UNCOLLIDED FLUX FROM FINITE RIGHT-CIRCULAR CYLINDER VIEWED ENDWISE

by

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INTRODUCTION

The cylinder is a shape quite frequently encountered in engineering work, and the nuclear field is no exception. Many reactors, many fuel elements, and many other sources of radiation have shapes approximating cylinders.

It is not uncommon to need to know the flux from the end of such a cylinder, whether the flux is composed of neutrons or gamma rays or both. This information is required for such reasons as the design of adequate shielding and for calculation of dose rates. To the author's knowledge, there is no method of calculation available at this time which can be performed without a computer in reasonable time periods and give answers with predictable accuracy.

An approximate solution has been developed by Rockwell (6) for determining upper and lower limits on the flux from the end of a cylinder. This technique, while bracketing the flux, in many cases provides such a large bracket that the actual flux is still very much in doubt.

An IBM 704 Computer code has been developed by Gillis et al. (3), which calculates the uncollided flux at any point outside a cylinder.

It is the purpose of this paper to develop empirical techniques enabling one to determine the centerline uncollided flux from the end of a finite cylinder without the aid of a computer.

NOMENCLATURE

Φ	Scalar flux (cm^{-2} sec^{-1})
S_A	Source strength of plane source ($cm^{-2}sec^{-1}$)
S_V	Source strength of volume source ($cm^{-3}sec^{-1}$)
μ_i	Macroscopic cross section of ith shield material (cm^{-1})
μ_s	Macroscopic cross section of source material (cm^{-1})
t_i	Thickness of ith shield material (cm)
t_o	Thickness of source disk (cm)
a	Distance from end of cylinder to observation point (cm)
$\bar{\mu}$	$\sum_i^n \mu_i t_i/a$ (cm^{-1})
b_1	$\sum_i^n \mu_i t_i$
z	Effective self-attenuation distance (cm)
b_2	$b_1 + \mu_s z$
h	Cylinder height (cm)
b_3	$b_1 + \mu_s h$
h'	Cone height having same volume as cylinder (cm)
b_3'	$b_1 + \mu_s h'$
R_o	Cylinder radius (cm)
θ_1	$\tan^{-1} R_o/a$
θ_2	$\tan^{-1} R_o/(a+h)$
NMAX+1	Number of disks in cylinder
δ	Depression of equivalent circular plane source (cm)
θ_N	$\tan^{-1} R_o/(a+Nt_o+\delta)$
θ_z	$\tan^{-1} R_o/(a+z)$
$E_n(b)$	$b^{n-1}\int_b^\infty \frac{e^{-t}}{t^n}\,dt \quad n > 0\ , \quad E_o(b) = \frac{e^{-b}}{b}$

THEORETICAL DEVELOPMENT

Problem

The equations for calculation of uncollided flux from some geometrically simple sources are developed in Rockwell and those used in this work are listed here. From a circular plane source (Fig. 1) of radius $\underline{R_o}$ emitting $\underline{S_A}$ particles per square centimeter - second,

$$\Phi\ (a) = \frac{S_A}{2}\left\{E_1(b_1) - E_1(b_1 \sec\theta)\right\} \quad . \tag{1}$$

From a truncated cone (Fig. 2) of height $\underline{h}$ emitting $\underline{S_V}$ particles per cubic centimeter - second the flux at $\underline{P}$, the imaginary apex of the cone is,

$$\Phi\ (a) = \frac{S_V}{2\mu_s}\left\{E_2(b_1) - \frac{E_2(b_1 \sec\theta\ )}{\sec\theta} - E_2(b_3) + \frac{E_2(b_3 \sec\theta)}{\sec\theta}\right\} \tag{2}$$

The flux from the end of a cylinder (Fig. 3) is not so easily obtained and must be calculated by approximation techniques. There are several approximate solutions available and these are listed and discussed. In all following discussion the orientation of the cylinder will be assumed to be such that the centerline is vertical and the detection point $\underline{P}$ is above the cylinder. All the solutions require that the point $\underline{P}$ be on the centerline of the cylinder. All solutions also require that the source $\underline{S_V}$ be of constant strength throughout the cylinder.

There are six parameters which must be considered in this problem area. Those associated with the cylinder are $\underline{\mu_s}$, $\underline{R_o}$, and $\underline{h}$. The parameters associated with the shield are $\underline{b_1}$, $\underline{a}$, and $\bar{\underline{\mu}}$. The shield is assumed to be composed of slabs perpendicular to the cylinder centerline.

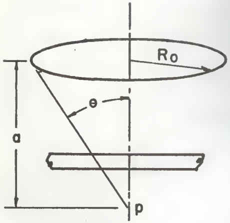

Fig. I. Circular plane source.

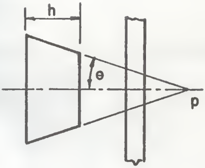

Fig. 2. Truncated right-circular cone source.

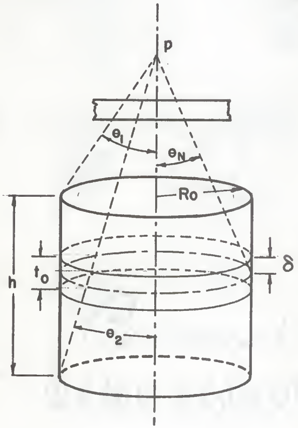

Fig. 3. Right-circular cylindrical source viewed endwise

Solutions

Stacked Disk Solution. In order to determine empirical relationships for the flux, it was necessary to determine the flux accurately and this solution served that purpose. A cylinder is assumed to be made up of a series of thin stacked disks. The flux at P from each disk will be calculated by assuming each disk to be an equivalent circular plane source with $S_A = S_V t_o$. The shielding of all disks above the one under consideration must be considered so each disk will "see" a different amount of shielding.

The self-shielding of each disk is considered by locating the plane source some distance δ beneath the upper surface of the disk as shown in Fig. 3. Since the location of the plane source within the disk is actually a weighting function applied to the source distributed within the disk, δ is expected to be less than $t_o/2$ because the upper portion of the disk is more important due to the fact that it "sees" less shielding.

A second reason exists for choosing $\delta < t_o/2$; that being the desire to always make conservative calculations where possible exposure to nuclear radiation may be involved. As the plane source is moved closer to the upper surface of the disk, it "sees" less of the shielding in the disk than is actually the case so the resultant flux calculation will be too high. As the disks are made thinner, the neglected shielding in the source will decrease and the solution becomes more accurate.

The mathematical expression for the flux is

$$\Phi\,(a) = \frac{S_V t_o}{2} \sum_{N=0}^{NMAX} \left\{ E_1(b_1 + N\mu_s t_o + \mu_s \delta) - E_1[(b_1 + N\mu_s t_o + \delta\mu_s)\sec\theta_N] \right\}, \quad (3)$$

where NMAX, t_o, and δ will be chosen to assure the calculated flux is within 1% higher than the true flux. Equation 3 is identical to Eq. A-1 in Appendix A which explains the computer code used to solve the equation.

Large Cone Approximation. This solution assumes the cylinder to be a truncated cone the same height as the cylinder with P at the apex. The angle subtended by the cone is θ_1 on Fig. 3, and the cone is obviously larger than the cylinder it represents. The flux from this approximation is calculated by

$$\Phi\,(a) = \frac{S_V}{2\mu_s}\left\{E_2(b_1) - \frac{E_2(b_1 \sec\theta_1)}{\sec\theta_1} - E_2(b_3) + \frac{E_2(b_3 \sec\theta_1)}{\sec\theta_1}\right\} \quad . \quad (4)$$

This solution provides an upper limit on the flux from the cylinder. Equation 4 is identical to Eq. A-3 in Appendix A which explains the computer code used to solve the equation.

Small Cone Approximation. This solution also assumes the cylinder to be a truncated cone which is the same height as the cylinder with P at the apex. The angle subtended by the cone is θ_2 on Fig. 3, and the cone is obviously smaller than the cylinder it represents. The flux from this approximation is calculated by

$$\Phi(a) = \frac{S_V}{2\mu_s}\left\{E_2(b_1) - \frac{E_2(b_1 \sec\theta_2)}{\sec\theta_2} - E_2(b_3) + \frac{E_2(b_3 \sec\theta_2)}{\sec\theta_2}\right\} \quad . \quad (5)$$

This solution provides a lower limit on the flux from the cylinder and when coupled with the large cone approximation provides a bracket on the expected flux. Equation 5 is identical to Eq. A-5 in Appendix A which explains the computer code used to solve the equation.

Equivalent Volume Cone Approximation. This solution also assumes the cylinder to be a truncated cone with P at the apex. The angle subtended by the cone is θ_1 on Fig. 3, and the height of the truncated cone is such that the volume is equal to that of the cylinder it represents. The flux from this approximation is calculated by

$$\Phi\,(a) = \frac{S_V}{2\mu_s}\left\{E_2(b_1) - \frac{E_2(b_1\ \sec\theta_1)}{\sec\,\theta_1} - E_2(b_3') + \frac{E_2(b'_3\ \sec\,\theta_1)}{\sec\,\theta_1}\right\}\ . \qquad (6)$$

Equation 6 is identical to Eq. A-4 in Appendix A which explains the computer code used to solve the equation.

Equivalent Circular Plane Source Approximation. This solution assumes that the cylinder can be represented by a single circular plane source the same radius as the cylinder. The equivalent source is assumed to be located somewhere within the space occupied by the cylinder it represents so that the shielding it "sees" is that of the cylinder within the confines of the cylinder. To allow for self-shielding within the source, the strength of the equivalent source must be considered in two parts. For cylinders with small mean free path height ($\mu_s h$) the equivalent source strength will be assumed to be $S_A = S_V h$. For cylinders with a mean free path height greater than some value K, which is chosen empirically, the source strength will be assumed to be $S_A = \frac{KS_V}{\mu_s}$. The flux from this approximation is calculated by

$$\Phi\,(a) = \frac{S_V h}{2}\left\{E_1(b_2) - E_1(b_2\ \sec\,\theta_z)\right\},\ \text{if}\ \mu_s h \leq K. \qquad (7)$$

or

$$\Phi\,(a) = \frac{KS_V}{2\mu_s}\left\{E_1(b_2) - E_1(b_2\ \sec\,\theta_z)\right\},\ \text{if}\ \mu_s h > K. \qquad (8)$$

Equations 7 and 8 are identical to Eqs. A-6 and A-7 respectively in Appendix A which explains the computer code used to solve the equations.

NUMERICAL ANALYSIS

Method of Solution

This problem has six parameters which may vary; $\underline{R_o}$, $\underline{\mu_s}$, $\underline{h}$, $\underline{\bar{\mu}}$, $\underline{b_1}$, and $\underline{a}$. In order to consider all possible combinations of parameters adequately, a large number of problems had to be solved. To do this an IBM 650 Computer code was written which solved the problems by each of the five previously listed solutions. This code is described in Appendix A.

By proper choice of disk thickness the stacked disk solution could be used to solve the problem with any desired degree of accuracy. This solution was used to provide an answer accurate to within 1%. The choice of disk thickness to assure this accuracy will be discussed later.

The three conical approximate solutions were compared with the stacked disk solutions and the relative error of each solution was calculated. The results were examined in an effort to determine some simple method of empirically presenting the data to enable one to calculate the correct flux within some set limits of accuracy without the use of a computer.

The plane source approximation was used as a trial and error calculation to determine the self-absorption distance which forced the solution to approximate the stacked disk solution within specified limits. The results were examined in an effort to determine a simple empirical relationship between the self-absorption distance and the flux.

Preliminary Investigations

Accuracy Analysis of Stacked Disk Solution. Using the computer code, it was first necessary to determine the disk thickness which gave sufficient accuracy. As the disks became thinner the solution became more accurate, so very thin disks were preferred. On the other hand, computer running time increased as disk thickness decreased since more disks were then required for any given problem. A compromise was made such that the flux was always calculated to within 1% of the asymptotic value, the result being always higher than the true value. The required disk thickness could then be determined for different combinations of parameters.

In order to better understand the problems associated with the work undertaken, it was necessary to approach the problems of disk thickness and location of the equivalent plane source within each disk in an oblique fashion. It was first assumed that the plane source was on the upper surface of each disk, i.e. $\delta = 0$, and disk thicknesses were determined. Problems solved with this choice of δ were quite lengthy, due to the necessity of using extremely thin disks since no self-absorption in each disk was considered. This extreme location of δ was used initially since the results would satisfy the original requirement that the flux always approach the correct flux from some higher value.

With the information provided from the initial set of problems, it was possible to compare the results with those obtained when δ was varied. Three facts were immediately apparent when these comparisons were made. First, the optimum location for δ was quite near $t_o/2$. Second, the optimum location for δ varied as the parameters of the cylinder and shield varied. Third, the major portion of the advantage of the depression of the plane source was observed as δ varied from 0 to $0.4t_o$. The choice was made for $\delta = 0.45t_o$ and proved to be satisfactory. The advantage of this depression of the plane source was a decrease in the number of disks required for any given cylinder, the decrease being at least a factor of ten which saved considerable computer time.

In the search to determine the proper disk thickness for each problem, three parameters were shown to have an appreciable effect on the thickness necessary to provide the 1% accuracy required. The results of this search are shown in Table 1 with the variation of a single parameter from some intermediate value shown as the cause with the change of disk thickness while still maintaining 1% accuracy of the calculated flux shown as the effect.

Table 1. Effect on disk thickness required to determine flux within 1% of the asymptotic value as parameters are varied from intermediate values.

Cause	Effect
Increase b_1	Thicker
Increase R_o	Thicker
Increase μ_s	Thicker

The disk thickness was determined in terms of mean free paths, $\underline{\mu_s t_o}$. Use of mean free paths makes it easier to explain the dependence on $\underline{\mu_s}$ while not affecting the other results.

By the choice of $\underline{\delta}$, the location of the circular plane source within each disk representing the disk, some small amount of the shielding within each disk has not been considered. This was done, as previously explained, to force the flux calculation to always approach the asymptotic value from some higher value. Certainly one expects this neglected shielding to become less important as the total amount of shielding is increased. This expectation is borne out by the observed effect that increasing $\underline{b_1}$ has on disk thickness.

In considering the dependence on $\underline{R_o}$, it is only logical to assume that to represent a disk by a plane the disk must "look like" a plane, that is, $\underline{R_o >> t_o}$. This being the case, one expects that disks with larger radii could be thicker and still "look like" a plane. This expectation is borne out by the observed effect that increasing $\underline{R_o}$ has on disk thickness.

The effect of $\underline{\mu_s}$ on disk thickness is again one of geometry. As $\underline{\mu_s}$ increases, the disk thickness in terms of mean free paths is expected to increase because this tends to hold the shape of the disk constant. If the thickness did not increase, the disk would approximate a plane even more closely than necessary. The expected results were observed and disk thickness did increase as $\underline{\mu_s}$ increased.

Parameter Analysis. Having chosen $\underline{\delta}$ it was possible to calculate the flux from cylinders whose parameters were chosen at random, as were the parameters of the shields. These problems were solved in an effort to determine which approximate method of solution or combination of methods showed the greatest promise as a tool to be eventually used in the simple empirical presentation of data which was desired.

The three conical solutions were shown to have little promise. As $\underline{\mu_s R_o}$ decreased no single solution or average combination of the approximate conical solutions could provide accurate results. Errors were greater than a factor of 10 in some cases. The errors varied in such inconsistent fashion that no pattern which might make the application of correction factors to the approximate solution(s) feasible could be observed. In most cases the large cone approximation and the equivalent volume cone approximation were more nearly correct and the large cone approximation was the more reliable of these two because it always gave a conservative result.

The equivalent plane source approximation was chosen as the only approach which showed some promise of lending itself to the empirical fit of large amounts of data. It was observed that for large $\mu_s R_o$, the self-absorption distance in terms of mean free paths, $\mu_s z$, depended only on b_1 for a given cylinder height and it was decided to present the results as a family of curves for different $\mu_s h$ with $\mu_s z$ plotted versus b_1.

It was possible at this point to choose a value for K, the mean free path cylinder height that fixed the constant source strength, for cylinders whose height exceeded K mean free paths. The artificial circular plane source having $S_A = S_V h$ kept increasing as h increased, although the flux from the cylinder did not. The self-absorption distance z necessarily increased as the plane source increased and these compensating effects were undesirable since the flux did not continue to increases. The value of K was fixed at 1.5 so that all cylinders more than 1.5 mean free paths tall were assumed to have an equivalent circular plane source strength such that $S_A = 1.5\ S_V/\mu_s$. The plane source strength then fell into one of two categories: if $\mu_s h \leq 1.5$, $S_A = S_V h$; if $\mu_s h > 1.5$, $S_A = 1.5\ S_V/\mu s$. The figure of $\mu_s h = 1.5$ was chosen as the minimum value which could be used to fix a constant source strength without a risk of developing a negative z, which is not anticipated in the computer program. The minimum value was desired since the accuracy of the empirical relationships improved as the cylinder height used to fix a constant source strength decreased.

Data Analysis

Typical values for R_o and μ_s were chosen and problems with varying $\bar{\mu}$, a, b_1, and h were solved and the resultant curves in Figs. 4a and 4b were determined. The self-absorption distance $\mu_s z$, expressed in terms of mean free paths, refers to the equivalent circular plane source which is assumed to replace the cylinder. Presentation of the data in this manner requires that $\mu_s z$ be dependent only on the shield mean free paths, b_1, for a given cylinder height. This requirement is satisfied for large $\mu_s R_o$.

For the cases of small $\mu_s R_o$, marked deviation of $\mu_s z$ from that suggested by Figs. 4a and 4b was observed. In general, $\mu_s z$ increased as $\mu_s R_o$ first dropped below some critical value dependent on b_1, and eventually decreased rapidly as $\mu_s R_o$ continued to decrease. Figure 5 indicates the area where fluxes may be calculated to within 10% of the actual value without the use of correction factors. As $\mu_s R_o$ exceeds the critical value shown for any b_1, correction factors are not required.

