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JOURNAL of NUCLEAR MEDICINE

February 1968

Medical Internal Radiation

Dose Committee

Supplement Number 1

Pamphlets 1-3



**mird/** PAMPHLET NO. 2

**ENERGY DEPOSITION IN WATER BY PHOTONS  
FROM POINT ISOTROPIC SOURCES**

Martin J. Berger

*National Bureau of Standards  
Washington, D.C.*

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# ENERGY DEPOSITION IN WATER BY PHOTONS FROM POINT ISOTROPIC SOURCES

Martin J. Berger

## 1. INTRODUCTION

This pamphlet contains a tabulation of buildup factors and related data which describe the deposition of energy by photons in a water medium. Water has been chosen as the reference medium because it is clearly defined and quite representative of other biological media (such as tissue or muscle) in regard to photon scattering and absorption\*. The radiation sources considered are monoenergetic and point-isotropic, i.e., of negligible dimensions and emitting photons of fixed energies uniformly in all directions. Nineteen source energies between 15 keV and 3 MeV are included. The energy grid is fine enough so that one can interpolate to other source energies. The results for point sources are of direct interest themselves and can also be used to obtain, by superposition, corresponding results for extended sources. To facilitate such superpositions and other manipulations, polynomial representations of the buildup factors are given in addition to numerical values.

The results in this pamphlet apply only to homogeneous media and do not cover situations in which there are significant variations in composition or density (such as those due to the presence of bone, lung tissue or voids in a human body). The applicability of the results is further restricted to media which are in effect unbounded, i.e., to configurations of medium, source and detector such that leakage of radiation across the boundaries of the medium has no influence on the absorbed dose received by the detector†. Data on energy deposition in bounded media of various shapes will be presented by Brownell, Ellett and Reddy in Pamphlet 3 (1) in this series.

## 2. DEFINITION OF BUILDUP FACTOR

Consider a point isotropic monoenergetic source of radiation in an unbounded homogeneous medium. Let  $R(x)$  be the absorbed dose rate at a distance  $x$  from the source. In accordance with the conventions

of MIRD Pamphlet No. 1 (2),  $R(x)$  can be expressed in the form

$$R(x) = A \cdot \Delta \cdot \Phi(x) \text{ rad/sec,} \quad (1a)$$

where  $\Delta = k n E$  g-rad/dis

and where  $\Phi(x)$  is the *point isotropic specific absorbed fraction*, i.e., the fraction of the emitted energy absorbed per gram at distance  $x$  from an isotropic point source. For a photon source

$$\Phi(x) = \Phi_{ph}(x) = \left[ \frac{\mu_{en}}{\rho} \cdot \frac{1}{4\pi x^2} \cdot e^{-\mu x} \right] \cdot B_{en}(\mu x). \quad (1b)$$

The quantity  $\Phi(x)$  has the dimensions of reciprocal grams ( $g^{-1}$ ). The factor in square brackets in Equation 1b represents the contribution of primary photons. The quantity  $B_{en}(\mu x)$  is the *energy-absorption buildup factor* and takes into account the contribution of scattered photons. The various symbols in Equations 1a and 1b have the following meaning:

- $R(x)$  = absorbed dose rate, rad/sec
- $x$  = distance from source, cm
- $k$  =  $1.60 \times 10^{-8}$  g-rad/MeV
- $n$  = number of photons of energy  $E$  emitted (corrected for internal conversion) per disintegration
- $E$  = energy of photons emitted by the source, MeV per photon
- $A$  = source activity, number of disintegrations/sec
- $\rho$  = density of the medium, g/cm<sup>3</sup>
- $\mu$  = linear photon attenuation coefficient at the source energy, cm<sup>-1</sup>
- $\mu_{en}$  = linear photon energy-absorption coefficient at the source energy, cm<sup>-1</sup>

\* It will be shown that there is hardly any significant difference between water and striated muscle in regard to the spatial pattern of energy deposition.

† These conditions are often satisfied if both the source and the detector are located at least a photon mean free path from the nearest boundary.

The energy-absorption buildup factor is a dimensionless quantity which we consider to be a function of  $\mu x$ , i.e., of the distance from the source in units of mean free paths. By this choice of units the variation of  $B_{en}(\mu x)$  with the source energy and with the composition of the medium is reduced. If one denotes the absorbed dose rate due to primary photons by  $R^P(x)$  and that due to scattered photons by  $R^S(x)$ , the buildup factor can also be written as

$$B_{en}(\mu x) = \frac{R^P(x) + R^S(x)}{R^P(x)} = 1 + \frac{R^S(x)}{R^P(x)} \quad (2)$$

For  $\mu x = 0$ , the buildup factor has the value unity, and at small distances from the source it increases linearly with  $\mu x$ . This is the case because for small  $\mu x$  the exponential absorption is unimportant, and  $R^P(x)$ , obeying the inverse square law, goes as  $1/x^2$  whereas  $R^S(x)$  can be shown (4) to go as  $1/x$ .

In the formulation of Equation 1 it has been tacitly assumed that the energy lost by photons in scattering or absorption events is given to the medium on the spot. Actually, of course, the energy is transferred to secondary electrons which travel a small distance while delivering the energy to the medium. The result is a small shift of the absorbed dose-rate distribution  $R(x)$  in the direction away from the source. As is shown in Table 1, the distance traveled by the electrons is small compared to the mean free path of photons at energies up to a few MeV. Therefore the shift in  $R(x)$  is relatively unimportant except in the close vicinity of a point source. The evaluation of the shift is difficult and has not been attempted here\*.

TABLE 1. RATIO OF THE ELECTRON MEAN RANGE  $r_o(E)$  TO THE PHOTON MEAN FREE PATH  $1/\mu(E)$  IN WATER

E (MeV)	Relative Range $r_o(E)\mu(E)$
0.015	0.0007
0.02	0.0006
0.03	0.0006
0.04	0.0007
0.05	0.0009
0.06	0.0011
0.08	0.0017
0.1	0.0024
0.15	0.0041
0.2	0.0060
0.3	0.0098
0.4	0.0134
0.5	0.0168
0.6	0.0199
0.8	0.0255
1.0	0.0303
1.5	0.0400
2.0	0.0474
3.0	0.0588

