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# ESTIMATION OF INTERNAL RADIATION DOSE FOR VARIOUS PHYSIQUES USING MIRD ADULT ABSORBED FRACTIONS

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Absorbed fractions of the Medical Internal Radiation Dose Committee (MIRD) have been the most useful for estimating an internal absorbed dose recieved from an administration of a radiopharmaceutical agent (SNYDER et coll. 1969). Recent publication of the absorbed dose for a number of radionuclides have made a practical dose calculation considerably convenient (SNYDER et coll. 1974, 1975). The absorbed fraction (AF), $\phi(T \leftarrow S)$ is defined as a ratio of energy absorbed in a target organ T to energy released in a source organ S. The specific absorbed fraction SAF, $\Phi(T \leftarrow S)$ is defined as $\phi(T \leftarrow S)$/(mass of T) (LOEVINGER et coll. 1968). Present publications of AF are mainly valid for the adult European and American standard man (adult phantom). SNYDER and his collaborators, Oak Ridge National Laboratry (ORNL), have attemped preliminary estimations of the age-dependences of AF and SAF by designing smaller mathematical phantoms (SNYDER & COOK 1971, SNYDER & FORD 1973, HILYER et coll. 1972, 1973, HWANG et coll. 1976 and JONES et coll. 1976).

The application of the MIRD adult AF to Japanese physiques has been investigated. Previously a simple transformation method was found which gives AF corresponding to an individual from the MIRD adult AF, and examined applicability of it by experiment (YAMAGUCHI et coll. 1975). The old transformation method is summarized as follows: (1) It consists of two parts, transformation of the target

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organ mass, and of the distance between S and T. The former is represented by ratio of the target organ mass for the actual individual and for the standard man. The latter was given by approximating the variation of SAF with distance in the human body with the traditional exponential form and by introducing two parameters, the effective distance and the scale factor. The effective distance characterizes a distance between S and T; it was approximated with the distance between the centres of mass of S and T. The scale factor characterizes a change in physique from MIRD phantom to an individual, it was approximated with a ratio of their trunk lengths. Moreover the energy dependence of the effective absorption coefficient was considered to reduce the error due to the approximation of the exponential distribution for photon energies from 0.1 to 0.5 MeV. The method does not consider the cases for photon energies below 0.1 MeV. (2) It does not discriminate the case where T is equal to S, from the case where T is not equal to S. (3) It does not take into account the case where target organ is the skeleton.

The present report deals with a new method for estimation of SAF for young persons.

## Transformation method

AF $\phi'(T' \leftarrow S')$ and SAF $\Phi'(T' \leftarrow S')$ of an individual are obtained from the corresponding MIRD adult AF $\phi(T \leftarrow S)$ and SAF $\Phi(T \leftarrow S)$ by the following equations:

$$\phi'(T' \leftarrow S') = S_m \cdot S_\varepsilon(Xg) \cdot \phi(T \leftarrow S), \quad (1)$$

$$\Phi'(T' \leftarrow S') = S_\varepsilon(Xg) \cdot \Phi(T \leftarrow S), \quad (2)$$

$$S_m = m'_T / m_T, \quad (3)$$

$$S_\varepsilon(Xg) = \overline{\Phi'(X')} / \overline{\Phi(X)}, \quad (4)$$

$$\cong f(\varepsilon \cdot Xg)/f(Xg), \quad (5)$$

where $S_m$ is a scale factor concerning to a change in mass of T from $m_T$ to $m'_T$ and $S_\varepsilon(Xg)$ is a transformation factor for the SAF when the adult phantom is transfigured to a corresponding phantom of the individual by scale factors selected separately for the head section, trunk section and leg section of the adult phantom (SNYDER et coll. 1971). Considering the importance of the trunk section, a scale factor of the trunk section is used and denoted $\varepsilon$. From the definition of SAF, $S_\varepsilon(Xg)$ is a ratio of two mean values $\overline{\Phi'(X')}$ and $\overline{\Phi(X)}$ of the point specific absorbed fraction $\Phi(X)$, which are defined in the individual and the adult phantom, respectively. $\overline{\Phi(X)}$ is the mean value of the point specific absorbed fraction for all pairs of points in S and T, and $\overline{\Phi'(X')}$ is one for all pairs of points in S′ and T′. The method is based on the assumption that $\overline{\Phi(X)}$ can be expressed as a function f(Xg), where the effective distance Xg is defined for every S–T pair in the adult phantom. In the

