

DOSE FROM PHOTON EMITTERS DISTRIBUTED UNIFORMLY IN THE TOTAL BODY AS A FUNCTION OF AGE*

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Abstract

The dose rate from photon emitters distributed uniformly in the total body has been estimated for phantoms corresponding to ages 0 (newborn), 1, 5, 10, 15, and 20 (adult) years. Estimation is by the Monte Carlo technique, and the computer code uses phantoms obtained by transformations from the anthropomorphic phantom essentially as described in MIRD Pamphlet No. 5. Interest here is centered on the distribution of dose in the various organs which include active bone marrow and gonads. The dose rates near the surface and near the central axis are found to differ by approximately a factor of 2 for most energies. The calculation is for 6 monoenergetic sources of photons ranging from 20 keV to 2 MeV. The absorbed fraction of energy is found to vary approximately as $(\text{mass})^{1/3}$ power for photon energies above 100 keV.

In this paper we give specific absorbed fractions for photon emitters distributed uniformly in the total body, i.e., the distribution is directly proportional to the density of the parts of the body. The total body becomes the source S, and any organ, including the total body, is a target organ T. The dose rate in the target organ is proportional to the specific absorbed fraction (SAF) or Φ , which is defined as that fraction of the energy emitted which is absorbed per gram of the target organ. Thus

$$\Phi(T \leftarrow S) = \frac{\text{Energy absorbed in T}}{(\text{Energy released in S}) (\text{Mass of T in g})}$$

Estimates of the specific absorbed fractions were obtained by the Monte Carlo technique for a modified phantom basically similar to the anthropomorphic phantom described in MIRD Pamphlet No. 5.¹ These modifications are mentioned in the report ORNL-4903.² The calculation was for six monoenergetic sources of photons ranging from 20 keV to 2 MeV with a sample of 60,000 photons used for each monoenergetic source. The SAF and the dose rate were estimated for phantoms corresponding to ages 0 (newborn), 1, 5, 10, 15, and 20 (adult) years. The phantoms representing the various ages were obtained by transformation from the adult anthropomorphic phantom as described by Snyder and Cook.³ The adult phantom was reduced by scale factors selected separately for the head, trunk, and leg sections of the

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phantom (Fig. 1). All organs and tissues within these sections were reduced by the scale factors for that particular section. Thus the loci of the organs which are nonintersecting in one phantom are nonintersecting in the other phantom.

When the source is the total body, the same general relationship for the SAF of the target organs seems to hold as when the source organ and the target organ are the same.⁴ That is,

- (1) The SAF decreases as age increases. The newborn has the highest SAF, apparently due to the effect of the inverse square law.
- (2) The ratios of the SAF at a specific age to SAF for the adult decrease as the age increases. For instance, the SAF ratio for red bone marrow of the newborn to the adult for 0.020 MeV differed by a factor of 20, while the same factor for the 5-year-old to the adult was 4.
- (3) The SAF decreases as energy increases.

For a photon source distributed uniformly over the total body, the SAF (and hence the dose rate) to a target organ near the surface of the phantom is found to differ by approximately a factor of 2 from the SAF to a target organ near the central axis of the phantom. The trunk skin was selected as the surface organ, and the five subregions located along the central axis of the five tiers in the trunk of the appropriate age phantom were selected to simulate a central axis organ and the results are shown in Fig. 2. The ratio of Φ averaged over the central axis subregions to the surface organ (trunk skin) is approximately 2 : 1. This ratio of a central axis organ SAF to the SAF of other organs will vary with the position of the organ relative to the central axis. In Fig. 2 this correlation is shown for the ovaries and testes for the 10-year-old phantom. The ovaries, which are positioned near the central axis, show a nearly 1 : 1 ratio with the central axis subregions of the trunk; while the testes, a more nearly surface organ, show a 1 : 1.5 ratio. Moreover, for larger organs, such as the liver, which extend from the center out toward the periphery of the body, the dose to that portion of the organ which is nearest the central axis will be somewhat higher than that part which lies near the surface.

Only data with a coefficient of variation < 30% were used in the statistical evaluations. In some instances, such as the ovaries and testes, the coefficient of variation for the calculated SAF estimates was > 30%. In the case of the testes, for more reliable data, the SAF estimates for the genitalia were used in Fig. 2. For the ovaries, a technique described by Poston and Snyder,⁵ in which the SAF estimates to the appropriate subregion or subregions of the phantom in which the organs lie were used; and it is believed these give a more reliable estimate of the SAF for these organs than do the Monte Carlo results.