### 3. METHOD OF CALCULATION

The buildup factors presented here were obtained by an application of the moment method of Spencer and Fano (3, 4). This method involves two steps: 1. The accurate numerical calculation of the first few even spatial moments of the absorbed dose-rate distribution  $R^S(x)$  through the solution of an appropriate moment transport equation; and 2. The construction of the function  $R^S(x)$  from a knowledge of its moments and with the use of other available information. This information includes the behavior of  $R^S(x)$  for small  $x$ , where the singly scattered photons make a predominant contribution which can be evaluated analytically, and the behavior for very large  $x$  which must be exponentially decreasing. The moments are defined as

$$M_{2j} = \int_0^\infty 4\pi x^2 R^S(x) (\mu x)^{2j} d\mu x \quad (3)$$

A functional form for  $R^S(x)$  is assumed which has the desired behavior both for very small and very large  $x$  and which we have taken to be

$$R^S(x) = R^P(x) \mu x \sum_{n=0}^N a_n (\mu x)^n \quad (4)$$

where  $R^P(x)$  is the primary absorbed dose rate (quantity in square brackets in Equation 1b). The coefficients  $a_n$  are chosen so that the spatial moments on the right side of Equation 4, up to a certain order, coincide with the moments  $M_{2j}$  calculated from the transport equation. The  $a_n$ 's are therefore obtained by solving the set of equations

$$\begin{aligned} \sum_{n=0}^N a_n \int_0^\infty 4\pi x^2 R^P(x) (\mu x)^{2j+n+1} d\mu x \\ = \sum_{n=0}^N a_n (2j + n + 1)! = M_{2j}, \quad (j = 0, 1, \dots, N). \end{aligned} \quad (5)$$

Finally, by the combination of Equations 2 and 4, the buildup factor is found to be

$$B_{en}(\mu x) = 1 + \sum_{n=0}^N a_n (\mu x)^{n+1} \quad (6)$$

\* Various factors combine to make the shift of  $R(x)$  smaller than is indicated by the "relative ranges" in Table 1. The energy of the secondary electrons, in the case of Compton scattering, is on the average much lower than that of the primary photons. To some extent, there is a cancellation of the displacements because one must average over all possible directions in which the secondary electron can be set in motion. The effective electron range is also shortened as the result of multiple Coulomb scattering.

Drastic changes in  $R(x)$  will occur only in the immediate vicinity of the source where the inverse-square law of Equation 1 will be replaced by a transition curve starting from zero at  $x = 0$  and rising to a peak at a value of  $x$  comparable with an electron range. However, for such small distances the assumption of a mathematical point source is in any case unrealistic, and one should take into account the actual size and shape of the source.

For each source energy, ten moments ( $M_0, M_2, \dots, M_{10}$ ) were calculated and used to determine ten polynomial coefficients ( $a_0, a_1, \dots, a_9$ ).

The photon attenuation and energy absorption coefficients used as input for the moment calculations were taken from a recent compilation by Hubbell and Berger (5) and are listed in Table 2. Several slightly different definitions of the energy-absorption coefficient are currently in use. The numerical values in Table 2 simply take into account the transfer of energy from photons to photoelectrons and Compton-recoil electrons, and correspond to the coefficient designated as  $\mu_a$  in ref. 5. By contrast, the coefficient  $\mu_{en}$  in ref. 5 discounts the small amount of energy that is first converted from photon into electron kinetic energy and is then re-radiated in the form of bremsstrahlung or annihilation quanta. For water there is no significant difference between  $\mu_{en}$  and  $\mu_a$  at energies below 1 MeV. At 1, 2 and 3 MeV,  $\mu_{en}$  is smaller than  $\mu_a$  by 0.7, 1.1 and 2.6%, respectively.

#### 4. BUILDUP FACTOR TABLES

A set of energy-absorption buildup factors, more detailed and extensive than previously available results (4, 6), will be found in Table 3. The buildup factors increase rapidly with the distance from the source and are in fact quite large. As the source energy is decreased, Compton scattering becomes more diffuse in angle, and the buildup factor increases. On the other hand, photoelectric absorption becomes increasingly important as the source energy is lowered, which tends to reduce the buildup factor. As the result of the interplay of these two phenomena, the buildup factor at a given distance in mean free paths from the source reaches a peak at a certain energy. The value of this energy depends slightly on the distance from the source and amounts to approximately 50–60 keV close to the source and approximately 100 keV far from the source.

Table 4 contains the polynomial coefficients  $a_n$ , evaluated by the moment method and used to compute the buildup factors in Table 3. They are given as obtained from a computer run without further editing. Undoubtedly fewer significant figures would be adequate, but the numerical analysis for the appropriate round-off has not yet been done. The coefficients have also been stored in binary-coded decimal form (BCD) on punched cards to facilitate their use in other machine calculations.

It would be convenient to approximate the buildup factors by other formulas involving fewer numerical parameters than the ten-term polynomial in Equation 6. This has not yet been done. It is often possible, however, to shorten the polynomial. To illustrate this we give in Table 5 the number of terms in the polynomial

**TABLE 2. MASS ATTENUATION COEFFICIENTS  $\mu/\rho$  AND ENERGY ABSORPTION COEFFICIENTS  $\mu_{en}/\rho$  FOR WATER AND MUSCLE (5)**

E (MeV)	Water		Muscle	
	$\mu/\rho$ (cm <sup>2</sup> /g)	$\mu_{en}/\rho$ (cm <sup>2</sup> /g)	$\mu/\rho$ (cm <sup>2</sup> /g)	$\mu_{en}/\rho$ (cm <sup>2</sup> /g)
0.01	4.99	4.79	5.09	4.87
0.015	1.48	1.28	1.53	1.32
0.02	0.711	0.512	0.730	0.533
0.03	0.337	0.149	0.342	0.154
0.04	0.248	0.0677	0.249	0.0701
0.05	0.214	0.0418	0.214	0.0431
0.06	0.197	0.0320	0.196	0.0328
0.08	0.179	0.0262	0.178	0.0264
0.1	0.168	0.0256	0.167	0.0256
0.15	0.149	0.0277	0.147	0.0275
0.2	0.136	0.0297	0.135	0.0294
0.3	0.118	0.0319	0.117	0.0317
0.4	0.106	0.0328	0.105	0.0325
0.5	0.0966	0.0330	0.0958	0.0328
0.6	0.0894	0.0329	0.0886	0.0325
0.8	0.0785	0.0321	0.0778	0.0318
1.0	0.0706	0.0311	0.0699	0.0308
1.5	0.0575	0.0284	0.0570	0.0282
2.0	0.0493	0.0263	0.0489	0.0259
3.0	0.0396	0.0233	0.0392	0.0227

that must be used to obtain a buildup factor differing by 2% or less from that obtained with the complete ten-point polynomial.

#### 5. SPECIFIC ABSORBED FRACTIONS AND ABSORBED DOSE RATES IN WATER AND MUSCLE

In Table 6 the point-isotropic specific absorbed fraction is given for selected source energies and distances from point sources in water. These results can be converted to absorbed dose rates through multiplication by the photon energy  $E$  and an energy conversion factor  $k$ . The user of Table 6 should keep in mind that—as discussed in Section 2—the calculated results only apply, strictly speaking, to the transfer of energy from photons to electrons and do not take into account the further migration of this energy when carried by the secondary electrons. The difference between energy transfer and eventual energy deposition in the medium may be significant for the highest source energies and smallest distances in Table 6.

