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SUBJECT: STRATIFIED SLAB GAMMA-RAY DOSE-RATE BUILDUP FACTORS FOR LEAD AND WATER SHIELDS

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FROM: L. A. Bowman* and D. K. Trubey

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NOTICE

837-1

Stratified Slab Gamma-Ray Dose-Rate Buildup Factors for Lead and Water Shields

L. A. Bowman[1] D. K. Trubey

The ORACLE Monte Carlo code[2] for the calculation of the penetration of gamma rays through stratified slabs was used to calculate a total of 512 problems for eight different lead and water configurations as shown in Fig. 1. The energy of the incident radiation, the angle of incidence, the thickness of the shield, and the percentage of lead preceding or following water were varied. The source was assumed to be a monodirectional beam with energies of 1, 3, 6, and 10 Mev. The incident angles chosen were those which would give slant thicknesses of 1, 2, 3, and 4 times the normal thickness. The infinite slabs had finite normal thicknesses of 1, 2, 4, and 6 mean free paths.

The results obtained included the dose rate and energy flux throughout the slab and at the rear; dose-rate buildup factors; the heat deposited throughout the slab; and the energy and angular distribution reflected from and transmitted through the slab. Only the buildup factors at the rear of the slabs for normal incidence are considered in this report.

Figures 2 and 3 show a comparison between the finite thickness slab and NDA[3] infinite medium buildup factors for pure lead and water, respectively. Table 1 and Figs. 4, 5, 6, and 7 show the buildup factors for the various percentages of lead preceding and following water for the four thicknesses used.

All of the buildup factors determined for composite slabs in this series have been compared with values obtained by use of a formula proposed by M. H. Kalos of NDA[4] in which the buildup factors independently computed for lead and water are combined to determine the buildup factor for a composite slab consisting of two materials. For a lead-water slab (that is, lead followed by water) the formula is written as follows:

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1. On assignment from U. S. Air Force.
2. S. Auslender, Compilations of Monte Carlo Calculations of Gamma-Ray Penetration in Multiregion Shields with Slab Geometry, ORNL-2310 (to be published).
3. H. Goldstein and J. E. Wilkins, Jr., Calculations of the Penetration of Gamma Rays, NYO-3075, June 30, 1954.
4. H. Goldstein, The Attenuation of Gamma Rays and Neutrons in Reactor Shields, pp. 192-193, U. S. Government Printing Office, Washington 25, D. C., May 1, 1957.

$$B(X_1,X_2) = B_2(X_2) + \frac{B_1(X_1) - 1}{B_2(X_1) - 1} \left[B_2(X_1 + X_2) - B_2(X_2) \right]$$

where

B_1, B_2 = gamma-ray dose rate buildup factors for the first and second materials, respectively,

X_1, X_2 = thickness in mean free paths of the first and second materials, respectively.

For a water-lead shield the formula is:

$$B(X_1,X_2) = B_2(X_2) + \left[\frac{B_1(X_1) - 1}{B_2(X_1) - 1} \; e^{-1.7X_2} + \frac{\left(\frac{\mu_{cs}}{\mu_t}\right)_1}{\left(\frac{\mu_{cs}}{\mu_t}\right)_2} \left(1 - e^{-X_2}\right) \right]$$

$$\times \left[B_2(X_1 + X_2) - B_2(X_2) \right]$$

where

μ_{cs} = Compton scattering cross section,

μ_t = total cross section.

Tables 2 and 3 give the buildup factors determined both by ORACLE calculations and by the Kalos' formula.