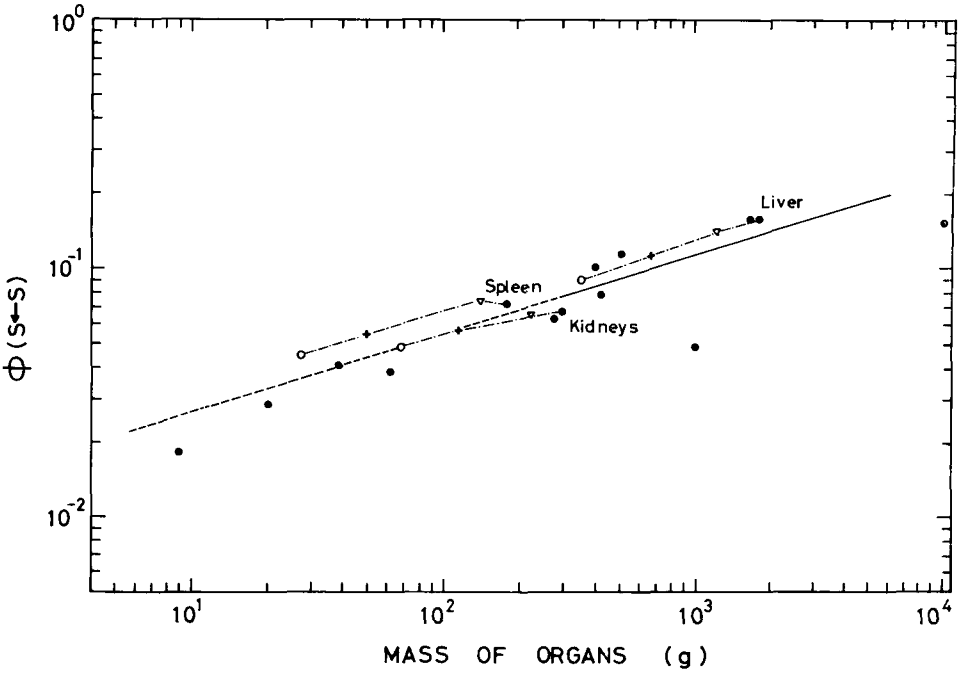



Fig. 1. Absorbed fractions for T being equal to S. Symbols ● are absorbed fractions estimated by an interpolation of MIRD adult absorbed fractions. Symbols ▽, + and ○ are absorbed fractions for 15-, 5- and 1-year old children which were given by the Monte Carlo method (Hwang et coll. 1976, Jones et coll. 1976). Solid line (——) shows absorbed fractions for the flat ellipsoids (Brownell et coll. 1968). Broken line (–––) shows an extrapolation of the solid line. Photon energy is 0.14 MeV.

following paragraphs, f(X) is classified into two groups—T is equal to or different from S— and the method of obtaining $S_\varepsilon(Xg)$ for each case is discussed.

*For the case where T is equal to S.* Brownell et coll. (1968) calculated AF for uniform distribution of activity in spheres, thick ellipsoids (the principal axes are the ratio of 1/1.5/2), and flat ellipsoids (1/2/4); the masses were from 0.3 to 6 kg. They pointed out that those AF for a given mass are a weak function of the target shape. Furthermore, those AF can be expressed well by the following equation:

$$\phi(S \leftarrow S) = p \cdot (m_S)^q \qquad (6)$$

where p and q are depending on photon energy, $m_S$ is the mass of S. The MIRD adult AF for self-absorption of unit density organ scatters closely along the curve given by eq. (6), although those organs have various shapes and different situations in the body. Moreover, AF for younger ages change along the curve as seen in Fig. 1. From these facts, it can be inferred that the adult AF would change along the curve when the adult phantom is reduced by scale factors, and that characteristics

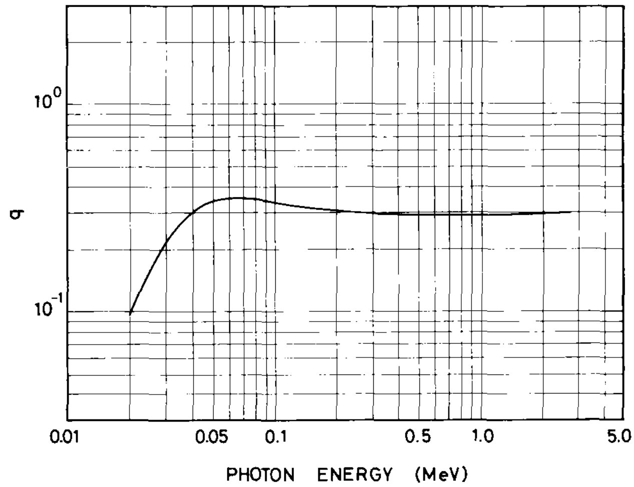



Fig. 2. Values of parameter q. Absorbed fraction $\phi(S \leftarrow S)$ of the flat ellipsoids are expressed by the equation; $\phi(S \leftarrow S) = p \cdot (m_S)^q \cdot m_S$ is the mass of the ellipsoids from 0.3 kg to 6 kg.