In Table 7 the ratio is given of the calculated absorbed dose rate in muscle to that in water, assuming the muscle to have unit density. It can be seen that for most source energies this ratio deviates only a few percent from unity. At the lowest source energies considerably larger deviations occur, but only at very large distances from the source where the absorbed dose rate is in any case extremely small and without much practical significance.

TABLE 3. ENERGY-ABSORPTION BUILDUP FACTOR

$\mu x$ (mfp)	Photon Energy, E(MeV)									
	0.015	0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.15	
0.05	1.02E 00	1.03E 00	1.08E 00	1.12E 00	1.13E 00	1.13E 00	1.12E 00	1.10E 00	1.08E 00	
0.10	1.03E 00	1.06E 00	1.16E 00	1.23E 00	1.27E 00	1.27E 00	1.24E 00	1.21E 00	1.17E 00	
0.20	1.06E 00	1.12E 00	1.31E 00	1.47E 00	1.55E 00	1.57E 00	1.51E 00	1.45E 00	1.36E 00	
0.30	1.08E 00	1.18E 00	1.45E 00	1.71E 00	1.86E 00	1.89E 00	1.82E 00	1.72E 00	1.57E 00	
0.40	1.10E 00	1.22E 00	1.59E 00	1.96E 00	2.18E 00	2.23E 00	2.15E 00	2.02E 00	1.80E 00	
0.50	1.12E 00	1.27E 00	1.72E 00	2.21E 00	2.51E 00	2.61E 00	2.52E 00	2.34E 00	2.05E 00	
0.60	1.14E 00	1.31E 00	1.85E 00	2.46E 00	2.86E 00	3.01E 00	2.92E 00	2.70E 00	2.33E 00	
0.80	1.17E 00	1.38E 00	2.10E 00	2.97E 00	3.62E 00	3.89E 00	3.81E 00	3.51E 00	2.96E 00	
1.00	1.19E 00	1.45E 00	2.34E 00	3.50E 00	4.43E 00	4.87E 00	4.85E 00	4.46E 00	3.69E 00	
1.20	1.21E 00	1.50E 00	2.57E 00	4.05E 00	5.30E 00	5.95E 00	6.03E 00	5.55E 00	4.53E 00	
1.40	1.23E 00	1.55E 00	2.79E 00	4.60E 00	6.23E 00	7.14E 00	7.37E 00	6.79E 00	5.49E 00	
1.60	1.25E 00	1.60E 00	3.00E 00	5.17E 00	7.22E 00	8.43E 00	8.85E 00	8.19E 00	6.58E 00	
1.80	1.26E 00	1.64E 00	3.21E 00	5.76E 00	8.27E 00	9.83E 00	1.05E 01	9.76E 00	7.80E 00	
2.00	1.28E 00	1.68E 00	3.42E 00	6.36E 00	9.37E 00	1.13E 01	1.23E 01	1.15E 01	9.16E 00	
2.50	1.31E 00	1.78E 00	3.93E 00	7.91E 00	1.24E 01	1.55E 01	1.76E 01	1.67E 01	1.32E 01	
3.00	1.34E 00	1.87E 00	4.42E 00	9.53E 00	1.57E 01	2.04E 01	2.40E 01	2.31E 01	1.83E 01	
3.50	1.37E 00	1.96E 00	4.91E 00	1.12E 01	1.93E 01	2.60E 01	3.17E 01	3.09E 01	2.46E 01	
4.00	1.40E 00	2.04E 00	5.39E 00	1.30E 01	2.33E 01	3.22E 01	4.06E 01	4.02E 01	3.21E 01	
4.50	1.43E 00	2.11E 00	5.86E 00	1.48E 01	2.76E 01	3.92E 01	5.10E 01	5.11E 01	4.09E 01	
5.00	1.45E 00	2.18E 00	6.32E 00	1.67E 01	3.22E 01	4.69E 01	6.28E 01	6.37E 01	5.13E 01	
6.00	1.48E 00	2.30E 00	7.22E 00	2.06E 01	4.23E 01	6.46E 01	9.13E 01	9.49E 01	7.69E 01	
7.00	1.51E 00	2.40E 00	8.09E 00	2.48E 01	5.38E 01	8.56E 01	1.27E 02	1.35E 02	1.10E 02	
8.00	1.54E 00	2.49E 00	8.96E 00	2.93E 01	6.67E 01	1.10E 02	1.70E 02	1.85E 02	1.51E 02	
9.00	1.57E 00	2.60E 00	9.84E 00	3.40E 01	8.10E 01	1.38E 02	2.23E 02	2.46E 02	2.03E 02	
10.00	1.60E 00	2.71E 00	1.07E 01	3.90E 01	9.68E 01	1.70E 02	2.86E 02	3.20E 02	2.65E 02	
11.00	1.64E 00	2.81E 00	1.16E 01	4.42E 01	1.14E 02	2.07E 02	3.59E 02	4.09E 02	3.40E 02	
12.00	1.66E 00	2.89E 00	1.25E 01	4.98E 01	1.33E 02	2.48E 02	4.45E 02	5.15E 02	4.28E 02	
13.00	1.67E 00	2.95E 00	1.33E 01	5.56E 01	1.54E 02	2.95E 02	5.45E 02	6.39E 02	5.33E 02	
14.00	1.66E 00	2.98E 00	1.42E 01	6.17E 01	1.77E 02	3.46E 02	6.60E 02	7.83E 02	6.54E 02	
15.00	1.66E 00	3.00E 00	1.50E 01	6.80E 01	2.01E 02	4.04E 02	7.91E 02	9.51E 02	7.95E 02	
16.00	1.66E 00	3.04E 00	1.59E 01	7.47E 01	2.28E 02	4.68E 02	9.41E 02	1.14E 03	9.57E 02	
17.00	1.69E 00	3.14E 00	1.68E 01	8.18E 01	2.57E 02	5.38E 02	1.11E 03	1.37E 03	1.14E 03	
18.00	1.76E 00	3.30E 00	1.78E 01	8.91E 01	2.87E 02	6.16E 02	1.30E 03	1.62E 03	1.35E 03	
19.00	1.88E 00	3.55E 00	1.89E 01	9.69E 01	3.21E 02	7.01E 02	1.52E 03	1.90E 03	1.59E 03	
20.00	2.02E 00	3.83E 00	2.01E 01	1.05E 02	3.56E 02	7.94E 02	1.76E 03	2.23E 03	1.86E 03	

\* The digits following the symbol E indicate the powers of ten by which each number is to be multiplied.

