FF

KEK Preprint 95-213
February 1996
R

Effects of the Photon Cross Sections and
Energy-Absorption Coefficients of Air
to the Gamma-Ray Point Isotropic Exposure Buildup Factors

Hideo Hirayama

CERN LIBRARIES, GENEVA

SCAN-9604190

SW9619

To be published in Nucl. Sci. Eng.

National Laboratory for High Energy Physics, 1996

KEK Reports are available from:

Technical Information & Library
National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi
Ibaraki-ken, 305
JAPAN

Phone: 0298-64-5136
Telex: 3652-534 (Domestic)
(0)3652-534 (International)
Fax: 0298-64-4604
Cable: KEK OHO
E-mail: Library@kekvox.kek.jp (Internet Address)

Effects of the Photon Cross Sections and Energy-Absorption Coefficients of Air to the Gamma-Ray Point Isotropic Exposure Buildup Factors

Hideo Hirayama

National Laboratory for High Energy Physics

1-1 Oho, Tsukuba-shi, Ibaraki 305 Japan

ABSTRACT

The effects of using different photon cross section libraries and energy-absorption coefficients on the gamma-ray point isotropic exposure buildup factors up to 40 mfp were studied using the EGS4 Monte Carlo code for water, iron and lead from the 0.1-MeV to the 10-MeV energy regions.

Differences due to the cross sections used exist, but are small, less than 10%, except those for lead at 0.1 and 10 MeV. The differences in the case of lead increase along with an increase in the depth, and are nearly 30% at 40 mfp depth.

The effects of using different energy-absorption coefficients of air are less than 2%.

I INTRODUCTION

Various photon cross section libraries were used in calculations of the gamma-ray buildup factors. For example, Hubbell's compilation (NSRDS-NBS-29)⁽¹⁾ was used in the moments method,⁽²⁾ and the PHOTX library⁽³⁾ was used in the PALLAS code⁽⁴⁾ to produce new standard data (ANSI/ANS-6.4.3).⁽⁵⁾ A compilation by Storm & Israel (DLC-15)⁽⁶⁾ was used also in calculations of the buildup factors.

It is important to know the effects of the photon cross section library used to calculate buildup factors for future studies in this field.

The energy-absorption coefficients of air are other important data for calculating the exposure buildup factors. The data included in NSRDS-NBS-29 were used in the moments method, and those of Hubbell(1982),⁽⁷⁾ which are cited as the standard data in the reference 5, were used in the PALLAS calculations. Recently, Seltzer presented new data based on a re-examination of the processes involved after the initial photon interaction.⁽⁸⁾

The effects of the photon cross section library and energy-absorption coefficients were studied using the Monte Carlo code EGS4⁽⁹⁾ for water, iron and lead from the 0.1-MeV to the 10-MeV energy regions. EGS4 calculations with particle splitting can provide accurate exposure buildup factors up to 40 mfp, as shown in reference 10.

The comparisons for each material were performed for source energies of 0.1, 0.3, 0.6, 1.0, 3.0, 6.0 and 10 MeV in order to study the effects of the cross section data and for source energies of 0.1 and 1.0 MeV for that of the energy-absorption

coefficients of air.

II CALCULATIONS

II.1 Method of Calculation

Details concerning the EGS4 code have been described previously.⁽⁹⁾

Regarding photon transport, EGS4 considers Compton scattering (Klein-Nishina cross section applied to free electrons), pair production, and the photoelectric effect with K X-rays.

Electron-positron transport is simulated using the condensed-history technique with energy-loss fluctuations being accounted for through the random nature of elastic-scattering events. The PRESTA⁽¹¹⁾ algorithm was used to obtain accurate results without setting a very small step size. Bremsstrahlung production, positron annihilation in flight and at rest, elastic Møller and Bhabha scattering from electrons and Moilère multiple scattering from atomic nuclei were all taken into account.

Particle-splitting was applied to obtain reasonable results at deep penetrations of up to 40 mfp. In an ordinary way, a particle is split into many particles having less weight in order to compensate for an increase in number when it arrives at the position of interest. The new algorithm was developed in order to apply particle splitting at each preset depth (5 mfp in this calculation) in the EGS4 calculation. The details concerning this algorithm are described in reference 10.

The data of 40 mfp in infinite water, iron and lead were estimated based on calculations in a sphere of 42-mfp thickness. In all of the calculations, 1,000,000

case histories were used.

II.2 Cross Section

Hubbell's compilation (NSRDS-NBS-29),⁽¹⁾ the PHOTX library⁽³⁾ and the compilation by Storm & Israel (DLC-15)⁽⁶⁾ were used in this study.

The original EGS4 system uses DLC-15 for the photoelectric and pair-production cross sections. Recently, cross section data for the EGS4 system, based on the PHOTX library, was created by Sakamoto,⁽¹²⁾ and was used in this study. The cross section data based on NSRDS-NBS-29 for the EGS4 system were created by the author for this study.

The photoelectric cross sections, pair-production cross sections and total cross sections of these three libraries are compared in Tables I, II and III. The pair-production cross sections are the same in both DLC-15 and NSRDS-NBS-29. Figs. 1 and 2 show the differences in the photoelectric cross section and the total cross section as the ratio to the PHOTX library, respectively.

II.3 Energy-Absorption Coefficients of Air

The exposure can be obtained from the product of the energy fluence of photons using the mass energy-absorption coefficients of air. The data included in NSRDS-NBS-29, those by Hubbell(1982)⁽⁷⁾ and the new data by Seltzer⁽⁸⁾ were used to study of the effects of the energy-absorption coefficients.

The data of Hubbell are cited as standard data in reference 5, and those by Seltzer were recently presented based on a re-examination of the processes involved after

the initial photon interaction.

These three data are compared in Table IV. Fig. 3 shows the differences between these three data as the ratio to Seltzer's data. Differences can be seen below 0.1 MeV.

III RESULTS AND DISCUSSIONS

III.1 Effects of the Cross Section Library

To see the effects of the cross section library used, the exposure buildup factors for water, iron and lead were calculated using the energy-absorption coefficients of Hubbell, which are shown in Tables V, VI and VII for 0.1, 1.0 and 10 MeV. In these tables, the standard data in reference 5 are also presented. The standard data of water and iron were calculated by the moments method⁽²⁾ using the NSRDS-NBS-29 library; those of lead were calculated by the discrete ordinates code, PALLAS,⁽⁴⁾ using the PHOTX library.

The differences due to the cross section library are shown in Figs. 4, 5 and 6 as the ratio to the results with the PHOTX library, including other energies.

Differences due to the cross sections used exist, but are small, less than 10%, except those for lead at 0.1 and 10 MeV.

In the case of the 0.1-MeV lead, the results of DLC-15 are larger than the other results, and the rate of the difference increases with the increase in the attenuation depth. The large buildup factors of 0.1 MeV for lead are caused mainly by differences in the total cross section between the primary photon and the produced K X-rays.

