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THE EFFECTS OF BODY AND ORGAN SIZE ON ABSORBED DOSE:

THERE IS NO STANDARD PATIENT*

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J. W. Poston
Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

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INTRODUCTION

The problem of estimating the absorbed dose to organs and tissues of the body due to the presence of a radiopharmaceutical in one or more organs is not a new problem. This problem is complicated by the fact that the body is not homogeneous and in many cases the organ shapes are not regular. The publications of the MIRD Committee, and in particular Pamphlets 5 and 11, have provided a direct means of estimating the absorbed dose (or absorbed fraction) for a number of radioisotopes. These estimates are based on Monte Carlo calculations for monoenergetic photons distributed uniformly in organs of an adult human phantom.

Almost immediately after accepting these estimates as the best available physical data, the medical physicist realizes that his patient does not resemble the adult phantom. The values of the absorbed fractions for individuals will differ depending upon the configuration of their organs and their general body structure. In addition, the absorbed fractions for the adult are not reasonable values for the child. How do these absorbed fraction estimates apply to a non-standard patient?

HISTORICAL DEVELOPMENTS IN INTERNAL DOSE ESTIMATION

The choice of a logical starting point for this discussion is almost as difficult as the problem itself. Nevertheless, the work of Ellett and his colleagues will serve as a launching point for the overview of internal dose estimation.

In 1964, Ellett, Calahan, and Brownell (1) published their calculations of absorbed dose delivered by a point source of gamma-rays in a tissue-

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ABSTRACT

The problem of estimating the absorbed dose to organs and tissues of the body due to the presence of a radiopharmaceutical in one or more organs is discussed. Complications are introduced by the fact that the body is not homogeneous and in many cases the organ shapes are not regular. Publications of the MIRD Committee have provided a direct means of estimating the absorbed dose (or absorbed fraction) for a number of radioisotopes. These estimates are based on Monte Carlo calculations for monoenergetic photons distributed uniformly in organs of an adult phantom. The medical physicist finds that his patient does not resemble the adult phantom. In addition, the absorbed fractions for the adult are not reasonable values for the child. The paper examines how these absorbed fraction estimates apply to a non-standard patient.

The historical developments in dose estimation related to body and organ size are traced. These developments include the early use of simple shapes, the design of a realistic adult phantom, and simple methods and scaling laws used to apply absorbed fraction estimates to any patient. In addition, more recent research in pediatric phantoms (or phantoms of smaller body size) is discussed. Sample absorbed fraction estimates obtained for these smaller

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phantoms are presented and compared to estimates obtained by other procedures.

INTRODUCTION

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Almost immediately after accepting these estimates as the best available physical data, the medical physicist realizes that his patient does not resemble the adult phantom. The values of the absorbed fractions for individuals will differ depending upon the configuration of their organs and their general body structure. In addition, the absorbed fractions for the adult are not reasonable values for the child. How do these absorbed fraction estimates apply to a non-standard patient?

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In 1964, Ellett, Calahan, and Brownell (1) published their calculations of absorbed dose delivered by a point source of gamma-rays in a tissue-

equivalent medium. They considered seven initial photon energies ranging from 40 keV to 2.75 MeV. The phantoms employed in these calculations were spheres, ellipsoids, and elliptical cylinders with masses varying from 2.1 to 198 kg. The calculational results were actually presented as absorbed fractions, i.e. the ratio of the energy absorbed to that emitted by the source.

Many important conclusions can be drawn from this paper. For example, for a central point source in a cylindrical phantom, as the mass of the phantom varied by two orders of magnitude the absorbed fraction changed by a factor of 3-4 depending on the photon energy. The absorbed fraction was a minimum for the smallest phantom. At the same time, the average dose rate varied by a factor of more than 20 and was a maximum for the smallest phantom. This finding is extremely important when considering the dosimetry of the child.

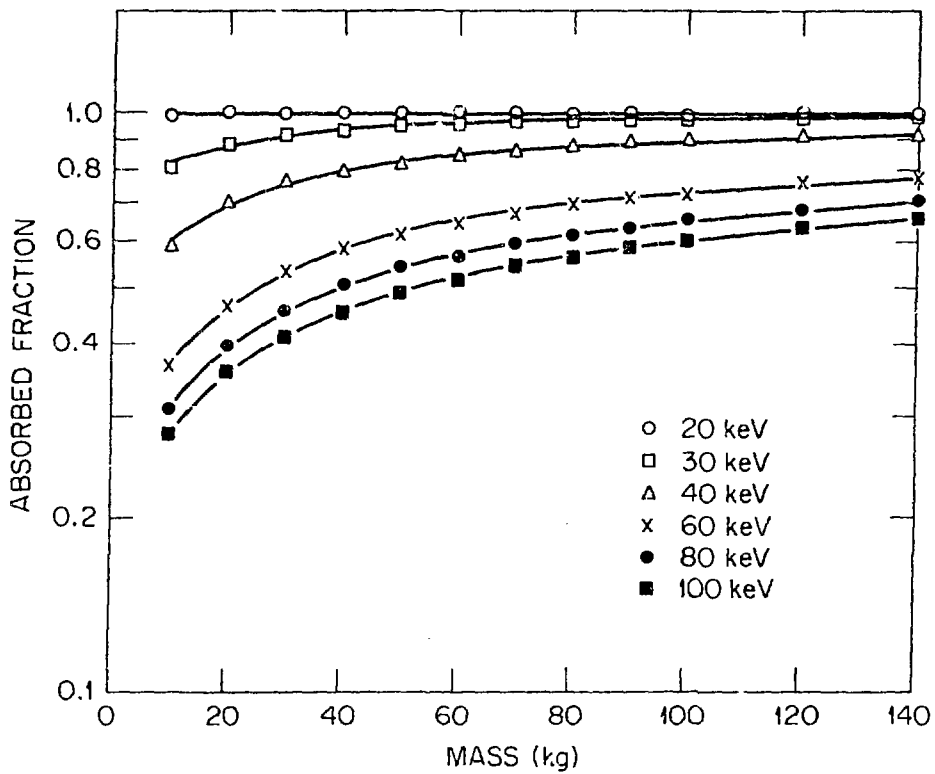
Ellett and his colleagues also concluded that the use of an elliptical cylinder to represent the trunk of the adult is justifiable. And similarly, they concluded that a spherical phantom was a very poor choice. Their data showed that the absorbed fraction for the spherical phantom was more than 35% larger than the absorbed fraction for an elliptical cylinder. This difference was due primarily to the larger effective radius of the sphere. In addition, they found that, except for very small phantoms, the absorbed fraction was relatively independent of the cylinder elongation and therefore, mass. Another calculation showed that the absorbed fraction was relatively independent of source position along the central axis of the cylinder. Thus the assumption of a centrally located source rather than a source located in the correct organ locations probably was in error by about 10%.

