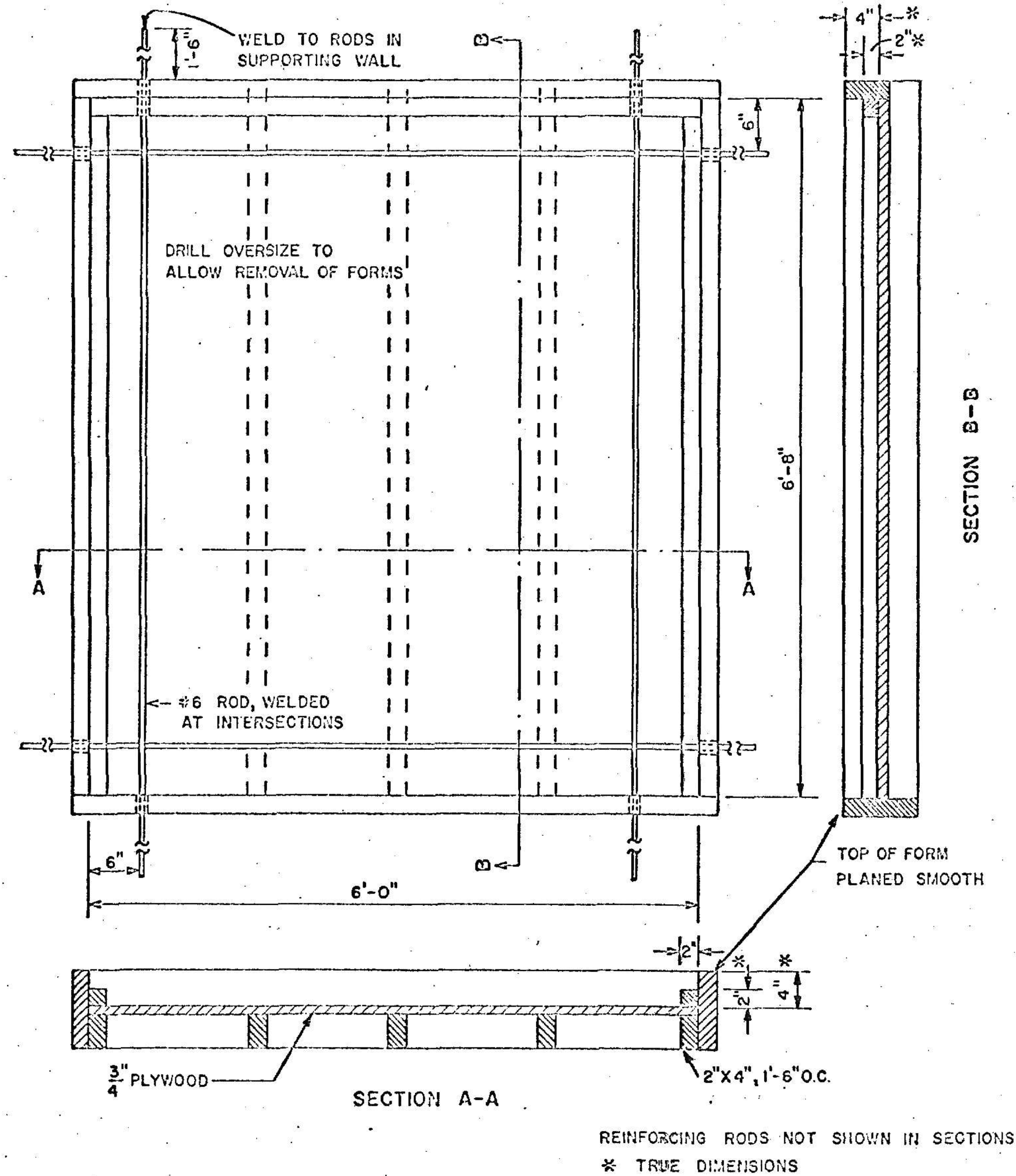

KANSAS STATE UNIVERSITY

DEPARTMENT OF NUCLEAR ENGINEERING SHIELDING FACILITY

Figure A-3 : WOODEN FORMS FOR CONCRETE TEST PANEL

R. E. FAW AUG. 3, 1967 SCALE 3/4" = 1'-0" SHEET 1 OF 2

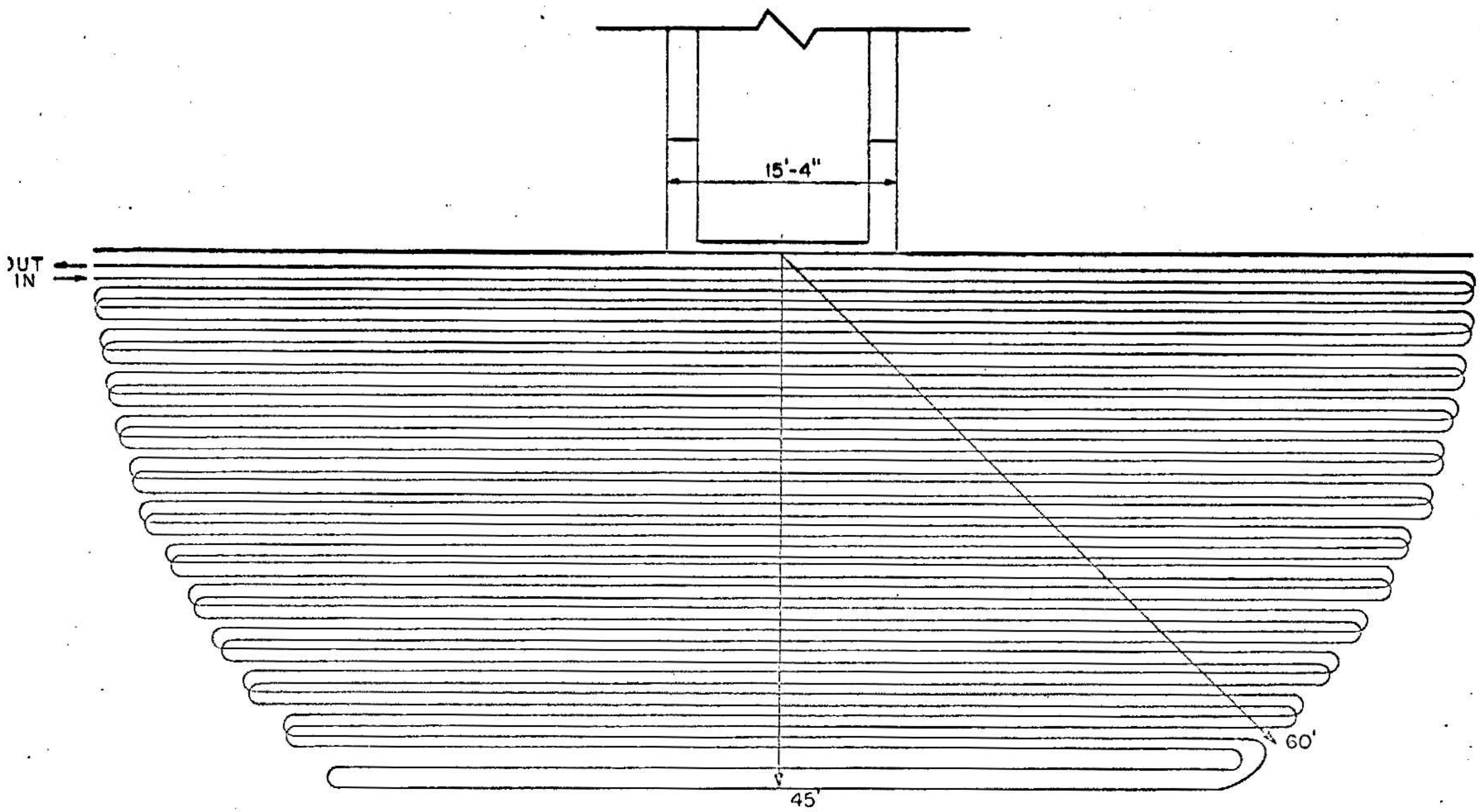

Figure A-4 Source tubing Area 1.

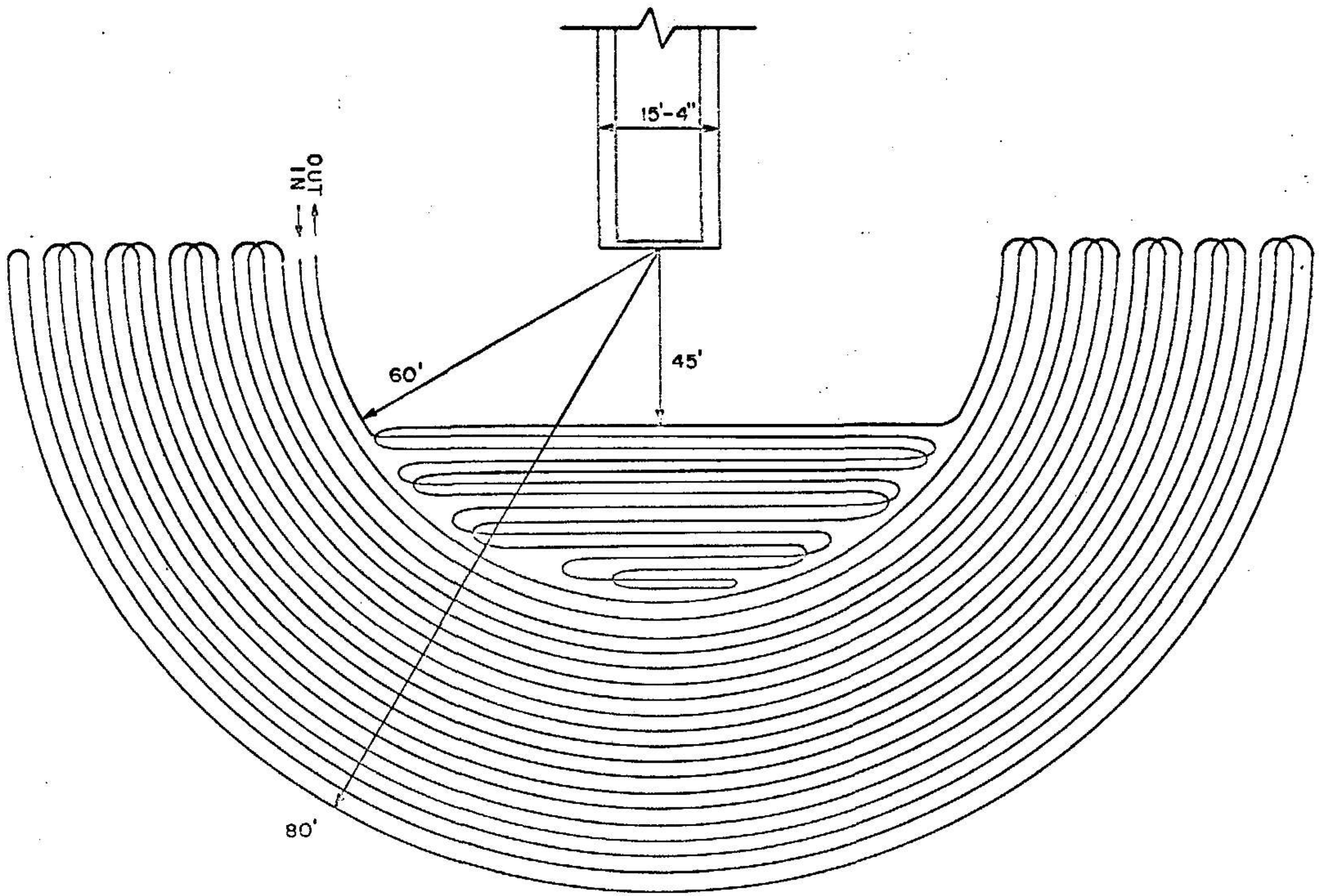

Figure A-5 Source tubing Area 2.