of AF (from shape, density and distance from the surface of the body) would be kept to some extent, if the adult AF changes on that curve parallel to the curve given by eq. (6). Therefore, f(X) is given from eq. (6) as follows:

$$f(X) = p \cdot (m_S)^{q-1}, \tag{7}$$

hence, the transformation factor is given from eqs (5) and (7),

$$S_\varepsilon(Xg) = (m_S'/m_S)^{q-1}, \tag{8}$$

$$= \varepsilon^{3(q-1)}, \tag{9}$$

where

$$\varepsilon^3 = m_S'/m_S. \tag{10}$$

The estimate of SAF for the individual is given as follows:

$$\Phi'(S' \leftarrow S') = \varepsilon^{3(q-1)} \cdot \Phi(S \leftarrow S). \tag{11}$$

The value of $\varepsilon$ is discussed in a later section (scale factors). The values of q for the flat ellipsoids are used (Fig. 2). These values are also assumed to be applicable to the lungs.

*For the case where T is different from S.* The SAF calculated on the basis of the Monte Carlo method and those given by the buildup method using the same adult phantom agree fairly well (SNYDER et coll. 1973). The buildup method used the point isotropic specific absorbed fraction $\Phi_{ph}(X)$, which is calculated for a point source in an infinite medium of water (Berger 1969). This suggests that $\Phi_{ph}(X)$ can be adopted as f(X), and that the transformation factor is given as follows:

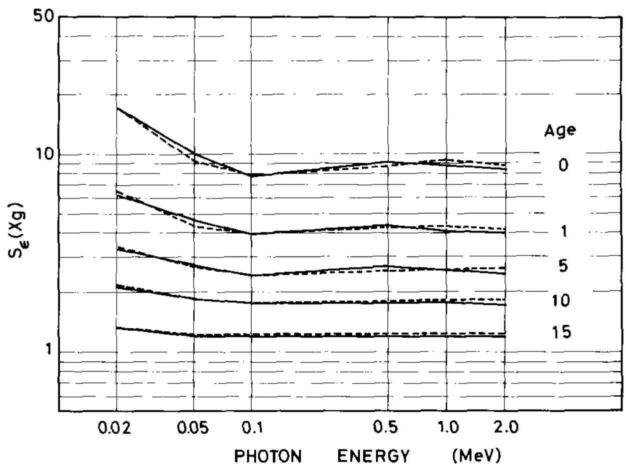



Fig. 3. Transformation estimates of $S_\varepsilon(Xg)$ compared with Monte Carlo estimates (Snyder et coll. 1972). Source and target organ is the total body. —— Monte Carlo estimates, --- transformation estimates.

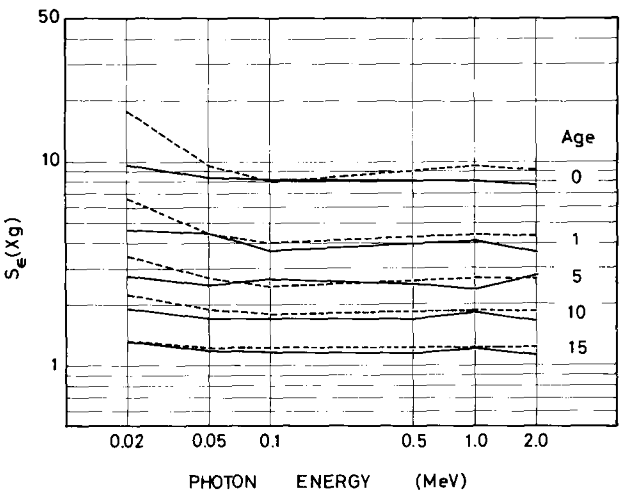



Fig. 4. Transformation estimates of $S_\varepsilon(Xg)$ compared with Monte Carlo estimates (Snyder et coll. 1973). Source and target organ is the ovaries. —— Monte Carlo estimates, --- transformation estimates.