The maximum deviation of $\mu_s z$ from the values predicted by Figs. 4a and 4b is observed for large $\bar{\mu}$. For a given value of $\mu_s R_o$ the deviation was greater for smaller μ_s as $\bar{\mu}$ was held constant. The relative deviation was slightly dependent on $\mu_s h$ and quite dependent on b_1. It was necessary to develop correction factors for $\mu_s z$ which depend on b_1, $\bar{\mu}$, and μ_s. This has been done in Figs. 6 through 12. These correction factors were determined by assuming cylinders having $\mu_s h = 2.$ and the results are most accurate for this case. For values of $\mu_s h$ not equal to two the error in the calculated flux for small $\mu_s R_o$ increases. Largest errors are noted when μ_s is small, R_o is small, and $\bar{\mu}$ is large. Errors are greatest for the smallest $\mu_s h$. Errors are positive, i.e. the empirically determined flux is greater than the flux determined by the stacked disk solution, for most cases, and the estimated maximum negative error is $<25\%$. The estimated maximum positive error is < 175% and these extreme errors apply only in isolated cases. Table 2 lists the estimated maximum errors anticipated for varying $\underline{\mu_s}$ and varying $\underline{\mu_s h}$ at values of $\underline{\mu_s h}$ other than 2. The comparable errors resulting from the use of the large cone approximation are included in Table 2. Appendix B explains the computer program used to calculate the error in flux determination by the empirical method.

Table 2. Study of maximum percentage errors in flux determination compared to stacked disk flux determination, by the curves in this paper and by the large cone approximation for varying source and shield parameters.

μ_s	$\mu_s h$	b_1	Percentage errors in flux determination							
			$\bar{\mu}=0.02$		$\bar{\mu}=0.1$		$\bar{\mu}=1.0$		$\bar{\mu}=4.0$	
			Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.
0.02	0.25	0.1	36.7	228.9	90.5	854.5	145.7	1312.5	155.8	1213.1
		1.0	1.5	23.6	20.0	116.5	99.2	756.3	139.9	779.8
		4.0	0	8.9	3.2	29.6	45.0	268.5	97.1	531.1
		10	1.1	-3.9	0.1	10.6	19.4	114.1	57.3	330.8
		30			0.7	-5.0**	4.5	39.0	25.0	138.9
0.02	1.00	0.1	10.3	690.7	10.9	2370.8	9.8	2756.6	10.2	2498.1
		1.0	-2.6	79.1	1.3	362.5	7.0	2118.8	3.2	2021.1
		4.0	-2.1	21.1	-4.5	97.8	-2.3	808.1	0.3	1539.2
		10	2.6	8.2	-4.7	40.0	-6.8	356.1	-5.8	995.7
		30			-2.0	9.3	-7.3	127.8	-6.5	432.8
0.02	1.25	0.1	10.7	785.5	8.5	2645.7	5.0	2943.8	5.1	2664.4
		1.0	0.4	92.1	1.2	414.8	2.9	2367.6	-2.6	2217.9
		4.0	4.3	24.1	2.5	113.7	2.7	917.9	2.8	1727.6
		10	0.3	8.2	-2.7	47.0	-8.3	407.6	-10.4	1128.5
		30			0.6	14.0	-7.1	148.2	-9.1	494.5
0.02	1.50	0.1	2.9	859.9	-1.8	2851.0	-6.5	3071.6	-6.3	2777.8
		1.0	-1.8	103.0	-5.0	456.2	-7.6	2554.1	-13.8	2358.6
		4.0	0.6	26.9	-6.6	126.8	-14.2	1003.7	-16.6	1870.1
		10	1.4	10.6	-4.5	53.0	-15.7	448.5	-20.2	1231.7
		30			0.6	16.1	-12.1	164.7	-17.2	543.3
0.02	1.75	0.1	4.3	918.0	-0.4	3004.5	-4.8	3160.2	-4.6	2856.5
		1.0	0.4	111.9	-1.4	488.9	-2.6	2693.9	-9.1	2459.9
		4.0	1.4	29.8	-1.7	137.5	-6.1	1070.7	-8.0	1977.9
		10	0.2	11.4	-0.9	58.1	-6.6	480.7	-9.7	1311.7
		30			0.4	18.9	-4.1	178.1	-6.7	581.7

Table 2. (cont).

μ_s	$\mu_s h$	b_1	Percentage errors in flux determination: $\bar{\mu}=0.02$, Curves in this paper *	$\bar{\mu}=0.02$, Large cone approx.	$\bar{\mu}=0.1$, Curves in this paper *	$\bar{\mu}=0.1$, Large cone approx.	$\bar{\mu}=1.0$, Curves in this paper *	$\bar{\mu}=1.0$, Large cone approx.	$\bar{\mu}=4.0$, Curves in this paper *	$\bar{\mu}=4.0$, Large cone approx.
0.02	3.00	0.1	8.1	1064.9	4.2	3353.1	-0.6	3338.0	-0.6	3014.3
		1.0	4.8	136.4	9.6	572.7	11.2	3013.9	4.8	2675.6
		4.0	4.2	38.1	13.1	166.3	18.8	1239.0	19.5	2230.0
		10	0.3	15.4	11.1	72.6	23.2	563.3	24.6	1510.0
		30			6.6	24.7	22.0	213.7	29.6	679.5
0.05	0.25	0.1	13.1	92.4	57.5	341.5	107.4	509.3	113.3	463.9
		1.0	-0.1	9.3	7.8	46.9	58.9	299.8	96.0	292.3
		4.0	0.02	5.2	0.4	11.9	20.5	108.1	63.9	203.6
		10	0.3	-4.7	0.2	3.5	6.1	45.9	26.9	130.0
		30			0.3	-7.0	0.3	15.6	9.9	55.4
0.05	1.00	0.1	3.3	289.9	14.4	973.9	18.4	1099.1	17.3	988.6
		1.0	-1.1	32.4	3.2	152.1	7.2	869.1	9.1	806.2
		4.0	0.3	8.7	-2.4	40.2	-1.5	337.9	14.2	625.1
		10	2.7	3.4	-1.1	16.1	-6.2	149.2	-5.4	411.1
		30			-0.2	1.4	-6.8	52.8	-3.2	180.4
0.05	1.25	0.1	5.4	332.2	13.1	1090.4	14.1	1176.5	13.0	1057.2
		1.0	2.5	38.2	5.9	175.9	4.9	975.0	3.9	888.8
		4.0	2.9	9.7	0.5	47.4	-2.3	387.5	10.3	708.4
		10	0.8	2.6	1.6	19.0	-6.1	172.9	-8.0	470.6
		30			1.8	4.6	-5.4	62.0	-3.5	208.8
0.05	1.50	0.1	0.3	365.9	4.3	1177.8	2.2	1229.4	0.7	1104.2
		1.0	2.4	43.1	2.6	195.1	-4.5	1054.6	-7.6	948.0
		4.0	3.3	10.7	-1.1	53.3	-9.6	425.2	-1.0	767.3
		10	0.4	4.2	1.3	21.7	-11.6	191.5	-16.9	515.1
		30			0.9	5.3	-8.4	69.6	-9.3	230.9

Table 2. (cont).

μ_s	$\mu_s h$	b_1	Percentage errors in flux determination							
			$\bar{\mu}$ 0.02		$\bar{\mu}$ 0.1		$\bar{\mu}$ 1.0		$\bar{\mu}$ 4.0	
			Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.
0.05	1.75	0.1	0.8	392.5	5.5	1243.2	3.7	1266.2	2.0	1136.8
		1.0	1.5	47.2	5.2	210.5	-0.1	1114.5	-2.2	990.7
		4.0	2.6	12.0	1.0	58.3	-2.4	455.9	8.9	814.8
		10	-1.5	4.1	2.3	24.0	-3.7	206.8	-7.1	551.3
		30			1.9	7.0	-3.1	76.0	-0.2	248.9
0.05	3.00	0.1	3.7	460.7	10.2	1392.5	5.5	1340.1	0.4	1202.4
		1.0	1.8	59.4	13.7	251.2	11.5	1251.1	6.2	1081.8
		4.0	1.4	15.7	9.4	72.7	20.5	532.8	28.1	923.4
		10	-3.2	6.2	6.5	30.9	19.2	246.8	18.0	640.2
		30			0.8	9.5	14.3	93.8	31.6	295.7
0.1	0.25	0.1	5.5	46.3	28.7	169.3	60.9	241.7	69.2	214.6
		1.0	-0.3	4.5	2.1	23.5	36.5	147.3	57.1	131.1
		4.0	0.5	4.0	0.3	5.9	9.1	54.1	31.0	95.1
		10	0.1	-4.9	0.2	1.0	1.5	22.7	11.0	62.7
		30			-0.6	-7.9	-0.02	7.6	1.8	27.3
0.1	1.00	0.1	3.8	150.0	4.7	498.1	3.4	541.2	14.8	481.1
		1.0	0.7	16.4	-0.6	78.4	11.7	443.7	12.2	395.9
		4.0	0.8	4.6	-0.6	20.4	-0.9	174.9	4.9	314.4
		10	0.5	1.2	0.02	7.8	-6.0	76.6	-7.5	209.4
		30			-1.2	-1.4	-3.3	26.7	-8.5	92.3
0.1	1.25	0.1	7.4	173.4	4.8	560.3	5.9	581.4	11.5	516.8
		1.1	4.6	19.4	2.7	91.4	12.8	500.4	6.6	439.7
		4.0	4.0	4.9	2.8	24.1	-1.6	202.2	2.7	359.0
		10	3.2	0.5	3.0	9.3	-4.8	89.4	-9.2	241.3
		30			0.6	11.8	-1.0	31.5	-8.2	107.7

Table 2. (cont).

μ_s	$\mu_s h$	b_1	Percentage errors in flux determination							
			$\bar{\mu}=0.02$		$\bar{\mu}=0.1$		$\bar{\mu}=1.0$		$\bar{\mu}=4.0$	
			Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.	Curves in this paper *	Large cone approx.
0.1	1.50	0.1	4.5	192.2	-2.2	607.1	-4.2	609.1	0.6	541.3
		1.0	5.4	21.9	0.6	102.0	2.9	541.9	-4.7	469.3
		4.0	4.5	5.2	2.6	27.3	-7.2	223.3	-6.3	391.4
		10	3.2	1.8	3.1	10.8	-8.2	100.1	-16.1	267.0
		30			3.0	1.7	-2.1	35.8	-12.5	120.4
0.1	1.75	0.1	4.5	207.3	-1.6	642.4	-3.0	628.3	1.5	558.4
		1.0	3.0	24.2	2.1	110.9	7.3	574.7	0.1	492.7
		4.0	1.9	5.9	2.8	30.1	-0.7	240.7	1.8	417.3
		10	0.9	1.7	2.6	11.9	-2.4	108.7	-7.4	286.6
		30			1.7	2.8	0.7	39.2	-5.3	130.5
0.1	3.00	0.1	5.9	247.0	2.4	723.4	1.2	667.2	6.2	592.9
		1.0	-0.3	31.1	7.5	135.2	20.9	650.8	17.1	542.9
		4.0	-2.0	7.9	5.6	38.4	18.6	285.2	28.4	477.5
		10	-1.3	2.8	3.0	15.7	15.4	132.5	20.4	337.5
		30			0.2	4.1	12.2	49.7	18.1	158.2
1.0	0.25	0.1	0.1	4.3	-0.6	15.8	1.0	14.9	1.1	7.0
		1.0	-0.1	0.07	-0.06	2.1	0.3	13.0	-0.8	4.3
		4.0	0.1	2.8	0	0.4	-0.2	5.1	-0.7	6.5
		10	-0.3	-5.3	-0.2	-1.2	-0.2	2.0	-0.4	5.6
		30			-0.1	-9.0	-0.4	0.5	-0.5	2.5
1.0	1.00	0.1	5.6	15.7	-0.6	50.9	-0.6	34.1	-0.8	23.1
		1.0	1.9	1.4	1.9	7.9	-2.1	43.4	-3.3	21.4
		4.0	1.0	0.8	1.0	1.8	-0.5	18.3	-3.9	25.2
		10	0.3	0.9	-0.2	0.3	-1.2	7.7	-3.4	20.3
		30			-0.9	-4.2	-1.6	2.5	-2.7	9.3

Table 2. (concl)

μ_s	$\mu_s h$	b_1	$\bar{\mu}=0.02$ Curves in this paper *	$\bar{\mu}=0.02$ Large cone approx.	$\bar{\mu}=0.1$ Curves in this paper *	$\bar{\mu}=0.1$ Large cone approx.	$\bar{\mu}=1.0$ Curves in this paper *	$\bar{\mu}=1.0$ Large cone approx.	$\bar{\mu}=4.0$ Curves in this paper *	$\bar{\mu}=4.0$ Large cone approx.
			Percentage errors in flux determination							
1.0	1.25	0.1	11.0	18.6	3.5	58.6	3.3	37.8	3.1	26.5
		1.0	5.7	1.7	6.0	9.4	1.3	50.3	-0.5	25.7
		4.0	4.1	0.3	4.3	2.2	2.7	21.6	-1.5	30.0
		10	2.5	-0.2	2.4	0.4	1.5	9.2	-1.1	24.1
		30			1.6	-2.0	0.9	3.0	-0.3	11.1
1.0	1.50	0.1	13.4	21.1	3.0	64.8	1.6	40.7	1.2	29.1
		1.0	7.4	2.0	7.4	10.8	-0.1	55.9	-2.9	29.2
		4.0	4.4	0	5.3	2.6	2.7	24.5	-3.0	34.1
		10	2.7	1.3	2.9	0.4	1.4	10.3	-2.4	27.0
		30			2.1	-2.2	0.8	3.2	-0.9	12.3
1.0	1.75	0.1	9.0	23.3	1.4	69.7	1.1	42.8	1.1	31.0
		1.0	2.8	2.2	3.9	12.0	0.5	60.4	-1.6	31.9
		4.0	2.1	0.2	2.4	2.9	2.8	27.0	-0.7	37.5
		10	-0.4	0.4	0.9	0.8	1.2	11.7	-0.1	30.1
		30			0	-1.1	-0.2	3.9	-0.3	14.0
1.0	3.00	0.1	1.7	29.9	0.3	82.1	2.3	47.8	2.1	35.6
		1.0	-6.2	3.0	-2.2	15.7	4.2	71.9	3.7	38.8
		4.0	-4.4	0.4	-3.1	3.7	4.9	34.1	7.2	46.3
		10	-3.4	0.6	-3.0	1.2	1.7	15.3	7.1	38.4
		30			-2.5	-1.2	-1.3	5.0	2.8	18.0

* The interpolation required to determine the self-absorption distance may give rise to errors in the flux determination which exceed these estimated maximum errors. In no case is the error expected to increase by more than 5%.

** For large a, i.e. large b_1 and small $\bar{\mu}$, the limitations of the computer were such that the large cone approximate calculation of flux was less than the stacked disk solution.

DESIGN CONSIDERATIONS

Use of Design Curves

The following curves are to be used to determine the location or self-absorption distance of a circular plane source assumed to represent a cylinder for purposes of calculating the centerline uncollided flux at some point P, at distance a beyond an end of the cylinder. The self-absorption distance is measured from the end of the cylinder closest to P. Necessary input data are $\bar{\mu}$, a, μ_s, R_o, h, and b_1. The following step-by-step procedure enables one to determine the self-absorption distance and the resultant flux. The following limits on the values of the parameters must be observed:

$$R_o \geq 1 \text{ cm}$$
$$0.1 \leq b_1 \leq 40$$
$$0.02\text{cm}^{-1} \leq \mu_s$$
$$0.02\text{cm}^{-1} \leq \bar{\mu} \quad .$$

To determine the self-absorption distance proceed as follows:

Step 1. Calculate $\mu_s h$.

Determine $\mu_s z$ from Fig. 4a or 4b.

Step 2. Calculate $\mu_s R_o$.

From Fig. 5 determine necessity of correction factor application. If correction factor is necessary go to step 3; if not, go to step 6.

Step 3. Using Figs. 6b, 7b, 8b, 9b, 10b, 11b, or 12b select the Figures at the b_1 values immediately larger and smaller than the given b_1. From these two Figures determine a relation to the appropriate F_i, G_i, H_i, J_i,

K_i, L_i, or M_i curves. For example, at $b_1 = 4$, on Fig. 8b at $\bar{\mu} = 0.3$ and $\mu_s = 0.1$ a location between H_2 and H_3 is observed approximately one-third of the distance from H_2 towards H_3.

Step 4. With the relations determined in Step 3, use Figs 6a, 7a, 8a, 9a, 10a, 11a, or 12a as appropriate, and by interpolation determine correction factors at the two values for b_1 used in Step 3.

Step 5. Interpolating between b_1 values, determine correction factor, CF, to be used at the given b_1, and multiply CF by $\mu_s z$ which is then the $\mu_s z$ to be used in succeeding steps.

Step 6. Calculate sec θ_z and z from $\mu_s z$,

where $\sec \theta_z = \sqrt{1 \quad \frac{R_o^{\,2}}{(a+z)^2}}$.

Step 7. Calculate $b_2 = b_1 + \mu_s z$.

Calculate $\left\{E_1(b_2) - E_1(b_2 \sec \theta_z)\right\}$,

where $E_1(x) = -0.5772 - \ln x + x - \frac{x^2}{4} + \frac{x^3}{18} \cdots$

if $x < 1$, Refs. (1,2,6).

$E_1(x) = \frac{e^{-x}}{x} \left\{\frac{0.251 + 2.335x + x^2}{1.082 + 3.331x + x^2}\right\}$,

if $x \geq 1$, Ref. (3).

Step 8. If $\mu_s h \leq 1.5$, $S_A = S_V h$

If $\mu_s h > 1.5$, $S_A = S_V(\frac{1.5}{\mu_s})$

Step 9. $\Phi\,(a) = \frac{S_A}{2} \left\{E_1(b_2) - E_1(b_2 \sec \theta_z)\right\}$

If the flux is desired at some point P not on the centerline of the cylinder a conservative estimate can be obtained by assuming the point P is on the centerline of the cylinder at the same vertical distance above the source, and solving the problem in the manner outlined above.