This ratio is 0.318, 0.314 and 0.317 for $K_{\beta 2}$ X-ray from Table III for the PHOTX, DLC-15 and NSRDS-NBS-29 library, respectively. The smaller value of DLC-15 is the reason that the results using DLC-15 are larger than the others at deep penetrations.

In the case of 10-MeV lead, on the other hand, both results are smaller than those with the PHOTX library, and the rate of the difference increases along with an increase in the attenuation depth. Above 2 MeV, the pair-production and the total cross section of PHOTX are larger than those of DLC-15 and NSRDS-NBS-29. The ratio of the total cross section of DLC-15 and NSRDS-NBS-29 to PHOTX varies from 0.991 to 0.974 for 6 and 10 MeV, respectively. At 10 MeV, bremsstrahlung photons produced by electrons or positrons contribute to the buildup factors. The differences seen at 10 MeV are therefore due to the differences in the pair-production cross sections.

Mfp for each mass attenuation coefficient data was used as the attenuation depth at the above comparisons. It is also important to see how would the comparisons change if the distances were given in absolute distances. To see this effect, the exposure buildup factors for lead at 0.1 MeV were calculated at the absolute distances, which is shown in Table VIII. The results of NSRDS-NBS-29 are smaller than those of PHOTX and the difference increases with the increase of the attenuation depth. This comes from the fact that the attenuation depth in mfp for NSRDS-NBS-29 at each depth is smaller than that for PHOTX. For example, 0.6580 cm corresponds to 40, 39.95 and 39.06 mfp for PHOTX, DLC-15 and NSRDS-NBS-29, respectively.

III.2 Effects of the Energy-Absorption Coefficients of Air

Exposure buildup factors of 0.1 and 1 MeV were calculated using PHOTX library and three data sets of the energy-absorption coefficients of air, which are shown in Tables IX and X.

As supposed based on the differences in the energy-absorption coefficients of air (Fig. 4), the calculated results agree well with each other within the deviations of the calculation.

IV SUMMARY

The effects of using different photon cross section data libraries and energy-absorption coefficients of air to the exposure buildup factors were studied using the EGS4 Monte Carlo code for water, iron and lead from the 0.1-MeV to the 10-MeV energy regions.

Although the effects of the cross section data used exist, they are small, except for the case of lead at 0.1 and 10 MeV. This fact shows the importance of checking the effects of the cross section library when studying of the gamma-ray buildup factors, especially for high-Z materials.

The effects of photon cross section data library at absolute distances such as cm differ from those at mfp calculated with each cross section library.

The effects of using different sources of energy-absorption coefficients are small in the studied energy region.

The calculations were performed using the PURE (Pilot Unix R&D Environment)

system at the Computing Center of National Laboratory for High Energy Physics (KEK).

References

- [1] J. H. Hubbell, "Photon cross sections, attenuation coefficients and energy absorption coefficients from 10 keV to 100 GeV," *NSRDS-NBS-29* (1969).
- [2] A. B. Chilton, C. M. Eisenhauer and G. L. Simmons, "Photon Point Source Buildup Factors for Air, Water and Iron," *Nucl. Sci. Eng.*, **73**, 97(1980).
- [3] Radiation Shielding Information Center Data Package DLC-136/PHOTX, *Photon Interaction Cross Section Library*, contributed by National Institute of Standards and Technology.
- [4] K. Takeuchi and S. Tanaka, "PALLAS-1D(VII); A code for direct integration of transport equation in one dimensional plane and spherical geometries," *JAERI-M* 84-214, (1984).
- [5] American National Standard, "Gamma-Ray Attenuation Coefficients and Buildup Factors for Engineering Materials," ANSI/ANS-6.4.3, American Nuclear Society. See also D. K. Trubey, "New gamma-ray buildup factor data for point kernel calculations; ANS-6.4.3 standard reference data," *NUREG/CR-5740*, U.S. Nuclear Regulation Commission (1991).

[6] E. Storm and H. I. Israel, "Photon cross sections from 1 keV to 100 MeV for elements Z=1 to Z=100," *Nucl. Data Tables* **A7**, 565(1970); also designed as Radiation Shielding Information Center tape DLC-15.

[7] J. H. Hubbell, "Photon mass attenuation and energy-absorption coefficients from 1 keV to 20 MeV," *Int. J. Appl. Radiat. Isot.* **33**, 1269-1290(1982).

[8] S. M. Seltzer, "Calculation of Photon Mass Energy-transfer and Mass Energy-Absorption Coefficients," *Radiat. Res.* **136**, 147-170(1993).

[9] W. R. Nelson, H. Hirayama, H. and D. W. O. Rogers, "EGS4 code system," *SLAC-265*, (1985).

[10] H. Hirayama, "Calculation of Gamma-Ray Exposure Buildup Factors up to 40 mfp using the EGS4 Monte Carlo Code with a particle splitting," submitted to *J. Nucl. Sci. Technol.*

[11] A. F. Bielajew and D. W. O. Rogers, *Nucl. Instrum. and Methods* **B 18**, 165(1987).

[12] Y. Sakamoto, "Photon Cross Section Data PHOTX for PEGS4 Code," Proceedings of the Third EGS4 Users' Meeting in Japan, 77-82, KEK Proceedings 93-15(1993).

TABLE I
Photoelectric, pair-production and total cross sections for Water

Photon	Photoelectric Cross Section			Total Cross Section		
	PHOTX	DLC-15	NSRDS -NBS-29	PHOTX	DLC-15	NSRDS -NBS-29
Energy (MeV)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)
1.00E-2 ^a	4.944E+0	4.76E+0	4.78E+0	5.158E+0	4.97E+0	4.99E+0
1.50E-2	1.369E+0	1.32E+0	1.27E+0	1.580E+0	1.53E+0	1.48E+0
2.00E-2	5.439E-1	5.25E-1	5.05E-1	7.505E-1	7.32E-1	7.11E-1
3.00E-2	1.458E-1	1.42E-1	1.38E-1	3.455E-1	3.42E-1	3.38E-1
4.00E-2	5.680E-2	5.52E-2	5.48E-2	2.503E-1	2.48E-1	2.48E-1
5.00E-2	2.725E-2	2.66E-2	2.67E-2	2.149E-1	2.15E-1	2.14E-1
6.00E-2	1.493E-2	1.47E-2	1.50E-2	1.973E-1	1.97E-1	1.97E-1
8.00E-2	5.770E-3	5.65E-3	5.95E-3	1.787E-1	1.79E-1	1.79E-1
1.00E-1	2.763E-3	2.69E-3	2.85E-3	1.675E-1	1.68E-1	1.68E-1
1.50E-1	7.308E-4	7.06E-4	7.76E-4	1.490E-1	1.49E-1	1.49E-1
2.00E-1	2.887E-4	2.82E-4	3.11E-4	1.362E-1	1.36E-1	1.36E-1
3.00E-1	8.160E-5	8.40E-5	8.86E-5	1.182E-1	1.18E-1	1.18E-1
4.00E-1	3.493E-5	3.51E-5	3.78E-5	1.059E-1	1.06E-1	1.06E-1
5.00E-1	1.883E-5		2.04E-5	9.667E-2	9.67E-2	9.67E-2
6.00E-1	1.173E-5		1.28E-5	8.943E-2	8.95E-2	8.95E-2
8.00E-1	5.920E-6		6.42E-6	7.856E-2	7.86E-2	7.86E-2
1.00E+0	3.681E-6		3.98E-6	7.062E-2	7.06E-2	7.07E-2