6. ACCURACY OF CALCULATED ABSORBED DOSE RATE

In addition to the error due to the neglect of electron travel, two other errors must be considered: that resulting from the uncertainty of the input cross sections and that resulting from numerical errors in the solution of the transport equation. According to Hubbell (7), a survey of all available theoretical and experimental information indicates that the photon attenuation and energy-absorption coefficients for water have an uncertainty of 1% between 3 MeV and 100 keV, -2% between 100 keV and 50 keV, 2-3% between 50 keV and 30 keV and 2% between 30 keV and 10 keV. These uncertainties have the same order of magnitude as the differences between corresponding coefficients for water and muscle given in Table 2. The muscle-water absorbed dose-rate ratios in Table 7

therefore provide an indication of the error that may result from the uncertainties of the cross sections.

The numerical accuracy of the buildup factor calculations has been checked by trial calculations in various stages in the computational procedure. The error increases with the distance from the source, and it is estimated to be smaller than 1% for  $0 \leq \mu x \leq 4$ , between 1 and 2% for  $4 < \mu x \leq 7$ , between 2 and 3% for  $7 < \mu x \leq 10$  and between 3 and 5% for  $10 < \mu x \leq 20$ . These error-limit estimates are quite conservative, and the actual error may be considerably smaller.

7. ABSORBED FRACTIONS

With the use of the buildup-factor polynomials, one can evaluate many other quantities of interest, for example the absorbed fraction. By absorbed fraction

$B_{en}(\mu x)$  FOR POINT ISOTROPIC SOURCES IN WATER \*

Photon Energy, E(MeV)										
0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00	3.00	$\mu x$ (mfp)
1.07E 00	1.06E 00	1.06E 00	1.05E 00	1.05E 00	1.04E 00	1.04E 00	1.04E 00	1.03E 00	1.03E 00	0.05
1.15E 00	1.12E 00	1.11E 00	1.10E 00	1.10E 00	1.09E 00	1.08E 00	1.07E 00	1.07E 00	1.06E 00	0.10
1.31E 00	1.26E 00	1.23E 00	1.22E 00	1.20E 00	1.18E 00	1.17E 00	1.15E 00	1.14E 00	1.13E 00	0.20
1.49E 00	1.41E 00	1.37E 00	1.34E 00	1.31E 00	1.29E 00	1.27E 00	1.24E 00	1.22E 00	1.19E 00	0.30
1.69E 00	1.57E 00	1.51E 00	1.47E 00	1.44E 00	1.39E 00	1.37E 00	1.32E 00	1.30E 00	1.26E 00	0.40
1.91E 00	1.74E 00	1.66E 00	1.60E 00	1.56E 00	1.51E 00	1.47E 00	1.41E 00	1.38E 00	1.33E 00	0.50
2.14E 00	1.93E 00	1.82E 00	1.75E 00	1.70E 00	1.63E 00	1.58E 00	1.51E 00	1.46E 00	1.39E 00	0.60
2.66E 00	2.34E 00	2.18E 00	2.07E 00	2.00E 00	1.89E 00	1.82E 00	1.71E 00	1.63E 00	1.53E 00	0.80
3.27E 00	2.82E 00	2.59E 00	2.44E 00	2.33E 00	2.18E 00	2.07E 00	1.91E 00	1.81E 00	1.68E 00	1.00
3.97E 00	3.35E 00	3.04E 00	2.83E 00	2.69E 00	2.49E 00	2.35E 00	2.13E 00	2.00E 00	1.82E 00	1.20
4.75E 00	3.95E 00	3.54E 00	3.27E 00	3.08E 00	2.82E 00	2.64E 00	2.36E 00	2.19E 00	1.97E 00	1.40
5.64E 00	4.62E 00	4.09E 00	3.75E 00	3.50E 00	3.17E 00	2.94E 00	2.59E 00	2.38E 00	2.12E 00	1.60
6.64E 00	5.36E 00	4.70E 00	4.26E 00	3.96E 00	3.54E 00	3.26E 00	2.84E 00	2.58E 00	2.27E 00	1.80
7.74E 00	6.17E 00	5.35E 00	4.81E 00	4.44E 00	3.93E 00	3.59E 00	3.08E 00	2.78E 00	2.41E 00	2.00
1.10E 01	8.54E 00	7.21E 00	6.37E 00	5.79E 00	5.00E 00	4.48E 00	3.73E 00	3.30E 00	2.79E 00	2.50
1.51E 01	1.14E 01	9.42E 00	8.16E 00	7.31E 00	6.18E 00	5.45E 00	4.40E 00	3.82E 00	3.16E 00	3.00
2.00E 01	1.48E 01	1.20E 01	1.02E 01	9.02E 00	7.47E 00	6.48E 00	5.11E 00	4.37E 00	3.54E 00	3.50
2.59E 01	1.88E 01	1.49E 01	1.25E 01	1.09E 01	8.86E 00	7.59E 00	5.84E 00	4.92E 00	3.93E 00	4.00
3.28E 01	2.34E 01	1.81E 01	1.50E 01	1.30E 01	1.03E 01	8.75E 00	6.60E 00	5.49E 00	4.31E 00	4.50
4.08E 01	2.86E 01	2.18E 01	1.78E 01	1.52E 01	1.19E 01	9.98E 00	7.38E 00	6.07E 00	4.71E 00	5.00
6.04E 01	4.11E 01	3.02E 01	2.40E 01	2.02E 01	1.54E 01	1.26E 01	9.04E 00	7.28E 00	5.51E 00	6.00
8.53E 01	5.65E 01	4.02E 01	3.13E 01	2.59E 01	1.93E 01	1.55E 01	1.08E 01	8.53E 00	6.32E 00	7.00
1.16E 02	7.51E 01	5.19E 01	3.96E 01	3.23E 01	2.35E 01	1.87E 01	1.26E 01	9.82E 00	7.14E 00	8.00
1.54E 02	9.73E 01	6.54E 01	4.90E 01	3.95E 01	2.82E 01	2.20E 01	1.45E 01	1.11E 01	7.97E 00	9.00
1.99E 02	1.23E 02	8.07E 01	5.96E 01	4.74E 01	3.33E 01	2.56E 01	1.65E 01	1.25E 01	8.80E 00	10.00
2.53E 02	1.54E 02	9.81E 01	7.13E 01	5.61E 01	3.87E 01	2.94E 01	1.86E 01	1.39E 01	9.63E 00	11.00
3.17E 02	1.88E 02	1.17E 02	8.41E 01	6.56E 01	4.45E 01	3.35E 01	2.07E 01	1.53E 01	1.05E 01	12.00
3.90E 02	2.28E 02	1.39E 02	9.82E 01	7.59E 01	5.06E 01	3.77E 01	2.29E 01	1.67E 01	1.13E 01	13.00
4.75E 02	2.73E 02	1.63E 02	1.14E 02	8.69E 01	5.71E 01	4.21E 01	2.52E 01	1.82E 01	1.22E 01	14.00
5.72E 02	3.24E 02	1.89E 02	1.30E 02	9.87E 01	6.40E 01	4.67E 01	2.75E 01	1.97E 01	1.31E 01	15.00
6.83E 02	3.80E 02	2.17E 02	1.48E 02	1.11E 02	7.12E 01	5.14E 01	2.99E 01	2.12E 01	1.40E 01	16.00
8.09E 02	4.43E 02	2.48E 02	1.67E 02	1.25E 02	7.87E 01	5.64E 01	3.23E 01	2.27E 01	1.49E 01	17.00
9.51E 02	5.13E 02	2.81E 02	1.87E 02	1.39E 02	8.66E 01	6.15E 01	3.47E 01	2.42E 01	1.57E 01	18.00
1.11E 03	5.90E 02	3.17E 02	2.09E 02	1.54E 02	9.49E 01	6.68E 01	3.72E 01	2.57E 01	1.65E 01	19.00
1.29E 03	6.74E 02	3.56E 02	2.32E 02	1.70E 02	1.03E 02	7.23E 01	3.96E 01	2.72E 01	1.73E 01	20.00