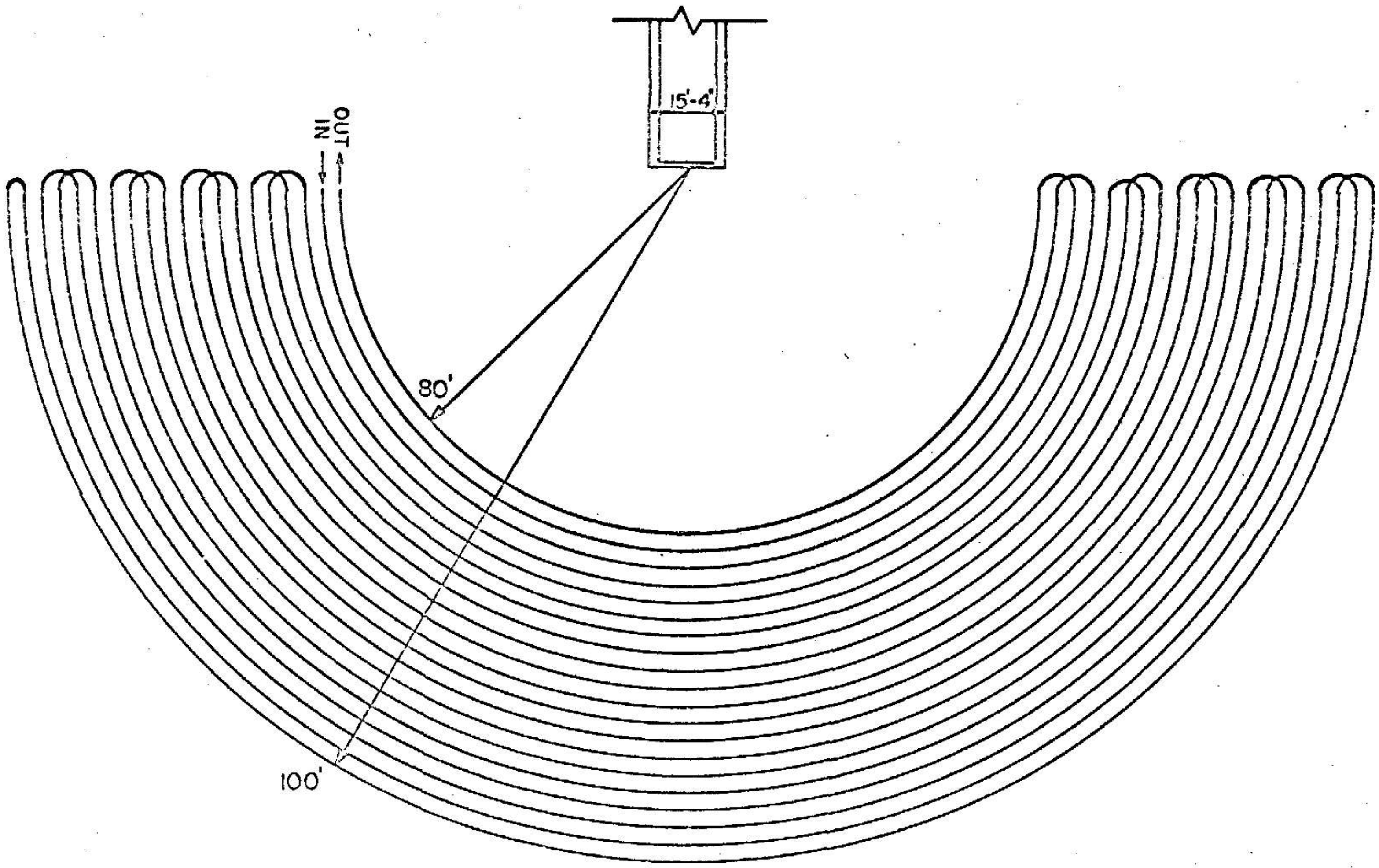

Figure A-6 Source tubing Area 3

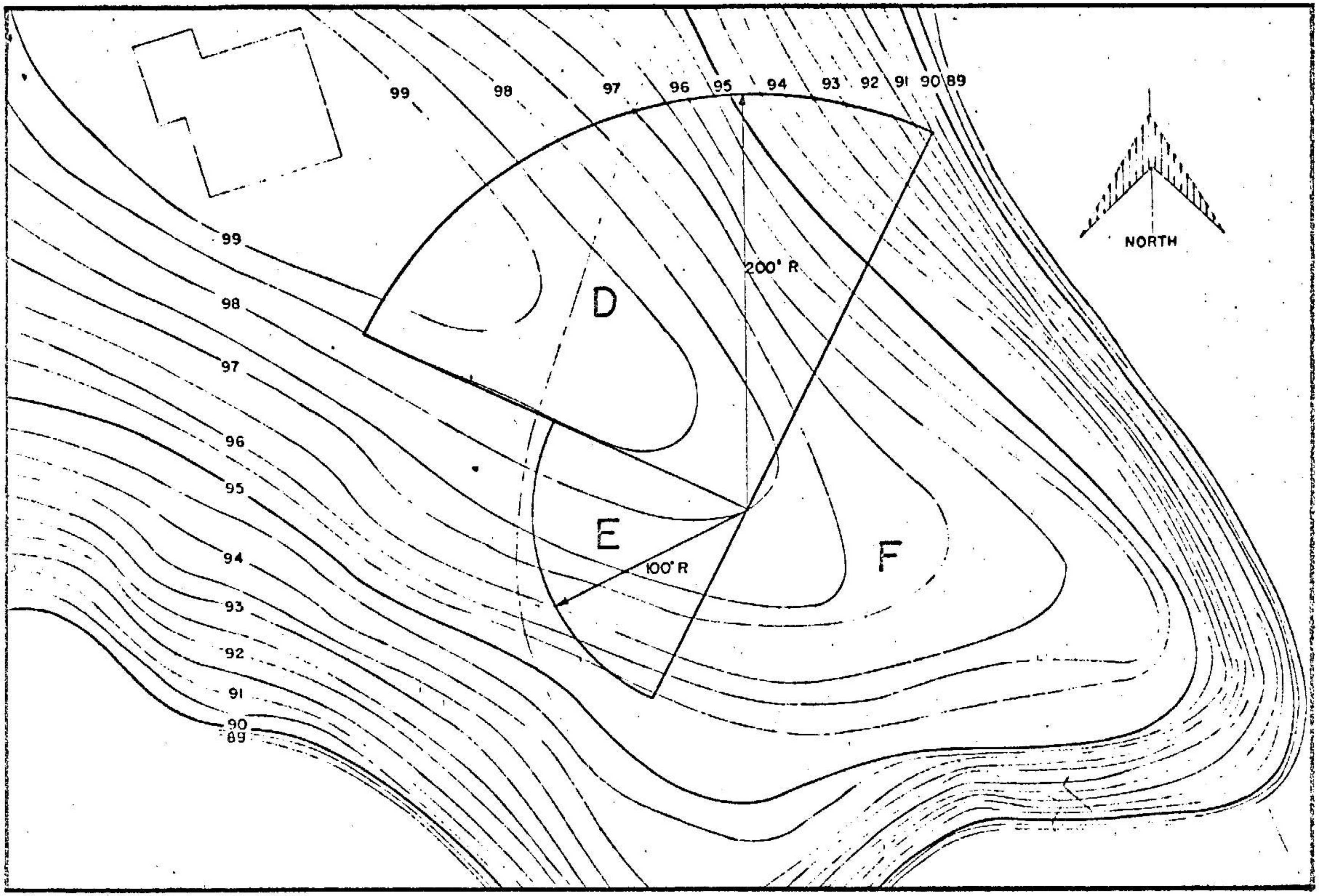

Figure A-7 **GRADING PLAN**

Data provided by the Applied Mechanics Department yielded a computed mass thickness of 47 psf for the test panel. To confirm this, an independent experiment was performed to measure indirectly the mass thickness. Test cylinders were poured along with the test panel. The mass thickness of each test cylinder was measured and a radiation-attenuation experiment was performed to determine the ratio of the mass thicknesses of the test panel and test cylinder.

The mass thickness of the test panel at the point of observation (center, 3 ft above grade) was determined by a comparison of the attenuation of ^{60}Co gamma rays in the test panel and the test cylinder. The experimental configuration is shown in Figure A-8. The source was nominally 5 mCi. A dose-ratemeter was used in a 2-in. lead collimator. The test cylinder was surrounded by at least 4 in. of lead to prevent gamma-ray scattering from nearby surfaces contributing to the dose rate.

If R is the ratio of the dose rate for the test cylinder to the dose rate for the test panel, then the mass thickness X of the test panel is

$$X = X_o + (\mu/\rho)^{-1} \ln R$$

in which X_o is the mass thickness of the test cylinder and (μ/ρ) is the gamma-ray mass attenuation coefficient for concrete. Two test cylinders were used; two dose-ratemeters were used; and for each case duplicate measurements were made. The result, along

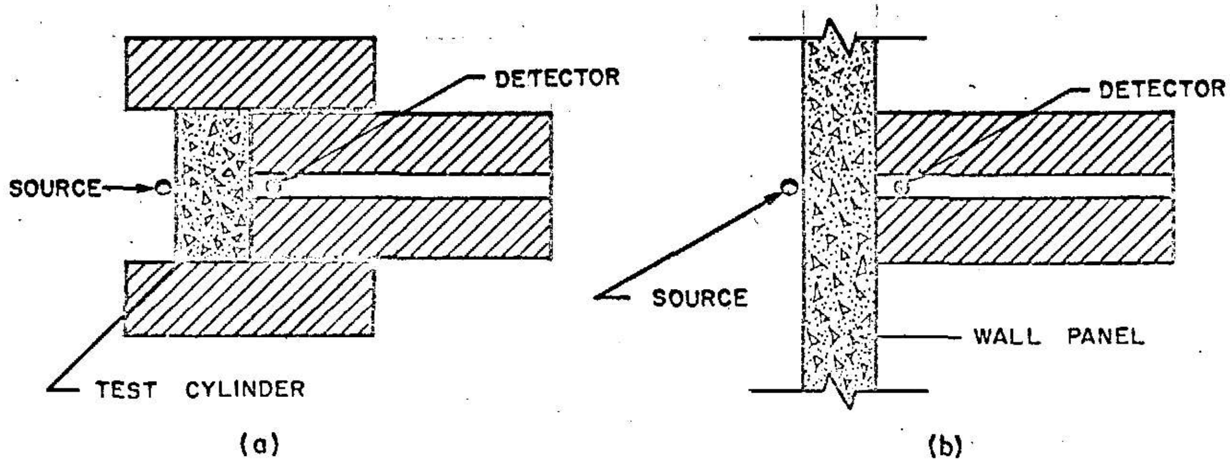

Figure A-8 Measurement of test panel mass thickness.

with the standard deviation, was

$$X = 48 \pm 1 \text{ psf.}$$

To investigate the variation in mass thickness of the test panel, measurements of the type described above were performed at intervals of 1 ft along a horizontal line 3 ft above grade. All the mass thicknesses were within 4 percent of the mass thickness at the center.

2.2.3 The Collimator-Spectrometer System

The experiments described in this report relied to a great extent on a collimator-spectrometer system developed at the KSUNESF. A machine drawing of the system is shown in Figure A-9. The design of a collimator system for gamma-ray spectroscopy involves many, sometimes conflicting, requirements. Some of the more important considerations for the present case are as follows: The collimator housing should be highly mobile, capable of being "aimed" in any direction and easily supportable for lifting. It should be small and light as possible, provide effective shielding, have good temperature control, permit interchange of different-sized, lead-lined apertures, allow insertion of detectors of different size and type at the center of rotation of the collimator housing, and have access for instrument cables. The collimator system described below achieves a reasonable compromise of these sometimes conflicting requirements at a modest cost.