Photon	Pair-Production Cross Section			Total Cross Section		
	PHOTX	DLC-15	NSRDS -NBS-29	PHOTX	DLC-15	NSRDS -NBS-29
Energy (MeV)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)
2.00E+0	3.908E-4	3.93E-4	3.93E-4	4.932E-2	4.94E-2	4.94E-2
3.00E+0	1.130E-3	1.14E-3	1.13E-3	3.960E-2	3.97E-2	3.97E-2
4.00E+0	1.867E-3	1.89E-3	1.89E-3	3.395E-2	3.40E-2	3.40E-2
5.00E+0	2.540E-3	2.56E-3	2.56E-3	3.024E-2	3.03E-2	3.03E-2
6.00E+0	3.156E-3	3.16E-3	3.17E-3	2.763E-2	2.77E-2	2.77E-2
8.00E+0	4.211E-3	4.21E-3	4.22E-3	2.423E-2	2.43E-2	2.43E-2
1.00E+1	5.090E-3	5.08E-3	5.08E-3	2.213E-2	2.22E-2	2.22E-2

^a Read as 1.00×10^{-1} .

TABLE II
Photoelectric, pair-production and total cross sections for Iron

Photon	Photoelectric Cross Section			Total Cross Section		
	PHOTX	DLC-15	NSRDS -NBS-29	PHOTX	DLC-15	NSRDS -NBS-29
Energy (MeV)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)
1.00E-2 ^a	1.694E+2	1.69E+2	1.71E+2	1.696E+2	1.69E+2	1.72E+2
1.50E-2	5.623E+1	5.60E+1	5.55E+1	5.641E+1	5.61E+1	5.57E+1
2.00E-2	2.505E+1	2.49E+1	2.49E+1	2.522E+1	2.51E+1	2.51E+1
3.00E-2	7.763E+0	7.68E+0	7.71E+0	7.930E+0	7.83E+0	7.88E+0
4.00E-2	3.316E+0	3.28E+0	3.30E+0	3.478E+0	3.44E+0	3.46E+0
5.00E-2	1.697E+0	1.67E+0	1.68E+0	1.855E+0	1.83E+0	1.84E+0
6.00E-2	9.776E-1	9.68E-1	9.75E-1	1.131E+0	1.12E+0	1.13E+0
8.00E-2	4.060E-1	4.03E-1	4.06E-1	5.510E-1	5.48E-1	5.50E-1
1.00E-1	2.044E-1	2.40E-1	2.04E-1	3.426E-1	3.40E-1	3.42E-1
1.50E-1	5.861E-2	5.78E-2	5.95E-2	1.830E-1	1.82E-1	1.84E-1
2.00E-1	2.433E-2	2.40E-2	2.51E-2	1.383E-1	1.38E-1	1.39E-1
3.00E-1	7.266E-3	7.17E-3	7.52E-3	1.064E-1	1.06E-1	1.07E-1
4.00E-1	3.209E-3	3.17E-3	3.33E-3	9.203E-2	9.20E-2	9.21E-2
5.00E-1	1.762E-3	1.74E-3	1.82E-3	8.287E-2	8.28E-2	8.29E-2
6.00E-1	1.110E-3	1.10E-3	1.15E-3	7.616E-2	7.61E-2	7.62E-2
8.00E-1	5.650E-4	5.61E-4	5.86E-4	6.648E-2	6.64E-2	6.65E-2
1.00E+0	3.514E-4	3.47E-4	3.64E-4	5.962E-2	5.96E-2	5.96E-2
Photon	Pair-Production Cross Section			Total Cross Section		
	PHOTX	DLC-15	NSRDS -NBS-29	PHOTX	DLC-15	NSRDS -NBS-29
Energy (MeV)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)
2.00E+0	1.364E-3	1.36E-3	1.36E-3	4.249E-2	4.25E-2	4.25E-2
3.00E+0	3.792E-3	3.78E-3	3.78E-3	3.611E-2	3.62E-2	3.62E-2
4.00E+0	6.085E-3	6.09E-3	6.09E-3	3.303E-2	3.31E-2	3.31E-2
5.00E+0	8.124E-3	8.13E-3	8.13E-3	3.139E-2	3.15E-2	3.14E-2
6.00E+0	9.950E-3	9.93E-3	9.93E-3	3.050E-2	3.05E-2	3.05E-2
8.00E+0	1.305E-2	1.30E-2	1.30E-2	2.985E-2	2.98E-2	2.98E-2
1.00E+1	1.559E-2	1.54E-2	1.54E-2	2.990E-2	2.98E-2	2.98E-2

^a Read as 1.00×10^{-1} .

TABLE III
Photoelectric, pair-production and total cross sections for Lead

Photon	Photoelectric Cross Section			Total Cross Section		
	PHOTX	DLC-15	NSRDS -NBS-29	PHOTX	DLC-15	NSRDS -NBS-29
Energy (MeV)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)
1.00E-2 ^a	1.256E+2	1.23E+2	1.28E+2	1.256E+2	1.23E+2	1.28E+2
1.50E-2	1.082E+2	1.07E+2	1.12E+2	1.083E+2	1.07E+2	1.12E+2
2.00E-2	8.398E+1	8.28E+1	8.31E+1	8.411E+1	8.30E+1	8.34E+1
3.00E-2	2.886E+1	2.85E+1	2.82E+1	2.900E+1	2.86E+1	2.84E+1
4.00E-2	1.335E+1	1.32E+1	1.30E+1	1.349E+1	1.33E+1	1.31E+1
5.00E-2	7.294E+0	7.15E+0	7.09E+0	7.426E+0	7.29E+0	7.22E+0
6.00E-2	4.433E+0	4.36E+0	4.30E+0	4.562E+0	4.49E+0	4.43E+0
8.00E-2	2.013E+0	1.98E+0	1.95E+0	2.136E+0	2.10E+0	2.07E+0
8.73E-2 ^b	1.581E+0	1.56E+0	1.53E+0	1.703E+0	1.68E+0	1.66E+0
8.80E-2	1.548E+0	1.53E+0	1.50E+0	1.668E+0	1.65E+0	1.62E+0
8.80E-2 ^c	7.323E+0	7.21E+0	7.12E+0	7.442E+0	7.33E+0	7.23E+0
1.00E-1	5.238E+0	5.23E+0	5.12E+0	5.355E+0	5.35E+0	5.23E+0
1.50E-1	1.815E+0	1.82E+0	1.78E+0	1.921E+0	1.93E+0	1.89E+0
2.00E-1	8.465E-1	8.49E-1	8.49E-1	9.432E-1	9.46E-1	9.45E-1
3.00E-1	2.930E-1	2.94E-1	2.99E-1	3.772E-1	3.78E-1	3.83E-1
4.00E-1	1.417E-1	1.41E-1	1.44E-1	2.172E-1	2.17E-1	2.20E-1
5.00E-1	8.180E-2	8.26E-2	8.49E-2	1.515E-1	1.52E-1	1.54E-1
6.00E-1	5.407E-2	5.41E-2	5.58E-2	1.179E-1	1.18E-1	1.20E-1
8.00E-1	2.901E-2	2.87E-2	2.97E-2	8.474E-2	8.47E-2	8.56E-2
1.00E+0	1.810E-2	1.81E-2	1.86E-2	6.848E-2	6.84E-2	6.90E-2
Photon	Pair-Production Cross Section			Total Cross Section		
	PHOTX	DLC-15	NSRDS -NBS-29	PHOTX	DLC-15	NSRDS -NBS-29
Energy (MeV)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)	(Ref. 3) (cm ² /g)	(Ref. 6) (cm ² /g)	(Ref. 1) (cm ² /g)
2.00E+0	5.451E-3	4.94E-3	4.94E-3	4.536E-2	4.53E-2	4.50E-2
3.00E+0	1.193E-2	1.15E-2	1.15E-2	4.199E-2	4.16E-2	4.16E-2
4.00E+0	1.716E-2	1.68E-2	1.68E-2	4.175E-2	4.16E-2	4.14E-2
5.00E+0	2.256E-2	2.13E-2	2.13E-2	4.257E-2	4.24E-2	4.24E-2
6.00E+0	2.535E-2	2.49E-2	2.49E-2	4.379E-2	4.36E-2	4.34E-2
8.00E+0	3.171E-2	3.07E-2	3.07E-2	4.667E-2	4.59E-2	4.59E-2
1.00E+1	3.699E-2	3.57E-2	3.57E-2	4.965E-2	4.85E-2	4.84E-2