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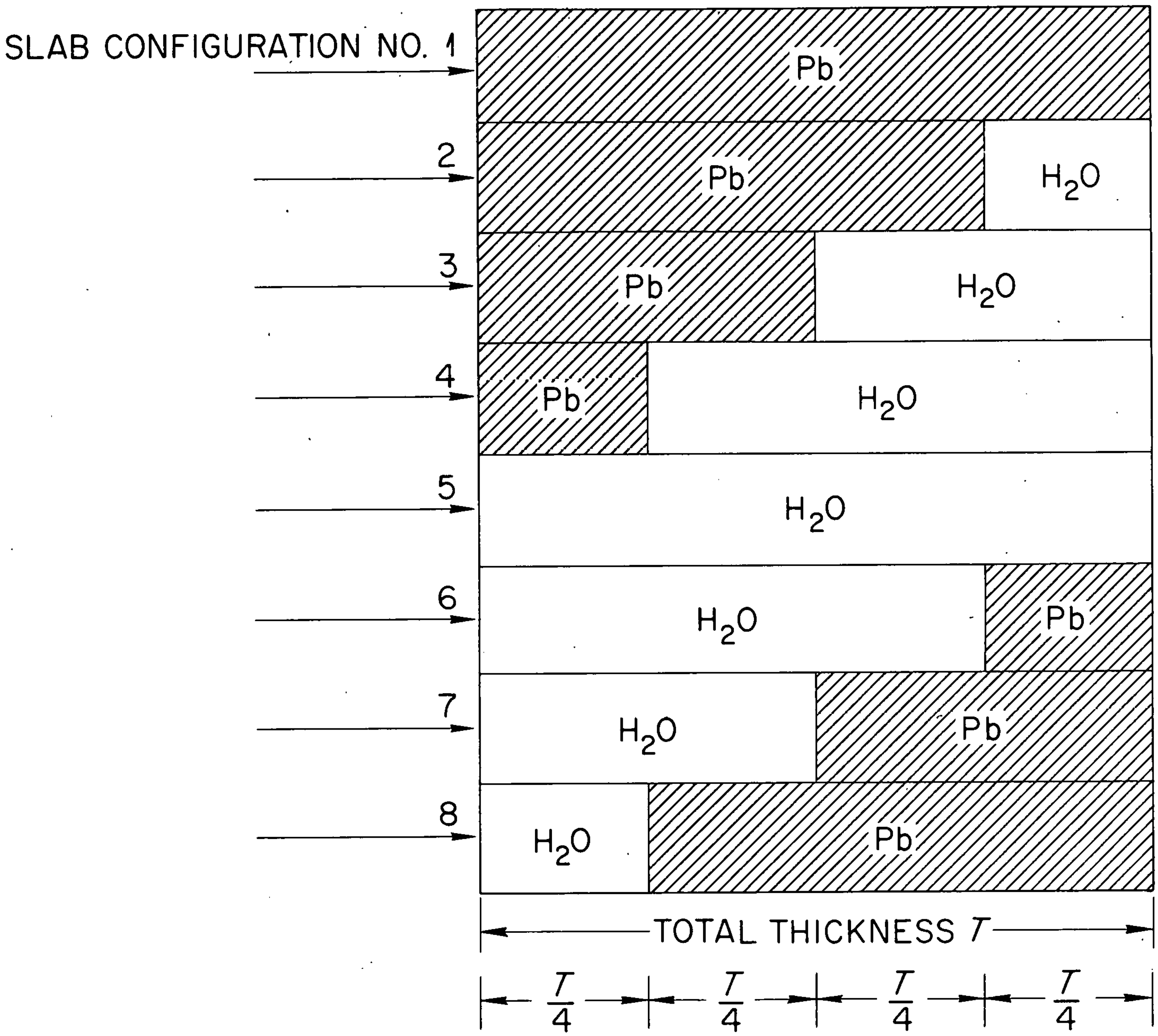

PARAMETERS:

INCIDENT ENERGY = 1, 3, 6, AND 10 Mev

TOTAL THICKNESS T = 1, 2, 4, AND 6 MEAN FREE PATHS

sec θ = 1, 2, 3, AND 4

Fig. 1. Stratified Slab Configurations.