(1) The dose effective distance Xg is determined from the MIRD adult SAF $\Phi(T \leftarrow S)$ by using the graph of $\Phi_{ph}(X)$ as

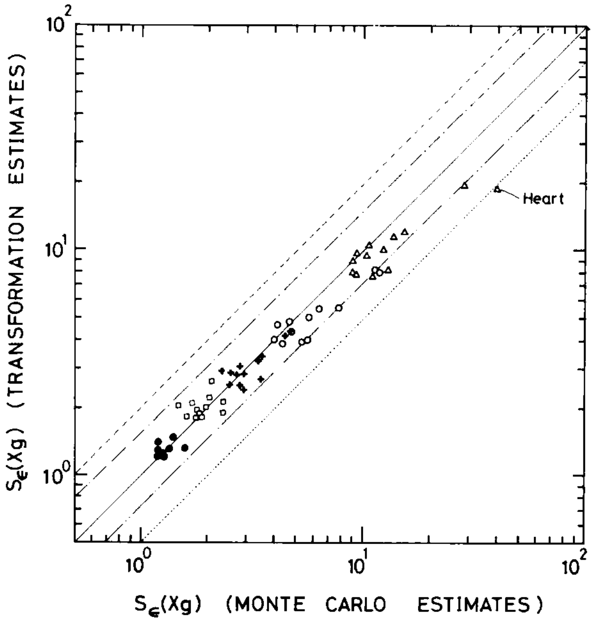
$$\Phi_{ph}(Xg) = \Phi(T \leftarrow S), \tag{12}$$

(2) $\Phi_{ph}(\varepsilon \cdot Xg)$ is read on the same graph, that is, the $S_\varepsilon(Xg)$ becomes

$$S_\varepsilon(Xg) = \Phi_{ph}(\varepsilon \cdot Xg)/\Phi_{ph}(Xg), \tag{13}$$

the SAF for the individual is obtained by

$$\Phi'(T' \leftarrow S') = \Phi_{ph}(\varepsilon \cdot Xg). \tag{14}$$

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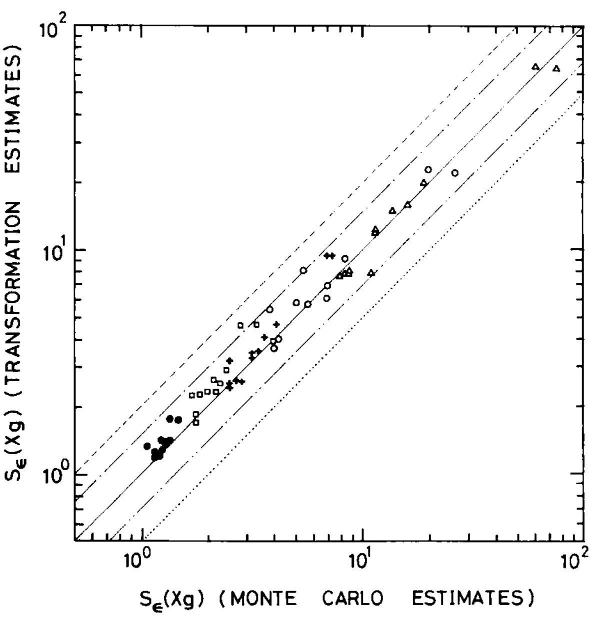


b

Fig. 5. Transformation estimates of $S_\varepsilon(Xg)$ compared with Monte Carlo estimates (Snyder et coll. 1973). Source organ is the ovaries, target organs of interest are not these shown, but these are the cases where a comparison is possible. Symbols ●, □, +, ○ and △ show $S_\varepsilon(Xg)$ corresponding to 15-, 10-, 5-, 1- and 0-year old phantoms respectively. $R = S_\varepsilon(Xg)_1/S_\varepsilon(Xg)_2$, where $S_\varepsilon(Xg)_1$ and $S_\varepsilon(Xg)_2$ are the two corresponding estimates. --- $R=2$, —·— $R=1.5$, —— $R=1$, —··— $R=0.7$, ······ $R=0.5$. Photon energies are (a) 1.0 (b) 0.1 and (c) 0.02 MeV respectively.