^a Read as 1.00×10^{-1} .

^b K_{β2} X-ray energy.

^c K edge energy.

TABLE IV
Mass Energy-Absorption Coefficients of Air

Photon Energy (MeV)	Hubbell (1982) (Ref. 7) (cm ² /g)	NSRDS -NBS-29 (Ref. 1) (cm ² /g)	Seltzer (Ref. 8) (cm ² /g)
1.00E-2 ^a	4.640E+0	4.61E+0	4.742E+0
1.50E-2	1.300E+0	1.27E+0	1.334E+0
2.00E-2	5.255E-1	5.11E-1	5.389E-1
3.00E-2	1.501E-1	1.48E-1	1.537E-1
4.00E-2	6.694E-2	6.69E-2	6.833E-2
5.00E-2	4.031E-2	4.06E-2	4.098E-2
6.00E-2	3.004E-2	3.05E-2	3.041E-2
8.00E-2	2.393E-2	2.43E-2	2.407E-2
1.00E-1	2.318E-2	2.34E-2	2.325E-2
1.50E-1	2.494E-2	2.50E-2	2.496E-2
2.00E-1	2.673E-2	2.68E-2	2.672E-2
3.00E-1	2.872E-2	2.88E-2	2.872E-2
4.00E-1	2.949E-2	2.95E-2	2.949E-2
5.00E-1	2.966E-2	2.96E-2	2.966E-2
6.00E-1	2.953E-2	2.95E-2	2.953E-2
8.00E-1	2.882E-2	2.89E-2	2.882E-2
1.00E+0	2.787E-2	2.78E-2	2.789E-2
1.50E+0	2.545E-2	2.54E-2	2.547E-2
2.00E+0	2.342E-2	2.34E-2	2.345E-2
3.00E+0	2.054E-2	2.05E-2	2.057E-2
4.00E+0	1.866E-2	1.86E-2	1.870E-2
5.00E+0	1.737E-2	1.74E-2	1.740E-2
6.00E+0	1.644E-2	1.64E-2	1.647E-2
8.00E+0	1.521E-2	1.52E-2	1.525E-2
1.00E+1	1.446E-2	1.45E-2	1.450E-2
1.50E+1	1.349E-2	1.32E-2	1.353E-2
2.00E+1	1.308E-2	1.31E-2	1.311E-2

^a Read as 1.00×10^{-1} .

TABLE V
Gamma-Ray Exposure Buildup Factor for Point Isotropic Source (0.1 MeV)
Results using μ_{en} of Hubbell(1982)