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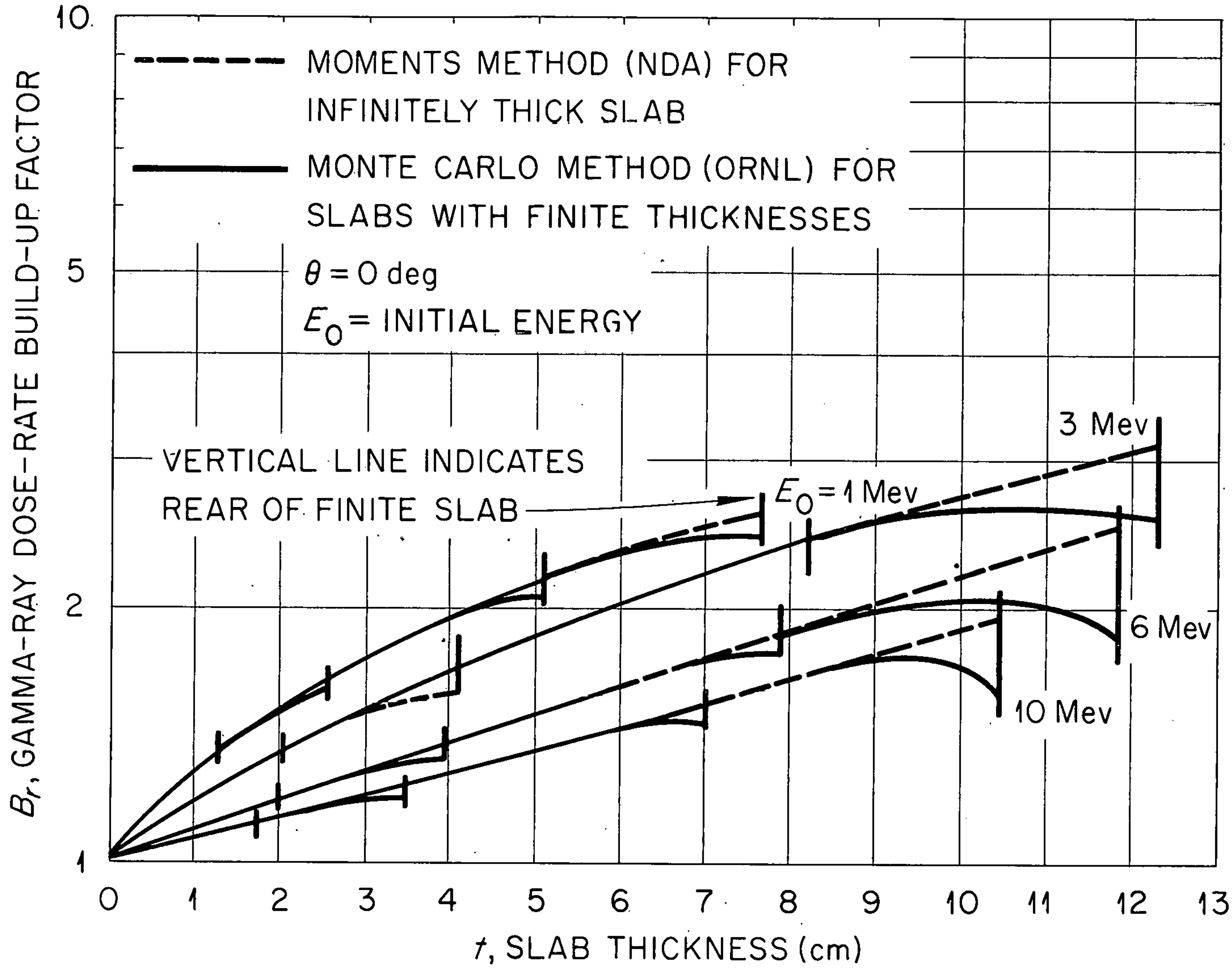

Fig. 2. Comparison of Dose-Rate Build-up Factors for Lead Slabs Computed by Monte Carlo Method with those Computed by Moments Method. Normally-Incident Gamma Rays.