The collimator housing, made of lead, is a cylinder, 1.5 ft in diameter and 3 ft in length. It is mounted in the yoke of a

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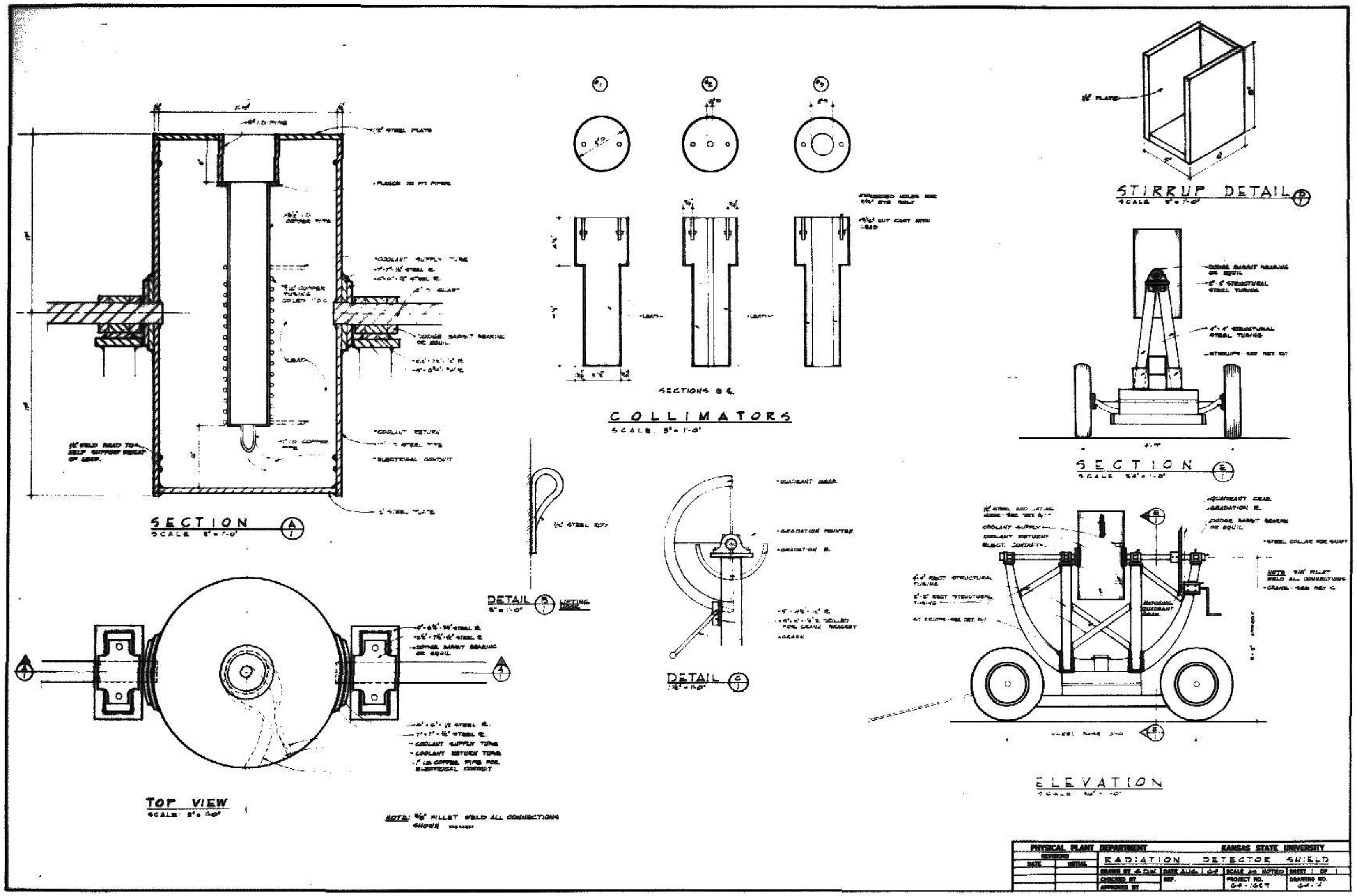

Figure A-9 Machine drawing of collimator system.

surplus military anti-aircraft searchlight. Use of the searchlight yoke assembly restricted the detector height to 5 ft-2 in. above the surface on which the collimator rested. On a level, smooth surface, one person could easily move and position the collimator. The bearings at the base of the yoke assembly allowed easy rotation of the yoke with the 3500-lb housing in place. The housing could be tilted and rotated through 360°; however, the geometrical configuration used in a given experiment usually constrained the movement to less than this amount. Collimator apertures up to 3 inches could readily be accommodated under this design. The housing was designed to provide a minimum of six inches of lead shielding around the central cavity.

Three fourteen-inch-long stepped cylindrical collimator inserts, made of lead, were constuucted for this collimator housing. Half-inch and two-inch-diameter apertures were accurately drilled through the centers of two of these collimator inserts. The third collimator insert was left solid for use in background determinations.

Copper tubing, 5/16 inch in diameter, was wound at one-inch centers around the central cavity prior to pouring the lead to facilitate temperature control of the central cavity during experimental usage. A circulating water pump heater was used to pump two gallons per minute of water from a constant-temperature bath through these coils, thus maintaining the collimator housing at a constant temperature. This temperature was usually chosen close to and slightly above the maximum ambient temperature so that the heat sink of the collimator housing would minimize the temperature "drift" of the detector system. This pump was mounted on the base of the collimator yoke (see Figure A-10).

The central cavity was designed to accommodate a three-inch by three-inch sodium iodide (thallium activated) crystal (Harshaw Model 12S12) with attached three-inch photomultiplier tube (RCA Model 8054) and tube base electronics. The dynode voltages were set to those recommended by RCA for the voltage-divider resistance string of these electronics. The center of the crystal of this "integral line assembly" was positioned at the center of rotation of the collimator housing.

A nuvistor White cathode-follower preamplifier (Hammer Model N-356) was positioned just outside the collimator housing with the requisite power supply (Kepco Model 413-2AM) and was connected to the signal cable approximately three feet from the photomultiplier tube base. The preamplifier drove one thousand feet of triaxial cable (Belden 8232) to a 400-channel pulse-height analyzer (Technical Measurements Corporation Model 402-6) with dead time meter and blower base unit. Spectra generated were simultaneously typed on a computer typewriter (TMC Model 530) and punched on perforated paper tape by a Tally punch unit (TMC Model 540R) for subsequent computer reduction. A tape-to-card punch unit (IBM Model 046) was used to convert the punched paper tape output to IBM punched card format. A type-punch-read unit (TMC Model 520) controlled the spectral readout. A paper tape reader

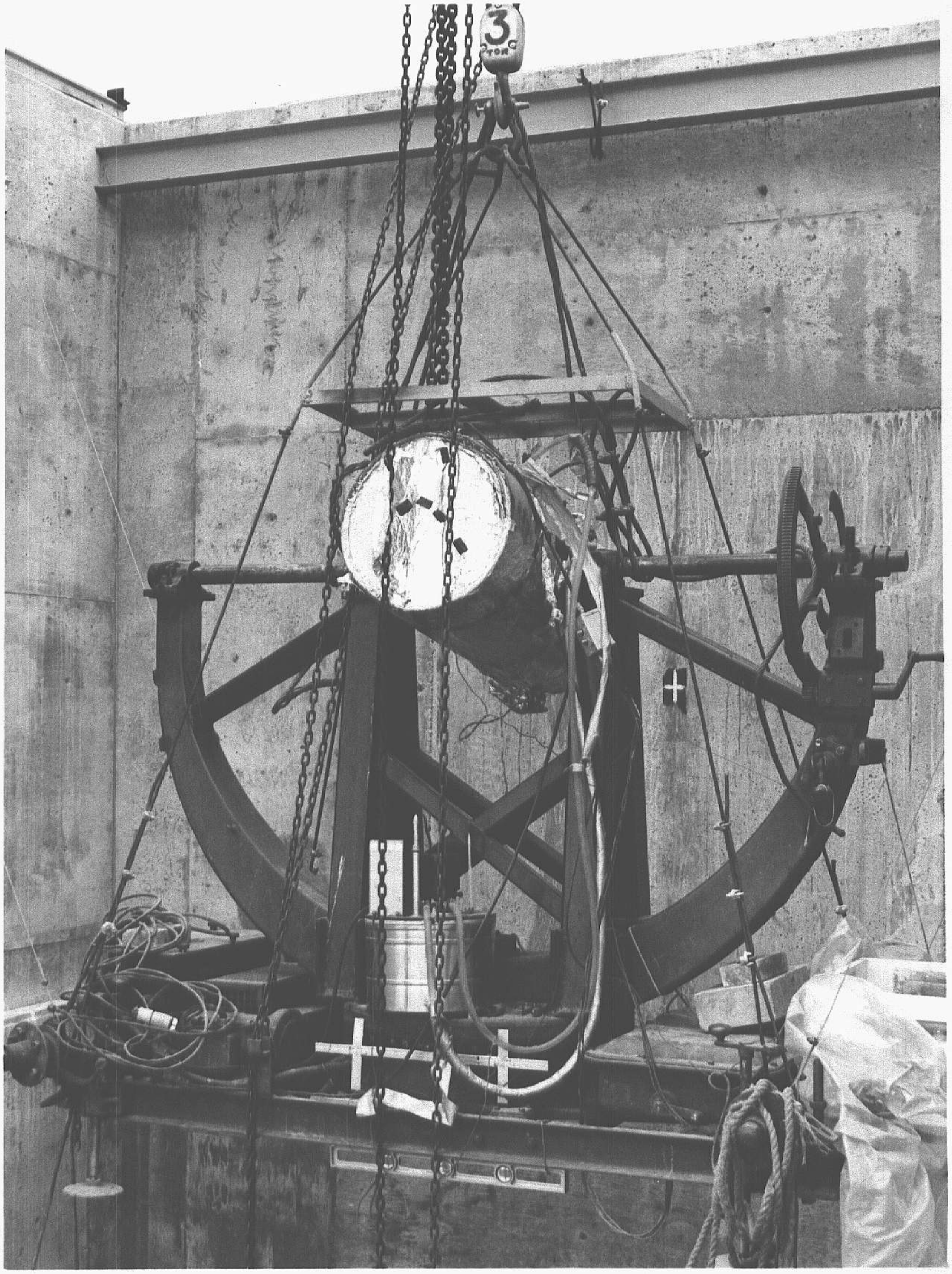

Figure A-10 View of collimator.

(Tally Model 420 PR) was also available to read the tapes back into the analyzer memory. One-thousand feet of high voltage power coaxial cable (Belden 8237) connected a high voltage power supply (John Fluke Model 412A), operated at +1100 volts, to the electronics of the photomultiplier tube base.

In this work a bridge crane was installed in the test structure to suspend the collimator at any desired point behind (on the cold side of) the test panel. High voltage and signal cables connecting the scintillator and preamplifier to the multichannel pulse-height analyzer were encased in plastic pipe and buried at a depth of 1 ft. Burial of the cables has been very successful in that previously encountered atmospheric and radio interference problems have been eliminated. Furthermore, deterioration of the cable by weathering and rodent attack seems no longer to be a problem.

2.3 Experimental Methods

2.3.1 Plane Source Simulation

A plane source of fallout is simulated by ^{60}Co sources using a hydraulic source-circulation system. Areas on which polyethylene tubing was laid for source circulation are illustrated in Figures A-4 through A-6. The first two tubing areas were used in all experiments. The third tubing area was used only in selected experiments for investigating far-field contributions.

The source circulation system (Tech/Ops Model 539) consists basically of five components: the source, the source storage container (a 2,200-lb lead pig), the hydraulic reservoir, the pump console, and the polethylene tubing. About 10,000 ft of tubing was used. The tubing was Union Carbide type DRD-0600 with 0.25 percent American Cyanamid UV531 ultraviolet inhibitor. Tubing was 5/8-in outside diameter and 3/8-in. inside diameter. Sources were calibrated using a Victoreen Model 570 R-Meter calibrated by the National Bureau of Standards. During calibration, both the source and meter were suspended from 50-ft towers at the KSUNESF.

2.3.2 Quality Control Program

A quality control program to maintain the energy per channel and the total energy range is essential in any gamma-ray scintillation spectrometer system. Extensive investigations[5-8] have indicated that drifts in the system gain and baseline which result in changes in the energy per channel and the total energy range may completely invalidate the calibration of the system.

Drift because of fluctuations in the gain is primarily attributed to small changes in 1) the conversion and optical efficiency of the crystal, 2) the photomultiplier gain and 3) the linear amplifier gain. Gain drift results in a change of the energy per channel of the system. The zero-energy intercept or baseline is determined from the acceptance threshold of the multichannel analyzer. Hence, a baseline drift will uniformly shift the entire spectrum as well as relocate the position of the zero-energy channel.