EGS4						ANS-6.4.3 ^a
mfp	PHOTX (A)	DLC-15 (B)	B/A	NBS (C)	C/A	
Water						
1.0	4.68 ± 0.001	4.68 ± 0.008	1.000	4.68 ± 0.001	1.000	4.55
2.0	12.3 ± 0.036	12.4 ± 0.032	1.008	12.4 ± 0.032	1.008	11.8
3.0	25.0 ± 0.095	25.2 ± 0.070	1.008	25.2 ± 0.068	1.008	23.8
4.0	43.7 ± 0.15	44.3 ± 0.17	1.014	44.2 ± 0.17	1.011	41.3
5.0	69.5 ± 0.25	70.7 ± 0.30	1.017	70.6 ± 0.27	1.016	65.2
6.0	103. ± 0.45	106. ± 0.51	1.029	105. ± 0.44	1.019	96.7
7.0	146. ± 0.71	150. ± 0.84	1.027	149. ± 0.64	1.021	137.
8.0	199. ± 1.3	205. ± 1.3	1.030	205. ± 1.3	1.030	187.
10.0	346. ± 2.9	359. ± 3.5	1.038	357. ± 3.1	1.032	321.
15.0	1.00+3 ^b ± 9.7	1.06+3±13.	1.060	1.06+3±13.	1.060	938.
20.0	2.36+3 ±39.	2.47+3±50.	1.047	2.37+3±35.	1.004	2.17+3
25.0	4.77+3 ± 1.2+2	4.99+3±97.	1.046	4.87+3± 1.1+2	1.021	4.36+3
30.0	8.35+3 ± 2.3+2	9.35+3± 2.4+2	1.120	8.66+3± 2.5+2	1.037	7.97+3
35.0	1.52+4 ± 5.7+2	1.54+4± 5.7+2	1.013	1.46+4± 5.4+2	0.961	1.35+4
40.0	2.34+4 ± 1.1+3	2.59+4± 1.4+3	1.107	2.47+4± 1.6+3	1.056	2.11+4
Iron						
1.0	1.40 ± 0.002	1.40 ± 0.002	1.000	1.39 ± 0.002	0.993	1.40
2.0	1.62 ± 0.003	1.62 ± 0.003	1.000	1.62 ± 0.003	1.000	1.61
3.0	1.80 ± 0.006	1.80 ± 0.004	1.000	1.79 ± 0.006	0.994	1.78
4.0	1.96 ± 0.009	1.95 ± 0.008	0.995	1.96 ± 0.009	1.000	1.94
5.0	2.10 ± 0.011	2.09 ± 0.010	0.995	2.10 ± 0.009	1.000	2.07
6.0	2.21 ± 0.009	2.22 ± 0.008	1.005	2.22 ± 0.008	1.005	2.20
7.0	2.32 ± 0.011	2.34 ± 0.009	1.009	2.34 ± 0.011	1.009	2.31
8.0	2.43 ± 0.015	2.46 ± 0.014	1.012	2.45 ± 0.013	1.008	2.41
10.0	2.64 ± 0.019	2.66 ± 0.016	1.008	2.65 ± 0.019	1.004	2.61
15.0	3.05 ± 0.028	3.11 ± 0.029	1.020	3.07 ± 0.029	1.007	3.01
20.0	3.41 ± 0.032	3.44 ± 0.037	1.009	3.42 ± 0.035	1.003	3.33
25.0	3.65 ± 0.039	3.74 ± 0.043	1.025	3.731 ± 0.036	1.022	3.61
30.0	3.94 ± 0.051	4.01 ± 0.054	1.018	4.02 ± 0.058	1.020	3.86
35.0	4.21 ± 0.068	4.30 ± 0.072	1.021	4.30 ± 0.076	1.021	4.07
40.0	4.31 ± 0.067	4.51 ± 0.070	1.046	4.51 ± 0.088	1.046	4.23
Lead						
1.0	2.17 ± 0.003	2.18 ± 0.003	1.005	2.17 ± 0.003	1.000	2.04
2.0	3.53 ± 0.005	3.54 ± 0.006	1.003	3.53 ± 0.005	1.000	3.39
3.0	5.57 ± 0.010	5.65 ± 0.011	1.014	5.60 ± 0.010	1.005	5.60
4.0	8.99 ± 0.020	9.14 ± 0.017	1.017	9.04 ± 0.020	1.008	9.59
5.0	14.8 ± 0.023	15.2 ± 0.026	1.027	15.0 ± 0.026	1.014	17.0
6.0	25.0 ± 0.036	25.9 ± 0.040	1.036	25.4 ± 0.036	1.016	30.6
7.0	43.2 ± 0.067	44.9 ± 0.061	1.039	44.0 ± 0.062	1.019	54.9
8.0	75.9 ± 0.11	79.6 ± 0.10	1.049	77.6 ± 0.11	1.022	94.7
10.0	243. ± 0.42	258. ± 0.41	1.062	250. ± 0.40	1.029	294.
15.0	5.12+03±11.	5.63+03± 9.8	1.100	5.33+03±11.	1.041	5.80+03
20.0	1.23+05± 3.0+2	1.39+05± 3.1+2	1.174	1.29+05± 3.4+2	1.049	1.33+05
25.0	3.17+06± 9.8+3	3.72+06± 9.2+3	1.212	3.35+06± 9.3+3	1.057	3.34+06
30.0	8.58+07± 3.0+5	1.04+08± 3.8+5	1.234	9.12+07± 2.9+5	1.063	8.77+07
35.0	2.39+09± 8.9+6	2.95+09± 7.7+6	1.276	2.55+09± 8.6+6	1.067	2.36+09
40.0	6.70+10± 2.7+8	8.55+10± 2.5+8	1.28	7.20+10± 2.7+8	1.075	6.43+10

^a Water and Iron data were calculated using NSRDS-NBS-29 data and lead ones using PHOTX data.

^b Read as 1.00×10^3 .

TABLE VI
Gamma-Ray Exposure Buildup Factor for Point Isotropic Source (1.0 MeV)
Results using μ_{en} of Hubbell(1982)

	EGS4					ANS-6.4.3 ^a
	PHOTX (A)	DLC-15 (B)	B/A	NBS (C)	C/A	
mfp	Water					
1.0	2.09± 0.002	2.09± 0.002	1.000	2.10± 0.003	1.005	2.08
2.0	3.64± 0.005	3.66± 0.005	1.006	3.66± 0.006	1.005	3.62
3.0	5.54± 0.012	5.58± 0.013	1.007	5.58± 0.011	1.007	5.50
4.0	7.76± 0.024	7.79± 0.018	1.004	7.83± 0.021	1.009	7.66
5.0	10.3 ± 0.036	10.3 ± 0.031	1.000	10.3 ± 0.035	1.000	10.1
6.0	13.0 ± 0.049	13.1 ± 0.043	1.008	13.0 ± 0.045	1.000	12.8
7.0	15.9 ± 0.071	16.1 ± 0.057	1.013	15.8 ± 0.071	0.994	15.7
8.0	19.1 ± 0.12	19.2 ± 0.11	1.005	19.2 ± 0.11	1.005	19.0
10.0	26.2 ± 0.24	26.6 ± 0.22	1.015	26.3 ± 0.21	1.004	26.1
15.0	47.7 ± 0.70	48.7 ± 0.63	1.021	48.9 ± 0.73	1.025	47.7
20.0	75.7 ± 1.8	75.4 ± 1.8	0.996	74.0 ± 1.8	0.978	74.0
25.0	104. ± 2.9	107. ± 2.9	1.029	106. ± 3.0	1.019	104.
30.0	138. ± 5.5	139. ± 6.1	1.007	138. ± 4.1	1.000	139.
35.0	172. ± 9.0	174. ± 7.9	1.012	175. ± 7.3	1.017	177.
40.0	206. ±13.	207. ±11.	1.005	209. ±11.	1.015	218.
mfp	Iron					
1.0	1.86± 0.002	1.86± 0.002	1.000	1.86± 0.002	1.000	1.85
2.0	2.87± 0.004	2.87± 0.004	1.000	2.87± 0.004	1.000	2.85
3.0	4.04± 0.009	4.04± 0.009	1.000	4.03± 0.008	0.998	4.00
4.0	5.36± 0.018	5.34± 0.017	0.996	5.34± 0.015	0.996	5.30
5.0	6.80± 0.023	6.80± 0.023	1.000	6.76± 0.028	0.994	6.74
6.0	8.38± 0.027	8.45± 0.028	1.008	8.37± 0.022	0.999	8.31
7.0	10.1 ± 0.035	10.2 ± 0.040	1.010	10.1 ± 0.032	1.000	10.0
8.0	11.9 ± 0.062	12.0 ± 0.062	1.008	11.9 ± 0.064	1.000	11.8
10.0	15.9 ± 0.13	16.0 ± 0.11	1.006	15.9 ± 0.12	1.000	15.8
15.0	27.7 ± 0.31	27.9 ± 0.31	1.007	28.1 ± 0.34	1.014	27.5
20.0	40.6 ± 0.65	41.0 ± 0.68	1.010	40.8 ± 0.82	1.005	41.8
25.0	56.7 ± 1.4	56.3 ± 1.4	0.993	56.4 ± 1.3	0.995	57.0
30.0	77.4 ± 2.4	74.0 ± 1.9	0.956	74.8 ± 2.4	0.966	74.5
35.0	98.0 ± 3.7	91.2 ± 3.0	0.931	93.8 ± 3.2	0.957	93.5
40.0	112. ± 4.5	108. ± 5.8	0.964	117. ± 5.5	1.045	114.
mfp	Lead					
1.0	1.38± 0.001	1.38± 0.001	1.000	1.37± 0.001	0.993	1.31
2.0	1.69± 0.002	1.69± 0.002	1.000	1.67± 0.002	0.988	1.61
3.0	1.97± 0.003	1.97± 0.003	1.000	1.97± 0.004	0.985	1.87
4.0	2.23± 0.006	2.22± 0.007	0.996	2.19± 0.006	0.982	2.10
5.0	2.49± 0.010	2.47± 0.010	0.992	2.44± 0.011	0.980	2.32
6.0	2.72± 0.012	2.71± 0.009	0.996	2.66± 0.010	0.978	2.54
7.0	2.95± 0.015	2.95± 0.012	1.000	2.88± 0.012	0.976	2.75
8.0	3.16± 0.018	3.17± 0.015	1.003	3.09± 0.016	0.978	2.96
10.0	3.62± 0.025	3.60± 0.023	0.995	3.50± 0.028	0.967	3.37
15.0	4.55± 0.046	4.64± 0.044	1.020	4.45± 0.049	0.978	4.30
20.0	5.45± 0.071	5.47± 0.065	1.004	5.32± 0.072	0.976	5.17
25.0	6.27± 0.12	6.31± 0.10	1.006	6.20± 0.099	0.989	5.99
30.0	7.10± 0.15	6.99± 0.13	0.956	6.83± 0.13	0.962	6.83
35.0	7.96± 0.20	7.87± 0.15	0.989	7.70± 0.19	0.967	7.53
40.0	8.94± 0.25	8.74± 0.19	0.978	8.46± 0.23	0.946	8.21