Ellett, Callahan, and Brownell continued their work and in 1965 published part two of their calculations (2). These data provided a comparison of the absorbed fraction in equal mass spheres, elliptical cylinders, and ellipsoids containing a uniform distribution of a 0.662 MeV gamma emitter. The mass of the phantoms ranged from 17.71 kg to 141.65 kg. In this case, the absorbed fraction for spheres was larger than that for other phantoms. Contrary to the central point source study discussed above, they found the absorbed fraction in ellipsoidal phantoms to be significantly less than that for elliptical cylinders. This time they recommended the use of ellipsoids as better models of the human body for use in dose calculations.

These authors also studied spheres, thick ellipsoids, and flat ellipsoids. The thick ellipsoids ranged from 20 to 160 kg while the flat ellipsoids and the small spheres ranged in mass from 0.3 kg to 6 kg. These calculations were performed for the same seven photon energies as the previous study, i.e. 40 keV to 2.75 MeV. They noted only a small difference (~3%) in the absorbed fractions for spheres and thick ellipsoids of equal mass. However, the absorbed fraction for the flat ellipsoids was significantly lower due to the higher probability of escape of the photons from the phantom.

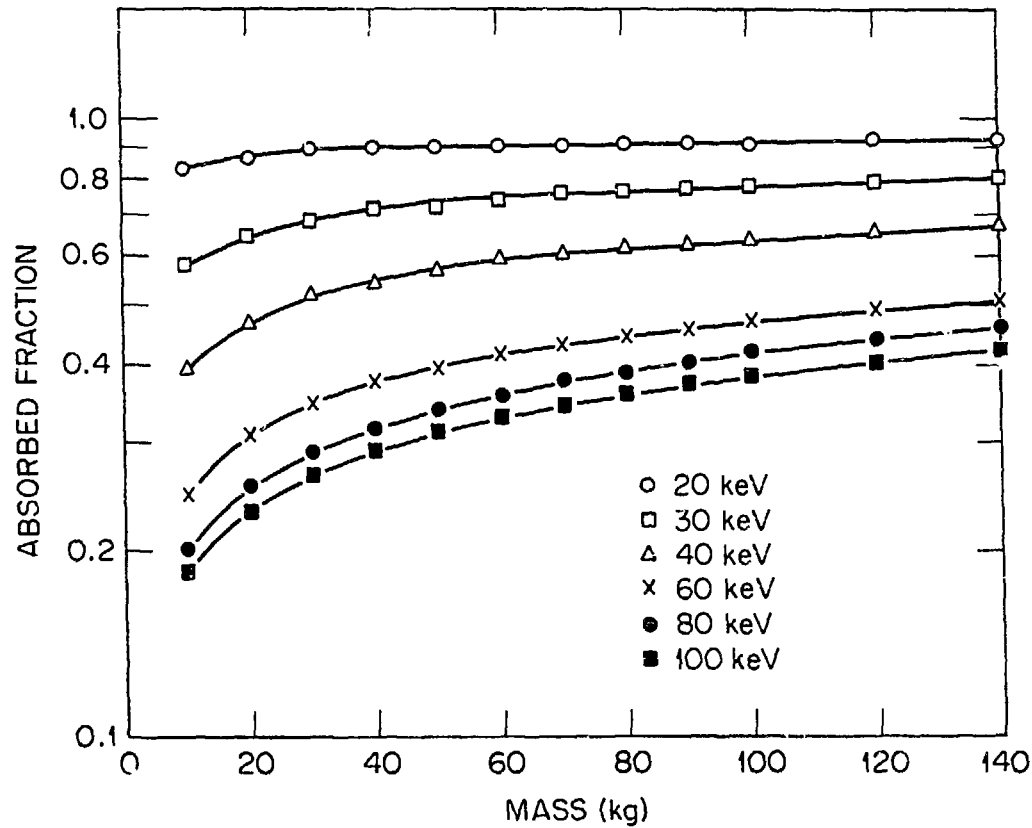
Installment three of this research was published by Reddy, Ellett, and Brownell (3) in 1967. These calculations were for both point and uniformly distributed sources in the energy range 20 to 100 keV. The phantoms were spheres, thick ellipsoids, and flat ellipsoids ranging in mass from 0.3 to 6 kg and from 10 to 160 kg (see Figures 1 and 2). These authors also considered the backscatter contribution to the absorbed fraction for small

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Absorbed Fractions for Central Point Gamma Emitters in Large Elliptical Cylinders or Ellipsoids (Data of Reddy, Ellett and Brownell, 1967)

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Absorbed Fractions for a Uniform Distribution of Activity in Ellipsoids
(Data of Reddy, Ellett and Brownell, 1967)

organs in a 70 kg phantom. The largest effect (~28%) was noted for photons of 80 keV.

The aforementioned three papers were summarized and republished as MIRD Pamphlet No. 3 (4) in 1968. Ellett and Humes continued these calculations and in 1971 published MIRD Pamphlet No. 8 (5). This pamphlet contained absorbed fractions for photon emitters (point sources and uniformly distributed sources) in small volumes (1-500 gms). The small volumes were assumed to be embedded in a large scattering medium of the same composition. Thus, these calculations included the effects of backscatter in a realistic fashion whereas previous calculations did not.

These authors also compared the absorbed fractions calculated in phantoms of water, "soft tissue", and ICRU muscle. At low photon energies the absorbed fractions for tissue were less than those for the other two materials. At higher energies, the absorbed fractions for soft tissue and water were approximately the same. Below 100 keV, the calculations showed that energy absorption was increasingly sensitive to the atomic composition of the phantom as might be expected due to increasing importance of photoelectric interactions.