The specific absorbed fraction (SAF) and coefficient of variation for some of the organs within the heterogeneous phantoms for ages 0 (newborn) and 5 years are shown in Tables 1 and 2 of this report. The data for the phantoms corresponding to other ages are given in ORNL-4903 but are omitted here because of limitations on space. In cases where the coefficients of variation were consistently > 30%, the corresponding data from the appropriate geometrical subregion or subregions in the phantoms in which the organ was located were substituted. The values are distinguished by an asterisk in the table.

As previously reported,⁷ when the source is distributed uniformly within an organ, the absorbed fraction (AF) for the organ might be expected to vary with the cube root of the mass, i.e., $(AF) \propto M^{1/3}$ is proportional to $\mu_{ab} M^{1/3}$. In Figs. 3 and 4 the ratios of the AF to $\mu_{ab} M^{1/3}$ are plotted for various photon energies and organs. For energies of 0.100 MeV and higher, the ratio is found to be approximately a constant for all ages in the case of the liver

as well as for the total body. This behavior appears to hold also for other organs for which the Monte Carlo results are statistically significant, and thus the principle seems to be supported fairly well regardless of age. For lower energies, the rule does not appear to hold as might be expected from its derivation.

References

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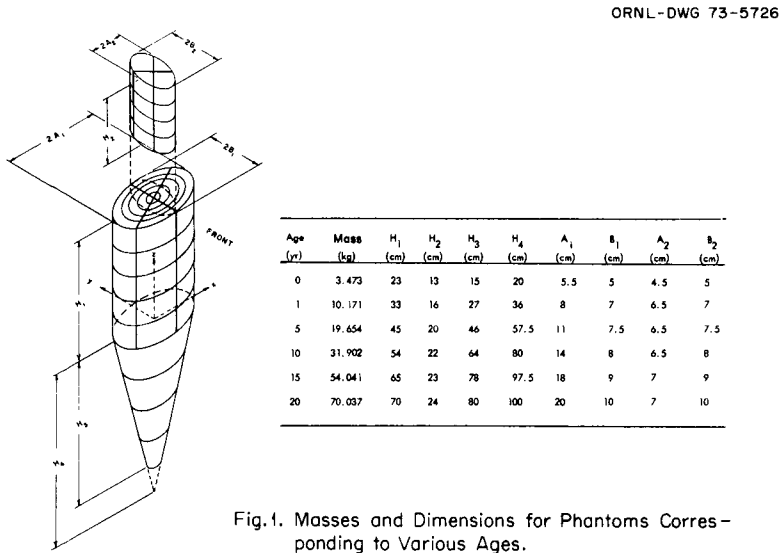
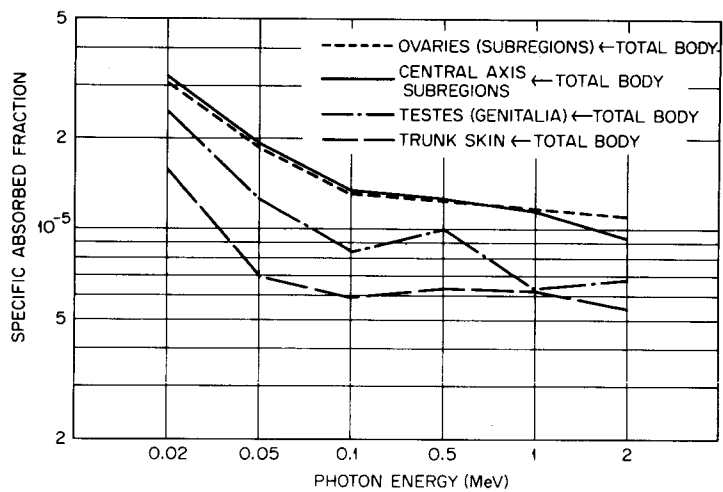
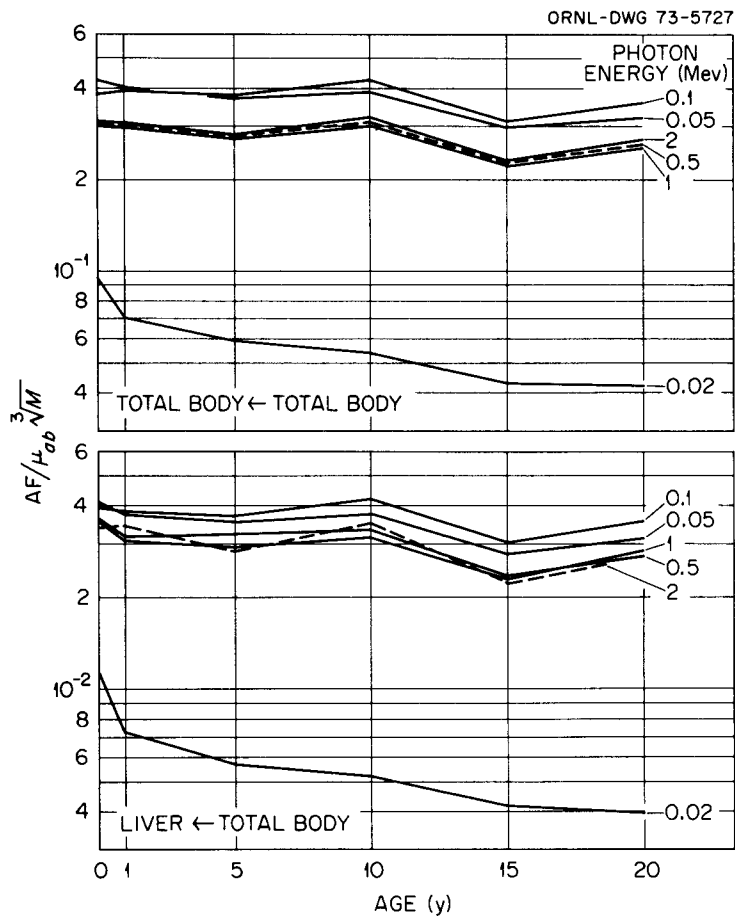