^a Water and Iron data were calculated using NSRDS-NBS-29 data and lead ones using PHOTX data.

TABLE VII
Gamma-Ray Exposure Buildup Factor for Point Isotropic Source (10.0 MeV)
Results using μ_{en} of Hubbell(1982)

	EGS4					ANS-6.4.3 ^a
	PHOTX (A)	DLC-15 (B)	B/A	NBS (C)	C/A	
mfp	Water					
1.0	1.44 ± 0.001	1.44 ± 0.002	1.000	1.44 ± 0.001	1.000	1.37
2.0	1.79 ± 0.002	1.78 ± 0.002	0.994	1.78 ± 0.002	0.994	1.68
3.0	2.11 ± 0.004	2.10 ± 0.003	0.995	2.11 ± 0.004	1.000	1.97
4.0	2.41 ± 0.007	2.41 ± 0.006	1.000	2.43 ± 0.005	1.008	2.25
5.0	2.72 ± 0.011	2.73 ± 0.011	1.004	2.73 ± 0.010	1.004	2.53
6.0	3.01 ± 0.012	3.02 ± 0.010	1.003	3.02 ± 0.012	1.003	2.80
7.0	3.30 ± 0.014	3.31 ± 0.014	1.003	3.31 ± 0.017	1.003	3.07
8.0	3.59 ± 0.018	3.61 ± 0.022	1.006	3.59 ± 0.018	1.000	3.34
10.0	4.09 ± 0.035	4.13 ± 0.037	1.010	4.17 ± 0.038	1.020	3.86
15.0	5.62 ± 0.076	5.59 ± 0.060	0.995	5.55 ± 0.057	0.988	5.14
20.0	7.01 ± 0.12	6.93 ± 0.085	0.989	6.82 ± 0.11	0.973	6.38
25.0	8.60 ± 0.20	8.33 ± 0.18	0.969	8.05 ± 0.17	0.936	7.59
30.0	9.87 ± 0.25	9.79 ± 0.31	0.992	9.48 ± 0.24	0.961	8.78
35.0	11.5 ± 0.37	11.1 ± 0.33	0.965	10.4 ± 0.32	0.904	9.96
40.0	12.9 ± 0.37	12.2 ± 0.44	0.946	11.6 ± 0.44	0.899	11.2
mfp	Iron					
1.0	1.52 ± 0.001	1.52 ± 0.001	1.000	1.51 ± 0.001	0.993	1.33
2.0	1.94 ± 0.002	1.94 ± 0.002	1.000	1.93 ± 0.002	0.995	1.59
3.0	2.36 ± 0.004	2.36 ± 0.004	1.000	2.34 ± 0.004	0.992	1.86
4.0	2.81 ± 0.007	2.79 ± 0.007	0.993	2.78 ± 0.007	0.989	2.16
5.0	3.29 ± 0.012	3.25 ± 0.011	0.991	3.28 ± 0.013	0.997	2.50
6.0	3.81 ± 0.015	3.77 ± 0.013	0.990	3.77 ± 0.013	0.989	2.87
7.0	4.36 ± 0.022	4.33 ± 0.020	0.986	4.30 ± 0.020	0.986	3.27
8.0	4.94 ± 0.030	4.91 ± 0.026	0.994	4.87 ± 0.027	0.986	3.71
10.0	6.22 ± 0.047	6.19 ± 0.057	0.995	6.16 ± 0.048	0.990	4.69
15.0	10.6 ± 0.13	10.3 ± 0.11	0.972	10.1 ± 0.12	0.953	7.88
20.0	16.5 ± 0.27	15.8 ± 0.23	0.958	15.5 ± 0.26	0.939	12.3
25.0	24.3 ± 0.49	23.3 ± 0.48	0.959	23.3 ± 0.40	0.959	18.1
30.0	33.6 ± 0.92	32.9 ± 0.96	0.979	32.8 ± 1.1	0.976	25.7
35.0	46.7 ± 1.5	43.1 ± 1.5	0.923	44.7 ± 1.3	0.957	35.3
40.0	60.7 ± 2.2	52.9 ± 2.4	0.954	60.3 ± 2.1	0.993	47.6
mfp	Lead					
1.0	1.56 ± 0.001	1.56 ± 0.001	1.000	1.56 ± 0.001	1.000	1.51
2.0	2.04 ± 0.003	2.03 ± 0.002	0.995	2.03 ± 0.002	0.995	1.97
3.0	2.59 ± 0.003	2.56 ± 0.003	0.988	2.54 ± 0.003	0.981	2.54
4.0	3.23 ± 0.008	3.21 ± 0.009	0.997	3.17 ± 0.009	0.985	3.26
5.0	4.04 ± 0.010	3.96 ± 0.010	0.980	3.94 ± 0.015	0.975	4.14
6.0	5.04 ± 0.012	4.91 ± 0.013	0.970	4.89 ± 0.019	0.970	5.32
7.0	6.24 ± 0.023	6.07 ± 0.022	0.973	6.02 ± 0.023	0.965	6.78
8.0	7.77 ± 0.029	7.51 ± 0.029	0.967	7.39 ± 0.033	0.951	8.60
10.0	12.0 ± 0.064	11.5 ± 0.062	0.958	11.2 ± 0.057	0.933	13.8
15.0	36.4 ± 0.27	32.8 ± 0.27	0.901	32.0 ± 0.27	0.889	42.8
20.0	109. ± 1.0	94.4 ± 1.0	0.866	91.4 ± 0.93	0.839	128.
25.0	327. ± 4.9	268. ± 4.1	0.820	259. ± 4.0	0.792	369.
30.0	965. ±15.	743. ±14.	0.770	723. ±13.	0.749	1030.
35.0	2.80+3 ^b ±55.	1.98+3±49.	0.707	1.94+3±39.0	0.693	2.82+3
40.0	7.65+3 ± 1.9+2	5.52+3 ± 1.7+2	0.722	5.25+3± 1.5+2	0.686	7.51+3

^a Water and Iron data were calculated using NSRDS-NBS-29 data and lead ones using PHOTX data.