During this period (i.e. the mid-1960's) Snyder and his colleagues at the Oak Ridge National Laboratory also examined the internal dosimetry problem. Snyder and Ford (6) reported on a Monte-Carlo-type computer program for estimating dose from gamma ray sources for a wide variety of exposure situations. The body was taken as a homogeneous right circular cylinder (30 cm in diameter and 60 cm in height) with the composition of standard man. The cylinder contained ellipsoidal volumes simulating the kidneys (each with a mass of 87 g), two spheres representing the ovaries, a thin cylinder at the

top of the phantom to simulate the thyroid gland, and a sphere located between the kidneys to represent a portion of the gastrointestinal tract. The kidneys were designed so that there was a cortex and a medulla and calculations were performed assuming that neohydrin (^{203}Hg) was concentrated in the cortex. Results were presented only for the 0.280 MeV photons from the decay of ^{203}Hg . As far as I can discover, this description was published only in the Health Physics Division's progress report and, therefore, many of those active in the field were not aware of this development. However, toward the end of this manuscript Snyder and Ford acknowledged the work of Ellett et al.(2) and the fact that the results of the two calculations were being compared.

In 1966, Ford and Snyder presented a tabulation of absorbed fractions for a uniform gamma source in the lungs of a tissue phantom (7). More importantly, in the same year, and in the same progress report, Fisher and Snyder presented a study of the variation of dose delivered by ^{137}Cs as a function of body size from infancy to adulthood. This research involved the use of Monte-Carlo techniques and six realistic phantoms representing humans of ages newborn, 1-, 5-, 10-, 15-, and 20 years. The phantoms were homogeneous throughout and, although these authors pointed out many deficiencies in the design, it represented a step forward in the estimation of internal dose. The design of these phantoms, including the selection of ages, etc., was probably the direct result of a paper by Kereiakes and his colleagues (9). These authors made a plea for standard children for use in internal dose estimation. In addition, they presented body masses, selected organ masses, and calculated geometrical factors ($\bar{g}$) for ages newborn, 1-, 5-, 10-, 15-years as well as for standard man.

The phantoms of smaller body size (or children phantoms, if you will) were shrunken versions of the adult phantom of Fisher and Snyder (10). Details of the adult phantom were not reported until the 1967 progress report even though certain dimensions were included in the 1966 manuscript. The adult phantom was shrunk by transformations which operated separately on the head, torso, and legs of the adult to produce the phantom for the child. Each of these transformations was a similitude so that non-intersecting loci (organs) remained non-intersecting. The primary advantage of this technique was that it avoided the redesign of the phantoms to match the characteristics of each age.

In the years that followed Snyder and his colleagues reported on the development of a heterogeneous phantom representing an adult human (11) and the use of this phantom in internal dose estimation. This adult phantom has become known in certain circles as the "MIRD Phantom" due to the publication of MIRD Pamphlet No. 5 (12) in 1969. In addition, this phantom and its "shrunken children" were used to produce dose estimates for various exposure situations. For example, Snyder and Cook (13) presented preliminary data on the age variation of the specific absorbed fraction (SAF) for photons in the six phantoms. (The SAF is defined as the absorbed fraction per unit mass of the target organ.) These data were for five different monoenergetic photon sources (0.5 MeV to 4 MeV) located in the stomach. The data showed clearly that the specific absorbed fraction increased by more than an order of magnitude as the age decreased. Thus, the use of specific absorbed fraction estimates for the adult would lead to a gross underestimate of the dose for children.

Hilyer, Snyder, and Warner (14) carried out further calculations with photon sources located in other organs and considered twelve monoenergetic sources ranging from 0.01 to 4 MeV. Their data showed that when the lungs or the contents of the stomach were the source organ and the target organs were the liver, skeleton, lungs, kidneys, or small intestine, that (1) generally the SAF will be greater for the younger ages, (2) for a given age and for the target organ being different from the source organ, the SAF passes through a maximum at about 30 to 50 keV, (3) when the source and target organs are the same, the SAF generally increases as energy decreases, (4) the ratio $(SAF)_{x \text{ age}} / (SAF)_{adult}$ seems generally to increase as energy decreases, and (5) the published values for the absorbed fractions for the adult should not be used for calculating the dose for the newborn and children.

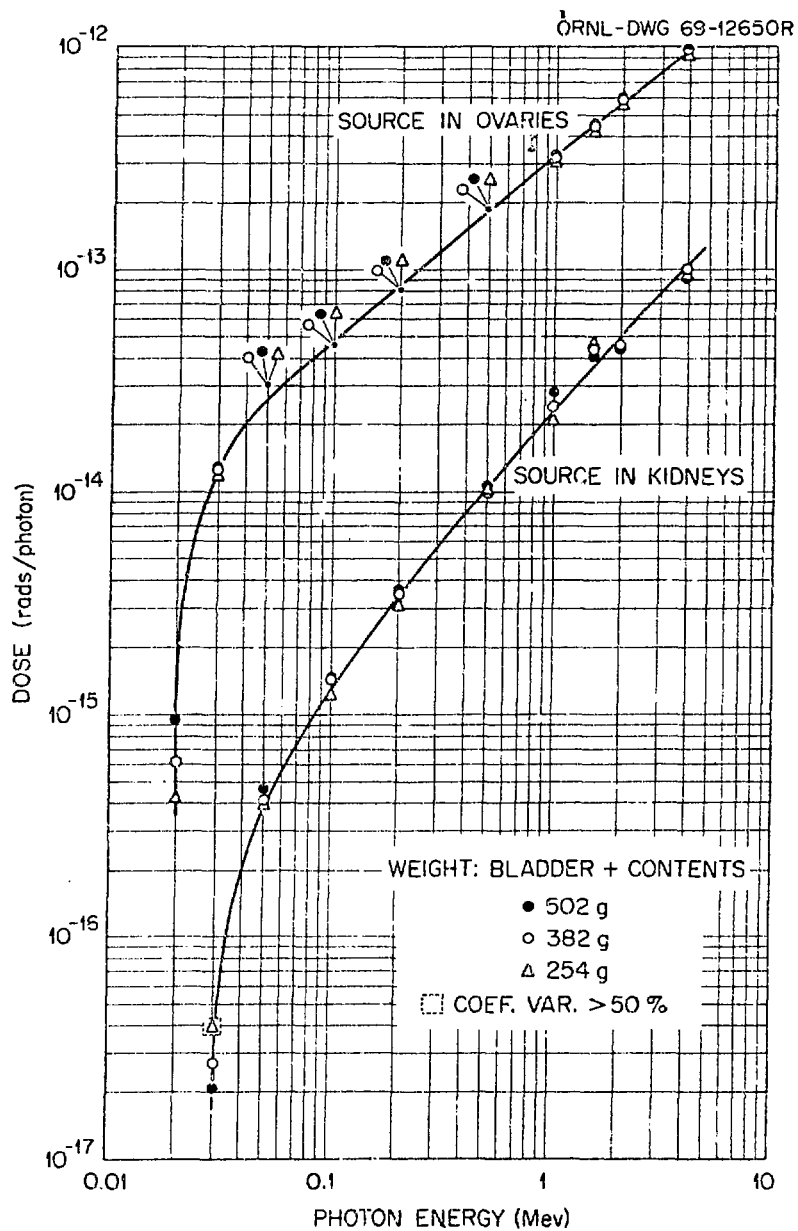
SCALING--APPLICATIONS TO THE NON-STANDARD PATIENT