Fig.1. Masses and Dimensions for Phantoms Corresponding to Various Ages.



SPECIFIC ABSORBED FRACTION AS A FUNCTION OF PHOTON ENERGY AND ORGAN LOCATION FOR 10-YR-OLD.

FIG. 2.



Figs. 3. and 4. Absorbed Fractions in Total Body and Liver as Related to Mass as a Function of Photon Energy and Age.

Table I
SPECIFIC ABSORBED FRACTIONS AND COEFFICIENTS OF VARIATION (PER CENT)

	SOURCE IN TOTAL BODY						OF NEW BORN PHANTOM					
	ENERGY (MEV)											
	0.020		0.050		0.100		0.500		1.000		2.000	
	S.A.F.	C.V.	S.A.F.	C.V.	S.A.F.	C.V.	S.A.F.	C.V.	S.A.F.	C.V.	S.A.F.	C.V.
*ADRENALS	3.1E-04	2.3E 01	7.5E-05	2.6E 01	8.1E-05	2.3E 01	*8.5E-05	6.8E 00	*8.9E-05	7.7E 00	*7.4E-05	9.0E 00
*BLADDER WALL	3.4E-04	1.2E 01	9.8E-05	1.2E 01	5.6E-05	1.6E 01	7.6E-05	2.2E 01	5.2E-05	2.9E 01	*8.8E-05	1.1E 01
STOMACH WALL	2.6E-04	7.7E 00	9.3E-05	7.3E 00	5.6E-05	9.0E 00	5.9E-05	1.4E 01	5.3E-05	1.6E 01	6.5E-05	1.6E 01
SMALL INTESTINE	3.0E-04	3.0E 00	1.0E-04	3.1E 00	6.5E-05	3.5E 00	6.9E-05	4.8E 00	6.5E-05	5.5E 00	5.1E-05	6.5E 00
U.L.I. WALL	3.0E-04	6.2E 00	1.1E-04	5.8E 00	6.5E-05	6.9E 00	6.5E-05	1.1E 01	5.6E-05	1.3E 01	7.1E-05	1.3E 01
L.L.I. WALL	2.7E-04	7.4E 00	1.1E-04	6.5E 00	5.9E-05	8.5E 00	6.8E-05	1.2E 01	6.3E-05	1.4E 01	4.4E-05	1.8E 01
HEART	2.7E-04	4.2E 00	1.2E-04	3.8E 00	7.4E-05	4.3E 00	8.5E-05	5.7E 00	8.5E-05	6.4E 00	6.5E-05	7.7E 00
KIDNEYS	2.1E-04	6.8E 00	8.2E-05	5.9E 00	5.6E-05	6.8E 00	6.3E-05	9.4E 00	5.6E-05	1.1E 01	5.2E-05	1.3E 01
LIVER	2.9E-04	2.4E 00	9.3E-05	2.6E 00	5.4E-05	3.0E 00	6.2E-05	3.9E 00	5.8E-05	4.5E 00	4.6E-05	5.3E 00
LUNGS	3.0E-04	2.9E 00	9.5E-05	3.0E 00	5.2E-05	3.7E 00	6.3E-05	5.0E 00	5.2E-05	6.3E 00	4.5E-05	7.3E 00