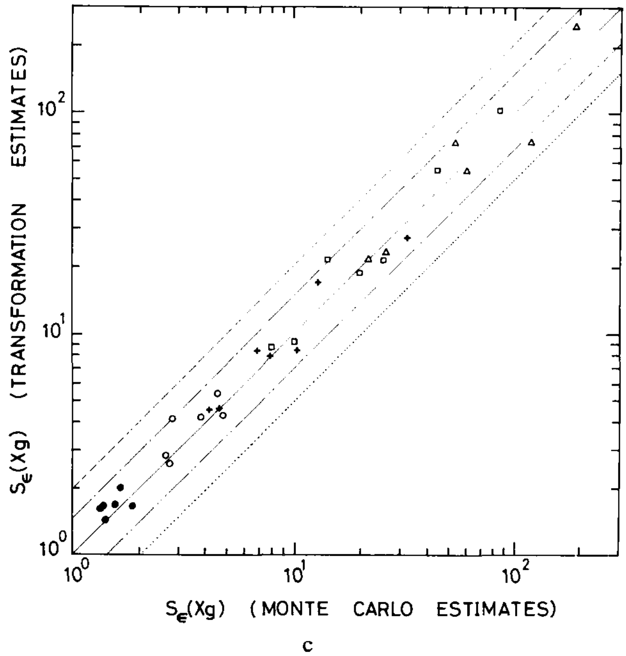


Fig. 5. (For legend see opposite page.)

It is a basic assumption that characteristics of SAF come from geometrical constitution between S and T and the way of energy deposition in T from scattering photons can be evaluated by Xg on a 'coordinate system of $\Phi_{ph}(X)$'. The present method appears to be more flexible than the previous one, since Xg can be determined whenever a MIRD adult SAF is available.

## Scale factors

Little information exists about the correlation between S–T distance of an individual and his observable physical constitution. If it is assumed that it may be more reasonable to consider effects of width and thickness for the individual into the scale factor $\varepsilon$:

$$\varepsilon = (\varepsilon_a \cdot \varepsilon_b \cdot \varepsilon_c)^{1/3} \quad (15)$$

where $\varepsilon_a$ = trunk width of the individual (cm)/40 cm,
$\varepsilon_b$ = trunk thickness of the individual (cm)/20 cm,
$\varepsilon_c$ = trunk length of the individual (cm)/70 cm.

Eq. (15) was suggested from eq. (10).

The mass scale factor was assumed as follows:

$$S_m = \frac{\text{mass of the individual in kg}}{\text{mass of the adult phantom (70 kg)}} \quad (16)$$

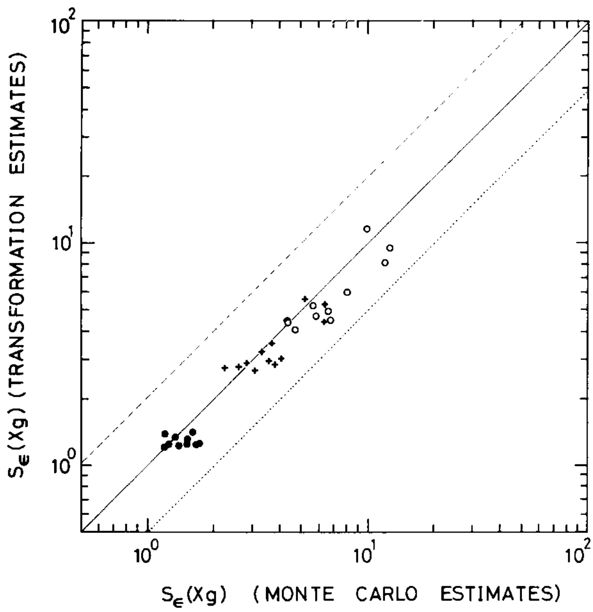


Fig. 6. Transformation estimates of $S_\varepsilon(Xg)$ compared with Monte Carlo estimates (Hwang et coll. 1976 and Jones et coll. 1976). Source organ is the liver, target organs of interest are not these shown, but these are the cases where a comparison is possible. Symbols ●, + and ○ show $S_\varepsilon(Xg)$ corresponding to 15-, 5- and 1-year old phantoms respectively. $R = S_\varepsilon(Xg)_1/S_\varepsilon(Xg)_2$, where $S_\varepsilon(Xg)_1$ and $S_\varepsilon(Xg)_2$ are the corresponding estimates. --- $R=2$, —— $R=1$ and ······ $R=0.5$. Photon energy is 0.14 MeV.