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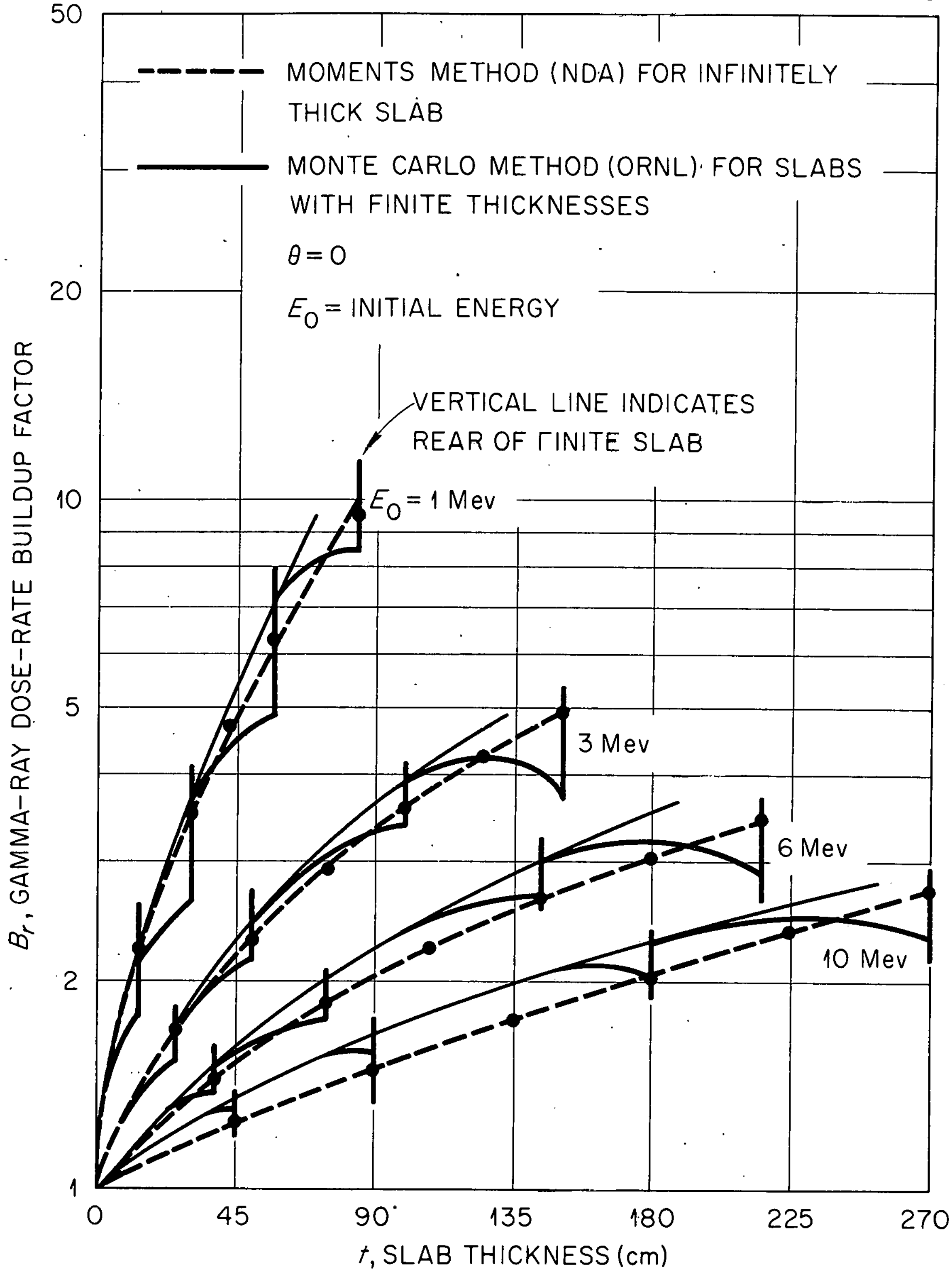

Fig. 3. Comparison of Dose-Rate Build-up Factors for Water Slabs Computed by Monte Carlo Method with those Computed by Moments Method. Normally Incident Gamma-Rays.