^b Read as 2.80×10^3 .

TABLE VIII
Gamma-Ray Point Isotropic Exposure Buildup Factor for Lead (0.1 MeV)
Results at absolute distance.
Results using μ_{en} of Hubbell(1982)

cm	mfp for PHOTX	PHOTX ^a (A)	DLC-15 ^b (B)	B/A	NBS ^c (C)	C/A
0.01645	1.0	2.17 ± 0.003	2.17 ±0.003	1.000	2.14 ±0.003	0.986
0.03290	2.0	3.53 ± 0.005	3.53 ±0.006	1.000	3.46 ±0.007	0.980
0.04935	3.0	5.57 ± 0.010	5.62 ±0.010	1.009	5.45 ±0.012	0.978
0.06580	4.0	8.99 ± 0.020	9.11 ±0.018	1.013	8.67 ±0.018	0.964
0.08225	5.0	14.8 ± 0.023	15.1 ±0.023	1.020	14.2 ±0.024	0.959
0.09870	6.0	25.0 ± 0.036	25.7 ±0.034	1.028	23.6 ±0.033	0.944
0.1152	7.0	43.2 ± 0.067	44.5 ±0.057	1.030	40.3 ±0.055	0.933
0.1316	8.0	75.9 ± 0.11	78.6 ±0.12	1.036	69.9 ±0.10	0.920
0.1645	10.0	243. ± 0.42	254. ±0.37	1.045	218. ±0.38	0.897
0.2458	15.0	5.12+03 ^a ±11.	5.50+03±9.6	1.074	4.30+03±9.2	0.840
0.3290	20.0	1.23+05 ± 3.0+2	1.35+05± 3.0+2	1.098	9.62+04± 2.4+2	0.782
0.4113	25.0	3.17+06 ± 9.8+3	3.57+06± 8.7+3	1.126	2.31+06± 5.8+3	0.729
0.4945	30.0	8.58+07 ± 3.0+5	9.85+07± 2.6+5	1.148	5.82+07± 1.7+5	0.678
0.5922	35.0	2.39+09 ± 8.9+6	2.78+09± 7.8+6	1.163	1.51+09± 5.3+6	0.632
0.6580	40.0	6.70+10 ± 2.7+8	7.98+10± 2.4+8	1.191	3.94+10± 1.6+8	0.588

^a 1mfp = 0.01645 cm.

^b 1mfp = 0.01647 cm.

^c 1mfp = 0.01685 cm.

^d Read as 5.12×10^3 .

TABLE IX Gamma-Ray Exposure Buildup Factor
for Point Isotropic Source (0.1 MeV)
Results using PHOTX library

	Seltzer (A)	Hubbell (B) (1982)	B/A	NRDS-NBS-29(C) (1969)	C/A
Water					
mfp					
1.0	4.71 ± 0.001	4.68 ± 0.008	0.994	4.68 ± 0.001	0.994
2.0	12.4 ± 0.037	12.3 ± 0.036	0.992	12.3 ± 0.036	0.992
3.0	25.2 ± 0.097	25.0 ± 0.095	0.992	24.8 ± 0.093	0.984
4.0	44.3 ± 0.15	43.7 ± 0.15	0.986	43.5 ± 0.14	0.982
5.0	70.4 ± 0.25	69.5 ± 0.25	0.987	69.1 ± 0.25	0.982
6.0	105. ± 0.46	103. ± 0.44	0.981	103. ± 0.44	0.981
7.0	148. ± 0.72	146. ± 0.71	0.986	144. ± 0.70	0.973
8.0	202. ± 1.3	199. ± 1.3	0.985	198. ± 1.3	0.980
10.0	351. ± 2.9	346. ± 2.9	0.986	343. ± 2.8	0.977
15.0	994. ±15.	1.02+3 ^a ± 9.8	1.026	1.00+3± 9.7	1.006
20.0	2.36+3±39.	2.36+3 ±39.	1.000	2.33+3±39.	0.987
25.0	4.84+3± 1.2+2	4.77+3 ± 1.2+2	0.986	4.72+3± 1.2+2	0.975
30.0	8.48+3± 2.3+2	8.35+3 ± 2.3+2	0.985	8.26+3± 2.3+2	0.974
35.0	1.54+4± 5.8+2	1.52+4 ± 5.7+2	0.987	1.50+4± 5.6+2	0.974
40.0	2.38+4± 1.1+3	2.34+4 ± 1.1+3	0.983	2.32+4 ± 1.1+3	0.974
Iron					
mfp					
1.0	1.39 ± 0.002	1.40 ± 0.002	1.007	1.40 ± 0.002	1.007
2.0	1.62 ± 0.003	1.62 ± 0.003	1.000	1.62 ± 0.003	1.000
3.0	1.80 ± 0.006	1.80 ± 0.004	1.000	1.80 ± 0.006	1.000
4.0	1.96 ± 0.009	1.96 ± 0.008	1.000	1.96 ± 0.009	1.000
5.0	2.10 ± 0.011	2.09 ± 0.011	0.995	2.10 ± 0.011	1.000
6.0	2.21 ± 0.009	2.21 ± 0.009	1.000	2.21 ± 0.009	1.000
7.0	2.32 ± 0.012	2.32 ± 0.011	1.000	2.32 ± 0.011	1.000
8.0	2.44 ± 0.015	2.43 ± 0.015	0.996	2.44 ± 0.015	1.000
10.0	2.64 ± 0.019	2.64 ± 0.019	1.000	2.64 ± 0.019	1.000
15.0	3.06 ± 0.028	3.05 ± 0.028	0.997	3.06 ± 0.028	1.000
20.0	3.41 ± 0.032	3.41 ± 0.032	1.000	3.42 ± 0.032	1.003
25.0	3.65 ± 0.040	3.65 ± 0.040	1.000	3.66 ± 0.039	1.003
30.0	3.94 ± 0.051	3.94 ± 0.051	1.000	3.94 ± 0.051	1.000
35.0	4.21 ± 0.068	4.21 ± 0.068	1.000	4.22 ± 0.068	1.002
40.0	4.32 ± 0.069	4.31 ± 0.067	0.998	4.32 ± 0.067	1.000
Lead					
mfp					
1.0	2.17 ± 0.003	2.17 ± 0.003	1.000	2.18 ± 0.003	1.005
2.0	3.54 ± 0.005	3.53 ± 0.005	0.997	3.54 ± 0.005	1.000
3.0	5.59 ± 0.010	5.57 ± 0.010	0.996	5.60 ± 0.010	1.002
4.0	9.02 ± 0.020	8.99 ± 0.020	0.997	9.03 ± 0.021	1.001
5.0	14.9 ± 0.023	14.8 ± 0.023	0.993	14.9 ± 0.023	1.000
6.0	25.1 ± 0.036	25.0 ± 0.036	0.996	25.1 ± 0.036	1.000
7.0	43.3 ± 0.067	43.2 ± 0.067	0.998	43.4 ± 0.067	1.002
8.0	76.2 ± 0.11	75.9 ± 0.11	0.996	76.3 ± 0.11	1.001
10.0	244. ± 0.42	243. ± 0.42	0.996	244. ± 0.42	1.000
15.0	5.14+03±11.	5.12+03±11.	0.996	5.15+03±17.	1.002
20.0	1.23+05± 3.0+2	1.23+05± 3.0+2	1.000	1.23+05± 3.0+2	1.000
25.0	3.18+06± 9.8+3	3.17+06± 9.8+3	0.997	3.18+06± 9.8+3	1.000
30.0	8.60+07± 3.0+5	8.58+07± 3.0+5	0.998	8.62+07± 3.0+5	1.002
35.0	2.39+09± 8.9+6	2.38+09± 8.9+6	0.996	2.39+09± 9.0+6	1.000
40.0	6.71+10± 2.7+8	6.70+10± 2.7+8	0.999	6.73+10± 2.7+8	1.003