## Results and Discussion

For the case where T is equal to S, the AF for total body and the ovaries are shown as examples in Figs 3 and 4. The solid lines show the ORNL results of $S_\varepsilon(Xg)$ (Snyder et coll. 1972, Snyder & Ford 1973) and the dashed lines the present ones. For the total body, they are in good agreement, although the total body is far heavier than the flat ellipsoids. For the ovaries, the agreement at 0.02 MeV becomes worse as the age decreases. It may be due to the contribution of photons scattered from the medium outside the ovaries. The fraction of the scattered photons contribution to total absorbed dose may be roughly proportional to the ratio of area of surface to volume of the organ for low photon energies. Therefore, similar discrepancy at low photon energies may occur for the organs of which ratio of the area of surface to volume is relatively high and which are surrounded by relatively thick medium. However, the accuracy of the estimates for those organs are expected to be even better than that of agreement within a factor of 2, since the ovaries can be considered as an extreme case: the volume of it is the smallest. Other examples appear in Fig. 1. The values of q (Fig. 2) show that the inverse square law holds approximately for photon energy of 0.04 MeV and above but does not hold for photon energy below 0.03 MeV. This agrees with the observation for the lungs obtained by Hilyer et coll. (1972). The value of q is not applicable to the skeleton.

Results on the transformation factor where T is different from S are plotted in Fig. 5. for photons of energies 1.0, 0.1 and 0.02 MeV, when the ovary is the source organ. The position of each point is determined by the two estimates of $S_\varepsilon(Xg)$; that is, the abscissa represents the estimate by the ORNL Monte Carlo method and the ordinate represents the one from the present method. When the points are on the line, the two estimates are equal. As a whole, they are in good agreement, although the present method slightly overestimates the SAF of younger ages as energy decreases. When $^{99}Tc^{m}$ is used and the liver is the source organ, the result is plotted in Fig. 6. The agreement is not as good as in the ovary case. It may be due to the fact that the liver is geometrically more complicated and is nearer to the surface of the body than the ovary. However, the present method is found to supply the estimates for younger ages within a factor of 2 of the values calculated by the Monte Carlo method.

When T is an extended organ such as the total body, the total skin or the total skeleton, it is necessary to consider energy deposition in a part of T. Although those considerations make the method rather complicated, some empirical experiences facilitate (YAMAGUCHI 1978).

When the source organ is the total body, the SAF for younger ages has been reported (HILYER et coll. 1973). Therefore, the SAF for the individual can be estimated by an interpolation of the ORNL SAF. Eq. (11) and the values of q are useful for the interpolation, except for T being the skeleton, since self-absorption is generally a major contribution to those SAF.

In practice, it is sufficient to carry out the transformation at a representative photon energy instead of every photon energy. The value of q is almost the same for 0.1 MeV and above, and changes for energy below 0.1 MeV. $\Phi_{ph}(X)$ has a similar shape for energy of 0.1 MeV and above, and considerably different shapes for energy below 0.1 MeV. When a nuclide also emits many gamma rays two average energies are obtained; these are over gamma rays of energy above or below 0.1 MeV. The representative energies are the energies near those average energies. This grouping method of gamma rays, especially for energy below 0.1 MeV, remains as a problem. The publication (ORNL-5000, SNYDER et coll. 1974) is available for a transformation calculation, since it provides the newest complete data of the adult SAF for 12 mono energies.

## Conclusions

The present method can estimate SAF of an individual from only present available data: a complete set of adult SAF, the values of q, and the graphs of $\Phi_{ph}(X)$. The accuracy of the estimates is within a factor of 2 of values reliably estimated by the Monte Carlo calculation, which is about the same as for the previously published method.

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## SUMMARY

A transformation method is proposed and used for application of MIRD specific absorbed fractions to various physiques. The results are compared with data calculated by SNYDER et coll. (1972) for younger persons at photon energies from 0.02 to 2.0 MeV.

## ZUSAMMENFASSUNG

Eine Transformationsmethode wird vorgeschlagen und zur Anwendung von MIRD-spezifischen absorbierten Fraktionen für verschiedene Körperbeschaffenheiten verwendet. Die Ergebnisse werden mit den von SNYDER et coll. (1972) kalkulierten Daten für jüngere Personen bei Photonenergien zwischen 0,02 und 2,0 MeV verglichen.

## RÉSUMÉ

L'auteur propose une méthode de transformation et l'utilise pour l'application des fractions absorbées spécifiques de MIRD à différentes conditions physiques. Il compare les résultats avec les données calculées par Snyder et coll. (1972) pour des personnes plus jeunes à des energies de photons de 0,02 à 2,0 MeV.

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