Sample Problem

The following problem will serve to illustrate the use of the design curves. The parameter values have been assumed to be as follows: $\mu_s = 0.07$, $\bar{\mu} = 0.3$, $b_1 = 6$, $R_o = 10$ cm, $h = 40$ cm, $a = 20$ cm.

Step 1. $\mu_s h = 2.8$

From Fig. 4b, $\mu_s z = 0.497$

Step 2. $\mu_s R_o = 0.7$ From Fig. 5, correction factor is necessary.

Step 3. From Fig. 8b, observe a location between H_2 and H_3 close to H_3.

From Fig 9b, observe a location between J_1 and J_2 close to J_2.

Step 4. From fig. 8a, by interpolation, the correction factor is estimated as 0.97. From Fig. 9a, by interpolation, the correction factor is estimated as 1.01.

Step 5. Correction factor is 0.983 for $b_1 = 6$.

Corrected $\mu_s z$ is 0.489.

Step 6. $z = 6.96$ cm.

$\sec \theta_z = 1.0665$.

Step 7. $b_2 = 6.489$.

$b_2 \sec \theta_z = 6.920$.

$E_1(6.489) = 2.078 \times 10^{-4}$.

$E_1(6.921) = 1.273 \times 10^{-4}$.

Step 8. $S_A = 21.428$ cm^{-2} sec^{-1}

Step 9. $\Phi(a) = 8.625 \times 10^{-4}$ cm^{-2} sec^{-1}

The stacked disk solution to this problem is 7.8×10^{-4} cm^{-2} sec^{-1}. The error in the empirical solution is 10.6%. The error in the large cone approximate solution is 64.7%.

DATA PRESENTATION

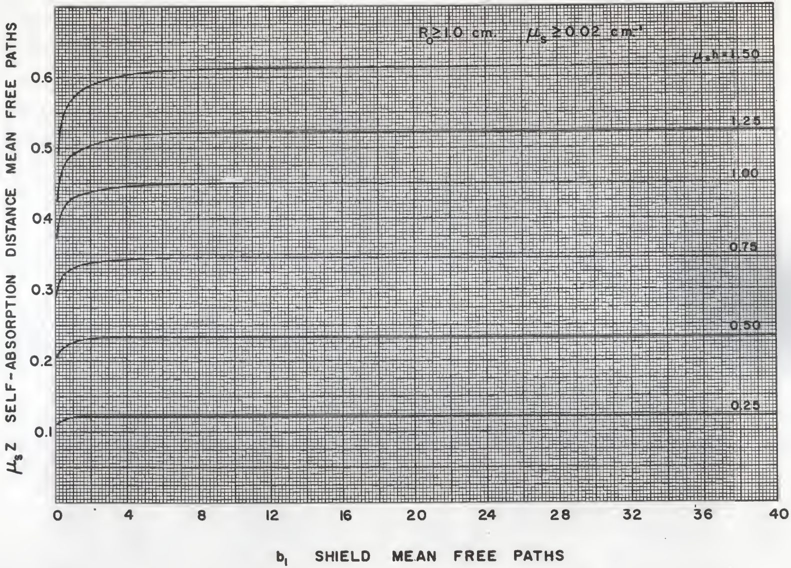

Fig. 4 a. Equivalent circular plane source self-absorption distance for $\mu_s h \leq 1.5$

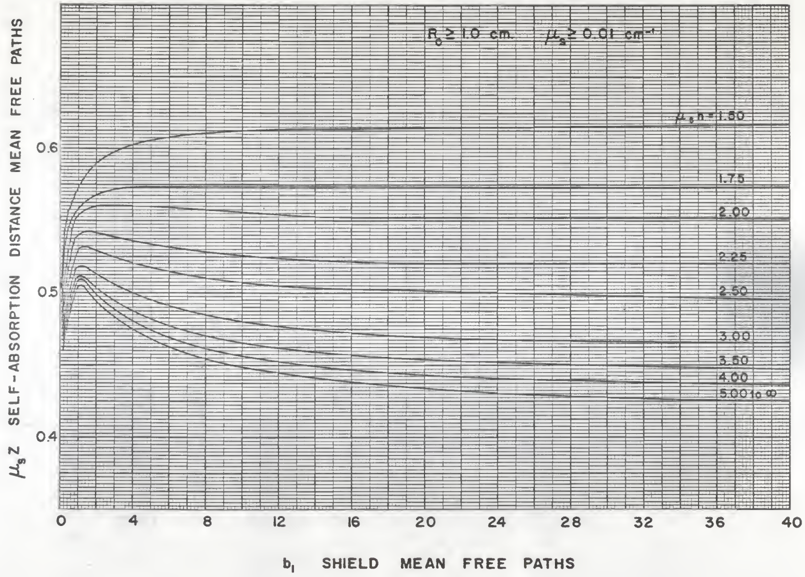

Fig. 4b. Equivalent circular plane source self-absorption distance for $\mu_s h > 1.5$

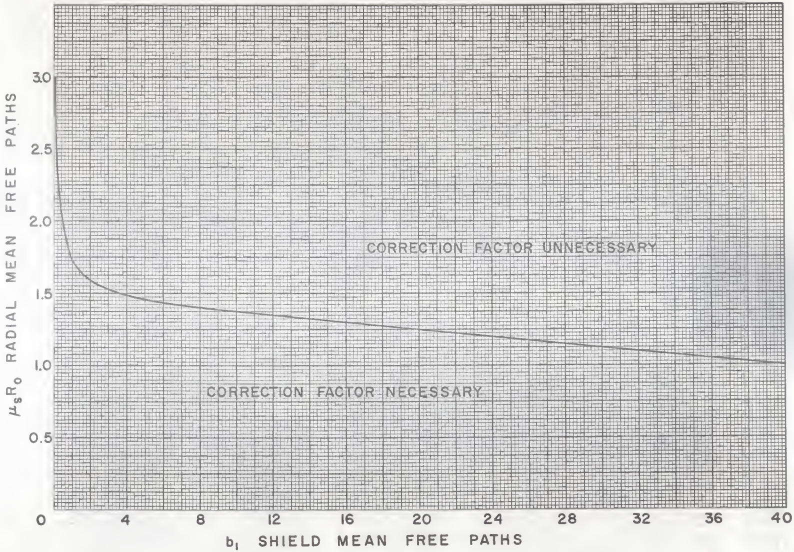

Fig. 5. Correction factor applicability.

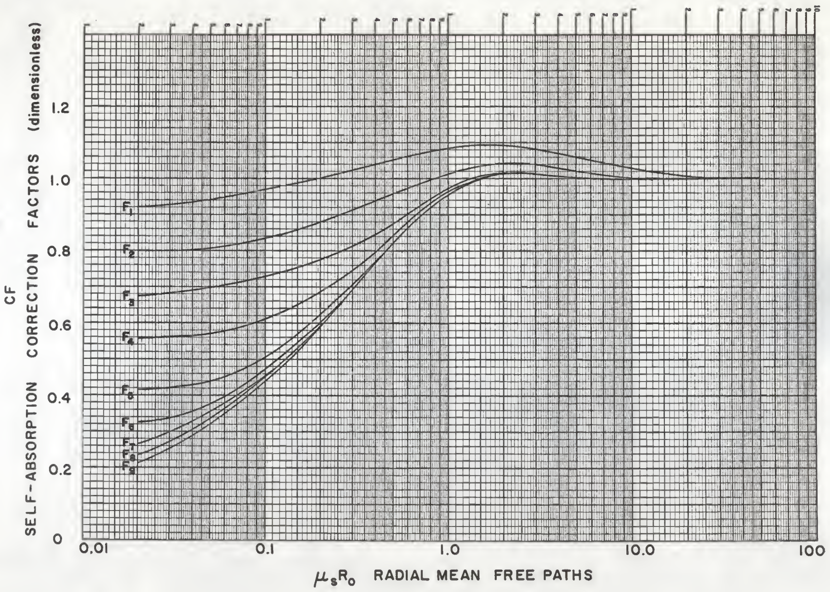

Fig. 6a. Correction factors for equivalent circular plane source self-absorption distance for b_1=0.1.

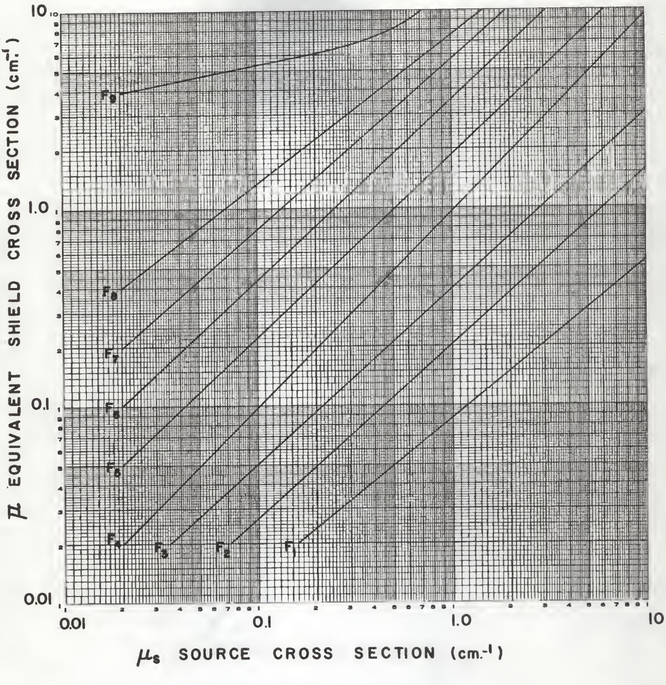

Fig. 6b. Source and shield cross sections correlation for $b_1 = 0.1$.

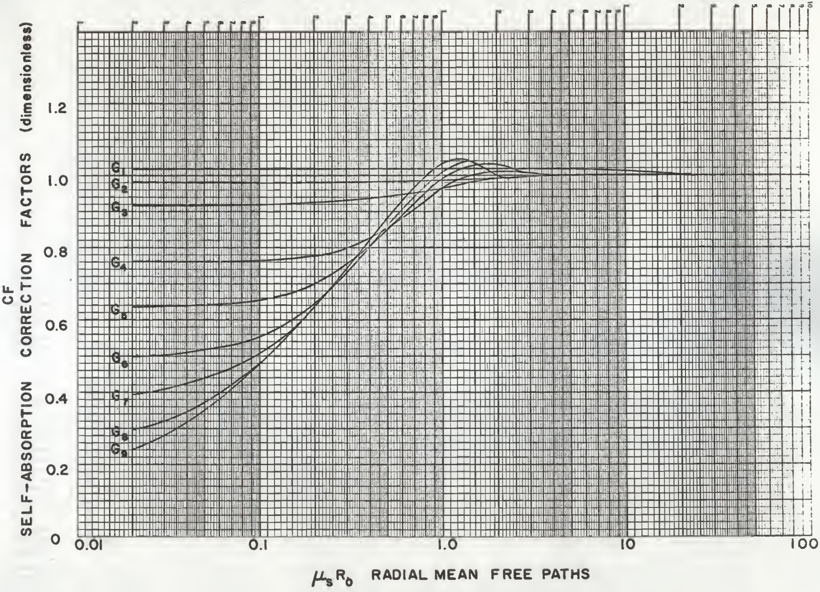

Fig. 7a. Correction factors for equivalent circular plane source self-absorption distance for $b_1 = 1.0$.

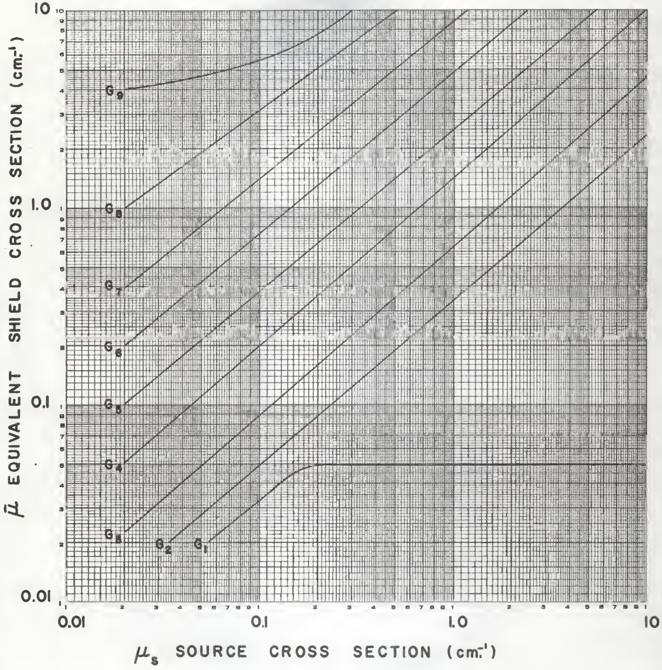

Fig. 7b. Source and shield cross sections correlation for $b_1 = 1.0$.

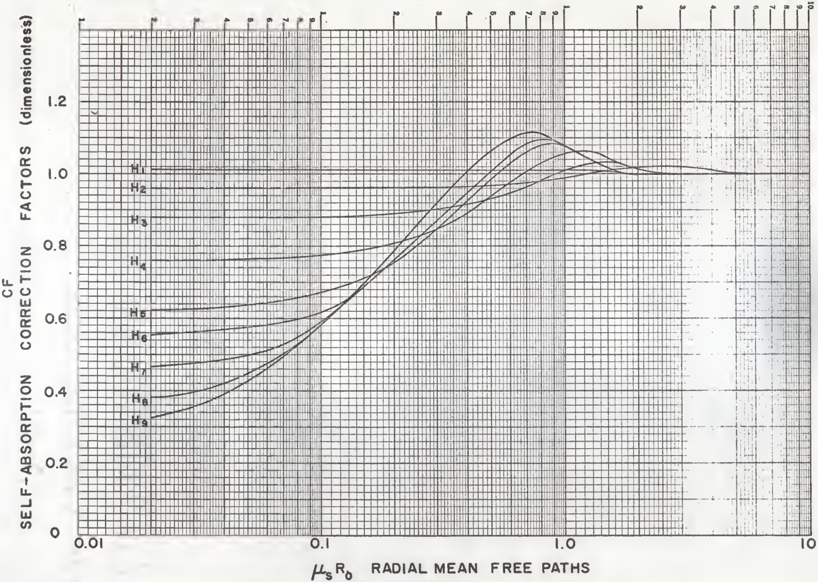

Fig. 8a. Correction factors for equivalent circular plane source self-absorption distance for $b_1 = 4.0$.

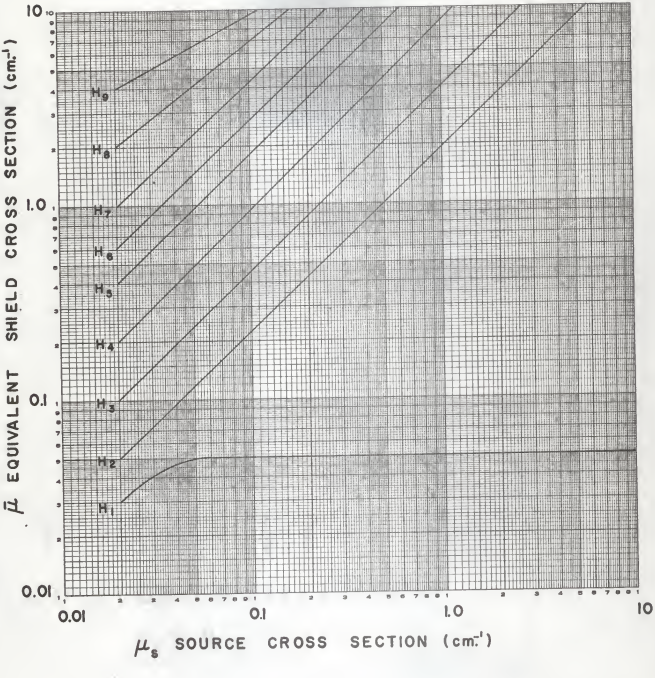

Fig. 8b. Source and shield cross sections correlation for $b_1 = 4.0$.

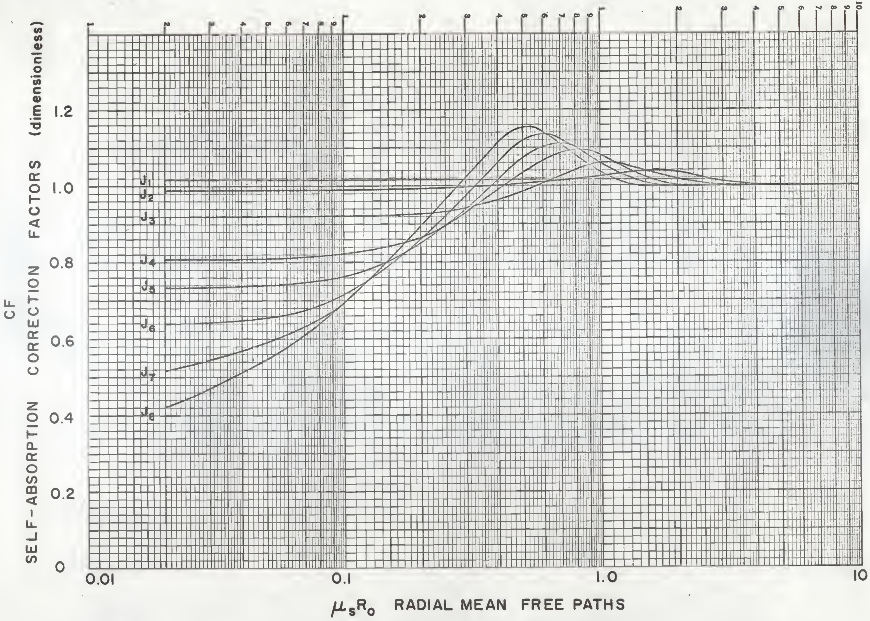

Fig. 9a. Correction factors for equivalent circular plane source self-absorption distance for $b_1 = 10$.

