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AN EXTENSION OF THE FORMULA OF ONO AND TSURO FOR THE FLUX FROM A CYLINDRICAL SOURCE

by

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NOTICE

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ABSTRACT

A semi-analytic approximate formula for the flux at a point outside the radial and axial extensions of a cylindrical source with an intervening slab shield perpendicular to the source axis has been derived, based on the work of Ono and Tsuro. The required function tables are available, and a detailed analysis of the error as a function of problem geometry has been calculated, so that this formula has a wide area of application. No other approximate calculation method for this case is available in the literature.

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I. Introduction

Hand calculation methods involving semi-analytic approximations of exact flux formulas continue to be useful in shielding calculations since they enable shield design personnel to make quick estimates of dose rates, check calculations made by more exact and time-consuming methods, and rapidly determine the scope of problems. They are also a valuable teaching tool.

The most useful approximate flux formula is that for the flux at a lateral detector point from a cylindrical source with an intervening slab shield. An improved formula for this case is given by Ono and Tsuro in Reference (1). Further improvements and extensions of this formula and tables of the required functions are given in References (2), (3) and (4).

The flux at a detector point outside the radial and axial extensions of a cylindrical source with an intervening slab shield perpendicular to the source axis is a case treated only in Reference (4). In this paper, a further extension of this case will be developed.

II. Flux at a Lateral Detector Point from a Cylindrical Source with a Slab Shield Perpendicular to the Source Axis

The semi-analytic formula of Ono and Tsuro is given in the References, along with tables of the required functions. This formula substitutes a section of an annulus for the cylindrical source.

As shown in Figure 1, a section of an annulus is also substituted for a cylindrical source (with radius R and height ℓ) in this case. The sector has height = 2R and thickness ℓ. Equating the Volumes of the annular section and the cylinder gives

$$\pi R^2 \ell = 2R\phi_0 \left[(h+\ell)^2 - h^2\right] \tag{1}$$

so that to preserve source volume,

$$\phi_0 = \frac{\pi}{2}\,\frac{R}{2h+\ell}\,. \tag{2}$$

Then if $\phi_0 > 60°$ or $\frac{\pi}{3}$ radians, this approximation does not apply. If $\phi_0 \le \frac{\pi}{3}$,