Changes in the temperature of the scintillation crystal and photomultiplier tube cause the gain of the system to drift. To minimize this effect, the crystal and photomultiplier tube are kept at a constant temperature during the day. In addition, during the summer, the lead collimator is covered with aluminum foil to reflect the sun's rays and keep temperature rises due to accumulation of heat from the sun to a minimum.

The quality control procedure developed utilizes frequent checks of the system using ^{60}Co and ^{137}Cs calibration sources. At the beginning of each day, these sources are used to place the three photopeaks in predetermined channels. Approximately every two hours thereafter during the day a pulse-height distribution is taken with these calibration sources. Corrections are made manually at these times to compensate for any drifts which occur.

In addition to these frequent checks of gain and baseline, a daily check of the multichannel analyzer is made according to the manufacturer's recommendations. These checks insure that the memory location and computer sections of the analyzer are working properly.

Finally, the multichannel analyzer and associated instruments are kept in a temperature controlled room to minimize temperature effects.

The quality control program and the precautionary measures employed in setting up the system proved to be of great aid in maintaining good quality control for the gamma-ray scintillation system. Also, the program has given early indications of system deficiencies and their probable location in the system, thereby saving experimental time which would have otherwise resulted in acquisition of highly erratic experimental data.

2.3.3 Collimator Angular Positions

Figure 3-3 shows the geometry for the wall measurements. Measurements were made with the detector viewing at a point three feet above grade at the following polar and azimuthal angles:

$$\cos \theta_d = 0.1,\ 0.2,\ 0.4,\ +0.7,\ -0.48$$

$$\phi_d = 0°,\ 10°,\ 20°,\ 35°,\ 45°$$

The collimator system is positioned indirectly using a transit. Figure A-11 shows the geometry for computing the transit angles, θ_M and ϕ_M. θ_d and ϕ_d are the required polar and azimuthal angles of the detector position. The quantities that can be measured are A, $s+\ell$, n, e, and ℓ. The necessary relationships to compute the transit angles are derived from Figure 2-11:

$$r' = [(s/\cos\phi_d)^2 + \ell^2 + 2\ s\ell]^{1/2} \qquad \text{(A-1)}$$

$$\sin\phi' = \frac{s}{r'}\ \tan\phi_d \qquad \text{(A-2)}$$

$$\phi_M = \sin^{-1}\left[\frac{s\ \tan\phi_d}{(r'^2 + Z^2 - 2\ r'Z\ \cos\phi')^{1/2}}\right] \qquad \text{(A-3)}$$

$$\theta_M = \tan^{-1}\{[\frac{s\ \tan\theta_d}{\cos\phi} - n + e]/[r'^2 + z^2 - 2r'z\ \cos\phi']^{1/2}\} \qquad \text{(A-4)}$$

The distance n is fixed by the construction of the collimator system. The height of the point of interest on the wall above the

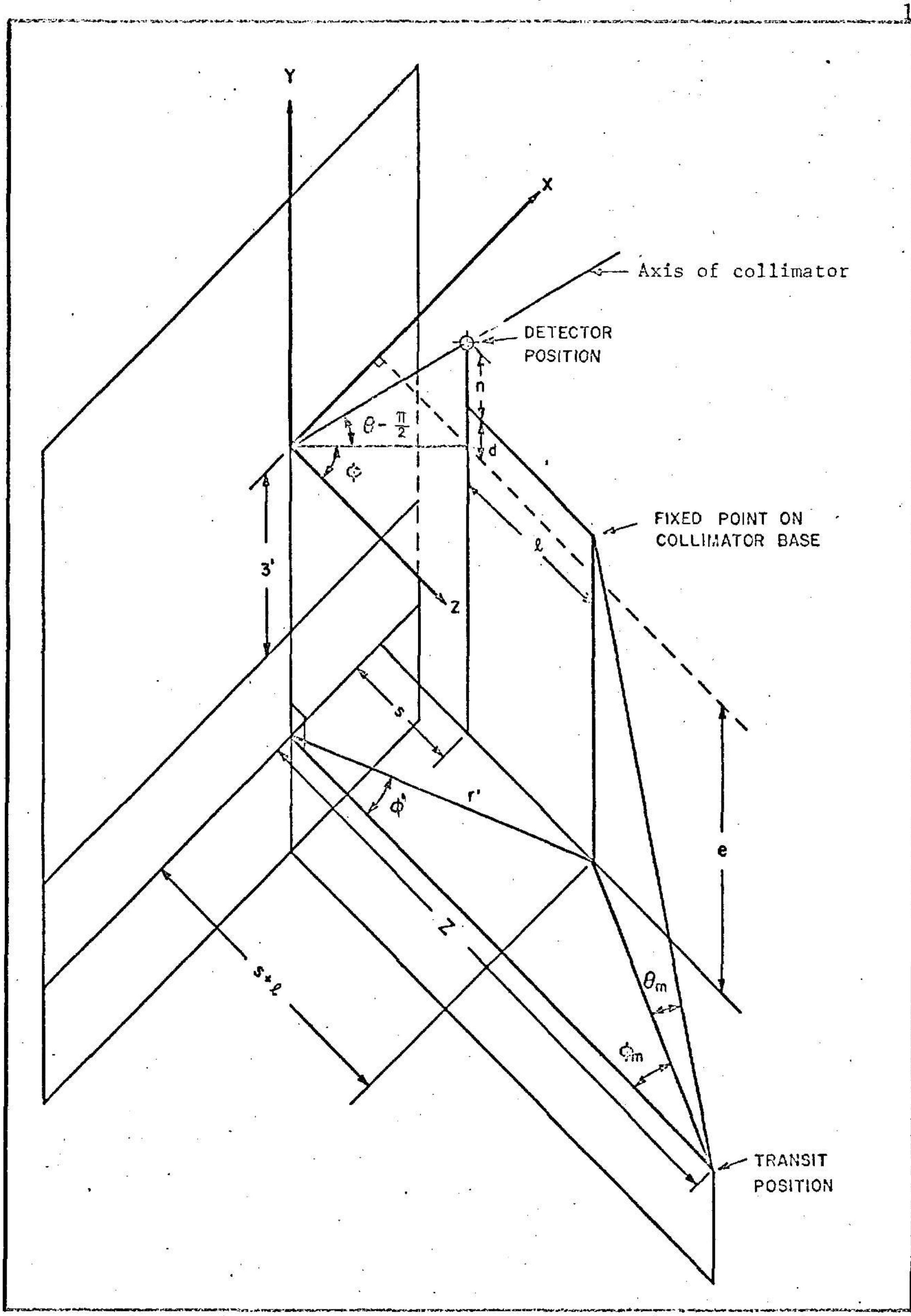

FIGURE A-11 CONFIGURATION FOR COLLIMATOR POSITIONING AND ALIGNMENT.

floor, e, is fixed by the construction of the test structure. The distance ℓ was chosen by fixing a convenient point on the collimator base. The distances Z and s may be varied.

Equations (A-3) and (A-4) were used to determine the best choice of Z and s. These were chosen in such a way that when the angles θ_d and ϕ_d are varied, there are measureable changes in θ_M and ϕ_M. Once Z and s are determined, the transit angles can be computed for all angles of interest.

An additional aid to positioning the collimator is a system of winches and pulleys shown schematically in Figure A-12. In addition, two spirit levels are attached to the collimator base. The use of a plumb line together with the winches, pulleys, and spirit levels allow the collimator to be positioned accurately at the desired angular position once the collimator has been raised to the correct height.

2.3.4 Background Radiation Levels

There are two primary sources of background radiation: skyshine and radiation penetrating the 8" concrete supporting walls for the test panel. In either case, gamma rays would have to be at least doubly scattered and the intensity would be expected to be very low indeed.

Background radiation from source area 1 would be the greatest contribution. Therefore measurements were made for that area only. Lead bricks were stacked 8" thick, 3' wide, and 6' high in front of the test slab. For this test, a 5-Ci source was

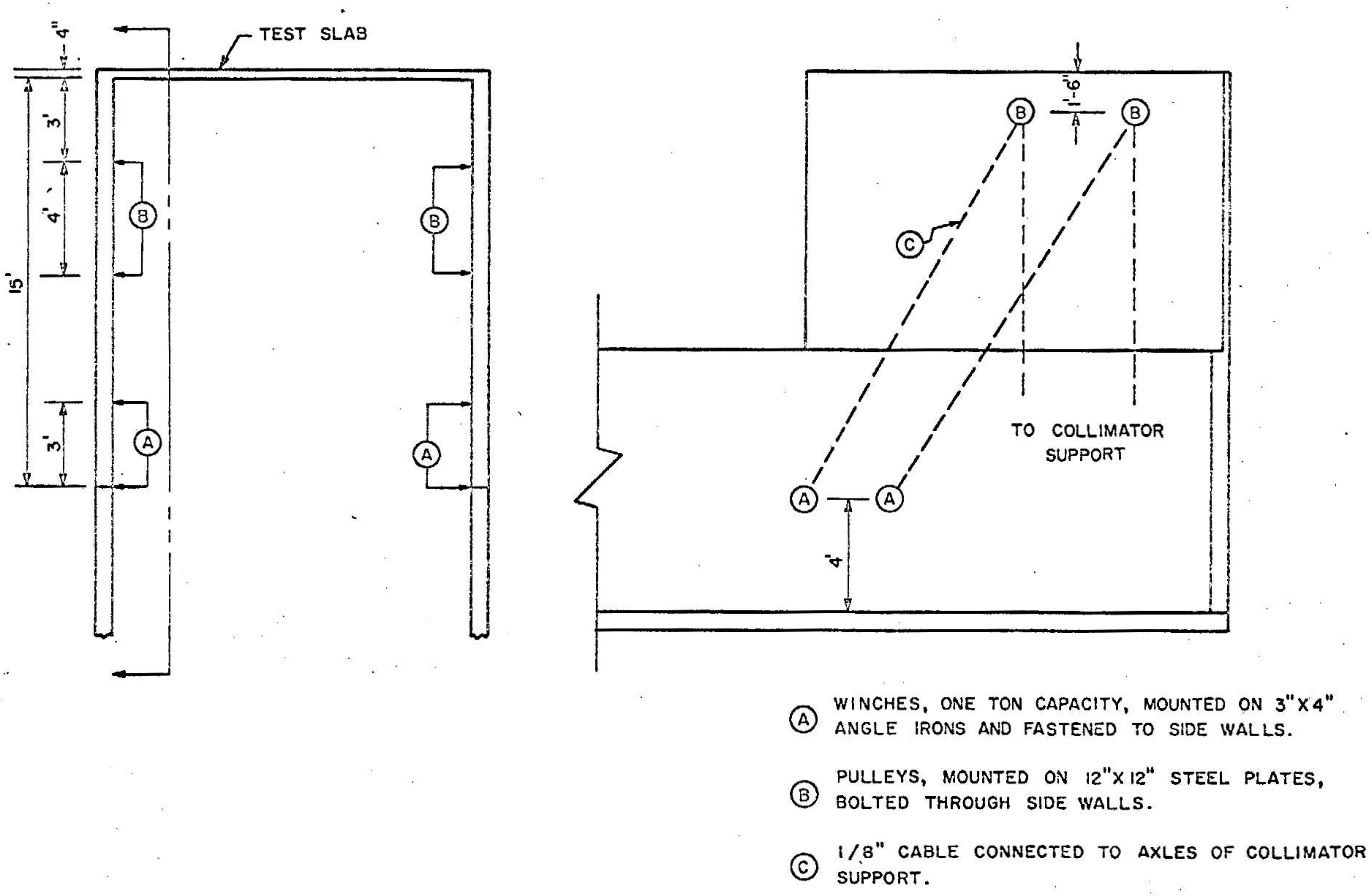

Figure A-12 Winch and pulley locations for collimator leveling system.

used. For the test without shielding, a 32-mCi source was used. Figure A-13 shows the double differential flux for the two cases on a relative scale. Overall, the background, even for area 1, is only about 2 percent of the total. No further background measurements of this type were made.