At the last Symposium of this series Snyder (15) presented a complete survey of the internal dose estimation situation as it stood in 1969. He also presented some rules of thumb which allowed the calculated results to be applied to a non-standard individual. He stated, as Loevinger and Berman (16) had done previously, that it is assumed that the $(AF)_{X \rightarrow Y}$ varies directly as the mass of the target organ Y. Also he stated that this assumption is obvious if only infinitesimal changes in mass are considered. He pointed out that it was less clear to what extent the assumption holds for individual variation of organ mass or for adapting dose estimates for adults to the organs of children. Snyder presented the results of calculations of the average dose to the bladder for three different bladder sizes (bladder wall plus contents weighed 254, 382, and 502 gms). The average dose to the bladder was calculated for a monoenergetic source of photons located either

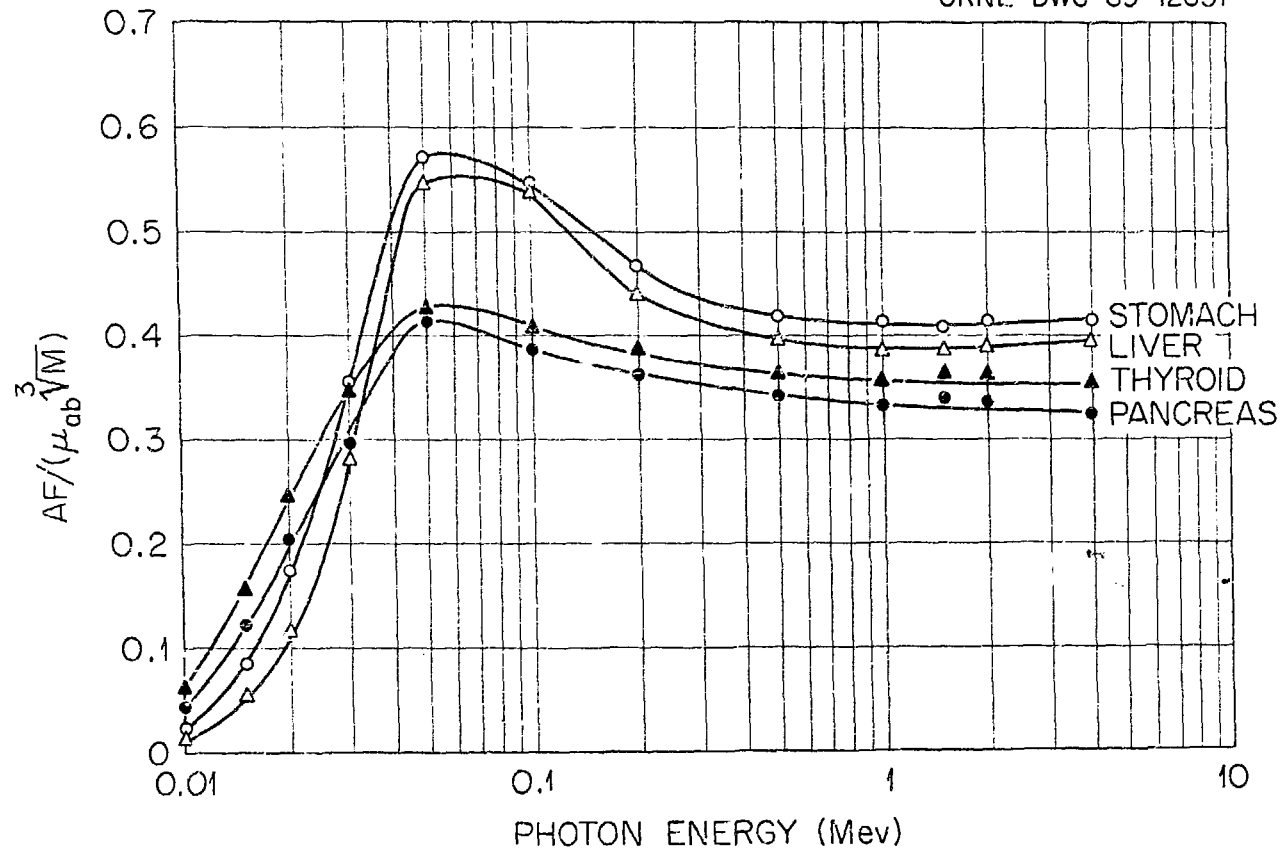
in the kidneys or the ovaries. These data are shown in Figure 3. Photon energies considered in the calculation ranged from 15 keV to 4 MeV. Even though the bladder size changed by about a factor of two the doses for the three bladders were essentially the same at every photon energy considered. Thus, he concluded that the principle appeared to be approximately correct for sources outside the target region. However, he pointed out that the distance from source to target organ should not change markedly due to the overriding effect of the inverse square law.

When the source is distributed uniformly within an organ, the dose to that organ would not be expected to vary with the mass. He stated that the absorbed fraction would be expected to vary with the cube root of the mass, i.e. $(AF)_{X \rightarrow Y}$ is proportional to $\mu_{ab} \sqrt[3]{M}$, where μ_{ab} is the absorption coefficient and M is the mass of the organ. Snyder pointed out that this principle seemed to hold even for organs whose shapes were not spherical. He showed a plot of $(AF)/\mu_{ab} \sqrt[3]{M}$ vs. energy (see Figure 4) for four organs (stomach, liver, thyroid, and pancreas) which was relatively constant over the energy region where Compton scattering predominates. Below about 200-300 keV the relationship was not valid. In addition, the organ must be so small in relation to the mean-free path of the photons that buildup did not contribute significantly to the dose or the absorbed fraction. Thus, Snyder concluded that the assumption should only be applied for the energy region where Compton scattering predominates and then only when the absorbed fraction is well below 1, i.e. ≤ 0.5 .