we mean here the fraction  $\phi_{ph}(x)$  of energy emitted by a point isotropic source that is deposited in a sphere of radius  $x$  around the source in an unbounded homogeneous medium.

It is necessary to evaluate the ratio of integrals

$$\phi_{ph}(x) = \int_0^x 4\pi x'^2 R(x') dx' / \int_0^\infty 4\pi x'^2 R(x') dx'. \quad (7)$$

With the use of Equations 1 and 6, and carrying out the indicated integrations, one finds that

$$\phi_{ph}(x) = \frac{\mu_{en}}{\mu} \left[ f_0 - e^{-\mu x} \sum_{n=0}^{N+1} f_n (\mu x)^n \right], \quad (8)$$

where  $f_0 = 1 + \sum_{i=0}^N (i+1)! a_i$

and  $f_n = \left( \frac{1}{n!} \right) \sum_{i=n-1}^N (i+1)! a_i \quad (1 \leq n \leq N+1)$ ,

and where the  $a_i$ 's are to be obtained from Table 4. The absorbed fractions for water have been calculated for a large set of sphere radii, and by interpolation those radii have been determined for which the absorbed fractions assumed values of 0.05, 0.10, ..., 0.95. These results are given in Table 8.

## ACKNOWLEDGMENT

The work of the MIRD Committee is supported by U. S. Public Health Service Research Grant RH 00416, National Center for Radiological Health. The work in this pamphlet was supported in part by the Defense Atomic Support Agency and by the Office of Civil Defense.

(For References see page 24.)

**TABLE 4. COEFFICIENTS  $a_n$  OF POLYNOMIAL REPRESENTATION OF ENERGY-ABSORPTION BUILDUP FACTORS FOR WATER\***

n	0.015 MeV	0.02 MeV	0.03 MeV	0.04 MeV	0.05 MeV
0	-3.1187801E-01	6.7244312E-01	1.6049021E 00	2.3258914E 00	2.6015869E 00
1	1.7175846E-01	-3.2219814E-01	-3.7443278E-01	1.6755887E-01	8.7214986E-01
2	-6.5231289E-02	1.1910705E-01	1.3404206E-01	1.4082448E-02	-4.9803181E-02
3	1.4651157E-02	-2.6496792E-02	-2.9722587E-02	-6.8449897E-03	5.3230159E-03
4	1.9829754E-03	3.5705853E-03	4.0175878E-03	1.1886303E-03	-2.7896369E-04
5	-1.6495732E-04	-2.9632295E-04	-3.3447682E-04	-1.1062963E-04	7.1722051E-06
6	8.4250159E-06	1.5112543E-05	1.7100141E-05	6.0027697E-06	5.6428014E-08
7	-2.5562337E-07	-4.5809152E-07	-5.1928160E-07	-1.8892413E-07	-9.1977777E-09
8	4.2000887E-09	7.5217418E-09	8.5380989E-09	3.1797274E-09	2.2973861E-10
9	-2.8607554E-11	-5.1206664E-11	-5.8186664E-11	-2.2023831E-11	-1.9306663E-12

  

n	0.06 MeV	0.08 MeV	0.1 MeV	0.15 MeV	0.2 MeV
0	2.5636192E 00	2.2740654E 00	1.9944842E 00	1.6105426E 00	1.4156760E 00
1	1.3126100E 00	1.4591243E 00	1.2912893E 00	9.0767161E-01	7.2018676E-01
2	-1.2297447E-02	1.2343571E-01	1.7504154E-01	1.7453811E-01	1.4124504E-01
3	3.7005698E-03	-5.1514559E-03	-4.6931543E-03	-6.9137843E-03	-7.8670955E-03
4	-2.0809395E-04	7.4261826E-04	5.7474698E-04	8.3705211E-04	8.0505787E-04
5	1.3803488E-05	-4.4729504E-05	-1.6654647E-05	-4.6405745E-05	-4.3429452E-05
6	-7.0410798E-07	1.8657546E-06	9.3820773E-09	1.8814298E-06	1.6003787E-06
7	2.2711260E-08	-4.9674830E-08	1.7482306E-08	-5.0288247E-08	-3.8876780E-08
8	-3.9936147E-10	7.5787695E-10	-5.0704327E-10	7.7505308E-10	5.5534479E-10
9	2.8902429E-12	-4.9928964E-12	4.6485283E-12	-5.1355447E-12	-3.4904063E-12

  

n	0.3 MeV	0.4 MeV	0.5 MeV	0.6 MeV	0.8 MeV
0	1.1945598E 00	1.0772469E 00	9.9238222E-01	9.3207923E-01	8.4798975E-01
1	5.3740039E-01	4.6034966E-01	4.1718270E-01	3.8918860E-01	3.5189649E-01
2	9.4870113E-02	6.1001775E-02	3.3088575E-02	1.0862793E-02	-2.3850962E-02
3	-9.7034674E-03	-1.0744514E-02	-8.7369286E-03	-5.7619216E-03	1.0505992E-03
4	1.0374319E-03	1.3505373E-03	1.2759176E-03	1.0139396E-03	1.8556544E-04
5	-6.5212691E-05	-1.0114269E-04	-1.0550458E-04	-9.2681960E-05	-3.1717948E-05
6	2.5855268E-06	4.6452829E-06	5.203283E-06	4.8885317E-06	2.1309767E-06
7	-6.3331138E-08	-1.2825195E-07	-1.5124722E-07	-1.4935017E-07	-7.4522243E-08
8	8.7103041E-10	1.9452602E-09	2.3826137E-09	2.4448272E-09	1.3313360E-09
9	-5.1173023E-12	-1.2393454E-11	-1.5611191E-11	-1.6519539E-11	-9.5638605E-12