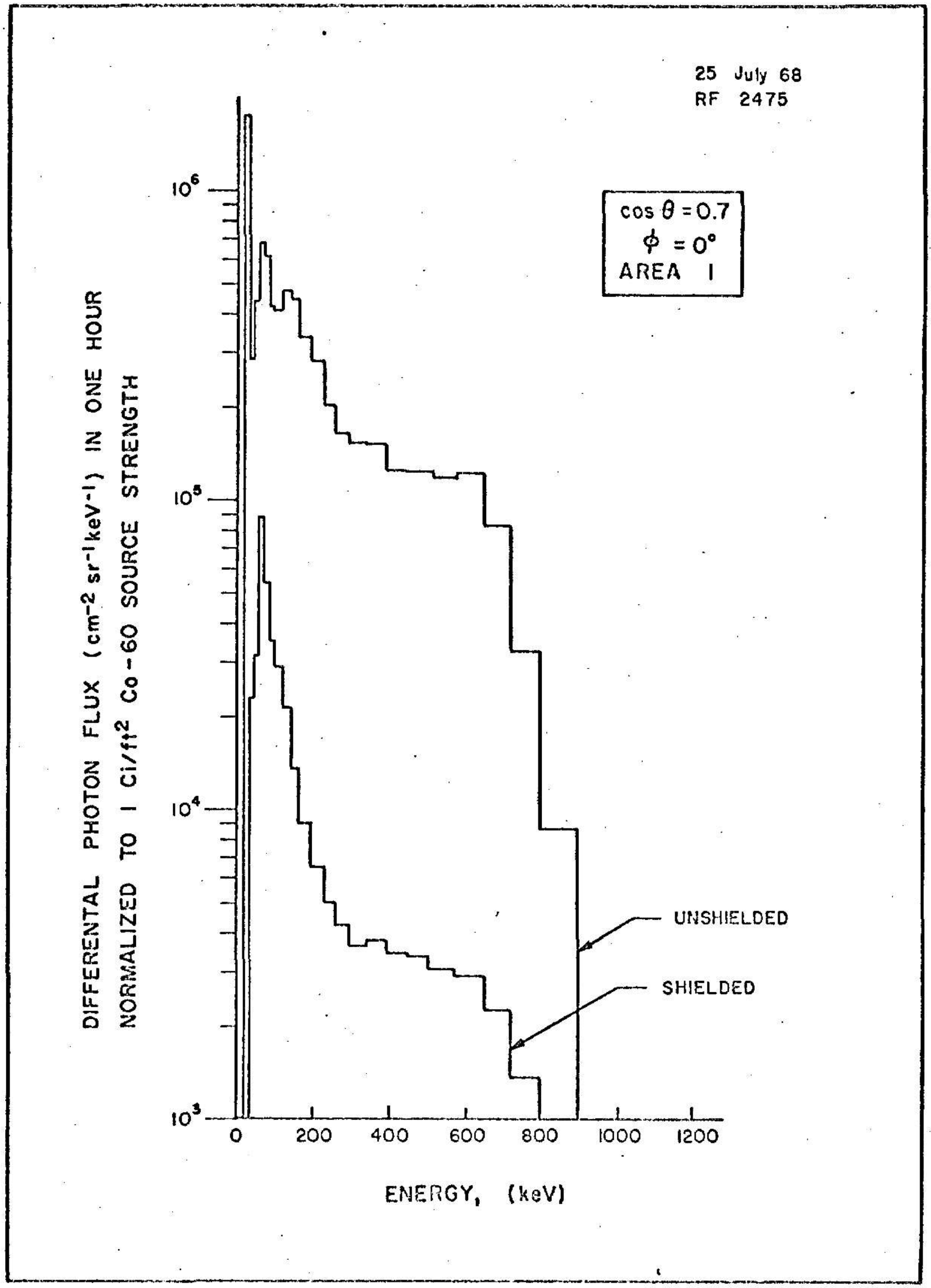

Figure A-13 Comparison of background spectrum with total spectrum.

APPENDIX B

INFINITE SOURCE APPROXIMATION

It was necessary to determine a distance R_N, the radius of a semi-circular, plane radiation source, such that the finite source would approximate a semi-infinite source within a prescribed allowable error. The single scattered differential flux for a specified η and ξ is given by Equation 2-1. The distance m from the source plane to the scattering point is a function of η, ξ, r, ν, and x as defined in Section 2.0. In Appendix C this relationship is shown to be

$$m\ (\mathrm{ft}) = \{r^2 + 2rx\cos\nu\tan\xi + x^2[2\tan^2\xi + \tan^2\eta] + H^2 + 2Hx(\tan^2\xi + \tan^2\eta)^{1/2}\}^{1/2}. \quad \text{(B-1)}$$

where H is the distance of the target point on the slab above the source plane (see Figure 3-1. For the calculations, the following maximum values were used:

$$\eta,\ \xi < 45° \qquad \tan\eta, \tan\xi < 1$$

$$H = 3\ \mathrm{ft}$$

$$x = 0.333\ \mathrm{ft}$$

$$\nu = 0 \rightarrow \pi \qquad |\cos\nu| < 1.$$

For large values of r (r > 500 ft), m was approximately equal to r. As an example, using the above maximum values and r = 500 ft, m was equal to 500.342 ft. For larger values of η and ξ a larger r would be needed for the approximation of m by r.

With the assumption that $r \simeq m$ and using Equation 2-1, the single scattered flux from a semi-infinite plane source is

$$\Phi_\infty(E,\eta,\xi) \simeq \Phi_{R_1}(E,\eta,\xi) + A(E,\eta,\xi) \int_{R_1}^{\infty} dr\ r^{-1} \exp{-\mu_a(E_\circ)\ r} \quad \text{(B-2)}$$

where $\Phi_\infty(E,\eta,\xi)$ = differential flux from a semi-infinite plane source

$\Phi_{R_1}(E,\eta,\xi)$ = flux contribution from source of radius $r = R_1$

$A(E,\eta,\xi)$ = a constant energy distribution of the flux for large r. Includes the integrals over ν and x. The Compton scattering cross-section becomes independent of r for large r.

R_1 = radius at which $m \simeq r$ and $K(E,E_\circ,\psi)$ is independent of r.

Integrating over energy and converting to an exposure rate leads to the following expression:

$$\begin{aligned} D_\infty(\eta,\xi) &= D_{R_1}(\eta,\xi) + D_A(\eta,\xi) \int_{R_1}^{\infty} dr\ r^{-1} \exp{-\mu_a(E_\circ)\ r} \\ &= D_{R_1}(\eta,\xi) + D_A(\eta,\xi) \int_{R_1}^{R_N} dr\ r^{-1} \exp{-\mu_a(E_\circ)\ r} \\ &\quad + D_A(\eta,\xi) \int_{R_N}^{\infty} dr\ r^{-1} \exp{-\mu_a(E_\circ)\ r} \end{aligned} \quad \text{(B-3)}$$

where $D_\infty(\eta,\xi)$ = exposure rate for a semi-infinite source

$D_{R_1}(\eta,\xi)$ = exposure rate for source of radius $r = R_1$

$D_A(\eta,\xi)$ = constant angular exposure rate for large r

R_N = radius at which calculations are terminated.

The last quantity in Equation B-3, i.e., $D_A(\eta,\xi \int_{R_N}^{\infty} dr\ r^{-1} \times \exp{-\mu_a(E_\circ)\ r}$, is the exposure rate not accounted for in the calculations. $D_A(\eta,\xi)$ may be evaluated by calculating the contribution from the source bounded by R_1 and R_N. This is then set equal to the second term of equation B-3.

$$D_{R_1 \rightarrow R_N}(\eta,\xi) = D_A(\eta,\xi) \int_{R_1}^{R_N} dr\ r^{-1} \exp{-\mu_a(E_\circ)\ r} \qquad \text{(B-4)}$$

$$D_A(\eta,\xi) = D_{R_1 \rightarrow R_N}(\eta,\xi) \,/\{E_1[\mu_a(E_\circ)\ R_1] - E_1[\mu_a(E_\circ)\ R_N]\}$$

$E_1[y]$ is the value of the exponential integral of argument y.

The percentage of the exposure rate not accounted for in the calculations is:

$$L(\%) = 100\ D_A(\eta,\xi) \int_{R_N}^{\infty} dr\ r^{-1} \exp{-\mu_a(E_\circ)\ r} \,/\, D_\infty(\eta,\xi) \qquad \text{(B-5)}$$

For R_N = 2000 ft and R_1 = 1000 ft, L = 0.02%.

APPENDIX C

SAMPLE CALCULATION

A step by step calculation following the logic of the computer code is given for a point source located at r = 10 ft and ν = 45° and the emergent gamma ray traveling in the direction ϕ_D = 30° and θ_D = 45° ($\phi_D = \phi_d$ and $\theta_D = 90° - \theta_d$, see figure C-1). The equivalent η and ξ values are ξ = 30° and η = 52.2°.

The problem is initialized to a reference axis located at the target point on the "cold face" of the slab (Figure C-1). The following parameters are then calculated:

$$z_{so} = H = 3 \text{ ft}$$

$$x_{so} = r\cos(90°-\nu) + t \text{ (wall thickness = 0.33 ft)}$$
$$= 7.40 \text{ ft}$$

$$y_{so} = r\cos(90°-\nu) = 7.07 \text{ ft}$$

$$\phi_{so} = \tan^{-1}(y_{so}/x_{so}) = 43.7°$$

$$\theta_{so} = \tan^{-1}[z_{so}/(y_{so}^2/x_{so}^2)^{1/2}] = 16.65°$$

$$\phi_D = 30° \text{ (specified)}$$

$$\theta_D = 45° \text{ (specified)}$$

$$x_{do} = 1 \text{ ft (specified)}$$

$$y_{do} = x_{do}\tan\phi_D = 0.577 \text{ ft}$$

$$z_{do} = x_{do}\tan\theta_D/\cos\phi_D = 1.155 \text{ ft}$$

The value of x_{do} is arbitrary and is only used as a convenience in the calculations.

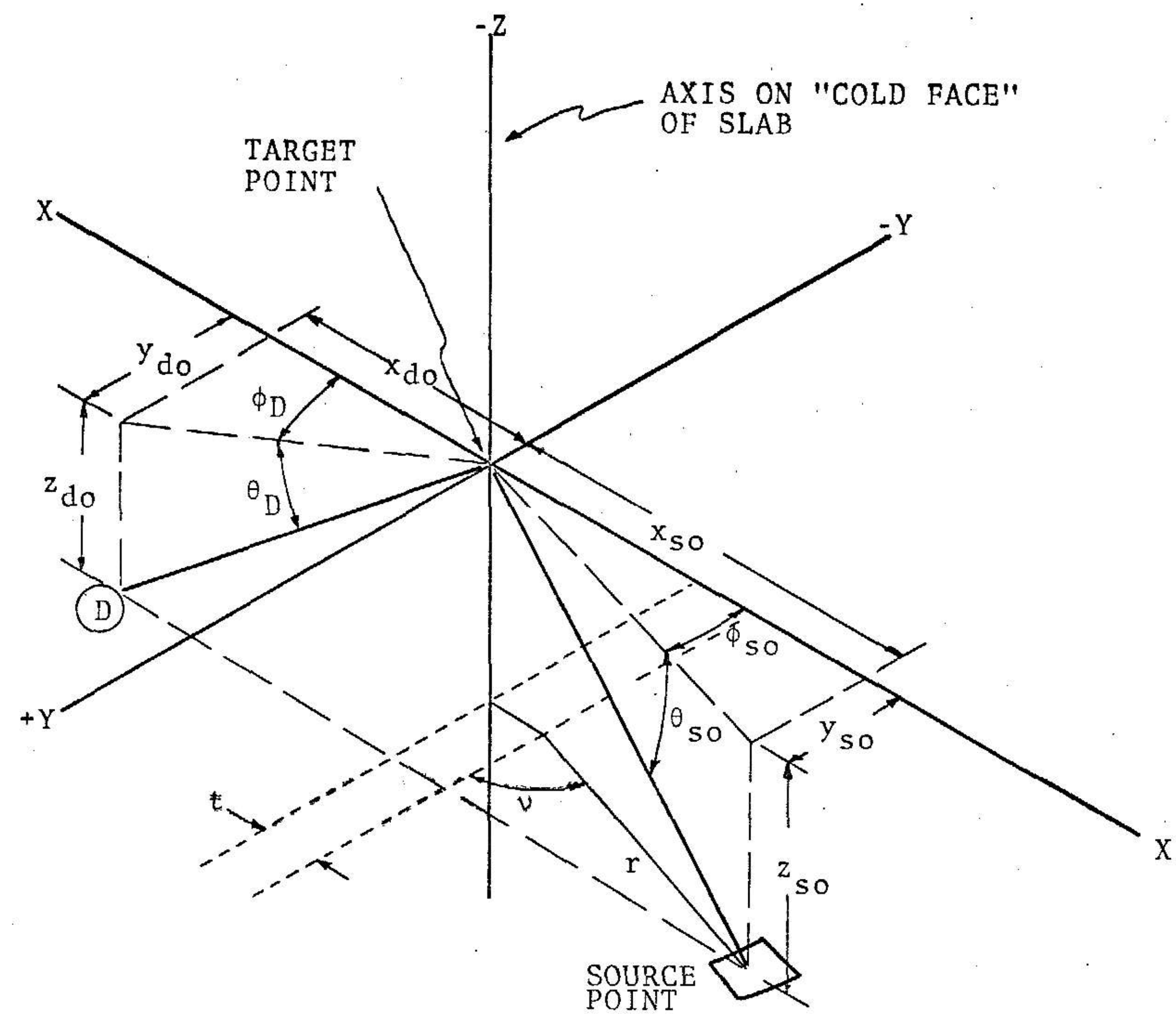

Figure C-1 Initial reference frame used in computer code.