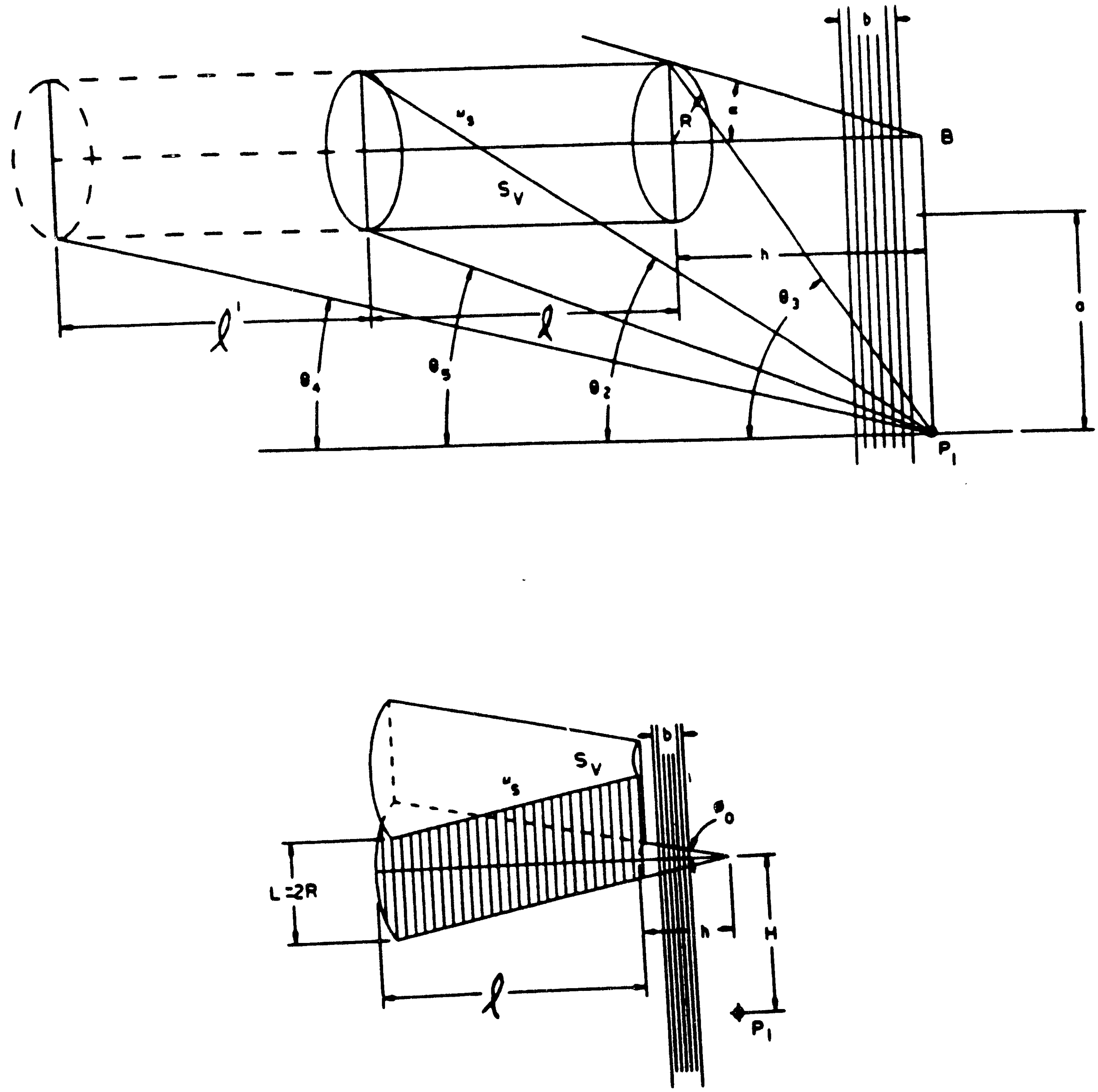

Figure 1. Cylindrical Source with a Detector Point Outside the Axial and Radial Extensions of the Source with Section of an Annulus Used as an Approximation

or $R \le ⅓ (2h + \ell)$, then (3)

$$\theta = \tan^{-1} \frac{a}{h+\ell} \quad (4)$$

$$\theta_3 = \tan^{-1} \frac{a+2R}{h} \quad (5)$$

and the flux at the point P_1 is approximately given by

$$\Phi_{P_1} = \frac{S_v \Phi_o}{2\pi\mu_s} L_o(\Phi_o, b)\{G(\theta_3, b) - G(\theta_3, b + \mu_s \ell) - G(\theta_2, b) + G(\theta_2, b + \mu_s \ell)\} \quad (6)$$

where b is the shield attenuation distance in mean-free-paths, μ_s as the source self-attenuation coefficient, and the functions $L_o(\phi_o, b)$ and $G(\theta_o, b)$ are defined and tabulated in the References.

Error ratios for a wide range of problem parameters are given in Table 1, assuming that the criterion of (3) is observed. The data in this table show that this approximation is useful for cases where $\frac{\mu_s \ell}{R} \ge 0.65$ and $\mu_s \le 0.1$ or $\frac{\mu_s \ell}{R} \le 1.5$, $0.1 < \mu_s < 0.5$ and $a/R > 1.0$.

For other cases a possible calculation technique is to use superposition. Calculate the flux from a source of height $\ell + \ell'$ and from that portion of the source defined by ℓ' and subtract the latter from the former. That is, for the cases which fall outside the above criteria, define a problem with source of height $\ell + \ell'$ and define the additional angles

$$\theta_4 = \tan^{-1} \frac{a}{h+\ell+\ell'} \quad (7)$$

$$\theta_5 = \tan^{-1} \frac{a+2R}{h+\ell} \quad (8)$$

Then for this case,

$$\Phi'_{P_1} = \frac{S_v \phi_o}{2\pi\mu_s} L_o(\phi_o, b) \left\{ \begin{array}{l} G(\theta_3, b) - G(\theta_3, b + \mu_s(\ell+\ell')) \\ -G(\theta_5, b) + G(\theta_5, b + \mu_s \ell') \\ +G(\theta_4, b + \mu_s(\ell+\ell')) - G(\theta_4, b + \mu_s \ell') \end{array} \right\} \quad (9)$$

This formula is new, and extends the work reported in Reference (4).