  

n	1.0 MeV	1.5 MeV
0	7.9276531E-01	7.1705743E-01
1	3.2093134E-01	2.4982775E-01
2	-4.5320471E-02	-6.3825660E-02
3	6.4806312E-03	1.2768833E-02
4	-5.8020372E-04	-1.5955824E-03
5	3.1937914E-05	1.2447039E-04
6	-1.0606565E-06	-6.0326459E-06
7	1.9962554E-08	1.7536365E-07
8	-1.8192761E-10	-2.7817859E-09
9	4.9467623E-13	1.8403903E-11

  

n	2.0 MeV	3.0 MeV
0	6.7488407E-01	3.0925391E-01
1	1.8814749E-01	1.0130699E-01
2	-6.0323813E-02	-4.1253766E-02
3	1.3251153E-02	9.9343531E-03
4	-1.7658312E-03	-1.3984767E-03
5	1.4458816E-04	1.1897410E-04
6	-7.2745224E-06	-6.1589190E-06
7	2.1774410E-07	1.8846267E-07
8	-3.5352635E-09	-3.1139299E-09
9	2.3830147E-11	2.1290227E-11

**TABLE 5. TERMS KEPT IN POLYNOMIAL IN EQ. 6\***

E(MeV)	$\mu x$					
	0.5	1	2	4	7	10
0.02	2	3	5	7	9	10
0.04	2	2	2	6	8	9
0.06	2	2	2	4	5	7
0.1	2	3	3	3	5	6
0.2	2	3	3	5	6	7
0.4	2	2	4	6	7	9
0.6	2	2	2	5	8	9
1	2	2	4	5	7	8
2	2	2	4	7	8	9

\* Those needed to obtain a buildup factor value differing no more than 2% from value obtained with a ten-term polynomial.

\* The digits following the symbol E indicate the powers of ten by which each number is to be multiplied.

**TABLE 6. SPECIFIC ABSORBED FRACTION  $\Phi_{ph}(x)$  FOR POINT-ISOTROPIC SOURCES IN WATER\***

x(cm)	Photon Energy, E(MeV)									
	0.015	0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.15	
0.1	9.16E+00	3.97E+00	1.21E+00	5.57E-01	3.44E-01	2.63E-01	2.13E-01	2.07E-01	2.22E-01	
0.2	2.04E+00	9.63E-01	3.07E-01	1.43E-01	8.87E-02	6.77E-02	5.45E-02	5.26E-02	5.61E-02	
0.4	4.00E-01	2.24E-01	7.84E-02	3.76E-02	2.35E-02	1.79E-02	1.42E-02	1.36E-02	1.43E-02	
0.6	1.37E-01	9.14E-02	3.53E-02	1.74E-02	1.10E-02	8.33E-03	6.56E-03	6.21E-03	6.45E-03	
0.8	5.90E-02	4.68E-02	1.99E-02	1.01E-02	6.44E-03	4.90E-03	3.83E-03	3.59E-03	3.68E-03	
1.0	2.87E-02	2.71E-02	1.27E-02	6.68E-03	4.29E-03	3.26E-03	2.54E-03	2.36E-03	2.39E-03	
1.5	6.36E-03	9.13E-03	5.50E-03	3.12E-03	2.06E-03	1.58E-03	1.22E-03	1.12E-03	1.10E-03	
2.0	1.77E-03	3.83E-03	2.94E-03	1.80E-03	1.23E-03	9.53E-04	7.31E-04	6.63E-04	6.40E-04	
2.5	5.58E-04	1.80E-03	1.76E-03	1.17E-03	8.21E-04	6.44E-04	4.95E-04	4.45E-04	4.22E-04	
3.0	1.90E-04	9.16E-04	1.13E-03	8.05E-04	5.87E-04	4.67E-04	3.60E-04	3.22E-04	3.00E-04	
4.0	2.53E-05	2.73E-04	5.25E-04	4.35E-04	3.39E-04	2.78E-04	2.18E-04	1.93E-04	1.76E-04	
5.0	3.79E-06	9.15E-05	2.72E-04	2.60E-04	2.16E-04	1.83E-04	1.46E-04	1.30E-04	1.16E-04	
6.0	6.16E-07	3.30E-05	1.50E-04	1.64E-04	1.46E-04	1.27E-04	1.04E-04	9.29E-05	8.23E-05	
8.0	1.90E-08	4.88E-06	5.15E-05	7.31E-05	7.32E-05	6.83E-05	5.91E-05	5.33E-05	4.70E-05	
10.0	6.31E-10	8.01E-07	1.95E-05	3.54E-05	3.98E-05	3.95E-05	3.62E-05	3.34E-05	2.96E-05	
12.0	2.38E-11	1.42E-07	7.84E-06	1.81E-05	2.27E-05	2.39E-05	2.33E-05	2.19E-05	1.98E-05	
14.0		2.67E-08	3.28E-06	9.51E-06	1.33E-05	1.49E-05	1.53E-05	1.48E-05	1.37E-05	
16.0		5.19E-09	1.41E-06	5.13E-06	7.94E-06	9.41E-06	1.03E-05	1.02E-05	9.68E-06	
18.0		1.02E-09	6.18E-07	2.81E-06	4.81E-06	6.03E-06	7.00E-06	7.16E-06	6.96E-06	
20.0		2.03E-10	2.76E-07	1.56E-06	2.95E-06	3.91E-06	4.80E-06	5.05E-06	5.07E-06	
25.0		4.05E-12	3.88E-08	3.76E-07	8.99E-07	1.36E-06	1.92E-06	2.17E-06	2.36E-06	
30.0			5.80E-09	9.42E-08	2.83E-07	4.84E-07	7.82E-07	9.50E-07	1.13E-06	
35.0			8.99E-10	2.43E-08	9.09E-08	1.76E-07	3.24E-07	4.22E-07	5.49E-07	
40.0			1.43E-10	6.40E-09	2.97E-08	6.46E-08	1.35E-07	1.88E-07	2.69E-07	