It was assumed all scatterings took place at the midpoint of one of the composite thin slabs. Each slab would be considered separately and the sum of the single-scattered fluxes from each slab taken as the total. In this calculation the slab was subdivided into 5 thin slabs (NOVOL = 5) and only the third thin slab in from the cold surface considered. The width of each thin slab is $\ell = t/5 = 0.066$ ft.

To obtain the correct scattering angle and attenuation distances a new reference frame is located at the point where a line defined by ϕ_D and θ_D intersect the mid-point plane of the desired thin slab. A new set of coordinates for the source point and detector are obtained by adding or subtracting a quantity Δx_i, Δy_i, Δz_i to the initial coordinates (Figure C-2):

$$i = \text{the number of the thin slab} = 3$$

$$\Delta x_i = \ell(i-1/2) = 0.165 \text{ ft}$$

$$\Delta y_i = \Delta x_i \tan\phi_D = 0.095 \text{ ft}$$

$$\Delta z_i = \Delta x_i \tan\theta_D/\cos\phi_D = 0.191 \text{ ft}$$

$$x_{si} = x_{so} - \Delta x_i = 7.235 \text{ ft}$$

$$y_{si} = y_{so} + \Delta y_i = 7.165 \text{ ft}$$

$$z_{si} = z_{so} + \Delta z_i = 3.191 \text{ ft}$$

$$x_{di} = x_{do} + \Delta x_i = 1.165 \text{ ft}$$

$$y_{di} = y_{do} + \Delta y_i = 0.672$$

$$z_{di} = z_{do} + \Delta z_i = 1.346 \text{ ft.}$$

The new source point angles θ_{si} and ϕ_{si} are also calculated:

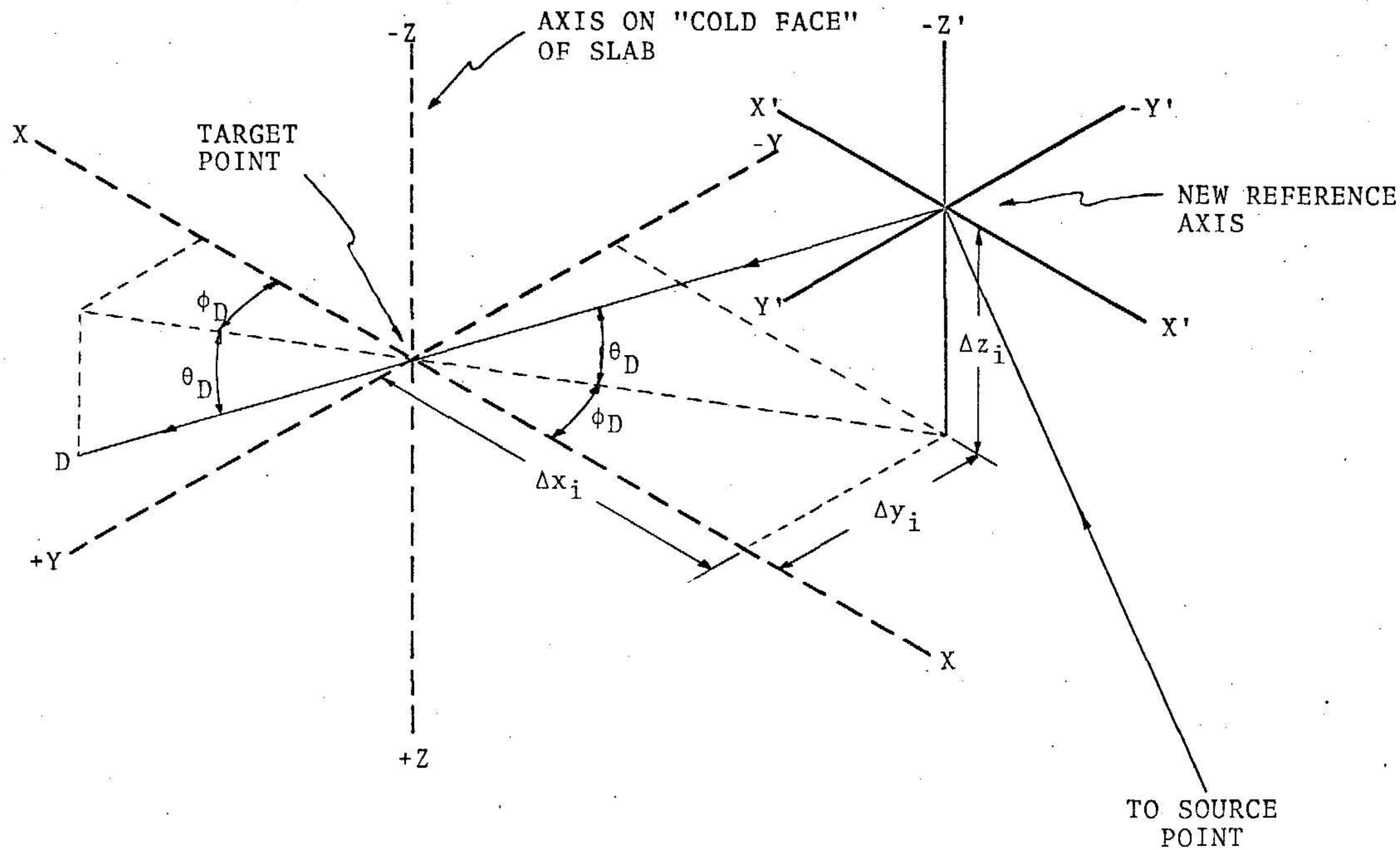

Figure C-2 Secondary reference frame used in single scattering computer code.

$$\phi_{si} = \tan^{-1}(y_{si}/x_{si}) = 44.78°$$

$$\theta_{si} = \tan^{-1}[z_{si}/(x_{si}^2 + y_{si}^2)^{1/2}] = 17.4°$$

All unknown quantities in Equation 2-2 can now be calculated.

1) m = the distance from the source plane to the scattering point

$$= z_{si}/\sin\theta_{si} = 10.671 \text{ ft}$$

m can also be expressed in terms of η,ξ,r,ν,x; $H = 3$ ft

$$m = \{r^2 + 2rx\cos\nu\tan\xi + x^2[2\cdot\tan^2\xi + \tan^2\eta] + H^2 + 2Hx(\tan^2\xi + \tan^2\eta)^{1/2}\}^{1/2}$$

2) $[m_{i,j,k} - \ell(i-1/2)\sec\eta_o]$ = the distance in air of the incident photon.

$$= [x_{si} - \ell(\text{NOVOL} - i + 1/2)]/\cos\theta_{si}\cos\phi_{si})$$

$$= 10.438 \text{ ft}$$

3) $\ell(i-1/2)\sec\eta_o$ = the distance in concrete of the incident photon

$$= m - \text{quantity } 2 = 0.233 \text{ ft}$$

4) $[t - \ell(i-1/2)]\sec\eta$ = the distance traveled in concrete by the scattered photon.

$$= \Delta x_i/(\cos\phi_D \cos\theta_D) = 0.2694 \text{ ft}$$

5) $K(E_o,E,\psi)$ = Compton scattering cross section defined by Equation 3-3. $E_o = 1.25$ MeV and $r_o = 2.82\times10^{-13}$cm. $\cos\psi$ is calculated as follows:

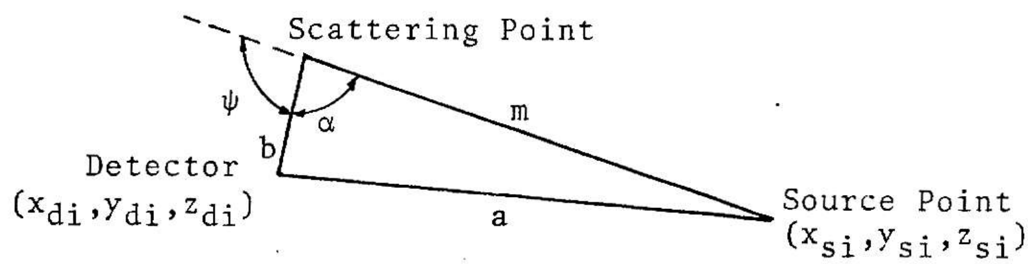

FIGURE C-3 Triangle defined in the scattering plane.

TABLE C-1 Values of the mass attenuation coefficient μ/ρ, less Rayleigh (coherent) scattering and the photonuclear effect, for air and concrete.[9]

Photon Energy (MeV)	Air (cm^2/g)	Concrete (cm^2/g)
0.01	4.82	26.5000
0.015	1.45	8.0100
0.02	0.691	3.44
0.03	0.318	1.12
0.04	0.229	0.559
0.05	0.196	0.361
0.06	0.179	0.273
0.08	0.162	0.201
0.10	0.151	0.171
0.15	0.134	0.140
0.20	0.123	0.125
0.30	0.106	0.107
0.40	0.0954	0.0957
0.50	0.0868	0.0872
0.60	0.0804	0.0806
0.80	0.0706	0.0708
1.00	0.0635	0.0637
1.50	0.0517	0.0519
2.00	0.0444	0.0493
3.00	0.0358	0.0365
4.00	0.0308	0.0319
5.00	0.0276	0.0290
6.00	0.0252	0.0270
8.00	0.0223	0.0245

$a = [(x_{di} + x_{si})^2 + (y_{di} - y_{si})^2 + (z_{di} - z_{si})^2]^{1/2}$

$= 10.777$ ft

$b = [x_{di}^2 + y_{di}^2 + z_{di}^2]^{1/2} = 1.902$ ft

$m = 10.671$ ft

$a^2 = b^2 + m^2 - 2bm \cos\alpha$

$\cos\psi = -\cos\alpha = -0.0331$

$K(E_\circ, E, \psi) = 0.4487 \times 10^{-26} (cm^2\ sr^{-1})$

$= 0.4829 \times 10^{-29} (ft^2\ sr^{-1})$

6) $\mu_c(E)$ = attenuation coefficient in concrete for the scattered photon.

The energy of the scattered photon, E, is calculated by Equation 2-3 (E = 0.354 MeV). The attenuation coefficient is obtained from a table using linear interpolation ($\mu_c(E) = 6.96$ ft^{-1}). These values are presented in Table C-1[9].

7) $\mu_a(E_\circ)$ and $\mu_c(E_\circ)$ = the attenuation coefficient in air and concrete respectively for the incident photon.

$\mu_a(E_\circ) = 0.00215$ ft^{-1}

$\mu_c(E_\circ) = 3.97$ ft^{-1}

8) $\sec\eta$ = secant of the exit polar angle

$= 1/(\cos\theta_D \cos\phi_D) = 1.633$

9) $S_A\ r_i\ \Delta r_i\ \Delta\nu_j$ = the source strength from a small area of the source plane.

= 1 photon/sec for case being considered.