In the same paper (15), he showed a plot of absorbed fraction and also $(AF)/\mu_{ab} \sqrt[3]{M}$ vs. age of the phantom (see Figure 5). The latter gave a nearly constant result for the six ages considered. However, Snyder did not

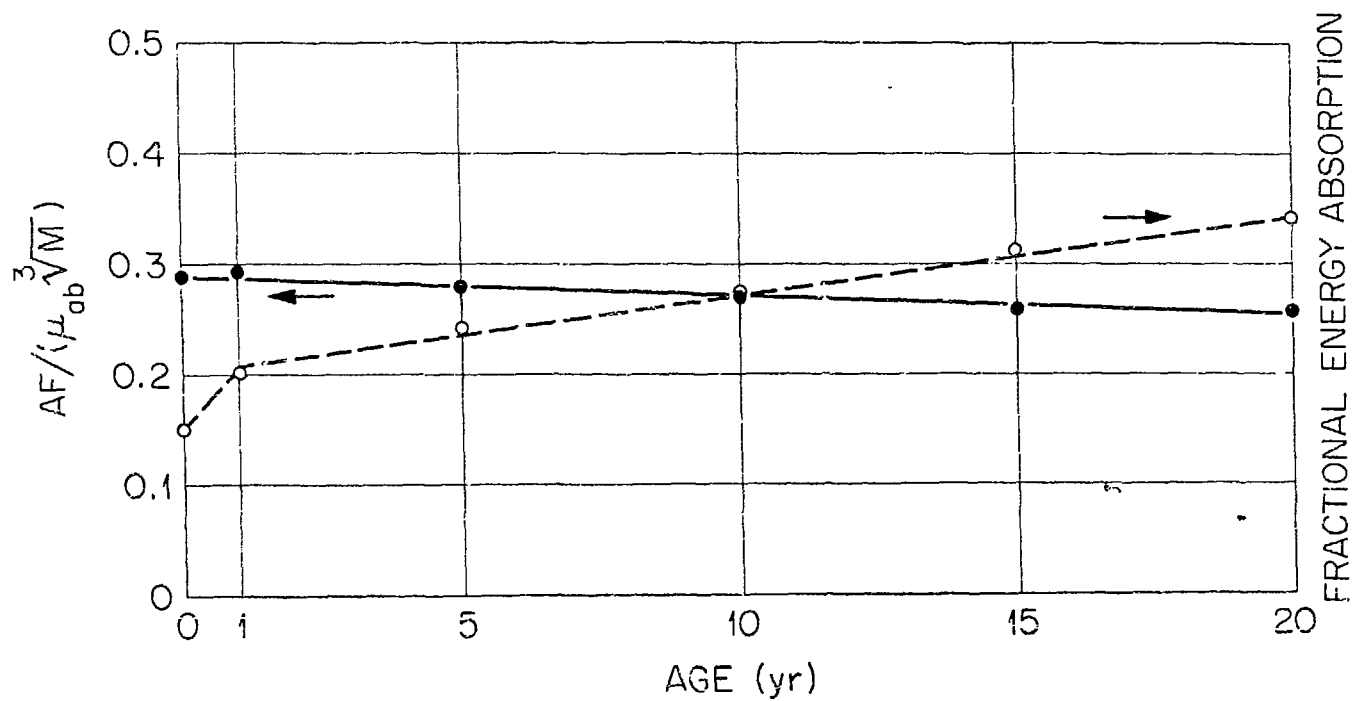


Dose for Three Bladder Sizes and Two Source Organs.



Absorbed Fractions for Source Organs in Relation to Organ Mass.

ORNL-DWG 69-12652



Absorbed Fractions for ^{137}Cs in Total Body in Relation to Age and Body Mass.

attribute a high degree of accuracy to the results and presented them only as an approximation.

A much more recent paper by Yamaguchi and his colleagues (17) at the National Institute of Radiological Sciences in Japan presents a transformation method which can be applied to the MIRD Pamphlet No. 5 (12) data in order to make the data useful for patients of different sizes. They point to the obvious problems with the MIRD data, i.e. not applicable to the non-standard patient nor to the child, and propose a simple set of transformations. The specific absorbed fraction for the MIRD phantom and the specific absorbed fraction for the individual are related by:

$$\phi'(T' \leftarrow S') = S(X/X') \phi(T \leftarrow S)$$

and

$$S(X, X') = \overline{\phi'(X')} / \overline{\phi(X)}$$

where the primes denote the parameters for the individual. $\overline{\phi(X)}$ is the mean value of the specific absorbed fraction $\phi(X)$ for all pairs of points in S and T. Similarly, a relation of the absorbed fraction between $\phi(T \leftarrow S)$ and $\phi'(T' \leftarrow S')$ is given by:

$$\phi'(T' \leftarrow S') = S_m S(X, X') \phi(T \leftarrow S)$$

$$S_m = m_{T'} / m_T$$

where m and $m_{T'}$ are target organ masses of the MIRD phantom and the individual, respectively.

These authors give an approximation for $S(X, X')$, i.e.:

$$S(X, X') = \frac{1}{\epsilon^2} \exp \frac{\mu_{\text{eff}}}{\rho} X_w (1 - \epsilon)$$

where μ_{eff} is the effective linear absorption coefficient (the value which would be chosen according to the photon energy), X_w is the effective distance between S and T in units of mass per unit area, and ρ is the density of soft tissue. An approximation for ϵ and S_m are given as follows:

$$\epsilon = \frac{\text{trunk length of the individual (in cm)}}{\text{trunk length of the MIRD phantom (70 cm)}}$$

and

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

Similar equations can be used to transform the absorbed fractions.

The applicability of the transformation method was tested by an experiment employing a RANDO phantom. A small ^{60}Co source was used and the ovaries and thyroid were chosen as source organs. Absorbed doses were measured with LiF-TLD powder. For these two exposure situations, the agreement was good between the experimental values and the "transformed" calculated values. These data are shown in Tables 1 and 2. The data of interest are shown in columns three and four labelled ϕ_{exp} and ϕ' respectively.