  

x(cm)	Photon Energy, E(MeV)									
	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00	
0.1	2.38E-01	2.54E-01	2.61E-01	2.63E-01	2.62E-01	2.55E-01	2.47E-01	2.26E-01	2.09E-01	
0.2	5.97E-02	6.38E-02	6.54E-02	6.58E-02	6.54E-02	6.37E-02	6.17E-02	5.65E-02	5.22E-02	
0.4	1.51E-02	1.60E-02	1.64E-02	1.65E-02	1.63E-02	1.59E-02	1.54E-02	1.41E-02	1.30E-02	
0.6	6.78E-03	7.14E-03	7.28E-03	7.31E-03	7.25E-03	7.04E-03	6.81E-03	6.24E-03	5.76E-03	
0.8	3.85E-03	4.03E-03	4.10E-03	4.11E-03	4.07E-03	3.95E-03	3.82E-03	3.50E-03	3.23E-03	
1.0	2.49E-03	2.59E-03	2.63E-03	2.63E-03	2.60E-03	2.52E-03	2.44E-03	2.23E-03	2.06E-03	
1.5	1.13E-03	1.16E-03	1.17E-03	1.17E-03	1.15E-03	1.11E-03	1.08E-03	9.84E-04	9.08E-04	
2.0	6.49E-04	6.58E-04	6.60E-04	6.55E-04	6.45E-04	6.23E-04	6.01E-04	5.49E-04	5.06E-04	
2.5	4.23E-04	4.24E-04	4.23E-04	4.19E-04	4.11E-04	3.96E-04	3.82E-04	3.48E-04	3.21E-04	
3.0	2.98E-04	2.96E-04	2.94E-04	2.90E-04	2.84E-04	2.73E-04	2.63E-04	2.40E-04	2.21E-04	
4.0	1.72E-04	1.68E-04	1.65E-04	1.62E-04	1.58E-04	1.52E-04	1.46E-04	1.33E-04	1.22E-04	
5.0	1.12E-04	1.08E-04	1.05E-04	1.03E-04	1.00E-04	9.56E-05	9.17E-05	8.34E-05	7.70E-05	
6.0	7.86E-05	7.46E-05	7.24E-05	7.05E-05	6.86E-05	6.53E-05	6.26E-05	5.69E-05	5.25E-05	
8.0	4.43E-05	4.13E-05	3.98E-05	3.85E-05	3.74E-05	3.55E-05	3.39E-05	3.08E-05	2.85E-05	
10.0	2.78E-05	2.57E-05	2.46E-05	2.38E-05	2.30E-05	2.18E-05	2.08E-05	1.89E-05	1.75E-05	
12.0	1.86E-05	1.71E-05	1.63E-05	1.58E-05	1.53E-05	1.45E-05	1.38E-05	1.26E-05	1.17E-05	
14.0	1.29E-05	1.19E-05	1.14E-05	1.10E-05	1.06E-05	1.01E-05	9.68E-06	8.85E-06	8.24E-06	
16.0	9.23E-06	8.53E-06	8.18E-06	7.92E-06	7.69E-06	7.32E-06	7.03E-06	6.46E-06	6.03E-06	
18.0	6.71E-06	6.25E-06	6.03E-06	5.86E-06	5.70E-06	5.45E-06	5.25E-06	4.85E-06	4.55E-06	
20.0	4.94E-06	4.65E-06	4.52E-06	4.41E-06	4.30E-06	4.14E-06	4.00E-06	3.73E-06	3.52E-06	
25.0	2.39E-06	2.33E-06	2.31E-06	2.29E-06	2.26E-06	2.22E-06	2.17E-06	2.07E-06	1.98E-06	
30.0	1.20E-06	1.22E-06	1.24E-06	1.25E-06	1.26E-06	1.26E-06	1.26E-06	1.23E-06	1.20E-06	
35.0	6.08E-07	6.51E-07	6.85E-07	7.09E-07	7.24E-07	7.44E-07	7.56E-07	7.67E-07	7.63E-07	
40.0	3.13E-07	3.54E-07	3.85E-07	4.09E-07	4.26E-07	4.51E-07	4.68E-07	4.92E-07	5.02E-07	

\* The corresponding absorbed dose rate (rad/sec) for a source emitting 1 photon per second is  $kE\Phi_{ph}(x)$ , where  $k = 1.60 \times 10^{-8}$  g-rad/MeV and E is the source energy in MeV. The digits following the symbol E indicate the powers of ten by which each number is to be multiplied.

TABLE 7. RATIO OF ABSORBED DOSE RATE IN MUSCLE TO THAT IN WATER\*

x(cm)	Photon Energy, E(MeV)								
	0.02	0.04	0.06	0.10	0.20	0.40	0.60	1.00	2.00
0.1	1.039	1.033	1.022	1.000	0.990	0.991	0.991	0.990	0.985
0.2	1.037	1.032	1.022	1.000	0.990	0.991	0.991	0.990	0.985
0.4	1.033	1.030	1.021	1.000	0.990	0.991	0.991	0.990	0.985
0.6	1.028	1.029	1.021	1.000	0.990	0.991	0.991	0.991	0.985
0.8	1.024	1.027	1.020	1.000	0.990	0.991	0.991	0.991	0.985
1.0	1.019	1.026	1.020	1.000	0.990	0.991	0.991	0.991	0.985
1.5	1.008	1.022	1.018	1.001	0.990	0.991	0.991	0.991	0.985
2.0	0.997	1.019	1.017	1.001	0.990	0.991	0.991	0.991	0.985
2.5	0.986	1.015	1.015	1.000	0.991	0.992	0.991	0.991	0.986
3.0	0.975	1.012	1.014	1.000	0.991	0.992	0.991	0.991	0.986
4.0	0.956	1.006	1.011	1.000	0.992	0.992	0.992	0.992	0.986
5.0	0.936	1.001	1.008	0.999	0.992	0.993	0.992	0.992	0.986
6.0	0.917	0.996	1.005	0.999	0.993	0.994	0.993	0.992	0.987
8.0	0.880	0.987	1.000	0.997	0.994	0.995	0.993	0.993	0.987
10.0	0.845	0.979	0.996	0.996	0.995	0.996	0.994	0.994	0.988
12.0	0.814	0.972	0.993	0.995	0.996	0.998	0.996	0.995	0.989
14.0	0.783	0.966	0.990	0.994	0.997	0.999	0.997	0.996	0.989
16.0	0.752	0.960	0.987	0.993	0.998	1.001	0.998	0.997	0.990
18.0	0.720	0.954	0.984	0.992	0.999	1.003	0.999	0.998	0.991
20.0	0.690	0.949	0.982	0.992	1.000	1.004	1.000	0.999	0.992
25.0	0.644	0.936	0.978	0.991	1.002	1.009	1.004	1.002	0.993
30.0		0.925	0.974	0.990	1.005	1.013	1.008	1.005	0.995
35.0		0.915	0.972	0.991	1.009	1.018	1.011	1.008	0.997
40.0		0.906	0.970	0.991	1.013	1.023	1.015	1.011	0.999

\* At various distances from point isotropic sources. Muscle is assumed to have unit density.