RED MARROW	3.1E-04	1.4E 00	1.5E-04	1.5E 00	5.4E-05	2.0E 00	3.3E-05	3.1E 00	3.1E-05	3.6E 00	2.6E-05	4.1E 00
YELLOW MARROW	4.3E-04	1.0E 00	1.9E-04	1.2E 00	6.4E-05	1.6E 00	4.3E-05	2.5E 00	4.0E-05	2.8E 00	3.4E-05	3.3E 00
*OVARIES	*2.3E-04	5.7E 00	1.6E-04	2.4E 01	1.1E-04	2.7E 01	*5.2E-05	9.2E 00	*4.5E-05	1.1E 01	*3.7E-05	1.3E 01
PANCREAS	3.2E-04	1.2E 01	1.1E-04	1.0E 01	5.1E-05	1.5E 01	7.4E-05	1.8E 01	5.5E-05	2.5E 01	6.7E-05	2.5E 01
SKELETON	3.2E-04	8.0E-01	1.5E-04	9.6E-01	5.1E-05	1.3E 00	3.5E-05	1.9E 00	3.2E-05	2.2E 00	2.6E-05	2.6E 00
TOTAL SKIN	1.1E-04	2.6E 00	3.6E-05	2.5E 00	2.4E-05	3.1E 00	2.9E-05	4.2E 00	3.0E-05	4.6E 00	2.3E-05	5.7E 00
SPLEEN	2.7E-04	7.5E 00	9.5E-05	7.5E 00	5.1E-05	9.5E 00	5.9E-05	1.3E 01	4.1E-05	1.7E 01	3.4E-05	2.0E 01
*TESTES	3.4E-04	1.8E 01	7.2E-05	2.0E 01	4.3E-05	2.9E 01	*6.3E-05	1.5E 01	1.3E-04	2.7E 01	*4.8E-05	2.0E 01
*THYMUS	2.6E-04	2.0E 01	7.8E-05	2.0E 01	5.1E-05	2.4E 01	*6.5E-05	8.6E 00	*5.8E-05	9.9E 00	*5.6E-05	1.1E 01
*THYROID	*1.3E-05	7.9E 00	*1.3E-05	5.4E 00	*7.2E-06	6.1E 00	*1.0E-05	7.2E 00	*8.8E-06	8.5E 00	*6.9E-06	1.0E 01
UTERUS	2.4E-04	1.3E 01	9.3E-05	1.1E 01	6.9E-05	1.3E 01	8.1E-05	1.8E 01	6.1E-05	2.1E 01	4.1E-05	2.8E 01
TOTAL BODY	2.2E-04	2.2E-01	8.0E-05	4.9E-01	4.2E-05	6.0E-01	4.4E-05	6.9E-01	4.1E-05	7.8E-01	3.4E-05	9.2E-01

* S.A.F. to an appropriate subregion(s) is used instead of S.A.F. to the organ, because the coefficient of variation of the latter exceeded 30%.

Note: The digit following the symbol E indicates the power of ten by which each number is to be multiplied.

Table 2

SPECIFIC ABSORBED FRACTIONS AND COEFFICIENTS OF VARIATION (PER CENT)