Yamaguchi and his coworkers also compared transformed MIRD data to data for children reported by Snyder (18) for a monoenergetic photon source in the lungs. Snyder's data were obtained by use of his own transformation technique (described previously). For the two energies considered (0.1 MeV and 1 MeV) the agreement between the two methods appeared to be good. However, for the liver as a target organ and a 1 MeV photon source in the

Table 1. Comparison Between Calculated and Measured Results* (The Ovaries are the Source Organ)

Target Organ	Experiment		Calculation	
	Avg. Absorbed Dose	Absorbed Fraction ϕ exp.	Transformed MIRD Value ϕ'	Original MIRD Value (1.25 MeV)
	⁺			⁺⁺
Lungs	14.8 (24)	0.96E-3	1.00E-3	0.56E-3 (23)
Liver	43.3 (45)	0.51E-2	0.64E-2	0.40E-2 (7)
Pancreas	45.8 (18)	0.18E-3	0.14E-3	0.90E-4 (37)
Kidneys	63.5 (14)	0.12E-2	0.16E-2	0.10E-2 (12)
Spleen	45.7 (27)	0.52E-3	0.45E-3	0.30E-3 (22)

*Data of Yamaguchi, et al., Phys. Med. Biol., 1975, Vol. 20, No. 4, 597

⁺Standard deviation (%)

⁺⁺Coefficient of variation (%)

Table 2. Comparison Between Calculated and Measured Results* (Thyroid is the Source Organ)

Target Organ	Experiment		Calculation	
	Avg. Absorbed Dose	Absorbed Fraction ϕ exp.	Transformed MIRD Value ϕ	Original MIRD Value (1.25 MeV) ϕ
	[†]			^{††}
Lungs	114.4 (44)	0.74E-2	0.57E-2	0.37E-2 (7)
Liver	30.7 (29)	0.36E-2	0.25E-2	0.14E-2 (12)
Pancreas	27.9 (27)	0.11E-3	0.10E-3	0.60E-4 (40)
Kidneys	11.7 (21)	0.22E-3	0.18E-3	0.10E-3 (33)
Spleen	26.3 (16)	0.30E-3	0.26E-3	0.15E-3 (33)
Ovaries	3.8 (6)	0.22E-5		
Testes	1.9 (17)	0.47E-5		

*Data of Yamaguchi, et al., Phys. Med. Biol., 1975, Vol. 20, No. 4, 597

[†]Standard deviation (%)

^{††}Coefficient of variation (%)

lungs there was some disagreement. The specific absorbed fractions for ages 2, 4, 6, and 8, estimated by Yamaguchi, were perhaps a factor of two above those estimated by Snyder for ages 1- and 5-years.

The final paper to be examined in this section does not present any rules for scaling the absorbed fractions. However, it contains some interesting and relevant data. These data are the work of Hilyer and Snyder (19) who presented estimates of dose from ^{133}Xe to infants and children for immersion in an infinite cloud. The absorbed dose varies but only because of variations in breathing rates and metabolism between children and adults. The data presented by these authors showed that the dose per μCi inhaled was a factor of ten higher for a newborn than for an adult. These data are shown in Table 3. However, the newborn breathes slightly less than $2\text{m}^3/\text{day}$ of air whereas the adult breathes about $20\text{m}^3/\text{day}$. Thus, if the ratio of the dose to the child and the dose to the adult ($D_{\text{child}}/D_{\text{adult}}$) is multiplied by the ratio of the breathing rates of the child and adult ($R_{\text{child}}/R_{\text{adult}}$) the result, in most cases, is:

$$\frac{D_{\text{child}}}{D_{\text{adult}}} \times \frac{R_{\text{child}}}{R_{\text{adult}}} \approx 1$$

All the data reported by Hilyer and Snyder fit this equation and it can be assumed to be approximately valid for many exposure situations.

RECENT PROGRESS AND THE NEAR FUTURE

The internal dosimetry research pioneered by Snyder and his colleagues has been continued at the Oak Ridge National Laboratory. During the past year or so we have completed the design of phantoms representing a newborn, and children of ages 1-, 5-, and 15-years. The design of a phantom for the

Table 3. Breathing Rate and Total Dose (μ rads) to Various Organs and Tissues of the Body From Inhalation of $1\mu\text{Ci } ^{133}\text{Xe}^*$

	Age					
	Newborn	1-Year	5-Years	10-Years	15-Years	Adult
Breathing Rate (m^3/day)	1.8	3.4	12	18	20	20
<u>Target Organs</u>						
Adipose Tissue	6.67	3.53	1.0	0.67	0.60	0.60
Skeleton	1.50	0.79	0.23	0.15	0.14	0.14
Red Marrow	2.67	1.41	0.40	0.27	0.24	0.24
Ovaries	0.94	0.50	0.14	0.094	0.085	0.085
Testes	0.83	0.44	0.13	0.083	0.075	0.075
Lungs**	1.3	1.3	1.3	1.3	1.3	1.3
Skin	0.72	0.83	0.11	0.072	0.065	0.065
Other Organs (range)	0.83- 1.0	0.44- 0.53	0.13- 0.15	0.083- 0.10	0.075- 0.090	0.075- 0.090

*Data of Hilyer and Snyder, 1973

**Dose from ^{133}Xe in air spaces of lung

10-year old is nearly complete. Table 4 presents a summary of organ weights for four of these phantoms plus the data on the adult. In addition, data from Spector (19) and Wellman et al. (20) are included for comparison. In general the organ weights assigned as a result of our analysis of the literature agree closely with those published previously.

At this point we have studied only two ^{99m}Tc labelled compounds. Actually, our calculations have considered only the photons emitted by this technicium isotope. Table 5 shows the specific absorbed fractions for five phantoms (excluding the 10-year old) with liver as the source organ. Values shown in parentheses are specific absorbed fractions for which the coefficient of variation is greater than 25%.

These data have been compared to the results obtained from use of the similitude transformation technique. As an example, Table 6 shows percentage differences between the one-year old pediatric and similitude phantoms where the pediatric phantom is used as the standard. The negative signs are used to indicate when calculated doses were lower for the pediatric phantoms than the similitude ones. As can be seen, absorbed doses for radiosensitive organs such as the gonads and red bone marrow varied from -150% to 88%.