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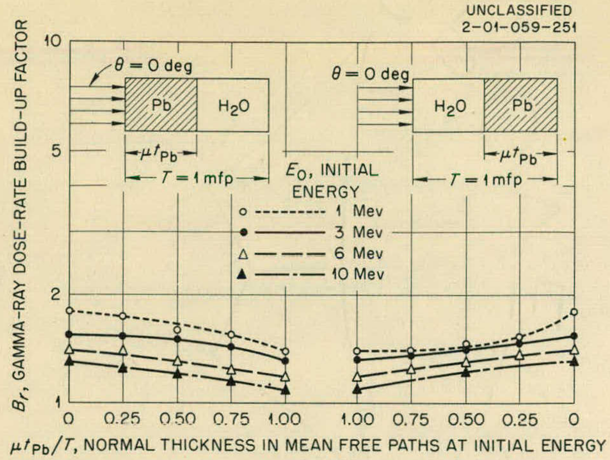

Fig. 4. Monte Carlo Dose-Rate Build-up Factors at the Rear of Composite Lead–Water Slab Shields 1 Mean Free Path Thick. Normally Incident Gamma Rays.

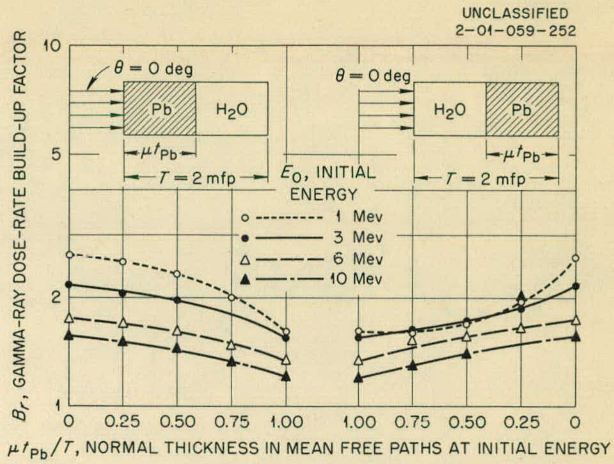

Fig. 5. Monte Carlo Dose-Rate Build-up Factors at the Rear of Composite Lead–Water Slab Shields 2 Mean Free Paths Thick. Normally Incident Gamma Rays.

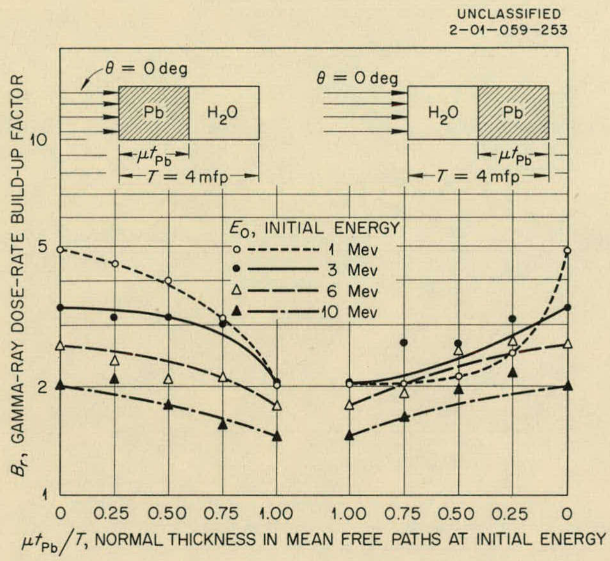

Fig. 6. Monte Carlo Dose-Rate Build-up Factors at the Rear of Composite Lead-Water Slab Shields 4 Mean Free Paths Thick. Normally Incident Gamma Rays.