10) n = electron density of slab = $1.93\ 10^{28}$ ft^{-3}

The differential flux for the sample case can be evaluated from:

$$\Phi_d(E,\eta,\xi) = \frac{S_A\ r_i\ \Delta r_i\ \Delta\nu}{4\pi}\ m^{-2}\ K(E_o,E,\psi)\ n\ \ell\ \exp-\{\mu_a(E_o)[m_{i,j,k}$$

$$-\ \ell(i-1/2)\ \sec\eta_o] + \ell(i-1/2)\ \sec\eta_o\ \mu_c(E_o)$$

$$+\ [t - \ell(i+1/2)]\ \sec\eta\ \mu_c(E)\}$$

$$\Phi_d(E,\eta,\xi) = 2.55 \times 10^{-7}\ (ft^{-2}sec^{-1}sr^{-1})$$

$$= 2.74 \times 10^{-10}(cm^{-2}sec^{-1}sr^{-1})$$

Since the energy of the flux is known it can be easily binned into one of the 27 energy bins of Table 3-1.

APPENDIX D

```
C      SINGSCAT - PROGRAM FOR CALCULATING THE DIFFERENTIAL WALL SINGLE SCATTERED
C                 FLUX FROM A PLANE SOURCE  SEPT. 1969
C
C      VARIABLES READ INTO THE PROGRAM
C           1) B(M) = THE UPPER ENERGY LIMIT OF ENERGY BIN M  (MEV)
C           2) CONV(M) = CONVERSION FACTOR FOR CHANGING THE FLUX IN BIN M TO AN
C                        EXPOSURE RATE
C           3) ENG(I) = THE ENERGY AT WHICH MASS ATTENUATION COEFFICIENTS XMU(I)
C                       ARE KNOWN.  USED IN SUBROUTINE INTERP.  (MEV)
C           4) XMU(I) = MASS ATTENUATION COEFFICIENTS FOR SUBROUTINE INTERP
C                       (CM.SQ./GM)
C           5) EO = ENERGY OF GAMMA RAY  (MEV)
C           6) NOVOL = NUMBER OF THIN SLABS USED IN CALCULATION
C           7) DELR = SIZE OF RADIAL INCREMENTS IN SOURCE PLANE USED IN
C                     SUMMATION  (FT)
C           8) RMIN = MINIMUM RADIUS OF SOURCE  (FT)
C           9) RMAX = MAXIMUM RADIUS OF SOURCE  (FT)
C          10) DELANG = SIZE OF AZMUTHAL ANGLE INCRIMENTS IN SOURCE PLANE  (RAD)
C          11) ANGMAX = MAXIMUM AZMUTHAL ANGLE OF SOURCE  (RADIANS)
C          12) ANGMIN = MINIMUM AZMUTHAL ANGLE OF SOURCE  (RADIANS)
C          13) VERAN = VERTICLE ANGLE OF EMERGENT GAMMA RAY.  IT IS
C                      90 DEGREES MINUS THE POLAR ANGLE MEASURED FROM THE
C                      Z-AXIS EMANATING DOWNWARD FROM THE TARGET POINT.
                       NOTE, ALL ANGLES ABOVE THE HORIZON ARE NEGATIVE.(DEG)
C          14) HORAN = HORIZONTAL ANGLE OF EMERGENT GAMMA RAY.  THE ANGLE BETWEEN
C                      A PLANE PERPENDICULAR TO BOTH THE GROUND AND WALL AND A
C                      AND A PLANE PERPENDICULAR TO THE GROUND PASSING THROUGH
C                      THE DETECTOR AND TARGET POINT ON THE WALL.  (DEGREES)
C          15) IPRINT - IF IPRINT = 1 AN ENERGY SPECTRA WILL BE PRINTED OUT AND
C                       ONE SET OF FLUXES ZEROED.  THERE IS ANOTHER SET OF FLUXES
C                       THAT WILL CONTINUE TO SUM FROM DIFFERENT PARTS OF THE
C                       SOURCE PLANE
C          16) JPRINT - IPRINT MUST = 1 BEFORE JPRINT WILL ACTIVATE ITS OUTPUT.
C                       IF JPRINT = 2 THEN A SUM OF ALL PREVIOUS FLUXES WILL BE
C                       PRINTED AND CARDS PUNCHED.    NOTE - IF JPRINT IS USED
C                       ALL FLUXES WILL BE ZEROED AND NEXT DATA CARD WILL START
C                       NEW SUMMATIONS
      DIMENSION DOSE(27),CONV(27)
      DIMENSION B(27),TC(27),XMU(18),ENG(18)
      DIMENSION TCC(27),TCE(27),TCCE(27)
      DIMENSION ATC(27),ATCC(27),ATCE(27),ATCCE(27)
      DIMENSION FONEE(27),FONE(27),FTWOE(27),FTWO(27),SUM(27),SUME(27)
  100 FORMAT('1')
   77 FORMAT(14X,'VERAN = ',F6.2,5X,'HORAN = ',F6.2,5X,'INITIAL ENERGY
     1EQUAL ',F6.2,5X,'VOLNO = ',I3//)
   78 FORMAT(14X,'DELR = ',F6.2,5X,'RMIN = ',F7.2,5X,'RMAX = ',F7.2,
     15X,'DELANG = ',F8.6,5X,'ANGMAX =',F8.6,5X,'ANGMIN = ',F8.6//)
   79 FORMAT(14X,'R DO LOOP PARAMETER(NR) = ',I4,5X,'ANG DO LOOP
     1PARAMETER(NANG) = ',I4//)
   80 FORMAT(F5.2,2F10.2,3F11.6,2F9.2,2I2)
```

```
120 FORMAT(12X,'ENERGY LIMITS')
121 FORMAT(3X,'BIN NO.',5X,'ON BIN',6X,'(PHOTONS/SQ.CM.-SEC)/SR',4X,
   1'(PHOTONS/SQ.CM.)/SR',4X,'(PHOTONS/SQ.CM.-SEC)/(KEV-SR)',2X,
   2'(PHOTONS/SQ.CM)/(KEV-SR)')
122 FORMAT(16X,'(KEV)',6X,'PER   PHOTON/SQ.FT.-SEC',2X,'PER   CURIE CO
   1-60/SQ.FT',5X,'PER   PHOTON/SQ.FT.-SEC',5X,'PER   CURIE CO-60/SQ.F
   2T'//)
123 FORMAT(6X,'1',4X,F7.2,'-',F7.2,6X,E14.8,11X,E14.8,14X,E14.8,14X,
   1E14.8)
124 FORMAT(5X,I2,4X,F7.2,'-',F7.2,6X,E14.8,11X,E14.8,14X,E14.8,14X,
   1E14.8)
125 FORMAT(///18X,'TOTAL DOSERATE = ',E14.8,' MR/HR'/)
126 FORMAT(10X,5E18.8)
127 FORMAT(///18X,'TOTAL DOSERATE = ',E14.8,' MR/HR')
128 FORMAT('DOSERATE BY THE BIN')
131 FORMAT(18X,'TOTAL FLUX = ',E14.8//)
132 FORMAT(18X,'GREATER THAN EMAX = ',F14.8,5X,'LESS THAN EMIN = '
   1,E14.8//)
230 FORMAT(9F8.3)
231 FORMAT(5E14.8)
510 FORMAT(18X,'COS THETA = ',F7.3,'PHI = ',F8.3,'ENERGY = ',F6.3)
511 FORMAT(5E16.8)
512 FORMAT(2E16.8)
513 FORMAT(F6.3,I3)
514 FORMAT(6X,'1',4X,F7.2,'-',F7.2,6X,E14.8,6X,E14.8)
515 FORMAT(5X,I2,4X,F7.2,'-',F7.2,6X,E14.8,6X,E14.8)
516 FORMAT(///18X,'TOTAL DOSE = ',E14.8,'  MR/HR')
517 FORMAT(50X,'1.17 MEV AND 1.33 MEV SUMMED'//)
518 FORMAT(32X,'(CM-2/CI/FT+2)',6X,'(CM/2/DELE*CI/FT+2)'//)
519 FORMAT(18X,'COS THETA = ',F7.3,5X,'PHI = 'F8.3//)
520 FORMAT(5X,'SUMMED SPEC',3X,'COS THETA = ',F7.3,5X,'PHI = ',F8.3)
521 FORMAT(/18X,'ANG = ',E14.8,'R = ',F8.2,'AREA = ',E14.8/)
523 FORMAT(E16.8)
    READ(1,230)(B(M),M=1,27)
    READ(1,231)(CONV(I),I=1,27)
 99 FORMAT(18F4.2)
    READ(1,99)(ENG(I),I=1,18)
 98 FORMAT(10F7.4)
    READ(1,98)(XMU(I),I=1,18)
    DO 822 L=1,27
    TCE(L)=0.0
    TCCE(L)=0.0
    TCC(L)=0.0
822 TC(L)=0.0
    DO 823 L=1,27,1
    ATCE(L)=0.0
    ATCCE(L)=0.0
    ATC(L)=0.0
823 ATCC(L)=0.0
    NPTSTP=2
    IMAXTP=18
```

```
      AMUA=2.15E-03
      AMUC=3.97
      SA=1.0
      EMAX=1425.
      EMIN=20.0
      WALL=.3333333
      XDO=5.
      ZSO=3.
      ED=1.93E 28
      RO=2.82E-13
      UNDER=0.0
      EXCEDE=0.0
      DUMFT=0.0
      ATDOSE=0.
  669 READ(1,513)EO,NOVOL
      IF(EO.LT.0.0)GO TO 668
      VOLNO=NOVOL
      GAMMA=EO/.51
      H=WALL/VOLNO
  555 READ(1,80)DELR,RMIN,RMAX,DELANG,ANGMAX,ANGMIN,VERAN,HORAN,IPRINT,
     1JPRINT
      IF(DELR.LT.0.0)GO TO 669
      THED=(3.141593/180.)*VERAN
      PHID=(3.141593/180.)*HORAN
      NR=(RMAX-RMIN)/DELR
      NANG=(ANGMAX-ANGMIN)/DELANG
      R=(DELR/2.)+RMIN
      DO 200 I=1,NR,1
      AREA=DELANG*DELR*R
      SO=SA*AREA
      ANG=(DELANG/2.)+ANGMIN
      DO 300 J=1,NANG,1
      XSO=.3333+R*SIN(ANG)
      YSO=R*COS(ANG)
      XSS=XSO-WALL
      DO 500 K=1,NOVOL,1
      AN=K
      CDO=XDO/(COS(THED)*COS(PHID))
      XD=XDO+((2.*AN-1.)*H)/2.
      CD=XD/(COS(THED)*COS(PHID))
      CDCON=CD-CDO
      TANPH=SIN(PHID)/COS(PHID)
      TANTH=SIN(THED)/COS(THED)
      DXSN=((2.*AN-1.)*H)/2.
      DYSN=(-(((2.*AN-1.)*H)/2.)*TANPH)
      DZSN=(-(((2.*AN-1.)*H)/2.)*(TANTH/COS(PHID)))
      PHIS=ATAN((YSO-DYSN)/(XSO-DXSN))
      THES=ATAN((ZSO-DZSN)*COS(PHIS)/(XSO-DXSN))
      CS=(XSO-((2.*AN-1.)*H/2.))/(COS(THES)*COS(PHIS))
      CSON=XSS/(COS(THES)*COS(PHIS))
      CSCON=CS-CSON
```

```
      FLUXC=S0*EXP(-(AMUA*CSON+AMUC*CSCON))/(4.*3.141593*CS*CS)
C     CALCULATION OF SCATTERING ANGLE
      YD=CD*SIN(PHID)*COS(THED)
      ZD=CD*SIN(THED)
      XS=CS*COS(PHIS)*COS(THES)
      YS=CS*SIN(PHIS)*COS(THES)
      ZS=CS*SIN(THES)
      ZSQ=(ABS(ZD-ZS))**2.
      ASQ=((ABS(XD+XS))**2.)+((ABS(YD-YS))**2.)+ZSQ
      COSPH=(ASQ-CD*CD-CS*CS)/(2.*CD*CS)
      W=COSPH
      IF(W.GT..999999.AND.W.LT.1.000001)GO TO 620
      GO TO 522
  620 WRITE(3,521)ANG,R,AREA
  522 W2=W*W
      G=(R0*R0/2.)*(1.+W2)/((1.+GAMMA*(1.-W))**2.)
      GAMM2=GAMMA*GAMMA
      SIGD=G*(1.+(GAMM2*(1.-W)*(1.-W))/((1.+W2)*(1.+GAMMA*(1.-W))))
      SIGDT=SIGD/929.0304