Table 1

APPROXIMATE FLUX

EXACT FLUX

from A Cylindrical Source at Detector Points Outside the Radial and Axial Extensions of the Source with an Intervening Slab Shield Perpendicular to the Source Axis

R= 10.00 MuS= .10 a/R= .20 MuS*R= 1.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
6.25	1.31	1.11	1.10	1.40	1.15	1.00	1.58	1.24	1.07	1.84	1.34	1.08
15.63	[illegible]	.88	1.01	.83	.88	1.01	.99	.88	1.00	1.15	.82	.99
31.25	.45	.78	.92	.40	[illegible]	.92	.37	[illegible]	.92	.68	.75	.91
78.13	.31	.84	.83	.31	.84	.83	.32	.84	.83	.34	.84	.83

R= 10.00 MuS= .10 a/R= .50 MuS*R= 1.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
2.50	1.01	1.24	1.14	1.80	1.34	1.13	2.10	1.54	1.14	2.40	1.78	1.17
6.25	.83	.92	1.04	1.01	.93	1.04	1.23	.96	1.03	1.44	1.03	1.02
12.50	.51	.75	.94	.58	[illegible]	.94	.63	.73	.94	.83	.78	.94
31.25	.33	.67	.85	.34	.67	.85	.38	.68	.85	.40	.68	.85

R= 10.00 MuS= .10 a/R= 1.00 MuS*R= 1.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
1.25	1.82	1.42	1.22	2.41	1.64	1.22	2.97	2.05	1.28	3.72	2.80	1.38
3.13	1.02	.99	1.08	1.27	1.01	1.07	1.57	1.08	1.07	1.89	1.23	1.08
6.25	.61	.82	.90	.72	.82	.90	.88	.82	.90	1.05	.84	.90
15.63	.37	.69	.80	.38	.68	.80	.43	.68	.80	.49	.69	.80

R= 10.00 MuS= .10 a/R= 2.50 MuS*R= 1.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
.50	2.10	1.62	1.37	2.88	2.12	1.44	3.94	3.01	1.65	5.82	4.32	2.10
1.25	1.37	1.13	1.14	1.79	1.24	1.14	2.31	1.47	1.15	2.98	1.83	1.18
2.50	.85	.88	1.00	1.05	[illegible]	1.00	1.29	.94	1.00	1.59	1.03	.99
6.25	.47	.72	.88	.53	[illegible]	.88	.63	.72	.88	[illegible]	[illegible]	.88

R= 10.00 MuS= .50 a/R= .20 MuS*R= 5.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
6.25	1.18	.94	.92	1.32	1.03	.93	1.38	1.10	.95	1.35	1.20	.99
15.63	.37	.66	.83	[illegible]	.58	.83	.69	.72	.83	1.05	.79	.84
31.25	.34	.59	.80	.40	.59	.80	.50	.60	.80	.82	.61	.80
78.13	.23	.58	.78	.24	.55	.78	.28	.59	.78	.29	.59	.78

R= 10.00 MuS= .50 a/R= .50 MuS*R= 5.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
2.50	1.34	1.03	.95	1.52	1.10	.98	1.58	1.33	1.00	1.82	1.46	1.00
6.25	.61	.78	.85	.87	.73	.85	1.07	.73	.85	1.24	.89	.88
12.50	.41	.62	.82	.49	.62	.82	.62	.63	.82	.77	.66	.82
31.25	.25	.57	.80	.27	.57	.80	.30	.57	.80	.30	.58	.80

R= 10.00 MuS= .50 a/R= 1.00 MuS*R= 5.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
1.25	1.45	1.12	.98	1.87	1.30	1.01	1.81	1.52	1.07	1.90	1.73	1.18
3.13	.82	.78	.87	1.04	.80	.87	1.28	.90	.87	1.46	1.04	.88
6.25	.50	.65	.83	.62	.66	.83	.78	.68	.83	.95	.72	.83
15.63	.29	.59	.81	.32	.58	.81	.37	.60	.81	.40	.60	.81

R= 10.00 MuS= .50 a/R= 2.50 MuS*R= 5.00

	b= .25			b= 1.00			b= 2.50			b= 5.00		
H'/L= L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
.50	1.43	1.19	1.02	1.79	1.42	1.08	1.83	1.74	1.22	2.28	2.11	1.45
1.25	1.14	.86	.88	1.31	[illegible]	.88	1.58	1.12	.91	1.84	1.32	.94
2.50	.70	.71	.84	.86	.73	.84	1.08	.75	.84	1.20	.89	.85
6.25	.39	.62	.81	.40	.62	.81	.57	.63	.81	.70	.65	.81