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TABLE 8. RADIUS OF SPHERE FOR  $\phi_{ph}(x)^*$ 

	Photon Energy, E(MeV)								
	0.015	0.02	0.03	0.04	0.05	0.06	0.08	0.1	0.15
$\phi_{ph}(x)$	Radius of Sphere, cm								
0.05	4.00E-02	9.84E-02	3.26E-01	6.74E-01	1.04E 00	1.32E 00	1.63E 00	1.72E 00	1.68E 00
0.10	8.18E-02	2.00E-01	6.41E-01	1.27E 00	1.91E 00	2.40E 00	2.96E 00	3.16E 00	3.20E 00
0.15	1.26E-01	3.04E-01	9.52E-01	1.84E 00	2.70E 00	3.36E 00	4.14E 00	4.47E 00	4.62E 00
0.20	1.72E-01	4.13E-01	1.27E 00	2.39E 00	3.45E 00	4.27E 00	5.25E 00	5.69E 00	5.98E 00
0.25	2.20E-01	5.27E-01	1.58E 00	2.94E 00	4.19E 00	5.15E 00	6.32E 00	6.88E 00	7.32E 00
0.30	2.72E-01	6.47E-01	1.91E 00	3.49E 00	4.93E 00	6.03E 00	7.38E 00	8.05E 00	8.64E 00
0.35	3.27E-01	7.73E-01	2.25E 00	4.06E 00	5.68E 00	6.91E 00	8.44E 00	9.22E 00	9.98E 00
0.40	3.86E-01	9.08E-01	2.61E 00	4.65E 00	6.44E 00	7.81E 00	9.51E 00	1.04E 01	1.13E 01
0.45	4.50E-01	1.05E 00	2.99E 00	5.26E 00	7.24E 00	8.73E 00	1.06E 01	1.16E 01	1.27E 01
0.50	5.19E-01	1.21E 00	3.39E 00	5.91E 00	8.07E 00	9.71E 00	1.18E 01	1.29E 01	1.42E 01
0.55	5.96E-01	1.38E 00	3.83E 00	6.60E 00	8.96E 00	1.07E 01	1.30E 01	1.42E 01	1.57E 01
0.60	6.81E-01	1.57E 00	4.31E 00	7.35E 00	9.91E 00	1.18E 01	1.43E 01	1.57E 01	1.74E 01
0.65	7.77E-01	1.79E 00	4.84E 00	8.18E 00	1.10E 01	1.30E 01	1.57E 01	1.72E 01	1.92E 01
0.70	8.87E-01	2.03E 00	5.45E 00	9.11E 00	1.21E 01	1.44E 01	1.73E 01	1.90E 01	2.11E 01
0.75	1.02E 00	2.32E 00	6.15E 00	1.02E 01	1.35E 01	1.59E 01	1.91E 01	2.09E 01	2.34E 01
0.80	1.18E 00	2.67E 00	6.99E 00	1.14E 01	1.50E 01	1.77E 01	2.12E 01	2.33E 01	2.60E 01
0.85	1.38E 00	3.11E 00	8.05E 00	1.30E 01	1.70E 01	2.00E 01	2.38E 01	2.61E 01	2.93E 01
0.90	1.67E 00	3.74E 00	9.51E 00	1.52E 01	1.97E 01	2.30E 01	2.73E 01	3.00E 01	3.37E 01
0.95	2.15E 00	4.79E 00	1.20E 01	1.88E 01	2.41E 01	2.80E 01	3.31E 01	3.62E 01	4.08E 01

  

	Photon Energy, E(MeV)								
	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.5	2.0
$\phi_{ph}(x)$	Radius of Sphere, cm								
1.62E 00	1.53E 00	1.51E 00	1.51E 00	1.52E 00	1.57E 00	1.62E 00	1.78E 00	1.93E 00	0.05
3.13E 00	3.02E 00	3.01E 00	3.03E 00	3.07E 00	3.17E 00	3.29E 00	3.61E 00	3.92E 00	0.10
4.59E 00	4.49E 00	4.51E 00	4.56E 00	4.63E 00	4.81E 00	5.00E 00	5.50E 00	5.98E 00	0.15
6.01E 00	5.96E 00	6.02E 00	6.11E 00	6.23E 00	6.49E 00	6.76E 00	7.46E 00	8.12E 00	0.20
7.41E 00	7.43E 00	7.55E 00	7.69E 00	7.86E 00	8.22E 00	8.58E 00	9.49E 00	1.03E 01	0.25
8.82E 00	8.92E 00	9.11E 00	9.32E 00	9.54E 00	1.00E 01	1.05E 01	1.16E 01	1.27E 01	0.30
1.02E 01	1.05E 01	1.07E 01	1.10E 01	1.13E 01	1.19E 01	1.24E 01	1.38E 01	1.51E 01	0.35
1.17E 01	1.20E 01	1.24E 01	1.27E 01	1.31E 01	1.38E 01	1.45E 01	1.62E 01	1.77E 01	0.40
1.32E 01	1.37E 01	1.41E 01	1.46E 01	1.50E 01	1.59E 01	1.67E 01	1.87E 01	2.05E 01	0.45
1.48E 01	1.54E 01	1.60E 01	1.65E 01	1.70E 01	1.80E 01	1.90E 01	2.13E 01	2.35E 01	0.50
1.64E 01	1.72E 01	1.79E 01	1.86E 01	1.92E 01	2.04E 01	2.15E 01	2.42E 01	2.67E 01	0.55
1.82E 01	1.92E 01	2.00E 01	2.08E 01	2.15E 01	2.29E 01	2.42E 01	2.73E 01	3.02E 01	0.60
2.02E 01	2.13E 01	2.23E 01	2.32E 01	2.41E 01	2.57E 01	2.72E 01	3.08E 01	3.41E 01	0.65
2.23E 01	2.37E 01	2.49E 01	2.59E 01	2.69E 01	2.88E 01	3.06E 01	3.47E 01	3.85E 01	0.70
2.47E 01	2.64E 01	2.78E 01	2.90E 01	3.02E 01	3.24E 01	3.45E 01	3.93E 01	4.36E 01	0.75
2.76E 01	2.96E 01	3.12E 01	3.27E 01	3.41E 01	3.67E 01	3.91E 01	4.47E 01	4.97E 01	0.80
3.12E 01	3.35E 01	3.55E 01	3.73E 01	3.90E 01	4.21E 01	4.49E 01	5.15E 01	5.74E 01	0.85
3.59E 01	3.88E 01	4.13E 01	4.35E 01	4.55E 01	4.93E 01	5.28E 01	6.08E 01	6.80E 01	0.90
4.36E 01	4.75E 01	5.07E 01	5.36E 01	5.62E 01	6.12E 01	6.58E 01	7.62E 01	8.56E 01	0.95

\* The values of radii  $x$ (cm) of spherical volumes centered around point isotropic sources in which indicated fraction  $\phi_{ph}(x)$  of energy  $E$ (MeV) is deposited. The digits following the symbol  $E$  indicate the powers of ten by which each number is to be multiplied.