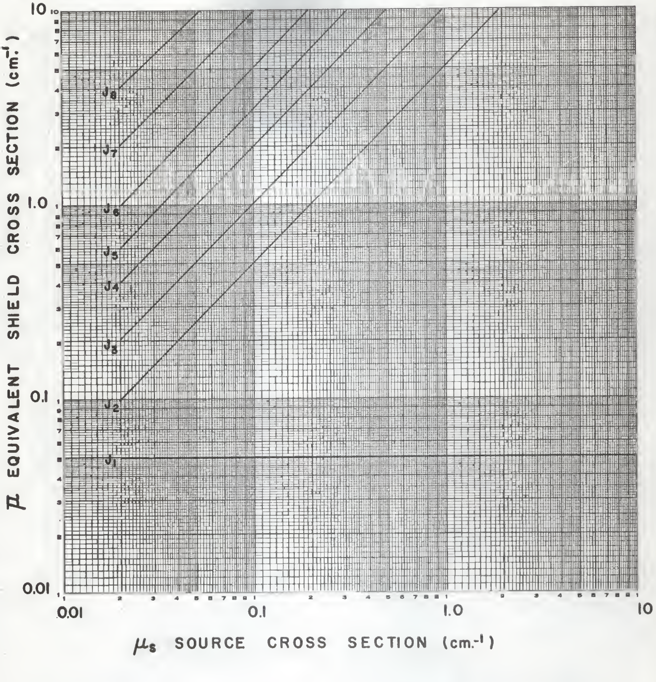

Fig. 9b. Source and shield cross sections correlation for $b_1 = 10$.

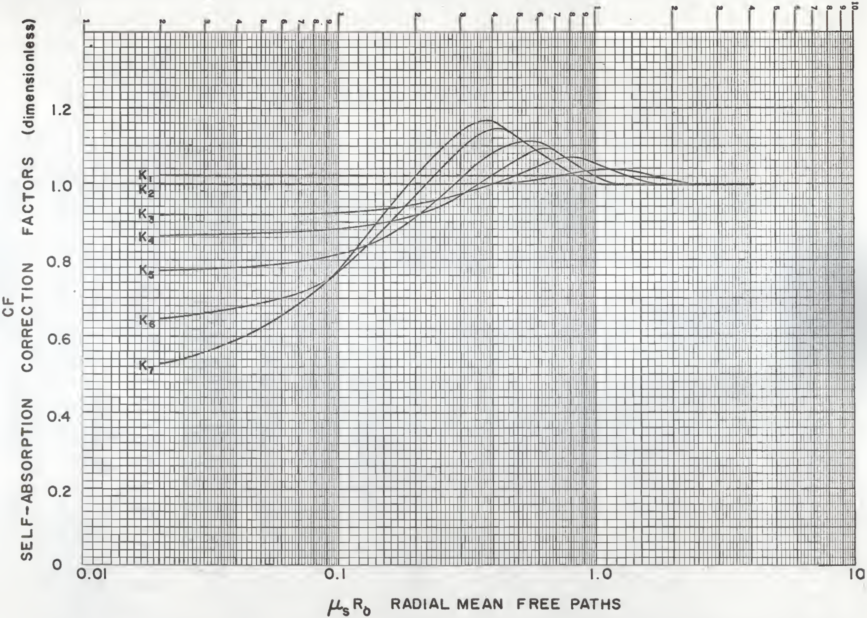

Fig. 10a. Correction factors for equivalent circular plane source self-absorption distance for $b_1 = 20$.

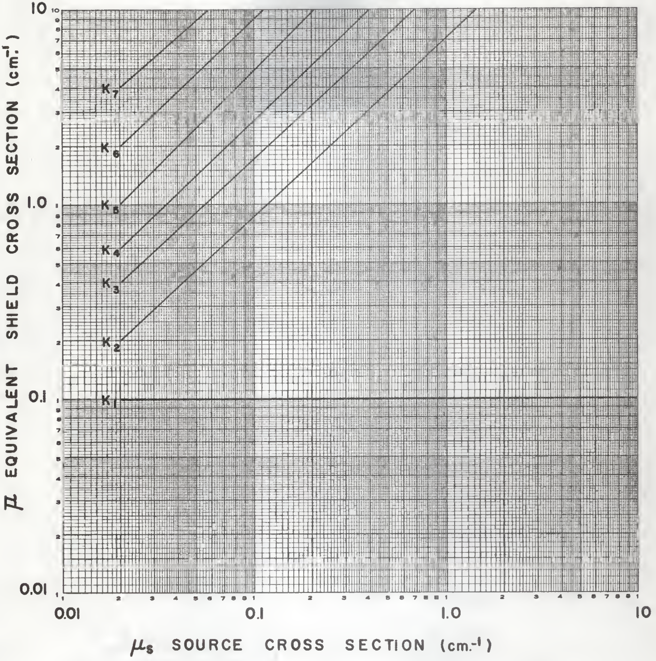

Fig. 10b. Source and shield cross sections correlation for $b_1 = 20$.

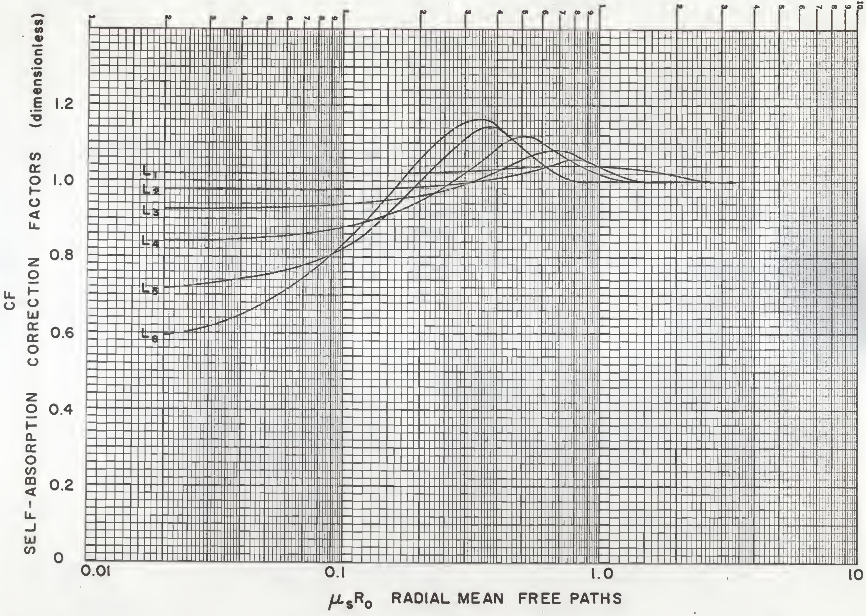

Fig. 11a. Correction factors for equivalent circular plane source self-absorption distance for $b_1 = 30$.

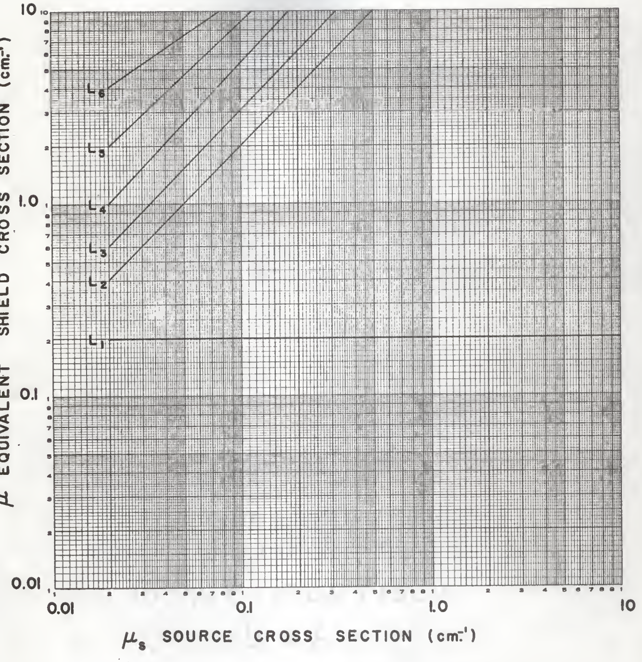

Fig. 11b. Source and shield cross sections correlation for $b_1 = 30$.

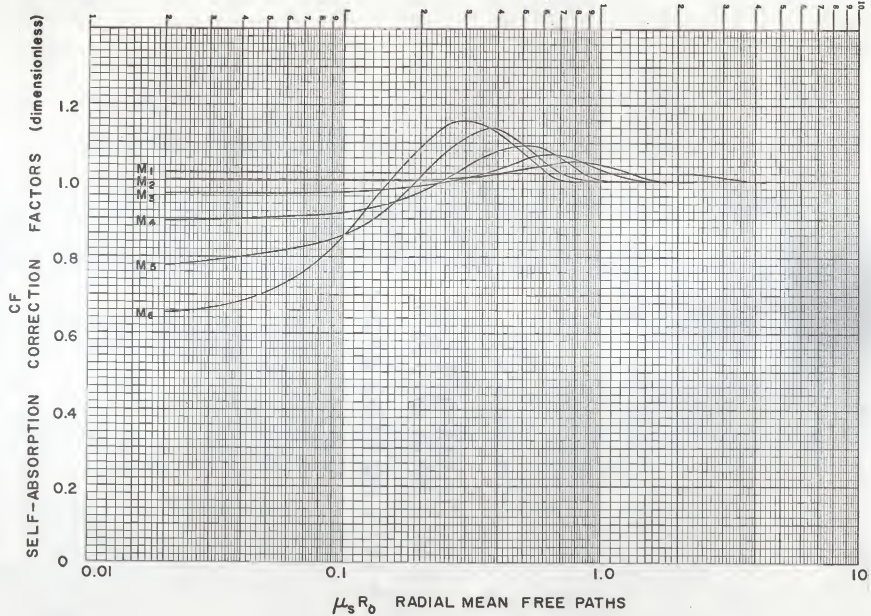

Fig. 12a. Correction factors for equivalent circular plane source self-absorption distance for $b_1 = 40$.

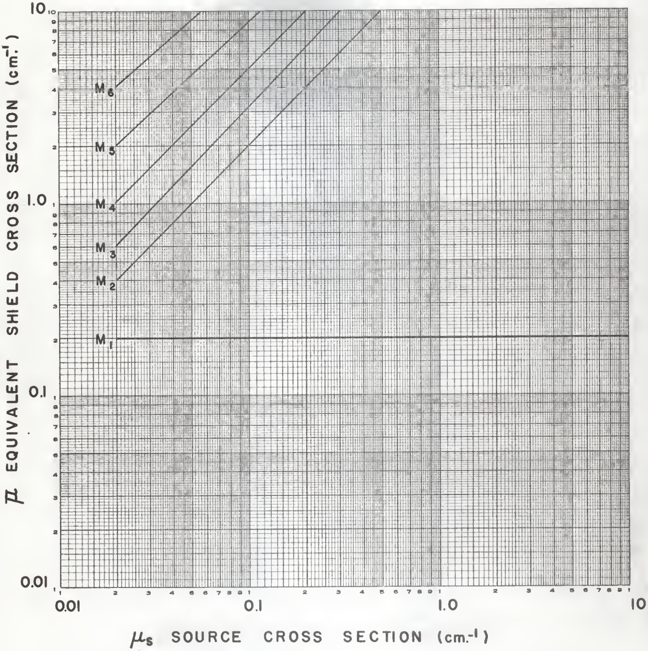

Fig. 12b. Source and shield cross sections correlation for $b_1 = 40$.

CONCLUSIONS

The largest errors in determination of fluxes by use of the curves presented in this paper will occur in the region where correction factors are necessary, due to the interpolation required to determine correction factors. Even so, this is the region where the greatest benefit is derived from this work, for it is here that currently used conical approximations are most in error.

For any given cylinder height, $\underline{h}$, the cylinder ceases to look like a disk and becomes a slender rod as $\underline{R_o}$ decreases. Similarly, for a fixed mean free path height, $\underline{\mu_s h}$, as $\underline{\mu_s}$ decreases the cylinder becomes longer and for a fixed radius the cylinder again appears rod-like. Certainly the artificial nature of the plane source approximation would be expected to have adverse effects in this region, if at all, and the correction factors necessary for small $\underline{\mu_s R_o}$ were no surprise although their shape could not be anticipated.

An empirical solution similar to the one presented herein is presented in Rockwell (6) which enables one to determine the flux from the side of a cylinder by approximating the cylinder by a line source located within the cylinder. This empirical solution provides a method amenable to hand calculation to reproduce the results shown by Taylor and Obenshain (7). This original work is applicable only for cylinders having $\underline{h \gg R_o}$ and $\underline{h > 1/\mu_s}$. These limitations are not mentioned by Rockwell and therefore his empirical solution may be frequently applied in instances which exceed the restrictions placed on the original data.

It is recommended that work be done in the area of accurate flux solutions from the side of a cylinder for cases excluded by Taylor and Obenshain (7), and that an effort be made to combine the results. Further effort should be made to present these results in some empirical form which lends itself to hand calculation. In particular, it is recommended that an effort be made to present the results in a manner analogous to that used in this paper.

ACKNOWLEDGMENT

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APPENDICES

APPENDIX A

Description and Explanation of the IBM 650 Computer Program Used to Calculate the Centerline Uncollided Flux from the End of a Finite Right-circular Cylinder

This program was written to calculate the centerline uncollided flux from the end of a finite cylinder, both accurately and by existing approximation methods, and to calculate the self-absorption distance of an equivalent source. This program was written in Soap II computer language using floating point operations. The logic diagram and the object program are given in this appendix.

The accurate solution is designated FLUX and the solution programmed was

$$\Phi\ (a) = \frac{S_V t_o}{2} \sum_{N=0}^{NMAX} \left\{ E_1(b_1 + (N + 0.45)\ \mu_s t_o) - E_1[(b_1 + (N + 0.45)\mu_s t_o)\ \sec\theta_N\ ] \right\} \tag{A-1}$$

$$\text{where } \sec\theta_N = \sqrt{1 + \frac{R_o^{\,2}}{(a + (N + .45)\ t_o)^2}} \tag{A-2}$$

Equation A-1 is derived as Eq. 3, the stacked disk solution on page 5, with $\underline{\delta}$ set at 0.45.

The solution to the large cone approximation was designated FLUXB and the solution programmed was

$$\Phi\ (a) = \frac{S_V}{2\mu_s} \left\{ E_2(b_1) - \frac{E_2(b_1\ \sec\theta_1)}{\sec\theta_1} - E_2(b_3) + \frac{E_2(b_3\ \sec\theta_1)}{\sec\theta_1} \right\}. \tag{A-3}$$

Equation A-3 appears as Eq. 4 on page 6.

The solution to the equivalent volume cone approximation was designated FLUXM and the solution programmed was

$$\Phi\,(a) = \frac{S_V}{2\mu_s}\left\{ E_2(b_1) - \frac{E_2(b_1 \sec \theta_1)}{\sec \theta_1} - E_2(b_3') + \frac{E_2(b_3' \sec \theta_1)}{\sec \theta_1}\right\} \qquad \text{(A-4)}$$

Equation A-4 appears on page 7 as Eq. 6.

The solution to the small cone approximation was designated FLUXS and the solution programmed was

$$\Phi\,(a) = \frac{S_V}{2\mu_s}\left\{ E_2(b_1) - \frac{E_2(b_1 \sec \theta_2)}{\sec \theta_2} - E_2(b_3) + \frac{E_2(b_3 \sec \theta_2)}{\sec \theta_2}\right\}. \qquad \text{(A-5)}$$

Equation A-5 appears on page 6 as Eq. 5.

The solution to the equivalent circular plane source approximation was designated FLUXZ and the solutions programmed were

$$\Phi\,(a) = \frac{S_V h}{2}\left\{E_1(b_2) - E_1\,(b_2 \sec \theta_z)\right\},\ \text{if } \mu_s h \leq 1.5 \qquad \text{(A-6)}$$

and

$$\Phi\,(a) = \frac{S_V(1.5)}{2\mu_s}\left\{E_1(b_2) - E_1(b_2 \sec \theta_z)\right\}\ \text{ if } \mu_s h > 1.5. \qquad \text{(A-7)}$$

This was a trial and error solution where $\underline{z}$ was altered as necessary to cause FLUXZ to approximate FLUX within a specified accuracy. Equations A-6 and A-7 appear on page 7 as Eqs. 7 and 8 with $\underline{K}$ set at 1.5.

The program subrouting for $E_1(x)$ used different solutions for values of $\underline{x < 1}$ and for $\underline{x \geq 1}$.

For $\underline{x < 1}$

$$E_1(x) = -0.57721566 - \ln x + x - \frac{x^2}{4} + \frac{x^3}{18} - \dots \ . \qquad \text{(A-8)}$$

For $\underline{x \geq 1}$

$$E_1(x) = \frac{e^{-x}}{x}\left\{\frac{a_o + a_1\,x + a_2\,x^2 + a_3\,x^3 + x^4}{b_o + b_1\,x + b_2\,x^2 + b_3\,x^3 + x^4}\right\} \qquad \text{(A-9)}$$

where

$a_o = 0.26777373$ $\qquad$ $b_o = 3.9584969$

$a_1 = 8.6347609$ $\qquad$ $b_1 = 21.099653$

$a_2 = 18.059017$ $\qquad$ $b_2 = 25.632956$

$a_3 = 8.5733287$ $\qquad$ $b_3 = 9.5733223$

Equation A-8 is an infinite series and the choice of number of terms used was set by requiring that the ratio of the absolute value of the last term to the complete series be less than some specified value. Equation A-9 is an approximate solution developed by Hastings (5), accurate to within the limitations of the computer.

Input and output data associated with this program are listed in Tables A-1 and A-2 respectively.