The differences in this Table may be due to several factors which relate to differences in design. For example, the bone marrow in the similitude phantom has a distribution similar to the adult. The pediatric phantom has only red bone marrow which is distributed uniformly in the skeleton. In addition, there are data which indicate that the location of the ovaries is significantly different in the two phantoms. However, these phantoms were designed as carefully as possible and represent an improvement over the previous methods of transforming adult data for use with children.

Table 4. Summary of Organ Weights for Pediatric and Adult Phantoms

Organ	Newborn		1-Year		5-Years		15-Years		Adult	
	Wellman et al.	ORNL	Wellman et al.	ORNL	Wellman et al.	ORNL	Wellman et al.	ORNL	Wellman et al.	ICRP**
Brain	350	372	945	1005	1241	1180	1350	1367	1400	1451
Bladder Wall	---	3	---	7	---	14	---	34	---	45
Intestines	146	32 [†]	398	140 [†]	550	301 [†]	1350	1265	1700	1770
Kidneys	23	19	72	68	112	116	247	230	300	284
Liver	136	110	333	300	591	608	1289	1267	1700	1809
Lungs	52	40	172	130	291	260	701	650	1000	1000
Red Marrow	---	40	---	150	---	400	---	950	---	1500
Yellow Marrow	---	0	---	0	---	50	---	1500	---	1500
Ovaries	0.29	0.3	1.0	0.7	2.0	2	6.5	5	8.5	8
Pancreas	2.8	2.6	14	9	23	19	68	57	80	60
Skeleton	---	500	---	1600	---	2800	---	8700	---	10500
Spleen	9.4	8.8	31	27	54	50	138	145	150	174
Stomach	6.5	5.9	27	27	57	52	120	118	160	150
Testes	0.67	0.8	1.5	1.5	1.7	1.6	18	16	28	37
Thyroid	1.5	1	2.2	2	4.7	5	11.2	13	16	20
Total Body	3540	3990	12100	10400	20300	20000	55000	56980	70000	70000
Total Height (cm)	50	52	75	76	108	112	166	167	170	174

*H.N. Wellman, J.G. Kereiakes, and B.M. Branson, "Total- and Partial-Body Counting of Children for Radiopharmaceutical Dosimetry Data", in Medical Radionuclides: Radiation Dose and Effects, AEC Symposium Series 20, June 1970. Most of these data from W.S. Spector, Handbook of Biological Data, W. B. Saunders Co., 1956

**Snyder-Fisher phantom based on ICRP Reference Man, ICRP Publication 23, Pergamon Press, 1975

[†]Not complete, does not include mass of contents for lower large intestine.

Table 5. Specific Absorbed Fractions ($\times 10^6 \text{g}^{-1}$) In Various Target Organs from the Photons of $^{99\text{m}}\text{Tc}$ Uniformly Distributed in the Liver in Five Phantoms

Target Organ	Newborn	1-Year	Age 5-Years	15-Years	Adult
Kidneys	90	40	25	15	14
Liver	585	300	190	110	90
Lungs	70	30	20	10	7
Red Marrow	40	30	20	8	5
Ovaries	(60)*	(30)	(15)	(5)	(6)
Skeleton	30	15	10	5	4
Testes	(15)	(6)	(1)	(36)	(0)
Thyroid	(11)	(7)	(1)	(0)	(0)
Total Body	55	30	20	10	6

*Values shown in brackets are specified absorbed fractions for which the coefficients of variation are greater than 25%

TABLE VI
COMPARISON OF ABSORBED DOSES FROM ^{99m}Tc
ONE-YEAR OLD PEDIATRIC PHANTOM COMPARED
WITH ONE-YEAR OLD SIMILITUDE PHANTOM

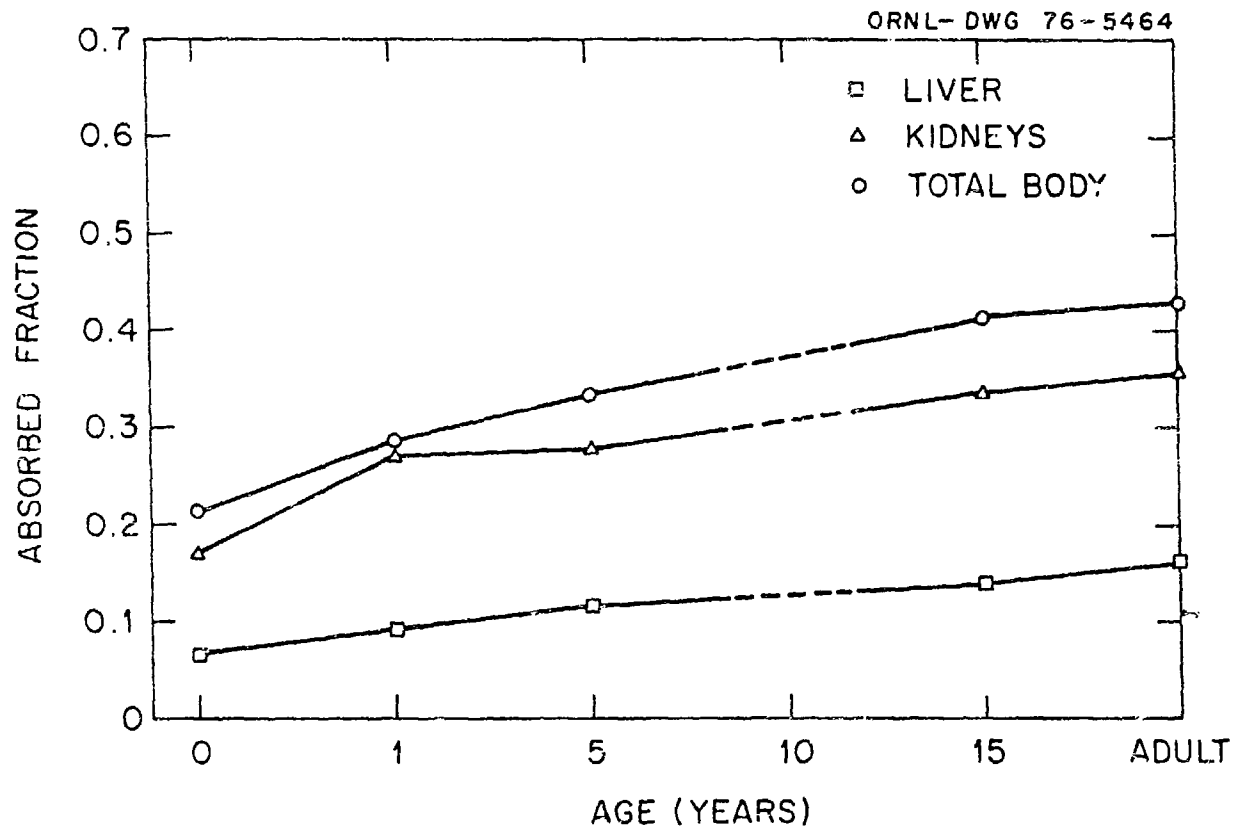
TARGET ORGANS	SOURCE ORGANS		
	LIVER	RED BONE MARROW	BLADDER CONTENTS
(NUMBERS REPRESENT PERCENT DIFFERENCE)			
OVARIES	12	37	150
TESTES	8	50	51
KIDNEYS	24	41	61
LIVER	10	16	95
SKELETON	- 13	- 7	22
RED MARROW	88	0.5	- 13
THYROID	- 75	---	---
TOTAL BODY	10	14	14