Table 1 (Continued)

R= 25.00   Mus= .10   a/R= .20   Mus*R= 2.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
6.25	1.23	1.00	.89	1.30	1.08	.89	1.44	1.19	1.00	1.40	1.20	1.03
15.63	.83	.72	.89	.73	.73	.89	.90	.78	.88	1.07	.82	.88
31.25	.37	.63	.83	.42	.63	.83	.51	.64	.83	.53	.65	.83
78.13	.25	.57	.79	.20	.57	.79	.27	.57	.79	.30	.57	.79

R= 25.00   Mus= .10   a/R= .50   Mus*R= 2.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
2.50	1.44	1.10	1.03	1.60	1.23	1.03	1.79	1.41	1.05	1.93	1.59	1.11
6.25	.71	.78	.91	.85	.78	.90	1.08	.83	.90	1.28	.92	.90
12.50	.43	.66	.85	.51	.66	.85	.63	.67	.85	.76	.69	.85
31.25	.27	.60	.81	.25	.60	.81	.31	.60	.81	.30	.60	.81

R= 25.00   Mus= .10   a/R= 1.00   Mus*R= 2.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
1.25	1.60	1.21	1.07	1.92	1.42	1.09	2.20	1.72	1.14	2.55	2.05	1.20
3.13	.88	.81	.92	1.08	.85	.92	1.32	.94	.92	1.55	1.08	.93
6.25	.52	.69	.86	.63	.70	.86	.79	.71	.86	.96	.75	.86
15.63	.31	.62	.82	.33	.62	.82	.38	.62	.82	.40	.62	.82

R= 25.00   Mus= .10   a/R= 2.50   Mus*R= 2.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
.50	1.59	1.27	1.13	2.01	1.62	1.29	2.48	2.12	1.37	3.19	2.77	1.68
1.25	1.10	.91	.95	1.41	1.11	.95	1.74	1.19	.96	2.11	1.44	1.00
2.50	.72	.74	.88	.90	.77	.88	1.11	.82	.88	1.33	.92	.88
6.25	.41	.65	.83	.47	.65	.83	.58	.65	.83	.71	.67	.83

R= 25.00   Mus= .50   a/R= .20   Mus*R= 12.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
6.25	1.10	.91	.87	1.20	1.01	.88	1.32	1.14	.91	1.30	1.22	.98
15.63	.58	.63	.80	.71	.65	.80	.88	.69	.80	1.04	.77	.81
31.25	.33	.58	.78	.39	.57	.78	.48	.57	.78	.62	.59	.78
78.13	.22	.54	.77	.23	.54	.77	.25	.54	.77	.29	.54	.77

R= 25.00   Mus= .50   a/R= .50   Mus*R= 12.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
2.50	1.30	.99	.90	1.44	1.12	.92	1.60	1.28	.96	1.44	1.38	1.02
6.25	.68	.67	.82	.86	.71	.82	1.00	.77	.82	1.22	.88	.83
12.50	.40	.59	.80	.49	.60	.80	.62	.61	.80	.77	.64	.80
31.25	.24	.56	.79	.20	.56	.79	.30	.56	.79	.35	.56	.79

R= 25.00   Mus= .50   a/R= 1.00   Mus*R= 12.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
1.25	1.38	1.07	.93	1.54	1.23	.98	1.58	1.41	1.02	1.80	1.54	1.13
3.13	.81	.73	.83	1.03	.78	.84	1.24	.88	.84	1.42	1.12	.86
6.25	.49	.62	.81	.61	.63	.81	.78	.66	.81	.94	.71	.81
15.63	.28	.58	.80	.31	.58	.80	.37	.58	.80	.45	.59	.80

R= 25.00   Mus= .50   a/R= 2.50   Mus*R= 12.50

H'/L=	b= .25			b= 1.00			b= 2.50			b= 5.00		
L/a	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50	1.10	1.50	2.50
.50	1.38	1.09	.98	1.52	1.31	1.02	1.80	1.52	1.14	1.71	1.72	1.31
1.25	1.01	.83	.85	1.27	.93	.86	1.48	1.09	.88	1.80	1.28	.92
2.50	.69	.69	.82	.87	.72	.82	1.07	.78	.82	1.29	.88	.83
6.25	.39	.61	.80	.46	.61	.80	.57	.62	.80	.70	.64	.80

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