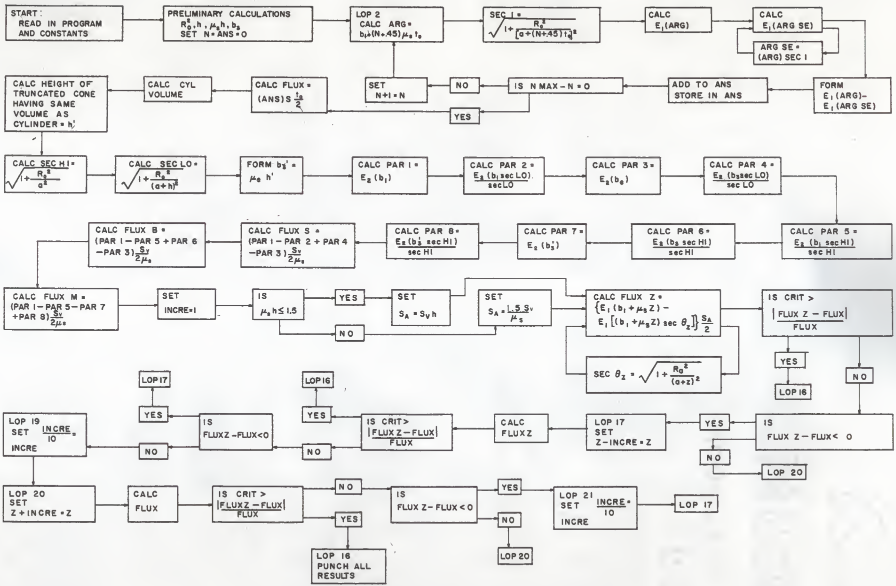
Table A-1. Input data required for use of the IBM 650 Computer program which calculates the centerline uncollided flux from the end of a finite right-circular cylinder.

Symbol	Explanation	Drum Storage Location
NMAX	One less than the number of disks in the cylinder	0100
TZRO	Disk thickness (cm)	0101
MUS	Cylinder cross section (cm^{-1})	0102
BONE	Shield mean free paths	0103
A	Shield thickness (cm)	0104
R	Cylinder radius (cm)	0105
S	Source strength (cm^{-3} sec^{-1})	0106
CHK	Check to calculate or pass by a given cylinder	0107
ZZRO	Initial self-absorption values (cm)	0108
CRIT	Required precision of equivalent source flux calculation	0500
CRIT1	Cylinder height (mean free paths) for constant equivalent source strength	0550
PT45	Ratio of δ to disk thickness	0350

Table A-2. Identification table for print outs for centerline uncollided flux calculation from the end of a finite cylinder.

Card	Word	Symbol and/or Explanation
1	1	FLUX
	2	FLUXB
	3	FLUXM
	4	FLUXS
	5	FLUXZ
	6	z Self-absorption distance (cm)
	7	(FLUX - FLUXZ) / FLUX
	8	$\mu_s z$ Self-absorption distance mean free paths
2	1	FLUXB - FLUX
	2	(FLUXB - FLUX)/FLUX
	3	FLUXM - FLUX
	4	(FLUXM - FLUX)/FLUX
	5	FLUX - FLUXS
	6	(FLUX - FLUXS)/FLUS
3	1	HITE Cylinder height (cm)
	2	NMAX
	3	TZRO
	4	MUS
	5	BONE
	6	A
	7	R
	8	S
4	1	HITE+ A
	2	(HITE) (MUS) Cylinder height mean free paths
	3	(TZRO) (MUS) Disk thickness mean free paths
	4	(R) (MUS) Radial mean free paths
	5	MU Shield cross section (cm^{-1})
	6	A +R
	7	A/R
	8	A/HITE

Approximate running time for the program is 5 minutes for NMAX equal to 100. The program is faster when $\underline{b_1 > 1}$ due to the difference in the series calculations to be made.