	SOURCE IN TOTAL BODY						OF FIVE YEAR OLD PHANTOM					
	0.020		0.050		0.100		0.500		1.000		2.000	
	S.A.F.	C.V.	S.A.F.	C.V.	S.A.P.	C.V.	S.A.P.	C.V.	S.A.P.	C.V.	S.A.P.	C.V.
E N E R G Y (MEV)												
* ADRENALS	4.7E-05	2.3E 01	2.0E-05	1.8E 01	1.5E-05	2.2E 01	2.2E-05	2.8E 01	*1.7E-05	7.0E 00	*1.6E-05	7.9E 00
BLADDER WALL	4.7E-05	1.3E 01	2.8E-05	9.4E 00	1.6E-05	1.1E 01	1.5E-05	1.9E 01	2.2E-05	1.9E 01	1.3E-05	2.6E 01
STOMACH WALL	4.8E-05	7.7E 00	3.8E-05	5.9E 00	1.6E-05	6.9E 00	1.7E-05	1.0E 01	1.4E-05	1.2E 01	1.3E-05	1.4E 01
SMALL INTESTINE	5.2E-05	3.1E 00	3.0E-05	2.6E 00	1.9E-05	2.8E 00	1.8E-05	3.8E 00	1.8E-05	4.3E 00	1.4E-05	5.3E 00
U.L.I. WALL	4.7E-05	6.6E 00	2.7E-05	4.7E 00	1.8E-05	5.5E 00	1.8E-05	8.5E 00	2.1E-05	8.9E 00	1.4E-05	1.2E 01
L.L.I. WALL	5.2E-05	7.4E 00	2.8E-05	5.5E 00	1.7E-05	6.2E 00	1.8E-05	9.5E 00	2.0E-05	1.1E 01	1.4E-05	1.3E 01
HEART	5.2E-05	4.2E 00	2.4E-05	3.7E 00	1.7E-05	3.9E 00	1.6E-05	5.6E 00	1.5E-05	6.3E 00	1.3E-05	7.3E 00
KIDNEYS	4.9E-05	6.0E 00	2.1E-05	5.1E 00	1.6E-05	5.5E 00	1.7E-05	7.6E 00	1.4E-05	9.1E 00	1.1E-05	1.1E 01
LIVER	5.0E-05	2.4E 00	2.5E-05	2.4E 00	1.5E-05	2.6E 00	1.7E-05	3.1E 00	1.5E-05	3.6E 00	1.2E-05	4.4E 00
LUNGS	5.7E-05	2.8E 00	2.6E-05	2.4E 00	1.7E-05	2.7E 00	1.7E-05	4.0E 00	1.5E-05	4.8E 00	1.2E-05	5.5E 00
RED MARROW	5.9E-05	1.4E 00	4.8E-05	1.3E 00	2.1E-05	1.6E 00	1.2E-05	2.3E 00	1.1E-05	2.7E 00	9.2E-06	3.2E 00
YELLOW MARROW	6.9E-05	1.1E 00	4.8E-05	1.0E 00	1.9E-05	1.3E 00	1.2E-05	1.9E 00	1.1E-05	2.2E 00	9.2E-06	2.6E 00
* OVARIES	6.4E-05	2.8E 01	2.4E-05	2.2E 01	2.2E-05	2.2E 01	*1.7E-05	6.7E 00	*1.5E-05	7.9E 00	*1.3E-05	9.2E 00
PANCREAS	4.8E-05	1.3E 01	3.0E-05	8.6E 00	2.0E-05	1.0E 01	2.1E-05	1.4E 01	1.4E-05	2.0E 01	9.3E-06	2.6E 01
SKELFTON	5.7E-05	8.4E-01	4.3E-05	7.9E-01	1.8E-05	1.0E 00	1.1E-05	1.5E 00	1.0E-05	1.7E 00	8.5E-06	2.0E 00
TOTAL SKIN	2.3E-05	2.5E 00	9.1E-06	2.0E 00	6.7E-06	2.3E 00	8.5E-06	3.2E 00	7.7E-06	3.7E 00	6.7E-06	4.3E 00
SPLEEN	4.6E-05	8.0E 00	2.4E-05	6.2E 00	1.5E-05	6.9E 00	1.2E-05	1.1E 01	1.2E-05	1.3E 01	1.3E-05	1.3E 01
* TESTES	4.4E-05	1.8E 01	1.9E-05	1.5E 01	1.5E-05	1.6E 01	1.1E-05	2.6E 01	1.5E-05	2.5E 01	*1.2E-05	1.4E 01
THYMUS	5.9E-05	1.7E 01	3.2E-05	1.3E 01	1.4E-05	1.5E 01	1.6E-05	2.7E 01	2.1E-05	2.5E 01	3.1E-05	2.5E 01
* THYROID	1.4E-05	2.8E 01	9.9E-06	1.9E 01	4.3E-06	2.6E 01	*3.2E-06	7.0E 00	*2.6E-06	8.2E 00	*2.2E-06	9.9E 00
UTERUS	6.3E-05	1.1E 01	3.2E-05	8.4E 00	2.0E-05	8.9E 00	1.6E-05	1.5E 01	1.8E-05	1.7E 01	1.3E-05	2.1E 01
TOTAL BODY	4.3E-05	1.7E-01	2.2E-05	3.7E-01	1.3E-05	4.7E-01	1.3E-05	5.2E-01	1.2E-05	5.8E-01	1.0E-05	6.9E-01

* S.A.F.to an appropriate subregion(s) is used instead of S.A.F.to the organ, because the coefficient of variation of the latter exceeded 30%.

Note: The digit following the symbol E indicates the power of ten by which each number is to be multiplied.