      EOS=E0/(1.+GAMMA*(1.-W))
      ENERGY=EOS*1000.
      SECO=CD/XD
      FLUXS=FLUXC*ED*H*SIGDT*SECO
      CALL INTERP(IMAXTP,ENG,XMU,NPTSTP,EOS,AMURHO)
      AMUCE=AMURHO*68.73
      FLUXD=FLUXS*(EXP(-(AMUCE*CDCON)))/929.0304
      Z=FLUXD
      ZC=FLUXD*7.4E+10*3.6E+03
      DUMFT=DUMFT+FLUXD
      IF(ENERGY.GT.EMAX)GO TO 998
      IF(ENERGY.LE.EMIN)GO TO 999
      CALL ANALYZ(ENERGY,B,L)
      TC(L)=TC(L)+Z
      TCC(L)=TCC(L)+ZC
      ATC(L)=ATC(L)+Z
      ATCC(L)=ATCC(L)+ZC
      GO TO 500
  998 EXCEDE=EXCEDE+Z
  999 UNDER=UNDER+Z
  500 CONTINUE
  300 ANG=ANG+DELANG
  200 R=R+DELR
      IF(IPRINT.EQ.1)GO TO 001
      GO TO 555
  001 DO 201 L=2,27,1
      M=L-1
  201 TCE(L)=TC(L)/(B(L)-B(M))
      TCE(1)=TC(1)/(B(1)-EMIN)
      DO 202 L=2,27,1
      M=L-1
  202 TCCE(L)=TCC(L)/(B(L)-B(M))
```

```
      TCCE(1)=TCC(1)/(B(1)-EMIN)
      TDOSE=0.0
      DO 203 I=1,27
      DOSE(I)=TCC(I)*CONV(I)*1.827/1.912
  203 TDOSE=TDOSE+DOSE(I)
      ATDOSE=ATDOSE+TDOSE
      WRITE(3,100)
      WRITE(3,77)VERAN,HORAN,EO,NCVOL
      WRITE(3,78)DELR,RMIN,RMAX,DELANG,ANGMAX,ANGMIN
      WRITE(3,79)NR,NANG
      WRITE(3,132)EXCEDE,UNDER
      WRITE(3,131)DUMFT
      WRITE(3,120)
      WRITE(3,121)
      WRITE(3,122)
      WRITE(3,123)EMIN,B(1),TC(1),TCC(1),TCE(1),TCCE(1)
      WRITE(3,124)(I,B(I-1),B(I),TC(I),TCC(I),TCE(I),TCCE(I),I=2,27)
      WRITE(3,125)TDOSE
      WRITE(3,128)
      WRITE(3,126)(DOSE(I),I=1,27)
      DO 601 L=1,27
      TCE(L)=0.0
      TCCE(L)=0.0
      TCC(L)=0.0
  601 TC(L)=0.0
      IF(JPRINT.EQ.2)GO TO 002
      GO TO 555
  002 DO 800 L=2,27,1
      M=L-1
  800 ATCE(L)=ATC(L)/(B(L)-B(M))
      ATCE(1)=ATC(1)/(B(1)-EMIN)
      DO 801 L=2,27,1
      M=L-1
  801 ATCCE(L)=ATCC(L)/(B(L)-B(M))
      ATCCE(1)=ATCC(1)/(B(1)-EMIN)
      WRITE(3,100)
  888 FORMAT(44X,'TOTAL FOR GIVEN COLLIMATIOR ANGLES'//)
      WRITE(3,888)
      WRITE(3,120)
      WRITE(3,121)
      WRITE(3,122)
      WRITE(3,123)EMIN,B(1),ATC(1),ATCC(1),ATCE(1),ATCCE(1)
      WRITE(3,124)(I,B(I-1),B(I),ATC(I),ATCC(I),ATCE(I),ATCCE(I),I=2,27)
      PHI=HORAN
      XCOS=COS((90.0-VERAN)*3.141593/180.)
      WRITE(2,510)XCOS,PHI,EO
      WRITE(2,511)(ATCC(I),I=1,27)
      WRITE(2,511)(ATCCE(I),I=1,27)
      WRITE(2,512)ATDOSE
      WRITE(3,127)ATDOSE
  889 DO 610 L=1,27,1
```

```
      ATCE(L)=0.0
      ATCCE(L)=0.0
      ATC(L)=0.0
  610 ATCC(L)=0.0
      ATDOSE=0.
      GO TO 555
  668 STOP
      END
```

```
      SUBROUTINE ANALYZ(ENERGY,B,L)
C     THIS SUBROUTINE BINS THE FLUXES INTO ONE OF 27 ENERGY BINS DEFINED BY B(M)
C
C         1) ENERGY = ENERGY OF THE QUANTITY TO BE BINNED
C         2) B(M) = UPPER LIMIT OF BIN M
          3) L = NUMBER OF THE BIN.  THIS NUMBER TAKEN BACK TO MAIN PROGRAM.
      DIMENSION B(1)
      IF(ENERGY.LE.B(10))GO TO 901
      IF(ENERGY.LE.B(17))GO TO 902
      IF(ENERGY.LE.B(22))GO TO 903
      GO TO 904
  901 IF(ENERGY.LE.B(1))GO TO 1
      IF(ENERGY.LE.B(2))GO TO 2
      IF(ENERGY.LE.B(3))GO TO 3
      IF(ENERGY.LE.B(4))GO TO 4
      IF(ENERGY.LE.B(5))GO TO 5
      IF(ENERGY.LE.B(6))GO TO 6
      IF(ENERGY.LE.B(7))GO TO 7
      IF(ENERGY.LE.B(8))GO TO 8
      IF(ENERGY.LE.B(9))GO TO 9
      L=10
      GO TO 910
  902 IF(ENERGY.LE.B(11))GO TO 11
      IF(ENERGY.LE.B(12))GO TO 12
      IF(ENERGY.LE.B(13))GO TO 13
      IF(ENERGY.LE.B(14))GO TO 14
      IF(ENERGY.LE.B(15))GO TO 15
      IF(ENERGY.LE.B(16))GO TO 16
      L=17
      GO TO 910
  903 IF(ENERGY.LE.B(18))GO TO 18
      IF(ENERGY.LE.B(19))GO TO 19
      IF(ENERGY.LE.B(20))GO TO 20
      IF(ENERGY.LE.B(21))GO TO 21
      L=22
      GO TO 910
  904 IF(ENERGY.LE.B(23))GO TO 23
      IF(ENERGY.LE.B(24))GO TO 24
      IF(ENERGY.LE.B(25))GO TO 25
      IF(ENERGY.LE.B(26))GO TO 26
      L=27
      GO TO 910
    1 L=1
      GO TO 910
    2 L=2
      GO TO 910
    3 L=3
       GO TO 910
    4 L=4
      GO TO 910
```

```
    5 L=5
      GO TO 910
    6 L=6
      GO TO 910
    7 L=7
      GO TO 910
    8 L=8
      GO TO 910
    9 L=9
      GO TO 910
   11 L=11
        GO TO 910
   12 L=12
      GO TO 910
   13 L=13
      GO TO 910
   14 L=14
      GO TO 910
   15 L=15
      GO TO 910
   16 L=16
      GO TO 910
   18 L=18
      GO TO 910
   19 L=19
      GO TO 910
   20 L=20
      GO TO 910
   21 L=21
      GO TO 910
   23 L=23
      GO TO 910
   24 L=24
      GO TO 910
   25 L=25
      GO TO 910
   26 L=26
  910 RETURN
      END
```

```
      SUBROUTINE INTERP(IMAXTP,XABCIS,FORDIN,NPTSTP,TVX,TVF)
C        IMAXTP=LENGTH OF INTERPOLATION LIST.
C        XABCIS=ABSCISSA.
C        FORDIN=ORDINATE LIST.
C        NTPSTP=NUMBER OF INTERPOLATION POINTS.
C        TVX=VALUE INTO X LIST AT WHICH INTERPOLATED F VALUE(TVF) IS DESIRED.
      DIMENSION XABCIS(100),FORDIN(100),XN(10),FN(10)
  800 IF(IMAXTP.GT.1)GO TO 830
      GO TO 801
  801 IF(IMAXTP.EQ.1)GO TO 820
  810 TVF=0.
      RETURN
  820 TVF=FORDIN(1)
      RETURN
C     THESE ORDERS TAKE CARE OF ECCENTRICALLY SHORT LISTS
  830 IF (NPTSTP.LT.IMAXTP)GO TO 850
  840 NPTSTP=IMAXTP-1
C     ORDER OF INTERPOLATION IS DECREASED IF LIST IS TOO SHORT
  850 XOTP=1.D60
      DO 890 INTP=1,IMAXTP
      ATP=TVX-XABCIS(INTP)
      IF(ATP.GE.0.)GO TO 870
  860 ATP=-ATP
  870 IF(ATP.GE.XOTP) GO TO 890
  880 ITP=INTP
      XOTP=ATP
  890 CONTINUE
C     THIS LOOP SELECTS THE VALUE OF XABCIS CLOSEST TO TVX
      IF((IMAXTP-ITP).GT.1) GO TO 889
      GO TO 892
  889 IF(ITP.GT.1) GO TO 891
  892 INNTP=1
      GO TO 894
  891 IF(ABS(TVX-XABCIS(ITP+1)).GT.ABS(TVX-XABCIS(ITP-1)))GO TO 893
      GO TO 892
  893 INNTP=-1
  894 NPTSTP=NPTSTP+1
C     THESE ORDERS DETERMINE ON WHICH SIDE OF TVX IS THE NEXT XABCIS
      DO 970 INTP=1,NPTSTP
      XN(INTP)=XABCIS(ITP)
      FN(INTP)=FORDIN(ITP)
      IF(INNTP.GT.0)GO TO 910
  900 IQTP=ITP-INTP
      GO TO 940
  930 ITP=ITP-1
      GO TO 970
  910 IQTP=ITP+INTP
  920 IF(IMAXTP.LT.IQTP) GO TO 930
  940 IF (IQTP.GT.0) GO TO 960
  950 ITP=ITP+1
```

```
      GO TO 970
  960 ITP=IQTP
      INNTP=-INNTP
  970 CONTINUE
C     THIS LOOP ORDERS THE INTERPOLATION POINTS
C     FOR INCREASING DISTANCES FROM TVX
      NPTSTP=NPTSTP-1
      TVF=0.
      FACT=1.
      DO 990 JNTP=1,NPTSTP
      TVF=TVF+FACT*FN(1)
      DO 980 INTP=JNTP,NPTSTP
      IQTP=INTP-JNTP+1
  980 FN(IQTP)=(FN(IQTP+1)-FN(IQTP))/(XN(INTP+1)-XN(IQTP))
  990 FACT = FACT*(TVX-XN(JNTP))
C     THIS IS THE MAIN LOOP FOR CALCULATING THE DIVIDED DIFFERENCES
 1000 RETURN
      END
```

CALCULATION OF ENERGY AND ANGULAR DISTRIBUTION OF WALL SINGLE SCATTERED GAMMA RADIATION FROM A SEMI-INFINITE ISOTROPIC PLANE SOURCE

by

JAMES MILTON ROYER

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ABSTRACT OF

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ABSTRACT

The calculation of the energy and angular distribution of gamma radiation scattering only once while penetrating a vertical slab bounded by a semi-infinite, horizontal, plane, isotropic, monoenergetic radiation source was made. All calculations were made for a point on the slab 3 ft above grade with air at 20 °C and 1 atm pressure. The test slab was a 4 inch concrete slab of mass thickness 48 psf. The results are given in terms of gamma-ray flux, $\Phi_d(E,\theta,\phi)$ differential with respect to energy and direction, in units $(cm^{-2}sec^{-1}sr^{-1}keV^{-1})$. The single scattered energy spectra were used in the calculations of an estimated far field correction factor for experimental measurements of gamma radiation penetrating a test wall at the Kansas State University Nuclear Engineering Shielding Facility.