LOGIC DIAGRAM APPENDIX A

OBJECT PROGRAM FOR CALCULATION OF FLUX AND EQUIVALENT CIRCULAR PLANE SOURCE SELF-ABSORPTION DISTANCE

```
         BLR  1951    1960                       1   0000   00 0000 0000   -0000000000000000
         BLH  1977    1984                       2   0000   00 0000 0000   -000000000-000000
         BLR  1700    1749                       3   0000   00 0000 0000   -000000000-000000
         SYN  NMAX    0100      DISKBLEBB1       4   0000   00 0000 0000   -000000000-000000
         SYN  TZRO    0101      OISKTHKNES       5   0000   00 0000 0000   -000000000-000000
         SYN  MUS     0102      SOURCE ABS       6   0000   00 0000 0000   -000000000-000000
         SYN  BONE    0103      SHIELO MFP       7   0000   00 0000 0000   -000000000-000000
         SYN  A       0104      SHIELO THK       8   0000   00 0000 0000   -000000000-000000
         SYN  R       0105      CYL RADIUS       9   0000   00 0000 0000   -000000000-000000
         SYN  S       0106      SOURCE          10   0000   00 0000 0000   -000000000-000000
         SYN  CHK     0107      POS OR NEG      11   0000   00 0000 0000   -000000000-000000
         SYN  ZZNO    0108                      12   0000   00 0000 0000   -000000000-000000
         SVN  STANT   1000      START LOCA      13   0000   00 0000 0000   -000000000-000000
ZRO       00  0000    0000      ZERO            14   0000   00 0000 0000
ONE       10  0000    0051      ONE             15   0050   10 0000 0051
TWO       20  0000    0051      TWO             16   0150   20 0000 0051
THNEE     30  0000    0051      THREE           17   0200   30 0000 0051
FOUR      40  0000    0051      FOUR            18   0250   40 0000 0051
TEN       10  0000    0052      TEN             19   0300   10 0000 0052
PT45      46  0000    0050      POINT 45        20   0350   45 0000 0050
FP100     10  0000    0053      NUNOREO         21   0400   10 0000 0053
FP80      80  0000    0052      EIGHTY          22   0450   80 0000 0052
CNIT      50  0000    0047      Z CRITERIA      23   0500   50 0000 0047
CNIT1     15  0000    0051                      24   0550   15 0000 0051
PI        31  4159    2751      PI              25   0600   31 4159 2751
START    NAU  CHK                               26   1000   60 0107 0011
         BMI  8000                              27   0011   46 8000 0015
         RAU  BONE                              28   0015   60 0103 0007
         FBB  1700                              29   0007   33 1700 0027
         NZE          LOP1                      30   0027   45 0030 0031
         LOO          EOOCL                     31   0030   69 0033 0036
         PCH  1977                              32   0033   71 1977 0077
         PCH  1977                              33   0077   71 1977 0127
         PCN  1977    LOP1                      34   0127   71 1977 0031
LOP1     HAU  R                                 35   0031   60 0105 0009
         FMP  8003                              36   0009   39 8003 0013
         STU  RSQO                              37   0013   21 0018 0021
         HAU  NMAX                              38   0021   60 0100 0005
         FAO  ONE                               39   0005   32 0050 0177
         STU  OISKS                             40   0177   21 0032 0035
         FMP  TZHO                              41   0035   39 0101 0001
         STU  NITE              CYL NEIGHT      42   0001   21 0006 0059
         FMP  MUS                               43   0059   39 0102 0002
         STU  CYMFP             CVL MFP         44   0002   21 0056 0109
         FAO  BONE                              45   0109   32 0103 0029
         STU  STNNE                             46   0029   21 0034 0037
         LOD  ZRO                               47   0037   69 0000 0003
         STO  N                                 48   0003   24 0156 0159
         STO  ANS     LOP2                      49   0159   24 0012 0065
LOP2     HAU  N                                 50   0065   60 0156 0061
         FAO  PT45                              51   0061   32 0350 0227
         FMP  TZHO                              52   0227   39 0101 0051
         STU  OIST                              53   0051   21 0206 0209
         FMP  MUS                               54   0209   39 0102 0052
         FAO  BONE                              55   0052   32 0103 0079
         STU  ARG                               56   0079   21 0084 0087
         FSB  FP100                             57   0087   33 0400 0277
         BMI           8000                     58   0277   46 0080 8000
         HAU  ARO                               59   0080   60 0084 0039
         LOO          EONE                      60   0039   69 0042 0045
         STU  EDNEX                             61   0042   21 0046 0049
         RAU  OIST                              62   0049   60 0206 0111
         FAD  A                                 63   0111   32 0104 0081
         STU  N                                 64   0081   21 0086 0089
         FMP  8003                              65   0089   39 8003 0043
         STU  NSOD                              66   0043   21 0048 0151
         RAU  RSQO                              67   0151   60 0018 0023
         FOV  HSQO                              68   0023   34 0048 0098
         FAD  ONE                               69   0098   32 0050 0327
         LOO          SQROT                     70   0327   69 0130 0083
         STU  SEC1                              71   0130   21 0134 0137
         FMP  ARG                               72   0137   39 0084 0184
         STU  ARGSE                             73   0184   21 0038 0041
         FSH  FP100                             74   0041   33 0400 0377
         BMI          LOP3                      75   0377   46 0180 0131
         HAU  ANGSE                             76   0180   60 0038 0093
         LOO          EONE                      77   0093   69 0096 0045
         STU  EONEY   LOP4                      78   0096   21 0650 0053
LOP3     LOO  ZRO                               79   0131   69 0000 0153
         STO  EONEY   LOP4                      80   0153   24 0650 0053
LOP4     HAU  EDNEX                             81   0053   60 0046 0201
         FSN  EDNEY                             82   0201   33 0650 0427
         FAD  ANS                               83   0427   32 0012 0139
         STU  ANS                               84   0139   21 0012 0115
         HAU  NMAX                              85   0115   60 0100 0055
         FSB  N                                 86   0055   33 0156 0133
         NZE          LOP5                      87   0133   45 0136 0187
         RAU  N                                 88   0136   60 0156 0161
         FAO  ONE                               89   0161   32 0050 0477
         STU  N       LOP2                      90   0477   21 0156 0065
LOP6     RAU  ANS                               91   0187   60 0012 0017
         FMP  S                                 92   0017   39 0106 0256
         FOY  TWO                               93   0256   34 0150 0700
         FHP  TZHO                              94   0700   39 0101 0251
         STU  FLUX                              95   0251   21 0306 0259
         STU   1977                             96   0259   21 1977 0230
         RAU  HITE                              97   0230   60 0006 U211
         FMP  PI                                98   0211   39 0600 0750
         FMP  RSQO                              99   0750   39 0018 0068
         STU  VOL               CYL VOLUME     100   0068   21 0022 0025
         FMP  THREE                            101   0025   39 0200 0800
         FOV  PI                               102   0800   34 0600 0850
         FDV  RSOO                             103   0850   34 0018 0118
         FAO  A                                104   0118   32 0104 0181
         FMP  A                                105   0181   39 0104 0004
         FMP  A                                106   0004   39 0104 0054
         LDO          CBROT                    107   0054   69 0057 0010
         FSB  A                                108   0057   33 0104 0231
         STU  HPN               EOUIY HITE     109   0231   21 0186 0189
         FMP  MUS                              110   0189   39 0102 0152
         STU  MFPPR                            111   0152   21 0356 0309
         FAD  HDNE                             112   0309   32 0103 0129
         STU  S3PRM                            113   0129   21 0234 0237
         RAU  RSQO                             114   0237   60 0018 0073
         FOV  A                                115   0073   34 0104 0154
```

```
          FOV  A                                116    0154    34  0104  0204
          FAO  ONE                              117    0204    32  0050  0527
          LOO            SOROT                  118    0527    69  0280  0083
          STU  SECHI                            119    0280    21  0284  0287
          RAU  HITE                             120    0287    60  0006  U261
          FAD  A                                121    0261    32  0104  0281
          STU  HPR2                             122    0281    21  0236  0239
          FMP   8003                            123    0239    39  8003  0143
          STU  HPR2S                            124    0143    21  0148  0301
          RAU  R800                             125    0301    60  0018  0123
          FOV  HPR2S                            126    0123    34  0148  0198
          FAO  ORE                              127    0198    32  0050  0577
          LOO            SQROT                  128    0577    69  0330  0083
          STU  SECLO                            129    0330    21  0334  0337
          RAU  SONE                             130    0337    60  0103  0157
          LOO            ETSO                   131    0157    69  0060  0063
          STU  PAR1                             132    0060    21  0014  0067
          RAU  BONE                             133    0067    60  0103  0207
          FMP  SECLO                            134    0207    39  0334  0384
          STU  ASC1                             135    0384    21  0088  0091
          FSR  FP100                            136    0091    33  0400  0627
          SMI            LOP6                   137    0627    46  0380  0331
          RAU  ASC1                             138    0380    60  0088  0193
          LOO            ETWO                   139    0193    69  0146  0063
          FOV  SECLO                            140    0146    34  0334  0434
          STU  PAR2      LOP7                   141    0434    21  0138  0141
LOP6      LOO  ZRO                              142    0331    69  0000  0203
          STO  PAR2      LOP7                   143    0203    24  0138  0141
LOP7      RAU  STHRE                            144    0141    60  0034  0289
          LOO            ETWO                   145    0289    69  0092  0063
          STU  PAR3                             146    0092    21  0196  0099
          RAU  STHRE                            147    0099    60  0034  0339
          FMP  SECLO                            148    0339    39  0334  0484
          STU  ASC2                             149    0484    21  0188  0191
          FSS  FP100                            150    0191    33  0400  0677
          SMI            LOP8                   151    0677    46  0430  0381
          RAU  ASC2                             152    0430    60  0188  0243
          LOO            ETSO                   153    0243    69  0246  0063
          FOV  SECLO                            154    0246    34  0334  0534
          STU  PAR4      LOP9                   155    0534    21  0238  0241
LOP8      LOO  ZRO                              156    0381    69  0000  0253
          STU  PAR4      LOP9                   157    0253    21  0238  0241
LOP9      RAU  SONE                             158    0241    60  0103  0257
          FMP  SECHI                            159    0257    39  0284  0584
          STU  ASC3                             160    0584    21  0288  0291
          FSS  FP100                            161    0291    33  0400  0727
          SMI            LOP10                  162    0727    46  0480  0431
          RAU  ASC3                             163    0480    60  0288  0293
          LOO            ETWO                   164    0293    69  0296  0063
          FOV  SECHI                            165    0296    34  0284  0634
          STU  PAR5      LOP11                  166    0634    21  0338  0341
LOP10     LOO  ZRO                              167    0431    69  0000  0303
          STO  PAR5      LOP11                  168    0303    24  0338  0341
LOP11     RAU  STHRE                            169    0341    60  0034  0389
          FMP  SECHI                            170    0389    39  0284  0684
          STU  ASC4                             171    0684    21  0388  0391
          FSS  FP100                            172    0391    33  0400  0777
          SMI            LOP12                  173    0777    46  0530  0481
          RAU  ASC4                             174    0530    60  0388  0343
          LOO            ETWO                   175    0343    69  0346  0063
          FOV  SECHI                            176    0346    34  0284  0734
          STU  PAR6      LOP13                  177    0734    21  0438  0441
LOP12     LOO  ZRO                              178    0481    69  0000  0353
          STO  PAR6      LOP13                  179    0353    24  0438  0441
LOP13     RAU  S3PRM                            180    0441    60  0234  0439
          LOO            ETWO                   181    0439    69  0142  0063
          STU  PAR7                             182    0142    21  0396  0149
          RAU  S3PRM                            183    0149    60  0234  0489
          FMP  SECHI.                           184    0489    39  0284  0784
          STU  ASC5                             185    0784    21  0488  0491
          FSS  FP100                            186    0491    33  0400  0827
          SMI            LOP14                  187    0827    46  0580  0531
          RAU  ASC5                             188    0580    60  0488  0393
          LOO            ETWO                   189    0393    69  0446  0063
          FOV  SECHI                            190    0446    34  0284  0834
          STU  PAR8      LOP15                  191    0834    21  0538  0541
LOP14     LOO  ZRO                              192    0531    69  0000  0403
          STO  PAR8      LOP15                  193    0403    24  0538  0541
LOP15     RAU  PAR1                             194    0541    60  0014  0019
          FSS  PAR2                             195    0019    33  0138  0165
          FAO  PAR4                             196    0165    32  0238  0215
          FSS  PAR3                             197    0215    33  0196  0173
          STU  ASC6                             198    0173    21  0028  0581
          RAU  5                                199    0581    60  0106  0311
          FOV  MUS                              200    0311    34  0102  0202
          FOV  TSO                              201    0202    34  0150  0900
          STU  ASC7                             202    0900    21  0254  0307
          FMP  ASC6                             203    0307    39  0028  0078
          STU  FLUXS                SMALL CORE  204    0078    21  0082  0085
          RAU  PAR1                             205    0085    60  0014  0069
          FSS  PAR5                             206    0069    33  0338  0265
          STU  PAR9                             207    0268    21  0020  0223
          FAO  PAR6                             208    0223    32  0438  0315
          FSS  PAR3                             209    0315    33  0196  0273
          FMP  ASC7                             210    0273    39  0254  0304
          STU  FLUXS                SIG CORE    211    0304    21  0008  0361
          RAU  PAR9                             212    0361    60  0020  0075
          FSS  PAR7                             213    0075    33  0396  0323
          FAO  PAR8                             214    0323    32  0538  0365
          FMP  ASC7                             215    0365    39  0254  0354
          STU  FLUXM                MEO CONE    216    0354    21  0058  0411
          LOO  ZZRO                             217    0411    69  0108  0461
          STO  Z                                218    0461    24  0064  0117
          LOO  ORE                              219    0117    69  0050  0453
          STO  IRCRE                            220    0453    24  0406  0359
          RAU  CYMFP                            221    0359    60  0056  0511
          FSS  CRIT1                            222    0511    33  0550  0877
          SMI            LOP50                  223    0877    46  0630  0631
          RAU  S                                224    0630    60  0106  0561
          FMP  HITE                             225    0561    39  0006  0456
          FOV  TSO                              226    0456    34  0150  0950
          STU  ASC8      LOP51                  227    0950    21  0404  0357
LOP50     RAU  CRIT1                            228    0631    60  0550  0185
          FOV  MUS                              229    0155    34  0102  0252
          FMP  S                                230    0252    39  0106  0506
          FOV  TSO                              231    0506    34  0150  1050
          STU  ASC8      LOP51                  232    1050    21  0404  0357
LOP51     RAU  Z                                233    0357    60  0064  0119
          LOO            CALC                   234    0119    69  0072  0185
          SMI  LOP17     LOP20                  235    0072    46  0175  0026
LOP17     RAU  Z                                236    0175    60  0064  0169
          FSS  IRCRE                            237    0169    33  0406  0183
          STU  Z                                238    0183    21  0064  0167
          LDO            CALC                   239    0167    69  0070  0125
          SMI  LOP17     LOP19                  240    0070    46  0175  0024
LOP19     RAU  IRCRE                            241    0024    60  0406  0611
          FOV  TER                              242    0611    34  0300  1100
          STU  IRCRE     LOP20                  243    1100    21  0406  0026
LOP20     RAU  Z                                244    0026    60  0064  0219
          FAO  IRCRE                            245    0219    32  0406  0233
```

```
        STU Z                                     246   0233   21 0064 0217
        LDD               CALC                    247   0217   69 0120 0125
        BMI LOP21         LOP20                   248   0120   46 0373 0026
LOP21   RAU INCRE                                 249   0373   60 0406 0661
        FDV TEN                                   250   0661   34 0300 1150
        STU INCRE         LOP17                   251   1150   21 0406 0175
LOP16   RAU ABC9                                  252   1200   60 0503 0407
        STU FLUXZ                                 253   0407   21 0062 0415
        STU  1981                                 254   0415   21 1981 0884
        LOD Z                                     255   0884   69 0064 0267
        STD ZZRO                                  256   0267   24 0108 0711
        STD  1982                                 257   0711   24 1982 0135
        LOD FLUX8                                 258   0135   69 0008 0761
        STD  1978                                 259   0761   24 1978 0681
        LOD FLUXM                                 260   0681   69 0058 0811
        5TD  1979                                 261   0811   24 1979 0132
        LOO FLUX8                                 262   0132   69 0082 0185
        STD  1980                                 263   0185   24 1980 0283
        LDO PCT                                   264   0283   69 0286 0539
        STO  1983                                 265   0539   24 1983 0336
        RAU Z                                     266   0336   60 0064 0269
        FMP MUS                                   267   0269   39 0102 0302
        STU  1984                                 268   0302   21 1984 0387
        PCH  1977                                 269   0387   71 1977 0927
        LOO               EOOCL                   270   0927   69 0680 0036
        RAU FLUX8                                 271   0680   60 0008 0113
        F58 FLUX                                  272   0113   33 0306 0333
        STU  1977                                 273   0333   21 1977 0730
        FOV FLUX                                  274   0730   34 0306 0556
        STU  1978                                 275   0556   21 1978 0731
        RAU FLUXM                                 276   0731   60 0058 0163
        FSB FLUX                                  277   0163   33 0306 0383
        STU  1979                                 278   0383   21 1979 0182
        FOV FLUX                                  279   0182   34 0306 0606
        STU  1980                                 280   0606   21 1980 0433
        RAU FLUX                                  281   0433   60 0306 0861
        FSB FLUX8                                 282   0861   33 0082 0409
        STU  1981                                 283   0409   21 1981 0934
        FOV FLUX                                  284   0934   34 0306 0656
        STU  1982                                 285   0656   21 1982 0235
        PCH  1977                                 286   0235   71 1977 0977
        LOO HITE                                  287   0977   69 0006 0459
        STO  1977                                 288   0459   24 1977 0780
        LOO NMAX                                  289   0780   69 0100 0553
        STO  1978                                 290   0553   24 1978 0781
        LOD TZRO                                  291   0781   69 0101 0454
        STO  1979                                 292   0454   24 1979 0232
        LOO MUS                                   293   0232   69 0102 0205
        STO  1980                                 294   0205   24 1980 0483
        LOO BONE                                  295   0483   69 0103 0706
        STO  1981                                 296   0706   24 1981 0984
        LOO A                                     297   0984   69 0104 0457
        STO  1982                                 298   0457   24 1982 0285
        LOD R                                     299   0285   69 0105 0158
        STO  1983                                 300   0158   24 1983 0386
        LDO S                                     301   0386   69 0106 0509
        STO  1984                                 302   0509   24 1984 0437
        PCH  1977                                 303   0437   71 1977 1027
        LOD HPR2                                  304   1027   69 0236 0589
        STO  1977                 HT PLUS A       305   0589   24 1977 0830
        RAU CYMFP                                 306   0830   60 0056 0911
        STU  1978                 CYL MFP         307   0911   21 1978 0831
        FOV OISKS                                 308   0831   34 0032 0282
        STU  1979                 DISK MFP        309   0282   21 1979 0332
        RAU R                                     310   0332   60 0105 0559
        FMP MUS                                   311   0559   39 0102 0352
        STU  1980                 RAOIAL MFP      312   0352   21 1980 0533
        RAU BONE                                  313   0533   60 0103 0507
        FDV A                                     314   0507   34 0104 0504
        STU  1981                 MU              315   0504   21 1981 1034
        RAU R                                     316   1034   60 0105 0609
        FAO A                                     317   0609   32 0104 0881
        STU  1982                 A PLUS R        318   0881   21 1982 0335
        RAU A                                     319   0335   60 0104 0659
        FOV R                                     320   0659   34 0105 0255
        STU  1983                 A OVER R        321   0255   21 1983 0436
        RAU A                                     322   0436   60 0104 0709
        FOV HITE                                  323   0709   34 0006 0756
        STU  1984                 A OVER HT       324   0756   21 1984 0487
        PCH  1977                                 325   0487   71 1977 1077
        LOD BDNE                                  326   1077   69 0103 0806
        STO  1700                                 327   0806   24 1700 0603
        LOO               EOOCL                   328   0603   69 0856 0036
        PCH  1977          8000                   329   0856   71 1977 8000
CALC    STD CAL1                                  330   0125   24 0128 0931
        FMP MUS                                   331   0931   39 0102 0402
        FAO BONE                                  332   0402   32 0103 0179
        STU ARGU                                  333   0179   21 1084 0537
        LOD               EONE                    334   0537   69 0040 0045
        STU EONE1                                 335   0040   21 0044 0047
        RAU A                                     336   0047   60 0104 0759
        FAD Z                                     337   0759   32 0064 0591
        FMP  8003                                 338   0591   39 8003 0095
        5TU HTSQO                                 339   0095   21 1250 0653
        RAU RSQO                                  340   0653   60 0018 0423
        FOV HT5QD                                 341   0423   34 1250 1300
        FAO ONE                                   342   1300   32 0050 1127
        LDO               SQROT                   343   1127   69 0880 0083
        FMP ARGU                                  344   0880   39 1084 1134