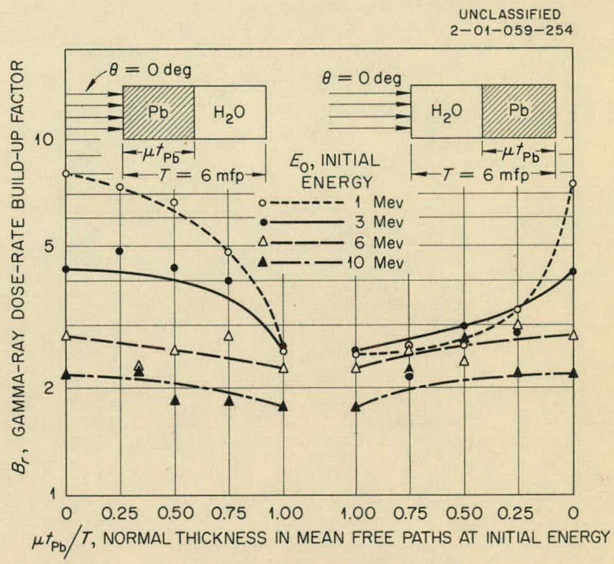

Fig. 7. Monte Carlo Dose-Rate Build-up Factors at the Rear of Composite Lead-Water Slab Shields 6 Mean Free Paths Thick. Normally Incident Gamma Rays.

Table 1. Transmission Dose Buildup Factors for Normally Incident Gamma Radiation on Stratified Slabs of Water and Lead Using a Point Isotropic Detector

Source Energy E_o (Mev)	Total Slab Thickness T(mfp)	Buildup Factor: Lead Followed by Water, $(\mu_o t)_{Pb}/T$ (a) = 0	0.25	0.50	0.75	1.0	Buildup Factor: Water Followed by Lead, $(\mu_o t)_{Pb}/T$ (a) = 1.0	0.75	0.50	0.25	0
1	1	1.78	1.73	1.64	1.53	1.37	1.37	1.40	1.43	1.53	1.78
	2	2.62	2.52	2.33	2.02	1.61	1.61	1.62	1.70	1.97	2.62
	4	4.95	4.48	3.90	3.10	2.04	2.04	2.06	2.16	2.50	4.95
	6	8.00	7.25	6.20	4.80	2.48	2.48	2.53	2.72	3.31	8.00
3	1	1.54	1.53	1.50	1.43	1.31	1.31	1.35	1.40	1.46	1.54
	2	2.16	2.08	1.97	1.80	1.56	1.56	1.63	1.73	1.87	2.16
	4	3.36	3.30	3.16	2.81	2.07	2.07	2.16	2.40	2.80	3.36
	6	4.30	4.22	4.00	3.55	2.57	2.57	2.71	2.96	3.35	4.30
6	1	1.39	1.35	1.30	1.24	1.17	1.17	1.23	1.29	1.35	1.39
	2	1.82	1.69	1.61	1.49	1.34	1.34	1.45	1.56	1.65	1.82
	4	2.61	2.51	2.36	2.12	1.78	1.78	2.02	2.26	2.49	2.61
	6	2.80	2.68	2.55	2.40	2.26	2.26	2.48	2.62	2.72	2.80
10	1	1.31	1.25	1.21	1.15	1.08	1.08	1.14	1.21	1.26	1.31
	2	1.57	1.50	1.42	1.33	1.20	1.20	1.31	1.39	1.48	1.57
	4	2.02	1.91	1.79	1.64	1.46	1.46	1.64	1.79	1.91	2.02
	6	2.18	2.12	2.06	1.94	1.75	1.75	1.97	2.08	2.15	2.18

a. $(\mu_o t)_{Pb}/T$ = lead fraction of total slab thickness.

Table 2. Monte Carlo Gamma-Ray Dose Rate Buildup Factors at Rear of Lead-Water Slab Shields: Comparison of Oracle Calculations with Values Obtained with Kalos Formula