^a Read as 1.02×10^3

TABLE X Gamma-Ray Exposure Buildup Factor
for Point Isotropic Source (1.0 MeV)
Results using PHOTX library

	Seitzer (A)	Hubbell (B) (1982)	B/A	NRDS-NBS-29(C) (1969)	C/A
mfp	Water				
1.0	2.09± 0.002	2.09± 0.002	1.000	2.09± 0.002	1.000
2.0	3.64± 0.005	3.64± 0.005	1.000	3.65± 0.005	1.003
3.0	5.55± 0.012	5.54± 0.011	0.998	5.56± 0.012	1.002
4.0	7.78± 0.024	7.76± 0.023	0.997	7.79± 0.023	1.001
5.0	10.3 ± 0.036	10.3 ± 0.036	1.000	10.3 ± 0.036	1.000
6.0	13.1 ± 0.049	13.0 ± 0.048	0.992	13.1 ± 0.049	1.000
7.0	16.0 ± 0.072	15.9 ± 0.071	0.994	16.0 ± 0.071	1.000
8.0	19.2 ± 0.12	19.1 ± 0.11	0.995	19.2 ± 0.12	1.000
10.0	26.3 ± 0.24	26.2 ± 0.24	0.996	26.3 ± 0.24	1.000
15.0	47.9 ± 0.70	47.7 ± 0.70	0.996	47.9 ± 0.70	1.000
20.0	75.9 ± 1.8	75.7 ± 1.8	0.997	76.0 ± 1.8	1.001
25.0	104. ± 2.9	104. ± 2.9	1.000	104. ± 2.9	1.000
30.0	139. ± 5.5	138. ± 5.5	0.993	139. ± 5.6	1.000
35.0	172. ± 9.0	172. ± 9.0	1.000	173. ± 9.0	1.006
40.0	207. ±13	206. ±12	0.995	207. ±13	1.000
mfp	Iron				
1.0	1.86± 0.002	1.86± 0.002	1.000	1.86± 0.002	1.000
2.0	2.87± 0.003	2.87± 0.004	1.000	2.86± 0.004	0.997
3.0	4.04± 0.009	4.04± 0.009	1.000	4.06± 0.008	1.005
4.0	5.36± 0.018	5.36± 0.018	1.000	5.38± 0.018	1.004
5.0	6.80± 0.023	6.80± 0.023	1.000	6.82± 0.023	1.003
6.0	8.38± 0.027	8.38± 0.027	1.000	8.40± 0.027	1.002
7.0	10.1 ± 0.035	10.1 ± 0.035	1.000	10.1 ± 0.035	1.000
8.0	11.9 ± 0.062	11.9 ± 0.062	1.000	12.0 ± 0.062	1.009
10.0	15.9 ± 0.13	15.9 ± 0.13	1.000	15.9 ± 0.13	1.000
15.0	27.6 ± 0.31	27.7 ± 0.31	1.004	27.8 ± 0.31	1.004
20.0	40.6 ± 0.65	40.6 ± 0.66	1.000	40.7 ± 0.65	1.002
25.0	56.7 ± 1.4	56.7 ± 1.4	1.000	56.8 ± 1.4	1.002
30.0	77.3 ± 2.4	77.4 ± 2.4	1.001	77.6 ± 2.4	1.004
35.0	97.9 ± 3.7	98.0 ± 3.7	1.001	98.3 ± 3.7	1.004
40.0	112. ± 4.5	111. ± 4.5	0.991	112. ± 4.5	1.000
mfp	Lead				
1.0	1.38± 0.001	1.38± 0.001	1.000	1.38± 0.001	1.000
2.0	1.69± 0.002	1.69± 0.002	1.000	1.69± 0.002	1.000
3.0	1.97± 0.003	1.97± 0.003	1.000	1.97± 0.003	1.000
4.0	2.23± 0.006	2.23± 0.006	1.000	2.23± 0.006	1.000
5.0	2.49± 0.011	2.49± 0.010	1.000	2.49± 0.010	1.000
6.0	2.72± 0.012	2.72± 0.012	1.000	2.72± 0.012	1.000
7.0	2.95± 0.015	2.95± 0.015	1.000	2.95± 0.015	1.000
8.0	3.16± 0.018	3.16± 0.018	1.000	3.17± 0.018	1.003
10.0	3.62± 0.025	3.62± 0.024	1.000	3.63± 0.025	1.003
15.0	4.54± 0.045	4.55± 0.046	1.002	4.56± 0.046	1.004
20.0	5.44± 0.071	5.45± 0.071	1.002	5.46± 0.071	1.004
25.0	6.24± 0.12	6.27± 0.12	1.005	6.29± 0.12	1.008
30.0	7.10± 0.15	7.10± 0.15	1.000	7.12± 0.15	1.003
35.0	7.96± 0.20	7.96± 0.20	1.000	7.98± 0.20	1.003
40.0	8.94± 0.25	8.94± 0.24	1.000	8.96± 0.25	1.002

Fig. 1 Comparison of the photoelectric cross sections as the ratio to PHOTX.

Fig. 2 Comparison of the total cross sections as the ratio to PHOTX.

Fig. 3 Comparison of the energy-absorption coefficients of air as the ratio to Seltzer's results.

Fig. 4 Ratio of the point isotropic exposure buildup factors for water to the results obtained with the PHOTX library.

Fig. 5 Ratio of the point isotropic exposure buildup factors for iron to the results obtained with the PHOTX library.

Fig. 6 Ratio of the point isotropic exposure buildup factors for lead to the results obtained with the PHOTX library.