        STU ABC15                                 345   1134   21 0588 0641
        FSB FP100                                 346   0641   33 0400 1177
        BMI               LOP52                   347   1177   46 0930 0981
        RAU ABC15                                 348   0930   60 0588 0443
        LOO               EONE                    349   0443   69 0496 0045
        STU EDNE2         LOP53                   350   0496   21 1350 0703
LDP52   LDO ZRO                                   351   0981   69 0000 0753
        STD EONE2         LOP53                   352   0753   24 1350 0703
LDP53   RAU EDNE1                                 353   0703   60 0044 0199
        FSB EONE2                                 354   0199   33 1350 1227
        FMP ASC8                                  355   1227   39 0404 0554
        STU ABC9                  Z FLUX          356   0554   21 0503 0906
        FSB FLUX                                  357   0906   33 0306 0583
        STU ERROR                                 358   0583   21 0638 0691
        RAU ZRD                                   359   0691   60 0000 0305
        FAM ERROR                                 360   0305   37 0638 0465
        FOV FLUX                                  361   0465   34 0306 0956
        STU PCT                                   362   0956   21 0286 0639
        FSB CRIT                                  363   0639   33 0500 1277
        BMI LDP16                                 364   1277   46 1200 1031
        RAU ERRDR         CAL1                    365   1031   60 0638 0128
DNE      10  0000          0051       ONE         366   0050   10 0000 0051
ZRD      00  0000          0000       ZERO        367   0000   00 0000 0000
CBROT   STO TEMPA                                 368   0010   24 0213 0016
        NZE               TEMPA              001  369   0016   45 0170 0213
        BMI MINUS                            002  370   0170   46 0473 0074
        STU ARGUM                            003  371   0074   21 0178 1081
        LOD FPDNE                            004  372   1081   69 1184 0587
        STD TEMPR         PROCE              005  373   0587   24 0090 0493
MINUB   RSU FPDNE                            006  374   0473   61 1184 0689
        STU TEMPB                            007  375   0689   21 0090 0543
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         FMP  ARGUM                           008  376   0543   39 0178 0228
         STU  ARGUM   PROCE                   009  377   0228   21 0178 0493
PROCE    LDD  FPONE                           010  378   0493   69 1184 0637
         STD  U       CONT4                   011  379   0637   24 0140 0593
CONT4    RAU  ARGUM                           012  380   0593   60 0178 0633
         FDV  U                               013  381   0633   34 0140 0190
         FDV  U                               014  382   0190   34 0140 0240
         FSB  U                               015  383   0240   33 0140 0317
         FDV  THREE                           016  384   0317   34 0200 1400
         STU  CHECK                           017  385   1400   21 0604 0557
         FDV  U                               018  386   0557   34 0140 0290
         RAM   8003                           019  387   0290   67 8003 0097
         RAU   8002                           020  388   0097   60 8002 0355
         FSB  PREC7                           021  389   0355   33 0208 0385
         BMI  TEMPC   CONT3                   022  390   0385   46 0688 0739
CONT3    RAU  CHECK                           023  391   0739   60 0604 0809
         FAD  U                               024  392   0809   32 0140 0367
         STU  U       CONT4                   025  393   0367   21 0140 0593
TEMPC    RAU  CHECK                           026  394   0688   60 0604 0859
         FAD  U                               027  395   0859   32 0140 0417
         FMP  TEMPB                           028  396   0417   39 0090 0340
         LDD   8003   TEMPA                   029  397   0340   69 8003 0213
FPONE     10   0000    0051                   030  398   1184   10 0000 0051
THREE     30   0000    0051                   031  399   0200   30 0000 0051
PREC7     10   0000    0044                   032  400   0208   10 0000 0044
LNX51    STO  LNX08           EXIT INSTR           401   1450   24 0803 1006
         NZE          LNX14                        402   1006   45 0110 0961
         BMI  LNX14                                403   0110   46 0961 0114
         STU  LNX09                                404   0114   21 0168 0071
         RSL  FPONE                                405   0071   66 1184 0789
         STO  LNX10                                406   0789   24 0192 0145
         STL  LNX02                                407   0145   20 0249 0452
         RAU  LNX09                                408   0452   60 0168 0523
         STL  LNX05                                409   0523   20 1327 0980
         STL  LNX11                                410   0980   20 0435 0738
         SLT   0008                                411   0738   35 0008 0607
         SUP  FIFTY                                412   0607   11 0160 0515
         NZE          LNX04                        413   0515   45 0218 0319
         BMI          LNX03                        414   0218   46 0121 0122
         RSU   8003                                415   0121   61 8003 0229
         LDD  FPONE                                416   0229   69 1184 0687
         STD  LNX02   LNX03                        417   0687   24 0249 0122
LNX03    SRT   0008                                418   0122   30 0008 0741
         SCT   0000                                419   0741   36 0000 0263
         AUP  SIXTY                                420   0263   10 0066 0171
         SUP   8002                                421   0171   11 8002 0279
         RAU   8003                                422   0279   60 8003 0737
         FMP  LNX02                                423   0737   39 0249 0299
         FMP  LNTEN                                424   0299   39 0502 0552
         STU  LNX05   LNX04                        425   0552   21 1327 0319
LNX04    RAL  LNX09                                426   0319   65 0168 0573
         SRT   0002                                427   0573   30 0002 0329
         RAU   8002                                428   0329   60 8002 0787
         ALO  FIFTY                                429   0787   15 0160 0565
         SLT   0002                                430   0565   35 0002 0221
         FAD  FPONE                                431   0221   32 1184 1011
         STU  LNX09                                432   1011   21 0168 0271
         FSB  FPTWO                                433   0271   33 0124 0351
         FDV  LNX09                                434   0351   34 0168 0268
         STU  LNX13                                435   0268   21 0172 0225
         STO  LNX12                                436   0225   24 0278 1131
         STD  LNX11                                437   1131   24 0435 0788
         FMP   8001                                438   0788   39 8001 0791
         STU  FACTR   LNX06                        439   0791   21 0546 0349
LNX06    RAU  LNX10                                440   0349   60 0192 0147
         FAD  FPTWO                                441   0147   32 0124 0401
         STU  LNX10                                442   0401   21 0192 0195
         RAU  LNX13                                443   0195   60 0172 1377
         FMP  FACTR                                444   1377   39 0546 0596
         FDV  LNX10                                445   0596   34 0192 0242
         STU  LNX13                                446   0242   21 0172 0275
         FAD  LNX12                                447   0275   32 0278 0405
         STU  LNX12                                448   0405   21 0278 1181
         FSB  LNX11                                449   1181   33 0435 1061
         FDV  LNX11                                450   1061   34 0435 0485
         RAM   8003                                451   0485   67 8003 0643
         RAU   8002                                452   0643   60 8002 0451
         FSB  SIZE7                                453   0451   33 0654 1231
         BMI  LNX07                                454   1231   46 1234 0535
         LDD  LNX12                                455   0535   69 0278 1281
         STD  LNX11                                456   1281   24 0435 0838
         RAU  LNX13                                457   0838   60 0172 1427
         FMP  LNX10                                458   1427   39 0192 0292
         STU  LNX13   LNX06                        459   0292   21 0172 0349
LNX07    RAU  LNX12                                460   1234   60 0278 0683
         FMP  FPTWO                                461   0683   39 0124 0174
         FSB  LNX05   LNX08                        462   0174   33 1327 0803
FPONE     10   0000    0051                        463   1184   10 0000 0051
FPTWO     20   0000    0051                        464   0124   20 0000 0051
SIZE7     10   0000    0044   CRITERIA             465   0654   10 0000 0044
LNTEN     23   0258    5151                        466   0502   23 0258 5151
FIFTY     50   0000    0000                        467   0160   50 0000 0000
SIXTY     00   0000    0060                        468   0066   00 0000 0060
LNX14     01   2345    6789   HALT                 469   0961   01 2345 6789
ETOX     STO  AAA1            EXIT INSTR           470   1500   24 0853 1056
         STU  AAA14           STORE ARG            471   1056   21 0210 0313
         RAU  AAA16           ZERO                 472   0313   60 0116 0321
         FAM  AAA14                                473   0321   37 0210 0837
         STU  AAA2                                 474   0837   21 0342 0245
         LDD  AAA3            ONE                  475   0245   69 0248 0501
         STD  AAA4    AAA8    COEFF                476   0501   24 0704 0657
AAA8     RAU  AAA2                                 477   0657   60 0342 0197
         FSB  AAA5            FIVE                 478   0197   33 1550 1477
         BMI  AAA6                                 479   1477   46 1030 1331
         STU  AAA2                                 480   1331   21 0342 0295
         RAU  AAA4                                 481   0295   60 0704 0909
         FMP  AAA7            E TO 5               482   0909   39 0112 0162
         STU  AAA4    AAA8                         483   0162   21 0704 0657
AAA6     RAU  AAA2                                 484   1030   60 0342 0247
         FSB  AAA3            ONE                  485   0247   33 0248 0325
         BMI  AAA28                                486   0325   46 0328 0379
         STU  AAA2                                 487   0379   21 0342 0345
         RAU  AAA4                                 488   0345   60 0704 0959
         FMP  AAA9            E TO 1               489   0959   39 0212 0262
         STU  AAA4    AAA6                         490   0262   21 0704 1030
AAA28    RAU  AAA2                                 491   0328   60 0342 0297
         FSB  AAA10           POINT TWO            492   0297   33 1600 1527
         BMI  AAA11                                493   1527   46 1080 1381
         STU  AAA2                                 494   1381   21 0342 0395
         RAU  AAA4                                 495   0395   60 0704 1009
         FMP  AAA12           E TO PT 2            496   1009   39 0312 0362
         STU  AAA4    AAA28                        497   0362   21 0704 0328
AAA11    RAU  AAA2                                 498   1080   60 0342 0347
         LDD          AAA17                        499   0347   69 1650 0903
         FMP  AAA4                                 500   1650   39 0704 0754
         STU  AAA13                                501   0754   21 0258 1111
         RAU  AAA14                                502   1111   60 0210 0615
         BMI  AAA15                                503   0615   46 0318 0369
         RAU  AAA13   AAA1                         504   0369   60 0258 0853
AAA15    RAU  AAA3                                 505   0318   60 0248 0953
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         FDV  AAA13    AAA1                     506    0953    34 0258 0853
AAA17    STO  AAA18              EXIT INSTR     507    0903    24 1106 1059
         RAU  AAA3               ONE            508    1059    60 0248 1003
         FAO  AAA2                              509    1003    32 0342 0419
         STU  AAA19                             510    0419    21 0224 1577
         LDD  AAA27              TWO            511    1577    69 1130 0733
         STO  AAA20              N              512    0733    24 0486 0839
         STO  AAA21              DENOM          513    0839    24 0392 0445
         RAU  AAA2                              514    0445    60 0342 0397
         FMP  AAA2                              515    0397    39 0342 0442
         STU  AAA23    AAA22     NUMERATOR      516    0442    21 0646 0399
AAA22    FDV  AAA21                             517    0399    34 0392 0492
         STU  AAA24              NTH TERM       518    0492    21 0696 0449
         FAO  AAA19                             519    0449    32 0224 0551
         STU  AAA19              TOTAL          520    0551    21 0224 1627
         RAU  AAA24                             521    1627    60 0696 0601
         FDV  AAA19                             522    0601    34 0224 0274
         FSB  AAA25              CRITERIA       523    0274    33 1677 1053
         SMI           AAA26                    524    1053    46 1156 0707
         RAU  AAA19    AAA18                    525    1156    60 0224 1106
AAA26    RAU  AAA20                             526    0707    60 0486 0841
         FAO  AAA3                              527    0841    32 0248 0375
         STU  AAA20              NEW N          528    0375    21 0486 0889
         FMP  AAA21                             529    0889    39 0392 0542
         STU  AAA21              NEW DENOM      530    0542    21 0392 0495
         RAU  AAA23                             531    0495    60 0646 0651
         FMP  AAA2                              532    0651    39 0342 0592
         STU  AAA23    AAA22                    533    0592    21 0646 0399
AAA3      10  0000     0051      ONE            534    0248    10 0000 0051
AAA5      50  0000     0051      FIVE           535    1550    50 0000 0051
AAA7      14  8413     1653      E TO 5         536    0112    14 8413 1653
AAA9      27  1828     1851      E              537    0212    27 1828 1851
AAA10     20  0000     0050      POINT TWO      538    1600    20 0000 0050
AAA12     12  2140     2851      E TO PT 2      539    0312    12 2140 2851
AAA16     00  0000     0000      ZERO           540    0116    00 0000 0000
AAA25     10  0000     0044      CRITERIA       541    1677    10 0000 0044
AAA27     20  0000     0051      TWO            542    1130    20 0000 0051
SQROT    STO  SQRT1                             543    0083    24 0536 0939
         NZE           SQRT1               002  544    0939    45 0642 0536
         SMI  SQRT2                        003  545    0642    46 0545 0746
         STU  SQRT3                        004  546    0746    21 1750 1103
         STO  SQRT4    SQRT5               005  547    1103    24 1206 1109
SQRT5    FDV  SQRT4                        006  548    1109    34 1206 1256
         FAO  SQRT4                        007  549    1256    32 1206 0783
         FDV  FPTWO                        008  550    0783    34 0124 0324
         STU  SQRT6                        009  551    0324    21 0378 1431
         FSB  SQRT4                        010  552    1431    33 1206 0833
         FDV  SQRT4                        011  553    0833    34 1206 1306
         RAM   8003                        012  554    1306    67 8003 0363
         RAU   8002                        013  555    0363    60 8002 0371
         FSB  SIZE8                        014  556    0371    33 0374 0701
         SMI  SQRT7                        015  557    0701    46 0804 0455
         LDD  SQRT6                        016  558    0455    69 0378 1481
         STO  SQRT4                        017  559    1481    24 1206 1159
         RAU  SQRT3    SQRT5               018  560    1159    60 1750 1109
SQRT7    RAU  SQRT6    SQRT1               019  561    0804    60 0378 0536
SQRT2    HLT   8888     8888               020  562    0545    01 8888 8888
FPTWO     20  0000     0051                021  563    0124    20 0000 0051
SIZE8     10  0000     0044                022  564    0374    10 0000 0044
ETWO     STO  E21                               565    0063    24 0166 0469
         STU  E22                               566    0469    21 0424 1777
         LDD           EONE                     567    1777    69 1180 0045
         FMP  E22                               568    1120    39 0424 0474
         STU  E23                               569    0474    21 0428 1531
         RSU  E22                               570    1531    61 0424 0429
         LDD           ETOX                     571    0429    69 0382 1500
         FSR  E23      E21                      572    0382    33 0428 0166
EOOCL    STO  ZZZ1               EXIT INSTR     573    0036    24 0989 0692
         LDD  ZZZ10                             574    0692    69 0595 0298
         STO   1977                             575    0298    24 1977 1230
         STO   1978                             576    1230    24 1978 1581
         STO   1979                             577    1581    24 1979 0432
         STO   1980                             578    0432    24 1980 0883
         STO   1981                             579    0883    24 1981 1284
         STO   1982                             580    1284    24 1982 0585
         STO   1983                             581    0585    24 1983 0586
         STO   1984    ZZZ1                     582    0586    24 1984 0989
ZZZ10     00  0000     0000                     583    0595    00 0000 0000
EONE     STO  EEE1               EXIT INSTR     584    0045    24 0348 0751
         STU  EEE2               ARGUMENT       585    0751    21 1356 1209
         FSB  ONE                               586    1209    33 0050 1827
         SMI  EONES    EONEL                    587    1827    46 1280 1631
EONES    RAU  EEE2               SMALL ARG      588    1280    60 1356 1161
         LDD           LNX51     LN ARG         589    1161    69 0164 1450
         STU  EEE5               LN EEE2        590    0164    21 0368 0421
         RSU  EEE13              GAMMA          591    0421    61 0524 0479
         FSB  EEE5                              592    0479    33 0368 0645
         FAO  EEE2                              593    0645    32 1356 0933
         STU  EEE12              PARTIALANS     594    0933    21 0888 0891
         RAU  TWO                               595    0891    60 0150 0505
         STO  EEE9               N              596    0505    24 0308 1211
         FMP   8003                             597    1211    39 8003 0665
         STU  EEE10              DENOM          598    0665    21 0220 0623
         LDD  EEE2                              599    0623    69 1356 1259
         STO  EEE8     EEE7      NUM            600    1259    24 0412 0715
EEE7     RSU  EEE2                              601    0715    61 1356 1261
         FMP  EEE8                              602    1261    39 0412 0462
         STU  EEE8               NUMERATOR      603    0462    21 0412 0765
         FDV  EEE10                             604    0765    34 0220 0270
         STU  EEE11              NTH TERM       605    0270    21 0574 1877
         FAO  EEE12                             606    1877    32 0888 0815
         STU  EEE12              TOTAL SUM      607    0815    21 0888 0941
         RAU  ZRO                               608    0941    60 0000 0555
         FAM  EEE11                             609    0555    37 0574 0801
         FDV  EEE12                             610    0801    34 0888 0938
         FSB  EEE15                             611    0938    33 0991 0467
         SMI           EEE14                    612    0467    46 0320 0471
         RAU  EEE12    EEE1                     613    0320    60 0888 0348
EEE14    RAU  EEE10                             614    0471    60 0220 0425
         FDV  EEE9                              615    0425    34 0308 0358
         STU  EEE10                             616    0358    21 0220 0673
         RAU  EEE9                              617    0673    60 0308 0413
         FAO  ONE                               618    0413    32 0050 1927
         STU  EEE9               NEW N          619    1927    21 0308 1311
         FMP   8003                             620    1311    39 8003 0865
         FMP  EEE10                             621    0865    39 0220 0370
         STU  EEE10    EEE7                     622    0370    21 0220 0715
EEE13     57  7215     6650      GAMMA          623    0524    57 7215 6650
EEE15     10  0000     0044      CRITERIA       624    0991    10 0000 0044
ZRO       00  0000     0000      ZERO           625    0000    00 0000 0000
ONE       10  0000     0051      ONE            626    0050    10 0000 0051
TWO       20  0000     0051      TWO            627    0150    20 0000 0051
EONEL    RAU  EEE2               LARGE ARG      628    1631    60 1356 1361
         FAO  0003                              629    1361    32 0214 1041
         FMP  EEE2                              630    1041    39 1356 1406
         FAO  0002                              631    1406    32 1309 0635
         FMP  EEE2                              632    0635    39 1356 1456
         FAO  0001                              633    1456    32 1359 0685
         FMP  EEE2                              634    0685    39 1356 1506
         FAO  0000                              635    1506    32 1409 0735
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         STU  EEE3              OENOMNATOR 636   0735   21 0390 0693
         RAU  EEE2                         637   0693   60 1356 1411
         FAD  CCC3                         638   1411   32 0264 1091
         FMP  EEE2                         639   1091   39 1356 1556
         FAD  CCC2                         640   1556   32 1459 0785
         FMP  EEE2                         641   0785   39 1356 1606
         FAO  CCC1                         642   1606   32 1509 0835
         FMP  EEE2                         643   0835   39 1356 1656
         FAD  CC00                         644   1656   32 1559 0885
         FOV  EEE3                  RATIO  645   0885   34 0390 0440
         FOV  EEE2                         646   0440   34 1356 1756
         STU  EEE4              ALLBUTETOX 647   1756   21 0260 0463
         RSU  EEE2                         648   0463   61 1356 1461
         LDD          ETOX                 649   1461   69 0314 1500
         FMP  EEE4    EEE1      EONEOFEEE2 650   0314   39 0260 0348
CCC0      26  7773    7350                 651   1559   26 7773 7350
CCC1      86  3476    0951                 652   1509   86 3476 0951
CCC2      18  0590    1752                 653   1459   18 0590 1752
CCC3      85  7332    8751                 654   0264   85 7332 8751
0000      39  5849    6951                 655   1409   39 5849 6951
0001      21  0996    5352                 656   1359   21 0996 5352
0002      25  6329    5652                 657   1309   25 6329 5652
0003      95  7332    2351                 658   0214   95 7332 2351
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APPENDIX B

Description of IBM 650 Computer Program Used to Calculate the Error in Centerline Uncollided Flux Determination from the End of a Finite Right-circular Cylinder by the Use of an Equivalent Circular Plane Source

This program was written to calculate the error of a flux determination by the empirical method developed in this thesis. The program was written in Soap II computer language using floating point operations. The logic diagram and the object program are given in this appendix.

The solution to the equivalent circular plane source approximation was designated ABC9 and the solutions programmed were

$$\Phi(a) = \frac{S_V}{2} \left\{ E_1(b_2)-E_1\ (b_2 \sec \theta_z)\right\}, \quad \text{if} \quad \mu_s h \leq 1.5; \qquad \text{(B-1)}$$

$$\Phi(a) = \frac{S_V(1.5)}{2\mu_s} \left\{ E_1(b_2) - E_1(b_2 \sec \theta_z)\right\}, \text{ if } \mu_s h > 1.5. \qquad \text{(B-2)}$$

Equations (B-1) and (B-2) appear as Eqs. A-6 and A-7 in Appendix A. The program subroutine for E_1 (x) is identical to that described in Appendix A.

Input data and output data associated with this program are listed in Tables B-1 and B-2 respectively.

Table B-1. Input data required for use of the IBM 650 Computer program which calculates the error in the empirical solution of the centerline uncollided flux from the end of a finite right-circular cylinder.

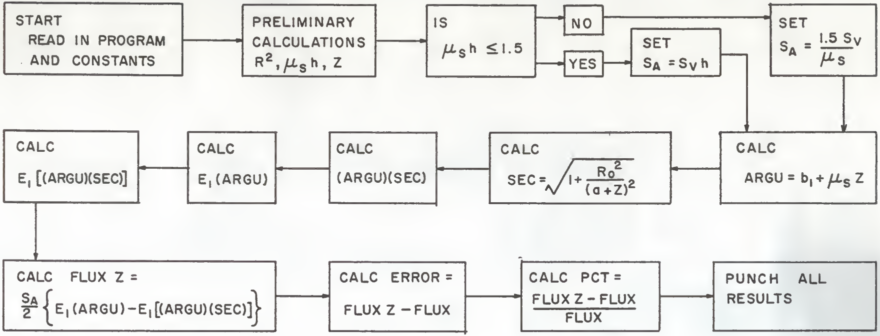
Symbol	Explanation	Drum Storage Location
HITE	Cylinder height (cm)	0000
BONE	Shield mean free paths	0001
FLUX	Actual flux (cm^{-2} sec^{-1})	0003
S	Source strength (cm^{-3} sec^{-1})	0004

Table B-1. (concl)

Symbol	Explanation	Drum Storage Location
R	Cylinder radius (cm)	0005
A	Shield thickness (cm)	0006
MUS	Source cross section (cm^{-1})	0008
MUSZ	Empirically determined self-absorption distance (mean free paths)	0009

Table B-2. Identification table for print outs for error calculation.

Card	Word	Symbol and/or Explanation
1	1	FLUX accurate flux solution
	2	ABC9 approximate flux solution
	3	ERROR ABC9 - FLUX
	4	PCT (ABC9 - FLUX)/FLUX
	5	z self-absorption distance
	6	A
	7	R
	8	BONE
2	1	HITE
	2	MUS
	3	$\mu_s h$ Cylinder height (mean free paths)
	4	$\bar{\mu}$ Shield cross section
	5	MUSZ
	6	MUSZ + BONE
	7	A + R
	8	A/R



LOGIC DIAGRAM APPENDIX B

OBJECT PROGRAM FOR CALCULATION OF ERROR IN EQUIVALENT CIRCULAR PLANE SOURCE FLUX DETERMINATION