Incident Gamma-Ray Energy (Mev)	Shield (mfp) Lead	Shield (mfp) Water	B_r Oracle Calculations	B_r Kalos Formula	Ratio of B_r(calc.) to B_r(Kalos)
1	1	1	2.33	2.18	1.069
		2	3.30	3.13	1.054
		3	4.48	4.27	1.049
		4	5.81	5.60	1.038
		5	7.51	7.14	1.052
	2	1	2.72	2.51	1.084
		2	3.90	3.47	1.124
		3	5.33	4.73	1.127
		4	6.95	6.06	1.147
	3	1	3.10	3.00	1.033
		2	4.50	4.05	1.111
		3	6.22	5.36	1.160
3	1	1	1.95	1.90	1.026
		2	2.58	2.54	1.016
		3	3.30	3.10	1.065
		4	3.80	3.60	1.056
		5	4.21	4.07	1.034
	2	1	2.47	2.46	1.004
		2	3.15	3.00	1.050
		3	3.69	3.52	1.048
		4	4.18	4.03	1.037
	3	1	2.80	2.85	0.982
		2	3.44	2.89	1.190
		3	4.00	3.47	1.153
6	1	1	1.60	1.55	1.032
		2	2.03	1.98	1.025
		3	2.50	2.43	1.029
		4	2.66	2.67	0.996
		5	2.71	2.74	0.989
	2	1	1.98	1.80	1.100
		2	2.34	2.14	1.093
		3	2.55	2.50	1.020
		4	2.62	2.70	0.970
	3	1	2.11	1.96	1.077
		2	2.31	2.18	1.060
		3	2.41	2.52	0.956
10	1	1	1.41	1.38	1.022
		2	1.68	1.64	1.024
		3	1.90	1.88	1.011
		4	2.04	2.03	1.005
		5	2.14	2.12	1.009
	2	1	1.55	1.50	1.033
		2	1.78	1.72	1.035
		3	1.97	1.93	1.021
		4	2.10	2.07	1.014
	3	1	1.65	1.65	1.000
		2	1.81	1.84	0.984
		3	1.94	2.02	0.960

Table 3. Monte Carlo Gamma-Ray Dose Rate Buildup Factors at Rear of Water-Lead Slab Shields: Comparison of Oracle Calculations with Values Obtained with Kalos Formula

Incident Gamma-Ray Energy (Mev)	Shield (mfp) Water	Shield (mfp) Lead	B_r Oracle Calculations	B_r Kalos Formula	Ratio of B_r(calc.) to B_r(Kalos)
1	1	1	1.70	1.66	1.024
		2	1.86	1.92	0.969
		3	2.05	2.12	0.967
		4	2.22	2.35	0.945
		5	2.42	2.55	0.949
	2	1	2.20	1.96	1.122
		2	2.18	2.17	1.005
		3	2.31	2.45	0.943
		4	2.52	2.63	0.958
	3	1	2.50	2.27	1.101
		2	2.46	2.50	0.984
		3	2.72	2.73	0.996
3	1	1	1.74	1.62	1.074
		2	1.92	1.88	1.021
		3	2.15	2.16	0.995
		4	2.39	2.44	0.980
		5	2.66	2.68	0.993
	2	1	2.28	1.96	1.163
		2	2.39	2.24	1.067
		3	2.51	2.54	0.988
		4	2.70	2.78	0.971
	3	1	2.80	2.33	1.202
		2	2.88	2.60	1.108
		3	2.97	2.88	1.031
6	1	1	1.55	1.50	1.033
		2	1.75	1.79	0.978
		3	2.01	2.04	0.985
		4	2.20	2.27	0.969
		5	2.40	2.56	0.938
	2	1	2.09	1.89	1.106
		2	2.24	2.23	1.004
		3	2.38	2.50	0.952
		4	2.48	2.82	0.879
	3	1	2.48	2.31	1.074
		2	2.58	2.68	0.963
		3	2.61	3.04	0.859
10	1	1	1.39	1.41	0.986
		2	1.52	1.55	0.981
		3	1.65	1.70	0.971
		4	1.77	1.92	0.922
		5	1.90	2.07	0.918
	2	1	1.70	1.72	0.988
		2	1.79	1.92	0.932
		3	1.88	2.16	0.870
		4	1.96	2.39	0.820
	3	1	1.95	2.00	0.975
		2	1.99	2.34	0.850
		3	2.08	2.61	0.797

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