SLIDE 4

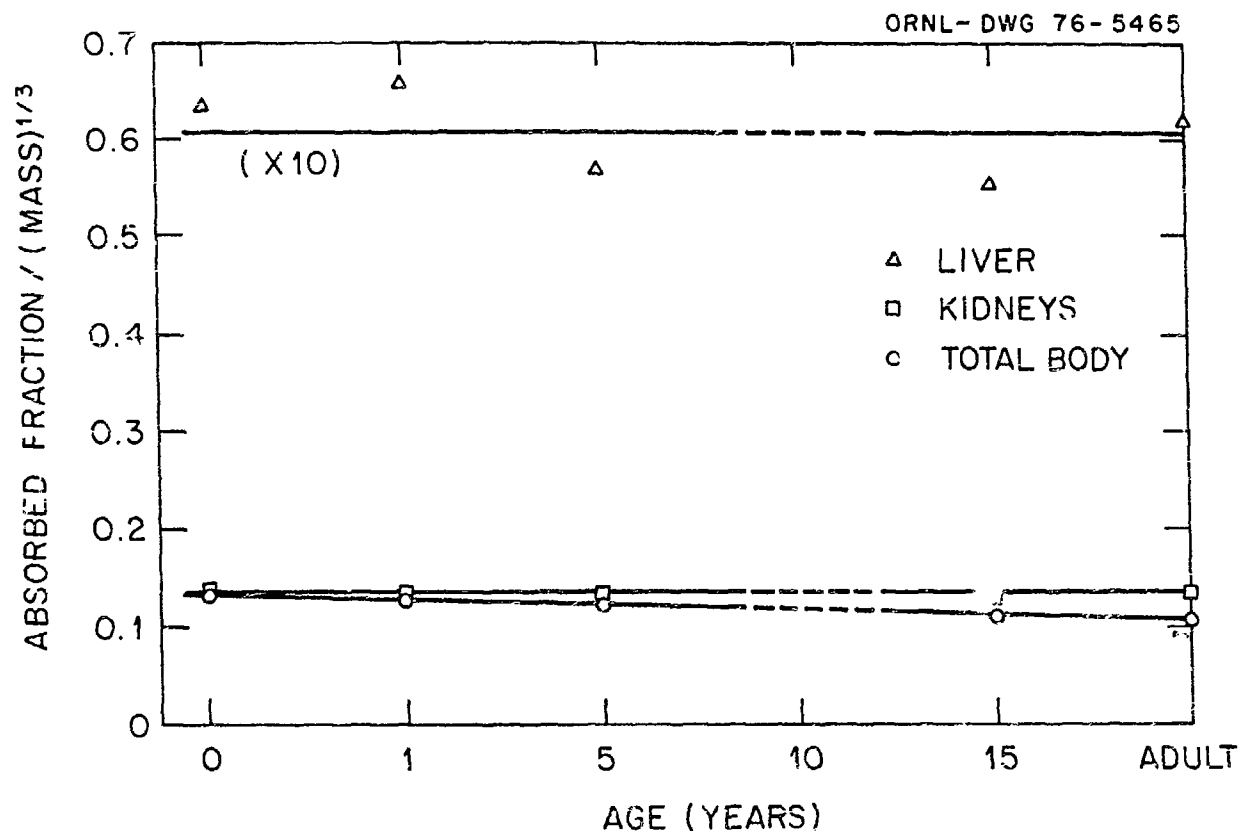
The absorbed fraction as a function of age is shown in Figure 6 for the liver, kidneys, and total body with the liver as the source organ. These data are quite similar to those reported by Snyder¹(15) in that the absorbed fraction increases as age increases. To scale the results for the adult to children, Snyder recommended dividing the absorbed fraction by $\mu_{ab} \sqrt[3]{M}$. Figure 7 shows the same absorbed fraction data divided only by the cube root of the mass of the target organ. This figure illustrates the point made previously, i.e. that for $AF \leq 0.5$, the relationship is correct and can be used to scale adult data for children.

Thus, in a year or perhaps two, data similar to that for the adult should be available for use in dose estimation. And, in some ways, a significant problem will be solved. A final decision on this point must wait for publication and wide-spread acceptance of the data. What techniques can be used in the interim? These have been discussed in this paper and are summarized below:

- (1) For small changes in target organ mass and separation distance between source and target organs the $(AF)_Y \propto X$ varies directly as the mass of the target organ Y.
- (2) For a source distributed uniformly in an organ the $(AF)_X \propto X$ varies as the cube root of the mass of the organ. However, it appears that this assumption should only be applied for the energy region where Compton scattering predominates and then only when the absorbed fraction is well below 1.0.
- (3) The transformation method of Yamaguchi and his colleagues (17) appears to provide reasonable estimates



Absorbed Fractions for ^{99m}Tc Distributed Uniformly In the Liver



Absorbed Fraction / (mass)^{1/3} for ^{99m}Tc Distributed Uniformly
In the Liver

of absorbed fraction as a function of age. However, the similitude data of Snyder and his colleagues provides a more useful data bank for children which is approximately correct for most exposure situations.

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