```
         BLR  1951    1960                  1  0000  00 0000 0000  -000000000000000
         BLR  1977    1984                  2  0000  00 0000 0000  -000000000-00000
         BLR  1700    1749                  3  0000  00 0000 0000  -000000000-00000
         SYN  HITE    0000                  4  0000  00 0000 0000  -000000000-00000
         SYN  BONE    0001                  5  0000  00 0000 0000  -000000000-00000
         SYN  FLUX    0003                  6  0000  00 0000 0000  -000000000-00000
         SYN  S       0004                  7  0000  00 0000 0000  -000000000-00000
         SYN  R       0005                  8  0000  00 0000 0000  -000000000-00000
         SYN  A       0006                  9  0000  00 0000 0000  -000000000-00000
         SYN  MUS     0008                 10  0000  00 0000 0000  -000000000-00000
         SYN  MUSZ    0009                 11  0000  00 0000 0000  -000000000-00000
         SYN  START   1000                 12  0000  00 0000 0000  -000000000-00000
FP100    10   0000    0053     HUNDRED     13  0198  10 0000 0053
ONE      10   0000    0051     ONE         14  0100  10 0000 0051
TWO      20   0000    0051                 15  0150  20 0000 0051
CRIT1    15   0000    0051                 16  0200  15 0000 0051
START    RAU  BONE                         17  1000  60 0001 0055
         FSB  1700                         18  0055  33 1700 0027
         NZE          LOP1                 19  0027  45 0030 0031
         LDD          EODCL                20  0030  69 0033 0036
         PCH  1977                         21  0033  71 1977 0077
         PCH  1977                         22  0077  71 1977 0127
         PCH  1977    LOP1                 23  0127  71 1977 0031
LOP1     RAU  R                            24  0031  60 0005 0059
         FMP  8003                         25  0059  39 8003 0013
         STO  RSQD                         26  0013  21 0018 0021
         RAU  MUSZ                         27  0021  60 0009 0063
         FDV  MUS                          28  0063  34 0008 0058
         STO  Z                            29  0058  21 0012 0015
         RAU  HITE                         30  0015  60 0000 0105
         FMP  MUS                          31  0105  39 0008 0108
         FSB  CRIT1                        32  0108  33 0200 0177
         BMI          LOP2                 33  0177  46 0080 0081
         RAU  S                            34  0080  60 0004 0109
         FMP  HITE                         35  0109  39 0000 0250
         FDV  TWO                          36  0250  34 0150 0300
         STO  ARC8    LOP3                 37  0300  21 0054 0007
LOP2     RAU  CRIT1                        38  0081  60 0200 0155
         FDV  MUS                          39  0155  34 0008 0158
         FMP  S                            40  0158  39 0004 0104
         FDV  TWO                          41  0104  34 0150 0350
         STO  ARC8    LOP3                 42  0350  21 0054 0007
LOP3     RAU  Z                            43  0007  60 0012 0017
         LDD          CALC2                44  0017  69 0020 0023
         LDD  FLUX                         45  0020  69 0003 0056
         STD  1977                         46  0056  24 1977 0130
         LDD  ARC9                         47  0130  69 0083 0086
         STD  1978                         48  0086  24 1978 0131
         LDD  ERROR                        49  0131  69 0034 0037
         STD  1979                         50  0037  24 1979 0032
         LDD  PCT                          51  0032  69 0035 0038
         STD  1980                         52  0038  24 1980 0133
         LDD  Z                            53  0133  69 0012 0065
         STD  1981                         54  0065  24 1981 0084
         LDD  A                            55  0084  69 0006 0159
         STD  1982                         56  0159  24 1982 0085
         LDD  R                            57  0085  69 0005 0208
         STD  1983                         58  0208  24 1983 0136
         LDD  BONE                         59  0136  69 0001 0154
         STD  1984                         60  0154  24 1984 0087
         STD  1700                         61  0087  24 1700 0053
         PCH  1977                         62  0053  71 1977 0227
         RAU  HITE                         63  0227  60 0000 0205
         STO  1977                         64  0205  21 1977 0180
         FMP  MUS                          65  0180  39 0008 0258
         STD  1978                         66  0258  24 1978 0181
         STO  1979                         67  0181  21 1979 0082
         RAU  BONE                         68  0082  60 0001 0255
         FDV  A                            69  0255  34 0006 0106
         STO  1980                         70  0106  21 1980 0183
         LDD  MUSZ                         71  0183  69 0009 0062
         STD  1981                         72  0062  24 1981 0134
         LDD  ARC0                         73  0134  69 0137 0040
         STD  1982                         74  0040  24 1982 0135
         RAU  A                            75  0135  60 0006 0011
         FAD  R                            76  0011  32 0005 0231
         STO  1983                         77  0231  21 1983 0186
         RAU  R                            78  0186  60 0005 0209
         FMP  MUS                          79  0209  39 0008 0308
         STO  1984                         80  0308  21 1984 0187
         PCH  1977                         81  0187  71 1977 0277
         LDD          EODCL                82  0277  69 0230 0036
         PCH  1977     8000                83  0230  71 1977 8000
CALC2    STD  CAL1                         84  0023  24 0026 0029
         FMP  MUS                          85  0029  39 0008 0358
         FAD  NONE                         86  0358  32 0001 0327
         STO  ARC0                         87  0327  21 0137 0090
         LDD          EONE                 88  0090  69 0043 0046
         STO  EONE1                        89  0043  21 0048 0051
         RAU  A                            90  0051  60 0006 0061
         FAD  Z                            91  0061  32 0012 0039
         FMP  8003                         92  0039  39 8003 0093
         STO  HTSQD                        93  0093  21 0098 0101
         RAU  RSQD                         94  0101  60 0018 0073
         FDV  HTSQD                        95  0073  34 0098 0148
         FAD  ONE                          96  0148  32 0100 0377
         LDD          SQROT                97  0377  69 0280 0233
         FMP  ARC0                         98  0280  39 0137 0237
         STO  ARC15                        99  0237  21 0042 0045
         FSB  FP100                       100  0045  33 0198 0025
         BMI          LOP52               101  0025  46 0028 0079
         RAU  ARC15                       102  0028  60 0042 0047
         LDD          EONE                103  0047  69 0400 0046
         STO  EONE2   LOP53               104  0400  21 0204 0057
LOP52    LDD  ZRO                         105  0079  69 0050 0103
         STD  EONE2   LOP53               106  0103  24 0204 0057
LOP53    RAU  EONE1                       107  0057  60 0048 0153
         FSB  EONE2                       108  0153  33 0204 0281
         FMP  ARC8                        109  0281  39 0054 0254
         STO  ARC9                 Z FLUX 110  0254  21 0083 0236
         FSB  FLUX                        111  0236  33 0003 0139
         STO  ERROR                       112  0129  21 0034 0287
         FDV  FLUX                        113  0287  34 0003 0203
         STO  PCT     CAL1                114  0203  21 0035 0026
ONE      10   0000    0051     ONE        115  0100  10 0000 0051
```

ZRO	00	0000	0000	ZERO		116	0050	00	0000	0000
SQROT	STU	SQRT1				117	0233	24	0286	0089
	NZE		SQRT1		002	118	0069	45	0092	0286
	BMI	SQRT2			003	119	0092	46	0095	0096
	STU	SQRT3			004	120	0096	21	0450	0253
	STU	SQRT4	SQRT5		005	121	0253	24	0156	0259
SQRT5	FDV	SQRT4			006	122	0259	34	0156	0206
	FAD	SQRT4			007	123	0206	32	0156	0283
	FDV	FPTWO			008	124	0283	34	0336	0386
	STU	SQRT6			009	125	0386	21	0140	0143
	FSB	SQRT4			010	126	0143	33	0156	0333
	FDV	SQRT4			011	127	0333	34	0156	0256
	RAM	8003			012	128	0256	67	8003	0113
	RAU	8002			013	129	0113	60	8002	0071
	FSB	SIZE8			014	130	0071	33	0024	0151
	BMI	SQRT7			015	131	0151	46	0304	0305
	LDD	SQRT6			016	132	0305	69	0140	0193
	STU	SQRT4			017	133	0193	24	0156	0309
	RAU	SQRT3	SQRT5		018	134	0309	60	0450	0259
SQRT7	RAU	SQRT6	SQRT1		019	135	0304	60	0140	0286
SQRT2	HLT	8888	8888		020	136	0095	01	8888	8888
FPTWO	20	0000	0051		021	137	0336	20	0000	0051
SIZE8	10	0000	0044		022	138	0024	10	0000	0044
ETOX	STD	AAA1		EXIT INSTR		139	0500	24	0303	0306
	STU	AAA14		STORF ARG		140	0306	21	0010	0163
	RAU	AAA16		ZERO		141	0163	60	0016	0121
	FAM	AAA14				142	0121	37	0010	0337
	STU	AAA2				143	0337	21	0142	0145
	LDD	AAA3		ONE		144	0145	69	0248	0201
	STU	AAA4	AAA8	COEFF		145	0201	24	0354	0107
AAA8	RAU	AAA2				146	0107	60	0142	0097
	FSB	AAA5		FIVE		147	0097	33	0550	0427
	BMI	AAA6				148	0427	46	0330	0331
	STU	AAA2				149	0331	21	0142	0195
	RAU	AAA4				150	0195	60	0354	0359
	FMP	AAA7		E TO 5		151	0359	39	0112	0162
	STU	AAA4	AAA8			152	0162	21	0354	0107
AAA6	RAU	AAA2				153	0330	60	0142	0147
	FSB	AAA3		ONE		154	0147	33	0248	0075
	BMI	AAA28				155	0075	46	0078	0179
	STU	AAA2				156	0179	21	0142	0245
	RAU	AAA4				157	0245	60	0354	0409
	FMP	AAA9		E TO 1		158	0409	39	0212	0262
	STU	AAA4	AAA6			159	0262	21	0354	0330
AAA28	RAU	AAA2				160	0078	60	0142	0197
	FSB	AAA10		POINT TWO		161	0197	33	0600	0477
	BMI	AAA11				162	0477	46	0380	0381
	STU	AAA2				163	0381	21	0142	0295
	RAU	AAA4				164	0295	60	0354	0459
	FMP	AAA12		E TO PT 2		165	0459	39	0312	0362
	STU	AAA4	AAA28			166	0362	21	0354	0078
AAA11	RAU	AAA2				167	0380	60	0142	0247
	LDD		AAA17			168	0247	69	0650	0353
	FMP	AAA4				169	0650	39	0354	0404
	STU	AAA13				170	0404	21	0408	0111
	RAU	AAA14				171	0111	60	0010	0115
	BMI	AAA15				172	0115	46	0068	0019
	RAU	AAA13	AAA1			173	0019	60	0408	0303
AAA15	RAU	AAA3				174	0068	60	0248	0403
	FDV	AAA13	AAA1			175	0403	34	0408	0303
AAA17	STD	AAA18		EXIT INSTR		176	0353	24	0356	0509
	RAU	AAA3		ONE		177	0509	60	0248	0453
	FAD	AAA2				178	0453	32	0142	0069
	STU	AAA19				179	0069	21	0074	0527
	LDD	AAA27		TWO		180	0527	69	0430	0383
	STD	AAA20		N		181	0303	24	0436	0139
	STD	AAA21		DENOM		182	0139	24	0192	0345
	RAU	AAA2				183	0345	60	0142	0297
	FMP	AAA2				184	0297	39	0142	0242
	STU	AAA23	AAA22	NUMFRATOR		185	0242	21	0146	0049
AAA22	FDV	AAA21				186	0049	34	0192	0292
	STU	AAA24		NTH TERM		187	0292	21	0196	0099
	FAD	AAA19				188	0099	32	0074	0251
	STU	AAA19		TOTAL		189	0251	21	0074	0577
	RAU	AAA24				190	0577	60	0196	0301
	FDV	AAA19				191	0301	34	0074	0124
	FSB	AAA25		CRITFRIA		192	0124	33	0627	0503
	BMI		AAA26			193	0503	46	0406	0157
	RAU	AAA19	AAA18			194	0406	60	0074	0356
AAA26	RAU	AAA20				195	0157	60	0436	0041
	FAD	AAA3				196	0041	32	0248	0125
	STU	AAA20		NEW N		197	0125	21	0436	0189
	FMP	AAA21				198	0189	39	0192	0342
	STU	AAA21		NEW DENOM		199	0342	21	0192	0395
	RAU	AAA23				200	0395	60	0146	0351
	FMP	AAA2				201	0351	39	0142	0392
	STU	AAA23	AAA22			202	0392	21	0146	0049
AAA3	10	0000	0051	ONE		203	0248	10	0000	0051
AAA5	50	0000	0051	FIVE		204	0550	50	0000	0051
AAA7	14	8413	1653	E TO 5		205	0112	14	8413	1653
AAA9	27	1828	1851	F		206	0212	27	1828	1851
AAA10	20	0000	0050	POINT TWO		207	0600	20	0000	0050
AAA12	12	2140	2851	E TO PT 2		208	0312	12	2140	2851
AAA16	00	0000	0000	ZERO		209	0016	00	0000	0000
AAA25	10	0000	0044	CRITERIA		210	0627	10	0000	0044
AAA27	20	0000	0051	TWO		211	0430	20	0000	0051
EOOCL	STD	ZZZ1		EXIT INSTR		212	0036	24	0239	0442
	LDD	ZZZ10				213	0442	69	0445	0298
	STD	1977				214	0298	24	1977	0480
	STD	1978				215	0480	24	1970	0431
	STD	1979				216	0431	24	1979	0132
	STD	1980				217	0132	24	1980	0433
	STD	1981				218	0433	24	1981	0184
	STD	1982				219	0184	24	1982	0185
	STD	1983				220	0185	24	1983	0486
	STD	1984	ZZZ1			221	0486	24	1984	0239
ZZZ10	00	.0000	0000			222	0445	00	0000	0000
LNX51	STD	LNX08		EXIT INSTR		223	0700	24	0553	0456
	NZE		LNX14			224	0456	45	0060	0161
	BMI	LNX14				225	0060	46	0161	0014
	STU	LNX09				226	0014	21	0118	0171
	RSL	FPONE				227	0171	66	0174	0229
	STD	LNX10				228	0229	24	0182	0235
	STL	LNX02				229	0235	20	0289	0492
	RAU	LNX09				230	0492	60	0118	0123
	STL	LNX05				231	0123	20	0677	0530
	STL	LNX11				232	0530	20	0285	0088
	SLT	0008				233	0088	35	0008	0207
	SUP	FIFTY				234	0207	11	0110	0165
	NZE		LNX04			235	0165	45	0168	0119
	BMI		LNX03			236	0168	46	0221	0022
	RSU	8003				237	0221	61	8003	0279
	LDD	FPONE				238	0279	69	0174	0727
	STD	LNX02	LNX03			239	0727	24	0289	0022
LNX03	SRT	0008				240	0022	30	0008	0091
	SCT	0000				241	0091	36	0000	0213
	AUP	SIXTY				242	0213	10	0066	0271
	SUP	8002				243	0271	11	8002	0329
	RAU	8003				244	0329	60	8003	0387
	FMP	LNX02				245	0387	39	0289	0339

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         FMP LNTEN                           246   0339   39 0542 U592
         STU LNX05   LNX04                   247   0592   21 0677 U119
LNX04    RAL LNX09                           248   0119   65 0118 U173
         SRT  0002                           249   0173   30 0002 0379
         RAO  8002                           250   0379   60 8002 U437
         ALO FIFTY                           251   0437   15 0110 0215
         SLT  0002                           252   0215   35 0002 0321
         FAD FPONE                           253   0321   32 0174 0401
         STO LNX09                           254   0401   21 0118 0371
         FSR FPTWO                           255   0371   33 0336 0263
         FOV LNX09                           256   0263   34 0118 U218
         STU LNX13                           257   0218   21 0072 U175
         STD LNX12                           258   0175   24 0128 U481
         STD LNX11                           259   0481   24 0285 0138
         FMP  8001                           260   0138   39 8001 0141
         STO FACTR   LNX06                   261   0141   21 0246 U149
LNX06    RAU LNX10                           262   0149   60 0182 U487
         FAO FPTWO                           263   0487   32 0336 U313
         STU LNX10                           264   0313   21 0182 0335
         RAO LNX13                           265   0335   60 0072 0777
         FHP FACTR                           266   0777   39 0246 0296
         FOV LNX10                           267   0296   34 01R2 U232
         STO LNX13                           260   0232   21 0072 0225
         FAO LNX12                           269   0225   32 0128 U355
         STO LNX12                           270   0355   21 0128 U531
         FSR LNX11                           271   0531   33 0285 0211
         FOV LNX11                           272   0211   34 0285 0385
         RAM  8003                           273   0385   67 0003 U243
         RAO  8002                           274   0243   60 8002 0451
         FSR SIZE7                           275   0451   33 0454 0581
         BMI LNX07                           276   0581   46 0234 0435
         LDD LNX12                           277   0435   69 0128 0631
         STD LNX11                           278   0631   24 0285 0188
         RAU LNX13                           279   0188   60 0072 0R27
         FMP LNX10                           280   0027   39 0182 0282
         STU LNX13   LNX06                   281   0282   21 0072 0149
LNX07    RAU LNX12                           282   0234   60 0128 0483
         FMP FPTWO                           283   0403   39 0336 0536
         FSR LNX05   LNX08                   204   0536   33 0677 U553
FPONE     10  0000    0051                   285   0174   10 0000 0051
FPTWD     20  0000    0051                   286   0336   20 0000 0051
SIZE7     1U  0000    0044    CRITERIA       287   0454   10 0000 U044
LNTEN     23  0250    5151                   288   0542   23 0258 5151
FIFTY     50  0000    0000                   289   0110   50 0000 0000
SIXTY     00  0000    0060                   290   0066   00 0U00 U060
LNX14     01  2345    6789    HALT           291   0161   01 2345 6789
EONE     STO EEE1             FXIT INSTR     292   0046   24 0199 0002
         STU EEE2             ARGOMENT       293   0002   21 0506 0559
         FSR ONE                             294   0559   33 0100 0877
         BMI EONES   EONEL                   295   0877   46 058U 0681
EONES    RAU EEE2             SMALL ARG      296   0580   60 0506 0261
         LOO         LNX51    LN ARG         297   0261   69 0064 0700
         STO EEE5             LN FEE2        298   0064   21 0268 0421
         RSU FEE13            GAMMA          299   0421   61 0224 U429
         FSR FFE5                            300   0429   33 0268 0495
         FAD FEE2                            301   0495   32 0506 0533
         STU EEE12            PARTIALANS     302   0533   21 0238 0191
         RAU TWO                             303   0191   60 0150 0405
         STU EEE9             N              304   0405   24 0458 0311
         FMP  8003                           305   0311   39 8003 0265
         STO EEE10            DENOM          306   0265   21 0070 0223
         LOO EEE2                            307   0223   69 0506 0609
         STU EEE8    EEE7     NUM            300   0609   24 0412 0315
EEF7     RBO EEE2                            309   0315   61 0506 U361
         FMP EEE8                            310   0361   39 0412 0462
         STO EEER             NUMFRATOR      311   0462   21 0412 0365
         FOV EEE10                           312   0365   34 0070 0120
         STU EFE11            NTH TENM       313   0120   21 0274 U927
         FAU EEE12                           314   0927   32 0230 U415
         STU EFE12            TOTAL SOM      315   0415   21 0238 0241
         RAU ZRO                             316   0241   60 0050 0455
         FAM EEE11                           317   0455   37 0274 U501
         FDV EEE12                           318   0501   34 0238 0288
         FBR EEE15                           319   0288   33 0291 0067
         BMI         EEE14                   320   0067   46 0170 0471
         RAO EEE12   EEE1                    321   0170   6U 0238 0199
EEE14    RAU EEE1U                           322   0471   60 0070 0275
         FDV EFE9                            323   0275   34 0458 0508
         STU EEE10                           324   0508   21 0070 0273
         RAO EEE9                            325   0273   60 0458 0363
         FAO ONE                             326   0363   32 0100 0977
         STU EEE9             NEW N          327   0977   21 0458 0411
         FMP  8003                           328   0411   39 8003 U465
         FMP EEE10                           329   0465   39 007U 0220
         STO EEE10   EEE7                    330   0220   21 007U U315
EEE13     57  7215    6650    GAMMA          331   0224   57 7215 6650
EFE15     10  0000    0044    CRITFRIA       332   0291   10 0000 0044
ZRU       00  0000    0000    ZERO           333   0050   00 0000 0000
ONE       10  0000    0051    ONE            334   0100   10 0000 0051
TWO       2U  0000    0051    TWO            335   0150   20 0000 0051
EONEL    RAU EEE2             LARGE ARG      336   0681   60 0506 0461
         FAO D003                            337   0461   32 0114 0341
         FMP EEE2                            330   0341   39 0506 0556
         FAD D002                            339   0556   32 0659 0485
         FMP EEE2                            340   0485   39 0506 U606
         FAU D001                            341   0606   32 0709 0535
         FMP FFE2                            342   0535   39 0506 U656
         FAU D000                            343   0656   32 U759 U5R5
         STU EEE3             OENOMNATUR     344   0585   21 019U 0293
         RAU EFE2                            345   0293   60 0506 0511
         FAU CCC3                            346   0511   32 0164 U391
         FMP EFE2                            347   0391   39 0506 0706
         FAU CCC2                            348   0706   32 0809 0635
         FMP EEE2                            349   0635   39 0506 0756
         FAU CCC1                            350   0756   32 0859 U685
         FMP EEE2                            351   0685   39 0506 UR06
         FAO CCC0                            352   0806   32 0909 0735
         FDV FEE3             RATIO          353   0735   34 0190 0240
         FDV FEE2                            354   0240   34 0506 UR56
         STU EEE4             ALLBUTETOX     355   0856   21 0160 U413
         RSU EEE2                            356   0413   61 0506 U561
         LDD         ETOX                    357   0561   69 0214 U500
         FMP EFE4    EEE1     FONFOFEEE2     358   0214   39 0160 0199
CCC0      26  7773    7350                   359   0909   26 7773 7350
CCC1      86  3476    0951                   360   0859   86 3476 0951
CCC2      18  0590    1752                   361   0809   18 059U 1752
CCC3      85  7332    8751                   362   0164   85 7332 8751
D000      39  5849    6951                   363   0759   39 5849 6951
D001      21  0996    5352                   364   0709   21 0996 5352
D002      25  6329    5652                   365   0659   25 6329 5652
D003      95  7332    2351                   366   0114   95 7332 2351
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UNCOLLIDED FLUX FROM FINITE RIGHT-CIRCULAR CYLINDER VIEWED ENDWISE

by

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An IBM 650 Computer code was written to solve for the flux from the end of a finite circular cylinder. This code was then used to solve for the flux from cylinders of varying size and absorption coefficient as well as for varying shield thickness and absorption coefficients.

From the information obtained, a method was developed to determine fluxes from cylinders by considering them to be replaced by a circular plane source. This circular plane source is located within the confines of the cylinder and has the same radius as the cylinder. This method makes it possible to determine the uncollided flux from the end of a cylinder more accurately than has previously been possible with only a desk calculator.

Curves and supporting information as necessary are presented to enable users to determine the source strength of the circular plane source and its location within the cylinder.